S. L. J. Tea Sci. 73(1). 74 - 89, 2008, Printed in Sri Lanka

Effect of Long-term Application of Urea and Sulphate of Ammonia on Soil Acidity, Soil and Plant Sulphur Status, Yield and Black Tea Quality

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ABSTRACT

A long term field experiment was carried out to investigate the performance of urea (U) and sulphate of ammonia (SA) at two rates (240 and 360 kg N ha^{-1} yr^{-1}) and five combinations of U and SA on yield, soil acidity, soil and leaf sulphur status and quality of processed black tea (*Camellia Sinensis (*L) O Kuntze) .

The results indicate that the yield obtained at 360 kg N ha^{-1} yr^{-1} is significantly higher compared to 240 kg N ha^{-1} yr^{-1} for both the N sources. No significant difference in yield was observed between different combination of urea and sulphate of ammonia. Soil pH levels have decreased linearly, as the proportion of sulphate of ammonia increased in Urea : SA combination at both soil depths. The soil sulphate sulphur concentrations is higher in sulphate of ammonia treated plots than in urea plots, and it increased linearly with the increased SA percentage. Further, concentration of SO_4^{2-} - S found to be more in the 15 - 30 cm depth than in 0 - 15 cm depth. It ranged from 45 - 290 and 59 - 482 $\mu g\ g^{-1}$ at 0 - 15 and 15 - 30 cm depths, in SA and urea treated plots respectively. Sulphur concentration in the mature leaf did not vary either with different sources or different rates of N.

The processed black tea quality parameters, Theaflavin, Thearubigin, liquor colour and strength did not show any significant difference between the source of N or N rates. Furthermore, combination of sulphate of ammonia and urea did not show any significant difference in quality. The organoleptic assessment of made tea samples confirmed these observations on processed black tea quality. Therefore application of urea is economical both in terms of productivity and quality of processed black tea.

Keywords: Quality, soil acidity, soil sulphur, SA, urea, yield

INTRODUCTION

Sri Lanka is the second largest tea producing country in the world, and tea accounted for approximately 14 % of Sri Lanka's total foreign exchange earnings. Out of about 300 million kg produced annually, approximately 92 percent is exported (Anon, 2002, 2006). Tea (*Camellia sinensis* (L.) O. Kuntze) is grown for its younger shoots and it grows well in acidic soil of pH 4.5 - 5.5. These shoots, having a bud and two to three succulent leaves, are generally plucked at regular intervals of 5-7 days depending on the elevation where it is grown. In order to increase the tea yield, the population of the shoots in the bush (shoot density), dry weight of plucked shoots and the number of times that the plucked shoots can be replaced for a given period of time by successive shoot generations should be increased. The regular use of mineral fertilizers containing N, P and K and at times Mg and S are necessary to maintain yield, while preserving the quality of processed tea.

The recommended quantities of N, P and K fertilizers for mature tea, vary from country to country (Willson, 1992). At present, 90 - 220 and 270 - 400 kg of N ha^{-1} yr^{-1} is recommended for seedling and vegetatively propagated mature tea fields respectively in Sri Lanka depending on potential yield categories. This is primarily to maintain tea bushes in vegetative phase of growth in order to harvest young shoots containing high N contents (30 - 50 g kg^{-1}) regularly. Nitrogen, phosphorus and potassium are given in the form of urea, muriate of potash and crushed Eppawela rock phosphate respectively. The total quantity of N to be given is recommended solely as urea (Anon, 2000a).

Nitrogen (N) fertilizer inputs largely contribute to yield followed by potassium and phosphorus. With every 1000 kg of processed tea, 30 - 50 kg of N is removed from one hectare of tea over a period of 12 months. About 15 - 30 kg K, 1.5 - 4 kg P are removed with every 1000 kg of processed tea while S amounts to about 2 - 5 kg. Sulphur is an essential element for tea and plays an important role in S-containing amino acids like methonine, cystiene and cystine. As urea does not contain any S, plants ought to depend on soil native S, recycling from leaf fall, atmospheric depositions, and foliar sprays of zinc and magnesium sulphates. It was reported by Amarasiri and Lathiff (1982) that the quantity of S precipitated with the rainfall was about 8 - 12 kg yr^{-1} in Sri Lanka. A recent study carried out by Tennakoon *et al.*(2006) revealed that the SO_4^{2-}-S brought down by rainfall amounts to 0.85 - 2.06 kg ha^{-1}. Natesan *et al.* (1989) reported that in south India, with every 100 kg processed tea sulphur removal is only 0.51 kg. However, the plant needs 3 to 4 times more S , for every 100 kg of made tea, in order to compensate for leaching losses and reduction of S to sulphides during monsoon periods.

