JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 10, Number 3 (April 2023):4405-4415, doi:10.15243/jdmlm.2023.103.4405
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Distribution of soil morphology and physicochemical properties to assess the evaluation of soil fertility status using soil fertility capability classification in North Galela, Indonesia

Tri Mulya Hartati[1*], Bambang Hendro Sunarminto[2], Sri Nuryani Hidayah Utami[2], Benito Heru Purwanto[2], Makruf Nurudin[2], Krishna Aji[1]

[1] Department of Soil Science Faculty of Agriculture, Universitas Khairun Ternate 97719, Indonesia
[2] Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

[*]corresponding author: trimulyahartati@gmail.com

Article history:
Received 1 November 2022
Accepted 3 January 2023
Published 1 April 2023

Keywords:
K deficiency
land productivity
slope
soil depth
soil fertility capability classification

Abstract

One of the indicators of land productivity assessment is soil fertility. The causes of infertile soil have been widely reported. This study aimed to evaluate soil fertility using the Soil Fertility Capability Classification (SFCC) approach and to determine the relationship between soil morphological and physiochemical properties and soil fertility. The research was conducted in North Galela Sub-district, North Halmahera Regency. The research framework began with the interpretation of thematic maps, surveys, field observations, and the making of soil fertility evaluation maps. Soil sampling was carried out based on the stratified random sampling method and supported by laboratory measurements according to USDA international standards. The research result showed that the research area had 14 soil fertility statuses. The fertility classes having the most significant limiting factor were loamy texture (Ø<0.002 mm), rock surface, gravel subsoil, moderate salinity (0.2-0.4 mS cm^{-1}), low exchangeable K (<20 $cmol_{(+)}$ kg^{-1}), and sloping slope (8%) with Lithic Haprendolls type and loamy texture (Ø<0.002 mm), subsoil >15% rock outcrop, moderate salinity (0.2-0,4 mS cm^{-1}), Na saturation >15%, and a rather steep slope (14%) with Lithic Eutrudepts type. Both of these classes have a top layer texture, and the bottom layer contains clay <35%, with limiting factors of hard layer inhibiting root to a depth of 50 cm, extremely low nutrient reserve, low electrical conductivity (EC) and high Na. The limiting factors found in North Galela Sub-district were hard root-restricting layer, exchangeable K, electrical conductivity, Na saturation, slope, and gravel.

To cite this article: Hartati, T.M., Sunarminto, B.H., Utami, S.H.N., Purwanto, B.H., Nurudin, M. and Aji, K. 2023. Distribution of soil morphology and physicochemical properties to assess the evaluation of soil fertility status using soil fertility capability classification in North Galela, Indonesia. Journal of Degraded and Mining Lands Management 10(3):4405-4415, doi:10.15243/jdmlm.2023.103.4405.

Introduction

The decline in soil fertility level will be a major challenge to sustainable land management (Tobi et al., 2013). Land degradation is one of the factors that affect the decline in soil fertility. This situation can disrupt the condition of ecosystem stability, and as a result, biomass productivity will decrease (Aji et al., 2020). Furthermore, the insufficient input of materials and the lack of management efforts are also affecting the decline in soil fertility (St. Clair and Lynch, 2011). Faye and Braun (2022) reported that monocropping soil management could decrease soil productivity. The monocropping system on peanuts for a long time can remove nutrients from the soil and trigger pest and disease attacks. In addition, climate change factors also affect soil fertility and health, indicated by increased temperature, drought, salinity, and increased rainfall (Mondal, 2021). Muluneh (2020) stated that climate change projections in the African region would reduce maize productivity by around 9% over the two periods of 2021-2050 and 2066-2095. On the other hand, the decline in soil fertility threatens agricultural production in most developing countries (Sanchez, 2002a). Soil conditions in the tropics are considered important for further study by the international community as an effort to provide policies for food security, poverty alleviation, land degradation, and service provision (Sanchez, 2002b).

Research on soil fertility status is one of the efforts to prevent land degradation in the long term and provide suggestions for sustainable land management. Evaluation of soil fertility status can be performed using the FCC method. The fertility capability classification system (FCC) is a technical soil classification system that quantitatively focuses on soil's physical and chemical properties (Tobi et al., 2013). According to Sanchez et al. (2003), based on quantitative topsoil attributes and soil taxonomy, the soil fertility capability classification (FCC) system is the starting point for synthesizing soil quality for the tropics. The concept of the Soil Fertility Capability Classification (SFCC) system was developed to facilitate understanding between the subdisciplines of soil classification and soil fertility, especially to examine soil taxonomy and additional soil attributes in a way that is directly relevant to plants (Geissen et al., 2009; Adhikary et al., 2010). Assessment of soil fertility status is an important step for better plant nutrient management. By mapping soil properties, the accuracy of site-specific production systems can be increased to integrate land resources and plant needs at any time and place (Syam, 2010).

This research was conducted in the Galela area, North Halmahera Regency. The research area has a unique landscape. This area has received attention for the development of plantation crops with a development pattern focusing on people's nucleus plantations (Local Government of North Halmahera, 2012). Some of the commodities produced in Galela are coconut, cloves, cocoa, and nutmeg. Plantations in this area are generally still cultivated by the community, not in the form of large-scale plantations (Hartati et al., 2017). The low productivity is due to the fact that not all available land is suitable for certain plantation commodities. As a result, each of the resulting products is not optimal. The annual average productivity of coconut, cocoa, cloves, and nutmeg in 2013 was 0.29 t ha^{-1}, 0.79 t ha^{-1}, 0.29 t ha^{-1}, and 0.64 t ha^{-1}, respectively. Meanwhile, the temporal national productivity of coconut, cocoa, cloves, and nutmeg is 1.16 t ha^{-1}, 0.82 t ha^{-1}, 0.30 t ha^{-1}, and 0.30 t ha^{-1}, respectively (Directorate General of Estate Crops, 2015). The community tends to manage their land in a traditional way, which triggers a decline in soil fertility. Thus, the assessment of soil fertility status is necessary to be studied to provide sustainable land management planning.

This study aimed to determine the distribution of soil fertility status in North Galela Sub-district, Halmahera, North Maluku.

Materials and Methods

Study area

The study was conducted in the Galela area, North Halmahera Regency, which is located between North Latitude of 01014'20"- 02011'58" and East Longitude of 127043'24"-12804'05", with a total area of 63,479 ha (Figure 1) and administratively covers four sub-districts, namely North Galela, South Galela, Galela, and West Galela. Geomorphologically, the research area is a structural hill composed of intrusive and sedimentary rocks that have changed shape (deformed) by tectonic forces, forming folds, faults, domes, or other structures resulting in mountain reliefs occupying elevations of <300 m asl. The Galela region has a rainfall of 2,500-3,000 mm $year^{-1}$ and an average temperature of 26.1 °C. The geology in the research area comprises reef limestone (reef limestone, Nepal, and sandy limestone), alluvium (gravel, sand, mud and boulders, step deposits), Holocene volcanic rock (andesite lava and breccia, and basalt lava), tuff rock, Togawa formation (tuffaceous sandstone and conglomerate of andesite and basal components), and Weda formations (sandstone, claystone, siltstone, marl, limestone, and conglomerate).

