

RESEARCH ARTICLE

SULPHUR STATUS OF SUGARCANE GROWING SOILS OF TAMIL NADU

A. Bhaskaran*, P. Rakkiyappan and C. Palaniswami

Abstract

Widespread S deficiency symptoms in sugarcane have been reported worldwide and in India. A study was conducted to develop a database on soil available S in sugarcane growing soils, plant TVD leaf S content and the extractant suitable for predicting the plant TVD leaf S content. The results revealed a wide variation in the available sulphur status of sugarcane growing soils. About 17% of the soils were low in available S status (<10 ppm) while 35% were in medium (10 - 20 ppm) and 48% were in high (>20 ppm) category. Various extractants viz., 0.15% CaCl₂, 500 ppm mono-calciumphosphate, ammonium acetate-acetic acid (0.5:0.25M), 0.5M sodium bicarbonate and neutral normal ammonium acetate varied significantly in their ability to extract soil S. A significant and positive correlation existed between the S extracted by various extractants revealing that all the extractants dissolved S from same forms but with different magnitude. Soil organic carbon and S extracted by various extractants had a significant positive correlation. TVD leaf S also correlated positively with soil organic carbon. A linear trend in plant TVD S was observed beyond the soil critical S content of 10 ppm up to 45 ppm. Principal Component analysis revealed that 0.15% CaCl₂, ammonium acetate-acetic acid and mono calcium phosphate extracted S contributed more towards plant TVD leaf S.

Key words: Sulphur nutrition, soil available sulphur, sugarcane, sulphur extractants, sugarcane TVD leaf sulphur

Introduction

Sulphur is one of the essential elements required for plant growth and it plays a major role in the synthesis of essential amino acids like cysteine and methionine; coenzyme A, biotin, thiamine, and glutathione; chlorophyll, secondary sulphur compounds like allins, glucosinolates and phytochelatins (Ceccotti 1996). Sulphur compounds are also of particular importance for plant protection against pests and environmental stress, food quality and production of phyto-pharmaceuticals (Eriksen 2009). It is a macronutrient and like N, P, K, Ca, and Mg, must be available in relatively large amounts for good crop growth. Increasing sulphur deficiency in previously sulphur sufficient areas has been reported in many parts of the world and in India (Tandon 1991; Blair 2002). Despite the essential role of sulphur for plant growth, it has historically received little attention because of adequate supply from the atmosphere and commercial fertilizers. However, during the last 20-30 years, the situation has changed dramatically and today we are facing the challenge of optimizing sulphur availability in cropping systems in synchrony with plant demand and in the required form and quantity. The main reasons attributed were use of high-analysis, low-sulphur-containing fertilizers and increase in yields obtained as a result of other technological advances (Blair 2002; Malcolm et al. 2007; Eriksen 2009). Yield limitation in sugarcane due to low soil available sulphur was reported by Mathew et al., 2003.

Soil sulphur exists in numerous forms and its dynamics play an important role in its availability to plants. Eriksen (2009) opined that the transient nature

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of plant available sulphur makes soil sulphur testing a difficult task and often sulphur balance considerations provide a better background for fertilizer sulphur recommendations. Compared to other macronutrients, sulphur use efficiency is low, about 25% as reported by Kyllingsbaek and Hansen (2007).

From a plant-nutritional viewpoint, inorganic sulphate was found to be the most important form of assimilation by plant roots. Generally, more than 95% of soil sulphur was found to be organically bonded with several hundred kilograms of organic sulphur present in the upper horizons of most soils. Although not readily available, this large organic sulphur pool may potentially be an important source of sulphur to plants in deficiency situations. Assessing the quantity of sulphur that a soil may supply during the cropping period continues to be a challenge. Several extractants have been tried to extract the labile pool of soil sulphur constituting part of organic and inorganic sulphur (Tabatabai 1982 and 1992). Calcium chloride (0.15%), monocalcium phosphate, ammonium acetate-acetic acid, sodium bicarbonate and neutral normal ammonium acetate are some of the extractants used to assess the available sulphur status.

