J. Indian Soc. Coastal Agric. Res. 41(2): 52-60 (2023) https://doi.org/10.54894/JISCAR.41.2.2023.135031

Characteristics and Soil Fertility Status of Southern Coastal Plains in Kerala

B.M. ATHULYA[1]*, GOWRI PRIYA[1]*, B. RANI[1], B. APARNA[2] and M.A. NISHAN[3]

[1]Department of Soil Science and Agriculture Chemistry, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, Kerala - 695 522, India
[2]Department of Organic Agriculture, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, Kerala - 695 522, India
[3]Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, Kerala - 695 522, India

Received: 04.04.2023 Accepted: 01.09.2023

Understanding the physicochemical and biological parameters of coastal soils is essential for developing climate-resilient and sustainable resource management strategies. A study was conducted to assess the characteristics of the coastal sandy soils in Thiruvananthapuram district (Agro-ecological unit 1- Southern Coastal Plains), Kerala. Fifty geo-referenced surface soil samples along with surface core samples were collected during March 2022 from the Thiruvananthapuram district which falls under the southern coastal plains covering an area of 19,344 ha. The analytical results for soil physical properties showed that the bulk density was in the range of 1.37 - 1.86 Mg m^{-3} while particle density was 2.22 - 2.89 Mg m^{-3}, with 22.7 - 56.0% water holding capacity and the soils came under sand and loamy sand textural classes. The soil chemical properties were found to be in the range of 5.11 - 7.19 for pH and 0.03 - 0.23 dS m^{-1} for electrical conductivity. Organic carbon was found to be in the range of 0.07 - 1.01%, available nitrogen 100 - 308 kg ha^{-1}, available phosphorus 7.05 - 59.94 kg ha^{-1} and available potassium 100 - 361 kg ha^{-1}. Secondary minerals were found to be present in the range: calcium 80 - 360 mg kg^{-1}, magnesium 47 - 152 mg kg^{-1} and sulphur 4.5 - 20.5 mg kg^{-1}. Available boron was found to be in the range of 0.11 - 0.82 mg kg^{-1}. Soil biological activity in these coastal sandy soils was poor with dehydrogenase activity in the range of 5.57 - 20.96 µg TPF hydrolysed g^{-1} soil 24 h^{-1}. Hence, these soils require site-specific nutrient management strategies including organic manure application to fully utilize their potential for sustainable agriculture.

(***Key words:*** *Coastal sandy soils, Agro-ecological unit 1, Soil physical properties, Soil chemical properties, Soil biological activity*)

The state of Kerala has 58,950 ha of coastal area distributed all along the western border. This constitutes 1.52% of the total geographical area of the state. About 40% of the people live in or near the coastal zone with a very high population density of about 2,262 persons per km^2 (Pavithran *et al.,* 2014). Kerala has been delineated into twenty-three Agro-ecological units (AEU's) based on climatic variability, landform and soils (KAU, 2016). The state coastal area comes under two AEUs, namely AEU 1- Southern Coastal Plains and AEU 2- Northern Coastal Plains. The major economic activities of the state are also concentrated within this area. As a result, over-exploitation of resources has contributed to severe coastal erosion.

Coastal soil is mainly composed of primary minerals, especially quartz (SiO_2), which are resistant to decomposition and contain little nutrients. Major constraints present in coastal sandy soil are its low water and nutrient retention due to the low clay and organic matter content (Finkl, 2005). Nutrient leaching is a serious problem in coastal sandy lands because sand is unable to hold water and nutrients efficiently. For developing sustainable resource management strategies, an understanding of coastal soil physicochemical and biological parameters is essential. By manipulating the constituent components of soil through addition and conservation practices, the potential productivity of the soils can be realized. This necessitates a site-specific and detailed analysis of soil fertility parameters of the region to understand the extent of variation and for revision of nutrient management schedule for various cropping systems. Therefore, the present study was conducted to assess the characteristics and fertility status of the

*Corresponding author: E-mail: gowry.p@kau.in; athulyabm97@gmail.com

coastal sandy soils in the Thiruvananthapuram district (Agro-Ecological Unit 1 - Southern Coastal Plains) of Kerala.

MATERIALS AND METHODS

Agro-ecological Unit 1 (AEU-1) - Southern Coastal Plains is distributed in 42 panchayats along the coast from Thiruvananthapuram district to Ernakulum district in Kerala. The study was carried out in AEU 1 of Thiruvananthapuram district which covers an area of 19,344 ha (8.84% of the district's area). AEU 1 lies between 8°28′58.872″and 8°47′ 26.5956″ N latitude and 76°43′20.7588″ and 76°56′47.292″E longitude. During March 2022, fifty geo-referenced surface soil samples (0-20 cm) following V-shaped cut sampling method, along with surface core samples were collected from coastal sandy areas in Thiruvananthapuram district (AEU 1) and their physical, chemical and biological properties were analyzed. The fifty geo-referenced soil samples were taken from locations which fairly represented the AEU 1 (Fig. 1).

