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CHARACTERIZATION AND SOIL SITE SUITABILITY EVALUATION OF KHASI MANDARIN GROWING SOILS OF KAMRUP DISTRICT, ASSAM, INDIA

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ABSTRACT

The present investigation was carried out in citrus growing soils of Kamrup district of Assam covering Boko, Rani and Sonapur in order to characterize and evaluate the soil site suitability for citrus and other crops like tea, coffee, rubber, maize, potato, turmeric, sesame, pineapple, and banana. Four soil profiles and 38 surface samples were collected from these areas. The colour of the studied soil samples was dark yellowish brown at the surface in all the pedons and very pale brown to dark reddish brown in the sub-surface with a dominant hue of 10YR. A huge textural variation ranging from sandy clay loam to clay loam was found in the surface layers and loamy sand to clay loam was found in the sub-surface layers. Sand, silt and clay content varied from 28 to 70.6 per cent, 13.5 to 37 per cent and 9.9 to 39 per cent, respectively. Soil organic carbon content varied from 0.13 to 0.89 per cent. Soil pH varied from 4.41 to 5.92. The cation exchange capacity varied from 5.2 to 17.4 cmol(p^+) kg^{-1}. Among the basic cations, Ca^{2+} was dominant. These soils were classified at subgroup level as *Typic Dystrudepts* (P1, P3 and P4) and *Typic Udorthents* (P2). The assessment of soil site suitability for citrus, coffee, maize, rubber, sesame, tea and turmeric showed that major portion of the soils was permanently not suitable (N2) for maize, banana and sesame, currently not suitable (N1) for pineapple, moderately suitable to permanently not suitable for citrus, tea and rubber, marginally suitable to permanently not suitable for potato, coffee and turmeric.

***Keywords*:** Characterization, Classification, Khasi mandarin growing soils, Suitability.

Introduction

Citrus fruits are a diverse group of fruits belonging to the Rutaceae family, known for their bright colours, tangy flavours, and rich nutritional value. It is regarded as one of the most profitable fruit crops, holding a significant and enduring position in global trade and world economy. According to recent data, China dominates global citrus production, accounting for 28% of total cropping areas and 27% of worldwide output (Yang *et al.*, 2020). In terms of production volume, China leads with approximately 45,000 tons per year, followed closely by Brazil with around 25,000 tons per year. The third, fourth and fifth highest production were India, Mexico, and the United states of America with 15,000, 9,000 and 7000 tons/year, respectively (Rafie-Rad *et al.*, 2022). Citrus is produced in 5.63 lakh acres in India, producing 56.8 lakh tonnes total and 10.1 tonnes ha-1 in productivity (Punekar *et al.*, 2017).

Northeast India is identified as a centre of origin for numerous citrus species. Among the citrus crops Khasi mandarin is the most economically significant citrus crops in the north eastern region, playing a crucial role in the socio-economic development of local communities. It occupies the largest cultivation area in the region due to its commercial value. The highest production and acreage of Khasi mandarin can be seen in Assam and Meghalaya. Khasi mandarin orange variety, called “the pride of Meghalaya” has made it to the world’s first food atlas. East Khasi hills district is the major producer of Khasi mandarin in Meghalaya covering 4252 ha area (46% of total orange production) producing 23585 M.T fruits which are 53% of the total state production. It is called Soh Niamtra or Soh Myntra in Khasi; Komola or

Humoptira in Assamese; and Komla in Bengali (Singh et al., 2016). Although India is the fourth largest producer of orange in the world but due to the problem of citrus decline the average yield of orange in India is alarmingly low as compared to other countries. Citrus decline is a complex problem, where there is gradual decline of production and productivity of orchards, finally making the orchards unproductive. This is a serious problem in citrus growing areas of Assam. Khasi mandarin is occupying an area of 0.104 Mha in the North Eastern hill region. The crop in the present years has been receiving worldwide attention due to rapid decline which affects almost all the cultivars among which Khasi mandarin is susceptible leading to nutrient deficiency viz. macronutrient specially Nitrogen and micronutrient Iron, Manganese, Zinc etc. Keeping this view in mind, the present study was undertaken to characterize and classify the soils and to evaluate the soil site suitability of khasi mandarin growing soils.

Materials and Methods

The study was carried out in citrus growing soils of Kamrup district, Assam covering Rani, Boko and Sonapur. The Kamrup district is situated in the western part of Assam, India with a geographical area of about 2,740 km^2 and the district is bordered by Udalguri and Baska districts to the north, Meghalaya state to the south, Darrang district and Kamrup Metropolitan district to the east, and Goalpara and Nalbari districts to the west. Rangiya is the sub-district of Kamrup. The district lies between latitudes of 25'46" N and 26'49" N and longitudes with 90'48" E and 91'50" E. The terrain of Kamrup district is mostly flat, with the Brahmaputra River flowing through the district. The overall elevation of the area is 60 meters above mean sea level. The elevation of Kamrup district is relatively flat with some slight variations across different areas.

