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ASSESSMENT OF AVAILABLE SECONDARY AND MICRONUTRIENTS IN ARECANUT (*Areca catechu* L.) GROWING SOILS OF MALNAD REGION KARNATAKA INDIA

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ABSTRACT

A field survey was taken up in the year 2022 in three selected taluks of Malnad region *viz*. Koppa, Sringeri and Thirthahalli. The soil samples were obtained from surface (0-30 cm) and sub-surface depths (30-60 cm) of healthy and unhealthy areca gardens and were analyzed for available secondary nutrients and micronutrients. In Koppa taluk, surface soils exhibited deficiencies of available calcium and magnesium in 66.7 per cent and 70.0 per cent of the samples, respectively. Similarly, surface soil samples from Sringeri showed calcium and magnesium deficiencies to the extent of 56.7 per cent and 63.3 per cent, while in Thirthahalli, calcium deficiency was observed in 53.3 per cent and magnesium deficiency in 73.3 per cent of the samples. Across all three taluks, available sulphur content remained at a medium level in both surface and sub-surface soils, with a marginal reduction noted in sulphur content with increasing depth. With respect to available micronutrients, soils from all the three taluks were generally sufficient in iron, manganese, and copper however, zinc deficiency was commonly observed across the taluks.
***Keywords* :** Arecanut gardens, Calcium, Magnesium, Micronutrients, Koppa, Sringeri and Thirthahalli.

Introduction

Arecanut (*Areca catechu* L.) is a perennial plantation crop extensively grown in the humid tropical regions of India, where it contributes significantly to agricultural income and land use systems. 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 6.8 lakh hectares, with recent figures suggesting around 6.8 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. Within Karnataka, the Malenadu region encompasses the western and eastern slopes of the Western Ghats or Sahyadri mountain range, spanning approximately 100 kilometers in width. Characterized by high rainfall, averaging from 1000 to 3800 mm annually, this region is susceptible to the leaching of secondary nutrients and soluble organic carbon. Arecanut thrives in areas with heavy rainfall, ranging from 750 mm in the Maidan parts of Karnataka to 4,500 mm in the Malnad areas. The predominant soil types for arecanut cultivation include red lateritic soils in the Western Ghats, West Bengal and Assam regions, as well as clay loam soils in the plains of Karnataka (Mohapatra, 1975). As such crop 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.

Soil content of nutrient elements ranges widely, influenced by factors such as high rainfall, intense leaching, soil type and parent material. Due to the limited presence of calcium (Ca) and magnesium (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). Among micronutrients, iron and manganese are usually present in adequate amounts, whereas, zinc deficiency is more commonly reported. Copper availability is generally sufficient but may decline in highly weathered soils. Additionally, at lower pH levels, the availability of Ca is hindered by the elevated presence of Al. Likewise, in acidic soils characterized by low CEC and a high saturation of iron (Fe) and aluminum (Al), magnesium remained in the soil solution and was susceptible to leaching losses (Myers *et al.*, 1988). The status of these nutrients plays a critical role in determining the nutritional balance and productivity of arecanut in the region. Therefore, it is imperative to provide Ca and Mg in the form of liming materials to address the challenges posed by acidic soils and enhance their production potential. The focus on 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.

Material 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 Malnad region was 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 respective taluks is mentioned in table 1, 2 and 3 and the map showing sampling points covered in arecanut gardens of respective taluks from Chikkamagalur district and Shivamogga district is represented in figure 1.

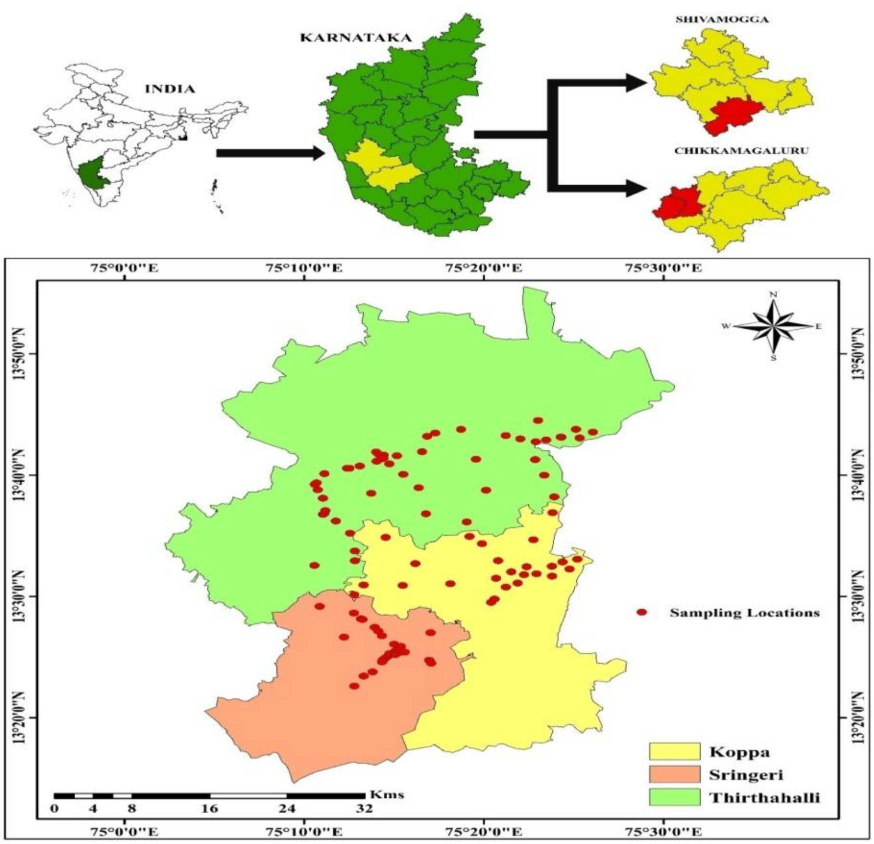

Fig. 1 : Map showing sampling points covered in arecanut gardens of Koppa and Sringeri from Chikkamagalur district and Thirthahalli from Shivamogga district

Table 1 : Location description for survey samples collected from arecanut gardens of Koppa taluk of 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 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
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 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

Collection of soil samples

Sampling in arecanut growing soils was carried out in Koppa, Sringeri and Thirthahalli of 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 available secondary and micronutrients.

