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A COMPARATIVE ANALYSIS OF NUTRIENT CONTENT OF SOILS SAMPLED FROM MID OF FOUR PLANTS AND DRIP CIRCLE OF COFFEE PLANTATIONS IN INDIA

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ABSTRACT
Coffee growers often apply fertilizers very close to the plants, which results in accumulation of nutrients in one place leading to poor nutrient use efficiency, whereas soil sampling is done in the middle of four plants. Hence the objectives of this study was to compare nutrient status of soils sampled from drip circle and mid of four plants and recommend cost-effective fertilizer management.

KEY WORDS
Nutrient content, coffee, soil, drip circle, middle of four plants.

About 49 per cent of soils in present research were strongly acidic (<5.5 pH) as a result phosphorus fixation is high leading to build up of soil phosphorus. Available nitrogen was found to be low to medium. Karnataka and Kerala recorded higher phosphorus in soils sampled from the drip circle 75.3 and 84% respectively compared to soils sampled from mid of four plants recording 48 and 77% respectively. In Karnataka, as much as 59.7% of soils sampled from the drip circle recorded high available potassium whereas 45.4 % of soils sampled from mid of four plants recorded medium potassium. Approximately 50 % of the coffee plantations of Karnataka and Kerala recorded available magnesium below the critical level <180 mg kg^{-1} irrespective of method of soil sampling. The majority of the soil samples of Karnataka (51%) and Kerala (75%) are low (<1.5 mg kg^{-1}) in available zinc irrespective of method of soil sampling. This study emphasis that soil sampling in the middle of four coffee plants is ideal in Indian condition.

MATERIALS AND METHODS OF RESEARCH

Depending on the extent of area under coffee cultivation, the number of soil samples to be collected were fixed giving due consideration of district, taluk and village. A total of 10,274 (5137 each from drip circle and middle of four plants) soil samples were collected. Soil attributes were analysed by adopting standard soil testing methods. The pH and electrical conductivity by 1:2.5 soil: water using pH and conductivity meters (Jackson, 1973); Soil organic carbon by wet digestion method (Walkley and Black, 1934); available nitrogen by alkaline $KMnO_4$ method (Subbiah and Asija, 1956); exchangeable calcium, magnesium, iron, manganese, copper and zinc by atomic absorption spectrophotometric method (Lindsay and Norwell,1978) and available sulphur by extraction with 0.15 % CaCl2, estimation by turbidometric method (William and Steinberg,1959).

RESULTS AND DISCUSSION

Coffee soils are acidic in nature due to leaching of base elements like calcium and magnesium which leads to the toxicity of manganese and aluminium and the lack of available phosphorus in the soil lead to reduced coffee growth and yield. Krishnappa et al. (1988) recorded high coffee yields in areas with normal soil pH. Ananthanarayan and Ravindra (1998) reported that coffee cultivation soils are generally acidic (4.0–6.0). Similar results have been reported in coffee cropped soils in India (Shivaprasad et al. 2018; Shivaprasad et al. 2020). Nagaraja (2003), as part of a new approach study of Diagnostic and Recommendation Integrated System (DRIS) for coffee cultivation in Karnataka (India), found that the optimum pH value for Arabica is 5.5 to 6.1.

The soil reaction was generally more acidic in coffee soils of Karnataka. The soil sampled from middle of four coffee plants recorded pH ranging from 3.6 to 6.9 and soils of drip circle ranged from 3.5 to 6.7 (Table 1). The results explicitly indicate that the zone of fertilizer application (drip circle) was more acidic (4.8) compared to the mid of four plants (5.4). A similar trend was recorded in other coffee growing areas of India.

The soil samples representing each state were classified into strongly acid (<5.5), slightly acid (5.6-6.0) and neutral (>6.0) classes with respect to soil reaction. In Karnataka about 82.9 and 55.1 per cent of soils were strongly acidic (<5.5 pH) in the drip circle and middle of four plants respectively as a result of high phosphorus fixation leading to build up of soil phosphorus (Table 2).