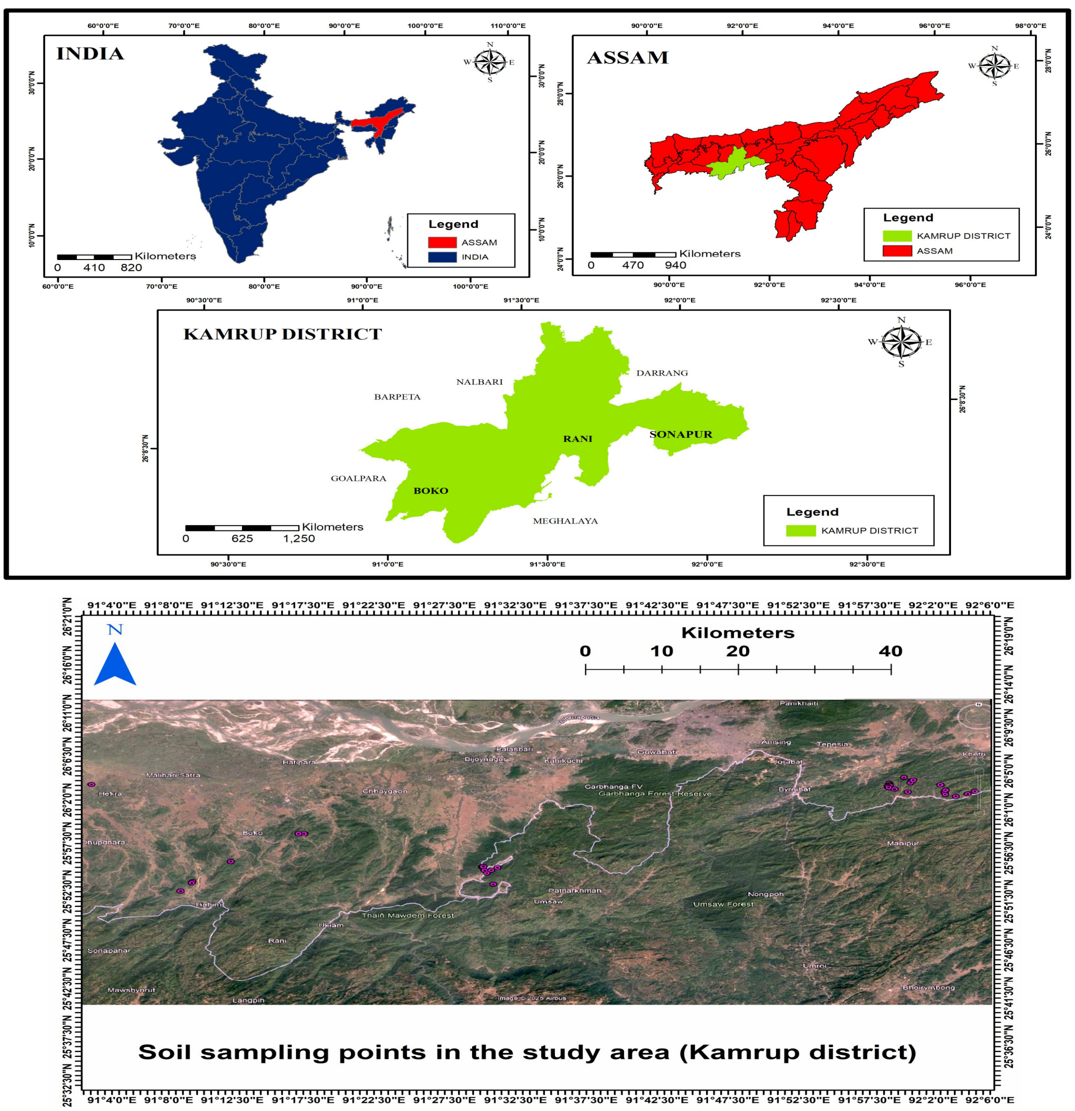

Fig. 1: Map and soil sampling points of the study area

Table 1: Site characteristics of the Pedons

Profile No	**Location**	Latitude	Longitude
Pedon 1 (P1)	Rani	25.91769 ºN	91.50306 ºE
Pedon 2 (P2)	Boko	25.88999 ºN	91.16056 ºE
Pedon 3 (P3)	Sonapur	26.05854ºN	91.98242 ºE
Pedon 4 (P4)	Sonapur	26.06001ºN	91.04163 ºE

The present study was conducted in citrus growing soils of Kamrup district, Assam. Representative soil profiles were exposed at three different locations of Kamrup district, Assam covering Boko, Rani and Sonapur. Additionally, 38 surface soil samples were collected from these locations. The details of the location of the profiles are described in table 1. A total 22 number of horizons were identified in the four soil profiles and soil samples were collected from each horizon. The samples were dried under shade, grounded, mixed thoroughly and passed through a 2 mm sieve. The processed samples were then kept separately in labelled plastic bags and subsequently used for various laboratory analysis. The morphological characteristics of the soils of the profiles were studied in the field itself as per the field guide (Nataranjan and Sarkar, 2009). The particle size analysis was determined by the international pipette method (Piper, 1966). Bulk density (BD) and particle density (PD) of the studied soils were analyzed by core (Bodman, 1942) and pycnometer (Black, 1965) methods. Soil porosity was calculated from its relationship with BD and PD. Organic carbon (OC) was estimated by Walkey and Black titration method (1934). The pH (1:25), exchangeable cations, cation exchange capacity (CEC), available potassium, exchangeable calcium and magnesium were analyzed following standard procedures (Jackson, 1973). Exchangeable acidity was done by KCl extraction method (Mclean, 1965). Free oxides of Fe and Al was done by sodium citrate bicarbonate dithionite method (Mehra and Jackson, 1958), Available Fe, Cu, Zn and Mn was estimated by DTPA extraction method (Lindsay and Norvell, 1978). The soils were classified as per Keys to Soil Taxonomy (Soil Survey Staff, 2014). Simple correlation analysis was done for selected parameter using the procedures of Snedecor and Cochran (1967). Soil site suitability was assessed by the method outlined by Sys (1985) and the potential land suitability classes was determined after considering the improvement measures to correct the limitations (Sys *et al.*, 1993).

