Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 90 (2005) 535–539
Food Chemistry
www.elsevier.com/locate/foodchem

Impact of sources and doses of potassium on biochemical and greenleaf parameters of tea

S. Venkatesan [a,*], S. Murugesan [a], V.K. Senthur Pandian [a], M.N.K. Ganapathy [b]

[a] UPASI Tea Research Foundation, Nirar Dam BPO, Valparai 642 127, Coimbatore, Tamil Nadu, India
[b] UPASI Tea Research Foundation, Regional Centre, Coonoor, The Nilgiris, Tamil Nadu, India

Received 16 February 2004; received in revised form 6 May 2004; accepted 6 May 2004

Abstract

Effect of different sources and doses of K on certain biochemical parameters, such as carotenoids, chlorophyll, polyphenols, catechins, amino acids and nutrient contents, such as phosphorus, magnesium, zinc, potassium and nitrogen, in tea flush shoots comprising three leaves with a bud were studied. The relationship existing for polyphenols and carotenoids with amino acids was inversely proportional, while leaf nitrogen had a positive and significant correlation coefficient with amino acids. Even though a linear increase in the biochemical parameters was noticed against rate of potassium application, a comparatively small quantity was sufficient to improve the same parameter in the case of sulphate of potash (SOP). Neither of the two sources influenced the chlorophyll content of tea shoots, irrespective of their doses over control. The ideal N:K ratios for maximum productivity and biochemical parameters would be 1:0.83 or 1:0.62 if the source of K is muriate of potash (MOP), while it is 1:0.21 or 1:0.42 for SOP.

Keywords: NK fertilisers; SOP; MOP; Carotenoids; Chlorophyll; Amino acids; Polyphenols; Tea

1. Introduction

Nitrogen (N) and potassium (K) are the major nutrients of tea (*Camellia sinensis*) without which it would not be feasible to achieve the commercial levels of production. There have been several attempts to study the changes of biochemical parameters in tea caused by change in manurial practices but still many of the basic relationships between the biochemical parameters and manurial practice remain unanswered. Tea contains more than 500 chemical compounds, among which the polyphenols are primary constituents having antioxidant properties. The strong astringency of tea liquor, that cheers, is often attributed to its high content of polyphenols. Moreover, it is also believed that the polyphenols can prevent the formation of cancer cells (Sharma, 2001; Zongmao Chen, 2003). There are reports on contributions of carotenoids to the aroma and flavour of tea (Ravichandran & Parthiban, 1997).

In south Indian tea gardens, where NK fertilisers are always applied together, there are three different sources of nitrogen, namely ammonium sulphate, urea and calcium ammonium nitrate, but the choice of potassium manuring is confined to MOP alone. Hence, the manuring strategy is left with no other suitable source for potassium nutrition which can substitute MOP. Thus MOP continues to remain as the only available source of potassium, even though it contains deadly chlorine. Invariable usage of this chemical may lead to chloride toxicity in tea plants. A study conducted in China (Wu Xun, 1995, Chap. 11) reveals that application of MOP can have deleterious effect on biochemical parameters. Such circumstances demand a suitable and harmless substitute for MOP as an absolute necessity in designing the manuring strategy for south Indian tea gardens. Hence, the possibility of using SOP as an alternative source in tea gardens of south India was explored. SOP contains sulphur, too, as an added advantage. The metabolic activity of applied nitrogen is expected to

* Corresponding author. Tel.: +91-4253-235301; fax: +91-4253-235302.
E-mail address: shivng@rediffmail.com (S. Venkatesan).

0308-8146/$ - see front matter
doi:10.1016/j.foodchem.2004.05.014

change, depending on the synergism/antagonism exerted by the other applied nutrients. In the present attempt, we tried to elucidate the impact of application of MOP and SOP on biochemical parameters and nutrient content of green leaves under south Indian conditions. The basic relationships between nutrient contents of green leaves and biochemical parameters were also studied statistically.

2. Materials and methods

Investigations were carried out by collecting flush shoots, consisting of three leaves and a bud, from long term fertilizer trial plots at UPASI Tea Experimental Farm between 2000 and 2003, in clone UPASI-2. The experiment, laid out in randomised block design, had nine treatments and four replications. The source of nitrogen was urea and the sources of potassium were muriate of potash (MOP) and sulphate of potash (SOP). The N:K ratios used were 1:0.83, 1:0.62, 1:0.42 and 1:0.21. While the control plots were restricted to urea application alone, all the other plots were fertilized with a uniform quantity of nitrogen with potassium in the above mentioned ratios. Other nutrients, such as phosphorus (P), calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn) and boron (B), were given at a uniform rate in all the treatments according to the standard recommendations of UPASI TRF (Verma & Palani, 1997). A portion of collected leaf samples was subjected to laboratory analysis to assess total chlorophyll, carotenoids (Wellburn, 1994), total polyphenols (Dev Choudhury & Goswami, 1983), catechins (Swain & Hillis, 1959), and free amino acids (Moore & Stein, 1948, Chap. 3). The remaining sample was dried at 55 °C and analysed for N, K, P, Mg and Zn (Bhargava & Raghupathi, 2001). The plot wise yield data were recorded and converted into made tea per hectare, using the following formula:

