AJAB

Asian J Agric & Biol. 2019; Special Issue:231-238.

Original Article

Chemical properties of forest soils developed on sedimentary rocks in Bintuni Bay, West Papua, Indonesia

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Received:
March 10, 2019

Accepted:
October 17, 2019

Published:
December 05, 2019

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Abstract

Agricultural development in Bintuni Bay requires detail information of soil properties, however, current data is inadequate. To provide the information on soil chemical properties in its coastal sediment area, we surveyed landform and soil morphology of Aroba and Sumuri Districts, each of 200 ha. The forest land in Aroba was composed of thick mudstone (claystone) with some inserts of sandstones, while that of Sumuri was dominated by sandstone with insert of mudstone and some lenses of conglomerates. The soils showed variation of pH, CEC, exchangeable bases, Organic-C, total-N, and available P in a relatively narrow area. The CEC value was positively correlated with clay content and total organic carbon. There were also variation of soil forming materials and serial processes of transportation, deposition, denudation, and pedogenesis that occurred in the studied lands.

Keywords: Soil chemical characteristics, sedimentary rocks, Bintuni Bay

How to cite this:

Nurcholis M and Herlambang S, 2019. Chemical properties of forest soils developed on sedimentary rocks in Bintuni Bay, West Papua, Indonesia. Asian J. Agric. Biol. Special Issue: 231-238.

Introduction

The land in Bintuni Bay of Papua has not been intensively managed by the community. Lands are relatively available, while social development of the community is moderate, therefore this region is relatively untouched. However, land has a very basic role to support the activities of human beings and other living things, therefore, it needs to be managed and developed based on the intrinsic characteristics to ensure it will serve in a long period of time, or sustainable. The harmony between the decisions made in forest conversion with the result of related academic studies might assure the sustainable benefit of the land to human life (Nkem et al., 2007).

Along with the social development of the community in a region, it is necessary to assess the carrying capacity of the land to provide the necessary data for a sustainable regional development. The assessment of land resources should be carried out by doing chemical analysis of soil. One example of land conversion with a distinct ecosystem was the conversion of mangrove forest into rice fields in the sediment land of Segoro Anakan lagoon in Cilacap. This conversion has changed the physical and chemical properties of this land (Nurcholis et al., 2002). Likewise, the potency of the soils on the land between the two incisions of the tributaries, need to be assessed in the context of land development. Based on the intensive deposition and denudation process, it is suspected that there is a very high lateral diversity. To know the diversity of the chemical properties in this area, we conducted the study of soil chemical properties in two locations, viz Aroba and Sumuri Districts. The collected data might serve as the basic information to consider in the development of the region.

Material and Methods

The study was conducted in Aroba and Sumuri Districts, the coastal plains that developed from old age beach deposits. First, we prepared land administration map to determine the access point to reach the location, and the geological map to analyze the distribution of constituent material units for parent soil. Sample point was determined based on the diversity of local landform(s) and the accessibility to the location. Field observation was conducted to analyze land surface morphology, soil covered with vegetation, surface hydrology, and selected soil properties in the field.

Soil samples were collected from 20 and 30 locations in Aroba and Sumuri respectively. Soil was sampled at the depth of 30 cm to analyze the pH (H_2O) and pH (KCl), and cation exchange capacity (CEC). CEC was analyzed with NH_4OAc 1N pH 7 (Bennema, 1966). The relationship between soil CEC with (clay and organic-C) was assessed according the mathematical correlation with the exchange characteristics of some Indonesian soils (Buurman and Rochimah, 1980). Regression analysis between CEC with levels (clay and *n* organic-C) was counted with the formula:

$$CEC = a + b\ (l + nC)$$

CEC = Cation exchange capacity
a = intercept of linear regression
b = slope of linear regression
l = the percentage of clay
C = organic-C level
n = constant

Exchangeable bases of Ca, Mg, K, Na was extracted with 1N ammonium acetate (NH_4OAc) at pH 7 and determined by atomic absorption spectrophotometer (AAS). Soil electrical conductivity was counted using 1: 2.5 extract, the content of organic matter with wet extraction using the Walkley and Black method. Total N content was determined using wet construction method. Exchangeable Al and H was analyzed with 1 N KCl extract, followed by titration method for H and AAS for Al.