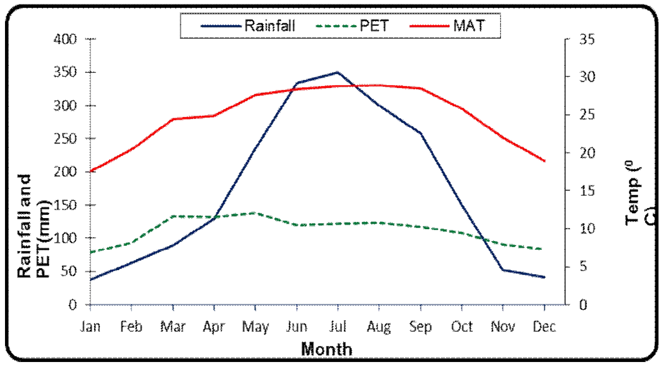

Fig. 2: Ombrothermic diagram of Kamrup district based on 25 years (1999-2023) climatic data

Results and Discussion

Morphological characteristics

The morphological properties of the soils are displayed in Table 2. The soil colour (moist) was dark yellowish brown at the surface in all the pedons and very pale brown to dark reddish brown in the subsurface horizon with a dominant hue of 10YR. However, a hue of 5YR and 7.5YR was observed in the sub-surface horizon of pedon 3 (P3) and pedon 4 (P4), respectively. Similar findings were also reported by Kuchanwar *et al.* (2023) in sweet orange growing soils of Jalna district, Maharashtra. Soils which were developed from phyllite have a colour with hue of 7.5YR/5YR (Likhar and Prasad, 2011). Mottles were found only in the lower horizon of pedon 1 (P1) and pedon 2 (P2). Presence of mottles in the lower horizon might be attributed to the fluctuating ground water which leads to oxidation-reduction cycles which segregated Fe and Mn in these layers. These results validate with the findings of Dutta *et al.* (2017b). A wide textural variation of the soils ranging from sandy clay loam to clay loam in the surface horizons and sandy loam to clay loam in the sub-surface horizons except in horizon C of pedon 1 (P1) where the texture was found to be loamy sand. In P3 the texture of all the horizons was found to be clay loam. Similar findings was also reported by Punekar *et al.* (2017). The texture became heavier with depth in pedon 4 (P4) which might be due to higher rate of weathering in the subsurface horizons. The structural development of the soils were found to be medium, weak to moderate, sub-angular blocky in the surface of all the pedons and fine to medium, weak to moderate, sub-angular blocky in the sub-surface horizons. These observation corroborates with the findings of Dhale and Prasad (2009). In the C horizon of pedon 1(P1) single grain structure was observed which was also observed by Chakravarty and Barua (1983) in the soils of North East India. Consistency of the soils of all the pedons was observed to be slightly hard to hard when dry, friable, slightly sticky and slightly plastic when wet. Similar observations were also made by Punekar *et al.* (2017). Only in horizon C of pedon 1 (P1) was found to be loose when dry, loose, non-sticky and non-plastic when wet because of presence of less quantity of clay.

Physical characteristics

The particle size distribution data indicated a significant variation in the proportions of sand, silt, and clay in the soils (Table 3). The sand fraction in the studied soils ranged from 28.0 to 70.6 per cent, highest fraction of sand was observed in the C horizon of P1 and lowest sand fraction was observed in the Bw3 horizon of P4. The highest clay content was recorded in the Bw4 horizon of P3 and C horizon of P1 recorded the lowest clay content. Higher clay content with increasing depth in P3 and P4 might be due to translocation of clay from surface horizon (Likhar and Prasad, 2011). In P1 clay content increased to a certain depth and then decreased thereafter. Such type of clay distribution indicates that the soils is moderately well developed (Barshad, 1964). The silt content showed irregular distribution in all the pedons. Decreasing trend of sand per cent was observed in P3 and P4 and irregular distribution was observed in P1 and P2 which indicates that sand has undergone transformation. To evaluate the consistency of parent materials, a threshold of 0.1 was established for the Silt/ (Silt + Clay) ratio between adjacent soils horizons. Lithological discontinuity was found in P1 and P2 pedons according to this criterion. The difference in the ratio is >1.5 in the horizon A2 and AC of P2 which indicated the presence of lithological discontinuity. Surface horizons exhibited higher BD as compared to sub-surface horizons except P1 which might be due to higher amount of organic matter and biotic activities in the surface layers (Das *et al*., 2019). In P1, bulk density increased with depth which might be due to to the accumulation of finer fraction and heavy minerals eluviated from the surface horizon (Singh *et al*., 2016). The particle density of the studied soils ranged from 2.05 to 2.33 Mg m^{-3}, the highest being in the surface soils as compared to sub-surface soil which might be due to high organic carbon (Das *et al*., 2019). In P4 particle density increased with depth which might be due to higher amount of heavy minerals in sub-surface soils (Gupta *et al.,* 2001). In P4, porosity was found to be low in surface layers as compared to sub-surface layers which was due to higher amount of clay content in the sub-surface horizons (Das *et al.*, 2019).

Table 2: Morphological characteristics of soils of Kamrup district.

Horizon	Depth (cm)	Matrix (colour)	Mottles (colour)	Texture	Structure	Consistency
P1						
A	0-10	10YR 4/4	-	scl	m1sbk	dsh, mfr, wss, wsp
Bw1	10-50	10YR 6/8	-	scl	m2sbk	dsh, mfr, wss, wsp
Bw2	50-105	10YR 5/8	-	scl	m2sbk	dh, mfr, wss, wsp
Bw3	105-145	10YR 5/6	c2d,5YR 6/8	sl	m1sbk	dh, mfr, wss, wsp
BC	145-180	10YR 7/4	c2d, 10YR 6/8	sl	m1sbk	dsh, mfr, wss, wsp
C	180-205	10YR 6/6	-	ls	sg	dl, ml, ws0, wp0
P2						
A1	0-5	10YR 4/4	-	scl	m1sbk	dsh, mfr, wss, wsp
A2	5-15	10YR 4/8	f1c, 5YR 6/8	scl	m1sbk	dsh, mfr, wss, wsp
AC	15-45	10YR 4/4	c1c, 5YR 5/8	sl	m1sbk	dsh, mfr, wss, wsp
C1	45-90	10YR 4/4	f1c, 5YR 6/8	sl	m1sbk	dsh, mfr, wss, wsp
C2	90-145	10YR 4/4	c1c, 7.5YR 6/8	sl	m1sbk	dsh, mfr, wss, wsp
C3	145-180	10YR 5/8	-	sl	m1sbk	dsh, mfr, wss, wsp
P3						
A	0-5	10YR 4/4	-	cl	m2sbk	dsh, mfr, wss, wsp
Bw1	5-15	5YR 3/4	-	cl	f2sbk	dsh, mfr, wss, wsp
Bw2	15-50	5YR 3/3	-	cl	f2sbk	dsh, mfr, wss, wsp
Bw3	50-95	5YR 4/6	-	cl	f2sbk	dsh, mfr, wss, wsp
Bw4	95-170	5YR 4/8	-	cl	f2sbk	dh, mfr, wss, wsp
P4						
A	0-5	10YR 4/4	-	scl	m1sbk	dsh, mfr, wss, wsp
AB	5-20	10YR 4/4	-	cl	m2sbk	dsh, mfr, wss, wsp
Bw1	20-45	10YR 4/4	-	cl	m2sbk	dsh, mfr, wss, wsp
Bw2	45-100	7.5YR 4/4	-	cl	m2sbk	dsh, mfr, wss, wsp
Bw3	100-165+	7.5YR 5/6	-	cl	m2sbk	dh, mfr, wss, wsp