Increasing rates of N fertilizers, particularly use of sulphate of ammonia generally increase soil acidity. Acidic soils is known to increase soil available aluminium. However, tea is an unique plant which can tolerate high levels of Al up to 20,000 mg kg^{-1} (Chenery, 1955; Matsumoto *et al.*, 1976) whereas many agriculturally important plant species, the presence of micro molar concentrations of Al^{3+} can result in inhibition of root growth (Morita *et al.*, 2004).

Black tea processing involves four important stages *viz.* withering, rolling, fermentation and firing. During fermentation the ployphenoloxidase present in tea leaves act on the polyphenols and form two groups of chemical compounds, Theaflavin (TF - Orange red in colour which is responsible for quality and brightness) and Thearubigin (TR - Brown in colour responsible for colour, body and strength) which are responsible for quality of made tea.

It was reported that black tea quality decreases with coarse plucking standards (Mahanta *et al.*, 1988; Obanda and Owuor, 1995; Owuor and Obanda, 1998). Variation in the black tea quality of a high yielding variety grown in Kenya was studied in response to application of NPKS fertilizer at 15:5:5:5 ratio over 200 - 400 kg N ha^{-1} $year^{-1}$ with different plucking standards and intervals by Owuor *et al.* (2000) and they found decline in quality with increasing N rate from 200 to 400 kg N ha^{-1} yr^{-1}. Effect of S on yield and quality of CTC tea in India was studied by Charkravartee (1995) and found that the addition of S in the form of both $MgSO_4$ and phosphogypsum gave rise to increases in TF, TR and flavanol-glycosides.

Many studies in assessing application of different rates of N fertilizer primarily either as urea or sulphate of ammonia in combination with K and P, and their impacts on yield, soil physico-chemical properties and leaf nutrient status, and processed tea quality have been carried out in Kenya (Obanda and Owuor, 1995; Owuor *et al.*, 2000) and south and north India (Mahanta *et al.*, 1988; Venkatesan and Ganapathy, 2004; Venkatesan *et al.*, 2004). However, only little information is available on the application of N fertilizers as urea and sulphate of ammonia in different combinations together with K and P fertilizers (Wickremasinghe *et al.*, 1983). Hence, a long-term experiment was used to investigate the effects of urea and sulphate of ammonia as source of N on the soil acidity, soil and leaf sulphur status, yield and quality of processed black tea.

MATERIALS AND METHODS

Investigations were started on 23-year-old mature tea plants of cultivar TRI 2025 in a long-term field experiment laid out in 1979 at the St. Coombs Estate, Talawakelle, Sri Lanka (latitude 6° 55' N, longitude 80° 40' E, altitude 1382m above mean sea level). The soil belongs to Red yellow podzolic and it is categorised as Rhodustult according to the USDA soil classification (De Alwis and Panabokke, 1972). It is characterised as Mattakelle series (Agro ecological region: Up country Wet zone 2 - WU2). The texture of surface soil is clay loam and subsurface soil is loam to clay. Structure of the surface soil is weak to moderate sub-angular blocky while the subsurface is weak sub-angular blocky (Dassanayake and Hettiarachchi, 1999). Since 1992 nitrogen was given at 2 rates *viz.* 240 and 360 kg N ha^{-1} yr^{-1} in the form of urea (U) and sulphate of ammonia (SA), in five combinations. Combinations are Urea:SA, 100:0; 75:25; 50:50; 25:75 and 0:100 (Treatment structure prior to 1992 was, 3 rates of N as 112, 224 and 336 kg N ha^{-1} yr^{1} with four combinations *viz.* Urea:SA, 100:0; 75:25; 50:50; and 0:100). Twelve plots that had either received 100 % urea or SA were chosen to continue with 100% urea and SA treatments at two new rates of N. Also six plots that had received Urea:SA 50:50 combination were chosen to continue with same combination at new rates of N. Since 1992, all plots received equivalent quantities of potash and phosphate *i.e.* 75 and 17.5 kg K, P ha^{-1} yr^{1} given as muriate of potash and Eppawela rock phosphate respectively. All fertilizers were applied in four equal quantities at 2 - 4 month intervals depending on the moisture availability in soil, and followed by spraying zinc sulphate solution over the foliage within 7 - 14 day interval at an annual rate of 11 kg ha^{-1} yr^{1}.

