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Development and Rainfed Paddy Soils Potency Derived from Lacustrine Material in Paguyaman, Gorontalo

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ABSTRACT

Rainfed paddy soils that are derived from lacustrine and include of E4 agroclimatic zone have many unique properties and potentially for paddy and corn plantations. This sreseach was aimed to: (1) study the soil development of rainfed paddy soils derived from lacustrine and (2) evaluate rainfed paddy soils potency for paddy and corn in Paguyaman. Soil samples were taken from three profiles according to toposequent, and they were analyzed in laboratory. Data were analyzed with descriptive-quantitative analysis. Furthermore, assessment on rainfed paddy soils potency was conducted with land suitability analysis using parametric approach. Results indicate that all pedon had evolved with B horizons structurization. However, pedon located on the summit slope was more developed and intensely weathered than those of the shoulder and foot slopes.The main pedogenesis in all pedons were through elluviation, illuviation, lessivage, pedoturbation, and gleization processes. The main factors of pedogenesis were climate, age (time) and topography factors. Therefore, P1 pedons are classified as *Ustic Endoaquerts, fine, smectitic, isohypertermic*; P2 as *Vertic Endoaquepts, fine, smectitic, isohypertermic*; and P3 as *Vertic Epiaquepts, fine, smectitic, isohypertermic*. Based on the potentials of the land, the highest of land suitability class (LSC) of land utilization type (LUT) local paddy was highly suitable (S1), while the lowest one was not suitable with nutrient availability as the limiting factor (Nna). The highest LCS of paddy-corn LUT was marginally suitable with water availability as the limiting factor (S3wa), while the lower LSC was not suitable with nutrient availabily as the limiting factor (Nna).

Keywords: Corn, lacustrine, land suitability, paddy, rainfed paddy soil

INTRODUCTION

National rice demand is increasing due to the increasing of population in a rate of about 2%. According to Ministry of Agriculture (2007), national rice production in 2006 reached 57,157,435 Mg of dry milled grain or equivalent with 32.30 Mg million rice, which is 94.83% contributed by lowland rice and the remainder are from rainfed fields. However, this achievement has failed to meet the same year demand of 36.35 Mg million (BPS RI 2007). In this context, it requires development of other potential wetland, especially rainfed paddy soils. Rainfed paddy soils (RPS) with an area of 2.1 million ha is the second source of grain after the irrigated lowland rice in Indonesia (Toha and Pirngadi 2004). In Gorontalo Province, RPS is of 13,081 ha or 0.47% of national RPS areas (BPS Gorontalo Province 2007), whereas 7,744 ha of it are in Paguyaman. One of the problems faced in RPS development is that its low production yield which is between 2.0-2.5 Mg ha^{-1} (Pirngadi and Makarim 2006), compare to 5.68 Mg ha^{-1} of Irrigated Paddy Soil (IPS) production (Pramono *et al.* 2005).

Rainfed paddy soils in Paguyaman Gorontalo areas were developed from lacustrine materials (Hikmatullah *et al.* 2002; Prasetyo 2007). Formation of lacustrine material depends on its natural properties, deposition process, and the environment characteristics where the deposition occurs resulting in various properties and characteristics of the soil derived from it. Paddy soils, including RPS are formed from various soil types and its characteristic depends on the soil properties (Arabia 2009) and its forming environments. Hikmatullah *et al.* (2002) and Prasetyo (2007) reported that Paguyaman areas consist of quartz minerals and a few of orthoclase, sanidine and andesine minerals. Epidote, amphibole, augite, and hyperstine minerals are found in very small amounts, so it can be said that nutrient stocks in this area are average. Thus, confirming that paddy soil properties are influenced by its original materials (Prasetyo *et al*. 2007). Factors influencing soil formation varies depend on soil development level. How the RPS development shown in horizonisation, primary mineral weathering, and forming of secondary minerals has been interesting objects of study.

The area is in E4 Agroclimate zones with 6-9 dry months and without wet months (Hikmatullah *et al.* 2002; Prasetyo 2007). This condition causes limited water availability, thus the area is unable to supply water needs for rice growing for one whole year. Pertaining to this field conditions, rice is planted only once a year and in the remaining months corn are planted or let fallow. In Indonesia, corn is the second staple food after rice. Corn production in Gorontalo was 572,784 Mg in 2007 which was yielded from 119,027 Mg of plantation area (BPS Gorontalo Province 2007). Although RPS area in Paguyaman constitutes 59.2% of the total RPS in Gorontalo Province its utilization for corn growing is relatively low. It is arguable to assume that RPS is potential for development. Therefore, land suitability assesments to get to know the potentials and the limiting factors to utilization are necessary. Recently, for land sutability assesment, land characteristic (LC) is generally used as a parameter and land quality (LQ) is relatively not used (Firmansyah *et al.* 2008), while Sys *et al.* (1991) stated that by using LQ there are several advantages to be gained namely: LQ is directly related to the specific needs of land utilization types (LUTs), it is able to calculate the interactions between environmental factors, and the number of LQ is less than LC.

This study was aimed to: (1) study the soil development of rainfed paddy soils derived from lacustrine and (2) evaluate rainfed paddy soils potency for paddy and corn in Paguyaman of Gorontalo.

