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An Investigation on Factors Responsible for Sulphur Nutrition of Tea in Sri Lanka

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ABSTRACT

An islandwide field survey was carried out during July 2001 to March 2003 to collect the detailed information on VP tea fields, from 200 corporate sector estates, out of a total about 400, representing different climatic zones, soils, ownerships and plantation management practices. This was primarily done to identify the factors affecting responses to applied fertilizers, with special emphasis on sulphur (S). A multi-stage sampling method was used to select the estates, in proportion to the extents present and categories considered.

From this study, a significant difference on available S and organic S was observed among soils of two different main climatic zones. Wet zone had the highest available and organic S. Soil organic and available S significantly differ among three different elevational categories *viz.* Low country (< 300 m amsl), Mid country (300 - 900 m amsl) and Up country (> 900 m amsl). The highest S levels were observed in Up country soils. Significant difference in organic S was observed among slope categories considered in the study as low (0 - 25%), moderate (25 - 70%) and high (> 70%). Soil organic S in low and moderate slopes was higher compared to high slope category. Significant differences in organic S were also observed among gravelliness categories considered in the study, low (0 - 10%), moderate (10 - 50%) and high (> 50%). Lowest gravel category had the highest organic S value.

There was a significant positive correlation between organic carbon content and organic S content of soils in tea growing areas. There was a reduction in soil available S with increasing soil available phosphorus. The relationship between soil pH and available S had a low negative correlation.

Significant differences in organic and available S were observed between with and without green manure application. Higher levels of S were observed in green manure applied fields. Significant differences in organic S were observed among different shade categories. Higher levels were observed under good shade establishment category.

There are significant differences in available soil S among fields under different foliar sprays, Zinc sulphate, Epsom salt, Zinc sulphate plus Epsom salt, and any other foliar sprays used in tea plantations. Highest levels for available soil S were found in Zinc sulphate and Epsom salt combination.

The study also revealed that good agricultural practices could reduce application of S based fertilizer.

Key words: Soil available sulphur, organic sulphur, sulphur nutrition

INTRODUCTION

Sulphur (S) is an essential plant nutrient for plant growth. In addition S could affect the quality of the final product. It is a constituent of the S bearing amino acids, such as cystine and methionine which are essential for the synthesis of the vital plant pigment chlorophyll and the vitamin thiamine. Thus, S plays a vital role in photosynthesis and carbohydrate metabolism of the plant. As a consequence of reduced S inputs to soils, S deficiency is becoming a major factor that limits yield and reduce quality of crops under intensive cultivation. Therefore, S fertilization is equally important as nitrogen, phosphorus and potassium, especially in intensive cropping systems. Sulphur in Sri Lankan agriculture is now gaining added importance because of the recognition of its role in increasing crop production, not only for oilseeds, pulses, legumes and forages but also for cereals and plantation crops.

Sulphur occurs in soils in organic and inorganic forms, with the organic S accounting for more than 95% of the total S in most soils. However, the proportion of inorganic S in a soil varies widely according to soil type and depth (Tabatabai, 1982). As a considerable proportion of S occurs in organic forms, those should be converted to the available inorganic form as sulphate (SO_4^{2-}), prior to be taken up by plants.

Sulphate sulphur concentrations in soils show a spatial and a seasonal variability, depending on factors such as soil water regime, microbial activity, atmospheric deposition, plant uptake, fertilizer applications and other agronomic practices. Agronomic efficiency of applied S mainly depends on optimal rate and frequency of application, residual availability and crop performance under different soil-crop management situations. Thus, there is a need to assess the reserves of S in well-defined soil groups and identify the factors responsible for variation in S status in tea growing areas in relation to agronomic efficiency of applied S. Such information will also be beneficial to growers of crops other than tea, where similar types of soils are used for cultivation.

MATERIALS AND METHODS

An islandwide field survey was carried out during July 2001 to March 2003 to collect the detailed information from vegitatively propagated (VP) tea fields, in 200 corporate sector estates, out of a total about 400, representing different climatic factors, soils, ownerships, and plantation management practices. The high yielding fields between 10 - 15 years of age after first canopy pruning were chosen. In general, no nutrient deficiency symptoms were observed in chosen fields. This was primarily done to identify the factors affecting responses to applied fertilizers, with special emphasis on S. A multi-stage sampling method was used to select the estates in proportion to the extents present and categories considered.

Detailed information on field management practices, bush characteristics, records on pest and disease, yield data, climate and site characteristics were collected. A questionnaire was used for data and information collection. A personal interviewing procedure was also adopted to collect information.