Soil sampling and design

Stratified random sampling was used for soil sampling based on different slope classes (0-8%, 8-15%, and 15-25%). Soil samples were taken from the soil depth of 0-20 cm and 20-50 cm. There were 17 SMUs divided into four, consisting of 4 SMUs in the North Galela Sub-district, 5 SMUs in the West Galela Sub-district, 5 SMUs in the Galela Sub-district, and 3 SMUs in the South Galela Sub-district. Thematic maps were made, including the 1:50,000 scale administrative map, 1:50,000 scale soil type map, 1:50,000 scale slope map, and 1:50,000 scale land use map. The assessment of soil fertility status was based on the SFCC method (Sanchez et al., 2003). Grouping was then made based on soil fertility constraints and assessed using SFCC. The SFCC assessment consists of three categories: topsoil texture, subsoil texture, and modifiers. The estimation of soil properties was then interpreted and determined as an alternative basis for soil management technology.

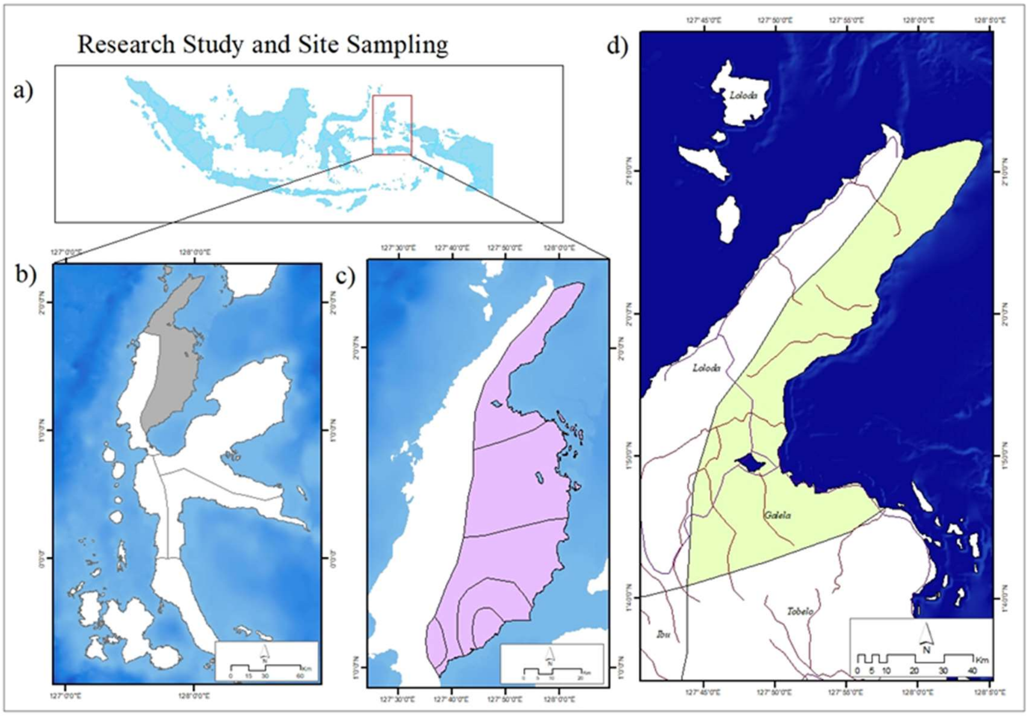

Figure 1. Study area. a) Indonesia map; b) North Halmahera Regency map; c) North Halmahera Sub-districts map; d) Galela Sub-district map.

Fieldwork and laboratory measurements

The soil sampling method used the standard USDA Field Book procedures for Describing and Sampling Soils (Schoeneberger et al., 2012) that consisted of landscape and soil profile observations. The observed variables were divided into two, namely landform conditions and soil morphological characteristics. Landform observations include landforms, slopes, geological formations, parent materials, areas prone to erosion and flooding, surface rocks, and land use. Meanwhile, the morphological characteristic conditions observed were soil depth, soil texture, soil color, soil structure, soil consistency (moist and wet conditions), plants root, and pH H_2O in the field. Quantitative observations that included the analysis of the physicochemical properties of the soil were measured using standard methods of laboratory procedures (van Reeuwijk, 2002) presented in Table 2.

Results

Seventeen soil morphological properties observed were different. Based on the identification results in the field, the soil types in the study area were classified as Mollisols, Inceptisols, Entisols, Alfisols, and Ultisols. Generally, soil thickness >100 cm comes from volcanic material that has not been weathered or has not weathered at mild to advanced intensity. Soil thickness <100 cm, with the presence of C and R horizons, indicates lithological discontinuity. Soil profiles of TR 2, TR 5, TR 11, and TR 15 show shallow soil solum. This means that land development is relatively limited. Soils with relatively shallow solum are very easily degraded (Aji et al., 2020; Rofita et al., 2021). Furthermore, soil texture is an indicator of the level of soil development. The soil profile of TR 9 is dominated by clay texture, indicating advanced soil development supported by the presence of a fairly thick Bt horizon in the subsoil layer (Table 1). Some soil profiles have an early stage of development. The presence of a Bw horizon indicates a weak horizon change, meaning that the level of soil development is still early. The difference is seen in the material that has not been weathered, which has a loose soil structure with fresh volcanic ash. Meanwhile, the gradually changed color shows that volcanic ash is starting to decompose, which was also formed due to the period of deposition of volcanic material in the past. The profiles of TR 1, TR 2, TR 4, TR 6, TR 8, and TR 9 show gradual A-A/B-Bw-C horizonization (Figure 2).

The physical and chemical properties of the soil are used as indicators to determine soil fertility level. Soil sampling at depths of 0-20 cm and 20-50 cm is assumed to show the ability of the soil to support plant growth. The distribution of soil texture at the study site varied. Soil profiles that develop in the early stages generally have a low clay percentage (<30%), while soil profiles developing at an advanced stage have a higher clay percentage (>30%), such as TR 6 and TR 9 profiles (Table 2). In addition, soil texture affects the

BD value. BD value indicates the soil density level. The BD values of the soil profiles TR 7, TR 12, and TR 17 in the subsoil layer showed a high value (>1.2 g cm^{-3}) compared to those of the topsoil layer. The process of soil compaction is accompanied by soil development indicated by changes in soil texture. Soil texture in the subsoil layer of the TR 17 soil profile is dominated by high clay content (>30%). Meanwhile, the soil profile dominated by coarse and balanced fractions has a low BD value because it has not undergone an advanced pedogenesis process, so the illuviation process has not occurred intensively in the subsoil layer. The BD value also affected soil porosity. There was no significant difference between BD value and soil porosity, so the availability of macro and micro pores was relatively balanced. A low BD value indicates that the soil is easy to manage. According to Hartati (2018), the ideal soil porosity is between 40-58%. The distribution of soil pH H_2O tends to be neutral (>6), while the soil pH in the soil profile TR 9 tends to be slightly acidic (<6) (Table 2). The decrease in soil pH occurred due to the differentiation of a further developed horizon (Horizon A-Bt-BC1-BC2). The organic C content of TR 4, TR 6, TR 7, TR 9, TR 10, TR 11, TR 12, TR 13, and TR 14 experienced a significant decrease (1.6-3.4%) (Table 2). Organic C affects the organic matter content of the soil. Organic matter in soil profiles TR 5 and TR 15 was the highest (Table 2). The addition of fresh volcanic material supports the productivity of biomass and lots of perishable plant litter, which accelerates the increase in soil organic matter.