Results and Discussion

The Bintuni Bay was formed by the process of deposition of eroded material originating from superior land for a very long period of time. Sediments that underwent lithification process formed clay stones, as well as new deposits like mud which have not undergone lithification, peat, and metamorphic sand deposits (Figure 1). The main rivers end in the estuary of the Bintuni Bay, which is characterized by brackish to salty water. These rivers have creeks that cut the land so that land surface is morphologically grouped into wavy. Naturally on this mud deposit area mangrove forests of various types were grown.

Land biophysics

The soil in Aroba and Sumuri Districts was built upon somewhat different compositions (Fig 1). In Aroba District the soil was consisted of thick claystones with several sandstones. The claystones were up to 5 m thick, while their color were varied from gray to black. However, the soil in Sumuri District was dominated by coal units with claystone inserts and conglomerate lenses. The composition of sandstone was fine to very coarse-grained, and lithic and quartzite. Whereas conglomerate had a very coarse to crusty sandstone material, round, with sandstone bases to clay. This conglomerate that was found in the north, near Sumuri, can be used as the pavement material for the road to refit the logging road that has not been used and overgrown.

The soil had a corrugated macro-surface landform. Internal drainage from the soil was generally slow. Surface drainage was highly dependent on the slope and the presence of trenches that developed due to the long-lasting erosion processes and the accumulation of runoff flows. The developed soil generally had clay texture. This was because the tertiary parent soil material underwent soil formation process which produced the soil dominated by clay fractions.

Soil as a natural formation derived from parent material, undergo weathering and formation processes. In delivering water from the surface into its body, soil is strongly influenced by its nature, especially the texture. The soil that developed in Aroba had a high clay content. Clay was very slow to pass water, so that the rain that falls onto its surface does not easily penetrate the soil, but floods the surface. The occurrence of rainwater on the soil surface in Aroba two days after the rain shown that this area has low permeability.

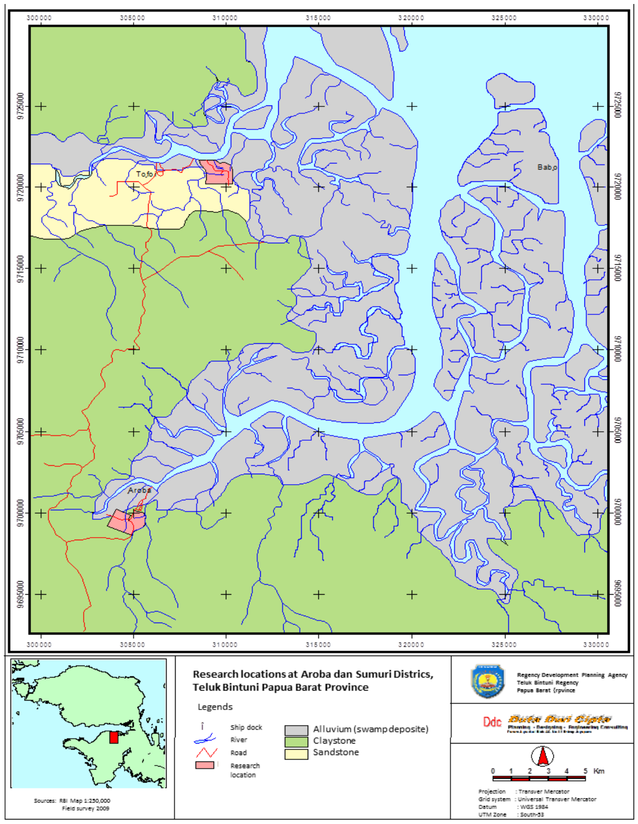

Figure-1: Geological map of Bintuni Bay area (figure was the courtesy of Bappeda of Teluk Bintuni)

The studied soil in Aroba District was developed from old sedimentary parent materials with the dominance of clay material with sand inserts. The process that had taken place on the parent materials had a very important role on soil development in this location. Surface runoff from upland soil had high velocity that decreased on lowland soil. When it reached lowland and spread horizontally, the velocity might change as shown from the pattern of river flows (Figure 1). This flowing water may erode soil surface, creating grooves that combine into a ditch, and then the ditches might form rivers. The continuing soil surface erosion form land with choppy relief which consists of ridges on the upland area, and then plains and basins on the lowland part. Due to this condition, land surface is sloped on the upland with various slope levels and their river flow directions.

