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Characterization of Calcium and Magnesium Status in Arecanut (*Areca catechu* L.) Growing Soils of Koppa, Sringeri and Thirthahalli Taluks of the Malnad Region

K. Reshma [a++*], Sarvajna B. Salimath [b] and Arun C. Kanagalabavi [c]

[a] Department of Soil Science and Agricultural Chemistry, College of Agriculture, KSNUAHS, Shivamogga, Karnataka-577204, India.
[b] AHRS, Kattalagere, KSNUAHS, Shivamogga, Karnataka-577204, India.
[c] Department of Soil Science and Agricultural Chemistry, KLE College of Agricultural Sciences, Tenikolla, Belagavi, Karnataka-591119, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

A survey was taken up in the year 2022 in the arecanut gardens of three selected taluks of the Malnad region *viz*. Koppa, Sringeri and Thirthahalli. The soil samples were collected at surface (0-30 cm) and sub-surface (30-60 cm) depths in healthy and unhealthy arecanut gardens and were characterized for secondary nutrients

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++Senior Research Fellow;
**Corresponding author: E-mail: reshmakanth1996@gmail.com.;*

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like calcium and magnesium. The diverse geological characteristics, rainfall patterns, organic matter content and agricultural practices all collectively contribute to the observed variations in calcium and magnesium content among different fractions and soil depths in these taluks. Among the various calcium and magnesium forms (water-soluble, exchangeable and residual/non-exchangeable), water-soluble form (3.3%) consistently showed the lowest quantities in the soils. Exchangeable form (26.3%) was found to be lower than residual form (70.4%). Also, exchangeable (61.5%) and water-soluble (38.5%) fractions contribute to the soil available pool. All the four forms of calcium and magnesium were relatively lower in Thirthahalli soils in comparison to the soils of the other two taluks. This could be attributed to lower content of calcium and magnesium containing minerals in acid soils coupled with their high rate of solubilization, low amounts of 2:1 clays and excessive leaching losses of ions in acid soils.The research study provides valuable insights into the distribution and forms of calcium and magnesium in arecanut-growing soils of the Malnad region, which is an important area for arecanut cultivation in India. Understanding the status and fractionation of secondary nutrients such as calcium and magnesium is essential for improving soil fertility management and sustaining crop productivity. The study contributes region-specific soil nutrient information that can support better nutrient management strategies for farmers and agricultural researchers working in humid tropical soils.

Keywords: Arecanut gardens; calcium; magnesium; Koppa; Sringeri; Thirthahalli.

1. Introduction

Arecanut (*Areca catechu* L.), a prominent cash crop in India, is renowned for its economic produce, the 'betel nut', primarily used for mastication and in various socio-religious ceremonies. This industry serves as the economic lifeline for nearly ten million people in India, many of whom depend solely on it for their livelihoods. India, being the largest global producer and consumer of arecanut, contributes to approximately 54 per cent of the world's production. Among the Indian states, Karnataka stands out as a major contributor (46%) with cultivation area estimates varying slightly by year, but generally around 2.15 to 6.80 lakh hectares, with recent figures suggesting around 6.80 lakh hectares for the year 2023-24 (Bhat *et al.,* 2024), a significant increase from figures in the year 2017-18 (around 2.79 lakh ha) and 2020-21 (around 5.49 lakh ha) and 47 per cent of the total production. The state has got two distinct tracts *viz.,* the malnad tract and maidan tract. The Malnad tract is said to be the traditional belt wherein the crop has been grown with considerable past history. Tracts essentially consist of coastal plains of Dakshina and Uttara Kannada, Udupi, parts of Shivamogga and hilly terrains of Chikkmagaluru districts. It is characterized by heavy rainfall, variation in altitude, temperature fluctuations *etc*. These factors play a dominant role in determining soil fertility and productivity. As such crops like arecanut is perennial in nature, and their productivity is affected by many reasons, out of which soil nutrient imbalance is one of the important productivity constraints.While primary nutrients like nitrogen, phosphorus and potassium are extensively studied, secondary nutrients, including calcium, magnesium and sulphur, often receive less attention. Thus, focus on the unique agricultural region of the Malnad region is needed, acknowledging the specific challenges and characteristics associated with arecanut cultivation in this area.

Calcium (Ca) and magnesium (Mg), essential macronutrients absorbed by plants in the form of Ca^{2+} and Mg^{2+} from the soil, play pivotal roles in plant growth and development. Calcium, a constituent of the cell wall as calcium pectate, maintains cell membrane integrity, supports cell division and neutralizes acidic molecules detrimental to plant growth. Magnesium is crucial for chlorophyll formation, photosynthesis, enzyme activation, carbohydrate metabolism and nucleic acid synthesis. Deficiencies in these nutrients manifest as various crop symptoms, emphasizing their importance (Tisdale *et al.,* 1975). Soil content of these elements' ranges widely, influenced by factors such as soil type and parent material. Due to the limited presence of Ca and Mg in acidic soils caused by soil acidity-related issues like leaching of essential bases, a high concentration of exchangeable aluminum (Al) and low cation exchange capacity (CEC), the productivity of acidic soils tends to be low (Craswell and Pushparajah, 1989). In a similar way, Haynes and Ludecke (1981) observed a decline in both soluble and exchangeable Ca as soil pH decreased. The critical role of secondary nutrients, specifically Ca and Mg in the context of arecanut cultivation in the Malnad region of Karnataka, aims to shed light on the availability of these nutrients, which is crucial for sustaining this vital cash crop and supporting the livelihoods of millions in the region. The focus on a specific geographical area, the Malnad region, contextualizes the study within a specific agricultural region, acknowledging the unique characteristics and challenges associated with arecanut cultivation in that particular area.

2. Materials and Methods

Malenadu covers the western and eastern slopes of the Western Ghats or Sahyadri mountain range, and is roughly 100 kilometers in width. Koppa, Sringeri and Thirthahalli taluks of the Malnad region were selected as study areas located in Hilly zone (Koppa and Sringeri belong to Chikkamagalur district and Thirthahalli belongs to Shivamogga district) of Karnataka between 13° 53' North latitude and 75° 36' East longitude (Koppa), 13° 25' North latitude and 75° 15' East longitude (Sringeri) and 13° 68' North latitude and 75° 24' East longitude (Thirthahalli), covering an area of about 56600 ha, 44400 ha and 125400 ha, respectively. The GPS coordinates of the sampling points in the respective taluks are mentioned in Tables 1, 2 and 3 and the map showing sampling points covered in arecanut gardens of the respective taluks from Chikkamagalur district and Shivamogga district is represented in Fig. 1.

