DISTRIBUTION OF PHOSPHORUS FRACTIONS FROM NORTH TO SOUTH TOPOSEQUENTLY IN WEST JAVA, INDONESIA PADDY SOILS

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(Received: February 22, 2019; Accepted: April 26, 2020)

ABSTRACT

Paddy soils in West Java, Indonesia distribute from northern part to southern part with different land characteristicts due to different in elevation. These land characteristics determine the distribution of phosphorus (P) fractions. This research sought to evaluate the P fractions distribution from north to south and the effect of elevation to the P fraction distribution. The research was conducted in paddy soils in West Java, Indonesia from May to December, 2015. Soil samples were collected in sixty (60) locations distributed from north to south of West Java, Indonesia toposequently. These soil samples were collected between 0 and 1162 meters above sea level (asl) representing different land characteristics. The levels of soil P in different fractions were determined by sequential fractionation. The study showed that paddy soils in West Java, as a whole, contained total-P amounting 72240 mg P kg^{-1}. Even though the total-P was very high, the labile P fractions were very low, only about 7% and almost 93% were moderately labile to non labile P fractions which accumulated in the soil. P accumulated mostly in residual-P and in NaOH-$P_{inorganic}$ (P_i), -$P_{organic}$ (P_o) in all elevations. NaOH-P_i, -P_o fractions increased significantly with elevation. The mean values of NaOH-P_i increased with the increase of elevation. It indicated that the higher elevation contained higher Al and Fe hydrous oxides. The other P fractions relatively were not affected by elevation indicating that effect of elevation was masked by other factors like fertilizer. From the total P, P was more accumulated at an elevation of 300-700 above sea level (asl) suggesting that fertilization was more intensive in that elevation. $NaHCO_3$-P_i, NaOH-P_i, -P_o and residual-P were positively correlated with resin-P_i which was readily available P indicating that $NaHCO_3$-P_i, NaOH-P_i, -P_o and residual-P could be transformed to resin-P_i. These results suggest that mining P is a must due to very high P accumulation in West Java paddy soils. The P fertilization management in West Java paddy soils must consider the elevation due to the different amount of NaOH-P_i and residual- P in different elevation. More attention should be given to paddy fields located at 300-700 asl due to very high P accumulation.

Key words: elevation, fertilization, management, NaOH-P_i

INTRODUCTION

The application of phosphorus (P) fertilizer in the paddy soils can be inefficient due to soil P retention by the soil particles. P fertilizer added to the paddy soils are transformed mostly to aluminium phosphate, ferric phosphate, calcium phosphate and organic phosphate with diffrent levels of bonding energies (Oberson et al. 2001, Schmidt et al. 1996, Verma et al. 2005, Zheng et al. 2002, Hartono et al. 2006).

Nutrient accumulation in paddy soils were demonstrated in Korea and China (Park et al. 2004, Li et al. 2015). In Indonesia, P status in paddy soils of Java were high, particularly in West Java (Sofyan et al. 2004, Setyorini et al. 2010). P fractionation in West Java was distributed mostly as NaOH-P_i which is more strongly held by chemisorption to Fe and Al oxides and in the form of residual P which is practically not available to plant (Hartono et al. 2015). P fractions in paddy soils were influenced by parent materials, soil type, physicochemical properties, clay mineral types, climate and the cultivation technique. Some factors can be represented by elevation from above sea level because different elevation are mostly different in soil properties. Paddy soils in West Java Indonesia, distributed from north to south with different soil characteristic, parent material, soil type, elevation and climate. Paddy soils topography in northern part of West Java are flat and their parent materials mostly from alluvium material. In mid-West Java the land elevation is between 400-1300 m above sea level (asl). South of West Java, the lands are flat, mostly developed from sediment parent materials.

This research sought to determine P fraction distribution from north to south of West Java, Indonesia and evaluate the effect of elevations on P fractions distribution.

MATERIALS AND METHODS

Soil sampling. The research was conducted in paddy fields in the West Java region, Indonesia. The research method used was a field survey and analysis in the laboratory. Field surveys were carried out to take composite soil samples using a soil auger at depth of 0-20 cm. Composite soil samples were collected at 60 points on three transects from north to south West Java (Fig. 1). In transect 1, 20 samples were collected covering Bekasi, East Bogor, northern part of Cianjur to Southern part of Cianjur. In transect 2, 20 samples were collected covering Subang, Sumedang, Bandung, Garut north to south. In transect 3, 20 samples were collected covering Indramayu, Cirebon, Kuningan, Majalengka, Ciamis and Southern part of Pangandaran. The soil samples were collected compositely.