Besides, soil samples were collected to a depth of 0 - 15 cm and 15 - 30 cm, from the selected estates and these soils were air dried and were passed through a 2 mm sieve. For total nutrient analysis the soils were ground and passed through 0.5 mm sieve. Total sulphur in soil was determined by magnesium nitrate/nitric acid digestion procedure of Butters and Chennery (1959) and available sulphur was extracted with potassium di-hydrogen phosphate solution (500P) method of Spencer and Freney (1960).

RESULTS AND DISCUSSION

a. Physical environment

Effect of main climatic zone on soil sulphur status

Rainfall is one of the most important climatic factors limiting the growth and yield of tea. Even though Sri Lanka is a very small island, there is a marked variation in the climate amongst the different regions. On the basis of rainfall distribution and duration of dry weather, the island is broadly classified into three main zones; wet zone with mean annual rainfall over 2500 mm, intermediate zone with mean annual rainfall between 1750 – 2500 mm and dry zone with mean annual rainfall less than 1750 mm.

The variation of total, organic and available S of soils in main tea growing climatic zones are given in Table 1. Significant difference in available S was observed among two different main climatic zones ranging from 40 - 486 mg kg^{-1} and 42 - 272 in wet and intermediate zones respectively. Wet zone showed the highest S levels. This is could be due to increase in transformation of organic S to available S (S mineralization) as a result of higher microbial activity in wet zone soils. The other reason could be the S deposition from the rain water which is higher in the wet zone than in the intermediate zone due to higher dissolution of SO_2 present in air as a result of combustion of organic fuels. Amarasiri and Lathiff (1982) determined the sulphur content of rainfall over a period of one year in the dry, intermediate and wet zones of Sri Lanka. According to them, the amounts of S brought annually by rain ranged from 4.9 kg ha^{-1} at Murunkan to 23.9 kg ha^{-1} at Bombuwela. The average values for dry, intermediate and wet zones were 9.72, 13.1 and 16.3 kg ha^{-1} S per year respectively. Average value for Sri Lanka was approximately 12 kg ha^{-1} S per year. The wide variation recorded at the coastal stations was due to oceanic spray. In general, S deposition was 71% higher in the wet zone than that in the dry zone.

Table 1. Effect of climatic zone on soil sulphur status

Climatic zone	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% Available to total S
Wet	121	576 (258-1418)	441 (85-948)	135 (40-486)	23.44
Intermediate	75	520 (278-998)	422 (110-926)	98 (42-272)	18.85
LSD		53	46	20	
P > F		0.040	0.40	0.004	

Tennakoon *et al.* (2006) monitored rainwater quality parameters such as, *in situ* pH, NO_3^--N, SO_4^{2-}-S, Mg^{2+} and Ca^{2+} at meteorological centers of the TRI regional centres at Talawakelle, Ratnapura, Hantane, Passara, Kottawa and Deniyaya. According to this study, the highest SO_4^{2-}-S has been reported from the Ratnapura centre. Mean value of monthly SO_4^{2-}-S deposition at Ratnapura was 2.43 kg ha^{-1}, while corresponding mean values of monthly SO_4^{2-}-S deposition were 1.78, 0.85, 2.06, 0.95 and 0.98 kg ha^{-1} in Deniyaya, Hantane, Kottawa, Passara and Talawakelle respectively.

Similarly, total S content also was significantly higher in wet zone compared to the intermediate zone. However, organic S fraction did not show a significant variation among two climatic zones.

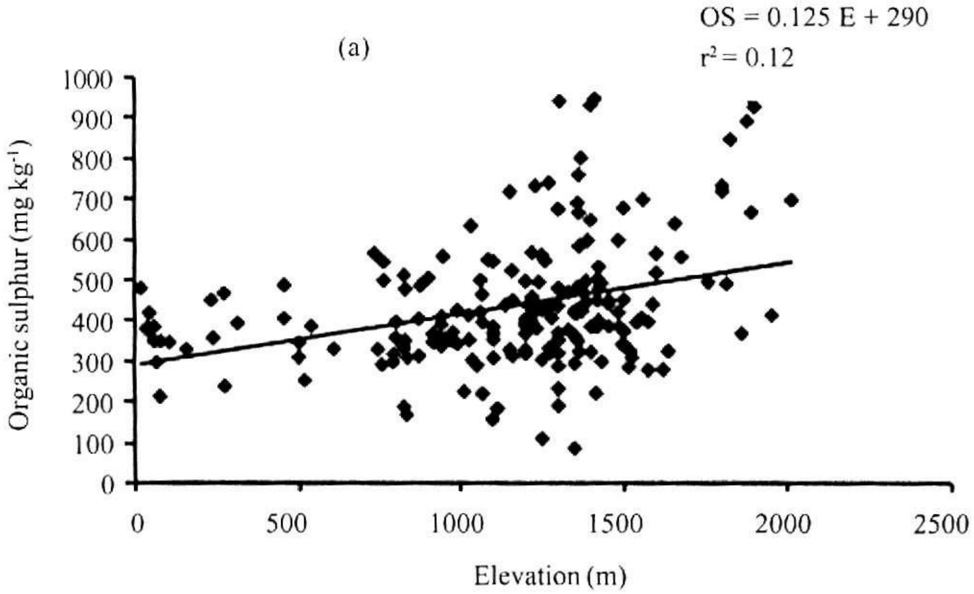
Effect of elevation on soil sulphur status