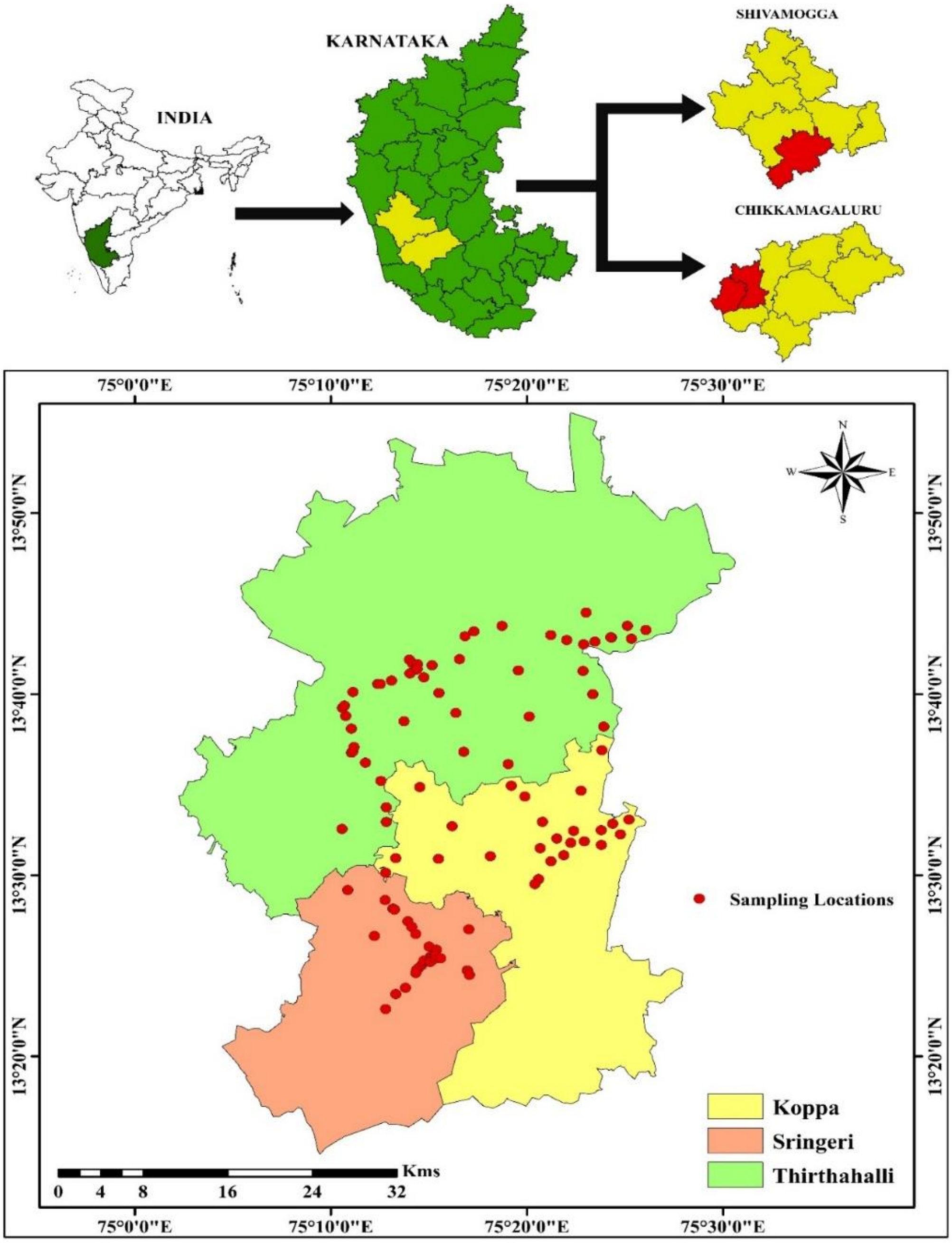

Fig. 1. Map showing sampling points covered in arecanut gardens of Koppa and Sringeri from Chikkamagalur district and Thirthahalli from Shivamogga district

Table 1. Location description for survey samples collected from arecanut gardens of Koppa taluk of the Malnad region

Sl No.	Location	North Latitude	East Longitude
1	Ammadi estate	13.5491	75.3465
2	Upperpet	13.5338	75.3586
3	Hulmakki bus stop	13.5231	75.3549
4	N K road, Kunchu	13.5128	75.3536
5	Hondadamane road	13.4964	75.3431
6	Narve	13.4918	75.3400
7	Koppa rural	13.5195	75.3554
8	Melpal	13.5316	75.3723
9	Old Balgadi	13.5298	75.3705
10	Haranduru	13.5311	75.3820
11	Kesave	13.5352	75.3879
12	Thalamakki estate	13.5359	75.3914
13	Vittalamakki	13.5492	75.4132
14	Seethur	13.5492	75.4160
15	Kudregundi	13.5511	75.4199
16	Kanive	13.6966	75.4231
17	Kandaka-Muduba road	13.6978	75.4235
18	Rasthe, Jambuvally	13.7092	75.4252
19	Muttinakoppa road, Lingapura	13.7131	75.4279
20	Jambuvally	13.7159	75.4245
21	Beguvalli	13.7187	75.4050
22	Thyanandur	13.7189	75.4045
23	Solapur-Mangalore highway, Beguvalli	13.7150	75.3911
24	Thudur	13.7125	75.3814
25	Kodige	13.7164	75.3671
26	Gabadi	13.7210	75.3535
27	Koppa rural	13.5823	75.3199
28	Koppa rural	13.5725	75.3315
29	Koppa rural	13.6194	75.4141
30	Koppa rural	13.6270	75.4236

Table 2. Location description for survey samples collected from arecanut gardens of Sringeri taluk of the Malnad region

Sl No.	Location	North Latitude	East Longitude
1	Sringeri main road, Kodur	13.5157	75.2216
2	Begar	13.5022	75.2131
3	Nallur colony	13.4771	75.2127
4	Marigebailumavinamara stop, Neelandur	13.4692	75.2194
5	Neelandur	13.4682	75.2206
6	Holekoppa	13.4575	75.2320
7	Honnavalli	13.4523	75.2352
8	Kaimane	13.4459	75.2386
9	Sringeri rural	13.4343	75.2500
10	Sanklapura	13.4313	75.2563
11	Sharadanagar	13.4264	75.2540
12	Solapur-Mangalore highway, Sringeri	13.4248	75.2511
13	Managar	13.4225	75.2503
14	C6CX+576, Sringeri	13.4205	75.2476
15	VidyaBharathiBhavana, National highway 13	13.4172	75.2437
16	Shankarapura	13.4147	75.2412
17	NH169	13.4124	75.2393
18	Durgadevasthana	13.4100	75.2388

Sl No.	Location	North Latitude	East Longitude
19	Yadadalu	13.3964	75.2300
20	Nemmaru	13.3906	75.2218
21	Sunkadamaki bridge, Solapur-Mangalore highway	13.3767	75.2131
22	Bolugudde	13.4214	75.2456
23	RastraKavi Kuvempu bus station	13.4202	75.2505
24	Menase	13.4201	75.2512
25	Kurbkeri circle, Bharathi St	13.4232	75.2554
26	Bayalurangamandira, Sharadanagar	13.4263	75.2561
27	Balehonnure, Sringeri road	13.4234	75.2599
28	ShidleGanapathidevasthana, Chikmanglur-Sringeri road	13.4123	75.2825
29	Kunthur	13.4120	75.2827
30	Vykuntapura	13.4082	75.2843

Table 3. Location description for survey samples collected from arecanut gardens of Thirthahalli taluk of the Malnad region