Each plot consisted 80 bushes at a spacing of 1.2 by 0.6 m and the treatments were replicated thrice and the design was completely randomized block.

Yield records, soil and leaf sampling

Yield of young shoots of tea have been recorded at 5 - 7 day intervals since 1992. Soil samples were collected once a year from the experimental plots 4 - 6 weeks after the fertilizer application to a depth of 0 - 15 and 15 - 30 cm using a post-hole auger. First mature leaf was also collected at the same time of soil sampling for the purpose of nutrient analysis.

Tea is generally pruned to a height of 45 - 60 cm once in every 4 years at St. Coombs Estate, in order to maintain the plucking height and for better bush health. The plants were pruned in July 1996 and 2000 respectively. Dolomite was applied prior to each pruning time depending on the soil pH level (Anon, 2000a).

Soil and leaf analysis

The pH of soils was measured (soil: solution 1:2.5). Available P was extracted by borax solution and P was determined by vanadomolybdate blue method (Beater, 1949). Exchangeable K and Mg were analyzed as per the methods developed by Jackson (1958). Organic carbon was determined by Walkley and Black (1934) method, and Cation Exchange Capacity (CEC) by leaching with 1.0 M ammonium chloride solution (Jackson, 1958). Total N was determined by standard Kjehdhal method (Bremner, 1965). Soil sulphate S was determined by Bardsley and Lancaster (1960) method. Total S in mature leaf was determined by Butters and Chennery (1958) method.

Analysis of processed black tea

Young tea shoots (2 - 3 leaves and a bud) were collected from these experimental plots and black tea was manufactured in a miniature manufacture unit at two weeks interval. Quantitative analysis of Broken Orange Pekoe tea (BOP), for TF and TR; total colour and percent brightness were carried out as described by Roberts and Smith (1961). Organoleptic evaluations were made by three professional tea tasters where they made observations in a semi-quantitative form for each samples for each characteristic, in turn judged on a Headonic scale (Charley, 1978).

Data Analysis

Yield, soil and leaf analyses were subjected to analysis of variance using Genstat (1997) package as appropriate to the experimental design. Data were assessed by analysis of variance taking N rate as main and five combinations as sub treatment. The data collected for quality parameters were pooled as replicates and were analysed using SAS (1996) package.

RESULTS AND DISCUSSION

Soil physico-chemical properties are presented in Table 1.

Table 1. Initial physico-chemical properties of the soil

pH	C	N	CEC	P	K	Mg	S
(soil:water) 1:2.5	($g\ kg^{-1}$)		($cmol\ kg^{-1}$)		($\mu g\ g^{-1}$)		
4.20	3.59	0.28	19.00	20	185	75	250

Effect of N rates and combinations of urea and sulphate of ammonia on yield

The yield data for 1st and 2nd cycles are presented in Figure 1 (a - c). Generally, after pruning, the yield of first year is low compared to the yields of 2nd and 3rd years. The diminishing pattern of yield increase over the growing cycles can be observed in Figure 1 (a, b, c, d) for both rates of N either as urea or SA. The yield data on two pruning cycles revealed that there was no significant difference between 100% urea or 100% SA treated plots. However, the higher rate of N gave significantly ($P = 0.05$) higher yields when compared to the lower rate of N regardless of the source or the combinations (Figure 1 a, c). Out of a large number of studies carried out in different agro-climatic zones of tea growing regions in Sri Lanka on urea, sulphate of ammonia and and/or calcium ammonium nitrate (CAN) as sources of N (Bhavanandhan and Manipura, 1969; Fernando *et al.*, 1969; Sandanam *et al.*, 1980), only two studies reported significantly higher yields for sulphate of ammonia compared to urea (Watson and Wettasinghe, 1972, 1973). Recent studies by Gunaratne *et al.* (2004) too revealed that there is no significant difference in yield between sources of N or any combination of urea and ammonium sulphate. All laboratory and glasshouse experiments carried out in Sri Lanka to substantiate the findings from field studies were in favour of urea (Wickremasinghe, 1986). In contrast, studies conducted by the United Planters' Association of South India, revealed that ammonium sulphate was superior source of N compared to urea (Anon, 2000b). Kanwar and Takkar (1966) too