Based on elevation, tea growing regions are divided into three main categories, Low country (< 300 m amsl [above mean sea level]), Mid country (300 - 900 m amsl) and Up country (> 900 m amsl). The variations related to total, organic and available S of soils in different elevational categories are given in Table 2. Significant differences in organic S were observed among the three different elevational categories. Up country soils recorded the highest level. As shown in Figure 1 there is a positive relationship between elevation and organic and available S content in soils.

It can be explained that, accumulation of soil organic matter occur in higher elevations owing to the low degradation rates of organic matter. As the elevation increases the

Table 2. Effect of elevation on soil sulphur status

Elevational category	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% available S to total S
Low country	19	455 (258-670)	365 (213-481)	90 (45-202)	19.78
Mid country	42	492 (330-640)	385 (167-566)	107 (44-317)	21.74
Up country	135	587 (278-1418)	458 (85-948)	129 (40-486)	21.97
P > F		0.0006	0.0037	0.0278	



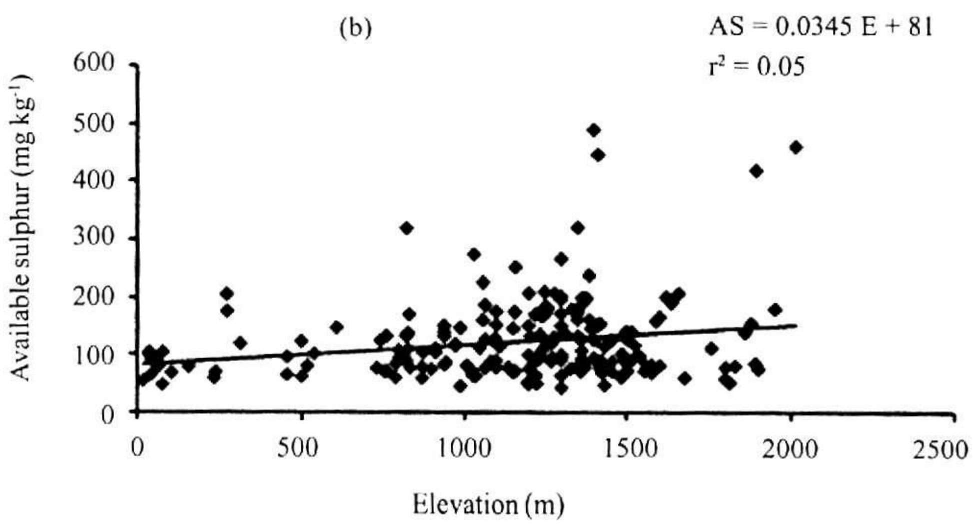


Figure 1. Relationship between elevation and (a) organic sulphur (b) available sulphur

activity of micro-organisms also reduces due to low temperature. In tea growing districts of Sri Lanka, the organic matter varies with elevation between 1.5 - 2.0 percent carbon at low elevation and 3.0 - 4.0 percent carbon at high elevations (Krishnarajah, 1984).

