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Assessment of Physico-Chemical Properties of Tea Garden Soils of Darjeeling, West Bengal, India

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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

The experiment was conducted in 2023-2024 to assess the physical and chemical properties of tea garden soils of Darjeeling, West Bengal within its geographical coordinates ranging from 27° 2' 9.6252'' N latitude to 88° 15' 45.6192''E longitude. Nine distinct villages located in the Darjeeling district covering Glenburn, Soureni, and Selimbong tea gardens were chosen for the study. The physical properties of tea garden soils, soil colour, texture, bulk density (Mg m^{-3}), particle density (Mg m^{-3}), percent pore space and percent water holding capacity were analysed at 0-15, 15-30 and 30-45 cm depths. The results showed that the soil colour varied from brown to yellowish brown in dry condition and dark brown to dark reddish brown in wet. The soils of Selimbong were sandy loam to sandy clay loam, Soureni were clay loam, and soils of Glenburn were clay loam to sandy clay loam in texture. The variation in bulk density and particle density was recorded non-significant with the values ranging from 1.01-1.22 Mg m^{-3} and 2.21-2.64 Mg m^{-3} respectively. The percent pore space and percent water holding capacity were found significant with the values ranging from

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50.53-68.96% and 53.36-79.43% respectively. The soil pH ranged from 4.32-5.28 and electrical conductivity (EC) 0.03-0.97 dS m^{-1} which were found to be non-significant. The organic carbon and available nitrogen were found to be significant with values ranging from 0.63-2.02% and 177.70-696.3 kg ha^{-1} respectively. The available phosphorus ranged from 16.13-29.54 kg ha^{-1} and available potassium 100.64-334.92 kg ha^{-1} which was found to be significant. The values of exchangeable calcium and magnesium were recorded significant ranging from 0.02-0.42 C mol(p^+) kg^{-1} and 0.016-0.223 C mol(p^+) kg^{-1} respectively.

Keywords: Physico-chemical properties; soil analysis; tea garden soil; Darjeeling.

1. INTRODUCTION

"One of the most vital natural resources for human well-being is soil. Among the eight districts of North Bengal, Darjeeling and Kalimpong are located in the foothills of the Himalayas [1-4]. The soil here is completely different from other parts of the state. This area is mainly found in hilly soils, forest soils, old alluvium and red soils" [5]. "Tropical to subtropical climates with more than 200 cm of annual precipitation are ideal for the growth of tea. Evaluations of soil fertility status under tea growing soils are necessary to make a proper management and sound fertilizer recommendation for optimizing the yield of tea" [6]. "Tea grows well in sandy loam, diverse soil, slope, acidic, and well-drained environments. It is well known fact that for the plant growth i.e. optimizing the yield of tea and its quality-quantity of secondary metabolites is highly influenced by the soil physicochemical characters" [7]. "The region's soil makeup is of rocky, clay, and loamy soils, each of which has unique qualities" [8]. "The world-renowned Darjeeling tea is of exceptional quality and is renowned for its muscatel taste. The tea is available in the form of black, green, white and oolong" (Anil et al. 2016). "Organic tea cultivation in Darjeeling hills is getting popularity day by day due to growing health awareness of consumers, fetching good prices and high demand in international market. Maintenance of the present tea crop productivity in the changing scenario of climate and mode of cultivation is a big challenge for every stakeholder of Darjeeling tea industry, while it has been established that the 12-30% reduction in yield is quite natural after conversion to organic" [9].