Chemical characteristics

The important soil chemical properties are displayed in Table 4. Results revealed that the soils of the study area had high organic carbon content at the surface and immediately below it, and then decreased to a minimum value with depth. Similar findings was also found by Rahate *et al.* (2014). This might be due to the decomposition of plant materials at the soil surface which led to a significant accumulation of organic matter. In addition, majority of orange producers are growing legumes and spices as intercrops, which raise the soil's organic matter content and, eventually the orchard's OC content. The regular decrease of organic carbon with depth suggests a pedogenic development of these soils (Dutta *et al.*, 2017b; Singh *et al.*, 2016). Among the surface horizons, the highest organic carbon content (0.89 per cent) was recorded in P4 and lowest (0.13 per cent) was noted in the sub-surface horizon of P1. Generally, organic carbon levels decreased with depth across all pedons, except for P3 and P4, where its distribution showed irregular patterns. The results revealed that the pH of the studied soil was acidic in nature. The surface soils pH was found to be low as comapared to sub-surface horizons except P3. The lower values of pH in the surface horizons might be attributed to the higher organic carbon content (Dhale and Prasad, 2009; Likhar and Prasad, 2011). The soils of P3 was comparatively more acidic than P1, P2 and P4 which might be due to the acidic parent materials and high rainfall in the study area (Kalita *et al.*, 2019). The electrical conductivity of the studied soils was very low. The values of electrical conductivity of soils ranged from 0.01 to 0.016 dSm^{-1} in P1, 0.016 to 0.024 dSm^{-1} in P2, 0.014 to 0.043 dSm-1 in P3 and 0.021to 0.058 dSm^{-1} in P4. It indicated that studied soils contains very low amount of soluble salts.

Data showed in table (4) revealed among all the exchangeable cations Ca^{2+} was dominant cation followed by exchangeable Mg^{2+} which was due to the clay micelle was dominantly saturated with exchangeable calcium. Similar findings were also observed by Lingade *et al.* (2008), Likhar and Prasad (2011) and Karmakar (2014). The concentration of divalent cations (Ca^{2+} and Mg^{2+}) was high as compared to monovalent cations (K^+ and Na^+) in the soils was consistent with Jenney's theory (1931) which showed that divalent cations were preferentially adsorbed over monovalent cations. The exchangeable acidity of the soils ranged from 1.2 to 2.2 cmol (p+) kg^{-1} in P2, 1.7 to 2.5 cmol (p+) kg^{-1} in P3 and 0.4 to 0.8 cmol (p+) kg^{-1} in P4. In P1, P2 and P4 exchangeable acidity shows decreasing trend with increasing depth. Similar observation was also observed by Reza *et al.* (2012). The CEC of the soils ranged from 5.2 to 15.3 cmol (p+) kg^{-1}. The cation exchange capacity of P4 was found to be the highest (15.3 cmol (p+) kg^{-1}) which might be due to basaltic parent material as evident from the presence of smectite dominant clay (Singh *et al.*, 2016) which can be explained by the positive and significant correlation of both cation exchange capacity and clay content (r =0.546*). Similar findings were also found by Karmakar (2014) and Gogoi *et al.* (2022). The per cent base saturation (Table 4.3) of the studied soils was found to be low which ranged from 10.5 to 14.9 per cent in P1, 10.1 to 23.0 per cent in P2, 10.5 to 17.5 per cent in P3 and 10.0 to 18.1 per cent in P4. The base saturation was found to be very low in all the profiles which might be due to dystric nature of the soils (Mohanty *et al.*, 2019).

Table 3: Physical properties of piedmont plain, alluvial plain and flood plain soils of Kamrup district.

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Silt/ (Silt+ Clay)	Bulk density ($Mg\ m^{-3}$)	Particle density ($Mg\ m^{-3}$)	Porosity (%)
P1								
A	0-10	51.6	26.4	22.0	0.55	1.48	2.33	36.4
Bw1	10-50	49.0	24.0	27.0	0.47	1.49	2.23	33.1
Bw2	50-105	48.0	23.0	29.0	0.44	1.50	2.24	33.0
Bw3	105-145	56.5	23.5	20.0	0.54	1.56	2.18	28.4
BC	145-180	60.0	24.0	16.0	0.60	1.58	2.20	28.1
C	180-205	70.6	19.5	9.9	0.66	1.59	2.16	26.3
P2								
A1	0-5	63.5	16.0	20.5	0.44	1.47	2.32	36.6
A2	5-15	62.5	13.5	24.0	0.36	1.43	2.23	35.8
AC	15-45	61.0	21.0	18.0	0.54	1.55	2.19	29.2
C1	45-90	58.0	25.8	16.2	0.61	1.49	2.10	29.0
C2	90-145	63.7	18.8	17.5	0.52	1.56	2.07	24.6
C3	145+	69.1	15.3	15.6	0.50	1.57	2.05	23.4