$$\text{MTY} = (\text{Green leaf weight} \times \text{No. of bushes per hectare} \times 22.5)/(\text{No. of bushes per plot} \times 100).$$

Statistical analysis was carried by the standard method (Gomez & Gomez, 1984). The correlation coefficients were worked out using Special Purpose Software for Statistics (Ver. 7.5).

3. Results and discussions

3.1. Biochemical parameters

The biochemical constituents, such as carotenoids, chlorophyll, polyphenols, catechins and amino acids, in harvestable tea shoots were estimated in four immediate harvesting rounds after manuring during 2003. The statistically analysed mean data are provided in Table 1, along with statistical elements. Application of MOP at 1:0.83 and 1:0.62 ratios resulted in significant increase in carotenoid contents. Further reduction in potassium rate decreased the carotenoids. This is in agreement with the earlier findings made elsewhere (Ravichandran & Parthiban, 1997). On the contrary, application of higher rates of potassium, in the form of SOP, decreased carotenoid contents. Statistical significance was noticed at the $P = 0.01$ level for the increase in carotenoid content at the N:K ratio 1:0.83 using MOP when compared to SOP. N:K ratios 1:0.42 and 1:0.21, using SOP as a source of potassium, resulted in statistically significant

Table 1
Biochemical parameters of tea shoots as influenced by different N:K ratios

Sl. No.	Treatments		Carotenoids (ppm)	Chlorophyll (ppm)	Polyphenols (%)	Catechins (%)	Amino acids (%)
	Source of K	NK ratio					
1	NA	–	154	772	26.2	18.8	1.36
2	MOP	1:0.83	$169^{*,b}$	751	29.3^{**}	21.8^{**a}	1.81^{**}
3	MOP	1:0.62	169^{*}	744	28.7^{*}	21.7^{**}	1.44
4	MOP	1:0.42	160	790	28.0	21.2^{**}	1.48
5	MOP	1:0.21	155	762	28.1	21.5^{**}	1.40
6	SOP	1:0.83	133	685	27.6	19.7	1.38
7	SOP	1:0.62	167^{*}	732	28.4^{*}	21.6^{*}	1.61
8	SOP	1:0.42	$171^{**,a}$	806	29.1^{**}	20.8^{*}	1.67^{*}
9	SOP	1:0.21	$166^{*,a}$	784	$31.8^{**,b}$	22.5^{**}	$1.67^{*,a}$
SEM±			5.3	32.3	0.99	0.77	0.12
CD at $P = 0.05$			11	67	2.04	1.59	0.26
CD at $P = 0.01$			16	90	2.77	2.15	0.34

MOP, Muriate of potash; SOP, sulphate of potash; NA, no potassium was applied.
[a] Statistically significant at 5% level over the same ratio of the other K source.
[b] Statistically significant at 1% level over the same ratio of the other K source.
[*] Significant at 5% level.
[**] Significant at 1% level.

(at $P = 0.05$) improvement in carotenoids in comparison to the application of MOP at the same ratio. Though the chlorophyll content of tea shoots seemed affected by potassium application, this failed to have statistical significance over the control. This trend clearly confirms that, under south Indian conditions, neither of the two sources influenced the chlorophyll content of tea shoots, irrespective of their doses over the control. This is contrary to the observation made by Krishnapillai and Ediriweera (1986) under Sri Lankan conditions. Sri Lankans apply NK along with P, which is not the practice in south India. Hence, it is assumed, in this study, that potassium application may have a promoting effect on chlorophylls in the presence of applied P.