2. MATERIALS AND METHODS

Soil samples were collected from nine different villages which lie in the Selimbong, Soureni, and Glenburn tea gardens of Darjeeling District at three respective depths of 0-15, 15-30 and 30-45 cm for the analysis of physical and chemical properties of soil. A total of 81 soil samples were collected from three tea gardens, in each of nine villages and at three depths out of which 27 samples are representing three depths of a tea garden to analyse the physical and chemical properties. These samples were air dried in shade for one week to obtain constant weight then crushed with wooden hammer, after that it was sieved with 0.2mm sieve to obtain composite samples of each site and each depth. The physical properties of soils, soil colour, texture, bulk density (Mg m^{-3}), particle density (Mg m^{-3}), percent pore space and percent water holding capacity were analysed with the following standard procedures: Munsell, [10], Bouyoucos [11] Muthuvel et al., [12] and chemical properties pH, EC (dSm^{-1}) $_{at\ 25^{\circ}C}$, percent organic carbon, available nitrogen, phosphorus and potassium (kg ha^{-1}), Ca^{+3} C mol(p^+) kg^{-1} and Mg^{+3} C mol(p^+) kg^{-1} were analysed by following Jackson [13], Wilcox [14] Walkley and Black [15] Subbiah and Asija [16] Olsen et al., [17] Toth and Prince [18] and Jackson (1973) at 0-15, 15-30 and 30-45 cm depths. The data recorded during the course of investigation was subjected to statistical analysis by the method of analysis of Completely Randomized Design (CRD) as per the method of "Analysis of Variance technique" (ANOVA) [19].

3. RESULTS AND DISCUSSION

The results depicted in Table 1 shows that the soil colour in dry condition varied from brown (7.5YR 5/4) to dark yellowish brown (10YR 3/4) in 0-15, brown (7.5YR 5/4) to yellowish brown (10YR 5/4) in 15-30 and brown (7.5YR 5/4) to pale brown (7.5YR 6/3) in 30-45cm depth and in wet condition from dark brown (7.5YR 4/4) to dark reddish brown (5YR 3/3) in 0-15, brown (7.5YR 5/4) to dark brown (7.5YR 4/4) in 15-30 and yellowish brown (10YR 5/4) to dark brown (7.5YR 4/4) in 30-45cm depth.