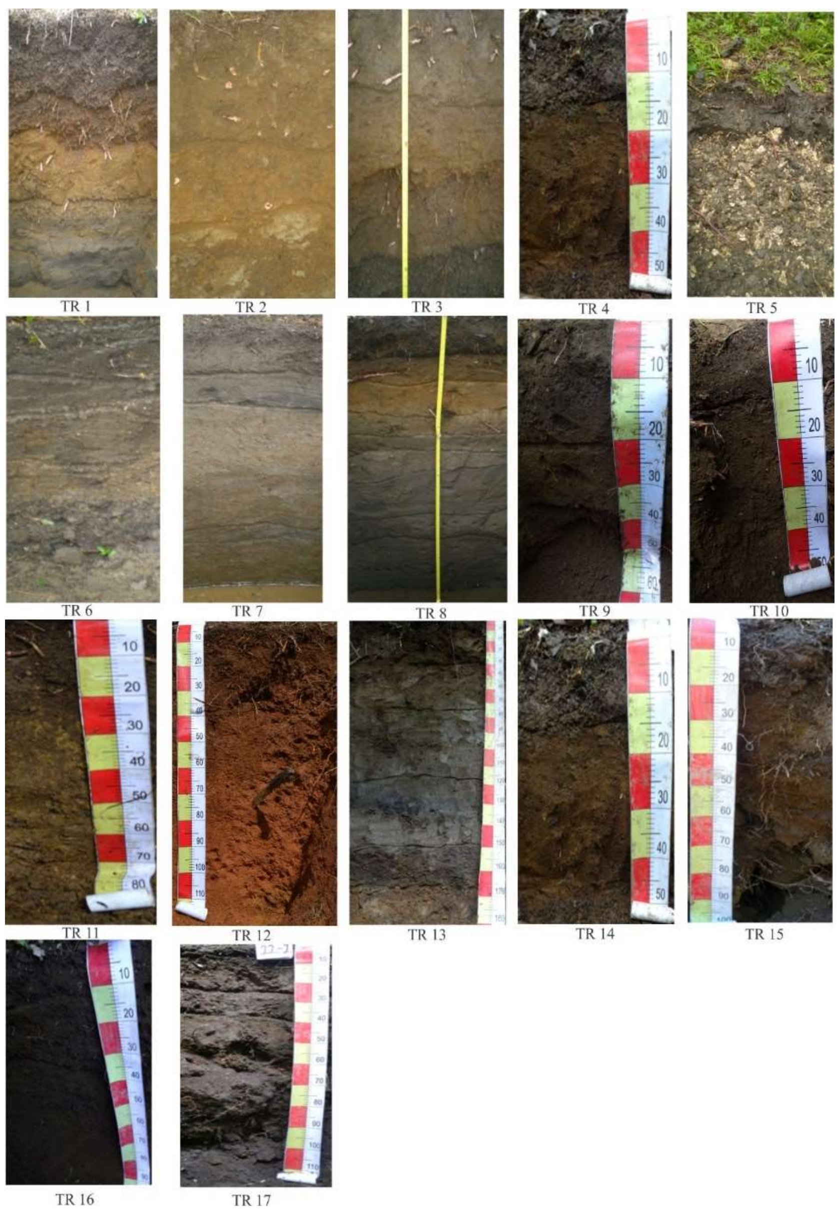

Figure 2. Soil profiles.

Table 1. Morphological properties of the soil.

Sample Code	Horizon	Depth (cm)	Texture	Color	Structure	Consistency		Root	pH H_2O	Soil Classification (Sub Order)
						Moist	Wet			
TR 1	A	0 – 27	Loamy Sand	10YR 2/2	Granular	Loose	Slightly Sticky	Many	6.3	Typic Eutrudepts
	A/B	27 – 48	Loamy Sand	10YR 3/3	Granular	Loose	Slightly Sticky	Many	6.8	
	Bw	48 – 68	Loamy Sand	10YR 3/6	Granular	Loose	Slightly Sticky	Medium	6.9	
	C	68 -158	Loamy Sand	10 YR 3/2	Granular	Loose	Slightly Sticky	Few	7.0	
	$2A_1$	158 – 176	Clay Loam	10YR 3/2	Angular Blocky	Loose	Slightly Sticky	-	7.1	
	$2A_2$	176 – 200	Loamy Sand	7.5YR 3/4	Granular	Loose	Slightly Sticky	-	7.0	
TR 2	A	0 – 20	Loamy Sand	10YR 2/2	Granular	Soft	Slightly Sticky	Many	6.7	Lithic Udorthents
	Bw	20 – 30	Loamy Sand	10YR 3/4	Granular	Hard	Slightly Sticky	Medium	6.9	
TR 3	A	0 – 23	Loamy Sand	10YR 2/2	Granular	Loose	Slightly Sticky	Many	6.8	Typic Udorthents
	Bw_1	23 – 38	Loamy Sand	10YR 3/3	Granular	Moderate Hard	Slightly Sticky	Medium	6.9	
	Bw_2	38 – 66	Sand	10YR 3/4	Granular	Loose	Non-Sticky	Few	6.8	
	C	66 – 100	Sand	-						
TR 4	A	0 – 22	Loamy Sand	10YR 2/1	Granular	Loose	Slightly Sticky	Many	6.8	Typic Humudepts
	Bw	22 – 31	Loamy Sand	10YR 4/6	Granular	Loose	Slightly Sticky	Medium	7.0	
	B/C	31 – 39	Loamy Sand	10YR 6/6	Granular	Loose	Slightly Sticky	Few	7.0	
	C1	39 – 59	Silty Loam	10YR 5/2	Granular	Loose	Non-Sticky	Few	7.0	
	C2	59 – 81	Silty Loam	10YR 5/1	Granular	Loose	Non-Sticky	-	7.0	
	R	81 – 138	Loamy Sand	10YR 5/1	Granular	Loose	Non-Sticky	-	-	
TR 5	A	0 -18	Loam	10YR2/1	Subangular Blocky	Hard	Sticky	Many	7	Lithic Haprendolls
	A/C	18 – 25	Clay Loam	10YR2/2	Angular Blocky	Hard	Sticky	Medium	7.9	
TR 6	A	0 – 27	Clay	10YR 2/1	Angular Blocky	Hard	Sticky	Many	6.5	Typic Hapludolls
	A/B	27 – 41	Clay	10YR 3/2	Angular Blocky	Hard	Sticky	Few	6.7	
	Bw	41 – 65	Sandy Clay Loam	10YR 4/3	Angular Blocky	Hard	Slightly Sticky	Few	6.4	
	B/C	65 – 83	Loamy Sand	2.5Y 4/3	Granular	Moderate Hard	Sticky	Few	6.5	
TR 7	A	0 – 12	Loam	10YR 2/1	Subangular Blocky	Moderate Hard	Sticky	Medium	7.0	Typic Endoaquents
	A/C	12 – 25	Silty Loam	10YR 2/1	Angular Blocky	Loose	Slightly Sticky	Few	6.8	
	Cg	25 – 81	Loamy Sand	2.5YR 3/2	Granular	Moderate Hard	Slightly Sticky	Few	7.0	
	2Cg	86 – 120	Silty Loam	2.5Y 5/4	Granular	Moderate Hard	Slightly Sticky	Few	7.3	
TR 8	A	0 – 27	Loamy Sand	10YR 2/2	Granular	Loose	Slightly Sticky	Many	6.3	Typic Eutrudepts
	A/B	27 – 39	Loamy Sand	10YR 3/3	Granular	Loose	Slightly Sticky	Many	6.5	
	Bw	39 – 58	Loamy Sand	10YR 4/4	Granular	Loose	Slightly Sticky	Medium	6.5	
	C	58 – 67	Loamy Sand	2.5Y 4/2	Granular	Loose	Non-Sticky	Few	6.6	
	IA_b	67 – 83	Loamy Sand	10YR 3/2	Granular	Loose	Slightly Sticky	-	6.5	
	IBw_b	83 – 95	Silty Loam	7.5YR 3/4	Granular	Loose	Slightly Sticky	-	6.5	
	IC	95 – 125	Loamy Sand	5Y3/2	Granular	Loose	Slightly Sticky	-	6.5	
	IIC	125 -146	Silty Loam	5Y 3/2	Granular	Loose	Slightly Sticky	-	6.5	
	R	146 -200	Loamy Sand	5Y 3/1	Granular	-	-	-	-	