The highest polyphenol content was observed in the treatment, where NK fertilizers were applied at a 1:0.21 ratio using SOP as the source of potassium. It was also inferred that application of SOP confers maximum quantity of polyphenols when applied at 1:0.42 and 1:0.21 ratios while, MOP gives a maximum at the other two ratios. The linear increase in the polyphenol content with the rate of MOP was just the reverse in the case of SOP. The direct increase of polyphenols with applied potash fertilizer has already been reported when MOP was used as a source of potassium (Ruan, Wu, & Hardter, 1998). Since all the treatments in this experiment were supplied with uniform quantum of nitrogen, the role of potassium for the increase in polyphenols or catechins was confirmed again. Hence, the notable improvement in biochemical parameters could certainly be attributed to rates of potassium and sulphur. This reveals that, apart from Mg and K as reported by Ruan, Wu, Yong Ye, and Hardter (1999), S also plays an important role in the production of polyphenols and catechins, which is an essential criterion for good quality teas. However, higher application of sulphur in combination with potassium resulted in an undesired effect.

The amino acid content was lower in the control block, where no potassium was applied. Findings by Pfluger and Widemann (1977) support this particular observation. They showed that K is required during the nitrate reduction, which is an important step in nitrogen metabolism. This could be the reason for obtaining an increased amino acid content in the presence of potassium. The increase in amino acid content was statistically significant for the ratios 1:0.42 and 1:0.21, when SOP was used as the source of potassium.The higher the MOP application, the greater was the value of amino acids which is in line with several literature reports (Ruan et al., 1998; Ruan et al., 1999). However, compared to SOP treated plots, the amino acid content recorded due to the application of the 1:0.21 ratio was statistically superior to that of its counterpart (MOP). The increase in amino acid contents could be because of improved nitrogen metabolism, induced by nitrate reductase at optimum N:K ratios (1:0.83 using MOP and 1:0.42 and 1:0.21 using SOP). It could also be inferred that the optimum ratio was different for MOP and SOP for the production of polyphenols.

3.2. Nutrient contents of tea leaves

The impact of different sources of K was not clearly seen in the case of phosphorus and zinc status of leaves (Table 2). Mg content was higher in the control where no potassium was applied, while the Mg content of leaves were significantly lower (at $P = 0.01$), when higher potassium was applied in the form of MOP. This could be because of antagonism between these two nutrients (Mengel & Kirkby, 1978, Chap. 3; Verma & Palani, 1993). Application of K in the form of SOP resulted in a decreased effect of antagonism (1:0.83 and 1:0.62 ratios). An antagonistic effect observed between Mg and K was totally absent, when the K doses were

Table 2
Phosphorus, magnesium and zinc status (%) of tea shoots as influenced by different K sources and N:K ratios

Sl. No.	Treatments		Phosphorus		Magnesium		Zinc	
	Source of K	N:K ratio	ML	3L + B	ML	3L + B	ML	3L + B
1	NA	–	0.12	0.27	0.21	0.26	31.4	39.5
2	MOP	1:0.83	0.14*	0.31	0.18**	0.24*	32.7*	44.8**
3	MOP	1:0.62	0.13	0.29	0.17**	0.24*	30.4	42.9*
4	MOP	1:0.42	0.13	0.29	0.16**	0.24*	29.6	43.9**
5	MOP	1:0.21	0.13	0.30	0.20	0.26	31.0	42.5*
6	SOP	1:0.83	0.13	0.30	0.19*	0.24*	31.7	44.0**
7	SOP	1:0.62	0.12	0.30	0.19*	0.25	31.5	48.0**
8	SOP	1:0.42	0.12	0.29	0.21	0.26	31.6	46.9**
9	SOP	1:0.21	0.13	0.28	0.20	0.26	32.1	44.1**
SEM±			0.01	0.01	0.01	0.01	1.3	1.3
CD at $P = 0.05$			0.02	0.02	0.02	0.02	2.6	2.6
CD at $P = 0.01$			0.03	0.03	0.03	0.03	3.5	3.5

MOP, Muriate of potash; SOP, sulphate of potash; NA, no potassium was applied.
* Significant at 5% level.
** Significant at 1% level.

Table 3
Potassium and nitrogen status (%) of tea shoots as influenced by different N:K ratios

Sl. No.	Treatments		Potassium		Nitrogen		Made tea yield (kg/ha)
	Source of K	N:K ratio	ML	3L + B	ML	3L + B	September 2000 to August 2003
1	NA	–	0.97	1.80	2.63	3.49	9923
2	MOP	1:0.83	1.15*	1.93*	2.85*	3.67	11,037*
3	MOP	1:0.62	1.23**	1.97**	3.22**	3.70*	11,396*
4	MOP	1:0.42	1.22**	1.97**	2.99**	3.69*	10,433
5	MOP	1:0.21	1.09*	1.88	2.73	3.71*	10,419
6	SOP	1:0.83	1.10*	1.88	2.87*	3.70*	10,867
7	SOP	1:0.62	1.06	1.97**	2.82	3.47	10,892
8	SOP	1:0.42	1.04	1.94**	2.81	3.62	11,047*
9	SOP	1:0.21	1.21**	1.89	3.12**	3.68*	11,849**
SEM±			0.06	0.05	0.13	0.09	528
CD at $P = 0.05$			0.12	0.10	0.27	0.19	1089
CD at $P = 0.01$			0.17	0.14	0.36	0.25	1476

MOP, Muriate of potash; SOP, sulphate of potash; NA, no potassium was applied.
* Significant at 5% level.
** Significant at 1% level.

reduced further. Hence it could be concluded that sulphur, which is present in SOP, has played a vital role in alleviating the antagonism between K and Mg.