Preparation of soil samples

The collected soil samples were air dried under shade and were grounded with a wooden pestle and morter and passed through 2 mm sieve to separate coarse fragments (> 2 mm). The processed soil samples were stored in plastic bags and used for various analysis of nutrients using standard procedure in the lab.

Soil analysis of available secondary nutrients and micronutrients of survey samples

Soil available calcium and magnesium occur mainly in exchangeable forms held on the soil colloidal complex. Available sulphur is present predominantly as sulphate in the soil solution and is closely associated with organic matter mineralization. Available micronutrients in soil exist in soluble, exchangeable and organically complexed forms which are effectively extracted using DTPA extractant. The availability of these nutrients is influenced by soil reaction, texture and management practices, and their imbalance can adversely affect crop growth and nutrient uptake efficiency.

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 versanate titration method involving 0.01 *N* EDTA, which exhibits strong complex formation with metal ions at different pH levels (Jackson, 1973).

Available sulphur (mg kg^{-1})

Available sulphur in the soil was extracted by using 0.15 per cent calcium chloride dihydrate solution and sulphur in the extract was estimated by turbidimetric method using $BaCl_2$. The turbidity was measured using UV spectrophotometer at 420 nm (Chesnin and Yien, 1951).

DTPA extractable Fe, Mn, Zn and Cu (mg kg^{-1})

The micronutrients *viz*., iron, manganese, copper and zinc were extracted by 0.005 *M* DTPA (Diethylene Triamine Penta Acetic acid) extractant and 0.01 *M* $CaCl_2$+ 0.1 *N* Triethanalamine at pH 7.3, in the ratio of 1:2 soil to extractant and shaken for two hours, as explained by Lindsay and Norvell (1978). The concentration of micronutrients (mg kg^{-1}) was estimated using atomic absorption spectrophotometer.

Results and Discussion

Status of secondary nutrient availability in arecanut growing soils of Malnad region

The condition of calcium, magnesium and sulphur availability in the soils of the Malnad region, where arecanut palms thrive, emphasizes the critical need for routine soil testing and effective nutrient management strategies to uphold the vitality and yield of arecanut palm cultivation. Given the substantial variations in these essential nutrients across this region, diligent monitoring and prompt rectification of nutrient imbalances are paramount for farmers. Comprehensive data on available calcium, magnesium and sulphur can be found in Tables 4 to 6.

Exchangeable calcium [cmol (p$^+$) kg^{-1}]

The status of exchangeable calcium in the soils of the Malnad region, where arecanut palms are cultivated, reveals variations that necessitate close attention to nutrient management. This essential nutrient is indispensable for robust root development, reinforcing cell walls and bolstering the overall structural integrity of arecanut palms. It plays a pivotal role in averting diseases like Koleroga, thereby ensuring the palms' resilience to prevalent pathogens. Furthermore, calcium's influence on soil pH regulation enhances its significance, as it helps create a favourable environment for arecanut palm growth. The data presented in Tables 4 to 6 provides insight into calcium availability, at different soil depths. These findings underscore the importance of regular soil testing and tailored nutrient management practices to ensure optimal calcium levels for successful arecanut palm cultivation in the Malnad region.

The calcium content within the arecanut gardens of Koppa, Sringeri, and Thirthahalli taluks exhibits depth-dependent variations. In Koppa taluk (Table 4), calcium levels gradually increase with soil depth, spanning from 0.216 to 4.791 cmol (p$^+$) kg^{-1} at 0-30 cm and from 0.247 to 4.806 cmol (p$^{+)}$ kg^{-1} at 30-60 cm. Notably, the surface layer of this taluk shows a deficiency in calcium content in the majority of samples, accounting for 66.67 per cent of cases. Similarly, in Sringeri taluk (Table 5), calcium content increases with depth, ranging from 0.467 to 6.613 cmol (p$^+$) kg^{-1} at 0-30 cm and from 0.501 to 7.111 cmol (p$^+$) kg^{-1} at 30-60 cm. In this case, 56.67 per cent of samples from the surface layer indicate a deficiency in calcium. In Thirthahalli taluk (Table 6), calcium content also exhibits an increasing trend with depth, varying from 0.313 to 4.206 cmol (p^+) kg^{-1} at 0-30 cm and from 0.368 to 3.707 cmol (p^+) kg^{-1} at 30-60 cm. Furthermore, 53.33 per cent of samples from surface layer indicate deficiency in Ca content.

When comparing the three taluks, Koppa and Thirthahalli exhibit comparable values for exchangeable calcium, while Sringeri records the highest value. This divergence could be attributed to the quantity and distribution of rainfall received, variations in soil properties among these taluks, along with the distinct agricultural practices practiced by local farmers, contribute to the dynamics of calcium leaching and retention within the soil. The diminished calcium status in soils was attributed to higher precipitation levels, leading to increased leaching losses, resulting in soils with slightly to moderately acidic pH levels (Amruthesh *et al.*, 2020). To examine the interplay between soil characteristics and available calcium, correlation and regression analyses were conducted, with the exclusion of soils from special zones due to their unique properties, including low pH, high electrical conductivity (EC), and elevated levels of both basic and acidic cations, which might introduce a biased influence. Notably, available calcium exhibited significant positive correlations with pH (0.73**), EC (0.28*), and exchangeable calcium (0.89**), aligning with the findings of Bhindhu and Sureshkumar (2021).