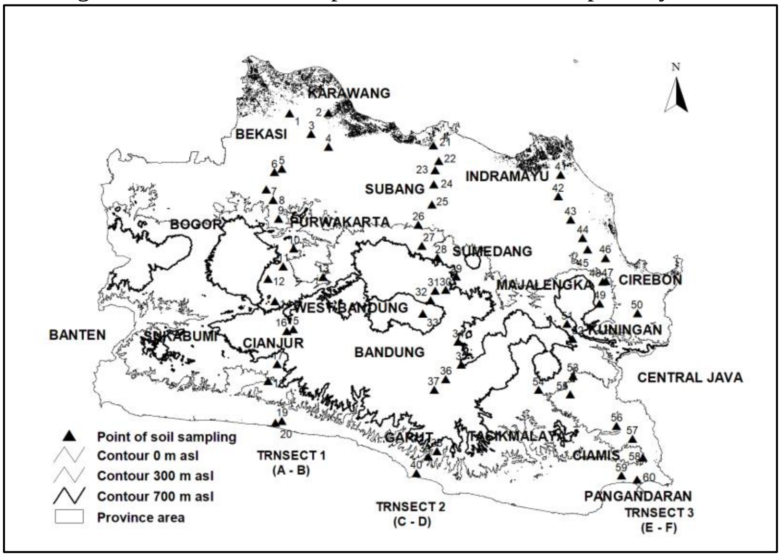


Fig. 1. Distribution of 60 soil sample points from north to south west Java at various elevations.

The composite samples point of 60 locations was determined by purposive random sampling by considering: 1) West Java Province Administration Map Scale 1:250,000 (Bakosurtanal 2009), 2) West Java Province Land Use Map Scale 1: 10,000 (Pusdatin 2014), 3) Map of P statue on paddy fields in West Java and Banten provinces, Scale 1: 500,000 (BBSDLP 2010), 3) West Java Province SRTM (Bakosurtanal 2003), and 5) Soil map of West Java Province, Scale 1: 250,000 (BBSDLP 2014). The parent material information for each sample point location was obtained from the soil map database. Arc.GIS 10.1 software was used to overlay the five maps, so that 60 sample locations are obtained.

Selected chemical soil properties and clay mineralogies. The soil samples were analyzed at the Laboratory of Soil Chemistry and Fertility, Department of Soil Science and Land Resource, Faculty of Agriculture, IPB University (Bogor Agricultural University). These included soil texture of three fractions (pippete method), pH (H_2O), organic C (Walkley and Black), total N (Kjeldahl), P (HCl 25%), P (Bray-I), CEC (NH_4OAc 1 mol L^{-1} pH 7), exchangeable bases (Ca, Mg, K, Na) (NH_4OAc 1 mol L^{-1} pH 7) (Sulaeman et al. 2005). Dithionite-citrate-bicarbonate (DCB) Fe and Al (Fe_d and Al_d) contents were determined by the method of Mehra and Jackson (1960). Oxalate Fe and Al content (Fe_o and Al_o) of soil samples were extracted by 0.3 mol of L^{-1} ammonium oxalate at pH 3 for 4 hours in a dark room (McKeague and Day 1966). The Fe and Al extracts in the form of Fe_d, Al_d, Al_o and Fe_o were filtered using a 0.45 µm filter (Hartono et al. 2005) and analyzed by atomic absorption spectrophotometry (Shimadzu Model AA-6300). Clay mineral analyses were carried out at the Bandung Geological Research Center Laboratory using an X-Ray diffractometer (Rigaku RAD-2RS Diffractometer). Composite soil samples of 13 representative samples originating from the top layer, 0-20 cm, from 60 soil samples collected based on transects from north to south in West Java were analyzed.

Soil P fractions. The procedure for determining P fractions sequentially refered to the fractionation procedure carried out by Hedley et al. (1982) modified by Tiessen and Moir (1993), Hartono et al. (2006) and Hartono et al. (2015). This procedure characterized P-inorganic fractions (P_i) and P-organic (P_o) based on their solubility.

Determination of total P was carried out separately using destruction method with concentrated nitric acid and perchloric acid. Residual-P was determined by subtracting the P-total from the sum of resin-P_i, $NaHCO_3$-P_i, -P_o, NaOH-P_i, -P_o, and HCl-P_i. Residual-P is interpreted as the occluded P (P_i and P_o adsorbed on the surface of Fe and Al oxide in soil aggregates) and recalcitrant organic P (Tiessen and Moir 1993, Dobermann et al. 2002, Velásquez et al. 2016a). Velásquez et al. (2016b), Costa et al. (2016) and Herrera et al. (2016) classify P fractions into three, namely: (i) labile P fractions (Resin-P_i, $NaHCO_3$-P_i and -P_o), (ii) moderately labile P fractions (NaOH-P_i, -P_o and HCl-P_i), and (iii) non labile P fraction (Residual-P). The procedure for determining the fractionation of P is described in Hedley et al. (1982), Tiessen and Moir (1993), and Hartono et al. (2015). P in the solution was determined at 770 nm using a UV-VIS spectrophotometer (UV-1280, UV-VIS Spectrophotometer, Shimadzu Corporation, Japan) (Murphy and Riley 1962).

