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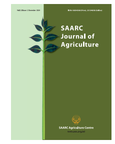

Research Article

Physico-Chemical Properties and Fertility Status of Forest Soils under AEZ-29 (Northern and Eastern Hills) of Bangladesh

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Abstract

Soil properties influence land management practices and differ in regions with diverse topography and ecological variations. An experiment was conducted at the Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh with 16 soil samples collected at 0-15 cm depth from various hilly forest locations of three districts of AEZ-29 (Northern and Eastern Hills) covering 12 series to assess their physical, chemical and fertility properties. Most of the soils were sandy loam in texture, strongly acidic to very strongly acidic (pH 4.23-5.46) and non-saline. The cation exchange capacity (CEC) was very low to medium with an average of 7.31 $cmol_c\ kg^{-1}$ and organic matter (OM) status was medium with mean of 2.62%. The soils had very low to low levels (0.07-0.16%) of total nitrogen (N) and available phosphorus (P) content (1.29-10.9 mg kg^{-1}) but low to medium level (10.33-22.51 mg kg^{-1}) of available sulphur (S). Besides, very low to very high levels of exchangeable potassium (K), calcium (Ca) and magnesium (Mg) with averages of 0.34, 3.10 and 1.64 $cmol_c\ kg^{-1}$, respectively, were observed. The status of available iron (Fe) and manganese (Mn) in all the soils were very high ranging from 20-108 and 24-217 mg kg^{-1}, respectively. The soils showed medium or low to very high levels of available zinc (Zn), copper (Cu) and boron (B) with averages of 2.64, 0.74 and 0.61 mg kg^{-1}, respectively. The variations in physico-chemical and fertility properties of these soils might be due to variation in parent material, land uses and soil erosion. Among different soil series, Sitakundu showed the maximum values of pH, CEC, OM, total N, exchangeable K, Ca and Mg and available B. Although some of the hill soils seemed to be inherently fertile, proper fertilizer management especially for macronutrients, liming and erosion control practices are crucial for agricultural crop production.

Keywords: Physico-chemical properties, Dupi tila, Tipam, Available nutrients

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Introduction

Bangladesh is the largest deltaic plain having a unique geographic position. Its landscape is remarkably diverse, formed by sediments ranging in age from recent to tertiary. The soils of Bangladesh derive from various parent materials, distributed across three main physiographic units: Northern and Eastern hills (12% of the area), Pleistocene terraces (8% of the area), and Recent floodplains (80% of the area) (Islam et al., 2017; Huq and Shoaib, 2013). Depending on their formation and appearance, these soils are categorized into 21 general classes (Moslehuddin et al., 1997), where fourteen soil types are found in floodplain areas, six in terraces, and one in hilly areas. Based on physiography, soils, inundation regimes and agro-climatology, thirty agro-ecological zones (AEZs) have been recognized in Bangladesh (FRG, 2018). Each AEZ refers to an area characterized by identical agricultural and ecological properties; these similarities are more pronounced at the sub-region and subunit levels. The present study area namely Northern and Eastern Hills in Bangladesh represents the 29th among 30 agroecological zones, encompassing the hilly areas. It spans about 12% of the land area and occupies about 18,171 km² (FRG, 2018). This region includes Chittagong Hill Tracts, Khagrachhari, Bandarban, Cox's Bazar, and small areas along the northern border of the Sherpur, Sunamganj, Mymensingh, and Sylhet districts. The Northern and Eastern Hills of Bangladesh feature a complex relief with steep slopes and rolling terrain in some areas. The landscape consists of high hills above 150-1,000 m mean sea level (MSL) with steep slopes and low hills below 150 m with steep to rolling topography (FRG, 2018). High hills are prone to landslides during heavy monsoon rains. Both high and low hills have strongly acidic and sandy soils.

Soil formation in Bangladesh varies due to its geological position which is at the junction of Indian, Burmese, and Eurasian plates (Chowdhury et al., 2021). The country is predominantly covered in alluvium, with Tertiary deposits found in the north, east, and southeastern parts of the Sylhet district, as well as the folded side of Chittagong and Chittagong hill tracts (Roy et al., 2012). The geology of Bangladesh is an integral part of the geology of the Bengal Basin. Tertiary hill sediments in the northern and eastern hills are one of the major geological formations in Bangladesh soils (Brammer, 1996) which comprise mainly the unconsolidated and little consolidated beds of sandstones, siltstones, shales, and some conglomerates. In the higher ranges of the Chittagong and Sylhet hill areas, the rocks are mainly formed from the Surma and Tipam formations in the late Oligocene to mid-Miocene period, and the lower hill ranges predominantly contain rocks from the Dupi Tila formation between the mid-Miocene to Pliocene periods (Huq and Shoaib, 2013). Tipam formation is a lithostratigraphic unit in the Bengal Basin consisting of shales and siltstones, varying in consolidation, with some regions containing calcareous materials and Dupi Tila is the primary aquifer of this Bengal Basin consisting of sandstones, siltstones, and shale layers (Huq and Shoaib, 2013).