Effect of slope of land on soil sulphur status

Tea lands have been classified into three categories, by TRI, according to their slope; low (0 - 25%), moderate (25 - 70%) and severe (70% >). The variation of total, organic and available S of soils in different slope categories are given in Table 3. Significant differences in organic S were observed among slope categories. Majority of estates are within the moderate slope category. Moderate slope category recorded the highest levels for S followed by low slope. It may be due to higher nutrient loss by soil erosion in high slope lands. Soil erosion occurs in tea cultivation due to various agronomic practices, *e.g.* land preparation, replanting, and also due to poor management of tea fields. It has been shown that most of the nutrient losses from tea lands occur as a result of soil erosion but not due to run-off water (Basnayake, 1985; Hasselo and Sikurajapathy, 1965; Holland and Joachim, 1933). In an experiment conducted by Basnayake (1985) in Uva region at 30% slope, under well managed and poorly managed seedling tea fields, they found estimated soil losses were 0.5 tons ha^{-1} and 1.3 tons ha^{-1} respectively during a three month period. The estimated nutrient losses were 0.8 - 1.4 kg N, 0.07 - 0.09 kg P, 0.14 - 0.29 kg K and 30 - 50 kg organic matter per ha^{-1} during the same period.

Table 3. Effect of slope of the land on soil sulphur status

Slope category	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
Low	18	431 (258-640)	343 (110-566)	87 (45-168)	20.19
Moderate	176	568 (283-1418)	444 (85-948)	124 (40-486)	21.83
Severe	2	414 (408-420)	290 (297-283)	124 (111-137)	29.95
P > F		0.0061	0.0152	0.1089	

Effect of gravelliness on soil sulphur status

The relative size distribution of mineral soil particles is usually expressed by the term texture, which refers to the fineness or coarseness of a soil. More specifically, texture is expressed as the relative percentage proportion of sand, silt and clay. All particles which are greater than 2 mm diameter are considered as gravels. The tea lands have been classified by TRI into three categories according to their gravelliness. They are low (0 - 10%), moderate (10 - 50%) and severe (> 50%).

The variation of total, organic and available S under different gravelliness categories are shown in Table 4. Significant differences in organic S were observed among gravelliness categories. Lowest gravel category showed the highest levels of S with increasing gravel percentage decreasing the soil organic S concentration. This has resulted largely due to the decreased organic matter content of soils with increasing gravel percentage.

Table 4. Effect of gravelliness categories on soil sulphur status

Gravelliness category	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
Low	96	611 (278-1390)	478 (85-948)	133 (40-458)	21.76
Moderate	94	501 (258-1418)	391 (157-931)	110 (42-486)	21.95
Severe	6	481 (465-518)	388 (335-449)	93 (69-130)	19.33
P > F		0.0001	0.0005	0.0513	

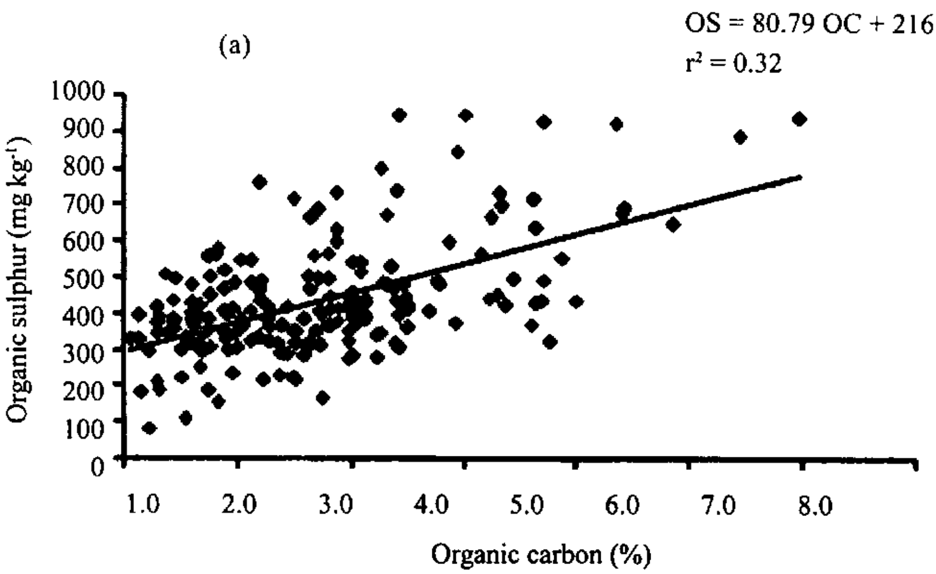
The available S content also significantly differs among gravelliness categories. As explained earlier, increase in gravel content in soil decreased the soil available S owing to decrease in soil colloidal fraction which is responsible for anion exchange. Results showed that, total soil S also significantly differs among gravelliness categories. Takkar (1988) has shown that, total S in soils of Maharastra is a function of clay content and substantiated this by a significant and positive correlation co-efficient of 0.70 between the two. Total S in fine textured soils of Bihar was 851 $mg\ kg^{-1}$ and 407 - 471 $mg\ kg^{-1}$ in the coarse and medium textured soils which is an almost two fold increase.

b. Soil chemical properties

Effect of soil organic carbon content on soil sulphur status

All soils contain organic matter in varying quantities and at different stages of decomposition. Soil organic matter plays a multiple role, *i.e.* supplying nutrients steadily to plants through mineralization, as well as forming humus which provides the necessary building material for the aggregation of soil colloids leading to formation of soil crumbs and increasing cation exchange capacity. The latter in turn helps to build a better soil structure and tilth thereby improving the water holding capacity, aeration, nutrient retention and buffering capacity of soil.