MATERIALS AND METHODS

Study Site

A Field survey was conducted on RPS derived from lacustrine materials in Paguyaman regions, *i.e.* Sidomukti village of Mootilango District, Gorontalo Regency of Province Gorontalo (Figure 1). Location of the research sites is mappped by superimposing to each other a geological map of Tilamuta 1:250,000 in scale, a topography map of Paguyaman 1:50,000 in scale and an agroclimate zone map of 1:250,000 scale. From the results of these maps superimpose established research sites. Pedon location specified in a toposequent of three profiles, each of which is denoted by P1 pedon located in the foot slope, P2 pedon in the shoulder slope and P3 pedon on the summit slope (Figure 2). Field implementation is based on the location of the previous example of the profile with the aim of testing the suitability of the research. Soil profile was created and sampled in accordance with the

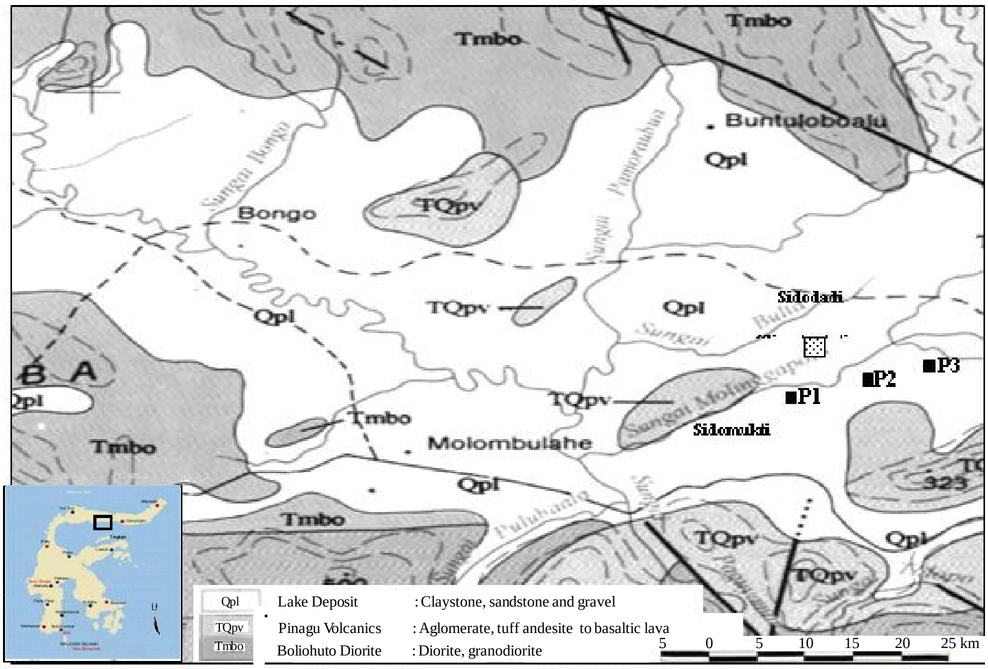

Figure 1. Location of soil profiles in Sidomukti village of Mootilango District, Gorontalo Regency of Province Gorontalo.

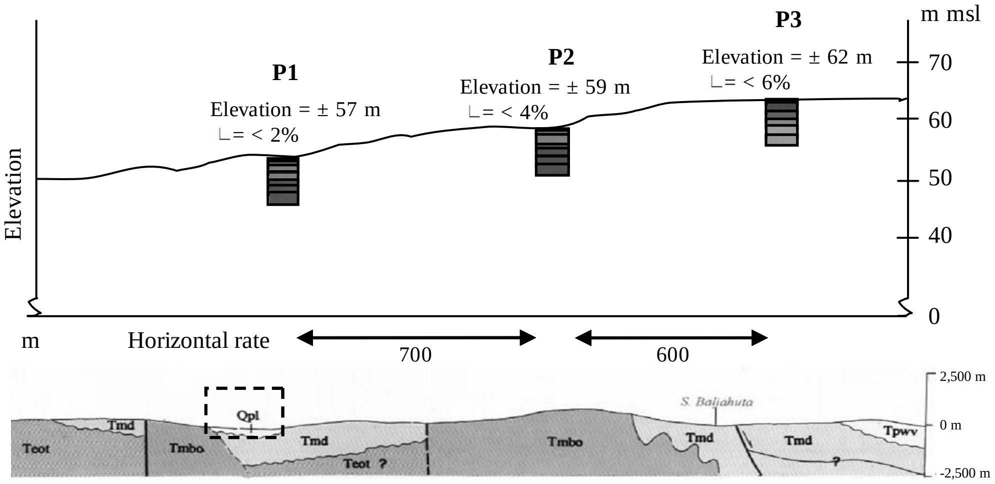

Figure 2. Relief position of each profile to toposequent.

principles of soil survey (USDA 2002). Climate data were taken from Sidodadi climate station of Boliyohuto district of Gorontalo Province.