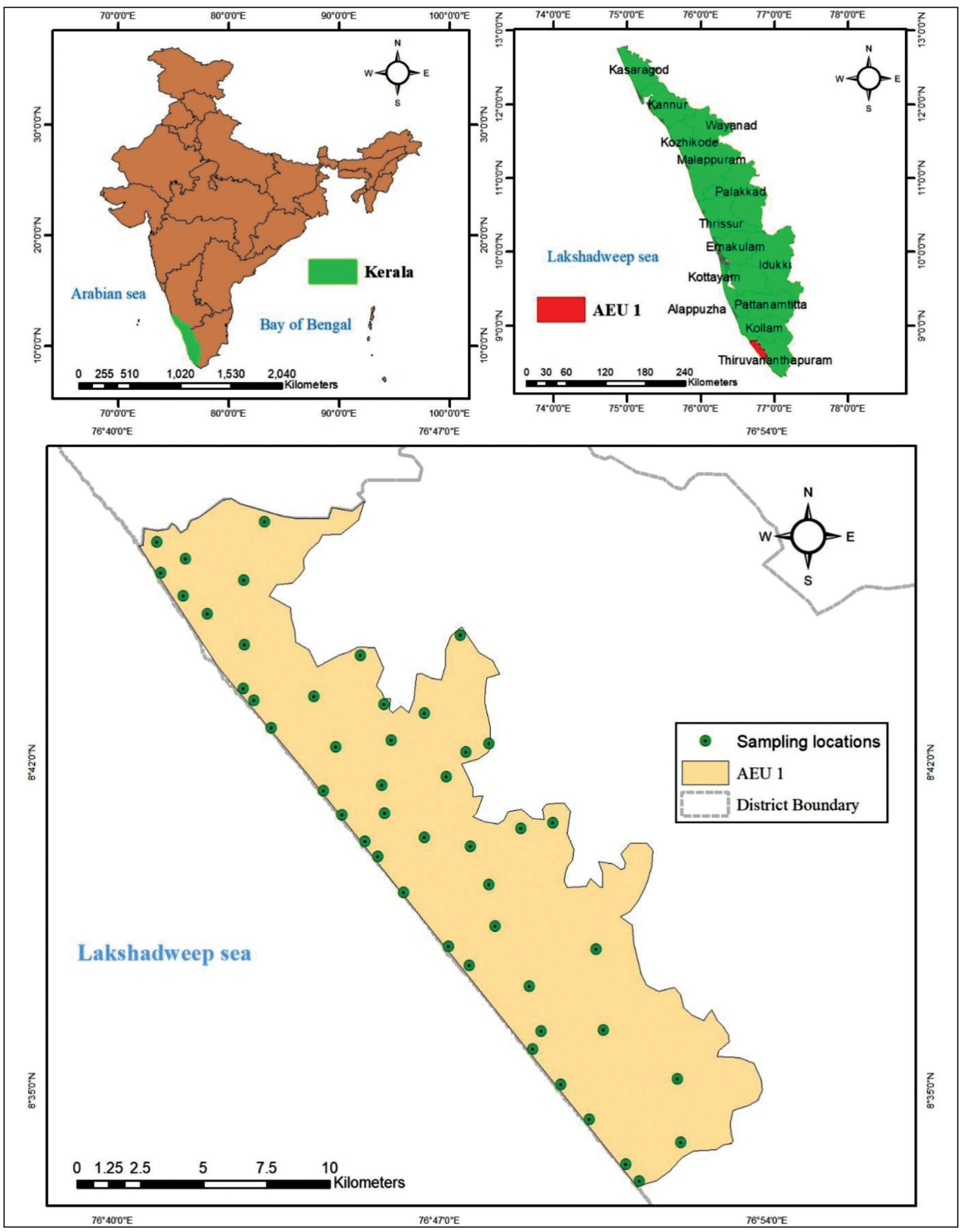

Fig.1. Sampling sites and location ofSouthern Coastal Plains (AEU 1) of Thiruvananthapuram district, Kerala

Soil samples were dried and sieved using a 2 mm sieve before analysis in the laboratory. The samples were analysed for soil texture, bulk density, particle density, water holding capacity, pH, electrical conductivity (EC), available nutrients - N, P, K, Ca, Mg, S, B, organic carbon content and enzyme activity (dehydrogenase) following standard analytical procedures. The soil textural analysis was done using the Bouyoucos hydrometer method (Bouyoucos, 1936). Bulk density (Blake and Hartge, 1986) and maximum water holding capacity (Dakshinamurthy and Gupta, 1968) were determined using core samples. Particle density was determined by the pycnometer method (Vadyunina and Korchagina, 1986). Soil pH and was electrical conductivity (EC) weremeasured in 1:2.5 soil water suspension using a pH meter (Systronics, Digital pH meter 335) and an EC meter (Systronics, Conductivity meter 304), respectively, as given by Jackson (1973).