Sl No.	Location	North Latitude	East Longitude
1	Kesalur	13.5625	75.2137
2	Kadthur	13.5490	75.2137
3	Kammaradi	13.5868	75.2090
4	Holalurbetagere	13.6036	75.1959
5	Harebailu	13.6127	75.1841
6	Bogarukoppa	13.6137	75.1850
7	Chikkodabailu	13.6179	75.1861
8	Heggodu	13.6349	75.1840
9	Kodlu	13.6466	75.1791
10	Kalmane	13.6540	75.1764
11	Agumbe-Thirthahalli road	13.6562	75.1780
12	Mulubagilu	13.6687	75.1853
13	Bintala	13.6761	75.2064
14	Ranjadakatte	13.6760	75.2085
15	Surali bale bailu	13.6792	75.2182
16	Yadehalli, Yoginarasipura	13.6985	75.2333
17	Seebinakere	13.6951	75.2359
18	Kolikalgudda	13.6943	75.2402
19	Kaimara	13.6892	75.2388
20	Balebailu	13.6858	75.2337
21	Doddamanekeri	13.6898	75.2400
22	Kuruvalli	13.6821	75.2455
23	Melina Kuruvalli, Buklapura	13.6678	75.2584
24	Balagatti	13.6494	75.2728
25	Kuppalli	13.6022	75.3173
26	Tudki	13.6933	75.2526
27	Kesare	13.6989	75.2759
28	Hugalavalli	13.7199	75.2806
29	Kudumallige	13.7244	75.2882
30	Bhandya	13.7295	75.3120

Soil sampling in arecanut growing soils was carried out in Koppa, Sringeri and Thirthahalli of the Malnad region, where sampling of surface and sub-surface soil was done in 2 depths, at 0-30 cm and 30-60 cm, in selected healthy and unhealthy arecanut gardens to study the distribution of forms of Ca and Mg and was brought to the laboratory for analysis. In the laboratory, soil samples were dried under shade, ground using wooden pestle and mortar, passed through 2 mm sieve and stored for analysis. The soil samples were analysed for fractions of Ca and Mg and available sulphur status by following standard methods as given below.

2.1 Fractionation of Calcium (Ca) and Magnesium (Mg)

Calcium and magnesium are essential macronutrients that exist in various forms within soils, including exchangeable and residual fractions and their distribution profoundly influences the suitability of soils for arecanut cultivation.

2.1.1 Water-Soluble Calcium and Magnesium (mg kg^{-1})

Water-soluble forms of calcium and magnesium were determined by treating the soil with distilled water (1:5) for 5 minutes, and the elements in the extract were estimated by the versanate titration method involving 0.01 *N* EDTA, which exhibits strong complex formation with metal ions at different pH levels (Page *et al.,* 1982).

2.1.2 Exchangeable Calcium and Magnesium (mg kg^{-1})

Exchangeable Ca and Mg contents of the soil were determined by extraction with neutral normal ammonium acetate solution and estimation of the elements in the extract by the versanate titration method involving 0.01 *N* EDTA, which exhibits strong complex formation with metal ions at different pH levels (Jackson, 1973).

2.1.3 Non-Exchangeable Calcium and Magnesium (mg kg^{-1})

A gram of soil was taken in a conical flask and treated with 1 *N* HCl and heated until boiling started. Boiling of soil suspension was continued for 15 minutes, and the contents were transferred to a funnel lined with Whatman no. 42 filter paper. The soil was washed with four 15 mL portions of 0.1 *N* HCl, and the filtrate was used for analysis of Ca and Mg by the versanate titration method (Page *et al.,* 1982).

2.1.4 Total Calcium and Magnesium (mg kg^{-1})

A gram of soil was taken in a polypropylene bottle, and 2 mL of aqua regia (HNO_3 + $HClO_4$) was added to this for the decomposition of the carbonates present and dispersing the sample. Further, 20 mL of HF was added to the bottle. The contents of the bottle were shaken for 8 to 10 hrs. After this, about 50 mL of saturated H_3BO_3 was added, shaken for 2 hours and kept for a week for the complete dissolution of the sample. Finally, the volume of the digested sample was made up to 100 mL as described by Sridhar and Jackson (1974), and the contents of calcium and magnesium were determined by the versenate titration method (Jackson, 1973).

3. Results and Discussion

3.1 Fractions of Calcium and Magnesium in Arecanut Growing Soils of the Malnad Region

The assessment of calcium and magnesium fractions in the soils of the Malnad region, where arecanut cultivation thrives, holds paramount importance for understanding soil health and its direct impact on crop productivity. Calcium and magnesium are essential macronutrients that play pivotal roles in soil structure, nutrient availability and overall plant nutrition. These nutrients exist in various forms within soils, including exchangeable and residual fractions (Fig. 2a and 2b) and their distribution profoundly influences the suitability of soils for arecanut cultivation. By investigating the fractions of calcium and magnesium in these soils, the intricate relationship between soil properties and the availability of these essential nutrients is derived, offering valuable insights for optimizing soil management practices. Tables 4 to 9 provide a comprehensive presentation of the data pertaining to various fractions of both calcium and magnesium.

3.1.1 Calcium (mg kg^{-1})

The calcium content in Koppa taluk exhibited significant variations across different fractions and soil depths. Specifically, at the 0-30 cm depth, water-soluble calcium ranged from 5.3 to 118.4 mg kg^{-1}, while at 30-60 cm depth, it varied between 6.1 and 118.8 mg kg^{-1}. Additionally, the exchangeable calcium content spanned from 43.3 to 958.2 mg kg^{-1} at the 0-30 cm depth and from 49.5 to 961.3 mg kg^{-1} at the 30-60 cm depth. The residual calcium content exhibited a range of 115.7 to 2562.0 mg kg^{-1} at the 0-30 cm depth and 132.3 to 2570.3 mg kg^{-1} at the 30-60 cm depth. Lastly, the total calcium content showed variability from 164.4 to 3638.6 mg kg^{-1} at the 0-30 cm depth and 187.9 to 3650.4 mg kg^{-1} at the 30-60 cm depth (Table 4).