Soil Analysis

Materials studied were RPS from lacustrine material and soil samples were taken from each selected soil profile.The instrument used was consisted of a set of ground survey equipment and a set of laboratory analysis tools. A laboratory analysis was conducted in the laboratory of Soil Science and Land Resources Department, Faculty of Agriculture, Bogor Agricultural University and in the laboratory of the Center of Land Resources, Bogor. The research activity was conducted from March until August 2009. Soil analysis was consisted of: textures (four fractions); water content (pF 2.5 and 4.2), pH (H_2O and KCl); C-organic; CEC (1 *N* NH_4OAc pH 7.0); Ca^{2+} and Mg^{2+} (Extraction NH_4oAc 1 N pH 7), K^+ and Na^+ (Extraction 1 *N* NH_4OAc pH 7.0); N total; P_2O_5 available (Bray 1); base saturation (calculation);

Table 1. The steps of water available profiles for paddy and corn.

Steps	Methods/assume
1. Determining of effective rainfall (ER) or R_{75} (rain opportunities exceeded 75%)	Determined on a monthly ranking of the R data ten-year periods. All research area were classified flats, so it is assumed R can seep into the soil by $ER_{90\%}$
2. Determining of ETo (reference crop evapotranspiration)	Blaney-Criddle methods.
3. Determining of ETc	ETc = kc x ETo, where Etc is the evapotranspiration potential, and kc is the crop coefficient.
4. Reduction of $ER_{90\%}$ with the ETc to same month.	If the $ER_{90\%}$ > ETc, then obtained a positive value. Conversely, if the $ER_{90\%}$ < ETc, then obtained a negative value.
5. Determining of water available profile. Water available profile (WAP) is the ability to store soil water available for plants or a water holding capacity (WHC).	When the stage-4 obtained a positive value indicates that the WAP on condition of WHC, where plant growth is influenced by climatic factors. However if the stage-4 obtained a negative value, then the amount of water on the WHC reduced by the amount of water to a deficit of stage-4 and indicate the period of growth which is influenced by soil factors. If the value of WHC is smaller than the deficit amount, the amount of WAP is negative or 0. When the WAP was equals zero, then the place of actual evapotranspiration (ETa).
6. Calculated of crop water use (ETc) from WAP	Based on the use of water in the soil with a ratio of 40%, 30%, 20% and 10% in the fourth part of the first, second, third and fourth. If the WAP is not sufficient in the first part of ETc, the plants take the water on the second layer, so on until all four layers until ETc met. If the value of WAP until the fourth layer does not provide for ETc, the water deficit for the month.

Table 2. Kc value in the various crops.

Crops	Stage and time (days)			Periods	Data source
	Initial	Middle Season	Late Season	(days)	
Local Paddy	1.05 (60)	1.20 (80)	0.70 (40)	180	Allen *et al.* (1998)
Superior Paddy	1.05 (40)	1.20 (54)	0.70 (26)	120	
Corn	0.30 (65)	1.20 (40)	0.50 (35)	140	FAO (2001) *cited by* Aqil *et al.* (2008)

Table 3. The conditions of ER and $ER_{90\%}$ during one year.

Rainfall	Month (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$ER_{75\%}$	100.5	39.75	75.75	95.25	198	51	53.25	60.75	23.25	31.5	62.25	84.75
$ER_{90\%}$	90.45	35.78	68.18	85.73	178.2	45.9	47.93	54.68	20.93	28.35	56.03	76.28

Note: ER=effective rainfall.

clay mineral (X-RD), and mineral sand fractions (line counting microscopes).

Data Analysis

Data were analyzed with descriptive and quantitative approaches and interpreted accordingly to meet the purpose of the research. For land potentials assesment LUTs were selected based on categories; staple food plants, economically valuable and as primadonna commodities in Gorontalo Province. The selected LUTs were local paddy LUT and paddy-corn LUT. Description of LUT attributes carried out on 11 attributes and selected two key attributes, namely the production and fertilization since it deals directly with the results of the estimation model of LQ. LUT was then divided into pattern A (local production without fertilization), pattern B (the national equivalent production by 100% dosage of fertilizing recommended), and pattern C (the national equivalent production by prescription fertilizings). Further, two LQs were selected, which were most influential to production, namely water availability (***wa***) and nutrient availability (***na***).

LQ Calculations of ***wa*** were based on plant water balance by Thornthwaite and Mather (1957) methods using climate data (rainfall monthly and air temperature averages), soil water content data in field capacity condition (pF = 2.5) and permanent wilting point (pF = 4.2), and effective rooting depth of 30 cm (Table 1).

For food crops, a thick layer of soil was used *i.e.* per 7.5 cm (0 to 7.5; 7.5 to 15; 15-30 cm). Value of crop coefficient (kc) depending on the stage of plant growth and plant species (Table 2) and the value of ER in the study area are listed in Table 3.

Determination of ***wa*** LQ index was done by using approximation models of production, namely: *Paddy*: y=1.2058$Ln(x)$-2,318 (R^2=0.97); Sudjito (1986) *cited by* Firmansyah *et al.* (2008).
Corn: y = -7.639+1,437x-0.008x^2 (R^2 = 0.99); Notohadiprawiro *et al.* (2006).
Where: y = Mg ha^{-1} and x = water available profile (mm).