P3								
A	0-5	43.0	28.0	29.0	0.49	1.47	2.30	36.0
Bw1	5-15	40.5	27.0	32.5	0.45	1.49	2.20	32.2
Bw2	15-50	39.0	25.0	36.0	0.41	1.54	2.15	28.3
Bw3	50-95	36.0	27.0	37.0	0.42	1.52	2.18	30.2
Bw4	95-170	30.5	30.5	39.0	0.44	1.49	2.18	31.6
P4								
A	0-5	57.5	16.0	26.5	0.47	1.45	2.12	31.6
AB	5-20	45.0	23.0	32.0	0.42	1.47	2.14	31.3
Bw1	20-45	34.0	33.0	33.0	0.50	1.45	2.17	33.1
Bw2	45-100	29.0	37.0	34.0	0.52	1.43	2.20	35.0
Bw3	100-165+	28.0	34.0	38.0	0.47	1.49	2.23	33.1

The content of CBD extractable Fe (Fed) ranged from 0.96 to 1.64 % and the content of CBD extractable Al (Ald) ranged from 0.68 to 0.98 per cent. A distinct increasing trend of CBD extractable Fe (Fed) was observed in profile P2. Similar findings were also observed by Dutta *et al.* (2017b) and Gangopadhyay *et al.* (2016). This might be attributed to fluctuating ground water table which causes seasonal reduction of iron and enhances its downward movement with recession of ground water or due to co-migration of Fe and clay (Blume and Schwertmann, 1969).

Soil Classification

Soil classification was done upto subgroup level following the criteria laid down in Soil Taxonomy using field and laboratory data (Soil Survey Staff, 2014).

Soils of P1, P3 and P4 have cambic subsurface horizon and udic soil moisture regime. So these soils were classified as Inceptisols order and Udepts suborder. The base saturation (by 1N NH_4OAc) of these soils was less than 60% in one or more horizons at a depth between 25 and 75 cm from the mineral soil surface. So these soils qualified for Dysrudepts at great group level and *Typic Dystrudepths* at sub group level. P2 soils did not show presence of B Horizon and hence classified under the order Entisols. These soils did not have any diagnostic subsurface horizon and amount of organic matter decreases regularly with soil depth, so these soils qualified for Entisols order and Orthents sub order. As the moisture regime is Udic, the soils were classified as Udorthents at great group level. Also these soils did not qualify for any sub group other than 'Typic' and hence classified as *Typic Udorthents.*

Table 4: Taxonomic classification of the studied soils

Pedon No.	Location	Order	Sub order	Great group	Subgroup
P1	Rani	Inceptisol	Udept	Dystrudepts	*Typic Dystrudepts*
P2	Boko	Entisol	Orthents	Udorthents	*Typic Udorthents*
P3	Sonapur	Inceptisol	Udepts	Dystrudepts	*Typic Dystrudepts*
P4	Sonapur	Inceptisol	Udepts	Dystrudepts	*Typic Dystrudepts*

Available N, P_2O_5 and K_2O

The NPK status of the studied soils was displayed in Table 5. The result showed that the content of nitrogen in the studied soils ranged from 12.5 to 168.5 kg ha^{-1}. The surface layers contained highest amount of nitrogen as compared to sub-surface horizons. The highest recorded value of available nitrogen (168.5 kg ha^{-1}) in A1 horizon of P2 and the lowest value (12.5 kg ha^{-1}) was observed in the C horizon of P1. The variation in the content of available nitrogen might be due to differences in organic carbon levels. As organic carbon, decomposes, it releases nitrogen into the soil, influencing its availability. This relationship is supported by strong positive correlations between nitrogen and organic carbon (r = 0.899**). Similar results were also observed by Basumatary *et al.* (2021). The content of phosphorus varied from 9.6 to 30.5 kg ha^{-1}. The surface layers was found to be high in phosphorus as compared to sub-surface layers which might be ascribed to confinement of crop cultivation to the rhizosphere and replenishing the depleted P with large amounts of external sources, such as fertilizers. In addition, the build-up of litterfall, residues, and debris from mandarin plants in the rhizosphere could be another factor (Singh *et al.,* 2014). The values of potassium in the studied soils ranged from 49.8 to 132.0 kg ha^{-1}. The surface layers contains highest concentration of available K as compared to sub-surface which might be due to the increased weathering which results in release of labile K from organic wastes, the use of K fertilizers, upward translocation of K from deeper depths and capillary rise of groundwater (Singh *et al.,* 2016). Furthermore, the regular accumulation of colloidal particles from the adjacent upper slopes of the catchment areas may also played a role in enriching the surface horizon with available potassium (Gogoi *et al.,* 2018).

Results showed that DTPA-Fe content ranged from 2.9 to 17.9 mg kg^{-1}in P1, 6.2 to 16.2 mg kg^{-1} in P2, 3.6 to 19.4 mg kg^{-1} in P3 and 2.4 to 20 mg kg^{-1} in P4. The highest content of DTPA-Fe in the surface layers as compared to sub-surface layers might be due to the formation of chelates with organic compounds, facilitating their downward movement with percolating water. This validates with the findings of Singh *et al.* (2019) and Athokpam *et al.* (2016). DTPA-Mn content ranged from12.5 to 25.5 mg kg^{-1} in P1, 12.5 to 24.5 mg kg^{-1} in P2, 20.5 to 27.4mg kg^{-1} in P3 and 14.3 to 25.5mg kg^{-1} in P4. In P2, P3 and P4 the surface layers contains the highest level of DTPA-Mn as compared to sub-surface layers which might be due to decrease in soil pH increased the solubility of DTPA-Mn (Singh *et al.*,2019). DTPA-Cu content ranged from 0.41 to 0.66mg kg^{-1} in P1, 0.54 to 0.89mg kg^{-1} in P2, 0.21 to 0. 68 mg kg^{-1} in P3 and 0.23 to 0.4mg kg^{-1}. The highest concentration (0.89mg kg^{-1}) of DTPA-Cu was observed in the surface horizon of all the profiles. Similar observations was also recorded by Punekar *et al.* (2017), Athokpam *et al.* (2018) and Kuchanwar *et al.* (2023). The content of DTPA-Zn ranged from 0.59 to 1.70 mg kg^{-1} in P1, 0.69 to 1.90 mg kg^{-1} in P2, 0.85 to 2.00 mg kg^{-1} in P3 and 0.78 to 2.10 mg kg^{-1} in P4. Considering the critical limit as 0.6 mg kg^{-1} as suggested by Takkar and Mann (1975) majority of the soils falls under deficient, marginal and sufficient categories. The concentration of DTPA-Zn was found to be decreasing down the depth with little variation. Similar findings was also reported by Athokpam *et al.* (2016) and Athokpam *et al.* (2018).