The predominant soil type found in the Northern and Eastern Hills is brown hill soil. This soil typically exhibits a yellow-brown to dark brown coloration and is characterized by its permeability, loamy texture, and high acidity levels. Brown hill soil also tends to have low moisture retention capacity, limited organic matter content, and relatively low fertility levels (Hossain et al., 2014). Soil properties of hills (physical, chemical and biological) are influenced by factors like altitude, water availability, temperature (Huq and Shoaib, 2013), topography (Akhtaruzzaman et al., 2014) and land use systems (García-Oliva et al., 1994). Land use systems cause losses in soil organic carbon (SOC), nutrients, groundwater reduction, soil structure changes, and reduction in biological elements (Al Mamun et al., 2021). In hilly regions (especially in the Chittagong Hill Tracts) and undulated areas of Bangladesh, land degradation is common due to heavy rainfall, soil erosion, and deforestation (Nath et al., 2005). This causes sedimentation, flooding, and interruptions in water storage, which are increased by the hydrological regime (NN, 2001). Hill soils are acidic due to increased topography, which facilitates basic cations removal through leaching and runoff processes, resulting in gradual acidification in forest hills (Brammer, 1971). Soil acidification decreases pH and increases micronutrient concentrations. The bioavailability and toxicity of excess amounts of micronutrients are significantly influenced by their forms (Gauthier, 2002). Acid forest soils often have high levels of soluble iron, manganese and aluminum, leading to increased plant uptake and root damage (Akhtaruzzaman et al., 2014). Land physiography and slope gradients also influence surface runoff and soil erosion in these areas (Akhtaruzzaman et al., 2014) leading to macronutrient loss, including phosphorus, nitrogen, potassium, and trace elements, which impact soil fertility (Biswas et al., 2010; Rasul and Thapa, 2007; Gafur et al., 2003). Besides, river-borne sediment from hills reduces the fertility of cultivable land (Islam et al., 2006). Deforestation, land degradation and soil erosion hamper sustainable hill farming in Bangladesh (Biswas et al., 2012). Jhum cultivation and other practices also have significantly degraded the soil in the Chittagong Hill Tracts (Biswas et al., 2012) which impacts both agricultural lands and natural forests, and results in rapid depletion of resources. Therefore, urgent action is needed from planners and policymakers to protect hill soil based on its use and properties.

In Bangladesh, agriculture accounts for approximately 11.38% of Gross Domestic Product (GDP) (BBS, 2023) which is not sufficient for the increasing population that grows at 2.5% annually. Limited land resources in the country have led to land conversion for agriculture, horticulture, and other uses (Hassan, 1994). Over time, vegetation and soil properties have changed due to climate fluctuations, soil erosion, and human activities including deforestation, land degradation, and pollution. Soil quality for agriculture depends on elements like nutrient content, proper fertilizer use, and management practices. People working with soil must understand the physical, chemical, and nutritional aspects of a soil and assess its suitability for agricultural or structural purposes (Foth, 1990). Previous studies have focused on the growth performance of planted species and planting techniques in hilly areas, neglecting the importance of soil characteristics in improving and maintaining soil resources (Akhtaruzzaman et al., 2014). Studies on soil characteristics particularly physicochemical properties and fertility status will provide basic information for better resource management in hilly forest regions. Therefore, the present study was conducted to evaluate the physical and chemical properties of soils in the Northern and Eastern Hill regions (AEZ 29) and to assess the fertility status for offering recommendations for improved agricultural practices at the farmer level.

Materials and Methods

Site Selection

The sites were selected that covered hill soils from Northern and Eastern Hills (AEZ 29) comprising 12 series *viz*. Rangamati, Salbon, Barkal, Khadimnagar, Nolua, Sitakundu, Dhum, Ghagra, Tamabil, Bijipur, Suvolong and Datmara. The sites covered three districts namely Chattogram, Bandarban and Cox's Bazar, four upazilas *viz.* Lohagora, Chokoria, Satkania and Bandarban Sadar and seven villages i.e. Borohatia, Chunti, Mekhla, Sualok, Badarkhali, Nilachal and Bajalia. The selected sites are shown in Figure 1. The experimental sites comprised of high lands, medium high lands, high hills, medium high hills, low hills and valleys. There were some constraints for crop production in these forest areas such as steeply slope, acidity, soil erosion and wild animal attack etc. The basic information regarding soil series, administrative units, geographical locations, land types, land uses and soil formation of the studied areas are enlisted in Table 1.

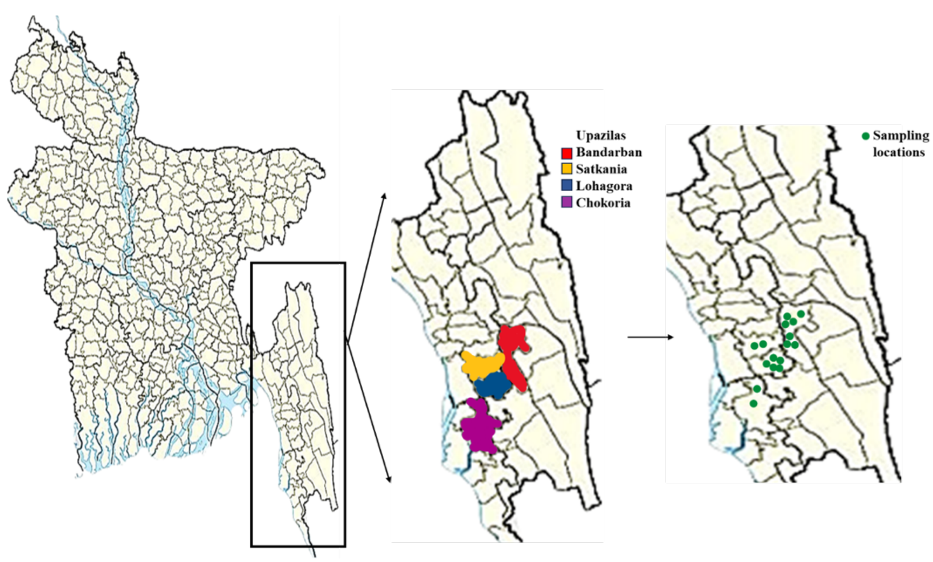

Fig. 1. Map showing the soil sampling locations

Table 1. Some basic information of soil samples collected from AEZ 29 under study