The yellow colour of the soil was probably due to hydrated iron oxides. The brown colour indicates that the soil contains a high concentration of iron oxides and the dark colour suggests a high level of organic matter in the soil. Wet soils are darker due to similarity in refractive properties of water and soil [20]. Similar results were also reported by Nayak et al., [21]. The results depicted in Table 2 show that the soil texture of Selimbong ranged from sandy clay loam (sand 64.3%, silt 13.9% and clay 21.8%) to sandy loam (sand 67.0%, silt 17.8% and clay 15.2%). The soil texture of Soureni was found to be clay loam (sand 26.2%, silt 39.4% and clay 32.6). The soil texture of Glenburn ranged from clay loam (sand 48.9%, silt 21.9% and clay 29.2) to sandy clay loam (sand 53.8%, silt 26.1% and clay 21.1%). It may be due to igneous and metamorphic rocks at an altitude of 2500 m in Darjeeling that have been eroded by various physical, chemical and biological weathering disorders to form such type of soil [5]. The results were found similar to that of Majumdar et al., [22]. The bulk density of soil at 0-15, 15-30 and 30-45 cm depths respectively, was found to be non-significant at 5% critical difference. The maximum bulk density was 1.22 Mg m^{-3} at 0-15, 1.13 Mg m^{-3} at 15-30 and 1.11 Mg m^{-3} at 30-45 cm depths found in Selimbong. The minimum bulk density was 1.01 Mg m^{-3} at 0-15 and 30-45 found in Selimbong and Glenburn respectively and 1.02 Mg m^{-3} at 15-30 cm depth found in Selimbong mentioned in Fig. 1. The higher values of bulk density indicates that the soil is widely composed of clay and aggregated loams and the lower values indicate the presence of high organic matter [23]. The results were found to be similar to that of Wankhade et al., [24]. The results graphically presented in Fig. 1 also shows the particle density of the soils at 0-15, 15-30 and 30-45 cm depths respectively and was found to be non-significant at 5% critical difference. The maximum particle density was 2.58 Mg m^{-3} at 0-15, 2.63 Mg m^{-3} at 15-30 and 2.64 Mg m^{-3} at 30-45 cm depth found in Soureni. The minimum particle density was 2.20 Mg m^{-3} at 0-15 found in Glenburn and 2.21 Mg m^{-3} in 15-30 as well as 30-45 cm depths found in Selimbong and Glenburn respectively. The high particle density values indicates that the soil has comparatively low organic matter content and the low particle density values indicates the presence of organic matter content (Anushka et al., 2021). Similar results were obtained by Barthwal et al., [25]. The results mentioned in Table 3 shows that the percent pore space of the soil at 0-15, 15-30 and 30-45 cm depths was found to be significant at 5% critical difference. The maximum percent pore space 68.96% at 0-15, 62.96% at 15-30 cm were found in Glenburn and 59.86% at 30-45 cm depth found in Soureni. The minimum percent pore space was 52.96% at 0-15 cm and 50.30% at 15-30 cm found in Glenburn while 50.53% at 30-45 cm depth was found at Selimbong. The pore space decreased with increase in depth and it may be due to the lower content of organic matter present in the sub-surface soils than that of the surface soils [23]. Similar findings were also reported by Pandey et al., (2013). The water holding capacity of soil at 0-15, 15-30 and 30-45 cm depths respectively was found to be significant at 5% critical difference. The maximum water holding capacity was 79.43% at 0-15, 78.83% at 15-30 and 72.66% at 30-45 cm depths respectively was recorded in Soureni. The minimum 60.23% at 0-15 cm was found in Glenburn, 53.36% at 15-30 cm depth found in Selimbong and 61.01% at 30-45 cm depth was found in Glenburn (Table 3). The sandy loam and clay loam soils indicate high clay content which can absorb a considerable amount of water for a long period in the micropores [20]. Water holding capacity depends upon number, capillary spaces of the soil and size of the soil's pore spaces [26]. These findings were similar to that of Deb et al., (2013). The results mentioned in Fig. 2 show the soil pH and EC dSm^{-1} $_{at\ 25^{\circ}C}$ at 0-15, 15-30 and 30-45 cm depths respectively were found to be non-significant at 5% critical difference. The maximum soil pH 5.16 at 0-15, 5.28 at 15-30 as well as 30-45cm depth was found in Selimbong. The minimum soil pH 4.40 at 0-15 as well as 15-30 and 4.46 at 30-45cm depth was found in Soureni. The results indicated that the soil is highly acidic in nature. This level of high acidity may be due to heavy rainfall and leaching persisting in the region [22]. Similar findings were recorded by Ganorker et al., [27]. Similarly, the maximum EC 0.13 at 0-15 as well as 15-30 and 0.14 at 30-45cm depth was found in Glenburn. The minimum EC 0.03 at 0-15, 0.05 at 15-30 and 0.06 at 30-45cm depth was found in Selimbong. The low values of EC might be due to leaching of soluble salts by heavy rainfall [6]. These findings were similar to that of Rai et al., [20]. The per cent organic carbon of soil at 0-15, 15-30 and 30-45 cm depths was found to be significant at 5% critical difference. The maximum per cent organic carbon 2.02 at 0-15 cm found in Selimbong while 1.45 at 15-30 cm and 1.42 at 30-45 cm depths was found in Soureni. The minimum per cent organic carbon was recorded in Selimbong with 1.46 at 0-15 cm, 0.74 at 15-30 and 0.63 at 30-45 cm depths respectively (Table 3). The high percentage organic carbon present in the surface soils may be due to the undecomposed and partially decomposed organic matter and lower values seen in the sub-surface soils may be due to decomposed organic matter which has undergone chemical and biological changes already [20]. These findings were similar to that of Arya, [28]. Table 4 shows the available nitrogen in kg ha^{-1} of soil at 0-15, 15-30 and 30-45 cm depth respectively where it was found to be significant at 5% critical difference. The maximum available nitrogen of 696.3 kg ha^{-1} at 0-15 and 340.7 kg ha^{-1} at 15-30 cm respectively was recorded in Soureni, while 209.73 kg ha^{-1} at the 30-45 cm depth was recorded in Selimbong. The minimum available nitrogen of 441.3 kg ha^{-1} at 0-15 cm depth was found in Selimbong, while 212.7 kg ha^{-1} was found at 15-30 cm and 177.70 kg ha^{-1} at the 30-45 cm depth at Glenburn. The high nitrogen content may be due to leaf litter or application of organic amendments in the soil. It may also be because of the high organic matter content in soil and addition of chemical fertilizers by the tea growing farmers [23]. These findings were similar with that of Mishra et al., [7]. The available phosphorus of soil at 0-15, 15-30 and 30-45 cm depths respectively, was found to be significant at 5% critical difference. The maximum available phosphorus of 29.54 kg ha^{-1} at 0-15, 27.79 kg ha^{-1} at 15-30 and 25.02 kg ha^{-1} at 30-45 cm depths was found in Glenburn. The minimum available phosphorus was found in Soureni, with 17.23 kg ha-1 at 0-15, 16.55 kg ha^{-1} at 15-30 and 16.13 kg ha-1 at 30-45 cm depth be due to the influence of soil pH which is acidic