Table 4. Calcium fractions of surface and sub-surface soils in the arecanut gardens of Koppa taluk of the Malnad region

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
K1	0-30	13.3	108.3	289.5	411.2
	30-60	22.8	185.2	495.1	703.2
K2	0-30	5.3	43.3	115.7	164.4
	30-60	6.1	49.5	132.3	187.9
K3	0-30	8.4	68.2	182.3	258.9
	30-60	9.6	77.8	208.0	295.4
K4	0-30	12.7	103.1	275.6	391.5
	30-60	13.8	112.3	300.2	426.4
K5	0-30	14.8	120.0	320.8	455.6
	30-60	16.0	130.2	348.1	494.4
K6	0-30	19.5	158.3	423.2	601.1
	30-60	22.6	183.2	489.8	695.6
K7	0-30	118.4	958.2	2562.0	3638.6
	30-60	118.7	961.0	2569.5	3649.3
K8	0-30	80.7	653.1	1746.2	2480.0
	30-60	74.1	600.2	1604.8	2279.2
K9	0-30	15.8	128.2	342.7	486.8
	30-60	16.1	130.6	349.1	495.9
K10	0-30	14.9	120.6	322.4	457.9
	30-60	14.1	114.3	305.6	434.0
K11	0-30	18.5	150.1	401.3	569.9
	30-60	19.0	154.0	411.7	584.8
K12	0-30	97.5	789.2	2110.2	2997.0
	30-60	74.4	602.3	1610.4	2287.1
K13	0-30	29.0	235.1	628.6	892.7
	30-60	31.6	255.7	683.6	970.9
K14	0-30	38.1	308.9	825.9	1173.0
	30-60	41.5	336.2	898.9	1276.6
K15	0-30	19.0	154.2	412.2	585.5
	30-60	32.1	259.8	694.6	986.5
K16	0-30	20.3	164.8	440.6	625.8
	30-60	20.1	163.1	436.0	619.3
K17	0-30	12.3	100.2	267.9	380.5
	30-60	15.2	123.6	330.4	469.3
K18	0-30	15.3	124.5	332.8	472.7
	30-60	27.3	221.6	592.5	841.5
K19	0-30	28.8	233.3	623.7	885.9
	30-60	49.5	401.2	1072.7	1523.5
K20	0-30	15.0	121.9	325.9	462.9
	30-60	27.8	225.7	603.4	857.0
K21	0-30	15.2	123.2	329.4	467.8
	30-60	17.0	138.1	369.2	524.4
K22	0-30	9.7	78.5	209.8	298.0
	30-60	7.6	62.0	165.7	235.4
K23	0-30	74.1	599.8	1603.7	2277.6
	30-60	77.0	623.1	1666.0	2366.1
K24	0-30	72.5	587.2	1570.0	2229.8
	30-60	74.6	604.1	1615.2	2294.0
K25	0-30	12.1	98.3	262.8	373.2
	30-60	10.7	87.1	232.8	330.7
K26	0-30	91.9	744.2	1989.8	2826.0
	30-60	105.3	852.1	2278.3	3235.7

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
K27	0-30	69.9	566.2	1513.9	2150.0
	30-60	91.5	741.0	1981.2	2813.8
K28	0-30	11.7	95.2	254.5	361.5
	30-60	12.3	100.1	267.6	380.1
K29	0-30	86.4	699.3	1869.7	2655.5
	30-60	71.9	582.1	1556.4	2210.4
K30	0-30	89.1	721.3	1928.6	2739.0
	30-60	118.8	961.3	2570.3	3650.4
Range	0-30	5.3 - 118.4	43.3 - 958.2	115.7 - 2562.0	164.4 - 3638.6
	30-60	6.1 - 118.8	49.5 - 961.3	132.3 - 2570.3	187.9 - 3650.4
Mean	0-30	37.6 ± 34.1	305.2 ± 276.6	816.0 ± 739.6	1159.0 ± 1050.5
	30-60	41.3 ± 35.0	334.6 ± 283.3	894.6 ± 757.5	1270.6 ± 1075.8

Table 5. Calcium fractions of surface and sub-surface soils in the arecanut gardens of Sringeri taluk of the Malnad region

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
S1	0-30	30.3	245.2	655.6	931.1
	30-60	32.9	266.3	712.0	1011.2
S2	0-30	28.4	230.1	615.2	873.7
	30-60	30.1	244.3	653.2	927.7
S3	0-30	69.9	566.1	1513.6	2149.7
	30-60	77.1	624.4	1669.5	2371.1
S4	0-30	37.0	299.4	800.5	1136.9
	30-60	37.3	302.5	808.8	1148.7
S5	0-30	163.4	1322.7	3536.6	5022.8
	30-60	175.8	1422.3	3802.9	5401.0
S6	0-30	32.2	260.9	697.5	990.7
	30-60	34.0	275.7	737.1	1046.9
S7	0-30	11.7	95.2	254.5	361.5
	30-60	12.3	100.2	267.9	380.5
S8	0-30	13.7	111.0	296.7	421.5
	30-60	12.4	100.5	268.7	381.6
S9	0-30	152.6	1234.7	3301.3	4688.6
	30-60	164.7	1332.6	3563.1	5060.4
S10	0-30	13.8	112.1	299.7	425.6
	30-60	15.3	124.3	332.3	472.0
S11	0-30	28.4	230.2	615.5	874.1
	30-60	29.8	241.3	645.1	916.3
S12	0-30	64.4	521.4	1394.1	1979.9
	30-60	77.8	629.5	1683.1	2390.4
S13	0-30	27.4	222.1	593.8	843.4
	30-60	36.8	298.3	797.5	1132.7
S14	0-30	105.3	852.1	2278.3	3235.7
	30-60	115.5	935.1	2500.2	3550.9
S15	0-30	12.3	100.1	267.6	380.1
	30-60	15.5	125.4	335.2	476.1
S16	0-30	151.7	1227.5	3282.0	4661.3
	30-60	163.6	1324.0	3540.1	5027.7
S17	0-30	40.8	330.6	883.9	1255.4
	30-60	40.7	329.5	881.0	1251.2
S18	0-30	76.7	620.9	1660.1	2357.8
	30-60	89.1	721.0	1927.8	2737.9

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
S19	0-30	29.7	240.8	643.8	914.4
	30-60	31.0	251.3	671.9	954.2
S20	0-30	41.0	332.1	887.9	1261.1
	30-60	52.1	421.7	1127.5	1601.3
S21	0-30	91.8	743.2	1987.1	2822.2
	30-60	77.2	625.1	1671.3	2373.7
S22	0-30	119.1	963.8	2577.0	3659.9
	30-60	121.8	985.7	2635.5	3743.1
S23	0-30	25.1	203.2	543.3	771.6
	30-60	35.3	285.6	763.6	1084.5
S24	0-30	123.8	1002.3	2679.9	3806.1
	30-60	149.0	1205.7	3223.7	4578.5
S25	0-30	31.4	254.1	679.4	964.9
	30-60	36.7	297.2	794.6	1128.5
S26	0-30	12.3	100.3	268.1	380.8
	30-60	14.2	115.2	308.0	437.4
S27	0-30	27.7	224.1	599.1	850.9
	30-60	40.3	326.5	872.9	1239.8
S28	0-30	13.6	110.7	295.9	420.3
	30-60	16.4	132.8	355.0	504.2
S29	0-30	11.8	95.8	256.1	363.7
	30-60	12.3	100.2	267.9	380.5
S30	0-30	105.3	852.1	2278.3	3235.7
	30-60	114.1	923.4	2468.9	3506.5
Range	0-30	11.7 - 163.4	95.2 - 1322.7	254.4 - 3536.6	361.5 - 5022.8
	30-60	12.3 - 175.8	100.2 - 1422.3	267.9 - 3802.9	380.5 - 5401.0
Mean	0-30	56.4 ± 47.7	456.8 ± 385.8	1221.4 ± 1031.7	1734.7 ± 1465.3
	30-60	62.04 ± 51.3	502.2 ± 415.0	1342.8 ± 1109.8	1907.2 ± 1576.2

Table 6. Calcium fractions of surface and sub-surface soils in the arecanut gardens of Thirthahalli taluk of the Malnad region