Sample Code	Horizon	Depth (cm)	Texture	Color	Structure	Consistency		Root	pH H_2O	Soil Classification (Sub Order)
						Moist	Wet			
TR 9	A	0-20	Clay	7.5YR 3/4	Angular Blocky	Loose	Slightly Sticky	Many	5.2	Typic Kandiudults
	Bt	20-55	Clay	5YR 3/4	Angular Blocky	Hard	Sticky	Medium	5.3	
	BC1	55-110	Clay	5YR 5/8	Angular Blocky	Hard	Sticky	Few	5.4	
	BC2	110-130	Clay	2.5YR 4/8	Angular Blocky	Hard	Slightly Sticky	Few	5.2	
	BC3	130-160	Sandy Clay Loam	7.5Y 6/8	Angular Blocky	Moderate Hard	Sticky	-	5.0	
TR 10	A	0-2	Sandy Clay Loam	7.5 YR 3/4	Angular Blocky	Loose	Slightly Sticky	Many	6.5	Typic Hapludolls
	Bw	12-82	Sandy Clay Loam	7.5 YR 4/4	Angular Blocky	Moderate Hard	Sticky	Medium	6.9	
	B/C	82-110	Loam	7.5 YR 3/2	Angular Blocky	Moderate Hard	Sticky	Few	7.1	
	C/R	110-135	Sandy Clay Loam	-	-	-	-	-	-	
TR 11	A	0-25	Sandy Clay Loam	10YR 3/2	Angular Blocky	Loose	Slightly Sticky	Many	6.1	Typic Hapludolls
	Bw	25-65	Loamy Sand	10YR 4/4	Granular	Loose	Slightly Sticky	Few	6.3	
TR 12	A	0-20	Loamy Sand	10YR 3/3	Granular	Loose	Slightly Sticky	Few	6.2	Typic Hapludolls
	Bw	20-50	Loamy Sand	10YR 4/4	Granular	Loose	Slightly Sticky	Few	6.2	
	B/C	50-100	Sand	10YR 5/6	Granular	Loose	Non-Sticky	-	6.0	
TR 13	Ao	0-20	Loamy Sand	10YR 2/2	Granular	Loose	Slightly Sticky	Many	6.8	Typic Eutrudepts
	A/B	20-45	Loamy Sand	10YR 4/4	Granular	Loose	Slightly Sticky	Many	6.8	
TR 13	Bw	45-75	Loamy Sand	10YR 4/6	Granular	Moderate Hard	Slightly Sticky	Few	6.6	Typic Eutrudepts
	BC1	75-120	Loam	10YR 5/3	Granular	Loose	Non-Sticky	Few	6.4	
	BC2	120-150	Loamy Sand	10YR 5/2	Granular	Loose	Non-Sticky	-	6.4	
TR 14	A	0-15	Sandy Clay Loam	7.5 YR 2.5/2	Angular Blocky	Loose	Sticky	Medium	6.0	Typic Eutrudepts
	A/B	15-60	Clay Loam	7.5YR 4/6	Angular Blocky	Moderate Hard	Sticky	Few	6.4	
	Bw	60-100	Loamy Sand	7.5 YR 5/8	Granular	Hard	Non-Sticky	-	6.2	
TR 15	A	0-35	Loamy Sand	7.5 YR 3/1	Granular	Loose	Slightly Sticky	Many	6.8	Lithic Hapludolls
	Bw	35-55	Loamy Sand	7.5YR 3/3	Granular	Loose	Non-Sticky	Medium	7.2	
TR 16	A	0-15	Loam	10YR 1/1	Subangular Blocky	Loose	Sticky	Many	6.9	Typic Eutrudepts
	AB	15-45	Loam	10YR 2/2	Subangular Blocky	Loose	Sticky	Many	6.9	
	Bw	45-145	Loam	10YR 3/3	Subangular Blocky	Loose	Sticky	Few	7.1	
	C/R	145-180	-	-	-	-	-	-	-	
TR 17	Ao	0-5	Silty Loam	10YR 1/1	Granular	Loose	Non-Sticky	Many	6.4	Typic Eutrudepts
	A	5-25	Loamy Sand	10YR 5/2	Granular	Loose	Non-Sticky	Many	6.2	
	Bw1	25-40	Silty Loam	10YR 6/2	Granular	Loose	Non-Sticky	Few	6.0	
	Bw2	40-90	Sandy Clay Loam	10YR 4/6	Angular Blocky	Loose	Slightly Sticky	Few	6.2	

Table 2. Soil physicochemical properties.