Exchangeable magnesium [cmol (p^+) kg^{-1}]

Magnesium is an essential component of chlorophyll, the green pigment vital for photosynthesis. Adequate magnesium levels are fundamental for robust photosynthetic activity, which directly impacts the growth and yield of arecanut palms. Additionally, magnesium influences nutrient uptake by plants and helps in the activation of various enzymes involved in metabolic processes. Magnesium also aids in neutralizing soil acidity, contributing to optimal pH levels for nutrient availability. Hence, maintaining adequate magnesium levels through proper soil management practices is imperative for sustaining healthy arecanut palm plantations in the Malnad region, ensuring not only crop quantity but also quality. The data presented in Tables 4 to 6 provides insight into magnesium availability, at different soil depths.

The magnesium content in the arecanut gardens of Koppa, Sringeri, and Thirthahalli taluks show depth-dependent variations. In Koppa taluk (Table 4), magnesium levels gradually increase with soil depth, ranging from 0.104 to 2.303 cmol (p^+) kg^{-1} at 0-30 cm and from 0.118 to 2.310 cmol (p^+) kg^{-1} at 30-60 cm. Significantly, the surface layer in this taluk exhibits magnesium deficiency in the majority of samples, accounting for 70.00 per cent of cases. Similarly, in Sringeri taluk (Table 5), magnesium levels progressively rise with soil depth, ranging from 0.276 to 4.212 cmol (p^+) kg^{-1} at 0-30 cm and from 0.289 to 4.529 cmol (p^+) kg^{-1} at 30-60 cm. Notably, the surface layer in this taluk also displays magnesium deficiency in the majority of samples, making up 63.33 per cent of cases. In Thirthahalli taluk (Table 6), magnesium levels also exhibit a depth-dependent pattern, varying from 0.146 to 2.325 cmol (p^+) kg^{-1} at 0-30 cm and from 0.171 to 2.044 cmol (p^+) kg^{-1} at 30-60 cm. Remarkably, the surface layer in this taluk indicates Mg deficiency in the majority of samples, accounting for 73.33 per cent of cases.

Similarly, mirroring the pattern observed in calcium content, magnesium levels exhibited a corresponding variation among the taluks. Koppa and Thirthahalli displayed similar magnesium status, while Sringeri recorded higher values for magnesium content. The previously mentioned factors that explain the variations in magnesium content also apply here. In contrast to calcium, the deficiency of available magnesium was more pronounced and widespread, possibly attributed to the prevalence of coarse textured soils, well-drained conditions, extensive leaching losses and limited nutrient inputs. Unlike calcium, magnesium is less strongly bound to soil colloids due to its larger hydrated ionic radii, making it susceptible to leaching. A parallel case of widespread magnesium deficiency is evident in soils within the Attapady hills of Palakkad, primarily due to low rainfall and near-neutral pH conditions (Chaitra *et al.*, 2016). Furthermore, available magnesium shows significant positive correlations with pH (0.62**), EC (0.31*) and exchangeable calcium (0.71**).

Available sulphur (ppm)

Sulphur holds pivotal importance in the arecanut growing soils of the Malnad region, playing a role in the overall health and productivity of arecanut crops. Sulphur is a vital component in amino acids, proteins and enzymes critical for various biochemical processes within the plant. Furthermore, sulphur contributes to chlorophyll formation, facilitating efficient photosynthesis and ultimately enhancing the plant's energy production. In the context of the Malnad region, where arecanut cultivation thrives, ensuring an adequate supply of sulphur is imperative to maintain robust plant growth, optimize photosynthesis and achieve high-quality arecanut yields. The data presented in Tables 4 to 6 provides insight into magnesium availability, at different soil depths.

In the arecanut gardens of Koppa taluk (Table 4), sulphur values vary significantly, ranging from 10.41 to 19.03 ppm at a depth of 0 to 30 cm and 8.16 to 15.33 ppm at 30 to 60 cm. These values exhibit a gradual decrease with increasing soil depth. Remarkably, all samples collected from the surface layer consistently indicate a medium sulphur status. Within Sringeri taluk (Table 5), sulphur values encompass a range from 11.65 to 18.46 ppm at 0 to 30 cm and 9.20 to 13.93 ppm at 30 to 60 cm. All samples obtained from the surface layer consistently fall within the medium range. Similarly, in Thirthahalli taluk (Table 6), sulphur values span from 10.45 to 18.37 ppm at the 0 to 30 cm depth and 9.20 to 14.33 ppm at the 30 to 60 cm depth. A subtle decline in sulphur values is observed with increasing depth, and notably, all surface-layer samples indicate a medium nitrogen status.

All three taluks display a similar range of values and depth distribution for available sulphur, which aligns well with the results reported by Ananthanarayana *et al.* (1986). In their study, available sulfur content ranged from 4.60 to 22.60 ppm, with samples from Hosanagar and Thirthahalli also exhibiting considerable variations. The availability of sulphur in soils appears to be closely tied to several key factors, including the type of fertilizers applied, parent material composition, rainfall patterns, clay content and organic matter levels, as documented by Reddy *et al.* (2012). Notably, the application of organic manures and fertilizers is primarily concentrated in the surface layer, potentially contributing to sulphur availability. Additionally, our preliminary survey reveals that arecanut gardens in the Malnad region have severe outbreaks of the fungal disease koleroga during the monsoon season. In response, local farmers have adopted a regular practice of applying Bordeaux mixture ($CuSO_4$) paste as a fungal control measure. This consistent use of Bordeaux paste, in conjunction with the application of sulphur-containing fertilizers, could be contributing to the notably high available sulphur content in the soil. This observation aligns with the findings of Dhumgond *et al.* (2017), who reported elevated available sulphur levels (ranging from 4.6 to 22.7 ppm) in the hilly zones of Karnataka, attributing it to the application of sulphur-containing fertilizers and $CuSO_4$. It's worth noting that soil pH also plays a pivotal role in sulphur availability.