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
T1	0-30	69.7	564.6	1509.6	2144.0
	30-60	85.9	695.2	1858.8	2639.9
T2	0-30	11.1	90.2	241.1	342.5
	30-60	12.8	103.8	277.5	394.1
T3	0-30	11.1	90.3	241.4	342.9
	30-60	13.6	110.6	295.7	419.9
T4	0-30	32.9	266.3	712.0	1011.2
	30-60	43.8	354.4	947.5	1345.8
T5	0-30	35.8	290.2	775.9	1102.0
	30-60	37.1	300.3	802.9	1140.3
T6	0-30	11.1	90.1	240.9	342.1
	30-60	14.1	114.5	306.1	434.8
T7	0-30	10.0	81.6	218.1	309.8
	30-60	11.4	92.3	246.7	350.5
T8	0-30	13.0	105.2	281.2	399.4
	30-60	15.8	128.3	343.0	487.2
T9	0-30	18.8	152.3	407.2	578.3
	30-60	29.8	241.1	644.6	915.5
T10	0-30	77.0	623.1	1666.0	2366.1
	30-60	89.6	724.9	1938.2	2752.7

Sl. No.	Depth (cm)	Calcium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
T11	0-30	66.7	540.2	1444.3	2051.3
	30-60	70.0	566.7	1515.2	2151.9
T12	0-30	20.2	163.9	438.2	622.3
	30-60	11.1	89.8	240.1	341.0
T13	0-30	29.3	237.5	635.0	901.8
	30-60	45.6	369.2	987.1	1402.0
T14	0-30	43.7	354.1	946.7	1344.6
	30-60	48.2	390.0	1042.7	1480.9
T15	0-30	59.6	482.3	1289.5	1831.4
	30-60	76.7	621.1	1660.6	2358.5
T16	0-30	9.2	75.2	201.0	285.5
	30-60	10.7	86.6	231.5	328.8
T17	0-30	50.9	411.9	1101.3	1564.1
	30-60	50.7	410.2	1096.7	1557.6
T18	0-30	52.0	420.9	1125.4	1598.3
	30-60	39.3	318.2	850.8	1208.3
T19	0-30	69.9	566.0	1513.3	2149.3
	30-60	76.8	621.4	1661.4	2359.7
T20	0-30	103.9	841.2	2249.1	3194.3
	30-60	89.5	724.5	1937.1	2751.2
T21	0-30	9.7	79.2	211.7	300.7
	30-60	10.1	82.1	219.5	311.7
T22	0-30	76.9	622.3	1663.9	2363.1
	30-60	91.6	741.4	1982.3	2815.3
T23	0-30	41.1	333.2	890.9	1265.2
	30-60	50.8	411.0	1098.9	1560.7
T24	0-30	7.7	62.7	167.6	238.0
	30-60	9.0	73.6	196.7	279.4
T25	0-30	64.6	522.8	1397.8	1985.2
	30-60	71.7	580.1	1551.0	2202.8
T26	0-30	13.4	109.2	291.9	414.6
	30-60	15.5	125.4	335.2	476.1
T27	0-30	25.6	207.6	555.0	788.3
	30-60	39.7	321.4	859.3	1220.4
T28	0-30	52.0	420.9	1125.4	1598.3
	30-60	70.0	566.4	1514.4	2150.8
T29	0-30	16.6	134.8	360.4	511.8
	30-60	18.4	149.6	400.0	568.0
T30	0-30	40.8	330.2	882.8	1253.9
	30-60	55.9	452.9	1210.9	1719.8
Range	0-30	7.7 - 103.9	62.7 - 841.2	167.6 - 2249.1	238.0 - 3194.3
	30-60	9.0 - 91.6	73.6 - 741.4	196.7 - 1982.3	279.4 - 2815.3
Mean	0-30	38.1 ± 26.3	309.0 ± 213.1	826.1 ± 569.9	1173.3 ± 809.4
	30-60	43.5 ± 28.5	352.2 ± 231.0	941.7 ± 617.7	1337.5 ± 877.2

In Sringeri taluk, calcium levels showcased significant variations across various fractions and soil depths. Specifically, at the 0-30 cm depth, the water-soluble calcium content ranged from 11.7 to 163.4 mg kg^{-1}, while at the 30-60 cm depth, it exhibited variability between 12.3 to 175.8 mg kg^{-1}. Moreover, the exchangeable calcium content spanned from 95.2 to 1322.7 mg kg^{-1} at the 0-30 cm depth and from 100.2 to 1422.3 mg kg^{-1} at the 30-60 cm depth. Additionally, the residual calcium content showed a range of 254.4 to 3536.6 mg kg^{-1} at the 0-30 cm depth and 267.9 to 3802.9 mg kg^{-1} at the 30-60 cm depth. Lastly, the total calcium content displayed variability from 361.5 to 5022.8 mg kg^{-1} at the 0-30 cm depth and 380.5 to 5401.0 mg kg^{-1} at the 30-60 cm depth (Table 5).

Table 7. Magnesium fractions of surface and sub-surface soils in the arecanut gardens of Koppa taluk of the Malnad region

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
K1	0-30	3.8	31.2	83.5	118.6
	30-60	6.6	53.4	142.8	202.8
K2	0-30	1.5	12.4	33.3	47.4
	30-60	1.7	14.2	38.1	54.2
K3	0-30	2.4	19.6	52.6	74.7
	30-60	2.7	22.4	60.0	85.2
K4	0-30	3.6	29.7	79.5	112.9
	30-60	4.0	32.3	86.6	123.0
K5	0-30	4.2	34.6	92.5	131.4
	30-60	4.6	37.5	100.4	142.6
K6	0-30	5.6	45.6	122.0	173.4
	30-60	6.5	52.8	141.2	200.6
K7	0-30	34.1	276.4	739.0	1049.6
	30-60	34.2	277.2	741.2	1052.6
K8	0-30	23.2	188.3	503.7	715.4
	30-60	21.4	173.1	462.9	657.4
K9	0-30	4.5	36.9	98.8	140.4
	30-60	4.6	37.6	100.7	143.0
K10	0-30	4.3	34.7	93.0	132.1
	30-60	4.0	32.9	88.1	125.2
K11	0-30	5.3	43.2	115.7	164.4
	30-60	5.4	44.4	118.7	168.6
K12	0-30	28.1	227.6	608.7	864.5
	30-60	21.4	173.7	464.5	659.7
K13	0-30	8.3	67.8	181.3	257.5
	30-60	9.1	73.7	197.2	280.0
K14	0-30	11.0	89.1	238.2	338.3
	30-60	11.9	96.9	259.3	368.2
K15	0-30	5.4	44.4	118.9	168.9
	30-60	9.2	74.9	200.3	284.5
K16	0-30	5.8	47.5	127.1	180.5
	30-60	5.8	47.0	125.7	178.6
K17	0-30	3.5	28.9	77.2	109.7
	30-60	4.4	35.6	95.3	135.3
K18	0-30	4.4	35.9	96.0	136.3
	30-60	7.9	63.9	170.9	242.7
K19	0-30	8.3	67.2	179.9	255.5
	30-60	14.3	115.7	309.4	439.4
K20	0-30	4.3	35.1	94.0	133.5
	30-60	8.0	65.1	174.0	247.2
K21	0-30	4.3	35.5	95.0	134.9
	30-60	4.9	39.8	106.5	151.2
K22	0-30	2.7	22.6	60.5	85.9
	30-60	2.2	17.8	47.8	67.9
K23	0-30	21.3	173.0	462.6	657.0
	30-60	22.2	179.7	480.5	682.5
K24	0-30	20.9	169.3	452.9	643.2
	30-60	21.5	174.2	465.9	661.7
K25	0-30	3.5	28.3	75.8	107.6
	30-60	3.1	25.1	67.1	95.4
K26	0-30	26.5	214.6	573.9	815.2
	30-60	30.3	245.7	657.2	933.3