Figure 2 shows a significant positive correlation between organic carbon content and organic S content. However, there is a poor correlation between soil organic carbon content and soil available S content. It may be due to many factors affecting soil S availability through mineralization other than organic matter content. In most soils, organically bound S provides the major S reservoir (Reisenauer *et al.*, 1973; Scott and Anderson, 1976). Organic S accounts for > 95 % of the total S in most soils and in peat soils it can be almost 100% of the total S.



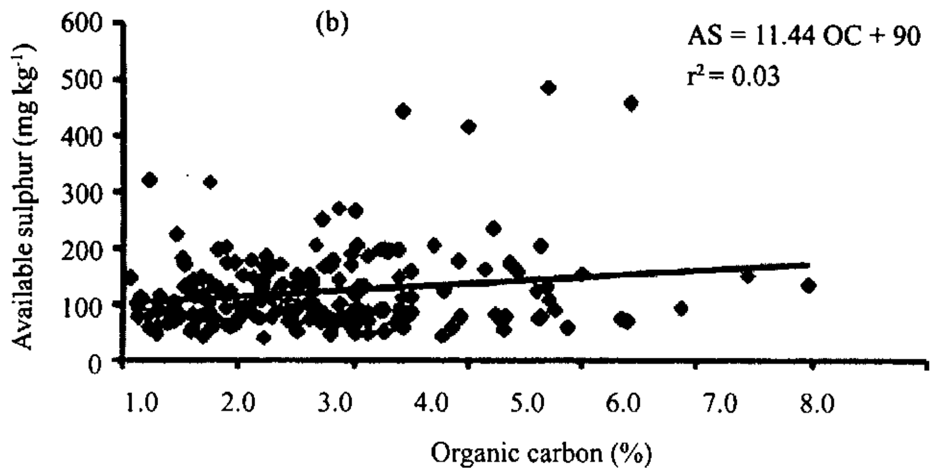


Figure 2. Relationship between Organic carbon and (a) organic sulphur (b) available sulphur

Inorganic S is usually < 5% of total S in the soil (Neptune *et al.*, 1975). A positive correlation between soil organic matter and available S was also reported by Ghosh *et al.*, (2003) in soils of tea growing areas of Doors region of India. The majority of soils studied had organic carbon content percentage between 1.5 – 4.0%.

Effect of soil phosphorus on soil available sulphur status

The effect of soil available P content on soil available S content is shown in Figure 3. Although the effect of soil available P content on soil available S content was less clear, there was an apparent reduction in soil available S with increasing soil available P.

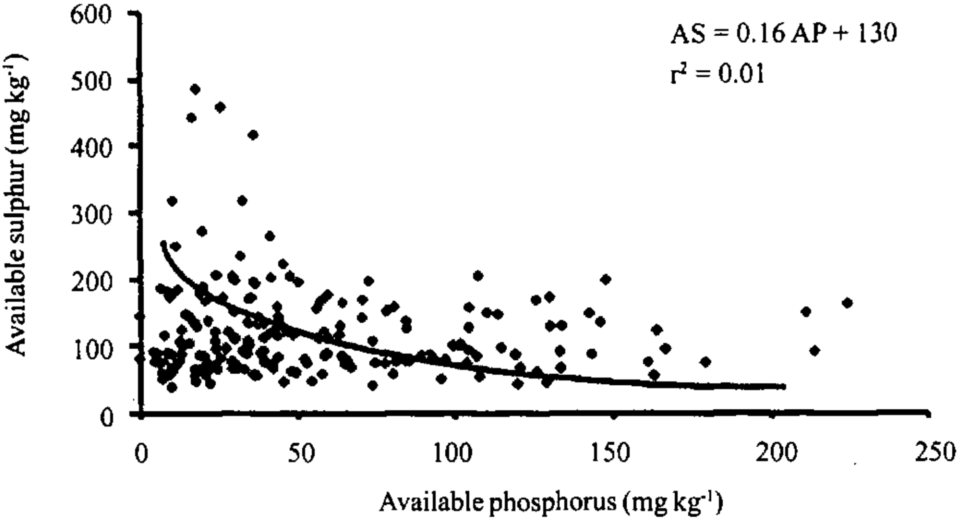


Figure 3. Relationship between soil available phosphorus content and soil available sulphur content