The ***na*** LQ was assessed from nutrient needs fulfillment level to meet local and national production potentials or equivalent to a 'very suitable grade of land suitablity grades. Plant nutrients were required from soil and fertilizers. The method that was used to calculate the adequacy of nutrient from the soil and fertilizers was prescription methods. Nutrients used in the determination of this LQ at all LUTs consist of N, P and K. Total nutrient that was used was calculated from the area of one hectare with a depth of 30 cm. The calculation of the amount of nutrients were added to the soil in each LUT depends on the attributes of fertilization technology in various patterns of LUT, *i.e.* A pattern then inferred from the availability of nutrients in the soil without fertilization, B pattern LUT was suspected of soil nutrients and fertilizer recommendations with additional doses full 100%, and C pattern LUT, the nutrient was expected from the amount of nutrients available from the soil added nutrients to meet crop nutrient needed to produce equivalent national level with prescription methods.

Fertilization efficiency was based on the clay textures as the dominant soil texture in the study area, where N (40%), P (20%) and K (60%)

Table 4. Dosage of fertilizer recommendation in each LUT commodities.

LUT commodities	N	P_2O_5	K_2O	Organic matter
	.... kg ha^{-1}	....		
Paddy	125	100	50	5,000
Corn	150	100	120	5,000

Source: Paddy recommended fertilizer based on Appendix Permentan No. 40/Permentan/OT.140/04/2007 on 11 April 2007 about the paddy recommendation of NPK fertilization specific location; corn N (Witt 2007 *in* Aqil *et al.* 2008), PK (Syafruddin *et al.* 2004).

Table 5. Land suitability classes based on land index.

Land index	Land suitability classes	Status
100-75	S1	Very suitable
75-50	S2	Moderately suitable
50-25	S3	Marginally suitable
0-25	N	Not suitable

Source: Sys *et al.* (1991).

(Leiwakabessy and Sutandi 2004 *cited by* Firmansyah *et al.* 2008). Equation estimated produce of each LUT commodity from previous research results were used to connect a number of soil nutrient and fertilizer with crop production. Doses of 100% fertilizer recommended in each LUT listed in Table 4.

Determination of ***na*** LQ index used the lowest produce expectations based on the Law of Minimum Leibig, namely:
Paddy (N): y = 0.4824Ln(x)-0.5027 (R^2= 0.80); Gupta and O'toole (2000), (P_2O_5): y = 0.4258Ln(x)-0.1402 (R^2= 0.95); Suwardjo and Prawirosumantri (1987), (K_2O): y = 2.1093Ln(x)-5.9543 (R^2= 0.76); Jumberi *et al.* (1994), Corn (N): = 3.322+0.0504x-0.0002x^2 (R^2= 0.99); Sirappa (2003), (P_2O_5): y = 2.276+0.0758x-0.0003x^2 (R^2=0.97); Syarifuddin *et al.* (2004), (K_2O): y = 3.16+0.0537x-0.0002x^2 (R^2= 0.99); Syarifuddin *et al.* (2004). Where: *y* = Mg ha^{-1} and *x* = kg ha^{-1}.

Production of the lowest prediction results were then sought through a comparison with the rates of commodity produce level according to set LUT patterns for determining ***na*** LQ index. Assessment of land suitability was using parametric approachs. Land index (LI) was calculated based on the square root of land index (Khaidir 1986 *in* Sys *et al.* 1991), namely:

$I = Rmin\ [(A/100) \times (B/100)]^{1/2}$

Where: *I* = square root of land index; *Rmin* = minimum LQ rating; *A*, *B* = other LQ in beside LQ minimum.

Determination of land suitability classification based on LI that was calculated of all LQ that was affected by production of each LUT commodity and would have a specific land suitability class. The LI that is used are listed in Table 5.

RESULTS AND DISCUSSION

Characteristic of Rainfed Paddy Soils

All pedons showed that their developments were characterized by the presence of structuring (B horizon). Color matrix of the soil pedon was located in the lower and middle slopes of 10YR hue and chroma $\leq$ 2 from top to $\geq$ 150 cm and the pedon was located on the slope above the 7.5 YR hue and chroma varied between 1 to 3 (Table 6). Color matrix indicates that the soil solum has developed. Subsequently, pedons located in the lower and middle slope have experienced strong gleization (g) at all horizons, temporarily located on the slope above the only Ap horizon. Gleys color formation caused by the influence of water saturation by a long (shallow ground water <100 cm) and reduced Fe, and Fe removed during soil formation. He *et al.* (2002) showed that on average it took 21 d for Fe reduction to begin after saturation. According to Morgan and Stolt (2006), the first occurrence of depletions marks the depth where the soil was saturated for at least 21 consecutive days. Their study resulted that soils were saturated 23 to 96 cm above horizons with depletions, and horizons with common 2-chroma depletions were saturated from 26 to 103 consecutive days. Prasetyo (2008) reported that paddy soil developed in depositional areas has gley color and rusty because this soil formed under conditions of shallow ground water. Rust were found in all pedons and dominated by brown color with chroma > 3, except pedons P3 with yellow color that was suspected of Al Oxide. This shows that the pedons are experiencing oxidation and reduction conditional.