Sample Code	Particle Distribution (%)			BD ($g\ cm^{-3}$)	PD ($g\ cm^{-3}$)	n (%)	pH		SOC (%)	OM (%)	N_{tot} (%)	P_2O_5 ($mg\ 100\ g^{-1}$)	K_2O ($cmol_{(+)}\ kg^{-1}$)	EC ($mS\ cm^{-1}$)	Base Cations ($cmol_{(+)}\ kg^{-1}$)				CEC (cmol(+) kg^{-1})	BS (%)
	Sand	Silt	Clay				H_2O	NaF							Ca	Mg	K	Na		
TR 1	59	33	8	0.8	1.55	51	6.3	10.8	3.6	6.2	0.5	13.9	0.9	0.25	7.5	2,3	0.9	3.1	25.5	54
	61	30	9	0.9	1.66	48	6.8	10.7	2.8	4.8	0.2	10.0	1.7	0.10	5.7	2.1	1.6	3.9	18.5	72
TR 2	56	29	15	1.0	1.63	40	6.7	10.4	3.4	5.8	0.3	14.8	1.5	0.15	7.7	2.4	1.4	3.6	23.7	64
	57	32	11	1.1	1.79	41	6.9	10.5	2.1	3.7	0.1	15.1	2.1	0,05	7.2	2.1	2.1	3.5	26.0	57
TR 3	56	39	4	1.0	2.03	49	6.8	11.3	2.7	4.6	0.20	5.6	0.4	0,05	4.4	0.6	0.3	2.3	10.8	71
	59	34	7	1.1	2.11	39	6.9	11.3	2.6	4.6	0.2	16.50	0.1	0,05	6.9	0.4	0.1	2.9	12,8	80
TR 4	53	38	9	0.9	1.87	51	6.8	10.8	4.9	8.4	0.3	9.29	0.7	0.15	4.7	1.8	0.7	3.5	20.2	53
	51	45	5	0.9	1.92	51	7.0	10.7	1.5	2.7	0.1	4.01	1.2	0.05	4.5	1.4	1.2	3.7	20,0	54
TR 5	47	29	23	0.8	1.70	52	6.7	10.2	7.8	13.4	0.3	9.9	0.1	0.2	26.7	1.4	0.1	2.7	52.4	59
	42	27	31	-	-	-	7.9	10.9	6.6	11.3	0.3	22.5	0.1	0.8	30.2	1.3	0.1	2.5	42.4	80
TR 6	22	4	73	1.2	2.03	41	6.5	9.8	3.4	5.9	0.2	38.7	1.1	0.25	22.2	4,8	1.1	3.5	31.8	99
	18	8	74	1.0	1.75	43	6.7	10.0	1.8	3.2	0.1	31.9	0.5	0.1	26.6	5,3	0.5	3.7	44.9	81
TR 7	51	40	9	1.2	2.01	41	7.0	9.61	3,1	5.4	0.3	67.8	1.4	0.55	6.3	1.2	1.2	2.0	16.0	67
	45	50	5	1.3	2,36	44	6.8	9.94	1.3	2.2	0.1	30.8	0.7	0.25	2.0	0.5	0.6	2.0	6.02	84
TR 8	53	36	11	0.9	2.15	60	6.3	-	3.2	5.5	0,09	6.7	0.8	0.06	8.2	0.8	0.8	1.5	15.9	71
	62	31	7	0.9	2.14	57	6.5	-	2.2	3.7	0.16	23.4	0.5	0.02	6.4	0.5	0.5	1.1	11.5	74
TR 9	21	17	62	1.0	1.99	52	5.2	-	3.5	6.1	0.33	24.4	0.4	0.04	2.5	0.2	0.4	0.7	14.5	26
	22	9	70	1.0	2.05	52	5.3	-	1.4	2.4	0.17	11.8	0.4	0.04	2.5	0.2	0.4	0.7	13.6	28
TR 10	50	27	22	0.9	1.95	53	6.5	-	4,3	7.5	0.37	33.4	2,5	0.32	14.7	0.9	2,4	4.1	30.6	72
	55	23	21	1.0	2.15	53	6.9	-	1.4	2.4	0.12	23.1	0.7	0.18	15.0	0.6	0.6	2.2	32.0	58
TR 11	56	24	21	1.1	1.98	45	6.1	-	4.4	7.5	0.25	10.5	0.2	0.11	16.1	1.1	0.2	1.7	34.8	55
	65	23	11	1.1	2.01	47	6.3	-	1.9	3.2	0.17	9.9	0.1	0,08	25.7	1.5	0.1	1.5	43.7	66
TR 12	56	39	5	0.9	2.02	58	6.0	8.1	4.5	7.8	0.13	31.9	1.0	0.11	7.6	0.5	0.8	0.6	13.2	72
	54	44	2	1.3	2.18	35	6.5	8.3	2.9	5.1	0.26	10.9	0.4	0,03	3.5	0.4	0.3	0.6	10.0	59
TR 13	53	43	4	0.9	1.64	48	5.9	-	3.6	6.1	0.11	76.3	1.4	0.46	5.4	0.6	1.4	2.2	15.6	62
	70	24	6	0.9	1.79	50	6.3	-	1.5	2.5	0.12	29.1	1.9	0.08	5.5	0.6	1.8	2.2	14.6	70
TR 14	44	29	28	0.9	2.00	55	6.0	-	4,1	7.1	0,06	17.4	2,2	0.15	4.2	0.8	2.2	3.6	14.9	73
	33	27	40	1.1	1.85	42	6.4	-	1.0	1.7	0,05	18.7	3,8	0,04	3.8	0.9	3.7	3.5	13.7	86
TR 15	65	35	0	0.9	1.61	47	6.8	8.0	6,4	22.0	0.71	6.3	3,4	0.43	8.8	1.7	2.9	4.3	23.7	74
	67	28	5	0.9	2.07	57	7.2	8.3	4.1	7.0	0.40	0.3	0.8	0.15	7.7	0.4	0.6	1.3	13.7	73
TR 16	52	34	14	0.9	2.15	58	6.9	7.8	3.4	5.8	0.22	13.0	1.5	0.1	2.6	0.6	1.4	1.5	11.2	55
	51	36	13	1.0	1.98	52	6.9	7.9	2.1	3.6	0.18	32.4	1.4	0.08	2.7	0.5	1.3	2.5	11.9	58
TR 17	50	46	4	1.0	2.38	60	6.6	8.2	1.4	2.4	0.07	30.4	0.2	0.05	5.5	0.0	0.1	0.5	7.31	84
	15	28	70	1.3	2.46	48	6.7	8.1	0.6	1.1	0.06	41.0	0.2	0.02	2.1	0.1	0.1	0.5	4.06	68

Remarks: BD = Bulk Density, PD = Particle Density, n = Porosity, SOC = Soil Organic Carbon, OM = Organic Matter, Ntot = Total N, EC = Electrical Conductivity, CEC = Cation Exchange Capacity, BS = Base Saturation.