Statistical analysis. Statistical analysis used cluster analysis, correlation and variance (ANOVA). Cluster analysis was used to compile paddy fields based on elevation. Correlation analysis was used to find the relationship of fraction P with some chemical properties of paddy fields. While ANOVA (Analysis of Variance) was used to test the effect of elevation groups on each P fraction using SPSS version 20.

RESULTS AND DISCUSSION

Elevation of the area study. Paddy fields in West Java are scattered at various elevations, ranging from 0-1,162 meters asl and spread from the north to the south coast. The altitude of the places are strongly related to the climate, especially rainfall, temperature and humidity which affect the weathering process of the parent material both physically, chemically and biologically (Dixon et al. 2016, Egli and Poulenard 2017). The results of the cluster analysis showed that the characteristics of paddy soils in West Java can be grouped into three, based on elevation, namely: (1) lowland paddy fields (LPF), 0-300 meters asl, (2) medium paddy fields (MPF), 300-700 meters asl and (3) upland paddy fields (UPF), > 700 meters asl.

The best number of clusters was three (Fig. 2), where at that time there was a sharp increase in the agglomeration coefficient (Morrison 1990). LPF were generally dominated by alluvium parent material formed in the landform of alluvial plains. MPF parent materials were generally alluvium, sediment and volcanic which were formed in the aluvio-colluvial landforms, volcanic plains, lower volcanic slopes, tectonic hills, karst hills, and lava flows. MPF were formed from a more diverse parent material and the soils were usually underwent more intensive weathering. UPF were almost the same as the MPF, which were formed from a variety of parent materials. Rainfall was greater at higher elevation. In West Java, the mean annual rainfall of 5-year rainfall data (2009-2014) ranged from 2300-3300 mm. The lowest mean annual rainfall was in the northern coast of West Java and increased with altitude from north to south West Java (Fig. 3). Elevation also correlated negatively with air temperature, which according to Braak Law (Arsyad 2006), every increase of 100 m asl results in a decrease in temperature of 1°C.

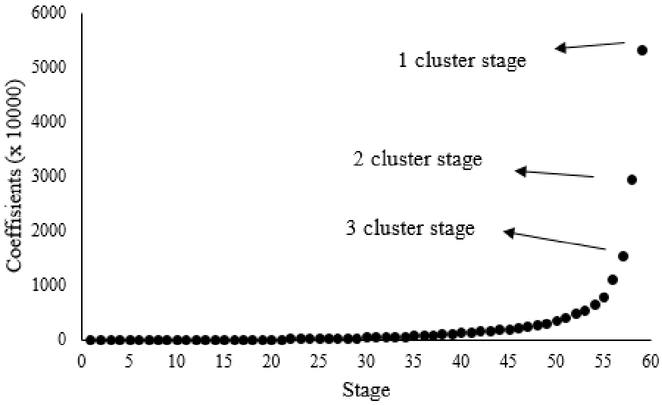


Fig. 2. Agglomeration coefficients to determine the number of clusters classifying altitude of paddy fields in West Java, Indonesia.

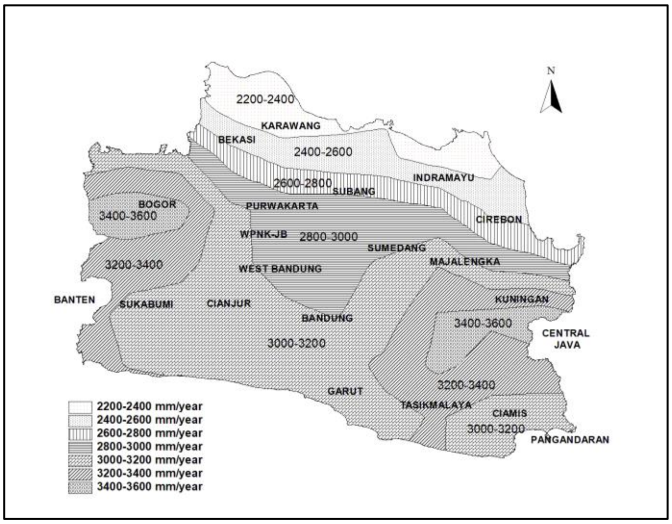


Fig. 3. Annual rainfall map in West Java Province

Parent materials and mineralogical propertis of the area study. Paddy fields in West Java in 2015 were approximately 912,794 ha, which consisted of 736,635 ha of irrigated and 176,159 ha of non-irrigated paddy fields (BPS West Java Province 2017). These paddy fields produce 10,854,438 tons of rice with a productivity of 6.20 tons per hectare. Based on the West Java Soil Map scale of 1: 250,000 (BBSDLP, 2014), paddy fields in West Java developed in three groups of parent materials, namely alluvium, sediment and volcanics with different mineralogical properties. The distribution of the parent material of paddy fields in West Java is shown in Fig. 4.