Soil series	Administrative units	Geographical locations	Land types (Topography)	Land uses	Soil formation
Rangamati	Village: Borohatia Upazila: Lohagora District: Chattogram	21° 59' 21" 92° 02' 52"	HL	Natural forest	Dupi-Tila
Salbon-1	Village: Borohatia Upazila: Lohagora District: Chattogram	21° 58' 45" 92° 02' 10"	HL (Terrace)	Plantation Forest	Dupi-Tila
Salbon-2	Village: Chunti Upazila: Chokoria District: Cox's Bazar	21° 55' 53" 92° 03' 38"	LH	Natural forest	Dupi-Tila
Barkal	Village: Mekhla Upazila: Bandarban Sadar District: Bandarban	22° 11' 43" 92° 11' 48"	HH	Natural forest	Tipam
Khadimnagar-1	Village: Borohatia Upazila: Lohagora District: Chattogram	22° 01' 96" 92° 05' 37"	LH	Plantation Forest	Dupi-Tila
Khadimnagar -2	Village: Sualok Upazila: Bandarban Sadar District: Bandarban	22° 40' 47" 92° 16' 11"	LH	Teak forest elevation: 190 Ft	Dupi-Tila
Nolua-1	Village: Badarkhali Upazila: Chokoria, District: Cox's Bazar	21° 56' 15" 92° 03' 50"	LH	Natural forest	Dupi-Tila
Nolua-2	Village: Sualok Upazila: Bandarban Sadar District: Bandarban	22° 09' 39" 92° 10' 34"	LH	Teak forest elevation: 170 ft	Dupi-Tila
Sitakundu	Village: Nilachal Upazila: Bandarban Sadar District: Bandarban	22°17' 13" 92° 21' 63"	MHH	Natural forest	Tipam
Dhum	Village: Mekhla Upazila: Bandarban Sadar District: Bandarban	22° 10' 55" 92° 11' 49"	MHH	Plantation Forest	Tipum
Ghagra	Village: Mekhla Upazila: Bandarban Sadar District: Bandarban	22° 10' 43" 92° 11' 46"	MHH	Natural forest	Tipam
Tamabil-1	Village: Borohatia Upazila: Lohagora District: Chattogram	21° 58' 51" 92° 01' 56"	MHH	Natural forest	Tipam

Soil series	Administrative units	Geographical locations	Land types (Topography)	Land uses	Soil formation
Tamabil-2	Village: Sualok Upazila: Bandarban Sadar District: Bandarban	22° 09' 44" 92° 10' 38"	MHH	Natural forest	Tipam
Bijipur	Village: Bajalia Upazila: Satkania District: Chattogram	22° 08' 05" 92° 09' 42"	Valley	Boro-Fallow-T. Aman	Piedmont
Suvolong	Village: Borohatia Upazila: Lohagora District: Chattogram	21° 58' 46" 92° 02' 06"	LH	Plantation Forest	Dupi-Tila
Datmara	Village: Bajalia Upazila: Satkania District: Chattogram	22° 12' 96" 92° 16' 46"	LH	Unestablished Farm	Dupi-Tila (Very shallow soil)

MHL: Medium High Land; LH: Low Hill; MHH: Medium High Hill; HH: High Hill; HL: High Land

Soil Sample Collection and Preparation

A total of sixteen composite samples were collected from AEZ 29 to represent hill forest soils with multiple uses. Ten of the sixteen samples were collected from natural forest areas and four samples were taken from plantation forest areas and forest tree species like teak, garjan, acacia, mahogany, gamhar etc. occupy the lands. On the other hand, one sample was collected from a valley where rice cultivation is recently practiced (yield is very low) in a small area, and the remaining one sample was taken from an unestablished farm (used for nursery purpose to grow fruit crops) in a forest area. Two composite samples were collected from each of the four series *viz.* Salbon, Khadimnagar, Nolua, and Tamabil. For each of the remaining series, one composite sample was collected as representative. For all the cases, the sampling depth ranged from 0 to 15 cm. The soil samples were brought to the laboratory of the Department of Soil Science, Bangladesh Agricultural University for physical and chemical analysis. At first the samples were air-dried at room temperature, crushed, thoroughly mixed, sieved through a 20-mesh sieve, and then stored in plastic bags for subsequent analysis.

Physical and Chemical Properties Determination

The particle size of the soils was analyzed by hydrometer method (Bouyoucos, 1962) using 10 mL of 5% Calgon solution as a dispersing agent. The hydrometer readings were taken at 40 seconds and 2 hours of sedimentation. The pH of the soils was determined electrochemically with a glass-electrode pH meter in a soil suspension with a soil-water ratio of 1:2.5 after 30 minutes of shaking (Jackson, 1973). The electrical conductivity (EC) of soil samples was measured with a conductivity meter (Hardie and Doyle, 2012) by maintaining a soil-water ratio of 1:5 after 30 min of shaking followed by resting for 1 hour. Cation exchange capacity of the studied soils was determined by sodium saturation method (Chapman, 1965) where Na^+ ions were replaced by 1 N NH_4OAc using a centrifuge machine and then the concentration of Na^+ ions in the solution was measured by a flame photometer.