Essential nutrients (N, P, and K) in the soil body play important roles in providing nutrients for plants. Total N in the topsoil layer of the TR 8 soil profile is very low (<0.1%), and total N in the topsoil and subsoil layer of TR 14 and TR 17 soil profiles tend to be very low (<0.1%). Meanwhile, the total N in TR 15 tends to be high (>0.51%) in the topsoil layer. Increasing nitrogen content in the topsoil layer can come from rotting plant litter. In addition, the condition of the vegetation in the study area is dominated by forest plant species. Phosphorus (P) content varied between the study sites (Table 2). Soil developments derived from volcanic materials are likely to produce low P content (<20 mg 100 g^{-1}). P content in subsoil layers of TR 5, TR 6, and TR 7 soil profiles tend to be moderate (20-40 mg 100 g^{-1}), while P content in topsoil layers of TR 7 and TR 13 tends to be high (>60 mg 100 g^{-1}). Organic matter and pH affect the P content in the soil. The potassium (K) content in TR 5 soil profile tends to be low, while the K content in the other soil profiles tends to be high (Table 2). Salinity at the study site is relatively stable.

The content of Ca and Mg in TR 5 and TR6 soil profiles is considered very high (>20 $cmol_{(+)}$ kg^{-1}). Geological conditions affect the availability of Ca and Mg in the soil. Soil profiles of TR 5 and TR 6 are located in the Bacan (Tomb) geological formation, with breccia and lava composed of andesite and basalt, which contain high Ca and Mg. CEC values in the TR 3, TR 7, TR 8, TR 9, TR 12, TR 13, TR 14, and TR 16 soil profiles tend to be low (<16 $cmol_{(+)}$ kg^{-1}), and those in the TR 4 soil profile tend to be moderate (17-24 $cmol_{(+)}$ kg^{-1}). Meanwhile, CEC values in the TR 1, TR 2, TR 5, TR 6, TR 10, TR 11, TR 15, and TR 17 soil profiles tend to be high (24-40 $cmol_{(+)}$ kg^{-1}) to very high (>40 $cmol_{(+)}$ kg^{-1}) (Table 3). Humus, pedogenic processes, and clay mineralogy affect the CEC value of the soil. Soils developed at an early stage and derived from volcanic material produced high soil CEC values (Notohadiprawiro, 2006). Meanwhile, the BS values for the TR 9 soil profile tend to be low (<35%), while the BS values in other soil profiles tend to be very high (>50%) (Table 2). Soil development affects the BS value of the soil. The soil profile of TR 9 is classified as a highly developed soil type (Table 1). The soil type of the TR 9 soil profile is Ultisol. Ultisols are geologically formed from tertiary-age geological landscapes. This type of soil has undergone an intensive process of illuviation and eluviation so that alkaline cations have been leached to the subsurface layer.

Discussion

The result of soil fertility capability classification based on problems seen in type, substrata type and modifier (Table 3) showed that there were 14 FCC units in the study area, namely LLRr^{+}s^{-}k (8%), CCv (10%), CCs^{-}v (15%), LLs^{-}n^{-} (5-18%), LL (3-50%), LLsn (1%), LLR^{-}n^{-}x (2%), LLs^{-}nx (3%), LCn (8%), LLx (8-15%), LLn (70%), LLkn^{-} (30%), LLr^{+++}s^{-}n (14%), and LLn^{-} (12%). Each type of soil has a different level of fertility. The fertility level at the study site was controlled by several factors, such as salinity (s), low nutrients (k), boundary layers, such as gravel and surface rock (r), high clay content (v), pH value of NaF (x), and slope factor.

Table 3. Unit fertility capability of each soil SMU.

SMU	Type	Sub Type		Modifier									SR >30%	Slope (%)	FCC Class
				r^{+}	r^{+++}	s	s^{-}	N	n^{-}	K	x	v			
TR1	L	L	-	-	-	-	√	√	-	-	√	-	-	3	LLs^{-}nx
TR2	L	L	R^{-}	-	-	-	-	-	√	-	√	-	-	2	LLR^{-}n^{-}x
TR3	L	L	-	-	-	-	-	-	-	-	√	-	-	15	LLx
TR4	L	L	-	-	-	-	-	-	-	-	√	-	-	8	LLx
TR5	L	-	R	√	-	-	√	-	-	√	-	-	-	8	LRr^{+}s^{-}k
TR6	C	C	-	-	-	-	√	-	-	-	-	√	-	15	CCs^{-}v
TR7	L	L	-	-	-	√	-	√	-	-	-	-	-	1	LLsn
TR8	L	L	-	-	-	-	-	-	√	-	-	-	-	12	Lln^{-}
TR9	C	C	-	-	-	-	-	-	-	-	-	√	-	10	CCv
TR10	L	L	-	-	-	-	√	-	√	-	-	-	-	5	LLs^{-}n^{-}
TR11	L	L	-	-	-	-	-	-	-	-	-	-	√	50	LL
TR12	L	L	-	-	-	-	-	-	-	-	-	-	-	3	LL
TR13	L	L	-	-	-	-	√	-	√	-	-	-	-	18	LLs^{-}n^{-}
TR14	L	C	-	-	-	-	-	√	-	-	-	-	-	8	LCn
TR15	L	L	-	-	√	-	√	√	-	-	-	-	-	14	LLr^{+++}
TR16	L	L	-	-	-	-	-	√	-	-	-	-	√	70	LLn
TR17	L	L	-	-	-	-	-	-	√	√	-	-	-	30	LLn^{-}k

Remarks: L = Loamy, <35% clay; C = Clayey, >35% clay, R = rock or another hard root-restricting layer within 50 cm, R^{-} = such as R but layer can be ripped, plowed or blasted to increase rooting depth, r+ = subsoil is pebbly 10-35%, r^{+++} = subsoil is >15% rock outcrop, s = Salinity >0.4 MS cm^{-1}, s- = Salinity 0.2 - 0.4 mS cm^{-1}, n = Na saturation is >15%, n^{-} = Na saturation is 6-15%, K = K-dd <0.20 $cmol_{(+)}$ kg^{-1}, x =: pH 10 (1M NaF), v = Clayey, >35% clay.