Some researchers have reported that soils rich in phosphate are not likely to retain much sulphate in surface layer (Hue *et al.*, 1985; Ensminger, 1954; Chao *et al.*, 1962). The work carried out by Ananthacumaraswamy (1987) showed that there is no difference in SO_4^{2-} -S content in the tea soils of Sri Lanka due to increasing levels of PO_4^{3-}. Both positive and negative interactions have been reported by Biswas and Prasad (1991) and Tandon (1986, 1987, 1991). Recent studies showed that nature of P-S interaction mainly depends on their rate of application. Several researchers have reported that the P-S interaction is synergistic at low to medium levels of P and antagonistic only at higher levels, usually 60 or more kg P_2O_5 ha^{-1} for field crops (Pasricha, 1987; Aulakh, 1990; Ali, 1991).

Effect of soil pH on available sulphur status

The relationship between soil pH and available S is shown in Figure 4. A relationship with a low negative correlation (r^2=0.02) was observed in this study. This indicates that the available S slightly decreased with the increase in soil pH. Elkins and Ensminger (1971) had shown that SO_4^{2-} -S retention by acid soils increased with decreasing pH. Mattson (1927) found that an appreciable quantity of SO_4^{2-}-S was adsorbed by some soil colloids and that the adsorption capacity of a soil colloid increased with increasing acidity. This results in increased retention of anions including SO_4^{2-}-S as well.

Continuous use of high levels of nitrogen fertilizers over the past decades has resulted in the tea soils becoming more acidic and certain plantations are recording soil pH

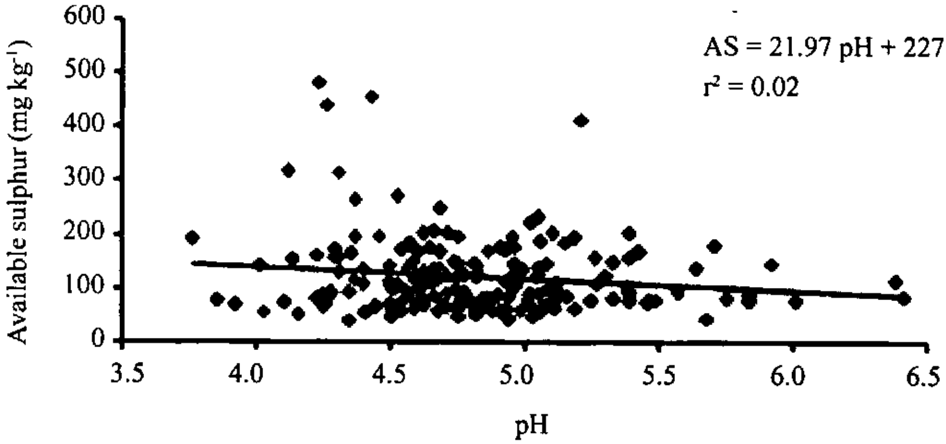


Figure 4. The relationship between soil pH and available sulphur in soils

values as low as 3.7 and 3.8. Despite the fact that tea thrives in acid soils (pH 4.5 – 5.5), when soil pH falls below 4.0, degeneration of the clay minerals would occur with the release of oxides of aluminium and silicon. The high acidity also results in the building up of high concentration of aluminium, silicon, iron and manganese in the soil solution. According to Ensminger (1954), SO_4^{2-}-S adsorption capacity follows the order: Al_2O_3> Kaolinite> Beauxite> Peat> Limonite> Haematite> Hydrated aluminium > Goethite. Therefore, the SO_4^{2-}-S retention could be higher in soils having oxide clays in tea growing soils of Sri Lanka.

The current practice of dolomitic limestone application is based on the soil pH. The objective is to control increasing soil acidity and to provide both Mg and Ca, needed for the growth of the tea plant. Therefore dolomite application could affect soil available S.

c. Agronomic practices

Effect of maintenance of tea stand on soil sulphur status

Bush stand is one of the major yield determinants of tea. The tea lands have been classified into three categories according to tea stand by TRI. They are low (20 - 50%), medium (50 - 70%) and good (> 70%). However, all tea fields under reference fall within medium and good categories indicating that the situation as satisfactory.