Alluvium materials were often found in the paddy fields of the northern coast of West Java from Bekasi to Cirebon. The materials of this alluvium were mostly clay deposits and only a small amount was in the form of sand deposits. Paddy fields developed in landforms of alluvial plains, alluvial basins, lacustrine basin, colluvial fields, aluvio-colluvial land, flood plains on river meanders, and coastal sand. The sediment material found in paddy fields in West Java originated from clay, sandstones, calcareous clay, and limestone. Theses paddy fields developed on landforms of undulating tectonics, tectonic hills, choppy tectonic plains, cliff plateau, flat tectonic plains, surging tectonic plains, horst, and karst hills. While the volcanic material found in paddy fields in West Java derived from andesite, basalt, and tuff. These paddy fields developed in volcanic terrain, subrescent lava flow, middle volcanic slope, lower volcanic slope, old volcanic hills subrescent lava flows, resident lava flows and old volcanic plains (BBSDLP 2014). The characteristics of the parent material are strongly influenced by the mineral composition in it. Weathering of primary minerals such as feldspar, ferromagnesium, volcanic glass, mica, zeolite and apatite in the soil produce nutrients such as Ca, Mg, Na, and K which are needed for plant growth. While secondary minerals, such as smectite or vermiculite (mineral 2:1), chlorite (2:1 clay mineral with Al inserted), kaolinite and halloysit (mineral 1:1) which are developed by neo formation determine the charges of the soils. Paddy fields dominated by clay minerals with high negative charge from 2:1 type minerals such as smectite are more reactive when compared to paddy fields dominated by minerals with Fe and Al hydrous oxides with low negative charge. Paddy fields dominated by type 1:1 minerals, in terms of soil management do not have significant obstacles when compared to paddy field dominated by 2:1 type which must be kept under moist conditions, unless the soils swell and shrink (Prasetyo et al. 2004).

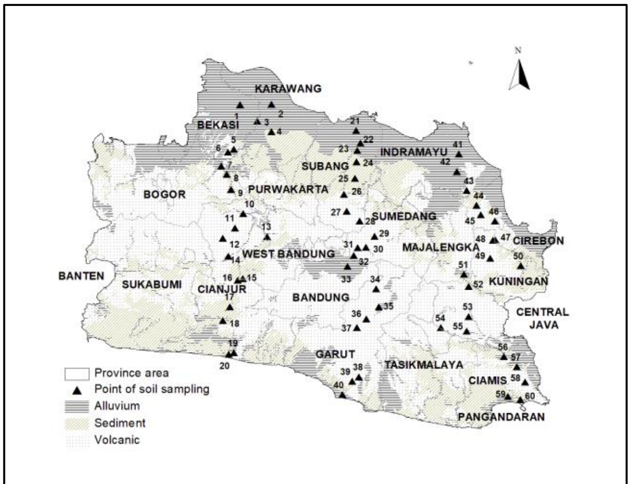
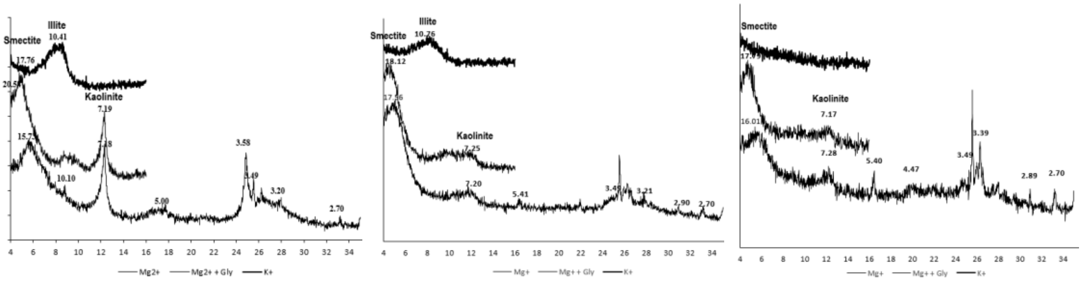


Fig. 4. Map of parent material distribution in West Java (BBSDLP 2014)

XRD (X-Ray Difraction) analysis showed paddy fields in West Java contained a lot of mixed 2:1 type minerals (smectite and illite) and 1:1 type minerals (kaolinite and halloysite) (Fig. 5). Environmental conditions in West Java paddy field such as: (1) sufficient rainfall for the weathering process to occur, but does not cause leaching of bases and silica (2) sufficient dry period so providing time for smectite crystallization (3) poor drainage which prevents the ions from leaching and loss of weathered materials and (4) high temperatures supporting the formation of 2:1 type minerals. Poorly drained environments with neutral pH to alkaline and accumulation especially Mg and silica are suitable environments for the formation of smectite minerals. In addition, paddy fields in West Java are formed from volcanic parent materials (andesite, basalt and tuff) and alluvium with environmental condition enhance the formation of smectites. In paddy fields developed from alluvium (alluvial regions) in general, smectite minerals were often found, because alluvial plains are generally environments where bases and silica accumulate. In general, the mineral condition of smectite in alluvial paddy fields is quite stable, because the pH change is not drastic (Prasetyo et al. 2004).