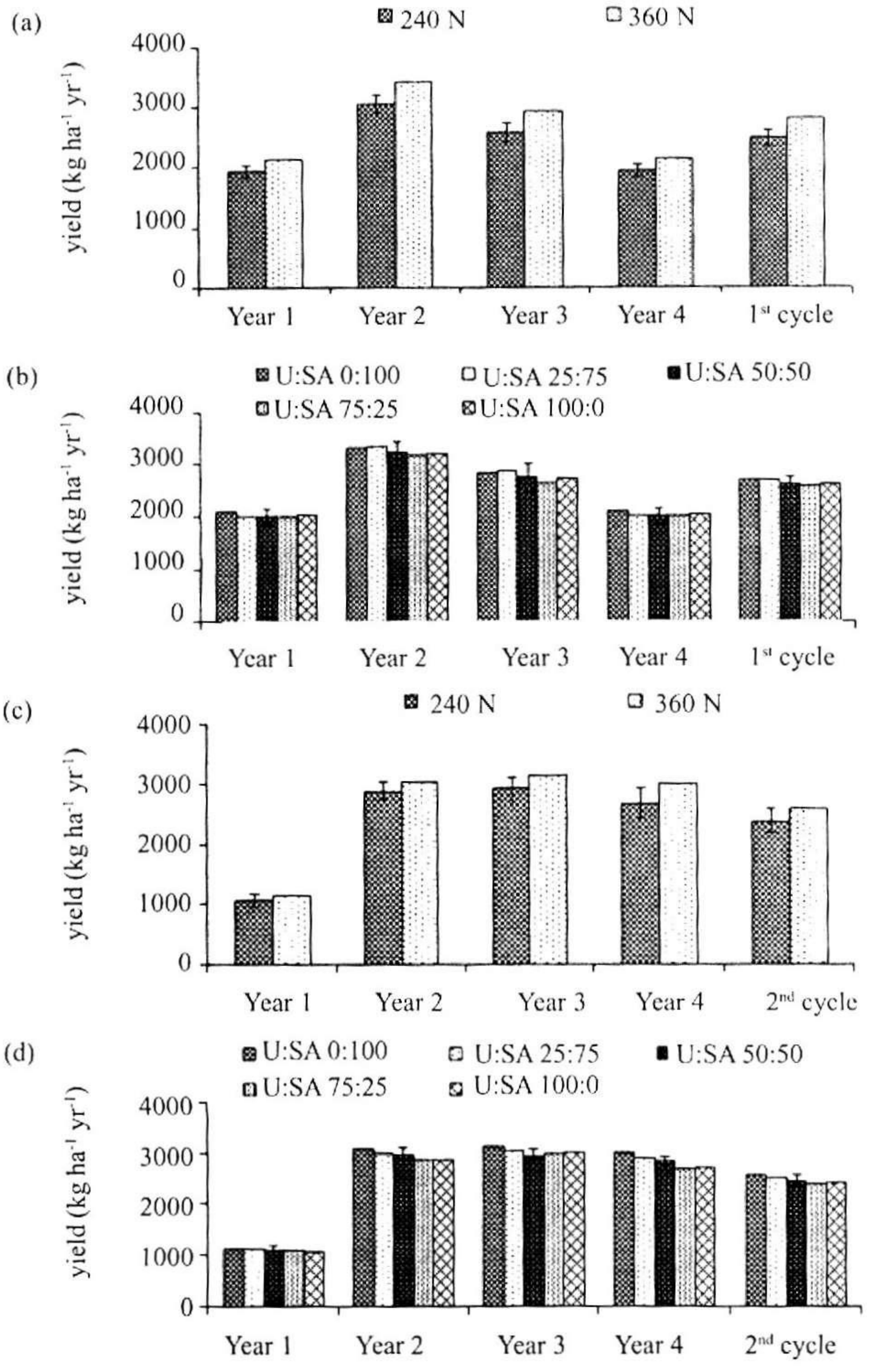

Figure 1. Effect of urea and sulphate of ammonia at different N levels (240, 360 a & c) and different combinations (b & d) during 1st and 2nd cycles, on yield (kg $ha^{-1}yr^{-1}$) (vertical bar denotes LSD at P = 0.05)

reported that the use of sulphate of ammonia on sandy loam soils of pH 4.8 significantly increased the yield in Himachal Pradesh. Significant yield responses, 6% for 90 kg N ha^{-1} and 9.7% for 180 kg N ha^{-1}, were found with ammonium sulphate over urea (Sinha *et al.*, 1992). In north india, urea is the source of N and sulphur is applied at 20 kg ha^{-1} when soil test values lower than the critical limit of available sulphur *i.e.* 40 ppm (Anon, 1988). South Indian tea plantations recommend 65% of total N requirement as urea during monsoon time, 20 % as ammonium suphate, and balance 15% N as calcium ammonium nitrate (Verma, 1992). During warm (pre-monsoon) weather conditions ammonium sulphate is recommended as the loss of N is minimum with SA under these conditions (Ranganathan, 1969; Ranganathan and Natesan, 1987; Anon, 2000 b). This indicates that the response to source of N, varied with different tea growing conditions and possible reasons could be due to soil type, the available soil -S present, presence of shade trees, *etc.*

Effect of N rates and combinations of urea and sulphate of ammonia on soil pH

The effect of rates and combinations of urea and sulphate of ammonia on soil pH at 0-15 and 15 - 30 cm depths over the different years of pruning cycles are presented in Table 2.