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
K27	0-30	20.1	163.3	436.7	620.2
	30-60	26.4	213.7	571.5	811.6
K28	0-30	3.3	27.4	73.4	104.2
	30-60	3.5	28.8	77.2	109.6
K29	0-30	24.9	201.7	539.3	766.0
	30-60	20.7	167.9	448.9	637.6
K30	0-30	25.7	208.0	556.3	790.1
	30-60	34.2	277.2	741.4	1053.0
Range	0-30	1.5 - 34.1	12.4 - 276.4	33.3 - 739.0	47.4 - 1049.6
	30-60	1.7 - 34.2	14.2 - 277.2	38.1 - 741.4	54.2 - 1053.0
Mean	0-30	10.8 ± 9.8	87.9 ± 79.8	235.3 ± 213.3	334.3 ± 303.0
	30-60	11.8 ± 10.1	96.4 ± 81.7	258.0 ± 218.5	366.4 ± 310.3

Table 8. Magnesium fractions of surface and sub-surface soils in the arecanut gardens of Sringeri taluk of the Malnad region

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
S1	0-30	11.6	93.7	35.3	140.6
	30-60	12.6	101.7	38.3	152.7
S2	0-30	10.9	87.9	33.1	132.0
	30-60	11.5	93.3	35.1	140.1
S3	0-30	26.8	216.3	81.5	324.7
	30-60	29.6	238.6	89.9	358.2
S4	0-30	14.2	114.4	43.1	171.7
	30-60	14.3	115.6	43.5	173.5
S5	0-30	62.7	505.4	190.5	758.8
	30-60	67.5	543.5	204.9	815.9
S6	0-30	12.3	99.7	37.5	149.6
	30-60	13.0	105.3	39.7	158.1
S7	0-30	4.5	36.3	13.7	54.6
	30-60	4.7	38.2	14.4	57.4
S8	0-30	5.2	42.4	15.9	63.6
	30-60	4.7	38.4	14.4	57.6
S9	0-30	58.6	471.8	177.8	708.3
	30-60	63.2	509.2	191.9	764.5
S10	0-30	4.8	38.8	14.6	58.3
	30-60	5.3	43.1	16.2	64.7
S11	0-30	9.9	79.8	30.0	119.8
	30-60	10.3	83.6	31.5	125.6
S12	0-30	22.4	180.8	68.1	271.4
	30-60	27.1	218.3	82.3	327.7
S13	0-30	9.5	77.0	29.0	115.6
	30-60	12.8	103.4	39.0	155.3
S14	0-30	36.7	295.5	111.4	443.6
	30-60	40.2	324.3	122.2	486.8
S15	0-30	4.3	34.7	13.0	52.1
	30-60	5.4	43.4	16.3	65.2
S16	0-30	52.8	425.7	160.4	639.1
	30-60	57.0	459.1	173.1	689.3
S17	0-30	14.2	114.6	43.2	172.1
	30-60	14.1	114.2	43.0	171.5
S18	0-30	26.7	215.3	81.1	323.2
	30-60	31.0	250.0	94.2	375.3

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
S19	0-30	10.3	83.5	31.4	125.3
	30-60	10.8	87.1	32.8	130.8
S20	0-30	14.3	115.1	43.4	172.9
	30-60	18.1	146.2	55.1	219.5
S21	0-30	32.0	257.7	97.1	386.9
	30-60	26.9	216.7	81.7	325.4
S22	0-30	41.5	334.2	126.0	501.8
	30-60	42.4	341.8	128.8	513.2
S23	0-30	8.7	70.4	26.5	105.7
	30-60	12.3	99.0	37.3	148.6
S24	0-30	43.1	347.6	131.0	521.8
	30-60	51.9	418.1	157.6	627.7
S25	0-30	10.9	88.1	33.2	132.2
	30-60	12.8	103.0	38.8	154.7
S26	0-30	4.3	34.7	13.1	52.2
	30-60	4.9	39.9	15.0	59.9
S27	0-30	9.6	77.7	29.3	116.6
	30-60	14.0	113.2	42.6	169.9
S28	0-30	4.7	38.3	14.4	57.6
	30-60	5.7	46.0	17.3	69.1
S29	0-30	4.1	33.2	12.5	49.8
	30-60	4.3	34.7	13.1	52.1
S30	0-30	36.7	295.5	111.4	443.6
	30-60	39.7	320.2	120.7	480.7
Range	0-30	4.1 - 62.7	33.2 - 505.4	12.5 - 190.5	49.8 - 758.8
	30-60	4.3 - 67.5	34.7 - 543.5	13.1 - 204.9	52.1 - 815.9
Mean	0-30	20.2 ± 17.4	163.5 ± 140.1	61.6 ± 52.8	245.5 ± 210.4
	30-60	22.2 ± 18.7	179.6 ± 150.7	67.6 ± 56.8	269.7 ± 226.2

Table 9. Magnesium fractions of surface and sub-surface soils in the arecanut gardens of Thirthahalli taluk of the Malnad region

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
T1	0-30	24.7	199.2	75.3	299.3
	30-60	30.4	245.3	92.7	368.5
T2	0-30	3.9	31.8	12.0	47.8
	30-60	4.5	36.6	13.8	55.0
T3	0-30	3.9	31.8	12.0	47.8
	30-60	4.8	39.0	14.7	58.6
T4	0-30	11.6	93.9	35.5	141.1
	30-60	15.5	125.0	47.2	187.8
T5	0-30	12.7	102.4	38.7	153.8
	30-60	13.1	105.9	40.0	159.2
T6	0-30	3.9	31.8	12.0	47.7
	30-60	5.0	40.4	15.2	60.7
T7	0-30	3.5	28.8	10.8	43.2
	30-60	4.0	32.5	12.3	48.9
T8	0-30	4.6	37.1	14.0	55.7
	30-60	5.6	45.2	17.1	68.0
T9	0-30	8.4	68.1	25.7	102.4
	30-60	13.3	107.9	40.8	162.1
T10	0-30	34.6	279.0	105.4	419.0
	30-60	25.2	203.2	76.8	305.2