The response of sugarcane to sulphur application in terms of yield and quality has been studied by several workers. Gosnell and Long (1969) observed good response in sucrose yield to the application of @ 50 kg S ha⁻¹ in a sandy loam soil; stalk population, cane yield, and sucrose and foliar sulphur content increased. Rakkiyappan et al. (1985 and 1989) also reported the influence of S sources on sugarcane juice and jaggery quality. Threshold level for S was found to be 0.16% and N:S ratio of 17 for the top visible dewlap (TVD) leaves. Sedl (1968) found that the threshold value for sulphur in third TVD leaf of sugarcane was 0.16% while a N:S ratio wider than 17 produced response to sulphur. The threshold level in the 3-6 sheaths was reported as around 0.2-0.5% (Bonnet 1965). Fox (1976) observed that the external S requirement of sugarcane at 35 days was about 9 ppm whereas after 70 days the requirement was about 5 ppm. The internal S requirement for early growth was 0.36% in the whole plant and 0.24% in leaf blades 3 through 6. When plants were 70 days old, 0.10% S in leaf blades or 0.08% S in leaf sheaths was sufficient. At 18 months, sulphur-deficient, field-

grown sugarcane contained 0.075% S in leaves 3 through 6 and 0.072% S in the corresponding leaf sheaths; sulphur fertilized sugarcane contained 0.138% and 0.232% for the same tissues. Distribution of S in the plant may be a valuable tool for assessing the S status of sugarcane. When S is deficient, old leaf blades contain more S than corresponding leaf sheaths, and blades and sheaths of leaves 3 to 6 contain about equal concentrations of S. Proper S nutrition is associated with an elevated concentration of S in leaf sheaths as compared with leaf blades.

With a view to ascertain the sulphur nutrient status of the sugarcane growing soils and its relationship with the sulphur content in the plant tissues, a survey was undertaken in the sugarcane growing soils of north western and western parts of Tamil Nadu.

Materials and methods

A survey was conducted in eight sugarcane growing districts of Tamil Nadu viz., Coimbatore, Erode, Tirupur, Karur, Dindigul, Madurai, Theni and Namakkal covering five sugar factory areas and a jaggery producing area. Forty eight distinct fields were selected based on the soil colour and texture representing major sugarcane growing soil series. Soil samples were collected from each field up to a depth of 30 cm. Depending on the field size, 10 - 20 samples were collected from each field, pooled and the sample size was reduced to about 500 g by quartering method. The soil samples were air dried and sieved through 2 mm sieve and the percent coarse fraction was recorded. Soil organic carbon was determined by wet oxidation method of Walkley and Black (1934). Available sulphur was extracted using 0.15% CaCl₂ (Williams and Steinbergs 1959), mono-calcium phosphate (500 ppm) (Fox et al. 1964), ammonium acetate-acetic acid (0.50:0.25M) (Bardsley and Lancaster 1960), sodium bicarbonate (0.5M) (Williams and Steinberg, 1959) and neutral normal ammonium acetate (McClung et al. 1959). The sulphur content in the extracts was determined by turbidimetric method (Chesnin and Yien 1950).

TVD leaf samples collected from each field were air dried first and then dried in hot air oven at 60°C to constant weight. The leaf blades were ground in a Wiley mill and 0.5 g of the sample was weighed and digested using di-acid mixture containing 2:1

nitric:perchloric acid. The sulphur content in the samples was determined colorimetrically by barium chloride method (Lisle et al. 1994). The descriptive statistics on the data were worked out as per Panse and Sukhatme (1967). Principal Component Analysis (PCA) was performed for the parameters to uncover the association among them using an Excel AddOn.