Table 1 – pH of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA*		NER#	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	3.6-6.9	5.4	4.2-7.5	6.0	4.1-7	5.7	4.7- 6.6	5.6	3.6- 6.8	4.8
Drip circle	3.5-6.7	4.8	4.3- 7.3	5.7	4.1-7.1	5.6	4.0- 6.4	5.2	3.4- 6	4.6
T test	*	39.4	NS	0.9	NS	13.0	NS	17.15	NS	3.3
SD		0.9		4.8		0.12		0.37		0.3

** NTA – Non traditional areas viz., Andhra Pradesh & Odisha.*
 # NER- North Eastern Region; M4P – Middle of four plants.

Table 2 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of pH

State	Method of soil sampling	pH		
		Strongly Acidic (<5.5)	Slightly Acidic (5.6-6.0)	Neutral (>6.0)
Karnataka	Middle of 4 Pl	55.1	33.5	11.4
	Drip circle	82.9	13.6	3.5
Kerala	Middle of 4 Pl	30	47	23
	Drip circle	27	50	23
Tamil Nadu	Middle of 4 Pl	26.9	47.1	26
	Drip circle	38.5	36.7	24.8
NTA	Middle of 4 Pl	41	41	18
	Drip circle	69.7	26.6	3.6
NER	Middle of 4 Pl	92.9	3.6	3.6
	Drip circle	91	7	2

Coffee is grown under shade of the trees, so addition of fallen leaves from shade trees accumulates a large amount of organic matter in the soil. On an average, about 10 tons of fallen leaves are collected per hectare each year in coffee plantation, which builds the Soil Organic Matter (SOM). Regular pruning of coffee plants contributes organic matter into the soil. Anantharayana and Ravindra (1998) found that most of the acidic soils in Chikkamagaluru and Kodagu districts, where coffee is grown, had high organic carbon content, and similar results were also reported (Shivaprasad et al. 2018; Shivaprasad et al. 2020) in Indian coffee cultivation soils. Organic matter influences chemical and biological properties of the soil and therefore it plays an important role in the productivity of coffee. SOM also provides aeration, increases water holding capacity and reduces soil erosion. In Karnataka, the soil samples collected in the middle of 4 coffee plants the per cent organic carbon ranged from 0.7 to 5.5 and in the drip circle it ranged from 0.7 to 6 with a mean of 3.00 indicating high soil organic carbon (Table 3). The mean soil organic carbon in soils of

Kerala, Tamil Nadu and NER was in the order of 2.0, 2.5 and 1.7 indicating high soil organic carbon in Kerala and Tamil Nadu and medium soil organic carbon in case of NER (Table 4).

Table 3 – Content of organic carbon (%) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	0.7-5.5	3.0	0.6- 4.2	2.0	1.1-4.6	2.5	0.9-1.5	1.3	1.1- 2.1	1.7
Drip circle	0.7-6	3.0	0.1- 4	2.1	1-5.1	2.5	0.7-1.4	1.1	1.2- 1.9	1.6
T test	NS	0.87	NS	3.1	NS	0.26		2.25	NS	2.4
SD		1.1		0.4		0.81		0.27		0.2

Table 4 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of organic carbon

State	Method of soil sampling	Organic carbon (%)		
		Low (<1.0)	Medium (1-2.5)	High (>2.5)
Karnataka	Middle of 4 Pl	0.39	33.8	65.8
	Drip circle	0.19	33.6	66.2
Kerala	Middle of 4 Pl	2	82	16
	Drip circle	1	76	23
Tamil Nadu	Middle of 4 Pl	0	61.5	38.5
	Drip circle	0	60.4	39.6
NTA	Middle of 4 Pl	20	80	0.0
	Drip circle	40	60	0.0
NER	Middle of 4 Pl	0	100	0
	Drip circle	0	100	0

Nitrogen is a major nutrient driving several functions in the coffee plant system. The use efficiency of nitrogen is about 50% indicating that the remaining is prone to loss mainly due to leaching.

Data indicates that there was no significant difference in the content of nitrogen in soils sampled from mid of four plants and drip circle. In case of Karnataka, the available nitrogen content of soils sampled from middle of four coffee plants ranged from 120 to 668 kg ha-1 with an average of 274 kg ha-1 and in case of soils sampled from drip circle nitrogen content ranged from 108 to 743 kg ha-1 with an average of 346 kg ha-1 (Table 5). Similar trend was noticed in other coffee growing regions.