Wet tropical climate was the main forming factor in the location. The availability of sufficient water during soil formation resulted in the formation of soil with further development. The vegetation of the wet tropical forests also contributed to soil formation. Over time, the soil that developed in this location was quite dominant in the process of soil formation.

Soil reaction

The soil pH in Aroba was quite different than that in Sumuri (Table 1). In Aroba the pH was ranged from 4.50 - 6.20, while in Sumuri it was ranged from 4.70 - 8.40. Thus, Aroba had acidic to slightly acidic soil, while Sumuri had acidic to alkaline soil. The significant different in soil pH might be derived from the parent soil material which was the old sedimentary rock. Sedimentary rocks are formed by the long period of sedimentation processes to deposit materials of various types and sizes. Nurcholis et al. (2002) reported similar condition of the soil that developed in the mangrove forest at the upstream of Donan-Tritih river which emptied into the Segoro Anakan lagoon in Cilacap, that is very acidic to neutral. Soil pH therefore, can be increased by accurately liming it based on buffer curve data (Nurcholis, 1998).

The minimum value of pH (H_2O_2) was 2.5 and even lower (Table 1). The value less than 2.5 is used as a simple indication of the presence of sulfidic material in the soil. Sulfidic material does not harm the environment during a reductive reaction, however if oxidized, it may produce free sulfuric acid that dramatically dropped soil pH to below 3.0. Free sulfate material can also be dissolved in ground water that caused sulfuric acid to flow laterally and vertically. Thus, the effect of sulfide oxidation is not only local, but can expand. Nurcholis et al. (2002) conducted similar H_2O_2 reaction to the soil in mangrove forest at the upstream of Donan-Tritih river found Pyrite (ferrosulfide). Thus, the use of this land for wetland agriculture such as paddy field, will close the possibility of the emergence of free sulfuric acid which might harm the soil at that location and the water that flows below the soil surface.

Organic C and nitrogen

Organic-C content in Aroba and Sumuri districs was ranged from 0.20%-2.50% (Table 1). In Aroba the C content was slightly higher than that in Sumuri, viz 0.39%-2.49% (very low to medium) and 0.20%-2.49% (very low to low) respectively.

Table-1: The pH, organic-C, total-N, and available-P, CEC, exchangeable cations, and base saturation of the soils in Aroba (n = 20) and Sumuri (n = 30) Districts, Papua

Parameters	Units	Mean	Minimum	Maximum
Aroba District				
pH(H_2O)	-	5.10	4.50	6.20
psH(H_2O_2)	-	4.20	2.20	5.90
pH(KCl)	-	4.00	3.60	5.20
Organic-C	%	0.79	0.39	2.45
Total-N	%	0.05	0.00	0.15
C/N ratio	-	8.35	0.00	41.67
Available P (Bray-1)	ppm	1.51	0.00	5.51
CEC	cmol(+)/kg	10.64	2.69	24.82
Exchangeable cations				
Ca^{2+}	cmol(+)/kg	3.84	0.00	37.19
Mg^{2+}	cmol(+)/kg	1.34	0.08	8.14
K^{+}	cmol(+)/kg	0.2	0.13	1.10
Na^{+}	cmol(+)/kg	0.58	0.35	1.33
Al^{3+}	cmol(+)/kg	2.70	0.00	7.67
H^{+}	cmol(+)/kg	2.84	0.00	9.11
Base saturation	%	84.05	4.94	>100
Sumuri District				
pH(H_2O)	-	6.50	4.70	8.40
pH(H_2O_2)	-	4.50	2.50	6.60
pH(KCl)	-	4.20	3.70	6.60
Organic-C	%	0.83	0.20	2.49
Total-N	%	0.11	0.00	0.20
C/N ratio	-	6.96	0.00	33.31
Available P (Bray-1)	ppm	3.46	0.34	10.93
CEC	cmol(+)/kg	12.25	4.06	26.26
Exchangeable cations				
Ca^{2+}	cmol(+)/kg	9.26	0.00	56.18
Mg^{2+}	cmol(+)/kg	3.39	0.00	11.89
K^{+}	cmol(+)/kg	0.34	0.07	1.37
Na^{+}	cmol(+)/kg	0.53	0.27	1.12
Al^{3+}	cmol(+)/kg	0.45	0.00	0.29
H^{+}	cmol(+)/kg	0.40	0.00	2.73
Base saturation	%	>100	2.40	>100