Results and discussion

The available sulphur status of the sugarcane growing soils extracted using 0.15% CaCl_2 ranged from 2.45 to 96.07 ppm with an average of 25.37 ppm up to 30 cm soil depth (Table 1). Seventeen per cent of the samples had an available S content of <10.0 ppm which are categorized as low, 35% were in medium category (10 to 20 ppm) and 48 % were in high (> 20 ppm) category. Among the extractants, 0.5 M sodium bicarbonate extracted the highest quantity of sulphur (54.19 ppm) followed by ammonium acetate-acetic acid (0.50:0.25M) (42.78 ppm), 500 ppm mono calcium phosphate (36.88 ppm), 0.15% CaCl_2 (25.37 ppm) and neutral normal ammonium acetate (18.02 ppm). Results of the student's *t* test revealed that the mean S extracted by various extractants was significantly different from one another. The organic carbon status of the soils ranged from 0.14 to 0.86% with an average of 0.41%. The sulphur content in the TVD leaf ranged from 0.04 to 0.14%.

Sulphur content of the sugarcane growing soils varied widely. About 17% of the soils surveyed were found to be deficit in available S. Widespread S deficiency in Indian soils was reported by Singh (2001). The S deficiency in soils of various Indian states varies from 5 to 83% with an overall mean of 41% and it was widespread in coarse textured alluvial, red and lateritic, leached acidic hill soils and black clayey soils. The magnitude of S deficiency was more in areas where continuously sulphur free fertilizers like DAP, urea *etc.*, were used. Sulphur deficiency was also found more in alkaline, coarse textured, low organic matter soils. Biswas et al. (2004) reported that S deficiency varied from 23 to 31% in alluvial soils of Bihar, and higher magnitude of deficiency was recorded in young alluvium, non-calcareous soils followed by recent alluvium, non-calcareous, non-saline and young alluvium calcareous soils. Widespread S deficiency in subtropical regions and crop response to its application has been reported by Pasricha and Fox (1993). The reason attributed was that during 1950s, sulphur-containing fertilizers like ammonium sulphate, super phosphate *etc.* were commonly used and during the past few decades use of N and P fertilizers that contain S has relatively decreased, resulting in a drastic decrease in the addition of S to soil. Soil tests carried out on a large number of samples revealed that 24.9% soils of Punjab contained sulphur below the critical level of 10ppm (Brar 1998).

Table 1. Descriptive statistics of available sulphur content of sugarcane growing soils extracted by different extractants, SOC and plant TVD leaf sulphur content

	Sulphur in different extracts (ppm)*					SOC (%)	TVD leaf S (ppm)
	CaCl_2 (0.15 %)	MCP (500ppm)	AAA (0.50:0.25M)	SBC (0.5M)	NNAA		
Min	2.45	8.09	4.29	9.60	1.60	0.14	0.04
Max	96.07	139.21	188.34	151.73	45.59	0.86	0.14
Average	25.37	36.88	42.78	54.19	18.02	0.41	0.10
SD	23.27	32.34	42.96	42.43	15.39	0.20	0.03
SE±	3.36	4.67	6.20	6.16	2.22	0.03	0.01
Confidence level ($\alpha=0.05$)	6.58	9.15	12.15	12.00	4.35	0.06	0.01

*MCP=Mono Calcium Phosphate (500 ppm); AAA = Ammonium Acetate-Acetic acid (0.50:0.25M); SBC = Sodium Bicarbonate (0.5M); NNAA = Neutral Normal Ammonium Acetate

Sulphur exists in soil as organic and inorganic forms. The inorganic S exists as water soluble, adsorbed and insoluble forms and the organic S exists in several known and unknown S containing organic compounds (Tabatabai 1982). Several methods of extraction had been tried in the past to estimate different S fractions. From the plant nutrition point of view, the fraction(s) of S that is absorbed by the plants during its growing period is termed as the available S. However, no single extractant is available for this purpose and hence several chemicals had been tried in the past to choose one which has the highest correlation with the plant S uptake. In the present study, five extractants have been tried. Comparison of the means conducted with student's *t* test revealed that the mean S extracted was significantly different among different extractants. This reveals that though different extractants extract the same form of S, the extent and magnitude of extraction vary. Similar variations in S extracted by different extractants were reported by Matula (1999), Huda et al. (2004) and Pandey and Girish (2007). The available sulphur content extracted by 0.15% CaCl₂ of different sugarcane growing soils varied widely. The plant available S present in the soil depends on the total sulphur content, organic matter, mineralization rate, soil physical and chemical properties (Tabatabai 1982). The colour, texture, physical and chemical properties, cropping system followed and fertilization practices in the sample fields varied widely and hence the available sulphur content is also likely to vary. This variation in the available S content is reflected in the

TVD leaf blade sulphur content. Similar variability in the S extracted was observed in the other extractants also. However, significant and positive correlations were observed between the S extracted by pairs of various extractants. Although the ability of S extraction differs between extractants, the S displacement from soil into solution follows a uniform trend (Huda et al. 2004).