Sl. No.	Depth (cm)	Magnesium (mg kg^{-1})			
		Water-soluble	Exchangeable	Residual	Total
T11	0-30	18.7	151.4	57.2	227.5
	30-60	19.7	158.8	60.0	238.6
T12	0-30	5.7	45.9	17.3	69.0
	30-60	3.1	25.1	9.5	37.8
T13	0-30	8.2	66.5	25.1	100.0
	30-60	12.8	103.5	39.1	155.4
T14	0-30	12.3	99.2	37.5	149.1
	30-60	13.5	109.3	41.3	164.2
T15	0-30	16.7	135.2	51.1	203.1
	30-60	21.6	174.1	65.8	261.5
T16	0-30	2.6	21.0	7.9	31.6
	30-60	3.0	24.2	9.1	36.4
T17	0-30	14.3	115.4	43.6	173.4
	30-60	14.2	115.0	43.4	172.7
T18	0-30	14.6	118.0	44.6	177.2
	30-60	11.0	89.2	33.7	134.0
T19	0-30	19.6	158.6	59.9	238.3
	30-60	21.6	174.2	65.8	261.6
T20	0-30	29.2	235.8	89.1	354.2
	30-60	25.2	203.1	76.7	305.1
T21	0-30	2.7	22.2	8.3	33.3
	30-60	2.8	23.0	8.7	34.5
T22	0-30	21.6	174.4	65.9	262.0
	30-60	25.7	207.8	78.5	312.2
T23	0-30	11.5	93.4	35.3	140.3
	30-60	14.2	115.2	43.5	173.0
T24	0-30	2.1	17.5	6.6	26.4
	30-60	2.5	20.6	7.8	30.9
T25	0-30	18.1	146.5	55.4	220.1
	30-60	20.1	162.6	61.4	244.3
T26	0-30	3.7	30.6	11.5	45.9
	30-60	4.3	35.1	13.2	52.8
T27	0-30	7.2	58.2	22.0	87.4
	30-60	11.1	90.1	34.0	135.3
T28	0-30	14.6	118.0	44.6	177.2
	30-60	19.7	158.8	60.0	238.5
T29	0-30	4.6	37.7	14.2	56.7
	30-60	5.2	41.9	15.8	63.0
T30	0-30	11.4	92.5	34.9	139.0
	30-60	15.7	126.9	47.9	190.7
Range	0-30	2.1 - 34.6	17.5 - 279.0	6.6 - 105.4	26.4 - 419.0
	30-60	2.5 - 30.4	20.6 - 245.3	7.8 - 92.7	30.9 - 368.5
Mean	0-30	11.7 ± 8.4	94.7 ± 67.7	35.7 ± 25.6	142.3 ± 101.7
	30-60	12.9 ± 8.2	104.6 ± 66.2	39.5 ± 25.0	157.2 ± 99.5

In Thirthahalli taluk, the calcium content displayed noteworthy variations among different fractions and soil depths. To elaborate, at the 0-30 cm depth, water-soluble calcium ranged from 7.7 to 103.9 mg kg^{-1}, while at the 30-60 cm depth, it exhibited variability between 9.0 to 91.6 mg kg^{-1}. Additionally, the exchangeable calcium content spanned from 62.7 to 841.2 mg kg^{-1} at the 0-30 cm depth and from 73.6 to 741.4 mg kg^{-1} at the 30-60 cm depth. Furthermore, the residual calcium content showed a range of 167.6 to 2249.1 mg kg^{-1} at the 0-30 cm depth and 196.7 to 1982.3 mg kg^{-1} at the 30-60 cm depth. Lastly, the total calcium content demonstrated variability from 238.0 to 3194.3 mg kg^{-1} at the 0-30 cm depth and 279.4 to 2815.3 mg kg^{-1} at the 30-60 cm depth (Table 6).

The variation in calcium content among the three taluks, Koppa, Sringeri and Thirthahalli, can be attributed to several factors influencing soil chemistry and mineral composition in the Malnad region. Firstly, differences in geological parent materials significantly affect calcium levels, with each taluk having distinct geological formations. Secondly, varying rainfall patterns impact calcium movement within the soil, with high rainfall areas experiencing more leaching effects. Thirdly, variations in organic matter affect calcium levels, as organic matter helps retain calcium through chelation processes. Lastly, differences in agricultural practices, such as the use of calcium-containing fertilizers and soil amendments, contribute to variations in soil calcium levels. In summary, diverse geological characteristics, rainfall patterns, organic matter content and agricultural practices collectively contribute to the observed variations in calcium content among different fractions and soil depths in these taluks.

Among the various calcium forms, including water-soluble, exchangeable and residual calcium, water-soluble calcium consistently showed the lowest quantities in the soils. Exchangeable calcium was found to be lower than residual calcium, indicating that the latter form likely predominantly existed in calcium-containing soil minerals, with a relatively smaller portion in adsorbed forms (Bhindhu and Sureshkumar, 2021). It is known that a percentage of adsorbed calcium often exists in residual forms on 2:1 clay minerals, particularly under high soil pH conditions (Tisdale *et al.,* 1975). These findings align with previous research work of Shanthakumari (2007). Exchangeable calcium is influenced by the type and amount of clay minerals and humus content, typically higher than other cations in most soils. Consequently, soils in the northern dry zone, primarily containing 2:1 clay minerals, had higher exchangeable calcium levels compared to soils in the southern transition and coastal zones, corroborating studies by Sudhir (1983). Furthermore, water-soluble calcium content was also lower in coastal and southern transition zone soils than in dry zone soils, likely due to lower calcium content in these soils and calcium loss via leaching.

3.1.2 Magnesium (mg kg^{-1})

The magnesium content in Koppa taluk exhibited significant variations across different fractions and soil depths. Specifically, at the 0-30 cm depth, water-soluble magnesium ranged from 1.5 to 34.1 mg kg^{-1}, while at the 30-60 cm depth, it varied between 1.7 to 34.2 mg kg^{-1}. Additionally, the exchangeable magnesium content spanned from 12.4 to 276.4 mg kg^{-1} at the 0-30 cm depth and from 14.2 to 277.2 mg kg^{-1} at the 30-60 cm depth. Moreover, the residual magnesium content exhibited a range of 33.3 to 739.0 mg kg^{-1} at the 0-30 cm depth and 38.1 to 741.4 mg kg^{-1} at the 30-60 cm depth. Lastly, the total magnesium content showed variability from 47.4 to 1049.6 mg kg^{-1} at the 0-30 cm depth and 54.2 to 1053.0 mg kg^{-1} at the 30-60 cm depth (Table 7).

In Sringeri taluk, magnesium levels showcased significant variations across various fractions and soil depths. Specifically, at the 0-30 cm depth, the water-soluble magnesium content ranged from 4.1 to 62.7 mg kg^{-1}, while at the 30-60 cm depth, it exhibited variability between 4.3 to 67.5 mg kg^{-1}. Moreover, the exchangeable magnesium content spanned from 33.2 to 505.4 mg kg^{-1} at the 0-30 cm depth and from 34.7 to 543.5 mg kg^{-1} at the 30-60 cm depth. Additionally, the residual magnesium content showed a range of 12.5 to 190.5 mg kg^{-1} at the 0-30 cm depth and 13.1 to 204.9 mg kg^{-1} at the 30-60 cm depth. Lastly, the total magnesium content displayed variability from 49.8 to 758.8 mg kg^{-1} at the 0-30 cm depth and 52.1 to 815.9 mg kg^{-1} at the 30-60 cm depth (Table 8).