The soil organic carbon was estimated using the Walkley and Black wet oxidation method (Walkley and Black, 1934). Available nitrogen was determined by alkaline permanganate method (Subbiah and Asija, 1956) and available phosphorus was extracted using Bray No. 1 solution (Bray and Kurtz, 1945) and estimated using a spectrophotometer (Systronics, VIS Double beam Spectro 1203). Available potassium was estimated using a flame photometer (Systronics, Flame photometer 130) after extraction with neutral normal ammonium acetate (Jackson, 1973). Exchangeable calcium and magnesium were determined by versenate titration method (Hesse, 1971) and available sulphur was extracted using calcium chloride and estimated using a spectrophotometer (Massoumi and Cornfield, 1963), while available boron was determined by hot water extraction and spectrophotometry (Azomethane-H reagent method) (Gupta, 1972). The dehydrogenase enzyme activity was determined by colorimetric estimation of TPF hydrolysedas per the method outlined by Casida (1977).

RESULTS AND DISCUSSION

Physical parameters

Soil texture

The predominant soil textural class observed in the present study area was sand (74%) followed by loamy sand (26%). While the mean value for sand content was 87.1%, the mean silt content was 8.11% and mean clay content was only 4.84%. When the soils are used for agricultural production, soil texture, particle distribution and clay content are very important. The presence of clay fraction helps in the development of a good soil structure providing better water retention and buffering capacity while protecting the nutrients against leaching loss and the clay itself may act as a source of plant nutrients upon degradation (Newman, 1984). The low content of clay in the coastal sandy soils could be a reason for poor water and nutrient retention and hence, low crop productivity.

Bulk density

The frequency distribution of bulk density in the study area is depicted in Fig. 2. Majority of samples (68%) showed a bulk density ranging between 1.6-1.8 Mg m^{-3}. Bulk density is influenced by the soil texture, mineral composition, porosity and organic matter content. Sandy soils have relatively higher bulk density since they have lesser pore space compared to silt or clay soils (Brady and Weil, 2002). Chaudhari *et al.* (2013) observed that the effect of sand content on soil bulk density was higher than that of other soil properties. A high degree of positive correlation was seen between sand and bulk density, while negative correlation was observed between clay content, silt content and bulk density. They also obtained a strong negative correlation between soil organic matter content and bulk density. Low clay and organic matter contents in the soils of the study area justify the observed higher values of bulk density.

Particle density

The particle density values in the study area ranged between 2.22 to 2.89 Mg m^{-3}, with a mean value of 2.62 Mg m^{-3}. The frequency distribution (Fig. 3) showed that the majority of samples (44%) had particle density in the range of 2.6-2.8 Mg m^{-3}. Traditionally, a constant value of 2.65 Mg m^{-3} has been assumed for the particle density of arable, mineral soils, but it has been found to vary considerably across different soil types and regions. Particle density is observed to have an inverse relationship with soil organic matter (Schjønning *et al.,* 2017).

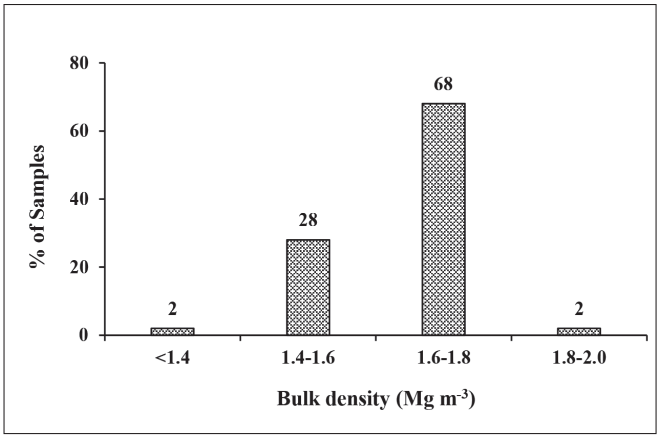

Fig. 2. *Frequency distribution of bulk density in soils of AEU 1 in Thiruvananthapuram district, Kerala*

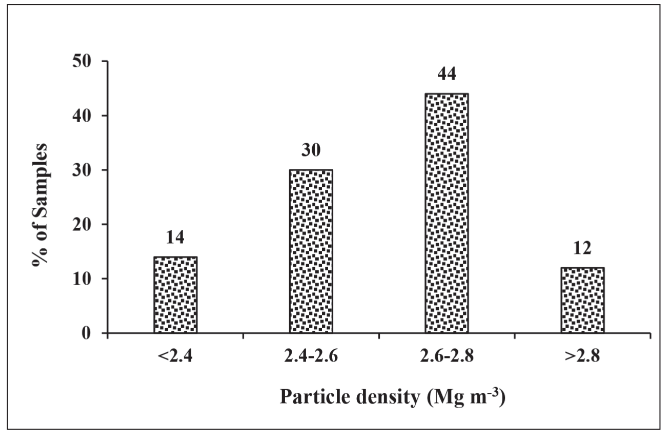

Fig. 3. *Frequency distribution of particle density in soils of AEU 1 in Thiruvananthapuram district of Kerala*