All pedons were dominated by clay textures. Upper horizon was generally much rougher than the lower horizon. The ratio of fine clay to total clay (FC/TC) in the middle of the solum (B-illuviation) higher than the horizons at the top (A-elluviation) and lower horizons. This shows that there has been elluviation process and illuviation (lessivage) smooths clay, although in each pedon the clay skins have not been found. Low degree of lessivage was related to low rainfall and the presence of shallow ground water at a certain profiles. This was a result of clay illuviation process, and in addition, also because of the influence of cracks in the dry season for the removal of clay (fine clay) in the wetting season, so that the clay content varied in each horizon. Liu *et al.* (2003) reported that increased fracture aperture and flooded water depth only temporarily increased the rate of infiltration. Soil swelling most strongly affected the rate of infiltration. When cracked, swelling soil mixtures were flooded with water that was rich in clay particles. Cracks might develop in the surface of paddy fields owing to continuous drying by the sun after harvesting. Soil structures on the surface of all horizons were massive because of the destruction of soil aggregates during the process. The horizon on the lower part had structures with sizes ranging from fine, medium to coarses with the level of development of under developed, weak and strong. According to Kishné *et al.* (2009), soil water content and stronger soil structure may also inûuence the balance between greater cracking potential and less actual crack formation. Besides, soil organic matter levels, and soil functions (such as water inûltration, and water holding capacity) were related to soil aggregation (Six *et al.* 2004; Pirmoradian *et al.* 2005).

The pH of investigated soil reaction ranges from base to slightly alkaline or from 5.38 to 7.91 (Table 7). The pH differencies of KCl to H_2O (ÄpH) of all pedons have negative charges. This is suitable to the results of clay minerals analysis that dominated by smectite which is a 2:1 clay types (Table 8). High value of pH is an indication to a depression and low washing areas.The neutral to slightly alkaline pH of soils indicates that the soil has not experienced further weathering. C-organic concentrations of all pedons are dominantly very low (< 1.0%), except on the low surface horizons ($\leq$ 1.38%). Kasno *et al.* (2003) reported that most of the rice land in Indonesia have a C-organic content < 2%. Its distribution pattern

Table 6. Soil Physical characteristics of RPS pedons in Sidomukti of Gorontalo.

Horizon	Depth (cm)	Color		Struc-ture	Texture (%)					% FC/TC	TeC/ GSC
		Matrix	Mottling		Sand	Silt	Coarse clay	Fine clay	Total clay		
					………………… % …………………						
P1											
Apg1	0-12	10 YR 5/1	-	massive	31	34	9	26	35	1.03	CL/F
Apg2	12-31	10 YR 5/1	10 YR 5/3	1 f ab	23	42	9	26	35	0.83	CL/F
Bwg1	31-53	10 YR 5/1		1 m ab	13	37	10	40	50	1.35	C/F
Bwg2	53-71/92	10 YR 6/1		1 c ab	12	31	10	47	57	1.84	C/F
Bwssg	71/92-119	10 YR 4/1	10 YR 5/3	2 m ab	10	30	6	54	60	2.00	C/VF
BCg1	119-150	10 YR 4/1	10 YR 5/3	3 c ab	11	21	18	50	68	3.24	C/VF
BCg2	150-200	10 YR 4/1	-	-	16	27	20	37	57	2.11	C/F
P2											
Apg1	0-10	10 YR 5/2	-	massive	36	37	5	22	27	0.73	L/FL
Apg2	10-31	10 YR 5/2	-	1 m ab	37	37	6	20	26	0.70	L/FL
Bwg1	31-64	10 YR 6/2	-	1 m ab	23	54	18	5	23	0.43	SiL/FL
Bwg2	64-84/103	10 YR 6/2	10 YR 5/3	1 m ab	20	29	8	43	51	1.76	C/F
Bwg3	84/103-150	10 YR 4/1	10 YR 4/6	2 m ab	16	22	10	52	62	2.82	C/VF
BCssg1	150-200	10 YR 4/1	-	2 m ab	23	32	17	28	45	1.41	C/F
BCssg2	>200	10 YR 4/1	-	2 m ab	24	35	20	21	41	1.17	C/F
P3											
Apg	0-10	7,5 YR 3/1		massive	38	28	10	24	34	1.21	CL/FL
Bw	10-34	7,5 YR 4/3	-	1 f ab	37	32	11	20	31	0.97	CL/FL
Bwg1	34-61	7,5 YR 5/2	-	1 m ab	35	22	10	33	43	1.95	C/F
Bwg2	61-86	7,5 YR 6/2	-	1 c ab	33	45	19	3	22	0.49	L/FL
Bwssg	86-120	7,5 YR 7/2	7.5 YR 7/6	2 m ab	29	20	9	42	51	2.55	C/F
Bwss	120-150	7,5 YR 7/3	7.5 YR 7/8	3 c ab	34	8	9	49	58	7.25	C/F

CL = coarse clay; FC = fine clay; TC = total clay; TeC =t exture class; GSC = grain size classes: C = clay, SiC = silty clay; L = loam, SiL = Silty loam; F = fine, VF = very smooth; and FL = fine loamy.

Table 7. Soil chemical properties of RPS pedons in Sidomukti of Gorontalo.