Table 4 : Status of available secondary nutrients status of surface and sub-surface soils in the arecanut gardens of Koppa taluk of Malnad region

Sl. No.	Depth (cm)	Exchangeable Ca [cmol (p^+) kg^{-1}]	Exchangeable Mg [cmol (p^+) kg^{-1}]	Avail. S (mg kg^{-1})
K1	0-30	0.54	0.26	10.41
	30-60	0.92	0.44	8.93
K2	0-30	0.21	0.10	19.03
	30-60	0.24	0.11	11.40
K3	0-30	0.34	0.16	12.03
	30-60	0.38	0.18	8.16
K4	0-30	0.51	0.24	15.53
	30-60	0.56	0.26	12.06
K5	0-30	0.60	0.28	12.18
	30-60	0.65	0.31	10.67
K6	0-30	0.79	0.38	15.46
	30-60	0.91	0.44	11.92
K7	0-30	4.79	2.30	12.08
	30-60	4.80	2.31	11.03
K8	0-30	3.26	1.56	18.40
	30-60	3.00	1.44	12.50
K9	0-30	0.64	0.30	11.38
	30-60	0.65	0.31	8.88
K10	0-30	0.60	0.28	13.20
	30-60	0.57	0.27	11.95
K11	0-30	0.75	0.36	12.03
	30-60	0.77	0.37	10.96
K12	0-30	3.94	1.89	13.58
	30-60	3.01	1.44	11.93
K13	0-30	1.17	0.56	14.61
	30-60	1.27	0.61	9.80
K14	0-30	1.54	0.74	15.05
	30-60	1.68	0.80	9.80
K15	0-30	0.77	0.37	11.68
	30-60	1.29	0.62	9.42
K16	0-30	0.82	0.39	16.65
	30-60	0.81	0.39	12.06
K17	0-30	0.50	0.24	15.31
	30-60	0.61	0.29	12.75
K18	0-30	0.62	0.29	10.80
	30-60	1.10	0.53	9.26
K19	0-30	1.16	0.56	11.65
	30-60	2.00	0.96	8.92
K20	0-30	0.60	0.29	12.51
	30-60	1.12	0.54	12.17
K21	0-30	0.61	0.29	12.86
	30-60	0.69	0.33	12.03
K22	0-30	0.39	0.18	13.20
	30-60	0.31	0.14	11.03
K23	0-30	2.99	1.44	18.01
	30-60	3.11	1.49	12.52
K24	0-30	2.93	1.41	15.33
	30-60	3.02	1.45	12.61
K25	0-30	0.49	0.23	12.32
	30-60	0.43	0.20	11.06
K26	0-30	3.72	1.78	17.11
	30-60	4.26	2.04	12.58
K27	0-30	2.83	1.36	18.38
	30-60	3.70	1.78	15.33

K28	0-30	0.47	0.22	12.17
	30-60	0.50	0.24	10.65
K29	0-30	3.49	1.68	15.28
	30-60	2.91	1.39	12.33
K30	0-30	3.60	1.73	16.52
	30-60	4.80	2.31	11.87
Range	0-30	0.21 - 4.79	0.10 - 2.30	10.41 - 19.03
	30-60	0.24 - 4.80	0.11 - 2.31	8.16 - 15.33
Mean	0-30	1.52 ± 1.38	0.73 ± 0.67	14.16 ± 2.49
	30-60	1.67 ± 1.42	0.80 ± 0.68	11.22 ± 1.55

Table 5 : Status of available secondary nutrients status of surface and sub-surface soils in the arecanut gardens of Sringeri taluk of Malnad region

Sl. No.	**Depth (cm)**	**Exchangeable Ca [cmol (p$^+$) kg^{-1}]**	**Exchangeable Mg [cmol (p$^+$) kg^{-1}]**	**Avail. S (mg kg^{-1})**
S1	0-30	1.22	0.78	15.66
	30-60	1.33	0.84	10.65
S2	0-30	1.15	0.73	15.78
	30-60	1.22	0.77	12.45
S3	0-30	2.83	1.80	17.71
	30-60	3.12	1.98	12.77
S4	0-30	1.49	0.95	12.64
	30-60	1.51	0.96	9.43
S5	0-30	6.61	4.21	13.92
	30-60	7.11	4.52	10.65
S6	0-30	1.30	0.83	15.81
	30-60	1.37	0.87	11.63
S7	0-30	0.47	0.30	13.97
	30-60	0.50	0.31	11.42
S8	0-30	0.55	0.35	11.65
	30-60	0.50	0.32	9.98
S9	0-30	6.17	3.93	14.63
	30-60	6.66	4.24	12.58
S10	0-30	0.56	0.32	14.41
	30-60	0.62	0.35	12.08
S11	0-30	1.15	0.66	16.92
	30-60	1.20	0.69	12.81
S12	0-30	2.60	1.50	18.08
	30-60	3.14	1.81	13.90
S13	0-30	1.11	0.64	13.96
	30-60	1.49	0.86	11.91
S14	0-30	4.26	2.46	15.08
	30-60	4.67	2.70	12.51
S15	0-30	0.50	0.28	12.46
	30-60	0.62	0.36	9.72
S16	0-30	6.13	3.54	18.46
	30-60	6.62	3.82	12.62
S17	0-30	1.65	0.95	17.11
	30-60	1.64	0.95	13.93
S18	0-30	3.10	1.79	16.83
	30-60	3.60	2.08	12.60
S19	0-30	1.20	0.69	12.48
	30-60	1.25	0.72	9.28
S20	0-30	1.66	0.95	13.61
	30-60	2.10	1.21	10.15
S21	0-30	3.71	2.14	12.61
	30-60	3.12	1.80	11.97
S22	0-30	4.81	2.78	15.33
	30-60	4.92	2.84	9.20
S23	0-30	1.01	0.58	16.22
	30-60	1.42	0.82	12.82
S24	0-30	5.01	2.89	12.43
	30-60	6.02	3.48	10.65
S25	0-30	1.27	0.73	13.70
	30-60	1.48	0.85	11.92
S26	0-30	0.50	0.28	16.65
	30-60	0.57	0.33	12.06
S27	0-30	1.12	0.64	14.26
	30-60	1.63	0.94	10.92
S28	0-30	0.55	0.31	12.61
	30-60	0.66	0.38	11.92
S29	0-30	0.47	0.27	13.96
	30-60	0.50	0.28	9.61
S30	0-30	4.26	2.46	15.26
	30-60	4.61	2.66	12.03
Range	0-30	0.46 - 6.61	0.27 - 4.21	11.65 - 18.46
	30-60	0.50 - 7.11	0.28 - 4.52	9.20 - 13.93
Mean	0-30	2.28 ± 1.93	1.36 ± 1.17	14.81 ± 1.87
	30-60	2.51 ± 2.08	1.49 ± 1.26	11.54 ± 1.34