Table 1. Soil colour of different villages in dry and wet condition of tea garden soils of Darjeeling district at 0-15 cm, 15-30 cm and 30-45 cm depths

Village	Dry condition			Wet condition		
	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
Pokhribung Khasmahal (V1)	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown	7.5YR 5/4 Brown	5YR 3/3 Dark Reddish Brown	7.5YR 5/4 Brown	7.5YR 4/4 Dark Brown
Soolbongs Tea Garden (V2)	7.5YR 5/4 Brown	7.5YR 6/3 Pale Brown	7.5YR 6/3 Pale Brown	10YR 5/4 Yellowish Brown	10YR 6/4 Light Yellowish Brown	10YR 5/4 Yellowish Brown
Selimbong (V3)	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown	7.5YR 5/4 Brown	2.5YR 4/4 Reddish Brown	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown
Phuguri Forest (V4)	10YR 5/4 Yellowish Brown	10YR 6/6 Brownish Yellow	7.5YR 6/3 Pale Brown	7.5YR 4/4 Dark Brown	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown
Sourinibasti (V5)	10YR 3/4 Dark Yellowish Brown	10YR 5/4 Yellowish Brown	10YR 8/6 Pale Yellow	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown	7.5YR 5/4 Brown
Singbulli Tea Garden(V6)	10YR 5/4 Yellowish Brown	10YR 5/4 Yellowish Brown	10YR 6/6 Brownish Yellow	7.5YR 5/4 Brown	7.5YR 6/3 Pale Brown	7.5YR 4/4 Dark Yellow
Singringtam (V7)	7.5YR 5/4 Brown	10YR 5/4 Yellowish Brown	10YR 5/4 Yellowish Brown	10YR 5/4 Yellowish Brown	7.5YR 4/4 Dark Brown	7.5YR 4/4 Dark Brown
Kambal Tea Garden (V8)	10YR 5/4 Yellowish Brown	10YR 5/4 Yellowish Brown	7.5YR 5/4 Brown	7.5YR 4/4 Dark Brown	5YR 3/4 Dark Reddish Brown	7.5YR 4/4 Dark Brown
Manedara (V9)	7.5YR 5/4 Brown	10YR 5/4 Yellowish Brown	7.5YR 4/4 Dark Brown	7.5YR 4/4 Dark Brown	7.5YR 4/4 Dark Brown	7.5YR 5/4 Brown

in nature and often limits nutrients that remain present in plant nuclei and act as an energy storage [29]. These findings were similar with that of Ram et al., [30]. Table 4 also shows the available potassium of soil at 0-15, 15-30 and 30-45 cm depths respectively was found to be significant at 5% critical difference. The maximum available potassium was 334.92 kg ha^{-1} at 0-15, 322.32 kg ha^{-1} at 15-30 and 320.32 kg ha^{-1} at 30-45 cm depths respectively and it was found at Selimbong. The minimum available potassium was found in Glenburn, with 101.43 kg ha^{-1} at 0-15, 99.90 kg ha^{-1} at 15-30 and 97.43 kg ha^{-1} at 30-45 cm depths respectively. The high proportion of potassium may be due to the feldspar and muscovite mica found in the Darjeeling region [31-32]. These findings were similar with that of Ram et al. [30]. The results in Fig. 3 show that the exchangeable calcium of soil at 0-15, 15-30 and 30-45 cm depths was found significant at 5% critical difference, with the maximum exchangeable calcium 0.42 C mol (p^{+}) kg^{-1} at 0-15, 0.39 C mol (p^{+}) kg^{-1} at 15-30 and 0.38 C mol (p^{+}) kg^{-1} at 30-45 cm depths respectively found at Selimbong. The minimum exchangeable calcium was found at Sourreni, with values of 0.03 C mol (p+) kg-1 at both 0-15