Fertility Properties Determination

Organic Matter (OM)

Soil organic carbon (SOC) content was assessed by wet oxidation method (Walkley and Black, 1934) using an excess amount of 1 N $K_2Cr_2O_7$. The remaining $K_2Cr_2O_7$ solution was titrated with 1 N $FeSO_4$ to determine SOC. The organic matter content was calculated by multiplying % organic carbon with the van Bemmelen factor, 1.73.

Macronutrients

The semi-Micro-Kjeldhal method was used to determine the total N content of soil (Bremner and Mulvaney, 1982). Available phosphorus (P) was extracted from the soils using Bray No 1 solution as an extractant (Bray and Kurtz, 1945) and then the concentration was colorimetrically measured. Available S was determined by using $CaC1_2$ solution (0.15%) as an extractant (Williams and Steinbergs, 1959) and the S content was estimated turbidimetrically with a spectrophotometer. Exchangeable potassium (K), calcium (Ca) and magnesium (Mg) were determined by ammonium acetate extraction method using a flame photometer (Knudsen et al., 1982; Kooch et al., 2017).

Micronutrients

Available Fe, Mn, Zn and Cu were determined by DTPA extraction followed by determination by an atomic absorption spectrophotometer as described by Lindsay and Norvell (1978). Available B was extracted by hot water 0.02 M $CaCl_2$ solution (1:2 ratio) followed by determination by a spectrophotometer using azomethine-H method (Keren, 1996).

Statistical Analysis

The soil analysis data were statistically evaluated using mean and standard error employing the Statistix 10 package program and Pearson's correlation coefficient matrix was estimated with statistical package R.

Results and Discussion

Physical and Chemical Properties

Soil is a heterogeneous system and many characteristics differentiate one soil from another. The study of physico-chemical properties of soils aids in management of resources while working with a certain type of soil (Balasubramanian, 2017). The soil texture plays an important role in the development of vegetation and nutrient cycling. It influences the supply of air, water, and essential nutrients required for root growth (Robertson, and Vituosik, 1981). Among the 16 soil samples, 11 were categorized as sandy loam, 2 as silt loam, and 3 as loam in texture (Table 2). Most locations had sandy loam as the predominant texture including Rangamati, Salbon (1 and 2), Khadimnagar (1 and 2), Nolua-1, Sitakundu, Tamabil-1, Bijipur, Suvolong, and Datmara. Meanwhile, Barkal and Dhum soils were identified as silt loam, and Nolua-2, Ghagra, and Tamabil-2 soils were characterized as loam in texture. That means, the soil texture of the hill soils varied among sandy loam, loam, and silt loam, with the majority (68%) of soil samples exhibiting a sandy loam texture. A significant portion of these soils contained higher sand content compared to silt and clay. According to Brammer (1971), sand is the dominant particle in hill soils and they are developed from sandstone parent materials. Sandy loam soils typically have good drainage and aeration, which can benefit root development. However, water runoff and erosion are major concerns in these soils.

In AEZ 29, The pH values of the studied soils ranged from 4.23 to 5.46, indicating that all the soils were acidic (Table 2). The highest pH value (5.46) was observed in the Sitakundu soil, while the lowest pH (4.23) was recorded in the Ghagra soil. On average, the pH of the sixteen soils was 4.73. Most of the soils were strongly acidic in reaction except Khadimnagar-1 and Ghagra soils which were very strongly acidic in reaction. Hassan et al. (2017) stated that the mean pH of high and medium hill soils is strongly acidic, while the mean pH of low hill soils is very strongly acidic. The source of this acidity is attributed to both the inherent acidity of the parent rocks like granite and granite gneiss (silica-saturated igneous and metamorphic rocks) (Dhumgond et al., 2012) and intensive leaching of basic elements like Ca and Mg. Generally, hill soils are unfavorable for crop production (BARC, 2012). To improve crop production in these acidic soils, amendment of liming materials in soil is essential for farmers. Liming materials change the pH, correct the negative effects of acid cations, and improve soil fertility (Reddy and Subramanian, 2016). The EC of the AEZ 29 soils ranged from 0.04 to 0.21 dS m^{-1} (Table 2). Ghagra soil had the highest EC (0.21 dS m^{-1}) and Salbon-1 had the lowest EC (0.04 dS m^{-1}). The average EC of the selected soils was 0.07 dS m^{-1}. The soils analyzed in this study were non-saline because the soluble salts were leached out from the soil (Rao, 1992). The CEC of the soils studied ranged between 3.85 and 12.60 $cmol_c$ kg^{-1} (Table 2). Sitakundu had the highest CEC (12.60 $cmol_c$ kg^{-1}), while Tamabil-2 had the lowest (3.85 $cmol_c$ kg^{-1}). On average, the CEC of the soils was 7.31 $cmol_c$ kg^{-1}. Some soils showed medium CEC (Tamabil-1, Dhum, Sitakundu, Nolua 1 and 2, Barkal and Salbon-2), while others had low (Rangamati, Salbon-1, Khadimnagar-2, Ghagra, Bijipur, Suvolong and Datmara) or very low (Tamabil-2 and Khadimnagar-1) CEC. The variation in CEC may be linked to factors such as soil texture, clay mineral composition, organic matter accumulation, and erosion levels (Shoji et al., 1982). In this study, the relatively low CEC values can be attributed to the sandy texture of the soils, primarily composed of kaolinite (Akhtaruzzaman et al., 2014; Alam et al., 1993).