Maximum water holding capacity

The maximum water holding capacity of the coastal sandy soils under study ranged between 22.7 and 56.0%, with a mean value of 32.7%. About 50% of the samples recorded values between 30 and 50%, followed by 48% of samples having values less than 30% (Fig. 4). Water holding capacity of the soil is dependent upon the soil texture, structure, porosity, organic matter content, etc. Coastal sandy soils are mainly made up of larger particles with smaller surface area, less pore space and low organic matter content. The infiltration rate of sandy soil is high and the capacity of these soils to store water is meagre (Nair *et al.,* 2018; Subramanian *et al.,* 2009). The results obtained confirmed that water-holding capacity values were lower in soils with more sand and less organic carbon.

Chemical parameters

Soil pH

Fifty four percent of the samples showed slightly acidic pH followed by 30% in the neutral, 12% in the moderately acidic and 4% in the strongly acidic range as per the rating given in the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2016) (Fig. 5). A comprehensive study by the Kerala State Planning Board encompassing all panchayats of the state showed that 91% of the soils were acidic and 54% of the soils were strong to extremely acidic (Rajasekharan *et al.,* 2013). Nair *et al.,* (2018) reported that the coastal sandy plains of Kerala showed near-neutral soil reaction. The humid tropical climate with high rainfall, leaching out the basic ions is the major reason behind widespread acidic soil reaction including in coastal areas.

Electrical conductivity

The electrical conductivity (EC) is indicative of the salt content in the soil solution and it was in the non-saline range for all the samples analysed. The EC value ranged between 0.03 to 0.23 dS m^{-1} only. This can be attributed to the humid tropical climate conducive to extremely heavy leaching of salts even in the near coastal soils (Nair *et al.,* 2018). The very low EC value also points to the deficient status of basic cations like calcium and magnesium which are required for plant growth.

Organic carbon

Fifty eight per cent of the samples had medium organic carbon content ranging from 0.3-0.9% (Fig. 6). For sandy soils, the soil organic carbon (SOC) content was rated as per Package of Practices Recommendations of Kerala Agricultural University (Denny, 2020; KAU, 2016). The adverse conditions like poor availability of water and nutrients and high soil temperature resulted in poor vegetation and hence very little organic matter addition to the coastal sandy soils. Similar findings were reported by Nair *et al.* (2018). The absence of sufficient quantities of organic matter in addition to the sandy nature aggravates the problems related to physico-chemical and biological properties of the soil like low

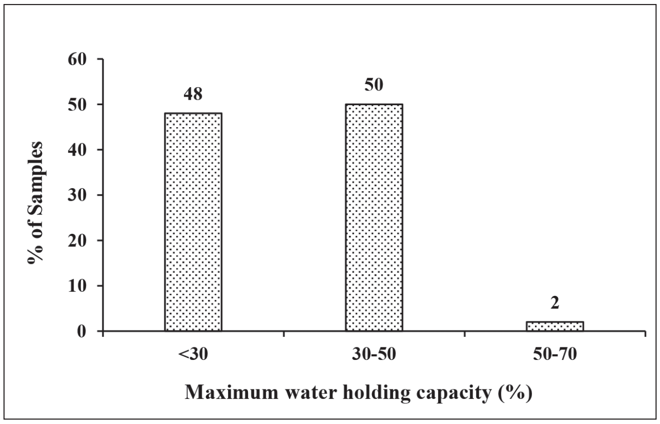

Fig. 4. *Frequency distribution of maximum water holding capacity in soils of AEU 1 in Thiruvananthapuram district of Kerala*

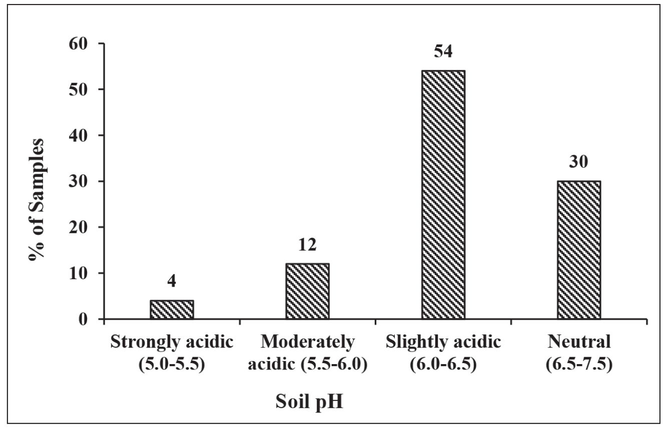

Fig. 5. *Frequency distribution of pH in AEU 1 in soils of Thiruvananthapuram district, Kerala*