Continuous use of sulphate of ammonia resulted in decline in soil pH significantly. Further soil pH decreased linearly as the proportion of SA increased in urea:SA combination at both 0 - 15 and 15 - 30 cm depths. This is mainly due to release of higher levels of hydrogen during hydrolysis of sulphate of ammonia in comparison to urea. When ammonium sulphate is added to the soil, a cation exchange reaction takes place instantaneously, wherein the ammonium ions enter the exchange complex and displace other basic ions mainly Ca and Mg. Urea too acidifies the soil, but to a lesser extent compared to sulphate of ammonia.

It was reported by Jeyaraman (1956) that continuous use of ammonium sulphate at 240 to 480 kg ha^{-1} yr^{-1} for 12 years resulted in significant reduction of pH and Ca of the soil. Continuous use of SA could enhance leaching of some important cations such as K and Mg, which in turn affect the yield.

With higher rate of N application (360 kg N) the decrease in pH was significant for both sources of N (Table 2). Dolomite is applied to correct the pH and supply Mg and Ca with every prune. Although tea prefers acidic soil of pH 4.5 - 5.5, when soil pH decreases below 4.0, more Fe, Al and Mn ions are released to the soil solution, which may invariably become toxic to tea plants.

Effect of N rates and combinations of urea and sulphate of ammonia on soil and leaf sulphur status

The effect of N rates and combinations of urea and SA on soil sulphur status at 0 - 15 and 15 -30 cm depths are shown in Table 3.

Table 2. Effect of urea and sulphate of ammonia and their combinations at different N levels (240 & 360 kg N) on soil pH at 0-15 and 15-30 cm depth

Year	Year 1*	Year 3	Year 1*	Year 3	Year 1*	Year 3
Combinations			0 - 15 cm depth			
Urea:SA 0:100	4.10	4.24	4.38	4.01	4.05	3.89
Urea:SA 75:25	4.13	4.25	4.24	4.28	4.28	3.96
Urea:SA 50:50	4.36	4.50	4.35	4.34	4.40	3.97
Urea:SA 75:25	4.41	4.50	4.42	4.49	4.43	4.36
Urea:SA 100:0	4.43	4.68	4.45	4.70	4.59	4.44
Std Error	0.051	0.053	0.062	0.099	0.097	0.14
LSD (P=0.05)	0.15	0.17	0.18	0.29	0.28	0.41