Based on the available nitrogen content, the soils are classified into three classes low (<280 kg ha-1), medium (280-560 kg ha-1) and high (>560 kg ha-1) (Table 6). The soils sampled from the middle of four coffee plants recorded medium nitrogen content in the order of Tamil Nadu (78%), North Eastern Region (57 %) and Karnataka (54.1 %).

In case of the soils sampled from the drip circle lower nitrogen content was recorded in case of Karnataka (60.1%) and NTA (77.1%).

Irrespective of the zone of soil sampling high nitrogen was not recorded in the soil samples of the five coffee growing areas indicating that nitrogen is prone to losses mainly due to leaching therefore it is important to split the application of nitrogen to improve use efficiency.

Table 5 – Content of available nitrogen (kg ha^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Rob	Rob	Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	120- 668	274	114-727	318	194-551	345	139- 739	244	182- 542	324
Drip circle	108- 743	346	92-825	266	209-727	345	139- 545	239	163- 462	292
T test	NS	0.1	NS	5.0	NS	0.9	NS	0.7	NS	2.0
SD		78.8		168		88.3		81.8		111

Phosphorous plays an important role in root development, flowering and fruit set, energy transformation and photosynthesis.

As a result of the soil being acidic due to sesqui oxides fixation of phosphorus is naturally high in coffee soils. Data on pH of soils sampled from drip circle indicates more acidity and hence higher phosphorus fixation compared to the soils sampled from mid of four plants.

Table 6 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available nitrogen

State	Method of soil sampling	Ava. Nitrogen (kg ha^{-1})		
		Low (<280)	Medium (280-560)	High (>560)
Karnataka	Middle of 4 Pl	36.7	54.1	9.2
	Drip circle	60.1	38.6	1.3
Kerala	Middle of 4 Pl	47.3	49.1	3.6
	Drip circle	71.0	27.0	2.0
Tamil Nadu	Middle of 4 Pl	22	78	0
	Drip circle	25	73	2
NTA	Middle of 4 Pl	76.2	23.1	0.7
	Drip circle	77.1	22.9	0
NER	Middle of 4 Pl	43	57	0
	Drip circle	47	53	0

Soil analysis in the coffee-growing region of Karnataka, over the past 10 years has shown that about 50% of the soil falls into the high category of phosphorus (> 56 kg ha^{-1}). This indicates that soil phosphorus has become enriched as a result of continuous application of phosphate fertilizers over a period of time (Shivaprasad et al. 2017; Shivaprasad et al. 2018; Shivaprasad et al. 2020). The data pertaining to Karnataka indicates high available phosphorus ranging from 9 – 1996 kg ha^{-1} in case of soils sampled by both methods (mid of four plants and drip circle), however the mean indicates that the drip circle recorded higher available phosphorus (with a mean of 499) compared to the soils sampled from mid of four plants (with a mean of 144) (Table 7). Similar was the trend in other states with higher mean values in case of content of available phosphorus in soils sampled from drip circle viz Kerala 160, Tamil Nadu 55, NTA 209 and NER 77.4, in comparison to the soils sampled from the mid of four plants recorded lower phosphorus.

Based on the phosphorus content the soils were classified into low (<23 kg ha^{-1}), medium (23-56 kg ha^{-1}) and high (>56 kg ha^{-1}) classes (Table 8). Based on this classification Karnataka and Kerala recorded higher phosphorus in soils sampled from the drip circle 75.3 and 84% respectively compared to soils sampled from mid of four plants recording 48 and 77% respectively.

Results of the present study indicated build up of phosphorus in the drip circle of the coffee growing soils of Karnataka (75.3%), Kerala (84%) and Tamil Nadu (36.4%). The build up of phosphorus in the drip circle could be due to the use of acid forming nitrogen fertilizers causing acidity, higher sesqui oxides leading to fixation and due to poor liming and base saturation. Unlike nitrogen and potassium, phosphorus does not leach from the soil and under acidic condition gets fixed in soil converting to unavailable forms.