(a) (b) (c)

Fig. 5. Mineral clay types in West Java paddy fields: (a) LPF (Indramayu 0-300 m asl), (b) MPF (Ciamis 300-700 m asl) and (c) UPF (Garut > 700 m asl)

Kaolinite mineral, also found in West Java paddy fields, is a breakdown of materials in a higher elevation area and deposited in the paddy fields. This is due to kaolinite minerals are generally formed in environments with intensive basic weathering, acid soil reactions with relatively good soil drainage (Tardy et al. 1973). Paddy soil containing kaolinite minerals does not mean poor in base saturation when viewed from the value of low cation exchange capacity possessed by kaolinite minerals which is only about 1.20-12.5 cmol (+) kg^{-1}. The results of research on paddy fields in Bogor (Subardja and Buurman 1980) showed that paddy fields dominated by kaolinite still had appropriate percentage of base saturation and high soil nutrient reserves. Kaolinite in paddy fields in West Java was not as dominant when compared to smectite minerals. Therefore, paddy fields in West Java can be considered fertile based on clay mineralogical properties.

Selected chemical soil properties. Some of the chemical properties of paddy fields in three different elevation clusters are presented in Table 1. The results showed that clay content, soil pH, CEC, base saturation, Al_d, and Al_o of three elevation clusters were not different statistically. The presence of plow pan layers and terraces causes erosion to be minimum and clay accumulation in the upper layers of paddy fields. Therefore, clay content in paddy fields was not significantly different among elevation clusters. The CEC values were also not significantly different among elevation clusters. This was supported by similar mineralogical properties among elevation clusters (Fig.5). The value of CEC was related to the amount clay and type of clay minerals (Tan 2010, Hartono et al. 2005).

Base saturation values also showed no significant difference among elevation clusters. This was due to the presence of limestone parent materials spread over these three culsters, so that the exchangeable Ca content quite affected on the base saturation values which caused the value to be almost same and they were not significantly different. Soil pH values were not different among elevation clusters caused by flooding. Inundation of acidic mineral paddy soils caused soil pH to increase and in alkaline soils the soil pH value decreased to near neutral. In neutral and slightly alkaline soils, pH is regulated by the balance of $CaCO_3$-CO_2-H_2O and in acidic soils containing a lot of Fe it is regulated by the balance of Fe $(OH)_2$-CO_2-H_2 (Kyuma 2004). Increasing pH in acid soils due to flooding is controlled by the Fe^{2+}-$Fe(OH)_3$ system where H^+ is consumed. Increasing acid soil pH can increase P availability due to increased mineral solubility P, namely strengite ($FePO_4.2H_2O$) and veriscit ($AlPO_4.2H_2O$) with the following reactions:

$$FePO_4.2H_2O + H_2O \longleftrightarrow H_2PO_4^- + H^+ + Fe(OH)_3.$$

Al_d and Al_o were also not significant statistically however these Al oxides had highest value in elevation > 300 asl. It means that elevation still affected the amount of these hydrous oxides.

The other soil properties such as organic C, total N, potential P, Fe_d, Fe_o, and Al_o + 1/2Fe_o were significantly different. The lowest C-organic value was found in LPF where farmers plant rice 2-3 times a year and using organic fertilizers. However rice straw which should be incorporated into the soil was either burned or used as animal feed. In UPF, farmers only grow rice once a year and in the second and third seasons they grow vegetables using very high organic fertilizer. In MPF, farmers still used high organic fertilizer when planting crops or vegetables. These differences in soil management produced the differences in level of organic C in the soil. The level of C organic of MPF was higher than that of LPF, but lower than that of UPF.

Table 1. Chemical properties of paddy soils in three different altitude groups in West Java.

Chemical soil properties	Elevation (m asl)								
	< 300 (LPF) Mean (Range)			300-700 (MPF) Mean (Range)			> 700 (UPF) Mean (Range)		
Clay content (%)	51.0	a	(28-67)	52.0	a	(25.0-71.0)	53.0	a	(33.0-65.0)
pH H_2O	5.18	a	(4.20-6.90)	5.08	a	(4.00-6.60)	4.93	a	(4.40-5.40)
Organic-C (%)	1.85	a	(0.70-2.70)	2.08	a	(1.30-4.30)	2.72	b	(2.10-4.30)
Total N (%)	0.16	a	(0.07-0.29)	0.17	a	(0.08-0.31)	0.24	b	(0.14-0.40)
Potential P (mg P_2O_5 100g^{-1})	67.0	a	(28-180)	120	b	(24.0-322)	98.0	ab	(48.0-174)
CEC cmol (+) kg^{-1}	37.0	a	(16-66)	32.0	a	(14.0-73.0)	33.0	a	(27.0-58.0)
Base Saturation (%)	14.0	a	(7-36)	13.0	a	(4.00-40.0)	14.0	a	(9.00-19.0)
Fe_d (g kg^{-1})	2.36	a	(0.86-4.62)	3.40	b	(1.16-5.45)	3.43	b	(0.96-4.79)
Al_d (g kg^{-1})	0.18	a	(0.11-0.29)	0.21	a	(0.11-0.34)	0.19	a	(0.11-0.32)
Fe_o (g kg^{-1})	1.67	a	(1.04-2.47)	2.13	ab	(1.10-3.90)	2.35	b	(0.96-4.51)
Al_o (g kg^{-1})	1.39	a	(0.79-2.46)	1.34	a	(0.84-2.58)	1.63	a	(0.96-4.00)
Al_o+1/2Fe_o (g kg^{-1})	2.23	a	(1.38-3.33)	2.41	ab	(1.59-3.64)	2.80	b	(1.86-4.85)
Total sample (N)				60					