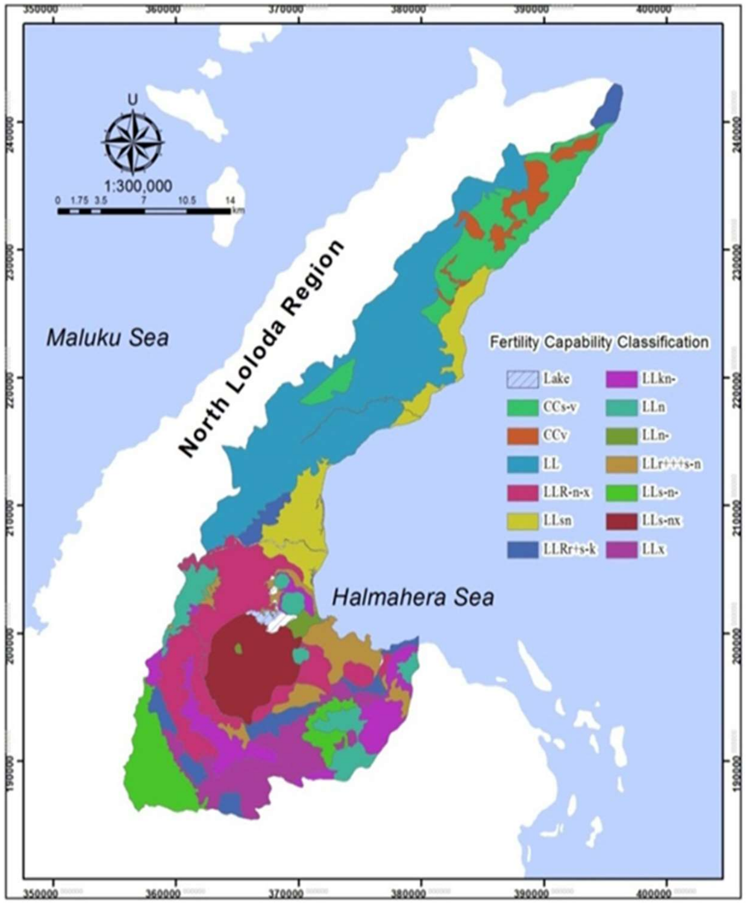

Figure 3. Soil fertility class map.

Soil fertility status is important in increasing agricultural land productivity (Al-Zubaid et al., 2008; Parnes, 2013; Nguemezi et al., 2020). Soil fertility level is influenced by several factors, one of which is soil development. Soil formed from volcanic ash material produces a thick soil solum. Volcanic ash is an easily weathered material that can improve soil physicochemical properties (Aini et al., 2018; Rofita et al., 2021).

Salinity can interfere with plant productivity. High salinity can reduce soil respiration, enzyme activity, and soil microbial activity, as well as disrupt soil biogeochemical cycles (Tripathi et al., 2006; Rousk et al., 2011; Wen-wen et al., 2019). Besides, soil salinity that tends to be high will reduce soil fertility. Kristiono et al. (2013) argue that salinity can cause plant stresses, such as osmotic stress, unbalanced nutrients, NaCl toxicity, and oxidative stress. In addition, salinity can also damage soil structure and increase osmotic pressure, thereby disrupting the availability of water and nutrients for plants (Bohnert, 2007). Soil fertility status can be influenced by the presence of roots on the soil surface, which is seen in areas of land that tend to be sloped (0-8%). The soil fertility level in the soil profile TR 5 is classified as the most severe class (LLRr$^+$s$^-$k) because it is limited by surface rock factors (r$^+$=10-35%), low K content, and low salinity (Table 2). TR 5 is a soil profile with shallow soil solum (<50 cm) and Lithic Haprendolls soil type, indicating lithological discontinuity (Table 1). Land management in shallow soil solum is classified as difficult to manage. Physically, gravel reduces the available water capacity in the soil body (Sanchez et al., 2003). In addition, the shallow soil solum disturbs the plant root system because the root system moves to the surface to look for the availability of water and nutrients, thus triggering the land to be easily degraded (Aji et al., 2020).

The steep slope (>25%), followed by the threat of erosion, is the limiting factor for soil fertility. This constraint occurs in TR 11 and TR 16 soil profiles. Erosion affects the physicochemical properties of the soil, especially on essential nutrients (N, P, and K) and humus in the topsoil layer. It can also damage soil structure and disrupt soil permeability (Chiurciu et al., 2022). The incidence of erosion on sloping land varies. Splash erosion generally occurs on the surface of the soil, followed by small groove erosion on the middle slopes and results in trench erosion on the lower slopes (Sartohadi et al., 2018). In addition, high rainfall intensity is able to transport soil material of different sizes depending on the volume and rate of runoff on the slopes (Rofita et al., 2021). However, soil fertility can be maintained. The existence of the Dokuno volcano contributes volcanic ash material that can fertilize the surrounding land despite its high slope, so it is not surprising that plantation crops can still grow well in areas with a slope of above 30% (Hartati et al., 2017). Volcanic ash contains various major (Al, Si, Ca, and Fe) and minor (Na, K, Mg, Mn, P, S, and Ti) elements (Wahyuni et al., 2012). The addition of volcanic material on a regular basis tends to produce different materials depending on the composition of the magma produced (Lowe, 2010, Nurcholis et al., 2019; Aji et al., 2020). Minerals derived from volcanic ash can enrich the availability of nutrients for the soil and improve the soil physicochemical properties.

Conclusion

Factors that limit soil fertility in the Galela area include hard root systems, K nutrient deficiency, electrical conductivity, Na saturation, steep slopes (>30%), and the presence of gravel and exposed rock on the surface. In addition, it was found that there were soils experiencing lithological discontinuities, thereby resulting in limited soil development. Alternative management to reduce limiting factors can be through fertilization and conservation practices to reduce soil erosion.

Acknowledgements

The authors are grateful to the Directorate of Research and Community Service of the Ministry of Research, Technology and Higher Education for funding this research with a Letter of Appointment Agreement of Doctoral Dissertation Research Program No. 003/PEN-DD/PL/2017 dated April 11, 2017.

References

Adhikary, P.P., Biswas, H., Trivedi, S.M. and Chandrasekharan, H. 2010. Soil fertility capability classification in a semi-arid region in Haryana with Special reference to soil biological condition modifier. *Journal of the Indian Society of Soil Science* 58(4):428-435.

Aini, L.N., Sunarminto, B.H., Hanudin, E. and Sartohadi, J. 2018. Soil morphogenesis diversity at the southern flank of Merapi Volcano, Indonesia five years post-eruption. *Indian Journal of Agricultural Research* 52:472-480, doi:10.18805/ijarea-325.

Aji, K., Maas, A. and Nurudin, M. 2020. Relationship between soil morphology and variability of upland degradation in Bogowonto Watershed, Central Java, Indonesia. *Journal of Degraded and Mining Lands Management* 7(3): 2209-2219, doi:10.15243/jdmlm.2020.073.2209.

Al-Zubaid, I.A., Yanni, S. and Bashour, I. 2008. Potassium status in some Lebanese soils. *Lebanese Science Journal* 9(1):81-97.

Bohnert, H.J. 2007. *Abiotic Stress*. John Wiley & Sons, Ltd., doi:10.1002/9780470015902.a0020087.

Chiurciu, I.-A., Dana, D., Chereji, A.-I., Chereji, I.J., Voicu, V and Firatoiu, A.-R. 2022. Research on soil and nutrient losses through liquid runoff, in order to mitigate the climate risks to which Romania is exposed, in the context of CAP. *Earth* 2022, 3:639-651, doi:10.3390/earth3020037.

Directorate General of Estate Crops, 2015. *Area and Plantation Plantation Production by Type of Plant*, 2000-2014 (*in Indonesian*).