Reducing the dose of P fertilizer (when soil available phosphorus is high) is necessary for ensuring balanced nutrient supply. Phosphorus and zinc are known to be antagonistic hence high phosphorus can cause zinc deficiency.

The drip circle being the zone of fertilizer application needs to be optimized in terms of pH by liming to release the fixed phosphorus. Further use of bio fertilizer would help release fixed phosphorus.

Table 7 – Content of available phosphorus (kg ha^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	9-1967	144	24- 448	101.6	2-317	51.3	13- 750	49	14- 54	26.5
Drip circle	9.0-1996	499	37- 592	160	2-361	55	13- 984	209	14- 254	77.4
T test	*	37.2	*	8.7	NS	6.9	*	6.6	*	2.6
SD		579		97		7.7		406		153

Hence, it is recommended that soils be tested for pH and other nutrients in order to know the fertility status and to apply the recommended quantity of lime and fertilizers.

Table 8 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available phosphorus

State	Method of soil sampling	Ava. Phosphorus (kg ha^{-1})		
		Low (<23)	Medium (23-56)	High (>56)
Karnataka	Middle of 4 Pl	19	33	48
	Drip circle	7.6	16.5	75.3
Kerala	Middle of 4 Pl	0	23	77
	Drip circle	0	16	84
Tamil Nadu	Middle of 4 Pl	45.9	21.9	32.2
	Drip circle	43.3	20.3	36.4
NTA	Middle of 4 Pl	21.9	65.7	12.4
	Drip circle	3.6	46.7	49.6
NER	Middle of 4 Pl	46.4	53.6	0.0
	Drip circle	21	57	21

Potassium plays an important role in plant metabolism and development. Potassium availability in soils below 141 kg ha-^{1} is considered to be low and 141–336 kg ha^{-1} as medium and >336 kg ha^{-1} is considered as high (CCRI 2014). Most of the coffee growing area falls under the medium to high category. It is known that high K content in the soil hinders the uptake of Ca and Mg, and the K content in coffee is closely related to the activity of Ca and Mg. Carvajal (1985) found that the Ca + Mg/K ratio is optimal when its value is 10 or slightly lower, and that above 24, the probability of reaction increases dramatically when K is added to coffee soils. Nagaraja (2003) found that the Ca+Mg/K ratio in the soil of Chikkamagaluru district was between 9.3 and 11.1 and similar results have been reported from other coffee growing soils (Shivaprasad et al. 2018; Shivaprasad et al. 2020). In Karnataka the available potassium content of soils sampled from middle of four coffee plants ranged from 36 to 1078 kg ha^{-1} with an average of 313 kg ha^{-1} and in case of soils sampled from the drip circle the potassium content ranged from 45 to 1273 kg ha^{-1} with an average of 466 kg ha^{-1}(Table 9). Similar trend was noticed in other coffee growing regions in soils sampled by both methods.

Based on the content of available potassium the soils were classified the following classes - low (<141 kg ha^{-1}), medium (141-336 kg ha^{-1}) and high (>336 kg ha^{-1}) (Table 10). A perusal of the data indicates that in case of Karnataka as much as 59.7% of soils sampled from the drip circle recorded high available potassium whereas as 45.4 % of soils sampled from mid of four plants recorded medium potassium. Similarly high available potassium was recorded in soils sampled from drip circle in case of Kerala (56%), NTA (83.8%), whereas in case of Tamil Nadu (50.8%) and NER (50.0 %) recorded medium available potassium in the soils sampled from the middle of four plants.

The results clearly indicate that the available potassium is medium to high irrespective of the zone of soil collection in different states. It is therefore recommended that potassium fertilizers be provided based on the actual content of available potassium in soil.