Soil organic carbon content was found to have significant and positive correlation with the S extracted by all the extractants studied, revealing the contribution of SOC to S availability. Although the nature of organic S present in the soil is not thoroughly understood, the contribution of organic S towards available S is well documented (Tabatabai, 1982). Soil S content was related to organic matter content and chemical transformation of forms of sulfur was found to be predominantly catalyzed by microbial action (Kertesz and Mirleau 2004) with microbial transporters playing a central role (Kertesz 2001). Gharmakher et al. (2009) found that S mineralization rates were mainly related to organic C. Sarkar et al. (1998) reported that soil organic sources supplied considerable sulphur to crop uptake. Like N and P, S in most soils was found predominantly bonded to organic matter (Zhao et al. 1996). The contribution of organic forms to dissolved S was reported to be 46% by Homann et al. (1990) and 50% by Kaiser and Guggenberger (2005). The organic S fraction in soil was reported to account for at least 90% of the total S (Tabatabai and Bremner 1972). Bohn et al. (1986) opined that

Table 2. Correlation coefficients among the available sulphur extracted by different extractants, SOC and plant TVD leaf sulphur

Parameter	CaCl ₂ (0.15%)	MCP (500ppm)	AAA (0.50:0.25M)	SBC (0.5M)	NNA	SOC (%)	TVD leaf S (ppm)
CaCl ₂ (0.15%)	1						
MCP (500ppm)	0.991**	1					
AAA(0.50:0.25M)	0.931**	0.943**	1				
SBC (0.5M)	0.835**	0.840**	0.804**	1			
NNA	0.559**	0.541**	0.476**	0.870**	1		
SOC (%)	0.907**	0.886**	0.796**	0.855**	0.710**	1	
TVD leaf S (ppm)	0.771**	0.718**	0.631**	0.750**	0.703**	0.846**	1