Table 6 : Status of available secondary nutrients status of surface and sub-surface soils in the arecanut gardens of Thirthahalli taluk of Malnad region

Sl. No.	**Depth (cm)**	**Exchangeable Ca cmol (p$^+$) kg^{-1}]**	**Exchangeable Mg cmol (p$^+$) kg^{-1}]**	**Avail. S (mg kg^{-1})**
T1	0-30	2.82	1.66	10.45
	30-60	3.47	2.04	9.67
T2	0-30	0.45	0.26	12.81
	30-60	0.51	0.30	11.93
T3	0-30	0.45	0.26	15.86
	30-60	0.55	0.32	10.58
T4	0-30	1.33	0.78	16.30
	30-60	1.77	1.04	10.70
T5	0-30	1.45	0.85	11.95
	30-60	1.50	0.88	9.26
T6	0-30	0.45	0.26	15.58
	30-60	0.57	0.33	12.50
T7	0-30	0.40	0.24	17.11
	30-60	0.46	0.27	12.58
T8	0-30	0.52	0.30	12.03
	30-60	0.64	0.37	10.65
T9	0-30	0.76	0.56	10.65
	30-60	1.20	0.89	9.40
T10	0-30	3.11	2.32	16.71
	30-60	3.62	1.69	10.65
T11	0-30	2.70	1.26	10.83
	30-60	2.83	1.32	9.20
T12	0-30	0.81	0.38	16.83
	30-60	0.44	0.20	12.52
T13	0-30	1.18	0.55	11.27
	30-60	1.84	0.86	10.27
T14	0-30	1.77	0.82	12.81
	30-60	1.95	0.91	12.45

T15	0-30	2.41	1.12	17.11
	30-60	3.10	1.45	13.60
T16	0-30	0.37	0.17	12.08
	30-60	0.43	0.20	10.65
T17	0-30	2.05	0.96	12.17
	30-60	2.05	0.95	10.58
T18	0-30	2.10	0.98	15.00
	30-60	1.59	0.74	12.48
T19	0-30	2.83	1.32	13.56
	30-60	3.10	1.45	10.98
T20	0-30	4.20	1.96	16.56
	30-60	3.62	1.69	12.58
T21	0-30	0.39	0.18	15.32
	30-60	0.41	0.19	14.00
T22	0-30	3.11	1.45	12.45
	30-60	3.70	1.73	10.92
T23	0-30	1.66	0.77	15.72
	30-60	2.05	0.96	14.33
T24	0-30	0.31	0.14	12.48
	30-60	0.36	0.17	10.68
T25	0-30	2.61	1.22	17.08
	30-60	2.90	1.35	12.45
T26	0-30	0.54	0.25	11.66
	30-60	0.62	0.29	10.56
T27	0-30	1.03	0.48	18.37
	30-60	1.60	0.75	12.46
T28	0-30	2.10	0.98	11.97
	30-60	2.83	1.32	9.47
T29	0-30	0.67	0.31	17.90
	30-60	0.74	0.34	12.60
T30	0-30	1.65	0.77	12.18
	30-60	2.26	1.05	10.67
Range	0-30	0.31 - 4.20	0.14 - 2.32	10.45-18.37
	30-60	0.36 - 3.70	0.17 - 2.04	9.20 - 14.33
Mean	0-30	1.54 ± 1.07	0.79 ± 0.57	14.09 ± 2.48
	30-60	1.76 ± 1.16	0.87 ± 0.55	11.38 ± 1.42

DTPA extractable micronutrient status in arecanut growing soils of Malnad region (mg kg^{-1})

The micronutrient status in arecanut growing soils of the Malnad region is a critical determinant of the overall health and productivity of arecanut crops. These soils typically exhibit varying levels of essential micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu). The availability of these micronutrients is influenced by factors including soil pH, organic matter content and mineral composition. Micronutrient deficiencies can result in a range of adverse effects, from reduced growth and flowering to fruit deformities and impaired photosynthesis. To address these issues and ensure optimal crop development, farmers in the Malnad region frequently employ soil testing and targeted fertilization strategies, including the application of micronutrient-rich fertilizers and foliar sprays, tailored to the specific micronutrient needs of arecanut plants. The availability of micronutrients is presented in Tables 7 to 9.