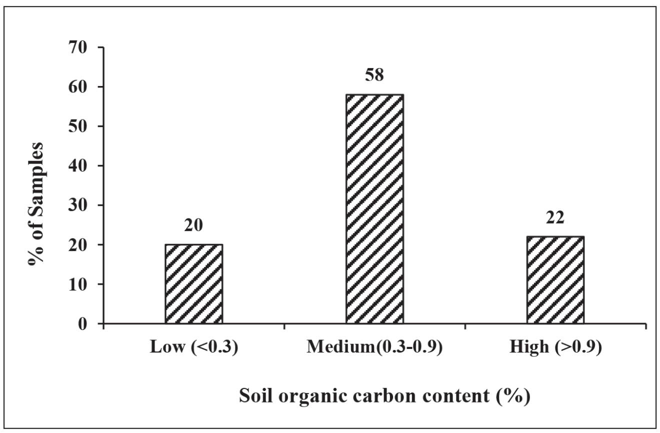

Fig. 6. *Frequency distribution of SOC content in soils of AEU 1 in Thiruvananthapuram district of Kerala*

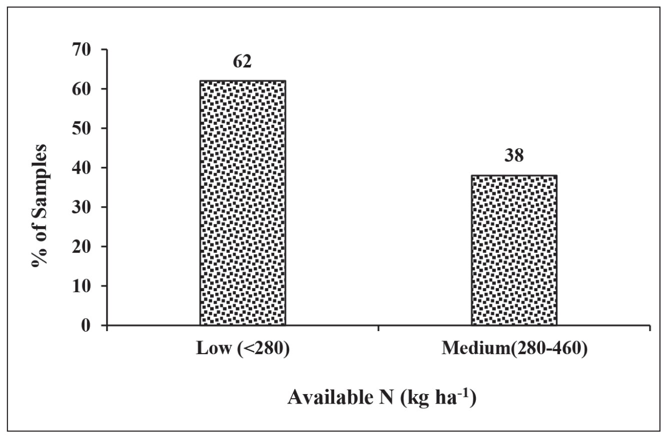

Fig. 7. *Frequency distribution of available N in soils of AEU 1 in Thiruvananthapuram district of Kerala*

cation exchange capacity, aggregate stability, water holding capacity and microbial activity.

Available nitrogen

Sixty two per cent of samples reported low values, and the remaining 38% were in the medium range for available N (Fig. 7). Very low available N content was observed in lands with excessive sand content and low organic carbon. In general, the soils of Kerala are highly weathered and dominated by low-activity clays with acidic pH, very low cation exchange capacity and base saturation, hence leading to low nutrient reserves. Coastal sandy soils recorded a very low status of organic carbon (GOK, 2019). Available N is correlated with organic carbon content and it was low for most parts of the study area and medium in areas with more organic carbon.

Available phosphorus

Available P was high for 50% of samples, medium for 28% and low for 22% (Fig. 8). Similar results with high levels of available P on coastal areas of AEU 1 in Thiruvananthapuram district such as Anchuthengu, Andoorkonam, Chenniyoor, Edava, Kizhuvilam, Mangalapuram, Vakkom, and Vettoor were also reported in a soil fertility survey conducted by the Government if Kerala (GOK, 2019). Low available P was mostly encountered in areas close to the sea with excessive deposition of sandy sediments. Heavy input of phosphatic fertilizers and the immobile nature of phosphate ions in soils might have caused the accumulation of P in soils. The high content of P in soils may induce Zn deficiency, and hence it is important to

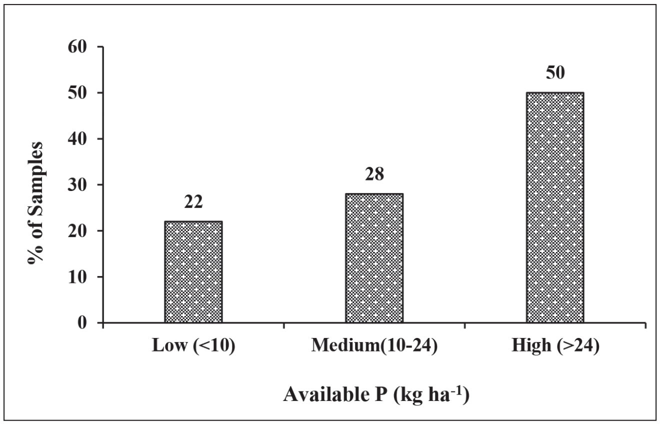

Fig. 8. *Frequency distribution of available P in soils of AEU 1 in Thiruvananthapuram district of Kerala*