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
Combinations			15 - 30 cm depth			
Urea:SA 0:100	4.23	4.18	4.37	4.23	4.16	3.96
Urea:SA 75:25	4.40	4.27	4.27	4.26	4.18	3.96
Urea:SA 50:50	4.70	4.48	4.30	4.28	4.32	4.10
Urea:SA 75:25	4.57	4.45	4.31	4.42	4.36	4.45
Urea:SA 100:0	4.58	4.60	4.42	4.56	4.69	4.32
Std Error	0.06	0.06	0.05	0.11	0.08	0.16
LSD (P=0.05)	0.18	0.18	0.15	0.32	0.23	0.47

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
N Rates ($kgha^{-1}yr^{-1}$)			0 - 15 cm depth			
240	4.42	4.55	4.42	4.56	4.47	4.18
360	4.15	4.33	4.31	4.47	4.21	3.99
Std Error	0.05	0.05	0.06	0.06	0.06	0.09
LSD (P=0.05)	0.15	0.15	0.18	0.18	0.18	0.27

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
N Rates ($kgha^{-1}yr^{-1}$)			15 - 30 cm depth			
240	4.26	4.48	4.34	4.43	4.40	4.29
360	4.19	4.32	4.29	4.28	4.29	4.03
Std Error	0.026	0.029	0.04	0.067	0.055	0.099
LSD (P=0.05)	0.08	0.085	0.12	0.19	0.16	0.29

*Dolomite application and year of prune

Table 3. Effect of urea and sulphate of ammonia and their combinations at different N levels (240 & 360 kg N) on soil sulphur content ($\mu g\ g^{-1}$) at 0-15 and 15-30 cm depth

Year	Year 1*	Year 3	Year 1*	Year 3	Year 1*	Year 3
Combinations			0 - 15 cm depth			
Urea:SA 0:100	316	233	143	263	274	309
Urea:SA 75:25	316	231	166	236	211	274
Urea:SA 50:50	351	178	132	228	161	284
Urea:SA 75:25	294	135	109	181	159	172
Urea:SA 100:0	135	45	68	97	49	114
Std Error	48	36	26	37	25	32
LSD (P=0.05)	142	107	77	109	74	95

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
Combinations			15-30 cm depth			
Urea:SA 0:100	364	296	278	349	368	401
Urea:SA 75:25	342	281	382	291	329	364
Urea:SA 50:50	342	275	273	312	251	321
Urea:SA 75:25	333	206	255	265	215	213
Urea:SA 100:0	191	113	157	156	132	130
Std Error	51	36	52	36	20	47
LSD (P=0.05)	151	107	154	107	59	139

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
N Rates ($kgha^{-1}yr^{-1}$)			0-15 cm depth			
240	256	141	121	188	162	228
360	308	187	125	214	180	221
Std Error	26	18	15	23	16	20
LSD (P=0.05)	77	53	44	68	17	59

Year	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
N Rates ($kgha^{-1}yr^{-1}$)			15-30 cm depth			
240	321	227	264	262	251	288
360	307	240	273	287	267	284
Std Error	22	14	19	23	13	30
LSD (P=0.05)	65	41	56	68	38	89

*Dolomite application and year of prune

There was a significant linear reduction in soil sulphate sulphur, as the proportion of urea increased in the combination at both depths. Further, at 15-30 cm depth, the SO_4^{2-}-S content is higher when compared to 0 - 15 cm depth. This is due to leaching of excessive SO_4^{2-}-S ion to deeper layers along with the percolation of rain water. In addition, several factors such as clay content, aluminium and iron oxides present in the soil and soil pH, too influence the retention of SO_4^{2-} ion. In ammonium sulphate treated plots, the pH decrease is higher and this favoured the retention of SO_4^{2-} ion. Sri Lankan tea soils are highly weathered, and generally Ultisol and Oxisols are rich in amophorus aluminium and iron oxides. It was reported that this type of soil helps to retain more SO_4^{2-}-S ion (Rajan, 1979). Further, the clay content in this soil series varies from 25 - 50 % and it increases with soil depth, and promotes adsorption of SO_4^{2-}-S ion. Effect of N rates and combinations of urea and sulphate of ammonia on mature leaf sulphur contents are depicted in Figure 2.