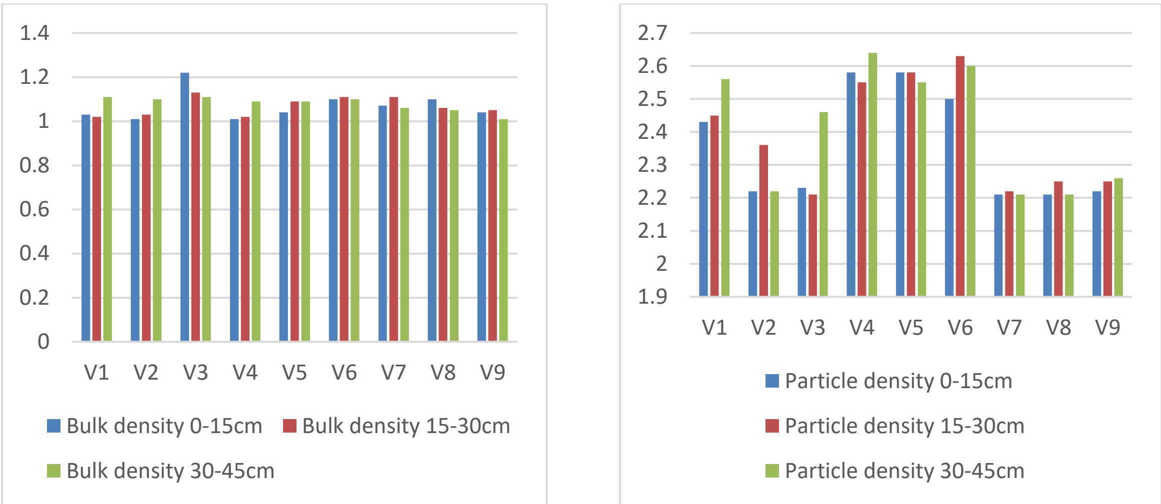

Fig. 1. Graphical representation of bulk density (Mg m-3) and particle density (Mg m-3) of soil in different villages of tea garden soil of Darjeeling at 0-15 cm, 15-30 cm and 30-45 cm depths respectively

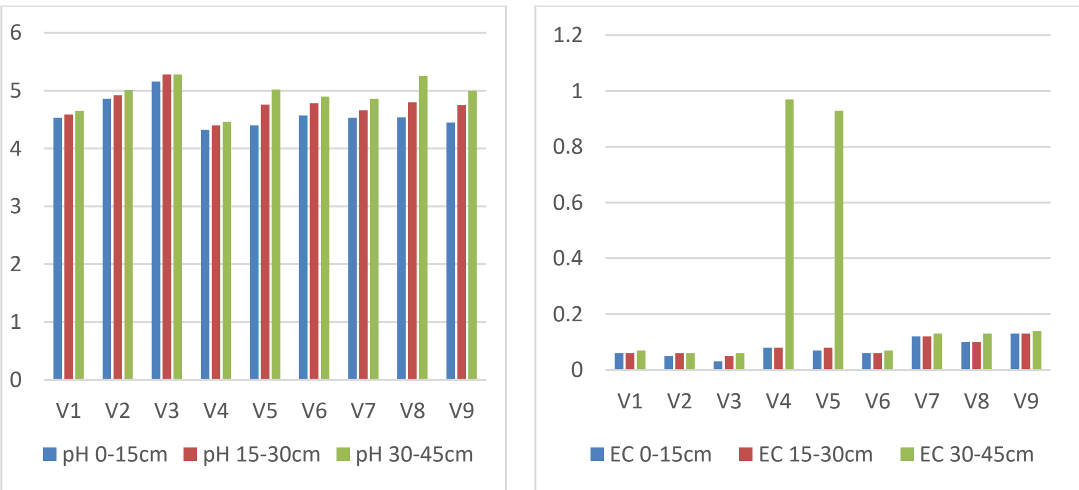

Fig. 2. Graphical representation of soil pH and EC (dSm^{-1}) $_{at\ 25^{\circ}C}$ of soil in different villages of tea garden soil of Darjeeling at 0-15cm, 15-30 cm and 30-45cm depth