Horizon	Depth (cm)	pH H_2O	C-Organic (%)	Bases exchangeable Ca	Mg	K	Na	∑ Base-Exc	CEC Clay	Soil	Base saturation	Total - N	P_2O_5
				……………cmol kg^{-1}							…… %	……	mg kg^{-1}
P1													
Apg1	0-12	6.13	0.93	14.63	5.51	0.22	0.45	20.81	85.56	29.95	69.50	0.08	2.21
Apg2	12-31	6.83	0.45	15.16	6.58	0.25	0.55	22.55	91.16	31.91	70.66	0.04	5.39
Bwg1	31-53	6.55	0.26	16.32	13.74	0.43	1.02	31.51	74.36	37.18	84.76	0.02	2.47
Bwg2	53-71/92	5.95	0.33	19.42	17.36	0.53	1.31	38.62	90.33	51.49	75.01	0.02	6.43
Bwssg	71/92-119	6.20	0.27	27.78	26.48	0.56	1.95	56.77	105.74	63.44	89.48	0.01	4.55
BCg1	119-150	7.09	0.27	25.05	26.52	0.47	2.13	54.17	94.22	64.07	84.55	0.02	6.48
BCg2	150-200	7.70	0.26	27.83	13.56	0.39	2.34	44.13	40.86	23.29	189.45	0.02	6.64
P2													
Apg1	0-10	6.35	0.71	10.33	2.52	0.15	0.27	13.26	135.66	36.63	36.20	0.06	4.02
Apg2	10-31	7.26	0.38	11.03	3.03	0.21	0.67	14.93	91.95	23.91	62.47	0.05	4.29
Bwg1	31-64	5.91	0.26	15.71	6.18	0.39	1.34	23.62	164.52	37.84	62.44	0.03	10.98
Bwg2	64-84/103	5.38	0.13	14.53	6.50	0.39	1.64	23.06	121.01	61.71	37.36	0.02	1.63
Bwg3	84/103-150	6.73	0.13	26.36	19.21	0.48	2.79	48.84	76.87	47.66	102.47	0.02	2.51
BCssg1	150-200	7.74	0.19	23.44	16.98	0.58	2.54	43.54	103.05	46.37	93.89	0.01	3.02
BCssg2	>200	7.91	0.13	21.42	16.86	0.49	2.30	41.07	83.91	34.40	119.38	0.01	3.27
P3													
Apg	0-10	6.31	0.77	13.99	5.77	0.25	0.22	20.23	101.18	34.40	58.79	0.08	4.57
Bw	10-34	6.86	0.51	14.98	7.05	0.21	0.30	22.54	111.31	34.51	65.34	0.05	3.51
Bwg1	34-61	6.07	0.32	15.04	12.60	0.24	0.52	28.40	82.73	35.58	79.83	0.04	4.36
Bwg2	61-86	5.51	0.26	14.91	14.26	0.22	0.63	30.03	180.46	39.70	75.63	0.03	1.37
Bwssg	86-120	5.60	0.19	16.79	16.12	0.29	0.75	33.95	81.24	41.43	81.94	0.02	1.10
Bwss	120-150	5.52	0.19	17.27	17.95	0.36	0.81	36.40	69.10	40.08	90.82	0.02	1.10

CEC = cation exchange capacity.

Table 8. The persentage of sand fraction minerals.

Pedons: Horizons	Depth cm	DWM Op	Qz	Lm	∑	EWM Ab	Ol	An	La	Or	Sn	Ao	Hh	Ep	En	∑	EWM/DWM
		……………… %															
P1																	
Bwg2	53-71/93	2	58	1	61	4	-	-	1	1	3	1	8	1	1	20	0.33
BCg2	150-200	2	50	-	52	4	-	-	4	2	3	-	4	1	-	18	0.35
P2																	
Bwg2	64-84/103	1	78	-	79	2	1	-	1	-	4	-	1	1	-	10	0.13
BCssg2	>200	1	80	-	81	1	1	2	5	2	3	-	1	-	-	15	0.19

Op = opaque, Qz = quartz, Lm = lymonite, ∑ = sum, Ab = albite, Ol = oligoclas, An = andesine, La = labradorite, Or = orthoclas, Sn = sanidine, Ao = anorthoclas, Hh = green hornblende, Ep = epidote, En = enstatite, EWM = easily weathered minerals, DWM = difficulty weathered minerals.

tends to be high on the surface, and decreases dramatically in the B horizon which continues to decline according depth, in accordance with the pattern reported by Prasetyo (2007). This is a general pattern of developed soil. The clay mineral type has some influences on that high and very high cation exchange capacity (CEC). Weathering process can be seen from the CEC clay values. All pedons have CEC clay >40 cmol kg^{-1} in all horizons. Thus, all the studied pedons have experienced weathering but not in advanced stage.

All pedons show very high base saturations. This condition occurs due to high number of exchangeable base. The study area is a depression where bases accumulate from the washing water brought from the hinterland. Dominant base is calcium (Ca) which is high to very high. The high value of exchangeable base is caused by low rates of bases leaching due to low rainfall and the relatively shallow ground water. Based on their consentration, the excangeable bases can be presented in a series: Ca>Mg>K>Na. Rate of

Table 9. Clay fraction mineral analysis with X-Ray diffraction.