Means followed by the same letter within a row are not significantly different (Duncan`s test, $P < 0.05$)

Similar to organic C, total-N on UPF land was higher and significantly different from that of MPF and LPF. N source is organic matter and is evidenced by the very strong positive correlation between N-total and organic C at the level of <1% with a value of r = 0.75. Potential-P (extracted HCl 25%) in MPF was the highest value and significantly different from that of LPF, but not significantly different from that of UPF. This was related to the presence of high Fe and Al oxides also in MPF. This potential-P was significantly correlated with Fe_d and Al_d at the level of 5% with a correlation values of each 0.39. The Fe_d and Fe_o was found more at MPF and UPF and Al_o + 1/2Fe_o were highest in UPF which suggested that elevation affected the amount of these hydrous oxides. It means that the increase of elevation increased Fe and Al hydrous oxide which were the main components in P retention in the soils (Hartono et al. 2005, Nishigaki et al. 2018). The highest levels of Fe_o and Al_o were found on UPF because these were associated with volcanic materials which have not yet undergone further weathering. The differences in chemical characteristics between paddy soils in the LPF, MPF and UPF affected the distribution of the P fractions in the three clusters of paddy fields.

Distribution of P fraction in different elevation and effect of elevation on the P fractions distribution. Paddy soils in West Java as a whole contained a total-P of about 72,242 mg P kg^{-1} (total-P of LPF + total-P of MPF + total-P of UPF) (Table 2). The biggest contribution was from the residual fraction-P. This fraction is the occluded P (P_i and P_o fixed strongly by Fe and Al hydrous oxides in soil particles) and recalcitrant organic P (Tiessen and Moir 1993, Dobermann et al. 2002, Velásquez et al.

2016a). This is classified as non labile P fractions that cannot be utilized by plants (Velásquez et al. 2016b; Costa et al. 2016; Herera et al. 2016).

The second substantial contribution to total-P was the NaOH-P_o fraction. This fraction is organic P which is chemically adsorbed strongly on the surface of the amorphous Fe and Al oxide. As moderately labile P and bound to amorphous Fe and Al oxide caused this P fraction to be unavailable for plants but it could be a source for labile P when it is depleted (Hartono et al. 2015). The NaOH-P_i fraction was the third largest contributor to the total P of paddy field in West Java. This fraction was interpreted as P which is chemically adsorbed strongly on the surface of amorphous Fe and Al oxide by ligand exchange. The NaOH-P_i fraction was the same as the NaOH-P_o fraction which was moderately labile so that it was slightly available for plants. It was 93% P accumulated as moderately labile P to non labile P in paddy soils in West Java (NaOH-P_o, NaOH-P_i, HCl-P_i, and residual-P), which consist of 63% were found in MPF (300-700 m asl), 10% were found in UPF (> 700 m asl) and 20% were found in LPF (<300 m asl).

Table 2. P fraction of paddy field with three different elevation groups in West Java.

P Fractions	Elevation (m asl)								
	0-300 (LPF)			300-700 (MPF)			>700 (UPF)		
	Total mg kg^{-1}	%	Mean mg kg^{-1}	Total mg kg^{-1}	%	Mean mg kg^{-1}	Total mg kg^{-1}	%	Mean mg kg^{-1}
Resin-P_i (labile P)	317	2.01	14.0 a	678	1.40	24.0 b	143	1.74	10.0 ab
$NaHCO_3$-P_i (labile-P)	918	5.83	40.0 a	1788	3.70	64.0 b	499	6.08	55.0 ab
$NaHCO_3$-P_o (labile-P)	286	1.82	12.0 a	246	0.51	9.00 a	122	1.49	14.0 a
NaOH-P_i (moderately labile-P)	1,270	8.07	55.0 a	2,940	6.09	105 b	1,027	12.5	114 b
NaOH-P_o (moderately labile-P)	4,924	31.3	214 a	10,777	22.3	385 ab	3,411	41.6	379 b
HCl-P_i (moderately labile-P)	1,170	7.43	51.0 a	1,928	3.99	69.0 a	475	5.79	53.0 a
Residual-P (non labile-P)	6,860	43.6	298 a	29,967	62.0	1,070 b	2,528	30.8	281 a
Total-P	15,745	100.0	685 a	48,292	100	1,726 b	8,205	100	912 a
Total sample (N)	60								