Table 9 – Content of available potassium (kg ha^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	36-1078	313	50- 880	310	78-806	409	34- 904	480	65- 574	243
Drip circle	45-1273	466	50- 930	402	56-874	437	89-996	613	63- 649	339
T test	*	37.1	*	8.7	NS	5.3	*	16.3	*	2.5
SD		250		151		87.3		241		304

Calcium is a secondary nutrient and has an important role in the development of cell walls, roots, terminal buds and flowers. It also contributes to the ripening and quality of coffee. According to the DRIS approach Nagaraja (2003) reported that, soil exchangeable Ca levels in coffee soils are ranged from of 700–1400 ppm and soil Mg levels ranged from 185–224 ppm and are ideal for coffee cultivation. The soils of NER recorded calcium below critical level of 700 mg kg-1 59% in case of soils sampled from mid of four plants and 73% in the drip circle (Table 11).

Table 10 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available potassium

State	Method of soil sampling	Ava. Potassium (kg ha^{-1})		
		Low (<141)	Medium (141-336)	High (>336)
Karnataka	Middle of 4 Pl	19.6	45.4	35
	Drip circle	9.2	31.1	59.7
Kerala	Middle of 4 Pl	20	42	38
	Drip circle	9	35	56
Tamil Nadu	Middle of 4 Pl	9.6	39.6	50.8
	Drip circle	18.7	44.4	36.9
NTA	Middle of 4 Pl	9.2	26.5	64.3
	Drip circle	2.6	13.6	83.8
NER	Middle of 4 Pl	32	52	16
	Drip circle	23.2	50.0	26.8

Based on the content of available calcium the soils were classified into two classes below critical level (<700 mg kg $^{-1}$) and above critical level (>700 mg kg $^{-1}$) (Table 12). The data indicated that irrespective of the method of soil sampling the content of available calcium in soils of the states growing coffee (except NER) was above the critical level of 700 mg kg^{-1}.

The soils of NER recorded calcium below critical level of 700 mg kg^{-1} 59% in case of soils sampled from mid of four plants and 73% in the drip circle. Application of agricultural lime based on pH values will help to improve the calcium content in the soil.

Table 11 – Content of available calcium (mg kg $^{-1}$) in soils sampled from middle of four plants and drip circle of coffee plantation in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	166-7881	1803	88- 5622	1415	141-5666	1723	316-4978	1980	47-1528	647
Drip circle	75-6547	1561	156-5003	1395	331-7144	1722	372-5803	2249	41-1438	496
T test	NS	8.9	NS	0.2	NS	0.19	NS	3.3	NS	2.5
SD		988		975		1312		1340		429

Table 12 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available calcium

State	Method of soil sampling	Calcium (mg kg^{-1})	
		Below Critical level (<700)	Above Critical level (>700)
Karnataka	Middle of 4 Pl	11.1	88.9
	Drip circle	18.6	81.4
Kerala	Middle of 4 Pl	23	77
	Drip circle	20	80
Tamil Nadu	Middle of 4 Pl	10.2	89.8
	Drip circle	12	88
NTA	Middle of 4 Pl	16	84
	Drip circle	7	93
NER	Middle of 4 Pl	59	41
	Drip circle	73	27

Magnesium is one of the important secondary nutrients and is a constituent of the chlorophyll. In the coffee estates of Karnataka the soils sampled from mid of four plants recorded 25 to 991 mg kg $^{-1}$available magnesium with an average of 240 mg kg $^{-1}$ and in the soils sampled from drip circle it ranged from 16 to 894 mg kg $^{-1}$ with an average of 212 mg kg^{-1} (Table 13). Similar trend was noticed in other coffee growing regions.

Based on the magnesium content soils were classified into two classes - below critical level (available magnesium <180mg kg $^{-1}$) and above critical level (magnesium >180 mg kg $^{-1}$) (Table 14). Irrespective of the method of soil sampling, 75 % of the coffee plantations in Tamil Nadu and NTA recorded available magnesium above critical level of 180 mg kg^{-1}.

About 50 % of the coffee plantations in Karnataka and Kerala recorded available magnesium above the critical level >180 mg kg^{-1} whereas the remaining 50% recorded available magnesium below 50%. In case of NER, about 70% of the soil samples recorded available magnesium below critical level <180 mg kg^{-1}.Application of Dolomite based on pH values will help to improve the magnesium content in the soil.