** Significant at 1% level

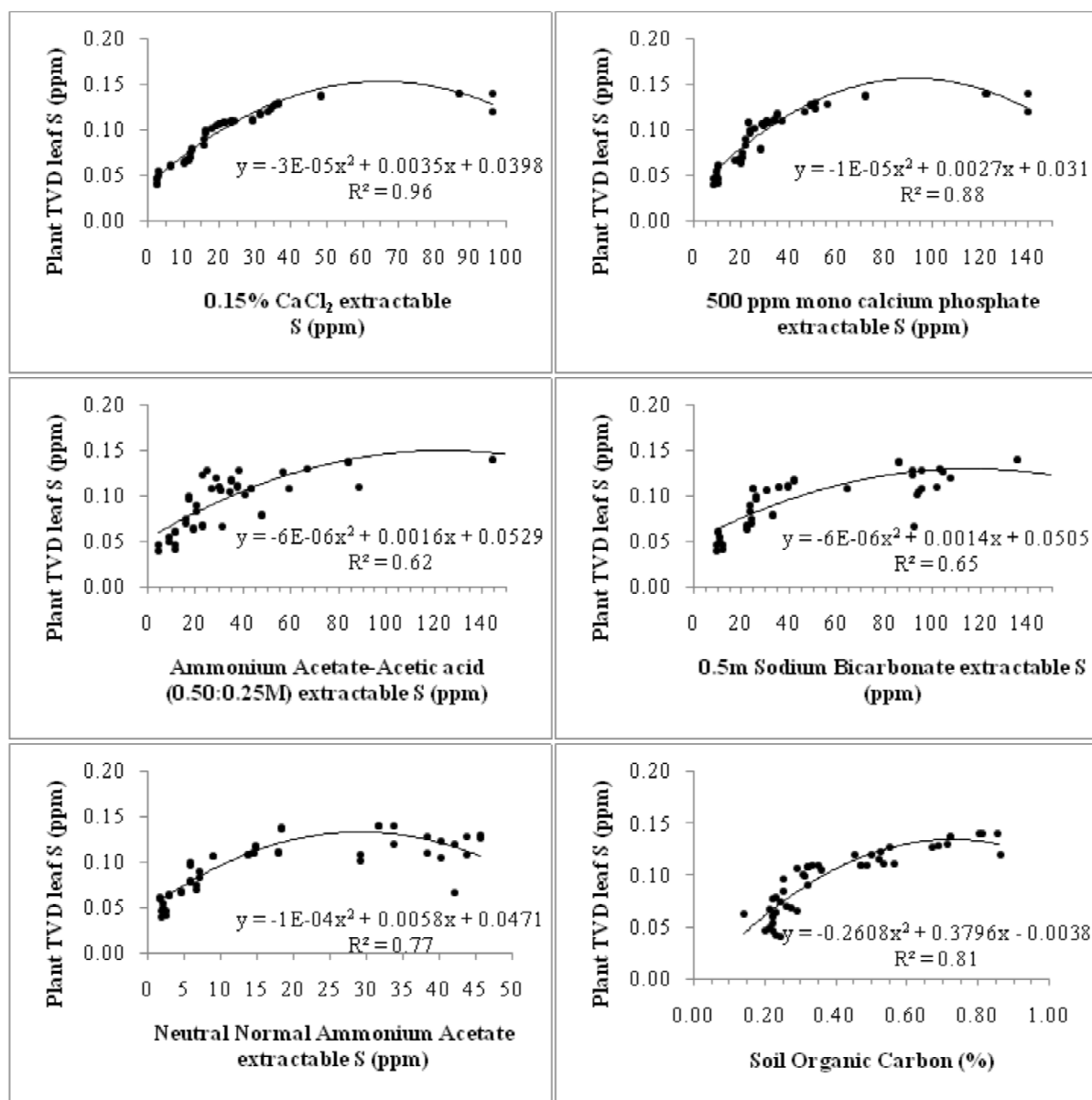


Fig.1. Relationship between sugarcane TVD leaf sulphur content and sulphur extracted by different extractants and soil organic carbon

Table 3. Factor pattern for the first three principal components (PC)

Variable	PC1	PC2	PC3
0.15% CaCl ₂ S	-0.859	-0.272	0.417
500 ppm mono calcium phosphate S	-0.892	-0.276	0.336
(0.50:0.25M) Ammonium acetate - acetic acid S	-0.928	-0.246	0.196
0.5M sodium bi-carbonate S	-0.618	-0.730	0.263
NN ammonium acetate S	-0.200	-0.923	0.316
Soil organic carbon	-0.646	-0.436	0.567
Plant TVD leaf S	-0.377	-0.401	0.821
Contribution of each PC (%)	81.49	11.02	4.82
Cumulative contribution (%)	81.49	92.51	97.33

inorganic S was generally much less abundant than organically bound S in most agricultural soils.

Riffaldi et al. (2006) observed a positive correlation between the cumulative amount of SO_4S mineralized and organic C in soils and concluded that the soil organic carbon is an important controlling factor in S mineralization. Sulphur deficient soils were often found with low organic matter, coarse-textured, well-drained, and subject to leaching (Kost et al. 2008).

