Magnesium Fertilization is Essential for Tea Gardens of Southern India

By N. Palani

Mr. Palani, Deputy Director of UPASI Tea Research Foundation, observing the visual symptoms of Mg deficiency in tea gardens.

Magnesium is the third most important nutrient (after N and K) for tea plants and is a critical input for profitable tea production (Jayaganesh and Venkatesan, 2010). It is the only mineral constituent in the chlorophyll molecule that regulates photosynthesis. In addition, Mg activates many enzymes involved in carbohydrate metabolism, synthesis of nucleic acids, and translocation of sugar. Harvestable tea shoots contain about 0.20 to 0.30% Mg on a dry weight basis (Venkatesan, 2006). However, Mg availability in the predominant tea-growing soils of southern India is generally low. This article summarizes the research findings from the UPASI Tea Research Foundation on the reasons for low Mg availability in tea gardens of southern India, the importance of Mg nutrition for the biochemical and quality constituents of marketable tea, and it proposes 4R management strategies for Mg use.

Factors Affecting Mg Availability

Tea-growing areas in South India run parallel and close to the west coast of the peninsula. The six major tea districts vary in elevation from 300 to 2,500 m above sea level and rainfall varies from 900 to 7,500 mm/yr. Poor base saturation of soils, coupled with low binding energy for cations make these tea-growing soils vulnerable to Mg deficiency due to

SUMMARY

Attention should be given to Mg nutrition in the tea gardens of Southern India to enhance tea quality and to break yield barriers. The antagonistic relationship of Mg and K, strong Mg adsorption capacity of some tea soils, and emerging responses to Mg application all highlight the need for 4R management strategies for Mg.

KEYWORDS:

crop quality; nutrient interactions; foliar application

ABBREVIATIONS AND NOTES:

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; B = boron; Mn = manganese; Zn = zinc.

intense leaching, especially under high rainfall. Senthurpandian et al. (2009) reported low to medium Mg availability (33 to 126 mg/kg) in these soils, which is inadequate to maintain high productivity.

Soil Type and Antagonism between K and Mg

In recent years, considerable attention has been focused on Mg deficiency induced by K fertilizer application. Tea, being a foliage crop, requires high rates of K fertilizer application to produce high yields. Application of high rates of K, however, reduces Mg uptake due to the antagonism between K and Mg and results in a Mg deficiency in the crop. It is estimated that about 150 to 300 kg/ha K_2O is added on most plantations every year to overcome K deficiency and to obtain sustainable tea yields (Venkatesan, 2006). High application of K can increase the leaching of Mg by displacing it from cation exchange sites, leading to lower Mg availability in the root zone. Jayaganesh et al. (2011) reported severe deficiencies of Mg in many tea gardens of southern India, especially in the high-yielding tea plantations. Although Mg removal through leaf harvesting is 6 to 8 times lesser than that of K, the higher K input reduces Mg uptake and results in the appearance of Mg deficiency in tea leaves.

Magnesium is mobile within the plant and the deficiency symptoms first appear in mature tea leaves. The deficiency is expressed as an inverted 'V' shaped chlorosis, coupled with yellow zones on either side of main veins of the older leaves, and eventually results in the shedding of mature leaves.

High Mg Adsorption Capacity of Soils

A study in three tea-growing regions (i.e., Anamallais, High Ranges, and Central Travancore) has showed that 46 to 52% of applied Mg can be adsorbed by the plantations' soils within 24 hours of application. Adsorption of Mg progressively increased as Mg input was increased (**Table 1**). The study indicated that the quantity of adsorbed Mg, at any concentration, was highest in the Travancore soils followed by the soils of Anamallais, and High Ranges. Travancore soils have higher clay content (270 g/kg) compared to Anamallais (190 g/kg), and High Ranges (170 g/kg) soils. The equilibrium concentration of Mg was highest for the soils of High Ranges and the lowest for Travancore soils, which is attributed to higher organic matter content (i.e., 97 g/kg in the former and 66 g/kg in the latter). The Freundlich coefficients 'K', an index of nutrients sorbed from a solution having unit equilibrium concentration, were 1.567, 1.683, and 2.443 for the High Ranges, Anamallais and Travancore soils, respectively. Thus Mg adsorption followed the order: Travancore soils > Anamallais soils > High Ranges. All these observations indicate a need to prioritize Mg fertilization in Travancore soils, followed by Anamallais, and High Ranges.