The potassium and nitrogen status of tea leaves were positively influenced by MOP and SOP at all the ratios. However, statistical significance was higher for MOP-treated blocks. Though the trend observed due to the application of SOP was not consistent, the yields were higher in SOP-treated blocks (Table 3).

3.3. Made tea yield

Made tea yield, recorded between September 2000 and August 2003, is given in Table 3. Potassium application, in both the forms, positively influenced the made tea yield, irrespective of the ratios/quantity applied. However, statistical significance was obtained only for the 1:0.21 and 1:0.42 ratios when SOP was used as the source of potassium and at the other two ratios when MOP was used as a source of potassium. It was quite encouraging to note that the ratios which contributed to the increase in biochemical parameters simultaneously increased the yield also. Generally the leaves were more succulent and fresh in the above – mentioned ratios. Though the removal of NK by way of harvesting is in the ratio of 1:0.5, slightly higher potassium (1:0.83 and 1:0.62) was found beneficial in augmenting the yield and biochemical parameters, when MOP was used as the source of potassium. This is in line with the existing recommendation on manuring of tea in south India (Venkatesan, Verma, & Navaneetha Krishna Ganapathy, 2003; Verma & Palani, 1997). Application of excess potassium in the form of MOP was aimed to optimize the nitrogen metabolism in tea plants despite the drawbacks in the soil properties. Achievement of higher yield and biochemical parameters at lower rates of K, due to SOP application, could be because sulphur must have entered into a crucial role in the nitrogen metabolism, which is in agreement with the findings made by Ruan et al. (1998).

3.4. Correlation coefficients

Correlation coefficients (bivariate) worked out among made tea yield, green leaf nutrients and biochemical parameters are given in Table 4. Zinc content of mature leaves was negatively correlated with amino acid content, while the correlation coefficient was positive and highly significant with polyphenols. A linear correlation between zinc and polyphenols has already been recorded under Sri Lankan conditions (Ramakrishna, Palmakumbura, & Chatt, 1987). Sulphur showed a negative and significant correlation coefficient with carotenoids, which could be the reason why carotenoids decreased with increase in SOP application (Table 1). There was a strong negative correlation for polyphenols with amino acids and leaf magnesium. Ruan et al. (1999) reported a decrease of polyphenols when Mg was applied. Since catechins form a part of polyphenols, they showed positive and significant correlation coefficient with polyphenols. The correlation coefficient determined between amino acids and nitrogen content of harvestable shoots was positive and significant. This could be because a major portion of leaf nitrogen is bound to amino acids. The antagonistic nature of magnesium with potassium was obviously shown by the strong negative correlation. Between the pigments, chlorophyll and carotenoids, the relationship was positive and significant, at the 1% level. The amino acids were negatively correlated with carotenoids.

Table 4
Relationship among biochemical and nutrients of green leaves

	Amino acids	Carotenoids	Chlorophyll	Catechins	Potassium	Magnesium	Nitrogen	Phosphorus	Polyphenols	Sulphur
Carotenoids	−0.451**	1.000								
Chlorophyll	−0.269	0.631**	1.000							
Catechins	−0.152	0.230	−0.269	1.000						
Potassium	−0.178	0.247	0.133	0.117	1.000					
Magnesium	0.233	−0.237	−0.202	−0.148	−0.568**	1.000				
Nitrogen	0.380*	0.098	0.348*	0.242	0.632**	−0.131	1.000			
Phosphorus	0.142	0.006	0.093	0.285	0.409*	0.107	0.121	1.000		
Polyphenols	−0.772**	0.434**	0.308	0.403*	0.220	−0.385*	−0.199	0.068	1.000	
Sulphur	0.208	−0.421*	−0.119	0.003	0.409*	−0.065	−0.058	−0.198	−0.217	1.000
Zinc	−0.650**	0.035	0.141	−0.047	0.062	−0.185	−0.237	−0.072	0.638**	−0.336*

* Significant at 5% level.
** Significant at 1% level.