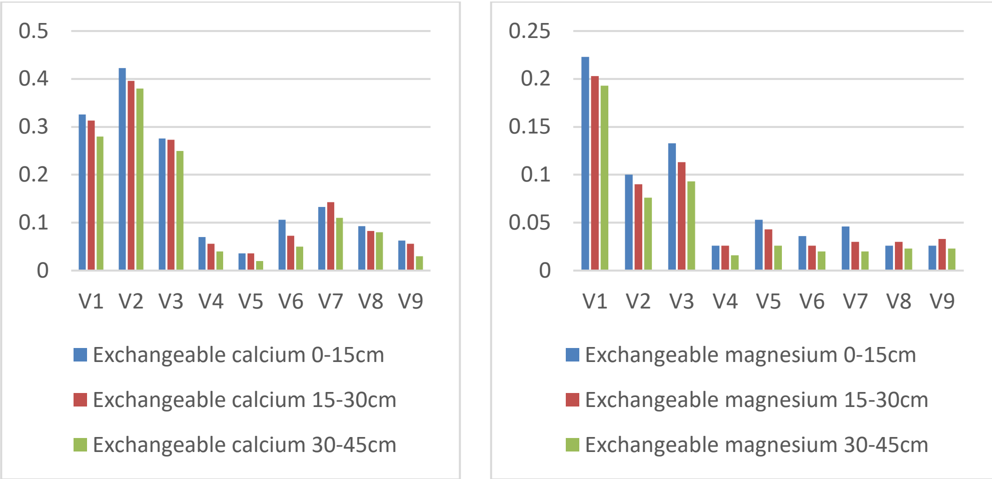

Fig. 3. Graphical representation of exchangeable calcium (C mol(p^+) kg^{-1}) and exchangeable magnesium (C mol(p^+) kg^{-1}) of soil in different villages of tea garden soil of Darjeeling at 0-15 cm, 15-30 cm and 30-45 cm depths respectively

Table 2. Soil texture of different villages of tea garden soils of Darjeeling district at 0-15cm, 15-30 cm and 30-45 cm depths

Tea Garden	Village	Sand %	Silt %	Clay %	Textural Class
Selimbong	V1	64.3	13.9	21.8	Sandy Clay Loam
	V2	67.0	17.8	15.2	Sandy Loam
	V3	61.5	22.0	16.5	Sandy Loam
Soureni	V4	26.2	39.2	34.6	Clay Loam
	V5	29.4	37.5	33.1	Clay Loam
	V6	23.9	37.1	39	Clay Loam
Glenburn	V7	48.9	21.9	29.2	Clay Loam
	V8	45.9	29.3	24.8	Clay Loam
	V9	53.8	26.1	21.1	Sandy Clay Loam

Table 3. Pore space, water holding capacity and percent organic carbon of soil in different villages of Darjeeling at 0-15 cm, 15-30 cm and 30-45 cm depths

	Villages	Pore space			Water holding capacity			Organic carbon		
		0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
Selimbong	V1	57.16	54.73	50.53	69.70	65.06	68.13	1.46	0.74	0.71
	V2	54.63	57.83	56.14	71.03	53.36	63.16	2.02	1.02	0.63
	V3	55.50	54.36	52.13	69.93	70.53	68.03	1.76	1.02	0.86
Soureni	V4	53.13	52.30	56.73	71.96	71.16	70.69	1.87	1.30	1.25
	V5	56.43	55.63	55.33	79.43	78.83	70.86	1.81	1.45	1.42
	V6	57.66	55.40	59.86	74.13	70.05	72.66	1.71	1.27	1.27
Glenburn	V7	52.96	50.30	52.06	70.56	68.68	68.40	1.59	1.44	1.31
	V8	68.96	62.67	54.36	65.96	63.86	66.25	1.51	1.27	1.03
	V9	58.73	62.96	53.23	61.01	62.51	60.23	1.53	1.15	1.09
F-test		S	S	S	S	S	S	s	s	s
S. Em. (±)		4.84	4.28	2.87	5.27	7.08	3.74	0.18	0.22	0.27
C.D @5%		1.24	4.39	4.4	1.92	0.57	8.73	3.10	1.41	1.59

Table 4. Available potassium, available nitrogen and available phosphorus of soil in different villages of Darjeeling at 0-15 cm, 15-30 cm and 30-45 cm depths respectively