Micronutrient levels in the arecanut gardens of Koppa taluk exhibit a significant range. For instance, Fe content varies from 12.26 to 29.13 mg kg^{-1} at depths of 0-30 cm and 7.20 to 20.89 mg kg^{-1} at depths of 30-60 cm. Similarly, Mn levels range from 2.83 to 21.33 mg kg^{-1} at 0-30 cm and 1.77 to 19.84 mg kg^{-1} at 30-60 cm. Zn content varies from 0.21 to 2.01 mg kg^{-1} at 0-30 cm and 0.10 to 1.95 mg kg^{-1} at 30-60 cm, while Cu levels span from 0.39 to 4.54 mg kg^{-1} at 0-30 cm and 0.28 to 4.41 mg kg^{-1} at 30-60 cm (Table 7). These values exhibit a gradual decrease with increasing soil depth. It is noteworthy that all samples from the surface layer indicate sufficiency for all micronutrients except zinc.

In Sringeri taluk, the trend continues, with Fe levels ranging from 13.22 to 30.23 mg kg^{-1} at 0-30 cm and 7.45 to 22.17 mg kg^{-1} at 30-60 cm, Mn ranging from 9.66 to 23.12 mg kg^{-1} at 0-30 cm and 8.25 to 20.17 mg kg^{-1} at 30-60 cm, Zn varying from 0.21 to 2.13 mg kg^{-1} at 0-30 cm and 0.11 to 2.07 mg kg^{-1} at 30-60 cm, and Cu ranging from 0.48 to 5.67 mg kg^{-1} at 0-30 cm and 0.17 to 5.20 mg kg^{-1} at 30-60 cm (refer to Table 8). These values also display a gradual decrease with increasing soil depth. As in Koppa taluk, all samples from the surface layer indicate sufficiency for all micronutrients except zinc.

In Thirthahalli taluk, the pattern persists, with Fe levels encompassing a range of 11.99 to 29.33 mg kg^{-1} at 0-30 cm and 7.24 to 22.01 mg kg^{-1} at 30-60 cm, Mn ranging from 2.33 to 23.16 mg kg^{-1} at 0-30 cm and 1.25 to 20.02 mg kg^{-1} at 30-60 cm, Zn varying from 0.21to 1.86 mg kg^{-1} at 0-30 cm and 0.11 to 1.74 mg kg^{-1} at 30-60 cm, and Cu spanning from 0.45 to 6.82 mg kg^{-1} at 0-30 cm and 0.33 to 5.74 mg kg^{-1} at 30-60 cm (refer to Table 9). These values, too, exhibit a gradual decrease with increasing soil depth. As seen in the other taluks, all surface layer samples indicate sufficiency for all micronutrients except zinc.

Soil pH plays a pivotal role in determining the availability of micronutrients. Typically, soil micronutrients are most accessible under slightly acidic to neutral conditions, owing to their increased solubility. The relatively higher levels of micronutrients observed in the Malnad region can be primarily attributed to the slightly acidic to neutral pH levels found in the study area. This trend aligns with findings by Dhumgonde*t al.* (2017), who noted elevated micronutrient levels in paddy-arecanut-coffee cropping systems in hilly zones of Karnataka, primarily due to lower pH levels. Furthermore, the increased levels of micronutrients can be attributed to the region's higher organic matter content, which aids in micronutrient retention through chelation. This chelation effect, facilitated by organic matter, helps reduce fixation and mitigate leaching losses, particularly important in the face of heavy rainfall. Notably, the high available copper content in arecanut-growing soils can be attributed to the regular use of Bordeaux mixture to combat koleroga fungal disease in arecanut cultivation. However, it's worth noting that a majority of samples from all three taluks display a deficiency in available zinc. This deficiency may be linked to the high pH levels in the region, exacerbated by the substantial annual rainfall, which can result in leaching losses of available zinc. These findings are in line with research by Jyothi *et al.* (2010), who reported similar deficiencies in available zinc due to leaching losses in arecanut soils within the traditional arecanut garden soils of South Karnataka.

Table 7 : Available micronutrient nutrient status of surface and sub-surface soils in the arecanut gardens of Koppa taluka of Malnad region