In Thirthahalli taluk, the magnesium content displayed noteworthy variations among different fractions and soil depths. To elaborate, at the 0-30 cm depth, water-soluble magnesium ranged from 2.1 to 34.6 mg kg^{-1}, while at the 30-60 cm depth, it exhibited variability between 2.5 to 30.4 mg kg^{-1}. Additionally, the exchangeable magnesium content spanned from 17.5 to 279.0 mg kg^{-1} at the 0-30 cm depth and from 20.6 to 245.3 mg kg^{-1} at the 30-60 cm depth. Furthermore, the residual magnesium content showed a range of 6.6 to 105.4 mg kg^{-1} at the 0-30 cm depth and 7.8 to 92.7 mg kg^{-1} at the 30-60 cm depth. Lastly, the total magnesium content demonstrated variability from 26.4 to 419.0 mg kg^{-1} at the 0-30 cm depth and 30.9 to 368.5 mg kg^{-1} at the 30-60 cm depth (Table 9).

The variations in magnesium content among the soils of Koppa, Sringeri and Thirthahalli in the Malnad region can be attributed to a complex interplay of geological, climatic and soil factors. These intricate interactions among various properties highlight the significance of local geological and environmental factors in shaping soil mineral composition, paralleling the trends observed for calcium in section 3.1.1.

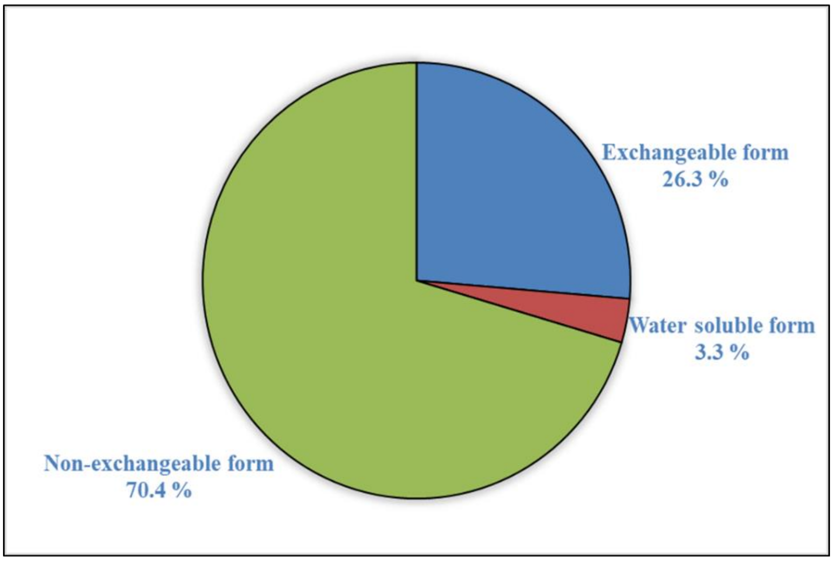

Fig. 2a. Per cent distribution of calcium and magnesium fractions recognized in soils in the arecanut gardens of selected taluks of the Malnad region

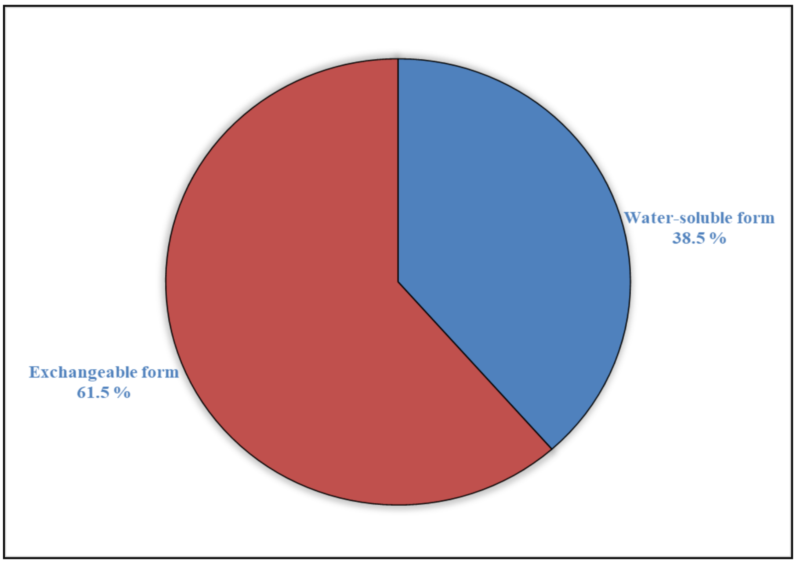

Fig. 2b. Per cent distribution of calcium and magnesium fractions contributing to the soil available pool in the arecanut gardens of selected taluks of the Malnad region

The results on the four forms of magnesium *i.e.*, water-soluble magnesium, exchangeable magnesium and residual magnesium and total magnesium, revealed a trend similar to that of four forms of calcium in respect of their distribution in soils of three different taluks of the Malnad region. All the four forms of magnesium were relatively lower in Thirthahalli soils in comparison to the soils of other two taluks (Vasundhara *et al.*, 2020). This could be attributed to lower content of magnesium-containing minerals in acid soils coupled with their high rate of solubilization, low amounts of 2:1 clays and excessive leaching losses of the ions in acid soils. These results are in accordance with those of Niranjana *et al.* (2016) and Ananthanarayana *et al.* (1986).

4. Conclusion

- The survey conducted across Koppa, Sringeri and Thirthahalli taluks of the Malnad region revealed considerable spatial variability in the calcium and magnesium status of arecanut-growing soils, influenced by soil depth, health of the gardens and inherent soil-forming factors.

- Calcium and magnesium were predominantly present in the residual (non-exchangeable) fraction, indicating that a major proportion of these secondary nutrients remains structurally bound within soil minerals and is not readily available for plant uptake.
- Among the different fractions, the water-soluble form constituted the smallest proportion of total calcium and magnesium, reflecting the highly leached nature of soils under high rainfall conditions prevailing in the Malnad region.
- Exchangeable calcium and magnesium, though lower than the residual fraction, formed the principal contributors to the plant-available nutrient pool, highlighting their importance in sustaining arecanut nutrition.
- Soils of Sringeri and Koppa taluks generally exhibited higher levels of calcium and magnesium fractions compared to Thirthahalli, suggesting relatively better nutrient retention capacity in these areas. The consistently lower content of all forms of calcium and magnesium in Thirthahalli soils can be attributed to acidic soil reaction, reduced presence of Ca and Mg bearing minerals, limited 2:1 clay content and intensified leaching losses under high rainfall.
- Depth-wise distribution showed only marginal variation between surface and sub-surface layers, indicating downward movement of bases and limited accumulation in the surface horizon.
- Sustained productivity of arecanut in these regions requires site-specific soil management strategies, including liming and balanced nutrient application, to enhance the availability of calcium and magnesium and mitigate nutrient imbalances.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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