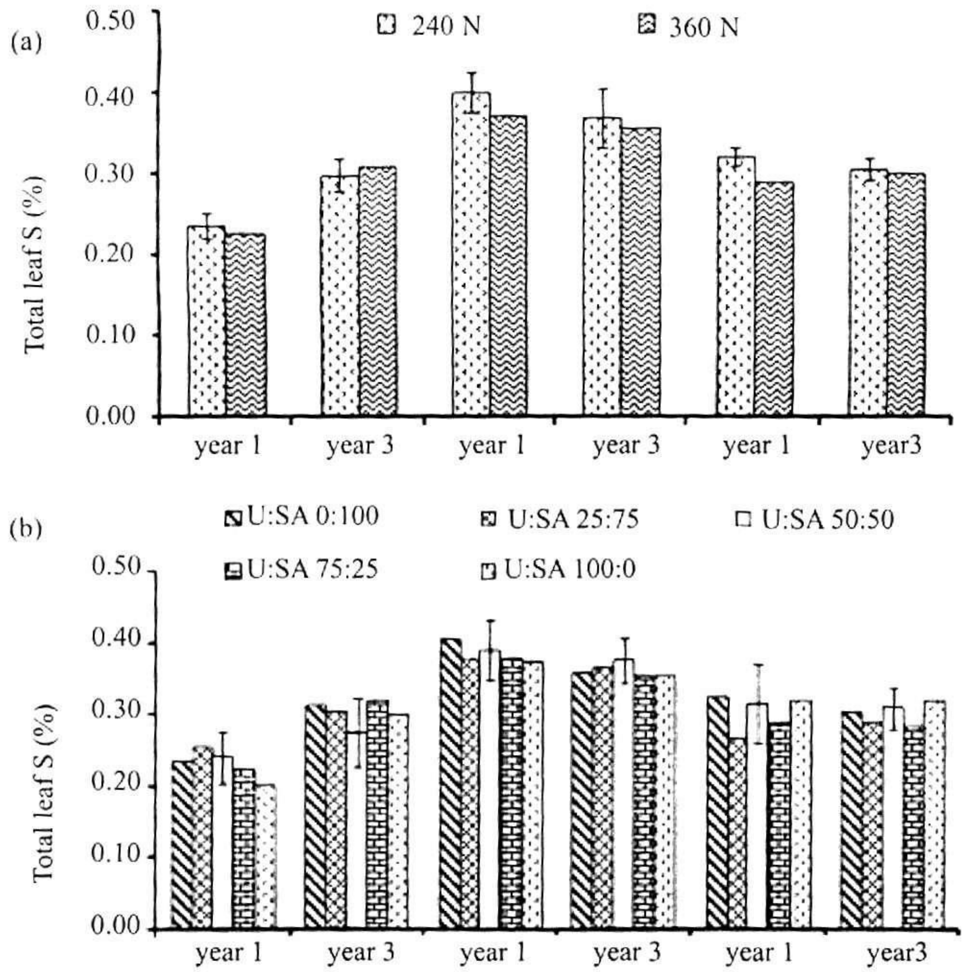

Figure 2. Effect of urea and sulphate of ammonia at different N levels (240 & 360) (a) and their combinations (b) on leaf sulphur content (%) . (vertical bar denotes standard error of means)