Sl. No.	Depth (cm)	Fe	Mn	Zn	Cu
		(mg kg^{-1})			
K1	0-30	16.96	2.83	0.21	2.13
	30-60	9.63	1.77	0.13	2.09
K2	0-30	21.56	5.67	0.56	2.25
	30-60	15.23	3.22	0.48	2.16
K3	0-30	12.96	7.65	0.23	1.96
	30-60	7.58	5.84	0.18	1.82
K4	0-30	19.58	21.33	0.29	1.67
	30-60	12.54	19.84	0.16	1.48
K5	0-30	15.52	15.42	0.84	0.95
	30-60	10.97	12.78	0.73	0.88
K6	0-30	16.24	6.97	1.85	0.56
	30-60	12.05	5.67	1.66	0.46
K7	0-30	27.38	12.11	2.01	0.39
	30-60	15.26	10.56	1.84	0.28
K8	0-30	12.98	19.24	0.66	0.44
	30-60	7.20	18.57	0.54	0.37
K9	0-30	29.13	13.22	0.56	4.21
	30-60	20.63	10.24	0.28	3.85
K10	0-30	14.24	6.25	0.44	4.04
	30-60	10.28	4.10	0.32	3.92
K11	0-30	15.07	7.11	0.43	3.03
	30-60	10.23	4.23	0.34	2.98
K12	0-30	18.57	9.66	0.22	3.69
	30-60	12.31	7.35	0.21	2.68
K13	0-30	15.26	16.54	0.39	4.28
	30-60	10.47	12.58	0.27	4.09
K14	0-30	21.53	13.22	0.67	4.54
	30-60	14.71	10.26	0.50	4.41
K15	0-30	22.63	19.22	0.33	2.36
	30-60	16.97	14.77	0.21	2.09
K16	0-30	27.44	13.22	0.96	1.56
	30-60	16.27	10.47	0.81	1.08
K17	0-30	15.24	20.49	0.51	0.66
	30-60	9.56	17.45	0.33	0.52
K18	0-30	16.47	17.42	0.54	0.89
	30-60	11.46	16.54	0.46	0.74
K19	0-30	21.11	16.23	2.01	1.23
	30-60	15.49	13.22	1.95	1.09
K20	0-30	25.55	19.57	0.46	3.56
	30-60	18.72	14.74	0.26	2.85
K21	0-30	26.24	4.55	0.52	3.33
	30-60	20.89	2.37	0.48	3.12
K22	0-30	24.87	5.29	0.57	4.20
	30-60	16.53	3.69	0.41	4.06
K23	0-30	17.35	8.54	0.23	4.21
	30-60	10.22	7.12	0.20	4.09
K24	0-30	18.27	10.25	1.22	0.56
	30-60	11.29	7.63	1.07	0.48
K25	0-30	12.26	13.28	0.29	1.28
	30-60	8.55	10.47	0.10	1.11
K26	0-30	29.11	16.29	0.44	3.26
	30-60	20.77	15.77	0.32	3.17
K27	0-30	15.06	20.08	1.56	3.09
	30-60	10.77	19.71	1.02	2.19
K28	0-30	20.68	10.08	0.34	2.09
	30-60	13.25	7.56	0.23	2.00
K29	0-30	21.77	11.23	0.85	2.56
	30-60	14.69	9.04	0.77	2.41
K30	0-30	17.23	15.64	0.92	0.65
	30-60	10.59	13.22	0.81	0.47
Range	0-30	12.26-29.13	2.83-21.33	0.21-2.01	0.39- 4.54
	30-60	7.20- 20.89	1.77-19.84	0.10-1.95	0.28-4.41
Mean	0-30	19.61±5.06	12.62 ± 5.39	0.70 ± 0.52	2.32 ± 1.38
	30-60	13.17±3.35	10.36± 5.31	0.57 ± 0.50	2.10 ± 1.33

Table 8 : Available micronutrient nutrient status of surface and sub-surface soils in the arecanut gardens of Sringeri taluk of Malnad region

Sl. No.	Depth (cm)	Fe	Mn	Zn	Cu
		(mg kg^{-1})			
S1	0-30	14.75	11.36	0.33	3.12
	30-60	10.95	10.23	0.29	2.96
S2	0-30	21.44	16.54	0.59	2.31
	30-60	17.43	14.33	0.41	1.93
S3	0-30	26.75	16.28	2.13	0.56
	30-60	17.49	13.29	2.07	0.44
S4	0-30	22.31	23.12	0.49	5.67
	30-60	15.62	20.17	0.32	4.89
S5	0-30	20.03	20.09	1.23	3.33
	30-60	11.85	17.45	1.07	2.19
S6	0-30	13.22	18.56	0.21	5.24
	30-60	8.54	13.33	0.19	5.20
S7	0-30	26.47	16.28	0.69	1.88
	30-60	20.15	14.59	0.57	1.52
S8	0-30	28.07	15.28	0.54	1.02
	30-60	12.33	14.71	0.39	0.98
S9	0-30	24.71	10.09	0.59	0.54
	30-60	18.55	9.55	0.44	0.41
S10	0-30	15.79	12.56	0.23	0.48
	30-60	10.56	11.28	0.12	0.17
S11	0-30	19.22	13.54	0.41	0.63
	30-60	11.41	10.70	0.38	0.45

S12	0-30	18.54	16.54	0.36	1.09
	30-60	11.22	12.33	0.29	1.00
S13	0-30	20.03	18.75	0.99	2.31
	30-60	13.00	12.08	0.84	2.08
S14	0-30	24.71	9.66	1.09	4.16
	30-60	15.58	8.52	1.00	4.00
S15	0-30	26.93	10.07	0.22	5.26
	30-60	20.11	9.77	0.18	5.18
S16	0-30	13.22	13.22	0.33	2.31
	30-60	7.45	11.47	0.27	2.09
S17	0-30	16.55	10.00	0.52	1.28
	30-60	11.02	9.82	0.48	1.05
S18	0-30	28.41	15.74	1.32	2.39
	30-60	17.23	12.33	1.09	2.26
S19	0-30	19.62	20.08	0.56	1.48
	30-60	13.07	19.84	0.49	1.22
S20	0-30	20.03	21.74	0.56	5.02
	30-60	14.29	20.13	0.42	4.87
S21	0-30	21.14	22.55	0.59	4.58
	30-60	14.23	20.17	0.48	4.11
S22	0-30	26.88	13.66	0.38	2.08
	30-60	20.76	12.45	0.29	1.97
S23	0-30	19.56	16.98	0.41	1.56
	30-60	12.57	14.75	0.33	1.14
S24	0-30	29.77	16.99	1.99	0.65
	30-60	20.01	13.28	1.82	0.48
S25	0-30	30.23	19.56	1.06	0.52
	30-60	22.17	17.77	1.00	0.33
S26	0-30	24.33	21.00	0.74	1.08
	30-60	17.45	18.26	0.63	0.97
S27	0-30	26.09	9.88	0.54	0.76
	30-60	18.47	8.74	0.35	0.42
S28	0-30	13.22	10.23	0.23	0.69
	30-60	8.56	9.66	0.11	0.52
S29	0-30	19.22	10.23	1.08	1.57
	30-60	10.74	8.25	1.01	1.44
S30	0-30	28.54	11.11	0.57	1.08
	30-60	16.74	10.27	0.38	1.00
Range	0-30	13.22-30.23	9.66-23.12	0.21-2.13	0.48-5.67
	30-60	7.45-22.17	8.25-20.17	0.11-2.07	0.17-5.20
Mean	0-30	21.99 ± 5.19	15.39 ± 4.28	0.70 ± 0.48	2.16 ± 1.64
	30-60	14.65 ± 4.07	13.32 ± 3.76	0.59 ± 0.47	1.91 ± 1.59