The source of organic material in both locations was the remnants of forest plants and animals that underwent decomposition. Post and Kwon (2000) stated that the amount of soil organic-C is determined by the rate of organic matter addition, remodeling, migration into the soil, and the mixing of organic materials with soil by soil animals. The low organic-C content in these areas needs to be managed properly to maintain soil fertility. One of the problems to be controlled is the erosion which transported soil carbon out of the locality. The tropical forest in the studied location, has large annual vegetation that can concentrate rainwater into large flows and increase erosion rate.

The influence of organic matter to plant growth physically, chemically and biologically is unquestionable. Soil organic matter and clay content are factors that determine the value of soil Cation Exchange Capacity (CEC). The mineralization of organic matter in plants to produce organic-N requires carbon as a source of energy for the microorganisms (decomposers). Therefore, soil organic matter is often used as an indicator of soil fertility, because it determines soil physical, chemical, and biological properties. The influence of organic matter on these properties is direct and indirect. It enhances the ability of the soil to retain moisture, as a source of macro nutrients such as N, P, K, Ca, Mg, S, and a number of micro nutrients that are needed by plants.

The total-N content in the soils in Aroba and Sumuri was categorized as very low to low (Table 1). In Aroba the N content ranged from 0.00-0.12%, while in Sumuri it was not very different, viz. 0.00-0.20%. The very low N content can be understood since almost all of the soil has not been fertilized. The total-N content in the soil therefore, was solely the result of mineralization of organic material derived from plant residues and other biota that develop naturally. Johnson (2010) found that N status in the soil is unique, because it does not originate from rock or parent material and it is a limiting factor in the terrestrial ecosystem. In several locations in Aroba particularly, the locals cleared the lands by cut and burn, which resulted in rapid loss of N from the ground. Then N was again absorbed by the plant roots and used for growth. Therefore, in both studied locations, N was following a natural cycle. These relatively narrow lands covered by a relatively natural forest, showed small variation in the total-N in the soil. The presence of N in forest land according to Zech et al., 1997 and Rennenberg et al. (2009) is strongly influenced by soil characteristics, forest vegetation type, and N cycle that takes place in forest ecosystems. The C/N ratio for the studied soil was very variable, but generally below 12 (Table 1). The soil in Aroba has a generally lower C/N value with a range of 0.00 – 41.67, while that in Sumuri has a higher value than 12 with a range of 0.00 - 33.31. C/N soil ratio was usually calculated to determine the level of organic matter remodeling in the soil. The more advanced the decomposition process of organic matter, the smaller C/N ratio (<20). Therefore, large C/N ratio (>20) indicates the immature level of organic matter decomposition.

Available phosphorus

The analysis of soil phosphorus (P) content showed that Aroba and Sumuri soils has a very low P levels, which was ranged from 0.00-5.51 ppm and 0.34-10.93 ppm respectively (Table 1). In a forest the only source of P was the soil, without the input from rainwater or plant fixation (Anderson and Spencer, 1991). Moreover, in the soils that have developed further with high acidity, P will be fixed by Al and Fe oxides in infertile soil. Anderson and Spencer (1991) reported that N and P in tropical forest soils range from 50 to 80% of the total of both elements in the entire forest system. To increase soil quality, the addition of P by fertilization or by the addition of phosphate rock was required to provide sufficient living conditions for the cultivated plants.

Cation exchange capacity

The soils that developed in Aroba and Sumuri Districts showed the variability of CEC and cations (Table 1). The soil in Aroba has an average value of CEC 10.64 cmol (+)/kg ranged from 2.69-24.82 cmol (+)/kg, while that of Sumuri has an average CEC value of 12.25 cmol (+)/kg, with the range of 4.06-26.26 cmol (+)/kg respectively. The chemical properties of the developing soil showed that its fertility varies from very low to high. This implies the need of appropriate soil management and location-specific technologies to be applied if later on the land is developed for other purposes, because of the large range of soil properties in a relatively narrow area.