Table 5. Effect of maintenance of tea stand on soil sulphur status

Tea stand	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
Medium	14	518 (283-758)	415 (157-690)	103 (46-195)	19.88
Good	182	557 (258-1418)	435 (85-948)	122 (40-486)	21.90
LSD		NS	NS	NS	
P > F		0.4529	0.6569	0.3271	

The variation of soil total, organic and available S in different tea stand categories are shown in Table 5. Though, no significant difference in organic S was observed among tea stand categories, good bush stand always showed higher S levels compared to medium category. This could be due to loss of nutrients owing to high runoff as well as poor. nutrient recycling due to less ground cover in medium bush stand category.

Effect of establishment of drains on soil sulphur status

The soil conservation methods adopted should aim to absorb the incident rainfall as much as possible and to lead any excess away from the fields at non-erosive velocities to minimize loss of soil. Among soil conservation methods used in tea plantations, establishment of leader and lateral drains are the most effective. The tea lands have been classified into five categories in this study according to the establishment of drain. They are very good, good, satisfactory, poor and none. The variation of soil total, organic and available S in lateral and leader drain categories is shown in Tables 6 and 7 respectively.

Table 6. Effect of establishment of lateral drains on soil sulphur status

Lateral drain	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
Good	116	568 (258-1418)	442 (85-948)	125 (44-486)	22.00
Satisfactory	67	545 (303-1390)	429 (219-947)	116 (40-458)	21.28
Poor	13	488 (283-770)	386 (157-666)	102 (51-148)	20.90
P > F		0.4625	0.4651	0.4156	

Table 7. Effect of establishment of leader drain on soil sulphur status

Main drain	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
Very good	2	605 (475-735)	422 (277-567)	183 (168-198)	30.24
Good	116	560 (258-1418)	436 (85-948)	124 (44-486)	22.14
Satisfactory	68	559 (303-1390)	443 (219-947)	116 (40-458)	20.75
Poor	78	436 (283-570)	335 (157-425)	101 (51-148)	23.16
P > F		0.2288	0.2435	0.4079	

No significant differences in organic, total and available S were observed among lateral and leader drain establishment categories considered in the study. However, higher S levels were seen in fields with proper lateral and leader drain establishment.

Effect of green manure on soil sulphur status

The tea lands have been classified into two categories according to green manure application in this study. They are with and without green manure application. The variation of soil total, organic and available S in green manure categories is shown in Table 8.

Significant differences in organic and available S were observed with and without green manure application situation. Higher S levels were seen in green manure applied fields. This is likely.due to increase of organic S content with the addition of green manure.

Table 8. Effect of application of green manure on soil sulphur status

Green manure	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% available to total S
Applied	134	620 (360-1418)	476 (85-948)	144 (40-486)	23.22
Not applied	62	524 (258-1390)	413 (110-947)	110 (42-443)	20.99
LSD		55	47	21	
P > F		0.0007	0.0098	0.0018	

Effect of establishment of shade on soil sulphur status

The tea land has been classified into four categories according to high and medium shade in this study. They are above recommended, recommended, below recommended levels and none. The variation of soil total, organic and available S in different high shade categories is shown in Table 9. No Significant difference in total, organic and available S was observed among four different high shade establishment categories. This result can be expected, as the high shade are planted at longer spacing, especially to provide shelter from winds and to reduce transpiration losses. Therefore, impact on soil fertility cannot be expected in a significant manner as the supply of green manure from high shade is not significant.

The variation in soil total, organic and available S in different medium shade categories is shown in Table 10. Significantly higher level of organic S was observed in fields with higher densities of shade. It can be explained that medium shade provides considerable quantities of green manure in the form of loppings and natural leaf fall, which supply organic matter and nutrients to soils.

Effect of synthetic fertilizer on soil sulphur status

The tea lands have been classified into three categories according to application of S containing and non S based fertilizer used in this study. They are urea, urea plus kieserite and sulphate of ammonia (SA).