Means followed by the same letter within a row are not significantly different (Duncan`s test, *$P < 0.05$*)

Labile P fraction (Resin-P_i, and $NaHCO_3$-P_i, -P_o) was 7.00% in paddy fields in West Java, where 2.11% were found in LPF (<300 m asl), 3.83% were found in MPF (300-700 m asl) and 1.06% in UPF (>700 m asl). Therefore, even though the total P of paddy fields was very high, what can be utilized by plants was still very small and 93% accumulated in the soil. Because paddy fields in West Java are scattered at various elevations, the information about the distribution of the P fractions is needed to assist in conducting P management for P fertilizer recommendations.

Resin-P_i. The amount of P_i (P inorganic) or available P fraction that is readily absorbed by plants in paddy soils in West Java in three different elevations showed a significant difference at the 5% level. The mean value of resin-P_i on paddy fields in West Java at three different elevation clusters (LPF, MPF and UPF) were 14.0 mg P kg^{-1}, 24.0 mg P kg^{-1} and 10.0 mg P kg^{-1} respectively. Resin-Pi in MPF was higher than that of LPF and UPF. This suggested that paddy field farmers in West Java from MPF applied P fertilizer higher than that of LPF and UPF or possibly this was because of replenishment by $NaHCO_3$-P_i. Once the resin-P_i was depleted due to paddy absorption, then the $NaHCO_3$-P_i replenished it. There was a very significant correlation between the Resin-P_i and the $NaHCO_3$-P_i at the level of 1% with the value was 0.76 (Table 3).

$NaHCO_3$-P_i and -P_o. P fraction extracted by $NaHCO_3$ consists of $NaHCO_3$-P_i (inorganic) and $NaHCO_3$-P_o (organic), namely fraction P which is interpreted as P which correlates strongly with P uptake by plants and microbes and is bound to mineral surfaces of crystalline of Al and Fe hydrous oxide (Mattingly 1975) or precipitation of Ca-P forms and Mg-P (Olsen and Sommers 1982) with weak electrostatic bonds. The amount of $NaHCO_3$-P_i of MPF was the highest and significantly different from those of UPF and LPF. The mean values of $NaHCO_3$-P_i of MPF, UPF and LPF were 64.0, 55.0 and 40.0 mg P kg^{-1} respectively. This was because P bound to crystalline Fe and Al hydrous oxides. MPF had Fe_d and Al_d higher than those of LPF and UPF. However, the $NaHCO_3$-P_o did not show significant difference in the three elevation clusters (Table 2).

NaOH-P_i and -P_o. NaOH-P_i and -P_o is the fraction P which is chemisorbed by amorphous Fe and Al hydrous oxide so that it is relatively not available to plants. The amount of NaOH-P_i and -P_o was mostly in MPF and UPF. The mean values of NaOH-P_i and -P_o of LPF, MPF and UPF were 55.0 and 214 mg P kg^{-1}, 105 and 385 mg P kg^{-1}, 114 and 379 mg P kg^{-1} respectively. The NaOH-P_i and -P_o of MPF and UPF were significantly different from those of LPF. The high amount of amorphous Fe and Al hydrous oxides (Fe_o and Al_o) in MPF and UPF soil increased the NaOH-P_i, -P_o. The NaOH-P_i had a very significant correlation with the available P fraction (Resin-P_i) and $NaHCO_3$-P_i at the level of 1% (r = 0.46 and r = 0.56), so that this fraction could be a source of P to replace Resin-P_i or $NaHCO_3$-P_i when the latters have depleted in the soil solution. NaOH-P_o fraction could also be a source of P for plants as NaOH-P_i. NaOH-P_o was positively correlated with Resin-P_i at the level of 5% with r = 0.41. NaOH-P_o was also positively correlated with $NaHCO_3$-P_i with r = 0.46 (Table 3).

HCl-P_i. HCl-P_i could still be a source of P for plants under conditions that allow it. HCl-P_i positively correlated very well with $NaHCO_3$-P_i and Resin- P_i like as NaOH-P_i, with a correlation value of r = 0.69 and r = 0.54 (Table 3). HCl-P_i was found on LPF, MPF and UPF. The level of HCl-P_i was not significantly different for the three groups of elevation, indicating the influence of limestone material in the paddy fields.

Residual-P. Residual-P is occluded and recalcitrant organic P which is very difficult to dissolve. It was found mostly in paddy fields at 300-700 m asl (MPF) and was very significantly different from that of LPF and UPF at the level of <1%. The residual-P fraction could also be transformed to a moderately labile P (NaOH-P_i, -P_o) and labile P ($NaHCO_3$-P_i and Resin-P_i) for plants. This can be seen from positive correlation between residual-P with NaOH-P_i (r = 0.57), NaOH-P_o (r = 0.47), $NaHCO_3$-P_i (r = 0.59) and Resin-P_i (r = 0.48) (Table 3).