4. Conclusion

It is ideal to use the ratio 1:0.83 or 1:0.62 if the source of K is MOP and 1:0.21 or 1:0.42 if the source of K is SOP, i.e., the same improvements in the biochemical constituents by using N:K ratios of 1:0.83 or 1:0.62 for MOP can be obtained even at lower ratios of 1:0.21 or 1:0.42, with a special increment of polyphenols, while using SOP. Hence with more polyphenols in the tea shoots, undoubtedly, the quality of the manufactured tea will be greater, because polyphenols are so important and responsible for all the biochemical reactions which contribute to make a good cup of tea.

Acknowledgements

The authors thank Dr. N. Muraleedharan, Director, for going through the manuscript. We acknowledge Dr. Vinod Haridas and Mr. T. Muthumani for their help in the construction of this manuscript. We also acknowledge the financial support provided by Suphate of Potash Information Board, Germany.

References

Bhargava, B. S., & Raghupathi, H. B. (2001). Analysis of plant materials for macro and micronutrients. In H. L. S. Tandon (Ed.), *Methods of analysis of soils, plants, waters and fertiliser* (pp. 49–82). New Delhi, India: Fertiliser Association and Consultation Organization.

Dev Choudhury, M. N., & Goswami, M. R. (1983). Arapid method for determination of total polyphenolic matter in tea (*Camellia sinensis* L). *Two and a Bud, 30*, 59–61.

Sharma, G. (2001). Tea wonderful health drink. *The Assam Review and Tea News*, 9–12.

Gomez, K. A., & Gomez, A. A. (1984). Two factor experiments. In *Statistical procedures for agricultural research* (pp. 84–129). New York: Wiley.

Krishnapillai, S., & Ediriweera, V. L. (1986). Influence of levels of nitrogen and potassium fertilizers on chlorophyll content in mature clonal tea leaves. *Sri Lankan Journal of Tea Science, 55*, 71–76.

Mengel, K., & Kirkby, E. A. (1978). *Principles of plant nutrition*. Switzerland: International Potash Institute.

Moore, S., & Stein, W. H. (1948). In S. P. Colowick & N. D. Kaplan (Eds.), *Methods in enzymol* (p. 468). New York: Academic press.

Pfluger, R., & Widemann, R. (1977). Der Einfluss monovaleant Kationene auf die Nitrate duktion bei Spinacia oleracea L. *Zeitschrift fur Pflanzenphysiologie, 85*, 125–133.

Ramakrishna, R. S., Palmakumbura, S., & Chatt, A. (1987). Varietal variation and correlation of trace metal levels with catechins and caffeine in Sri Lanka tea. *Journal of the Science of Food and Agriculture, 38*, 331–339.

Ravichandran, R., & Parthiban, R. (1997). Tea carotenoids. *Planters' Chronicle, 93*, 327.

Ruan, J., Wu, X., & Hardter, R. (1998). Effect of potassium, magnesium and sulphur applied in different forms of fertilizers on free amino acids content in leaves of tea (*Camellia sinensis* L). *Journal of the Science of Food and Agriculture, 76*, 107–113.

Ruan, J., Wu, X., Yong Ye, & Hardter, R. (1999). Effects of potassium and magnesium nutrition on the quality components of different types of tea. *Journal of the Science of Food and Agriculture, 79*, 47–52.

Swain, T., & Hillis, W. E. (1959). The phenolic constituents of *Prunus domestica.* I. The quantitative analysis of Phenolic constituents. *Journal of the Science of Food and Agriculture, 10*, 63–68.

Venkatesan, S., Verma, D. P., & Navaneetha Krishna Ganapathy, M. (2003). Targetted yield equations of nitrogen for clonal teas under south Indian conditions. *Journal of Indian Society of Soil Science, 51*, 178–183.

Verma, D. P., & Palani, N. (1993). Magnesium fertilization for sustainable tea productivity in south India. *Journal of Plantation Crops, 21*, 81–85.

Verma, D. P., & Palani, N. (1997). Manuring of tea in south India (revised recommendations). In *Handbook of tea culture*. Valparai, Tamil Nadu: UPASI Tea Research Institute (Section 11, p. 33).

Wellburn, R. (1994). The spectral determination of chlorophylls *a* and *b*, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology, 144*, 307–313.

Wu Xun (1995). Effect of potassium and magnesium on polyphenols in black tea. In A. WuBinghua (Ed.), *K and Mg in balanced fertilization in China's tea gardens* (pp. 1–16). Switzerland: International Potash Institute.

Zongmao Chen (2003). Pharmacological functions of tea. *Planters' Chronicle*, 20–37.