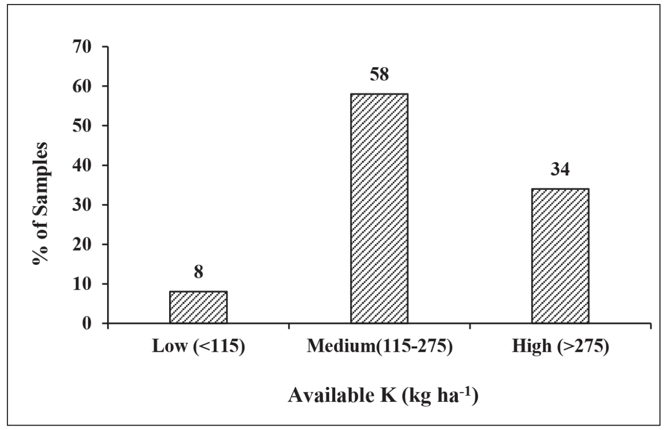

Fig. 9. *Frequency distribution of available K in soils of AEU 1 in Thiruvnanthapuram district of Kerala*

follow soil test-based recommendations (KAU, 2016).

Available potassium

Fifty eight per cent of the samples were medium in available K, 34% high and 8% low (Fig. 9). Available K was comparatively higher in soils with high EC and available Ca. In coastal sandy areas, the light-textured soils and low CEC do not support the retention of nutrients and encourage leaching losses. Thus, it is best to administer K fertilizers in split applications as needed (Mini and Mathew, 2015).

Available calcium

The results revealed that there is a deficiency of Ca throughout the study area (88% of samples) in the southern coastal sandy plains (Fig. 10). Calcium deficiency can be anticipated in highly leached tropical soils, and if exchangeable Ca level is less than 300 mg kg^{-1}, soils are classified as deficient (DOA, 2013). There exists a direct relationship between pH and available Ca content (Chandrakala *et al.,* 2018). Severe leaching loss of basic cations in the light textured sandy soils can contribute to their deficiency and acidic pH in these soils.

Available magnesium

Deficiency of exchangeable Mg was also widespread (90% of samples) in the study area which can be due to the low Mg content in parent materials and the intensive leaching losses in sandy soils (Fig. 11). The soils are classified as deficient if the exchangeable Mg level is less than 120 mg kg^{-1} (DOA, 2013). Similar findings were also reported by Bhindu and Suresh Kumar (2021) for the soils of AEU 1.

Available sulphur

Available sulphur was present in adequate quantities in 94% of the coastal sandy soil samples analyzed. The soils are said to be deficient when the available S levels are less than 5 mg kg^{-1} (DOA, 2013). Similar findings were also reported by Singh (2010).

Available boron

The results revealed that the study area in AEU 1 was mostly deficient (<0.5 mg kg^{-1}) in available B. Eighty eight percent of the samples were deficient in boron availability (Fig. 12). Also, the study of Dept. of Agriculture and Farmers' Welfare (GOK, 2019) to determine the soil fertility status revealed thatboron content in the coastal sandy soils of AEU 1 in Thiruvananthapuram district were deficient. Boron deficiency is common in acidic, coarse textured soils which are low in organic matter (Gupta, 1993). Nair *et al.* (2018) reported that weathered soils in humid climatic regions experience B deficiency due to the high water solubility of boron bearing minerals. Being highly mobile in soil, boron is prone to heavy leaching losses in the coarse textured soil especially in areas of high rainfall.

Biological parameters

Dehydrogenase activity

Among the various soil enzymes, dehydrogenases are the most critical and reflect the extent of microbial

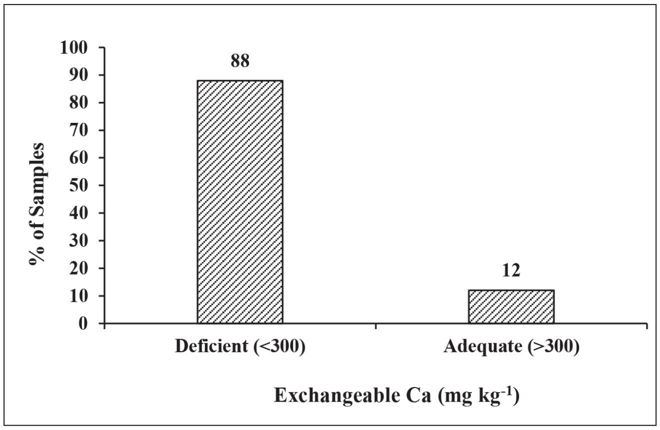

Fig. 10. *Frequency distribution of exchangeable Ca in soils of AEU 1 in Thiruvananthapuram district of Kerala*