Faye, J.B. and Braun, Y.A. 2022. Soil and human health: Understanding agricultural and socio-environmental risk and resilience in the age of climate change. *Health & Place* 77:102799, doi:10.1016/j.healthplace.2022.102799.

Geissen, V., Sanchez-Hernandeza, R., Kampicher, C., Ramos-Reyesa, R., Sepulveda-Lozadaa, A., Ochoa-Goana, S., de Jong, B.H.J., Huerta-Lwanga, E. and Hernandez-Daumas, S. 2009. Effects of land use change on some properties of tropical soils–an example from Southeast Mexico. *Geoderma* 151:87-97, doi:10.1016/j.geoderma.2009.03.011.

Hartati, T.M. 2018. Evaluation of Land Appropriation, Soil Fertility of Several Plantation Crops and Improvement of Soil Properties to Increase Production of Pala in Galela, North Halmahera. Fakultas Pertanian. Universitas Gadjah Mada (*in Indonesian*).

Hartati, T.M., Sunarminto, B.H., Utami, S.N.H., Purwanto, B.H. and Nurudin, M. 2017. Land suitability evaluation for nutmeg (*Myristica fragrans* Houtt) in Galela region, North Halmahera Districts, North Maluku, Indonesia. *International Journal of Soil Science* 12(2):84-96, doi:10.3923/ijss.2017.84.96.

Kristiono, A., Purwaningrahayu, R.D. and Taufik, A. 2013 Soybean, Peanut and Green Bean Response Against Salinity Straits. *Buletin Palawija* 26:45-60 (*in Indonesian*).

Local Government of North Halmahera Regency. 012) Regional Spatial Plan (RSP) of North Halmahera Regency for 2012-2032. Regional Regulation of Halmahera Utara Regency No. 09, 2012 (*in Indonesian*).

Lowe, D.J. 2010. Quaternary volcanism, tephras, and tephra-derived soils in New Zealand: An introductory review. In: Lowe, D.J., Neall, N.E., Hedley, M., Clothier, B. and Mackay, A. (eds.), *Guidebook for Pre-conference North Island, New Zealand, Volcanoes to Oceans field tour* (pp. 7-29). North Palmerston, New Zealand: Soil and Earth Sciences Occasional Publication No. 3, Massey University.

Mondal, S. 2021. Impact of climate change on soil fertility. In: Choudhary, D.K., Mishra, A. and Varma, A. (eds.), *Climate Change and the Microbiome: Sustenance of the Ecosphere* (*Soil Biology, 63*), 1st Ed. 2021 Edition, Springer, doi:10.1007/978-3-030-76863-8_28.

Muluneh, A. 2020. Impact of climate change on soil water balance, maize production, and potential adaptation measures in the Rift Valley drylands. *Journal of Arid Environments* 179:104195, doi:10.1016/j.jaridenv.2020.104195.

Nguemezi, C., Tematio, P., Yemefack, M., Tsozue, D. and Silatsa, T.B.F. 2020. Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon, *Heliyon* 6(2):e03432, doi:10.1016/j.heliyon.2020.e03432.

Notohadiprawiro, T. 2006. *Soil and Environment*. Soil Science. Universitas Gajah Mada. Yogyakarta (*in Indonesian*).

Nurcholis, M., Yudiantoro, D.F., Haryanto, D., Dianputra, A.B. and Aji, K. 2019. Process and mineralogy of volcanic materials on the south side of the old Lawu Volcano in Java Island. *Sains Tanah-Journal of Soil Science and Agroclimatology* 16(2):127-138, doi:10.20961/stjssa.v16i2.27118.

Parnes, R. 2013. *Soil Fertility. A Guide to Organic and Inorganic Soil Amendments*. Soil & Health Library Inc.

Rofita, Utami, S.N.H., Maas, A. and Nurudin, M. 2021. Spatial distribution of soil morphology and physicochemical properties to assess land degradation under different NDVI and TRI in North Halmahera, Indonesia. *Journal of Degraded and Mining Lands Management* 9(1):3137-3154, doi:10.15243/jdmlm.2021.091.3137.

Rousk, J,, Elyaagubim F., Jones, K. and Godbold, D.L. 2011. Bacterial salt tolerance is unrelated to soil salinity across an arid agroecosystem salinity gradient. *Soil Biology and Biochemistry* 43:1881-1887, doi:10.1016/j.soilbio.2011.05.007.

Sanchez, P.A. 2002a. Soil fertility and hunger in Africa. *Science* 295:2019-2020, doi:10.1126/science.1065256.

Sanchez, P.A. 2002b. Soil Science as a major player in world development. *17th World Congress of Soil Science, Keynote Lectures*. The Soil and Fertilizer Society of Thailand, Bangkok, pp. 53-64.

Sanchez, P.A., Palm, C.A. and Buol, S.W. 2003. Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma* 114:157-185, doi:10.1016/S0016-7061(03)00040-5.

Sartohadi, J., Pulungan, N.A.H.J., Nurudin, M. and Wahyudi, W. 2018. The ecological perspective of landslides at soils with high clay content in the middle Bogowonto watershed, Central Java, Indonesia. *Applied and Environmental Soil Science* 2018:1-9, doi:10.1155/2018/2648185.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C. and Soil Survey Staff. 2012. *Field Book for Describing and Sampling Soils*. In Natural Resources Conservation Service, National Soil Survey Center, USDA. Lincoln, NE.

St Clair, S.B. and Lynch, P.J. 2011. The opening of Pandora's box: climate change impacts on soil fertility and crop nutrition in developing countries. *Plant and Soil* 335:101-115, doi:10.1007/s11104-010-0328-z.

Syam, T. 2010. Spatial variability of soil nutrients content related to rice yield. *Journal of Tropical Soils* 15(2):153-157, doi:10.5400/jts.2010.15.2.153.

Tobi, F.O., Ngobesing, E.S.C., Yinda, G.S., Boukong, A., Omoko, M., Bitondo, D. and Mvondo, Z.A.D. 2013. Soil fertility capability classification (FCC) for rice production in Cameroon lowlands. *African Journal of Agricultural Research* 8(119):1650-1660, doi:10.5897/AJAR12.1576.

Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, K. and Bandyapadhyay, B.K. 2006. Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils* 42:273-277, doi:10.1007/s00374-005-0037-6.

van Reeuwijk, L.P. 2002. *Procedures for Soil Analysis*. International Soil Reference and Information Centre. Den Haag: Netherlands.

Wahyuni, E.T., Triyono, S. and Suherman. 2012. Determination of chemical composition of vulcanic ash from Merapi Mountain eruption. *Jurnal Manusia dan Lingkungan* 19 (2): 150-159 (*in Indonesian*).

Wen-wen, Z., Wang, C., Xue, R. and Wang, L-j. 2019. Effects of salinity on the soil microbial community and soil fertility. *Journal of Integrative Agriculture* 18(6):1360-1368. doi:10.1016/S2095-3119(18)62077-5.