Nurcholis et al. (2002) reported that soil CEC in mangrove forest at Donan-Tritih river was greater than 25 me% with narrow range. This was possible due to the young sedimentary materials. The sediment develops in Bintuni Bay however, is old with various geological and geomorphological processes and pedogenesis to create large range of soil chemical properties.

Exchangeable cations

Soil analysis in both studied districts showed that there were very high variations in cations like Ca, Mg, K, and Na (Table 1). The level of exchangeable cation in the soil indicated a general tendency that calcium ion was the highest and Natrium ion was the lowest, with the order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. The maximum value of Ca and Mg in Aroba were 37.19 and 8.14 cmol (+)/kg, respectively, while in Sumuri, they were even higher, viz. 56.18 and 11.89 cmol (+)/kg respectively. In general, the process of pedogenesis greatly determined the levels of Ca and Mg. At the beginning of pedogenesis, the content of Ca and Mg in the soil was still high. Further soil development might leach them from the soil layer to the subordinate layer. The soil under study was developed from old sedimentary parent material. The content of Ca and Mg in this soil might vary as a result of the various processes such as erosion, leaching, and relocation of the two elements from the soil of the superior deposited onto a stable location, viz. the sediment where the soil developed.

The amount of exchangeable Al in Aroba was also varied from very low to high (Table 1). In general, the soil in Sumuri had low exchangeabe Al. Aluminum in an exchangeable state can be formed by the dissolving minerals through weathering, because aluminum was easily dissolved in high acidity condition. Nurcholis et al. (1997) reported that clay mineral typology significantly affects soil pH and Al, that it could increase pH and decrease Al as a result of calcification. Moreover, the type of clay mineral also influences Al levels as reported by Nurcholis et al. (1998) that exchangeable Al value is high in soil dominated by type 2: 1-2: 1: 1 clay minerals.

The relationship between CEC, clay and organic levels

The results of soil chemical analysis in the two studied locations showed the variation of CEC (Table 1). Soil CEC was strongly influenced by the type of constituent material as well as organic-C. Linear regression analysis of the relationship between soil CEC with (clay + 4 c) was shown in Fig. 2. The results of the study on the role of SOC to CEC in tropical soils with clay minerals dominated by Fe and Al oxides showed that the role of SOC could increase soil CEC 44 times compared to the role of clay fraction (Soares and Alleoni, 2008). Therefore, it was clear that organic-C has a significant contribution to soil CEC.

For the soils in Aroba, the regression coefficient (R^2) was 0.4148 (r= 0.6440) which was significant (P<0.50%, dF = 18, calc-t= 0.5614), while in Sumuri the regression coefficient (R^2) was 0.3357 (r= 0.5793) which was also significant (P<0.50%, dF = 28, calc-t= 0.3061). The results showed possibility that the type of clay minerals that making up the clay fraction were relatively uniform, and the role of clay minerals on CEC value was relatively small. The studied soil was the natural soil covered by a close ecosystem of natural forest, therefore, the source of C in the forest came from the process of restoring plant and animal waste material and biota outside and inside the soil. In general, it can be said that organic-C determined the value of soil CEC. As an implication, whenever the land is converted into non-forest use, the high level of C should be maintained to retain soil quality.