Pedons/horizons	Peak of X-Ray diffractions (Å)	Note	Mineral kinds
P1			
Bwg2	15.20; 5.03; 16.15;12.31; 10.07	+++ (dominant)	Smectite
	7.29; 3.56	+++ (dominant)	Kaolinite
	9.29	+ (minor)	Illite
	3.20	+ (minor)	Feldspar
	4.26; 3.33	+ (minor)	Quartz
BCg2	15.07; 5.00; 18.68; 12.71; 10.07	+++ (dominant)	Smectite
	7.32; 3.58	+++ (dominant)	Kaolinite
	10.34	+ (minor)	Illite
	3.20	+ (minor)	Feldspar
	4.26; 3.33	+ (minor)	Quartz
P2			
Bwg2	15.05; 5.00; 17.04;12.61; 10.01	+++ (dominant)	Smectite
	7.19; 3.56	+++ (dominant)	Kaolinite
	10.20	+ (minor)	Illite
	3.20	+ (minor)	Feldspar
	4.26; 3.33	+ (minor)	Quartz
BCssg2	15.35; 5.00; 18.68;13.03; 10.21	+++ (dominant)	Smectite
	7.19; 3.56	++ (moderate)	Kaolinite
	9.02	+ (minor)	Illite
	3.20	+ (minor)	Feldspar
	4.26; 3.33	+ (minor)	Quartz

weathering can be seen from the ratio of easily weathered minerals (EWM) to difficultly weathered minerals (DWM), where the ratio of EWM to DWM decreses with increasing weathering. The ratio of EWM/DWM ranged from 0.13 to 0.35 (Table 8) due to more intensive tillage.

Pedogenesis process of all pedons is relatively influenced by three main factors; low rainfall, young age of the land, flat to undulating topography (depression) which is important as base accumulation place, so that the pH is generally neutral ground which allows the formation of 2:1 mineral types and allow the transfer of material occurs due to soil erosion. Low rainfall causes limited leaching and so, increse of the base. In addition, the shallow ground water (<100 cm) causes the infiltration and perculation of water hampered. Poor drainage and young age of the soil (*Pleistocene* and *Holocene epochs quarter*), are reasons why a more developed horizon of cambic is not formed yet. A climatic and drainage condition causes the development of vertic properties.

Based on the soil characteristics described previously, all pedons have Ap-ochric epipedon and Bw-cambic diagnostic horizons. The horizon sequence indicated that the soils have moderate pedons development (Van Ranst *et al.* 2002; Hikmatullah and Nugroho 2010). Pedon P1 located on the foot slope were classified (Soil Survey Staff 2010) as *Ustic Endoaquert, smooth, smectitic,* and *isohypertermic*. This is because the pedon has slikenside at <100cm depth, aquic condition originating from below the surface (endosaturation), has a matrix color chroma $\leq$ 2, and cracks of 5 mm or more with 25 cm depth from the soil surface. Pedon P2 located in the shoulder slope is classified as *Vertic Endoaquept, smooth, smectitic,* and *isohypertermic*. This is due to this pedon has slikenside at depths >150 cm, all the horizons have aquic conditions, where the water comes from below the surface for some time in normal years with chroma $\leq$ 2 due to the concentration of redox, has been cracks widely of 5 mm or more to depth of >125 cm. While the P3 pedon located on the summit slopes were classified as *Vertic Epiaquept, smooth, smectitic,* and *isohypertermic*. This was caused by slikenside, clay content of the total weighted average of 34% in the fine soil fraction between the soil surface and a depth of 18 cm or in the Ap horizon, 36% total clay in the fine soil fraction in all horizons between a depth of 18 cm and 50 cm, a condition akuik at a depth of 50 cm from the surface (episaturation) with chroma $\leq$ 2, and has been cracks widely of 5 mm to depth of 25 cm.

Table 10. Land index and land suitability class of local paddy LUTs on some patterns and types of RPS in Paguyaman, Gorontalo.

Patterns	Nutrient/water availability	Soils/location					
		Ver Sid		Inc-1 Sid		Inc-2 Sid	
		LI	LSC	LI	LSC	LI	LSC
A	N/WAP	39	S3na	39	S3na	44	S3na
	P/WAP	26	S3na	29	S3na	28	S3na
	K/WAP	100	S1	100	S1	100	S1
	Final LSC		*S3na*		*S3na*		*S3na*
B	N/WAP	53	S2na	53	S2na	53	S2na
	P/WAP	52	S2na	52	S2na	52	S2na
	K/WAP	100	S1	100	S1	100	S1
	Final LSC		*S2na*		*S2na*		*S2na*
C	N/WAP	100	S1	100	S1	100	S1
	P/WAP	100	S1	100	S1	100	S1
	K/WAP	-	-	-	-	-	-
	Final LSC		*S1*		*S1*		*S1*

WAP = water availability profile; Ver = Vertisol; Inc = Inceptisol; Sid = Sidomukti; LI = land index; and LSC = land suitability class.

Potential of Rainfed Paddy Soils

Local paddy LUTs. The highest land index value for local paddy LUT occurs in Pattern C compare to Pattern A and B (Table 9). The highest index value that occurs at Patterns A and B related to availability of kalium (K) which is very high.This differencies occurs due to different results in LQ index calculation as the attributes in production are differed. Rice production in Pattern A at local level is only 1.5 Mg ha^{-1} and production in Pattern B at national level is 3.5 Mg ha^{-1}. In addition, the precence of fertilization technology in Pattern B had increses its production at ***na*** LQ.