Table 13 – Content of available magnesium (mg kg^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	25- 991	240	9- 634	198	34- 1506	350	41- 584	246	38- 369	142
Drip circle	16- 894	212	22- 894	203	34- 3825	399	38- 581	233	22- 441	150
T test	NS	6.6	NS	0.2	NS	1.65	NS	1.8	NS	0.8
SD		153		212		417		114		88

Table 14 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available magnesium

State	Method of soil sampling	Magnesium (mg kg^{-1})	
		Below Critical level (<180)	Above Critical level (>180)
Karnataka	Middle of 4 Pl	42.8	57.2
	Drip circle	50.4	49.6
Kerala	Middle of 4 Pl	49	51
	Drip circle	58	42
Tamil Nadu	Middle of 4 Pl	20	80
	Drip circle	22.5	77.5
NTA	Middle of 4 Pl	22	78
	Drip circle	26	74
NER	Middle of 4 Pl	69	31
	Drip circle	71	29

Sulphur is a component of amino acids and it influences the quality of coffee. Organic matter provides for sulphur in the coffee plantations. The data indicates that irrespective of the method of soil sampling the average sulphur content in coffee soils of Karnataka, NTA and NER was 40 mg kg-1, indicating that the coffee plantations are rich in sulphur.

There was no significant difference in the content of sulphur in soils sampled from the mid of four coffee plants and the sulphur content ranged from 8 to 101 mg kg^{-1} with an average of 40 mg kg^{-1} and in the soils sampled from the drip circle it ranged from 6 to 128 mg kg^{-1} with an average of 40 mg kg^{-1} (Table 15). However in case of NTA and NER the range was narrow – NTA recording 14 – 62 mg kg^{-1} (M4P) with a mean of 38 mg kg^{-1} & 15 – 77 mg kg^{-1} (DC) with a mean of 41 mgkg-1. The soils of NER recorded 25 -73 mg kg^{-1} with a mean of 40 mg kg^{-1} and 18 – 85 with a mean of 44.2 mg kg^{-1} of available sulphur.

The soil samples were classified into two categories based on the content of available sulphur 1) below critical level (<16 mg kg^{-1}), 2) above critical level (>16 mg kg^{-1}) (Table 16). The data clearly indicates that irrespective of the method of soil sampling and the region the available sulphur content in the soils of coffee plantations was high (>16 mg kg^{-1}).

Table 15 – Content of available sulphur (mg kg^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka		Kerala		Tamil Nadu		NTA		NER	
	Ara & Rob		Robusta		Ara & Rob		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	8- 101	40	13-83	21	19-40	30	14- 62	38	25- 73	40
Drip circle	6- 128	40	14-92	30	11-29	16	15- 77	41	18- 85	44.2
T test	NS	0.24	NS	1.7	*	2.9	NS	3.0	NS	1.5
SD		29.1		25.4		25		14.7		19.8

Zinc is a constituent of many enzymes; influences translocation and transportation of phosphorus in plant and plays major role in many metabolic activities. Zinc and phosphorus are antagonistic *i.e* higher the phosphorus the lesser the zinc. Further zinc is subject to leaching as a result the coffee growing regions are usually low in zinc. A study by Raju and Deshapande (1987) found that widespread zinc deficiency in Arabica plantations was associated with high levels of phosphorus, potassium, calcium and high soil pH in coffee soils.

Table 16 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of available sulphur

State	Method of soil sampling	Sulphur (mg kg^{-1})	
		Below Critical level (<16)	Above Critical level (>16)
Karnataka	Middle of 4 Pl	1.6	98.4
	Drip circle	3	97
Kerala	Middle of 4 Pl	36	64
	Drip circle	16	84
Tamil Nadu	Middle of 4 Pl	0	100
	Drip circle	56	44
NTA	Middle of 4 Pl	0.7	99.3
	Drip circle	0.4	99.6
NER	Middle of 4 Pl	0	100
	Drip circle	0	100

There was no significant difference in the content of zinc in soils sampled from the mid of four plants and from the drip circle in the different regions growing coffee. In Karnataka, the zinc content of the soils sampled from the middle of four coffee plants ranged from 0.5 to 31 mg kg^{-1} with an average of 2.9 mg kg^{-1} and in the drip circle it ranged from 0.01 to 41 mg kg^{-1} with an average of 3.5 mg kg^{-1} (Table 17). Similar trend was noticed in other coffee growing states.