	Villages	Available potassium			Available nitrogen			Available phosphorus		
		0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
Selimbong	V1	314.44	306.67	302.16	484.0	268.5	209.73	25.35	25.02	24.35
	V2	334.92	322.32	320.32	441.3	241.5	194.56	20.12	19.90	19.25
	V3	278.84	273.00	268.47	442.9	279.6	193.86	17.86	17.29	16.13
Soureni	V4	125.76	124.02	120.88	612.1	282.7	189.90	18.72	17.28	16.89
	V5	110.92	106.10	100.64	679.4	314.2	189.03	24.03	23.43	22.84
	V6	149.90	145.31	141.08	696.3	340.7	182.30	17.23	16.55	16.20
Glenburn	V7	219.46	214.37	210.83	543.5	217.5	183.16	28.79	27.79	25.02
	V8	143.84	138.48	136.76	553.8	212.7	185.76	24.26	22.87	21.73
	V9	101.43	99.90	97.43	574.8	275.4	177.70	29.54	27.50	24.13
F-test		s	s	s	s	s	s	s	s	s
S. Em. (±)		91.29	88.54	88.53	93.30	41.96	9.35	4.61	4.39	3.65
C.D @5%		5.63	9.58	5.99	1.10	2.81	3.16	0.001	0.008	0.138

and 15-30 cm depths, and 0.02 C mol (p^+) kg^{-1} at 30-45 cm depth. Very low values of calcium were recorded which may be due to the leaching of calcium as hydrogen is added to the soil by decomposition of organic matter as well as due to heavy rainfall [23]. These findings were similar with that of Ray et al. [6]. The exchangeable magnesium of soil at 0-15, 15-30 and 30-45 cm depths was found significant at 5% critical difference, the maximum exchangeable magnesium 0.22 C mol (p^+) kg^{-1} at 0-15, 0.20 C mol (p^+) kg^{-1} at 15-30 and 0.19 C mol (p^+) kg^{-1} at 30-45 cm depth found in Selimbong. In the case of Soureni, the minimum exchangeable magnesium was 0.02 C mol (p^+) kg^{-1} at the 0-15 as well as the 15-30 cm depths while it was 0.01 C mol (p^+) kg^{-1} at 30-45 cm depth (Fig. 3). Very low magnesium was recorded in all sites which may be due to heavy rainfall prevailing in the area and surface leaching of basic cations (Mg^{+2}) by the excessive rainfall, as also reported by Ray et al., [6,33,34].

4. CONCLUSION

It is evident that the Darjeeling district soils are in good physical condition, which is favourable for tea cultivation. The soil colour varied from brown to yellowish brown in dry condition and dark brown to dark reddish brown in wet condition. The soils of Selimbong were sandy loam to sandy clay loam in texture, soils of Soureni were clay loam in texture, and soils of Glenburn were clay loam to sandy clay loam in texture. The bulk density and particle density of soil was found to be in low levels ranging from 1.22 Mg m^{-3} to 1.01 Mg m^{-3} and 2.64 Mg m^{-3} to 2.20 Mg m^{-3} respectively. The high clay component of the soil was discovered to contribute to its good pore space and water-holding capacity. Low pH and EC values have been recorded. Mostly all the villages showed high organic carbon content as well as high available nitrogen concentration which may be due to the adoption of organic farming in the tea gardens. The soils had a medium to high range of phosphate and potassium, with values decreasing as depth increased. Very low values of exchangeable calcium and magnesium was found in all the regions which may be due to heavy rainfall prevailing in the area and surface leaching of basic cations (Ca^{+2} and Mg^{+2}) by the excessive rainfall. The main aim of the study was to determine the physical and chemical properties of the soils in the selected tea gardens. Not only would this be beneficial to make practical decisions in adopting farming techniques and incorporate fertilizers but also add to the database on soils in these areas for reference for further scientific research. The findings suggested that implementing excellent agricultural practises, such as the use of organic amendments, herbicides, and micronutrients, could help to ensure the sustainability of tea crop yield and quality. However, applying additional labile organic inputs, liming materials, and appropriate inorganic fertilizers (N-P-K) would be useful for long-term management and boosting soil fertility in the tea-growing region.

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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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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