Wide variability in the S content of the TVD leaves was observed between the samples. Positive and significant correlations between the available S and the TVD leaf S confirmed that all the extractants extracted the plant available S but with different magnitudes. The highest correlation was with 0.15% CaCl_2 extracted S ($r=0.771^{**}$) followed by 0.5M NaHCO_3 ($r=0.750^{**}$) (Table 2). Soil organic carbon had a positive and significant correlation with the TVD leaf S ($r=0.846^{**}$) revealing that SOC is a significant factor controlling the plant available S. Though the critical limit for available S had been fixed as 10 ppm by various researchers, a linear trend in TVD leaf S was observed for various extractants. Fig.1 shows second order polynomial relationship between plant TVD leaf S and the S extracted by various extractants as well as the SOC. The plant TVD leaf S increased linearly up to 45 ppm of 0.15% CaCl_2 extractable S ($R^2=0.96$). Linear relationship was observed up to 65 ppm of calcium phosphate extractable S ($R^2=0.88$), 85 ppm of ammonium acetate-acetic acid extractable S ($R^2=0.62$), 90ppm of sodium bicarbonate extractable S ($R^2=0.65$) and 17ppm of NN ammonium acetate extractable S ($R^2=0.77$). Increasing SOC up to 0.55% had a linear response in TVD leaf S ($R^2=0.81\%$). Though literature suggest that the critical limit for soil available S as 10 ppm, a linear response was observed till a higher concentration of available S suggesting that the S uptake by plants follows a linear response as that of other macro nutrients like N, P and K rather than a critical limit as that of micro nutrients. These results suggest that the response of sugarcane crop to soil available S is linear up to a certain concentration which can be called as optimum S concentration, which may vary according to the extractant used. However, this requires to be confirmed based on the total sulphur uptake by sugarcane and its yield response.

Principal component analysis of soil available S with different extractants and S content of TVD leaf had revealed that the elements were correlated with three principal components (PCs) in which 97.33% of the total variance in the data was found (Table 3). The first PC with 81.49% of variance comprises 0.15% CaCl_2 S, 500 ppm mono calcium phosphate S and (0.50:0.25M) ammonium acetate - acetic acid S with high loadings. These three extractants can be considered as having a strong relationship and representing the available S than the other extractants. These extractants represent water soluble S, and part of adsorbed and organic S and had higher concentrations as compared to NN ammonium acetate extracted S. The second PC was found to be responsible for 11.02% of the total variance and significant loading was obtained for NN ammonium acetate S. The low concentration of S extracted by AA ammonium acetate and its higher loading in PC2 suggest that this PC explains the contribution of water soluble S alone. The third PC with 4.82% of the variance had the highest loading for plant TVD leaf S suggesting that this PC explains the plant nutrient concentration. Based on the factor loadings of variables on the first two principal components shown in Fig. 2, the S extracted by 0.50:0.25M ammonium acetate-acetic acid, 500 ppm mono calcium phosphate and 0.15% CaCl_2 were found to contribute more towards plant S.

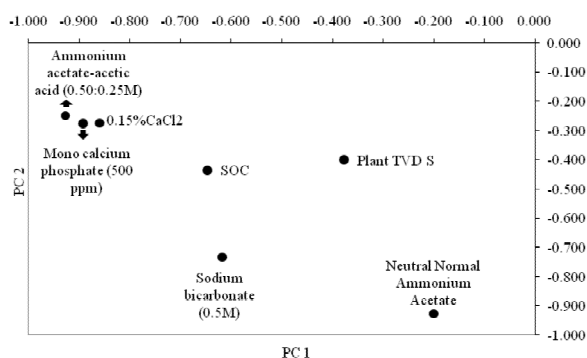


Fig. 2. Factor loadings of variables on the first two principal components

Conclusion

The present study indicated that the available sulphur status of sugarcane growing soils vary widely. About 17% of the soils were low in available S status (<10 ppm) while 35 % were in medium (10 - 20 ppm) and 48% were in high (>20 ppm) category. Various extractants viz., 0.15% CaCl_2 , 500 ppm mono

calcium phosphate, ammonium acetate-acetic acid (0.5:0.25M), 0.5M sodium bicarbonate and neutral normal ammonium acetate varied significantly in their ability to extract soil S. A significant and positive correlation existed between the S extracted by various extractants and between S extracted and soil organic carbon and TVD leaf S. A linear trend in plant TVD S was observed beyond the soil critical S content of 10 ppm, which was extended up to 45 ppm. PC analysis revealed that 0.15% CaCl_2 , ammonium acetate-acetic acid and mono calcium phosphate extracted S contributed more towards PC1 and the plant TVD leaf S.

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