Fertility Properties

Bangladesh soils typically have low organic matter content, with most soils having less than 1.5% at 0-15 cm depth (BARC, 2005). Based on organic matter content, agricultural soils are classified into very low, low, medium, high, and very high categories (Osman, 2013). In Northern and Eastern Hill soils, organic matter content ranged from 1.71 to 5.10% (Table 2). The highest organic matter content (5.10%) was found in Sitakundu, and the lowest content (1.71%) was recorded in Rangamati, Salbon-1, and Suvolong series. The average organic matter content was 2.62%. Sitakundu and Dhum had high organic matter status, while the rest of the soils showed medium level of organic matter (FRG, 2018). Sitakundu soils had the highest status of organic matter, followed by Dhum soils, which could be due to natural forest and forest plantation in areas where the soils have a higher cation exchange capacity than other soils. Most hill soils in developing countries are not fertilized, and the nutrient demands of trees are met primarily through nutrient recycling (Hassan et al., 2017).

Table 2. Particle size distribution, textural classes, pH, EC, CEC and organic matter status of the soils under study

Soil series	Particle size			Textural class	pH	EC ($dS\ m^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	OM (%)
	Sand (%)	Silt (%)	Clay (%)					
Rangamati	58.96	27.28	13.76	Sandy Loam	4.60	0.06	7.12	1.71
Salbon-1	72.96	17.28	9.76	Sandy Loam	4.73	0.04	5.51	1.71
Salban-2	58.96	31.28	9.76	Sandy Loam	4.63	0.07	6.79	3.39
Barkal	30.24	53.28	16.48	Silt Loam	4.54	0.07	8.72	3.44
Khadimnagar-1	72.96	15.28	11.76	Sandy Loam	4.45	0.05	1.99	1.87
Khadimnagar-2	72.24	19.28	8.48	Sandy Loam	4.63	0.05	7.44	2.40
Nolua-1	66.96	23.28	9.76	Sandy Loam	4.90	0.08	8.39	2.97
Nolua-2	34.24	49.28	16.48	Loam	4.74	0.04	4.23	2.49
Sitakundu	60.24	31.28	8.48	Sandy Loam	5.46	0.11	12.6	5.10
Dhum	32.24	51.28	16.48	Silt Loam	4.72	0.09	11.6	3.79
Ghagra	36.24	41.28	22.48	Loam	4.23	0.21	6.47	3.09
Tamabil-1	58.96	31.28	9.76	Sandy Loam	4.98	0.07	8.72	2.28
Tamabil-2	44.24	43.28	12.48	Loam	4.99	0.07	3.85	1.79
Bijipur	62.24	31.28	6.48	Sandy Loam	4.81	0.05	8.72	2.35
Suvolong	54.96	35.28	9.76	Sandy Loam	4.67	0.08	8.39	1.71
Datmara	60.24	25.28	14.48	Sandy Loam	4.66	0.06	6.47	1.87
Average	-	-	-	-	4.73	0.07	7.31	2.62
SE (±)	-	-	-	-	0.06	0.01	0.09	0.04

Data are means of three replicates

In AEZ 29, the total N ranged from 0.07 to 0.16% with an average of 0.11% (Figure 2a). The lowest total N (0.07%) was found in Rangamati and Khadimnagar-1 soils, while the highest N content (0.16%) was observed in Sitakundu, Nolua-1, Ghagra, and Dhum soils. In terms of soil test interpretation, Rangamati, Salbon-1, Khadimnagar (1 and 2), Tamabil-2, Suvolong, and Datmara series had very low levels of total N. On the other hand, Salbon-2, Barkal, Nolua (1 and 2), Sitakundu, Dhum, Ghagra, Tamabil-1, and Bijipur soils had low levels of total N (FRG, 2018). Normally soils with low organic matter contain low N. The amount of available P in the studied soils varied from 1.29 to 10.9 mg kg^{-1} (Figure 2b). The lowest P (1.29 mg kg^{-1}) was recorded in Tamabil-1 soil, and the highest P (10.9 mg kg^{-1}) was noted in Dhum soil. On average, there was 5.39 mg kg^{-1} of available P in AEZ 29. Based on soil test value interpretation, the soil available P status was grouped as very low (Salbon 1 and 2, Nolua-1, Tamabil-1, and Suvolong), low (Rangamati, Barkal, Khadimnagar 1 and 2, Nolua-2, Tamabil-2, Bijipur, and Ghagra), and medium (Sitakundu, Dhum, and Datmara) (FRG, 2018). In the terrace and hilly areas of Bangladesh, acidic soils lack available P. This is because P easily binds with Fe and Al in acidic soils, despite applying additional P (Moslehuddin et al., 1997). Notably, lower pH levels can enhance the availability of metallic ions, particularly Mn, Fe and Al, which can combine with soluble P to form insoluble compounds (Lalljee, 1997). Moreover, the limited microbiological activities in strongly acidic soils can further reduce the availability of soil P (Havlin et al., 1999). Exchangeable K content ranged from 0.16 to 0.99 cmol$_c$ kg^{-1} (Figure 2c). The highest exchangeable K (0.99 cmol$_c$ kg^{-1}) was found in Sitakundu soil, while the lowest exchangeable K content (0.16 cmol$_c$ kg^{-1}) was observed in Nolua-2, Bijipur, and Suvolong soils. The average exchangeable K content for AEZ 29 was 0.34 cmol$_c$ kg^{-1}. Sitakundu and Ghagra soils had a very high level of exchangeable K, while Dhum and Tamabil-2 soils exhibited a high level. Khadimnagar-2, Barkal, Tamabil-1, and Salbon-2 soils had an optimum level of exchangeable K, and Nolua-1 and Datmara soils had a medium level. The remaining soil samples in AEZ 29 showed a low level of exchangeable K. Soil available S content ranged from 10.33 to 22.51 mg kg^{-1} (Figure 2d), with Rangamati having the highest (22.51 mg kg^{-1}) and Ghagra the lowest (10.28 mg kg^{-1}). The average S content was 16.28 mg kg^{-1}. Rangamati, Khadimnagar-1, and Sitakundu soils had a medium S level, while others had low S levels. Low availability of S in the hill soils might be attributed to the sandy texture and leaching loss of sulphate ions from the soils. Exchangeable Ca in the soils ranged from 0.78 to 9.42 cmol$_c$ kg^{-1} (Figure 2e). Sitakundu soil had the highest (9.42 cmol$_c$ kg^{-1}), and Rangamati had the lowest (0.78 cmol$_c$ kg^{-1}) exchangeable Ca. The average was 3.10 cmol$_c$ kg^{-1}. Sitakundu soil showed very high Ca levels, Barkal, Nolua (1 and 2), Tamabil (1 and 2), and Salban-2 had medium Ca levels, while Salbon-1, Dhum, Ghagra, Suvolong, Datmara, and Khadimnagar-2 had low Ca levels. Rangamati, Bijipur, and Khadimnagar-1 had very low Ca levels. The exchangeable Mg content in the collected soils ranged from 0.58 to 3.83 $cmol_c\ kg^{-1}$ (Figure 2f). Sitakundu soil had the highest exchangeable Mg, while Khadimnagar-1 soil had the lowest. The average exchangeable Mg content was 1.64 $cmol_c\ kg^{-1}$. In terms of soil test value interpretation, Sitakundu, Salbon-2, Barkal, Nolua-2, and Tamabil (1 and 2) soils showed a very high level of exchangeable Mg. Nolua-1, Dhum, Ghagra, Datmara, and Suvolong had a high status, while Salbon-1 had an optimum status of exchangeable Mg. Rangamati, Bijipur, and Khadimnagar (1 and 2) soil series exhibited low exchangeable Mg content. According to Akhtaruzzaman et al. (2014), higher topography enhances the removal of base cations (K, Ca, Mg) through leaching and runoff processes that cause forest hill soils to become gradually acidified.