Land suitability class (LSC) is distributed evenly based on the LUT patterns. Comparison between the LSC of each pattern is 1:1:1 of very suitable (S1), moderately suitable (S2), and marginally suitable (S3). The limiting factor of these LUTs was the nutrient availability (S2na and S3na) for A and B patterns. While the C patterns are all

Table 11. Land index and land suitability class of paddy corn LUTs on some pattern and types of RPS in Paguyaman, Gorontalo.

Patterns	Nutrient/water availability	Soils/location					
		Ver Sid		Inc-1 Sid		Inc-2 Sid	
		LI	LSC	LI	LSC	LI	LSC
A	N/WAP	28	S3na	30	S3na	29	S3na
	P/WAP	22	Nna	23	Nna	22	Nna
	K/WAP	44	S3wa	46	S3wa	43	S3wa
	Final LSC		*Nna*		*Nna*		*Nna*
B	N/WAP	38	S3wa	43	S3wa	39	S3wa
	P/WAP	40	S3wa	46	S3wa	41	S3wa
	K/WAP	43	S3wa	49	S3wa	44	S3wa
	Final LSC		*S3wa*		*S3wa*		*S3wa*
C	N/WAP	45	S3wa	51	S3na	45	S3wa
	P/WAP	45	S3wa	51	S3wa	45	S3wa
	K/WAP	-	-	-	-	-	-
	Final LSC		*S3wa*		*S3wa*		*S3wa*

Ver = Vertisol; Inc = Inceptisol; Sid = Sidomukti; LI = land index; and LSC = land suitability class included LSC is very suitable (S1). This indicates that prescriptional fertilization and water availability are crucial to increase production of commodities. However, if one compares the land index and LSC of Patterns A and B to those of Pattern C, Pattern C has a higher value. This is in line with the report presented by Firmansyah *et al.* (2008) that prescriptional fertilization assure production achievement higher than the recommended 100% dosage fertilization.

Paddy-corn LUTs. Land index value in these LUTs was lower than local paddy LUTs in all patterns (Table 11). This is due to the low of nutrient availability LQ index in the A pattern and the low of ***wa*** LQ index for B and C patterns. According to Olnes and David (2005), water availability content is strongly influenced by levels of C-organic and C-organic influence its effect varies with soil texture. In addition, there are differences in the calculation of the land index due to the different attributes of the production. Paddy production of pattern A on the local level was just as much as 1.5 Mg ha^{-1} and corn was only of 5 Mg ha^{-1}, while paddy production on the national level in the pattern B and C was 3.5 Mg ha^{-1} and corn was 7 Mg ha^{-1}. The lowest index value was contained in Pattern A and the highest was in Pattern C.

In overall, LSC in this LUT was only consisted of marginally suitable with the limiting factor of water availability (S3wa) and not suitable with nutrient availability as limiting factor (Nna). This is in line with the statement of Raihan (2000) that crops cultivated today requires nutrients of various types and in high amount, so that no cultivated plants can give the expected result without fertilization. This condition is quite reasonable because the pattern A only source of nutrients in the soil without fostered, so that nutrient deficiency for the application of paddy corn LUTs. Based on this LUTs pattern, the pattern A including not suitable LSC (Nna). While the pattern B and C are more dominant as the marginally suitable with the water availability as limiting factors (S3wa).

One of the improvements that can be done is provision of organic materials to improve water movement and retention. According to Wahjunie *et al.* (2008) that to improve water movement and retention in paddy soils additional organic matters are needed. This was also to increase C-organic consentration in soil that were very low (0.13 to 0.93%) at all locations. Prasetyo and Setyorini (2008) state that if actions to elevate the level of C-organic are not taken immediately, then within the next few years the paddy productivity will decrease and fertilizer input requirement will increase. Organic materials can be sourced directly in situ or from outside. Another improvement effort can be done by adjusting the soil properties that have a Vertisol and Inceptisol vertic nature. According to Prasetyo (2007), a vertisol soil types has dark grey to black color, clay texture, slinckenside, and cracks which can periodically open and close. For reduction of cracking after rice harvest in vertisol, the wheat residue of the previous crop should be retained (Mohanti *et al.* 2006).

CONCLUSIONS

All pedons has developed in the presence of B-cambic horizon with the middles level development, where pedons located on the summit of the slope was more developed and weathered intensively than pedons in the shoulder and foot slopes. The main weathering processes of all pedons are elluviation, illuviation, lessivage, and pedoturbation and gleization process. The main factors of the soil forming in all pedons are climate, age and topography. Therefore, P1 Pedons classified as *Ustic Endoaquert, smooth, smectitic, isohypertermic*; P2 as *Vertic Endoaquept, smooth, smectitic, isohypertermic*; and P3 as *Vertic Epiaquept, smooth, smectitic, isohypertermic.*

Based on the soil potency, the highest LSC of local paddy LUT is very suitable in the pattern C, while the lowest is marginally suitable with the nutrient availability as limiting factor in the pattern A. For the pattern B, the LSC is moderately suitable with the same limiting factor in Pattern A. The highest of paddy-corn LUT were marginally suitable with the water availability as limiting factor in pattern B and C, while the lowest is not suitable with the nutrient availability as limiting factor in the pattern A.

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