Table 5: Chemical properties of soils of Kamrup district

Horizon	Depth (cm)	O.C (%)	pH (1:2.5)	EC (1:2.5) dsm^{-1}	Exchangeable bases				Exch. acidity	CEC	BS (%)	Fe_d (%)	Al_d (%)
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}					
					cmol(p^+) kg^{-1}								
P1													
A	0-10	0.67	4.66	0.016	0.84	0.21	0.06	0.12	2.1	8.2	14.9	1.22	0.76
Bw1	10-50	0.50	4.82	0.015	0.60	0.33	0.09	0.11	1.8	8.5	13.7	1.18	0.74
Bw2	50-105	0.32	5.09	0.014	0.48	0.36	0.05	0.12	1.5	9.5	10.6	1.16	0.76
Bw3	105-145	0.29	5.10	0.011	0.42	0.34	0.07	0.09	1.4	7.8	11.7	1.09	0.78
BC	145-180	0.15	5.20	0.010	0.41	0.20	0.09	0.10	1.3	7.7	10.5	1.10	0.82
C	180-205	0.13	5.40	0.010	0.36	0.22	0.07	0.10	1.2	5.2	14.5	1.08	0.85
P2													
A1	0-5	0.81	5.05	0.024	0.88	0.45	0.06	0.15	2.2	11.5	13.4	1.37	0.83
A2	5-15	0.69	5.14	0.023	0.64	0.55	0.12	0.14	1.8	10.6	13.6	1.33	0.82
AC	15-45	0.51	5.19	0.022	0.56	0.21	0.09	0.12	1.6	8.2	11.9	1.22	0.79
C1	45-90	0.48	5.12	0.021	0.36	0.24	0.08	0.12	1.5	7.9	10.1	1.10	0.72
C2	90-145	0.34	5.23	0.018	0.87	0.57	0.09	0.09	1.3	9.5	17.1	1.04	0.80
C3	145+	0.22	5.25	0.016	0.92	0.54	0.10	0.06	1.2	7.0	23.0	0.96	0.84
P3													
A	0-5	0.71	4.42	0.032	0.84	0.55	0.05	0.15	2.3	15.1	10.5	1.64	0.71
Bw1	5-15	0.55	4.44	0.021	0.70	0.35	0.06	0.13	1.9	11.1	11.7	1.50	0.69
Bw2	15-50	0.33	4.53	0.043	0.66	0.32	0.06	0.11	1.7	11.0	10.4	1.17	0.69
Bw3	50-95	0.57	4.43	0.024	0.88	0.51	0.04	0.13	2.2	10.5	14.8	1.28	0.68

Table 5: Chemical properties of soils of Kamrup district (Continued)

Horizon	Depth (cm)	O.C (%)	pH (1:2.5)	EC (1:2.5)dsm^{-1}	Exchangeable bases				Exch. acidity	CEC	BS (%)	Fe_d (%)	Al_d (%)
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}					
					cmol(p^+) kg^{-1}								
Bw4	95-170	0.48	4.41	0.014	0.90	0.58	0.05	0.12	2.5	9.4	17.5	1.11	0.68
P4													
A	0-5	0.89	5.32	0.022	0.80	0.56	0.05	0.13	0.8	15.3	10.0	1.31	0.94
Bw1	5-20	0.79	5.47	0.021	0.64	0.39	0.05	0.12	0.7	11.5	10.4	1.19	0.71
Bw2	20-45	0.61	5.70	0.034	0.77	0.34	0.06	0.11	0.6	10.8	11.8	1.23	0.68
Bw3	45-100	0.58	5.92	0.053	0.88	0.66	0.04	0.10	0.5	15.5	10.8	1.47	0.90
BC	100-165+	0.63	5.83	0.058	0.82	0.69	0.04	0.08	0.4	9.0	18.1	1.41	0.98

Table 6: Profile distribution of available macronutrients and micronutrients in soils of Kamrup district

Horizon	Depth (cm)	Avail. N	Avail. P_2O_5	Avail. K_2O	DTPA-Fe	DTPA-Mn	DTPA-Zn	DTPA-Cu
		kg/ha			mg/kg			
P1								
A	0-10	112.9	30.5	104.1	17.9	20.5	1.70	0.66
Bw1	10-50	87.8	29.4	93.8	15.5	16.5	0.96	0.54
Bw2	50-105	90.5	25.5	103.5	10.5	25.5	0.86	0.51
Bw3	105-145	45.5	18.5	74.4	5.5	24.5	0.89	0.41
BC	145-180	27.5	16.7	91.3	3.6	13.5	0.78	0.63
C	180-205	12.5	13.5	88.7	2.9	12.5	0.59	0.62
P2								
A1	0-5	168.5	28.5	132.0	16.2	24.5	1.90	0.89
A2	5-15	100.0	23.4	119.0	14.5	21.5	1.12	0.88
AC	15-45	87.0	19.5	101.0	9.9	18.5	0.86	0.76
C1	45-90	75.2	16.4	102.7	6.2	16.6	0.91	0.78
C2	90-145	46.5	12.5	78.2	8.9	14.3	0.75	0.64
C3	145-180	25.0	11.5	49.8	9.4	12.5	0.69	0.54
P3								
A	0-5	135.0	20.5	131.0	19.41	27.4	2.00	0.68
Bw1	5-15	125.4	13.5	113.0	17.5	26.5	1.80	0.55
Bw2	15-50	62.7	9.6	98.0	10.5	24.5	0.85	0.24
Bw3	50-95	55.9	12.5	110.0	4.8	23.5	0.87	0.23
Bw4	95-170	44.5	11.5	101.0	3.6	20.5	0.85	0.21
P4								
A	0-5	163.0	30.3	112.0	20.0	25.5	2.10	0.40
AB	5-20	145.5	25.5	106.0	14.0	22.4	1.80	0.25
Bw1	20-45	112.8	20.5	97.5	7.3	21.5	0.84	0.25
Bw2	45-100	87.8	18.5	86.8	4.0	18.5	0.86	0.24
Bw3	100-165+	88.3	21.5	74.3	2.4	14.3	0.78	0.23