Table 1. Magnesium (Mg) adsorption capacity in the major tea-growing soils of southern India.

	Adsorbed Mg, mg/kg			Equilibrium concentration of Mg in solution, g/kg		
Added Mg, mg/kg	Anamallais	High Ranges	Central Travancore	Anamallais	High Ranges	Central Travancore
25	14	13	16	11	12	9
50	27	26	29	23	24	21
100	52	51	57	48	49	43
150	76	74	82	74	76	68
200	99	99	107	101	101	93
300	146	138	155	154	162	145
400	190	187	204	210	255	196
SEm±	-	-	-	0.81	1.77	0.63
C.D. (p = 0.05)	-	-	-	1.76	3.87	1.38

Adapted from Jayaganesh and Venkatesan, 2006.

Mg Release Pattern

Soil samples from 16 agro-climatic zones representing four predominant tea-growing zones of Southern India (i.e., Anamallais, High Ranges, Nilgiris, and Central Travancore) were collected to study the Mg release characteristics through repeated extraction by 1 N ammonium acetate (Hanway and Heidal, 1952). The Cobb-Douglas exponential function, $Y = ax^b$ (Meeusen and Van Den Broek, 1977), where Y = cumulative nutrient, a = degree of steepness of nutrient release, x = number of extractions, and b = exponential constant, was employed to study the Mg release pattern. The results indicated that the net cumulative Mg release varied from 112 to 138, 139 to 165, 87 to 217, and 32 to 82 mg/kg in the soils of Anamallais, High Ranges, Nilgiris, and Central Travancore, respectively. The 'a' values from Cobb-Douglas response equations (**Table 2**) indicated that tea grown on all of the analyzed samples should respond to Mg application, except for the Coonoor region of Nilgiris (Venkatesan, 2006; Jayaganesh and Venkatesan, 2006; Senthurpandian et al., 2009).

Role of Mg on Biochemical Activity and Quality of Tea

Amino acids are important chemical constituents influencing the quality and freshness of marketable tea. Magnesium activates several enzymes involved in carbohydrate and N metabolism that are reported to improve the free amino acid content and quality of tea (Ruan et al., 1999; Ma et al., 2005). Amino transferease enzymes play a major role in the synthesis of amino acids. Alanine and aspartate amino transferease are important enzymes in the amino acid synthesis pathway, and are mainly responsible for the conversion of amides into plant-available amino acids. Foliar application of 1% magnesium sulphate ($MgSO_4$) in various tea cultivars increased the alanine amino and aspartate amino transferease activities of tea shoots by 22 to 63 and 20 to 68%, respectively (**Table 3**). The total amino acid content of marketable tea significantly increased when the plants were treated with either soil or foliar application of Mg fertilizer, confirming the Mg-induced, amino acid synthesis pathway (Ma et al., 2005).

Another study in Southern India on the influence of soil applied $MgSO_4$ (300 kg/ha) on biochemical constituents of green, tea leaves (Jayaganesh and Venkatesan, 2010) resulted in increased polyphenol, catechin, and carotenoid content (data not shown). Soil-applied Mg also influenced the chlo-

Table 2. Response of tea soils to Mg application.

Zone	Cobb-Douglas equation
Anamallais	
Eastern facing	$Y = 65.470X^{0.0619}$ (R^2 = 0.915)
Intermediate	$Y = 81.780X^{0.0460}$ (R^2 = 0.932)
Western facing	$Y = 72.430X^{0.0779}$ (R^2 = 0.813)
High Ranges	
Eastern end	$Y = 77.260X^{0.0724}$ (R^2 = 0.872)
Lower elevation	$Y = 92.080X^{0.0559}$ (R^2 = 0.893)
Plateau	$Y = 80.820X^{0.0635}$ (R^2 = 0.913)
Top station	$Y = 96.740X^{0.0583}$ (R^2 = 0.820)
Western end	$Y = 87.280X^{0.0782}$ (R^2 = 0.783)
Nilgiris	
Coonoor	$Y = 143.85X^{0.0487}$ (R^2 = 0.834)
Kotagiri	$Y = 80.850X^{0.1049}$ (R^2 = 0.893)
Kullakamby	$Y = 49.230X^{0.0715}$ (R^2 = 0.888)
Kundah	$Y = 42.000X^{0.0852}$ (R^2 = 0.920)
Ooty	$Y = 82.570X^{0.0823}$ (R^2 = 0.895)
Central Travancore	
Elappara	$Y = 40.370X^{0.0776}$ (R^2 = 0.921)
Peermade	$Y = 43.180X^{0.0700}$ (R^2 = 0.892)
Vandiperiyar	$Y = 38.710X^{0.0840}$ (R^2 = 0.919)

Senthurpandian et al., 2009

Table 3. Effect of foliar application of Mg on amino transferase activity in tea plants.