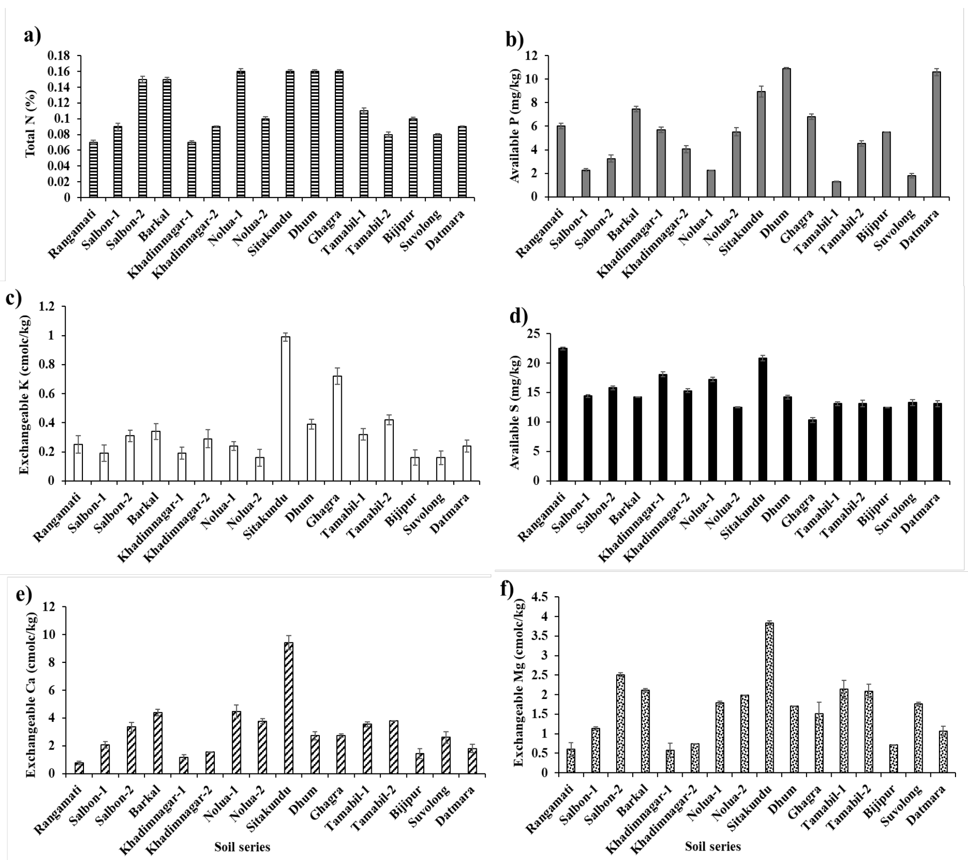

Fig. 2. Macronutrient contents in selected soils of AEZ 29. The status of total N (a), available P (b), exchangeable K (c), available S (d), exchangeable Ca (e), and Mg (f) of 16 soil series at 0-15 cm depth.