The soils were classified into two classes depending on the zinc content - below critical level (<1.5 mg kg^{-1}) and above critical level (>1.5 mg kg^{-1}) (Table 18).

The data in Table 18 clearly indicates that a majority of the soil samples of Karnataka, Kerala and NTA are low in available zinc whereas Tamil Nadu and NER recorded sufficient zinc. It is recommended that zinc be supplied as zinc sulphate during the post monsoon season to offset deficiencies.

Table 17 – Content of available zinc (mg kg^{-1}) in soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER

Method of soil sampling	Karnataka (n = 2442)		Kerala (n = 420)		Tamil Nadu (n = 1108)		NTA (n = 550)		NER (n = 112)	
	Ara & Rob		Robusta		Arabica		Ara & Rob		Ara & Rob	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
M4P	0.5- 31	2.9	0.1- 12.4	1.3	0.2- 13.9	2.2	0.1- 5.7	1.4	0.2-39	18
Drip circle	0.01- 41	3.5	0.2- 14.8	1.3	0.3- 18.6	2.6	0.2- 6.9	1.7	0.5- 34	10.4
T test	NS	3.4	NS	0.03	NS	2.4	NS	3.5	NS	5.6
SD		6.0		2.0		2.6		1.2		9.5

Table 18 – Percentage of soils sampled from mid of four plants and drip circle of coffee plantations in Karnataka, Kerala, Tamil Nadu, NTA and NER under different classes of zinc

State	Method of soil sampling	Zinc (mg kg^{-1})	
		Below Critical level (<1.5)	Above Critical level (>1.5)
Karnataka	Middle of 4 Pl	51.6	48.4
	Drip circle	51.5	48.5
Kerala	Middle of 4 Pl	79	21
	Drip circle	75	25
Tamil Nadu	Middle of 4 Pl	43	57
	Drip circle	32.5	67.5
NTA	Middle of 4 Pl	64	36
	Drip circle	60	40
NER	Middle of 4 Pl	24	76
	Drip circle	24	76

There was no significant difference in the content of copper, boron, iron and manganese in the soils sampled by either of the two methods namely mid of four plants and drip circle.

CONCLUSION

The exchangeable magnesium and zinc levels were less than critical limits but the coffee plants have not exhibited any deficiency symptoms in majority of the plantations. The coffee soils are highly buffered in nature as the organic carbon status of the soils are mostly medium to high due to coffee cultivation under shade trees. The high phosphorus and potassium status of soils may be responsible for the lower status of magnesium and zinc due to antagonistic effect. It is possible to correct the deficiency by gradually reducing phosphorus and potassium application over the years without affecting coffee yield and quality.

Reduction in phosphorus fertilizer doses by 25 to 50 per cent is recommended in areas where the soil phosphorus is high (> 57 kg ha^{-1}) to extremely high levels (>200 kg ha^{-1}). Similarly reduction in potassium fertilizer doses by 25 per cent is recommended in areas where the soil potassium is high (> 336 kg ha^{-1}). As the cost of phosphorus and potassium fertilizers are high it must be used judiciously based on the soil test recommendations leading to balanced nutrition and reduced costs. Use of phosphorus solubilizing micro organisms and potassium mobilizing micro organisms for recycling fixed phosphorus and mobilizing the potassium will reduce the use of these fertilizers and cost of cultivation.

In well established coffee plantations, soils should be sampled between four plants (@ one and half feet away from main stem in case of Arabica and two feet away from the main stem in case of Robusta as the nutrient-absorbing roots are mostly concentrated in this area.

Coffee growers often apply fertilizers very close to the plants, which results in accumulation of nutrients in one place leading to poor nutrient use efficiency. It is recommended to apply fertilizers in the drip circle, specifically one and half feet away from main stem in case of Arabica and two feet away from the main stem in case of Robusta where the feeding roots are concentrated.

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