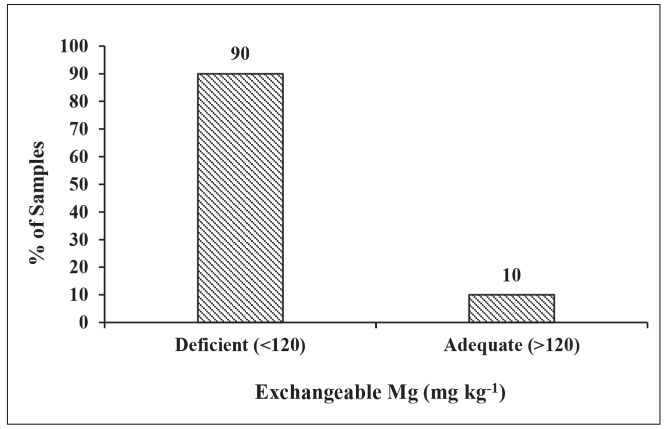

Fig. 11. *Frequency distribution of available Mg in soils of AEU 1 in Thiruvananthapuram district of Kerala*

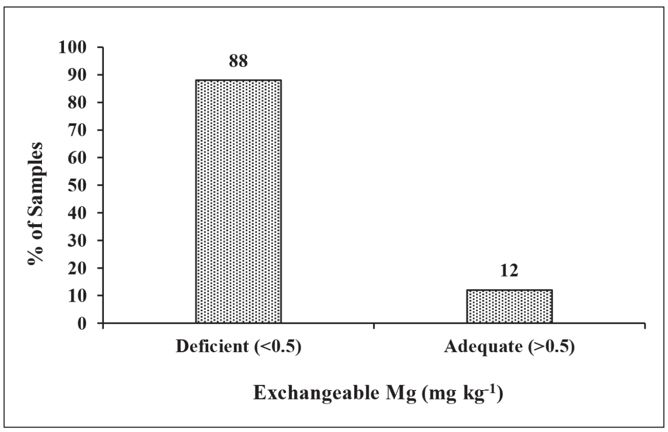

Fig. 12. *Frequency distribution of available B in soils of AEU 1 in Thiruvananthapuram district of Kerala*

activity. It is an appropriate indicator of soil fertility as it is influenced by the same factors as the abundance and activity of microorganisms (Kaur and Kaur, 2021). The dehydrogenase enzyme activity was less than 75 µg TPF hydrolysed g^{-1} soil 24 h^{-1} in all the samples analysed. This indicates that the biological activity in these soils is low, which may have multiple impacts on the fertility of the soils.

The predominant soil textural class of AEU 1 in Thiruvananthapuram district is sand and sandy loam, with bulk density varying between 1.37-1.86 Mg m^{-3} and particle density 2.22-2.89 Mg m^{-3}, while half of the samples had maximum water holding capacity ranging between 30-50%. Soil pH showed high variability ranging from strongly acidic to neutral values, with entire samples showing EC values less than 1 dS m^{-1}. Organic carbon was medium for most of the soil samples in coastal sandy areas. Available N was low, available P high and available K were medium for most of the area. Available Ca was deficient for more than 80% of the area, while Mg deficiency was shown in 90%. Available S was adequate for over 94% of the area, while 88% showed B deficiency. Soil biological activity was also found to be poor with entire samples showing values less than 75 µg TPF hydrolysed g^{-1} soil 24 h^{-1}. On the whole, the fertility status of these soils needs improvement to support better agricultural production. Improvement of soil physical, chemical and biological characteristics with sufficient input of organic manures, mulching, efficient irrigation practices and adoption of suitable crops and varieties may have to be implemented to achieve the potential productivity of these soils.

CONFLICTS OF INTEREST

The authors do not have any conflict of interest.

ACKNOWLEDGEMENT

The authors hereby acknowledge the financial assistance and research facilities extended by the Kerala Agricultural University.

REFERENCES

Bhindu, P.S. and Sureshkumar, P. (2021). Availability indices of calcium and magnesium in soils of Kerala. *Journal of Tropical Agriculture* **59**(1): 38-44.

Blake, G.R. and Hartge, K.H. (1986). *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods,* Volume 5, Soil Science Society of America, Madison, USA. pp 363-375.

Bouyoucos, G.J. (1936). Directions for making mechanical analyses of soils by the hydrometer method. *Soil Science* **4**: 225-228.

Brady, N.C. and Weil, R.R. (2002). *The Nature and Properties of Soils,* Thirteenth edition, Prentice Hall, Upper Saddle River, New Jersey, USA. 960 p.

Bray, R.H. and Kurtz, I.T. (1945). Determining total organic and available forms of phosphate in soils. *Soil Science* **59**: 39-45.

Casida, L.E. (1977). Microbial metabolic activity in soil as measured by dehydrogenase determinations. *Applied and Environmental Microbiology* **34**: 630-636.

Chandrakala, M., Ramesh, M., Sujatha, K., Hegde, R. and Singh, S.K. (2018). Soil fertility evaluation under different land use system in tropical humid region of Kerala, India. *International Journal of Plant and Soil Science* **25**(4): 1-13.

Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chakravarty, M. and Maity, S. (2013). Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications* **3**(2): 1-8.

Dakshinamurthi, C. and Gupta, R.P. (1968). *Practices in Soil Physics,* ICAR-Indian Agricultural Research Institute, New Delhi, India.

Denny, M. (2020). Assessment of soil quality in the post-flood scenario of AEU 3 in Alappuzha district of Kerala and generation of GIS maps. *Unpublished M.Sc. (Ag) Thesis,* Kerala Agricultural University, Thrissur, Kerala, India.

DOA [Department of Agriculture]. (2013). *Manual on Soil Plant and Water Analysis,* Vol. 1, V.K. Venugopal, K.M. Nair, M.R. Vijayan, K.S. John, P. Sureshkumar and C.R. Ramesh (eds.), Government of Kerala, Kerala, India. 157 p.

Finkl, C.W. (2005). Coastal soils. In: *Encyclopedia of Coastal Science,* M.L. Schwartz (ed), Springer, Dordrecht, Netherlands. pp 78-302.

GOK [Government of Kerala]. (2019). *Soil Health Management for Sustainable Crop Production in Kerala,* Department of Agriculture Development and Farmers' Welfare, Kerala, India. 426 p.

Gupta, U.C. (1972). Effects of boron and limestone on cereal yields and on B and N concentrations of plant tissues. *Communications in Soil Science and Plant Analysis* **6**: 439-450.

Gupta, U.C. (1993). Factors affecting boron uptake by plants. In: *Boron and its Role in Crop Production,* U.C. Gupta (ed.),CRC Press, Boca Raton. pp 87-104.

Hesse, P.R. (1971). *A Textbook of Soil Chemical Analysis,* John Murray Publishers Ltd., London, UK. 520 p.

Jackson, M.L. (1973). *Soil Chemical Analysis,* Prentice Hall of India Ltd., New Delhi, India. pp 219-221.

KAU [Kerala Agricultural University]. (2016). *Package of Practices Recommendations: Crops,* Fifteenth edition. Kerala Agricultural University, Thrissur, Kerala, India. 392 p.

Kaur, J. and Kaur, G. (2021). Dehydrogenase activity as a biological indicator of soil health. *Chemical Science Review and Letters* **10**(39): 326-329.

Massoumi, A. and Cornfield, A.H. (1963). A rapid method for determining sulphate in water extracts of soils. *Analyst* **88**(1045): 321-322.

Mini, V. and Mathew, U. (2015). Soil based nutrient management plan for Onattukara sandy tract of Kerala. *An Asian Journal of Soil Science*

10(1): 99-103.

Nair, K.M., Kumar, K.S.A., Kumar, S.C.R., Ramamoorthy, V., Lalitha, M., Srinivas, S., Koyal, A., Parvathy, S., Sujatha K., Sivanand, Hegde, R. and Singh, S.K. (2018). Coconut growing soils of Kerala: 1. Characteristics and classification. *Journal of Plantation Crops* **46**(2): 75-80. https://doi.org/10.25081/jpc.2018.v46.i2.3718.

Newman, A.C.D. (1984). The significance of clays in agriculture and soils. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* **311**(1517): 375-389. http://www.jstor.org/stable/37331.

Pavithran, S.A.P., Menon, N.R. and Sankaranarayanan, K.C. (2014). An analysis of various coastal issues in Kerala. *International Journal of Scientific Research and Education* **2**(10):1993-2001.

Rajasekharan, P., Nair, K.M., Rajasree,G., Sureshkumar, P., Narayanan Kutty, M.C. (eds). (2013). *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala,* Kerala State Planning Board, Thiruvananthapuram, Kerala, India. 514 p.

Schjønning, P., McBride, R.A., Keller, T. and Obour, P.B. (2017). Predicting soil particle density from clay and soil organic matter contents. *Geoderma* **286**: 83-87.

Singh, S.S. (2010). Primary and secondary nutrients management for crops in rainfed agro-ecosystem,Winter school on *Water and nutrient management for crops under rainfed ecosystem in eastern part of Uttar Pradesh,* Department of Soil Science and Agricultural Chemistry, January 10-30, 2010, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. pp 29-33.

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25**: 259-260.

Subramanian, P., Dhanapal, R., Palaniswami, C., Maheswarappa, H.P., Gupta, A. and Thomas, G.V. (2009). *Coastal Sandy Soil Management for Higher Coconut Productivity*. Technical Bulletin No. 50. ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala, India. 20 p.

Vadyunina, A.F. and Korchagina, Z.A. (1986). *Methods of Studying the Physical Properties of Soils,* Agropromizdat, Moscow, Russia. 416 p.

Walkley, A.J. and Black, I.A. (1934). Estimation of soil organic carbon by chromic acid titration method. *Soil Science* **37**(1): 29-38.