Table 9 : Available micronutrient nutrient status of surface and sub-surface soils in the arecanut gardens of Thirthahalli taluk of Malnad region

Sl. No.	Depth (cm)	Fe	Mn	Zn	Cu
		(mg kg^{-1})			
T1	0-30	19.23	13.14	0.57	0.45
	30-60	12.42	9.99	0.51	0.33
T2	0-30	25.44	18.23	0.33	1.59
	30-60	19.68	17.45	0.21	1.54
T3	0-30	27.11	11.23	0.26	1.27
	30-60	22.01	9.26	0.17	0.98
T4	0-30	12.24	5.27	0.33	5.63
	30-60	9.67	3.10	0.27	4.17
T5	0-30	27.44	19.88	1.24	5.22
	30-60	21.88	15.67	0.95	5.10
T6	0-30	16.07	3.33	0.46	4.87
	30-60	9.93	2.12	0.32	4.17
T7	0-30	20.48	5.55	0.44	3.96
	30-60	11.25	3.21	0.28	3.58
T8	0-30	20.77	8.45	0.55	2.69
	30-60	12.69	7.55	0.42	2.53
T9	0-30	15.32	9.63	0.84	2.11
	30-60	11.96	7.12	0.79	2.07
T10	0-30	23.33	16.23	0.52	1.09
	30-60	14.56	15.22	0.45	0.87
T11	0-30	28.14	19.66	0.99	5.64
	30-60	11.22	18.74	0.85	5.31
T12	0-30	27.45	20.03	1.24	4.87
	30-60	20.78	18.75	1.11	4.66
T13	0-30	13.23	13.27	1.09	3.97
	30-60	8.55	11.22	0.97	3.56
T14	0-30	16.99	10.09	0.37	2.09
	30-60	11.47	8.23	0.28	1.75
T15	0-30	23.17	2.33	1.64	2.67
	30-60	18.45	1.25	1.08	2.22
T16	0-30	16.94	8.23	0.54	1.17
	30-60	10.28	4.23	0.49	1.09
T17	0-30	25.48	9.78	0.44	2.33
	30-60	20.11	8.56	0.32	2.09
T18	0-30	27.36	11.23	0.29	3.54
	30-60	18.77	10.04	0.17	3.17
T19	0-30	21.08	11.29	0.22	3.00
	30-60	10.77	10.26	0.21	2.56
T20	0-30	18.27	20.01	0.52	6.82
	30-60	11.55	17.99	0.41	5.74
T21	0-30	14.52	13.22	0.39	1.52
	30-60	9.97	11.95	0.28	1.09
T22	0-30	17.26	18.21	0.21	2.44
	30-60	13.06	16.23	0.13	2.09
T23	0-30	29.33	11.29	1.58	2.14
	30-60	1654	10.47	1.47	1.99
T24	0-30	11.99	23.16	0.44	2.54
	30-60	7.24	20.02	0.37	2.13
T25	0-30	29.05	7.56	1.86	2.08
	30-60	20.11	6.58	1.74	1.97
T26	0-30	14.78	9.23	0.54	3.69
	30-60	11.26	7.25	0.41	3.20
T27	0-30	18.77	19.57	1.09	4.19
	30-60	9.04	14.74	0.96	4.07
T28	0-30	22.44	2.55	0.50	2.03
	30-60	14.56	1.29	0.36	1.47
T29	0-30	13.99	3.25	0.24	5.99
	30-60	10.87	2.17	0.11	5.26
T30	0-30	14.56	20.04	0.57	4.89
	30-60	10.23	19.57	0.43	3.88
Range	0-30	11.99 -29.33	2.33 -23.16	0.21 -1.86	0.45 -6.82
	30-60	7.24 -22.01	1.25 -20.02	0.11 -1.74	0.33 -5.74
Mean	0-30	20.41 ±5.56	12.16 ± 6.12	0.68 ±0.45	3.22 ±1.68
	30-60	13.70 ±4.43	10.34 ± 5.96	0.55 ±0.41	2.82 ±1.50

Conclusion

- The field survey conducted during 2022 across Koppa, Sringeri and Thirthahalli taluks of the Malnad region revealed pronounced imbalances in secondary nutrient availability in arecanut-growing soils, particularly in the surface layer (0–30 cm).
- A high proportion of surface soil samples across all three taluks were deficient in exchangeable calcium and magnesium, with magnesium deficiency being more severe and widespread than calcium, indicating a major nutritional constraint for sustained arecanut productivity. Available sulphur content remained consistently within the medium range in both surface and sub-surface soils of all taluks, though a slight decline with increasing depth was evident.
- The DTPA-extractable micronutrient analysis showed that iron, manganese and copper were generally sufficient across soil depths in all taluks, largely attributed to favourable soil pH, high organic matter content and regular use of copper-based fungicides. Zinc deficiency emerged as a common and critical micronutrient limitation across the Malnad region, likely due to leaching losses under high rainfall conditions and soil chemical constraints.
- The observed nutrient deficiencies, particularly of calcium, magnesium and zinc, highlight the necessity for site-specific nutrient management strategies, including periodic soil testing, liming interventions and balanced application of secondary and micronutrient fertilizers.
- Overall, the study underscores that addressing secondary and micronutrient imbalances in the acidic, high-rainfall soils of the Malnad region is essential for improving soil health, enhancing nutrient use efficiency and sustaining long-term productivity of arecanut plantations.

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