The hill soils of Bangladesh are slight to very strongly acid, rich in Fe and Mn and deficient in some macro and micronutrients (Gafur, 2014). The available Fe content of the collected soils varied from 20 to 108 mg kg^{-1} (Figure 3a), with Dhum soil having the highest (108 mg kg^{-1}) and Barkal soil having the lowest (20 mg kg^{-1}) status. The average available Fe content was 67.19 mg kg^{-1} in the hill soils. Based on soil test value interpretation, all the soil samples showed very high level of available Fe. The available Mn content in the studied soils ranged from 24 to 217 mg kg^{-1} (Figure 3b). Barkal soil had the highest (217 mg kg^{-1}) available Mn, while Rangamati and Bijipur soils had the lowest (24 mg kg^{-1}) available Mn. In AEZ 29, the average available Mn content was 79.56 mg kg^{-1}. In terms of soil test value interpretation, all the soil samples exhibited a very high level of available Mn. The higher concentrations of Fe and Mn, are possibly due to parent materials and predominant soil-forming processes prevailing under existing environmental conditions (He, 1990). The available Zn content in the collected soils ranged from 1.09 to 5.07 mg kg^{-1} (Figure 3c). Tamabil-2 soil had the highest (5.07 mg kg^{-1}) available Zn, while Nolua-2 soil had the lowest (1.09 mg kg^{-1}) available Zn. The average available Zn content was 2.64 mg kg^{-1}. Based on soil test value interpretation, Khadimnagar-1, Salbon-2, Nolua-1, Bijipur, Sitakundu, Ghagra, Dhum, Barkal, and Tamabil-2 soils exhibited a very high level of available Zn. Suvolong, Khadimnagar-2, and Datmara had a high Zn level. Rangamati and Tamabil-1 soils showed an optimum Zn level, while Salbon-1 and Nolua-2 had a low level of available Zn. Again, the available Cu content in the collected soils ranged from 0.22 to 1.22 mg kg^{-1} (Figure 3d). Salbon-2 soil had the highest (1.22 mg kg^{-1}) available Cu, while Rangamati soil had the lowest (0.22 mg kg^{-1}) available Cu. The average available Cu content was 0.74 mg kg^{-1}. In terms of soil test value interpretation, Suvolong, Salbon-2, Nolua (1 and 2), Bijipur, Ghagra, Barkal, and Tamabil-2 soils displayed a very high level of available Cu. Khadimnagar-1 had high level, and Sitakundu, Dhum, Tamabil-1, and Datmara had optimum level of available Cu. Rangamati, Salbon-1, and Khadimnagar-2 soils had low status of available Cu. Hassan et al. (2017) reported that mean Zn content is very low for high and medium hill soils and low for low hill soils, while mean Cu content is low for both high and low hill soils but very low for medium hill soils. Cu is scavenged most efficiently by Fe-Mn oxide minerals, clay minerals, and coatings, and it is less mobile than other microelements (Sanaullah and Akhtaruzzaman, 2020). The amount of Zn in soil is mainly determined by the type of rocks and minerals in the parent material of soil (Lindsay, 1979). Research by Kabata-Pendias and Pendias (1952) noted that sandy soils tend to have lower Zn content. The available B status of the collected soils varied from 0.28 to 0.99 mg kg^{-1} (Figure 3e). The highest available B (0.99 mg kg^{-1}) was recorded in Sitakundu soil and the lowest (0.28 mg kg^{-1}) was found in Nolua-2. The mean value of available B in the studied soils was 0.61 mg kg^{-1}. Kadimnagar-1, Salbon-2, Nolua-1, Bijipur, Sitakundu, and Datmara soils showed very high B level whereas Rangamati, Barkal, and Khadimnagar-2 had high B content. Again, Salbon-1, Tamabil-1, and Dhum had optimum B level, while Ghagra, Suvolong, and Tamabil-2 had medium B content. Nolua-2 soil showed low status of available B (FRG, 2018). Here more than 80% soil samples showed a very high level of B which might be due to the low soil pH.