			- - - Aspartate Activity* - - -			- - - Alanine Activity* - - -		
S. No	Clone	Variety	Control	Foliar $MgSO_4$	% Increase	Control	Foliar $MgSO_4$	% Increase
1	UPASI 1	Assam	190 ± 2.1	272 ± 3.3	43	101 ± 1.2	142 ± 2.3	41
2	UPASI 2	Assam	248 ± 4.2	352 ± 4.5	42	164 ± 2.2	228 ± 3.1	39
3	UPASI 3	Assam	285 ± 3.7	479 ± 4.1	68	182 ± 2.1	310 ± 2.8	63
4	UPASI 7	Assam	252 ± 2.7	348 ± 2.2	38	115 ± 1.4	155 ± 3.3	35
5	UPASI 8	China	110 ± 1.9	132 ± 1.6	20	87 ± 0.9	106 ± 2.2	22
6	UPASI 9	Assam	271 ± 3.9	409 ± 3.8	51	190 ± 1.9	283 ± 1.9	55
7	UPASI 11	Assam	198 ± 4.9	289 ± 2.6	46	106 ± 1.3	158 ± 2.2	49
8	UPASI 12	Cambod	260 ± 3.6	374 ± 3.4	44	176 ± 1.9	257 ± 3.1	46
9	UPASI 13	Assam	245 ± 4.9	264 ± 1.7	56	109 ± 1.0	166 ± 1.6	52
10	UPASI 14	Cambod	91 ± 2.2	132 ± 1.9	45	70 ± 0.5	99 ± 1.9	41
11	UPASI 15	China	155 ± 4.1	211 ± 2.6	36	38 ± 0.6	52 ± 2.2	38
12	UPASI 17	Cambod	230 ± 4.0	311 ± 3.3	35	55 ± 0.5	76 ± 1.1	39
13	UPASI 22	Assam	220 ± 2.5	293 ± 1.8	33	122 ± 1.1	171 ± 2.4	40

*micromole of pyruvate formed (min/g) of fresh weight of leaf.
Adapted from Venkatesan and Jayaganesh, 2010.

Table 4. Quality constituents and yield of made tea as influenced by application of Mg.

Treatment details	TF, %	TR, %	HPS, %	TLC	FI	AA,%	PP, %	MTY, kg/ha
T_1 - Control	1.07	11.99	10.32	3.52	1.58	1.3	15.9	3,820
T_2 - Recommended NPK	1.3	14.35	10.42	4.01	1.75	1.42	17.43	4,231*
T_3 - T2 + 200 kg Mg	1.38	15.41	10.77	4.15	2.42	1.51	17.33	4,344**
T_4 - T2 + 300 kg Mg	1.4	15.55	10.78	4.25	2.52	1.53	17.23	4,495**
T_5 - T2 + 200 kg Mg minus 50% K_2O	1.35	14.75	10.55	3.75	2.18	1.45	16.21	4,245*
T_6 - T2 + 300 kg Mg minus 50% K_2O	1.34	14.85	10.56	3.68	2.08	1.46	16.45	4,250*
T_7 - T2 + 1% Mg as foliar + micros	1.33	15.21	10.78	4.37	1.76	1.69	17.92	4,355**
T_8 - T2 + 2% Mg as foliar + micros	1.36	15.33	10.78	4.45	1.56	1.72	18.21	4,568**
SEm±	0.04	0.26	0.12	0.06	0.4	0.05	0.19	155
C.D. at $p = 0.05$	0.08	0.56	0.25	0.13	0.86	0.11	0.41	333
C.D. at $p = 0.01$	0.11	0.78	0.35	0.18	1.19	0.15	0.57	462

TF = Theaflavins; TR = Thearubigins; HPS = Highly polymerized substances; TLC = Total liquor colour; AA = Amino acids; PP = Polyphenols; FI = Flavour index; MTY = Made tea yield.
*, ** Denotes significantly superior over control at $p = 0.05$ and $p = 0.01$, respectively.
Jayaganesh and Venkatesan, 2010.