The results of P distribution showed that P was accumulated mostly in non labile and moderately labile P. Efforts are needed to mine P in paddy fields of West Java. It will reduce the adverse effects of excessive use of P fertilizer on soil and environment such as eutrophication and pollution of heavy metals especially Cd and Pb. Some treatments for examples the application of calcium silicate or organic matter released P from the NaOH-P_i fraction into the available P form (Hartono and Bilhaq 2014, Wang et al. 2015). The application of organic matter or silicate material were suggested to mine the accumulated P in West Java paddy soils to increase the efficiency of P fertilization.

Table 3. Correlation matrix between soil P fractions with selected chemical soil properties

	NaHCO$_3$-P$_i$	**NaHCO$_3$-P$_o$**	**NaOH-P$_i$**	**NaOH -P$_o$**	**HCl-P$_i$**	**Residual -P**	**Total -P**	**pH**	**Clay**	**Org-C**	**Total-N**	**Potential-P**	**CEC**	**BS**	**Fe$_d$**	**Al$_d$**	**Fe$_o$**	**Al$_o$**	**Al$_o$+ 1/2Fe$_o$**
Resin-P$_i$	0.76**	-0.38*	0.46**	0.41*	0.54**	0.48**	0.56**	0.14	-0.08	-0.09	-0.05	0.72**	-0.18	-0.22	0.16	0.13	0.00	-0.11	-0.10
NaHCO$_3$-P$_i$		-0.35*	0.56**	0.46**	0.69**	0.59**	0.67**	-0.12	-0.27	0.19	0.17	0.77**	-0.36*	0.05	0.12	0.18	0.09	-0.14	-0.08
NaHCO$_3$-P$_o$			0.06	0.07	-0.23	-0.14	-0.10	-0.37*	0.04	0.22	0.08	-0.30	0.11	0.13	-0.07	0.16	-0.07	0.02	-0.03
NaOH-P$_i$				0.94**	0.18	0.57**	0.76**	-0.29	-0.28	0.54**	0.52**	0.73**	-0.44**	-0.04	0.63**	0.44**	0.39*	0.06	0.30
NaOH-P$_o$					0.14	0.47**	0.69**	-0.22	-0.30	0.57**	0.56**	0.63**	-0.40*	-0.01	0.65**	0.43**	0.41**	0.15	0.40*
HCl-P$_i$						0.17	0.25	0.17	-0.21	0.27	0.05	0.36*	-0.01	0.11	-0.14	-0.07	0.11	-0.29	-0.21
Residual-P							0.96**	-0.24	-0.02	0.01	0.04	0.77**	-0.32	-0.15	0.35*	0.46**	0.21	-0.30	-0.16
Total-P								-0.26	-0.12	0.19	0.20	0.84**	-0.38*	-0.12	0.46**	0.50**	0.30	-0.22	-0.03
pH									-0.02	-0.14	-0.22	-0.19	0.45**	-0.01	-0.12	-0.33*	-0.08	0.06	0.01
Clay										-0.16	-0.01	-0.11	0.17	0.09	-0.03	0.15	-0.21	-0.01	-0.14
Org-C											0.75**	0.15	-0.21	0.41*	0.31	0.19	0.34*	0.19	0.40*
Total-N												0.22	-0.24	0.21	0.37*	0.03	0.29	0.27	0.44**
Potential-P													-0.45**	-0.13	0.39*	0.39*	0.13	-0.06	0.03
CEC														-0.32	-0.54**	-0.27	-0.26	-0.12	-0.28
BS															0.14	0.25	0.02	0.26	0.26
Fe$_d$																0.47**	0.66**	0.07	0.48**
Fe$_o$																	0.23	0.00	0.15
Al$_d$																		-0.27	0.36*
Al$_o$																			0.80**

CEC = Cation Exchange Capacity; BS = Base Saturation
**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

CONCLUSION

Paddy soils in West Java were clustered into three, namely lowland rice fields (0-300 m above sea level), medium plain rice fields (300-700 m above sea level), and upland rice fields (> 700 m above sea level). The characteristics of paddy soils which include parent material, clay mineral types and chemical properties in each elevation cluster affected the P fraction distribution. About 93% of P fractions on paddy soil in West Java accumulated in moderately labile P fraction (NaOH-P_i, -P_o, HCl-P_i) and in non labile P fraction (residual-P). Of these, 63% were found in paddy soils located 300-700 m asl, 10% were found in paddy fields located > 700 masl and 20% were found in paddy fields <300 m asl. There is a need for site-specific P nutrient management according to elevation. Application of organic matter or silicate in West Java paddy soils is recommended to release P of moderately labile P fraction and non labile P fraction especially at 300-700 m above sea level where P was mostly accumulated.

ACKNOWLEDGEMENT

Thanks to the Agricultural Research and Development Agency of the Ministry of Agriculture of the Republic of Indonesia for funding this research.

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