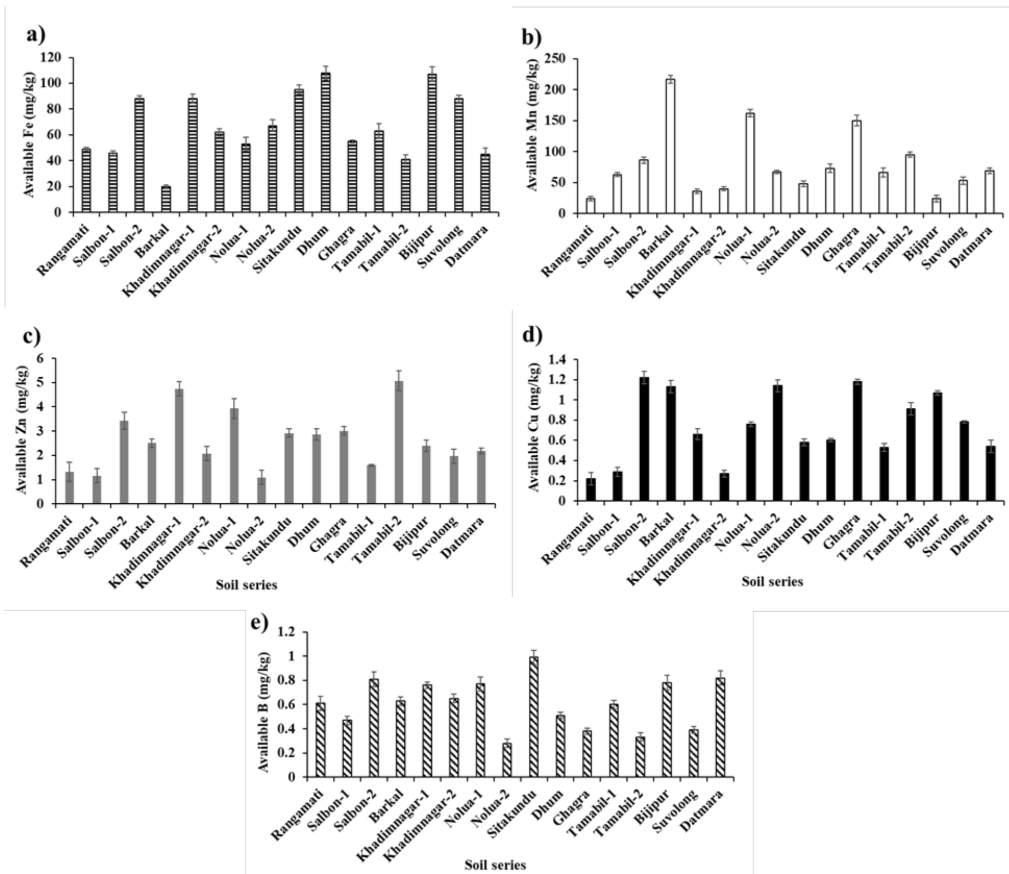

Fig. 3. Micronutrient contents in selected soils of AEZ 29. The status of available Fe (a), Mn (b), Zn (c), Cu (d), and B (e) of 16 soil series at 0-15 cm depth.

Correlation Among Different Properties of Soils

Pearson's correlation coefficient revealed positive and negative correlations among different physical, chemical and fertility properties of soils (Figure 4). There was positive significant correlation among 24 associations and negative significant correlation among 7 associations. Organic matter had positive significant correlation with total N, exchangeable K, Ca, Mg and CEC. CEC was significantly correlated with Ca and Total N. Clay content (%) showed a significant positive correlation with EC and silt (%) but had a negative significant relation with pH and sand (%). Soil pH showed significant positive association with exchangeable Ca and Mg. Total N had a significant positive association with exchangeable K, Ca, Mg, Mn and EC. Exchangeable Ca and Mg both showed significant positive relationship with exchangeable K. Exchangeable K had significant positive relation with EC. Available B showed significant positive relation with available S and sand%. Available Mn showed significant positive relation with Cu but significant negative relation with available Fe. Sand (%) showed significant negative association with silt (%), clay (%) as well as available Mn and Cu.

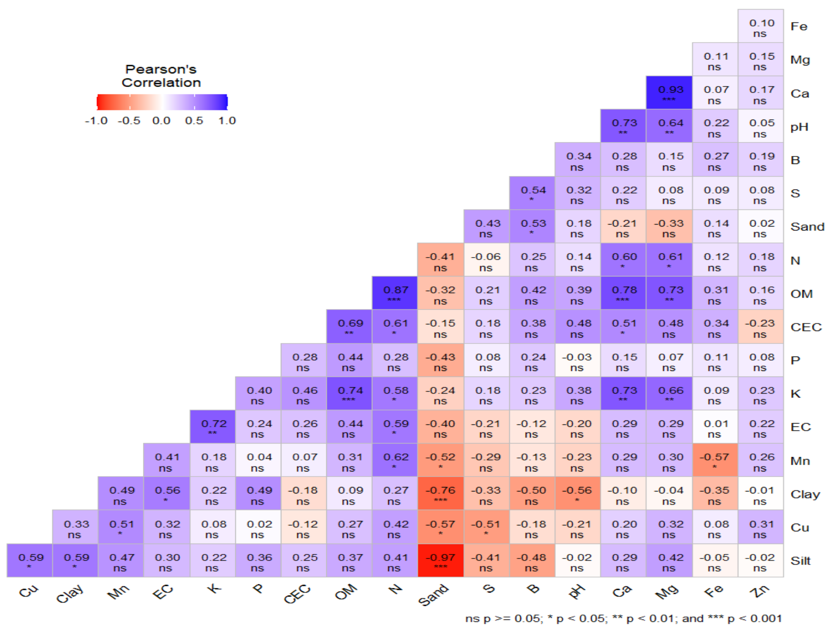

Fig. 4. Estimation of Pearson's correlation coefficients among different properties of hill soils

These findings shed light on the complex relationships among various physicochemical and fertility properties of the studied soils. Sitakundu and Dhum series have the most fertile soils in this region, with higher organic matter content and better nutrient retention. Proper fertilization and management can make this region suitable for crop production. The overall poor status of essential macronutrient elements in all series, such as total N, available P, exchangeable K, and available S, can be attributed to several factors including the low soil pH, sandy texture, soil erosion, run off and leaching of nutrient elements from soil as well as land degradation. A long-term fertility management program by using both organic sources of nutrients such as poultry manure, cow dung, green manure, household wastes, rice straw and other crop residues and inorganic fertilizers may improve soil health and ensure the sustainability of crop production in the studied areas to some extent.

Conclusion

The soils of AEZ 29 were generally poor in physico-chemical properties such as texture, pH, organic matter, CEC, as well as fertility status, making crop production difficult in this region. The use of lime is mandatory for better crop production and combat soil acidity in the hilly areas of AEZ 29. The soils of this region had low to medium CEC and OM, low levels of total N and available P, and low to medium levels of available S. Exchangeable K, Ca and Mg levels of this soil varied widely from very low to very high. These hill forest soils showed high levels of Fe and Mn, and moderate to high levels of Zn, Cu and B. Overall, some management practices are crucial for agricultural productivity such as erosion control, organic matter addition and precise fertilization for macronutrients etc. Besides, soil test values must be confirmed with crop response studies, and soils should be tested regularly to assess their suitability for crop production. Furthermore, new agricultural technologies and policies should be established with information on resource management in hilly areas that might be useful in facing the challenges of crop production and in preventing soil degradation.

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Competing Interest

The authors declare no competing interest

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