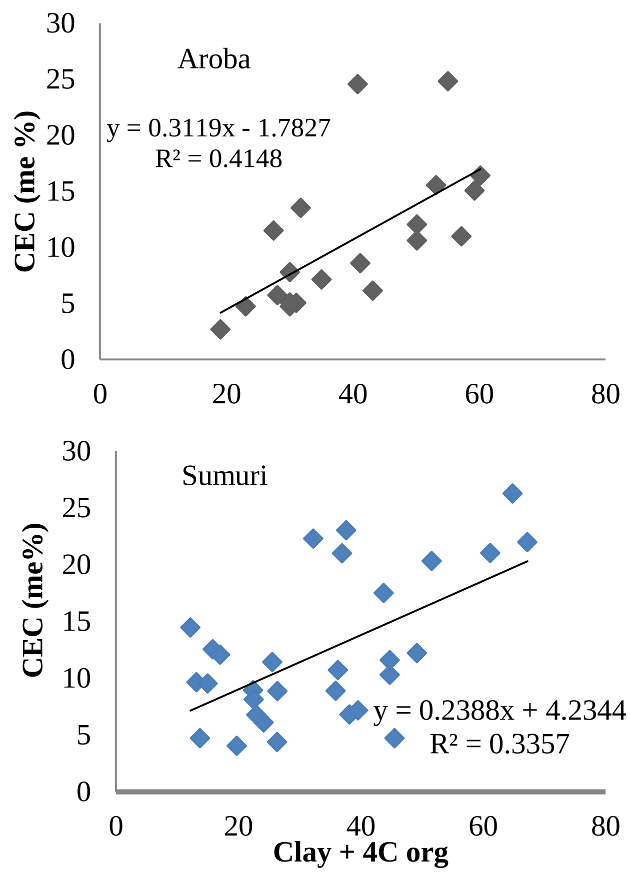

Figure-2: The relationship between CEC, clay, and organic C levels in Aroba and Sumuri Districts.

Estimation of soil diversity processes

Soil chemical analysis showed that there was a wide range of chemical properties in a relatively narrow area. It is possible that sedimentary rocks are formed as a series of sedimentation processes (Fig. 3). The deposited material depended on the source of the material, the transport, and the deposition processes. These materials were then turned to soil through the pedogenesis process, continued with the transfer of elemental sites and the reduction of cations through leaching. During these two processes of geogenesis and pedogenesis, the content of exchangeable cations may slightly vary.

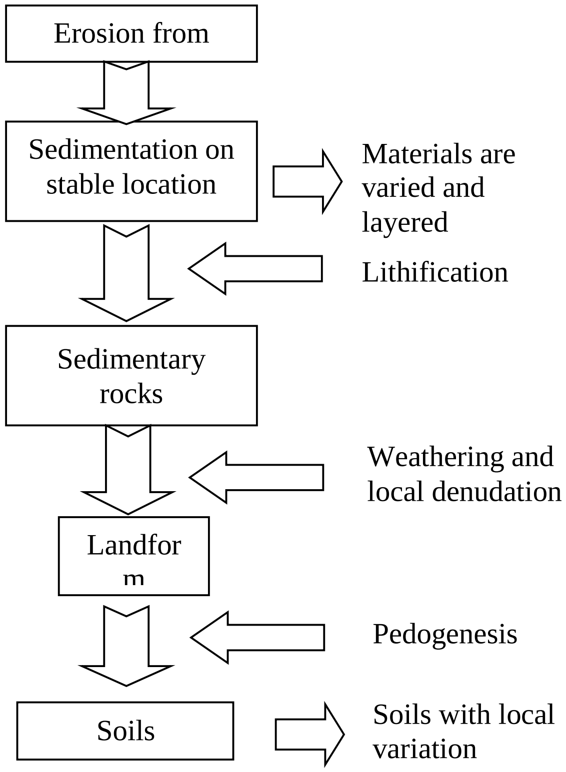

Figure-3: The formation of soils with various properties from sedimentary rock as the parent material.

Conclusion

The forest soil in Aroba District consisted of thick mudstone (claystone) with some inserts of sandstones, while that in Sumuri District was dominated by sandstone inserted by mudstone and some lenses of conglomerate. The soils showed the wide range of soil chemical properties in a relatively narrow area. Variation of the source of soil forming materials, as well as serial processes of transportation, deposition, denudation and pedogenesis were also observed.

Acknowledgement

We thank Universitas Pembangunan Nasional Veteran Yogyakarta for the permission given to the authors for research in the Teluk Bintuni Regency. We appreciate the Bappeda Teluk Bintuni Regency for the study on the Compillation of Regional Input-Output Tables in Teluk Buntuni Regency.

Contribution of Authors

Nurcholis M: Conducted survey, soil analysis, and write up of article

Herlambang S: Helped in data compilation and analysis

Disclaimer: None.
Conflict of Interest: None.
Source of Funding: Funded through Bappeda Teluk Bintuni Regency, West Papua Province, Indonesia

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