Table 7: Correlation coefficient (r) between different soil properties

	Clay	pH	OC	CEC	N	P	K	Ca	Mg
Clay									
pH	-0.187								
OC	0.432^{*}	0.008							
CEC	0.546^{**}	-0.001	0.691^{**}						
N	0.309	0.003	0.899^{**}	0.681^{**}					
P	-0.020	0.199	0.628^{**}	0.266	0.712^{**}				
K	0.232	-0.437^{*}	0.638^{**}	0.512^{*}	0.693^{**}	0.398			
Ca	0.476^{*}	-0.109	0.489^{*}	0.505^{*}	0.306	0.014	0.054		
Mg	0.478^{*}	0.177	0.371	0.547^{**}	0.153	-0.054	-0.082	0.714^{**}	

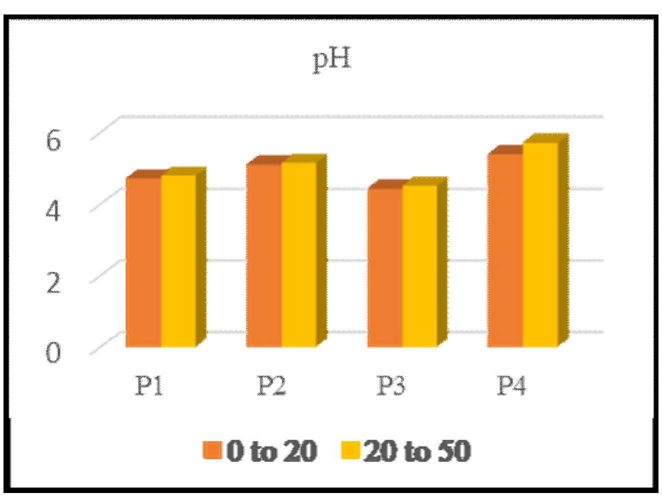

Fig. 3a: Average value of pH at 0-20 cm and 20-50cm depth

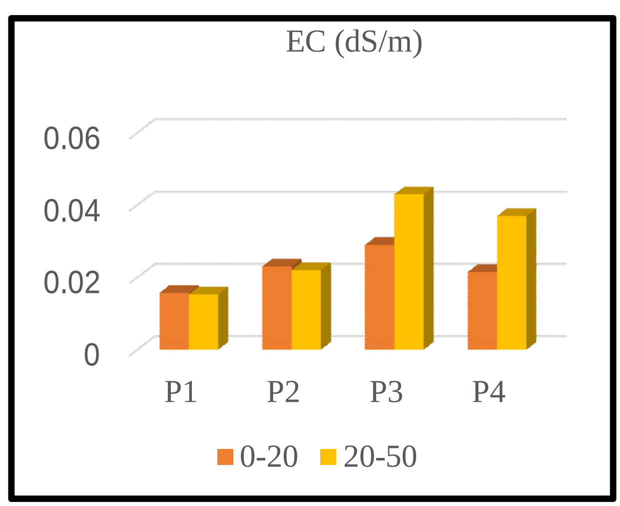

Fig. 3b: Average value of EC at 0-20 cm and 20-50cm depth

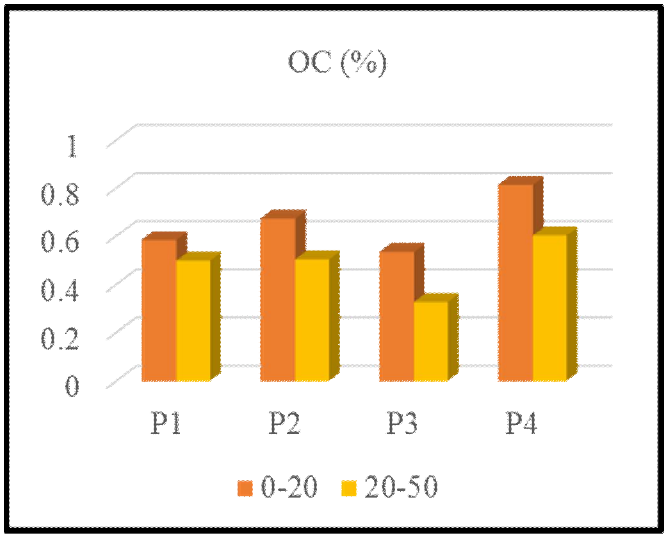

Fig. 3c: Average value of OC at 0-20cm and 20-50 cm depth

Soil Site Suitability Evaluation

Soil Site Suitability Analysis of Citrus

The parametric method revealed that the soils of Sonapur were permanently unsuitable (N2) to moderately suitable (S2), the soils of Boko were currently unsuitable (N1) to marginally suitable (S3) and the soils of Rani were found to be currently unsuitable (N1) to moderately suitable (S2) for citrus cultivation. Based on limitation approach, the soils of the studied area could be categorized as currently not suitable (N1) to moderately suitable class (S2). The unsuitable class in the study area was due to low pH. Chapman (1961) reported that ideal soil for citrus should have pH which is slightly acidic nature.