Table 9. Effect of high shade on soil sulphur status

High shade	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% available to total S
Above R	10	574 (420-905)	456 (283-666)	117 (40-272)	20.38
R	105	557 (278-1390)	434 (85-948)	123 (47-443)	22.08
Below R	62	576 (303-1418)	455 (219-931)	121 (42-486)	21.00
None	19	459 (258-640)	348 (167-566)	112 (45-317)	24.40
P > F		0.9345	0.0713	0.1131	

R : Recommended shade

Table 10. Effect of medium shade on soil sulphur status

Medium shade	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% available to total S
Above R	6	621 (360-1418)	478 (85-948)	143 (40-486)	23.02
R	98	523 (258-1390)	407 (110-947)	115 (45-443)	21.98
Below R	39	556 (303-905)	447 (219-759)	109 (42-272)	19.60
None	53	466 (278-550)	378 (190-497)	89 (46-145)	19.09
P > F		0.0103	0.0442	0.0426	

R : Recommended shade

The variation of soil total, organic and available S in fields where different fertilizers are used is shown in Table 11. Analysis of data showed that there is no significant difference in available soil S among application of sulphur containing fertilizer with non S sources considered in the study as urea, urea and kieserite, and sulphate of ammonia as sources of S. The fields where S containing fertilizer was applied showed higher available soil S than non S applied fields. This may be due to S received from regular synthetic fertilizer applications containing S. It could also be due to very low removal of S by harvest, addition of Zn as Zinc sulphate in the form of foliar application after each ground fertilizer application which indirectly adds S and the contribution from leaf litter and from rainfall.

Table 11. Effect of synthetic fertilizer on soil sulphur status

Fertilizer	No. of estates	Total S (mg kg^{-1})	Organic S (mg kg^{-1})	Available S (mg kg^{-1})	% available to total S
Urea	77	552 (258-1390)	439 (187-948)	113 (44-456)	20.47
Urea + kieserite	102	554 (278-1418)	434 (110-941)	121 (40-486)	21.84
SA	14	578 (335-905)	415 (85-675)	164 (77-318)	
P > F		0.9608	0.9158	0.1217	

Wickremasinghe *et al.* (1986) studied the S nutrition of tea in relation to soil and leaf sulphur status with 3 levels of N *viz.* 112, 224 and 336 kg N ha^{-1} yr^{-1} and combinations of SA : urea as 100:0, 75:25, 50:50, 75:25, 0:100. Results revealed that there was a linear reduction in soil SO_4^{2-}-S as the proportion of urea increased in the sulphate of ammonia to urea combinations (Anon, 2003, 2004, 2005, 2006).

Effect of foliar feeds on soil sulphur status

Tea lands have been classified into three categories according to foliar feeds application in this study as zinc sulphate, zinc sulphate plus commercial epsom salt (CES) and any other foliar feeds. The variation of soil total, organic and available S in different foliar feeds is given in Table 12. Among different foliar sprays, a significantly higher value in available S was seen from the fields sprayed with zinc sulphate plus CES.

Table 12. Effect of foliar feeds on soil sulphur status

Foliar feeds	No. of estates	Total S ($mg\ kg^{-1}$)	Organic S ($mg\ kg^{-1}$)	Available S ($mg\ kg^{-1}$)	% available to total S
$ZnSO_4$	120	533 (258-1418)	424 (85-931)	108 (40-486)	20.26
$ZnSO_4$ + CES	58	619 (278-1390)	479 (110-948)	140 (48-458)	22.61
Any other	14	504 (323-780)	359 (219-584)	145 (59-264)	28.76
P > F		0.0099	0.0123	0.0220	

Assessment of cost-benefits

From the results of this study, it is evident that, there are ample opportunities available to ensure steady supply of S for tea cultivations by adopting good agricultural practices (GAPs) and thereby promoting integrated nutrient management (INM) concept and reducing cost on S fertilization.

Cost of S fertilization per hectare per year is worked out as follows;

S recommendation for mature tea	= 20 kg S ha^{-1} yr^{-1}
If Micronized sulphur is used to supply S requirement	= 20*100/80
Micronized sulphur quantity	= 25kg S ha^{-1} yr^{-1}
Cost per hectare	= 30,000/1000*25
	= Rs. 750 ha^{-1} yr^{-1}

Total cost on S fertilization in Sri Lanka per year;

The mature tea extent in Sri Lanka	= 187,971 ha
If extent in Low country and Uva areas need to be fertilized with S input	= 100,000 ha x 750 ha^{-1} yr^{-1}
Therefore, total savings per year	= Rs. 75,000,000
	= Rs.75 million

As per findings of the study, it is possible to save approximately a sum of Rs.75 million per annum on S fertilization in tea sector of Sri Lanka.

CONCLUSION

By identifying factors affecting plant available soil S systematically and adopting good agricultural practices (GAPs), the cost on S fertilization can be saved. This contributes to soil S improvements and promote integrated nutrient management (INM) concept which improve physico-chemical properties of soil rather than application of synthetic fertilizers.

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