No significant differences in leaf S concentrations was found between source or combinations of N at both N rates. Although the urea treated plots have lower soil SO_4^{2-}-S content, the leaf sulphur concentrations were not affected by the source, rates or combinations of N. A survey conducted in tea growing regions of Sri Lanka revealed that the mean concentration of total sulphur in mature tea leaf varied from 0.12 to 0.41% and it is significantly different between the locations (Ananthacumaraswamy *et al.*, 2003). Another survey conducted in tea growing regions in Sri Lanka found that the optimum, deficient and excess nutrient range for leaf S is between 0.23 - 0.37, 0.08 - 0.23 and >0.37 % respectively and the optimum range of soil-S level for tea is between 39 - 57 $\mu g\ g^{-1}$ (Gunaratne *et al.*, 2004). The crop removal of S with 1000 kg made tea per hectare per year (by flush *i.e.* 2 leaves and a bud) is in the range of 3 – 5 kg. The leaf fall from tea bush and foliar application of zinc sulphate too contributes 5 - 6 kg S $ha^{-1}year^{-1}$. Prunings (leaves twigs and some branches) as well as shade trees supply appreciable quantity of S after mineralization (Wickremasinghe *et al.*, 1983; Wickremasinghe, 1986). In addition, 8 - 12 kg ha^{-1} of sulphur is brought down to the soil annually with rain fall (Amarasiri and Lathiff, 1982). This indicate, there is adequate amount of S available for the growth of tea in the soil and therefore, S deficiency, characterized by leaf yellowing called "net veining" is not observed in the experimental plots, where urea was applied during three pruning cycles.

Effect of N rates and combinations of urea and sulphate of ammonia on quality of processed black tea

The chemical quality parameters such as Theaflavin (TF), Thearubign (TR), total colour (TC), brightness (BR) and TR/TF ratio at 240 and 360 kg N ha^{-1} $year^{-1}$ for selected urea : SA combinations are presented in Table 4.

Table 4. Effect of urea and sulphate of ammonia and their combinations at different N levels (240 & 360 kg N) on quality of processed black tea

Treatment	TF %	TR %	TC	BR %	TR/TF
U:SA 100:0 – 240 N	0.89 a	12.15 a	3.12 a	27.04 a	13.76 a
– 360 N	0.89 a	11.97 a	2.97 a	27.18 a	13.35 a
U:SA 50:50 – 240 N	0.88 a	12.03 a	2.94 a	27.30 a	14.04 a
– 360 N	0.86 a	11.64 a	3.05 a	27.80 a	13.60 a
U:SA 0:100 – 240 N	0.87 a	11.97 a	3.01 a	27.30 a	13.88 a
– 360 N	0.80 a	11.47 a	2.83 a	26.45 a	14.40 a

Value with the same letters within each column are not significantly different (P = 0.05)

There is no significant differences found with source or combinations of urea : SA at 240 and 360 kg N rates. However, at 360 N level TF and TC gave higher values for urea treatment when compared to ammonium sulphate treatment. But, the tasters evaluation did not reflect the differences in both level and source of N, indicating that chemical differences observed for TF and TC were not significant enough for the tasters to detect in their sensory evaluations. However, a study carried out by Venkatesan *et al.* (2004) revealed that, the increased N rate (360 kg ka^{-1} yr^{-1}) with increased K, the quality precursors such as amino acids and polyphenol content increased. They concluded that the south indian tea soils should be enriched with nitrogenous fertilizers in combination with potash fertilizers at an N:K ratio of 1:0.83, for tea production and formation of quality precursors for made tea. The work carried out on Kangra teas showed that TF, TR and colour were positively influenced by S application (Nagendra Rao, 1955; Barbora, 1995; Ali *et al.*, 1997). Further, Wu and Ruan (1994) reported that S, had a positive effect on flavour compound such as Linalool, Geraniol and B-Ionone.

CONCLUSIONS

The application of higher rate of N (360 kg N) resulted higher yields regardless of source of N or combinations of urea : SA. The source of N (urea or SA) did not affect the yield. Use of sulphate of ammonia decreased the soil pH significantly when compared to urea application. Higher rate of N increased soil acidity and as a result, pH decreased significantly. Soil SO_4^{2-}-S content was higher at 15 - 30 cm soil depth. There was a significant reduction in soil sulphate sulphur as the proportion of urea increased in the combination at both soil depths. However, leaf sulphur concentrations were not affected by the source and rates of N. Processed black tea chemical quality parameters such as TF, TR, TC, BR TR/TF showed no significant difference between urea and sulphate of ammonia source at 240 and 360 kg N rate. It may be concluded that at higher elevations urea could be used as the sole source of N fertilizer for mature tea without any affect on yield and quality as it does not acidify soil and economical compared to SA.

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