Soil Site Suitability Analysis of Coffee

The parametric method suggests that the area is permanently unsuitable to marginally suitable, falling under the N2 and S3 suitability classes. The majority of the samples falls under marginally suitable class (S3). On the basis of limitation approach the studied soils could be categorized as currently not suitable (N1) to moderately suitable class (S2). The cultivation of coffee is primarily constrained by two key factors-soil pH and base saturation. Low base saturation might be ascribed to leaching in hilly areas with heavy rainfall. Irawan *et al.* (2022) reported that base saturation and pH are intimately connected. When soil pH drops to acidic levels, the colloid adsorption complex becomes saturated with acidic cations, primarily aluminium (Al^{3+}) and hydrogen (H^{+}) ions which leads to low base saturation. This can be improved by inclusion of cover crops which will minimize the rate of leaching and low pH.

Soil Site Suitability Analysis of Tea

This index revealed that the area is moderately suitable to currently not suitable for tea cultivation, falling under the S2 and N1 suitability classes. Similar findings were also recorded by Dutta *et al.* (2022) in Tipukjan watershed of Assam. The majority of the samples of Boko and Rani falls under marginally suitable class whereas in the soils of sonapur majority of the samples of Boko and Rani falls under marginally suitable class whereas in the soils of sonapur of the samples falls under moderately suitable class. The main constraint of tea cultivation was mostly organic carbon which can be improved by applying organic mulches.

Soil Site Suitability Analysis of Rubber

The parametric method revealed that area is currently not suitable to moderately suitable for rubber cultivation, falling under the N1 and S2 suitability classes. The majority of the samples falls under marginally suitable class. Based on the limitation approach the studied soils could be categorized as currently not suitable (N1) to moderately suitable (S2) class. The major limiting factor for rubber cultivation in these areas was low pH. Rubber generally grows well in acid soils, however extreme acidic conditions are not favourable for good performance of rubber. Stunted growth condition are observed under extreme acidic conditions (Samarappuli *et al.*, 2014). Liming can help in increasing the soil pH to a favourable level.

Soil Site Suitability Analysis of Potato

Based on the limitation approach the studied soils could be categorized as currently not suitable (N1) to marginally not suitable (S3) class. The parametric method revealed that the area is permanently not suitable to marginally suitable for potato cultivation, falling under the S3 and N2 suitability classes. Similar findings were also recorded by Dharumarajan and Singh, (2014). The majority of the samples in the soils of sonapur falls under marginally suitable category whereas the soils of Boko and Rani falls under currently not suitable (N1) class. The major constraint for potato cultivation was low pH. Appropriate liming of soils can help in bringing the soil to ideal level for potato cultivation.

Soil Site Suitability Analysis of Banana

The land index revealed that the area is permanently not suitable to marginally suitable for banana cultivation. Based on the limitation approach the studied soils could be categorized as permanently not suitable (N2) to marginally suitable (S3) class. In this study the major limiting factor for banana cultivation was low pH and base saturation. Similar findings were also reported by Basumatary *et al.* (2020) in the soils of Kokrajhar district. Management practices to combat this problem includes addition of lime and improving the fertility status of soil which can be done by growing cover crops and applying organic mulches.

Soil Site Suitability Analysis of Pineapple

On the basis of limitation approach the studied soils could be currently not suitable (N1) to marginally suitable (S3). The parametric method revealed that the area is permanently not suitable to marginally suitable for pineapple cultivation, falling under the S3 and N2 suitability classes. The majority of samples falls under currently not suitable class. Similar observations were also reported by Peter *et al.* (2022) in Nigeria. The major limiting factor for pineapple cultivation in the study area was low base saturation and low organic carbon. The soils fertility can be improve by growing cover crops and by incorporation of organic manures like compost organic carbon content can be increased to an ideal level in that area.

Soil Site Suitability Analysis of Maize

The parametric method revealed that the area is permanently not suitable to currently not suitable for maize cultivation, falling under the N2 and N1 suitability classes. The major portion of the area was under permanently not suitable class. Similar findings were also reported by Ahukaemere *et al.* (2015) with soil fertility as the major constraints in south eastern, Nigeria. On the basis of limitation approach the studied soils could be permanently not suitable class (N2) to currently not suitable (N1). The major limiting factor for maize cultivation was low base saturation and in some areas both low base saturation and low pH. In order to make the soil suitable for maize cultivation proper agronomic practices should be carried out.

Soil Site Suitability Analysis of Sesame

On the basis of limitation approach the studied soils could be permanently not suitable (N2) to marginally suitable (S3) class. The parametric approach index revealed that the area is permanently not suitable to currently not suitable for maize cultivation, falling under the N2 and N1 suitability classes. The major portion of the area was under permanently not suitable class. This corroborates with the findings of Hakla *et al.* (2020) in soils of Gujarat. The major limiting factor for maize cultivation was low base saturation and in some areas low base saturation, low pH and organic carbon which was not ideal for sesame cultivation. Appropriate agronomic practices should be applied to make the soils suitable for sesame cultivation.

Soil Site Suitability Analysis of Turmeric

The land index revealed that the area is marginally suitable to currently not suitable for turmeric cultivation, falling under the S3 and N1 suitability classes. The majority of area was under marginally suitable classes. This corroborates with the findings of Ingle *et al.* (2019) in Madhya Pradesh. The major limiting factor for turmeric cultivation was slope. Appropriate engineering measures should be applied to make soil suitable for turmeric cultivation.

Conclusion

The soil resource data generated in the present study could be well utilized for crop planning as well as management of citrus growing soils of Kamrup district, Assam. The studied soils were classified as Inceptisols (Sonapur and Rani) and Entisols (Boko). These soils showed different degrees of suitability for growing citrus and other crops like tea, coffee, rubber, maize, potato, turmeric, sesame and currently not suitable for pineapple due to very severe limitation of low base saturation. Future line of research for development of soil based agro techniques is important to make marginal soils suitable for citrus and other commercial crops in Assam.

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Author contributions

The corresponding author and each writing team member actively contributed to the research, data processing, discussion, and preparation of the paper collectively and were responsible for its contents.

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