rophyll content in tea leaves. A similar study on the influence of Mg application on made tea quality (**Table 4**) revealed an increase in theaflavin and thearubigin content due to soil application of $MgSO_4$ at 300 kg/ha, but this effect decreased when K was reduced by 50%. Improved theaflavin content can play a major role in determining price premiums for South Indian black teas (Jayaganesh and Venkatesan, 2010). The increase in theaflavin could be attributed to increased content of polyphenol, which is the precursor for theaflavin and thearubigin. Highly polymerized substances, which are believed to be part of thearubigin, responsible for imparting strength, richness, and colour of the liquor, increased due to both the soil and foliar application of Mg. Magnesium application improved the total liquor color, responsible for increasing the cuppage and flavor index of made tea (**Table 4**). The presence of higher flavor compounds in made tea due to field application of $MgSO_4$ has resulted in higher amino acid content, which are precursors of flavour components.

4R Magnesium Management in Tea Gardens

Applying the right source of Mg at the right rate, time, and place following the 4R Nutrient Stewardship Principles (IPNI, 2016) may help in achieving the economic, social, and environmental sustainability in South Indian tea gardens. Application of dolomitic lime (12.6% $MgCO_3$) once or twice in a pruning cycle is a regular practice in tea plantations and can partially manage Mg deficiency in acidic tea soils. Supplying Mg through dolomitic lime is not a feasible practice; however, $MgSO_4$ could be used as a standard source depending on the age of plantation, yield level, physiological stage, or the pruning cycle. The right rate of Mg application is site-specific and nutrient requirement is based on yield target, available nutrient status in the soil, and the synergistic (Mg x P) and antagonistic (Mg x K) relationship of Mg with other nutrients. At high levels of K application, the available soil Mg may not be adequate to meet the Mg requirement of tea plants, particularly in high-yielding plantations. Hence, in addition to meeting the Mg requirement through liming with dolomitic lime, it is recommended to apply the right rate of $MgSO_4$ at right time through a right method, either by soil broadcast or foliar application, following the guidelines provided in **Table 5**. Foliar spray of $MgSO_4$ (1 to 2%) may be carried out using a spray volume of 200 L/ha. Mixing other limiting micronutrients and growth regulators (such as Zn, Mn, B, and naphthalene

Table 5. Guidelines for 4R management of Mg in tea gardens of Southern India.

Yield, kg/ha	Right Rate, kg $MgSO_4$/ha/yr	Right Time
Soil application		
< 2,000	100	During May/June
2,000 to 3,000	200	Twice; During May/June and October/November
3,000 to 4,000	250	Twice; During May/June and October/November
4,000 to 5,000	300	Twice; During May/June and October/November
> 5000	350	Twice; During May/June and October/November
Foliar application		
< 3000	8	4 splits, after plucking
3,000 to 4,000	10	4 to 5 splits, after plucking
4,000 to 5,000	12	4 to 6 splits, after plucking
> 5,000	14	6 splits, after plucking

Palani et al., 2015.

acetic acid) along with Mg in the spray tank, economizes the application of Mg in tea gardens (Palani et al., 2015). Foliar application of $MgSO_4$ on the day after plucking helps in effectively covering the maintenance foliage for better absorption. Visual symptoms of Mg deficiency, coupled with yield stagnation of tea gardens may require combined soil and foliar application of $MgSO_4$. Soil application of $MgSO_4$ in tea gardens may be carried out by broadcasting method, alone or in combination with the NK fertilizers. When applied together, urea should be mixed with $MgSO_4$ on the day of application due to the hygroscopic nature of urea.

Conclusion

Magnesium is an essential nutrient responsible for increasing the photosynthetic efficiency of tea that reflects directly on the yield. A large quantity of K fertilizer is generally applied to maintain good tea foliage. However, the antagonistic relationship between K and Mg often leads to Mg deficiency in both the soil and plant, especially in the high-yielding tea gardens of southern India. On one hand application of fertilizer K increases the yield of tea and thereby the Mg requirement of the plant, but K also has an antagonistic effect on Mg uptake.

Availability of Mg in the tea plantations of southern India is also constrained by acidic and lateritic soils, and strong Mg adsorption capacity of some soils. This article highlighted the significant role of Mg nutrition in improving the biochemical activity and quality aspects of tea. Thus, it is important to use 4R principles of Mg management through soil and foliar application of Mg fertilizer as opposed to only resorting to the application of dolomitic lime to amend the acidic, tea plantations soils in southern India. **BCSA**

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