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Spatial Variability of Soil Inherent Fertility Status at Irrigation Rice Field in Waeapo Plain, Buru Regency

Andriko Noto Susanto[1] and Bambang Hendro Sunarminto[2]

[1]Maluku Assessment Institute of Agricultural Technology, Chr. Soplanit Street, Rumah Tiga - Ambon 97233, Indonesia, e-mail: andriko_notosusanto@yahoo.co.id
[2]Department of Soil Science, Faculty of Agriculture, Gadjah Mada University - Yogyakarta

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ABSTRACT

Analysis and interpretation of spatial variability soils properties are a basis in site-specific nutrients management. Evaluation inherent potentiality (IP) of soil fertility status is the method to know variability of soil fertility and spatial distribution at the area. Evaluation of IP was conducted by mathematical calculation to eleven soil properties namely total C, total N, N-NH_4^+, total P, P-Bray 1, P (extract HCl 25%), [Ca+Mg]-exch., K-exch., CEC, available Si, and sand content. Result of IP evaluation in Waeapo plain indicated that from the total rice field area of 25,848.83 ha, 75.64% or 19,552.44 ha showed very low IP class, and the rest for the width of 6,296.39 ha or 24.36% had low IP class. Content of C-total, N-total, N-NH_4^+, P_2O_5 total, P_2O_5 extracted by HCl 25%, available P_2O_5 and Si was not limited IP, because they were all classified as moderate class. Limiting factor of very low and low IP was a combination of three elements of [Ca+Mg]-exch., K-exch, and CEC. Increasing CEC and availability of K with addition of ameliorant such as organic materials, calcite, zeolite and dolomite would improve IP status class.

Keywords: Buru Island, inherent potentiality of soil fertility, rice, Waeapo Plain

INTRODUCTION

Uniforming of irrigation rice fertilization dosage such as conducted in Waeapo plain, causes to decrease efficiency usage of fertilizer, and also reduce rice productivity and farming profit (Haefele *et al*. 2000; Haefele and Wopereis 2005). So that, assessment of soil fertility for delineation variability of soil fertility is needed. Mapping of soil fertility is important step which must be done to improving precision agriculture, that is integrating between characteristic of land resource with requirement of crop in each time and place (Syam 2010; McBratney and Pringle 1997). Soil nutrients variability mapping had been reported as an important component for establishing management zone. These digital maps could be used to delineate management zone for variable rate fertility in site-specific nutrient management (SSNM) systems (Yesrebi *et al*. 2009). Witt *et al*. (2007) suggested that reliance on existing soil maps in the delineation of borderlines for fertilizer recommendations can be problematic, because maps are often old and soil classifications are not developed for agronomic purposes. Adequate survey strategies and classification approaches used in precision agriculture will have to be further explored to provide robust evidence that an expected variation in crop nutrient needs is manageable at an appropriate scale. Results can further contribute to the development of simplified soil classification systems for agronomic purposes that can be provided to farmers in the form of a few simple guidelines for their use in the local adaptation and evaluation of SSNM.

Kyuma (2004) reported the method to mapping soil inherent potentiality fertility status, especially for paddy soil. Inherent potentiality of soil fertility represent situation of soil fertility which its value determined especially by clay content and bases ions. These mapping bases on soil properties have strong correlation (negative or positive) to rice growth and productivity; from 29 soil properties, chosen 11 important parameters to assess inherent potentiality of soil fertility, that are total C; total N; N-NH_4^+; total P; available P; P extract of HCl 25%; exchangeable Ca, Mg, and K; CEC, available Si; and sand content.

This research aimed to determine value, class and spatial distribution inherent potentiality of soil fertility status, and also to identify limiting factor of soil fertility status and its alternative management at irrigation rice in Waeapo plain, Buru regency.

MATERIALS AND METHODS

Study Site

Research conducted at irrigation rice field in Waeapo plain, Waeapo district, Buru regency, Moluccas province. Wide of land surveyed about 25,848.83 ha, and geographically at co-ordinate 3°15'45 - 3°32'04"S and 126°48'03 - 127°06'42"E. This area is intensive agriculture land, and represent main food source Moluccas province.

Map Used

Especial materials of this research is regional semi detail soil map of Waeapo plain scale 1:50,000 (Sirappa *et al.* 2005); Waeapo TM-7 Landsat Image 2000 Year and Waeapo Image Satellite by Globe Digital, Tele Atlas, Map Data PlyLtd from Google 2010 Year with 0.1 ha accuracy. Map of job obtained pursuant to overlay between result of interpretation satellite image with semi detail soil map (scale 1:50,000), so that yielded boundary new map with detail scale (1:25,000).

Soil Mapping Unit and Sampling Point

Rice field area at Waeapo plain distribute in six Soil Mapping Unit (SMU); that is 1st SMU (association of Aquic Udifluvents and of Fluvaquentic Endoaquepts), 3rd SMU (association of Fluvaquentic Endoaquepts and of Typic Endoaquepts), 4th SMU (complex of Fluvaquentic Endoaquepts, Typic Fluvaquents, and Typic Eutrudepts), 5th SMU (association of Typic Endoaquepts and of Typic Epiaquepts), 6th SMU (association of Typic Endoaquents and of Fluvaquentic Endoaquepts), and 11th SMU (association of Sulfic Endoaquepts and Sulfic Fluvaquents). Total wide soil mapping unit about 25,848.83, but existing wide of rice field approximately 9,379.96 ha (36.29%).

Soil sampling conducted to point observation that its co-ordinate has been marked previously, and distribute by purposive at rice field in six SMU. Constructively by GPS, each point observation taken five diagonally sample, then identified of physical soil properties that is texture and soil colors. Total

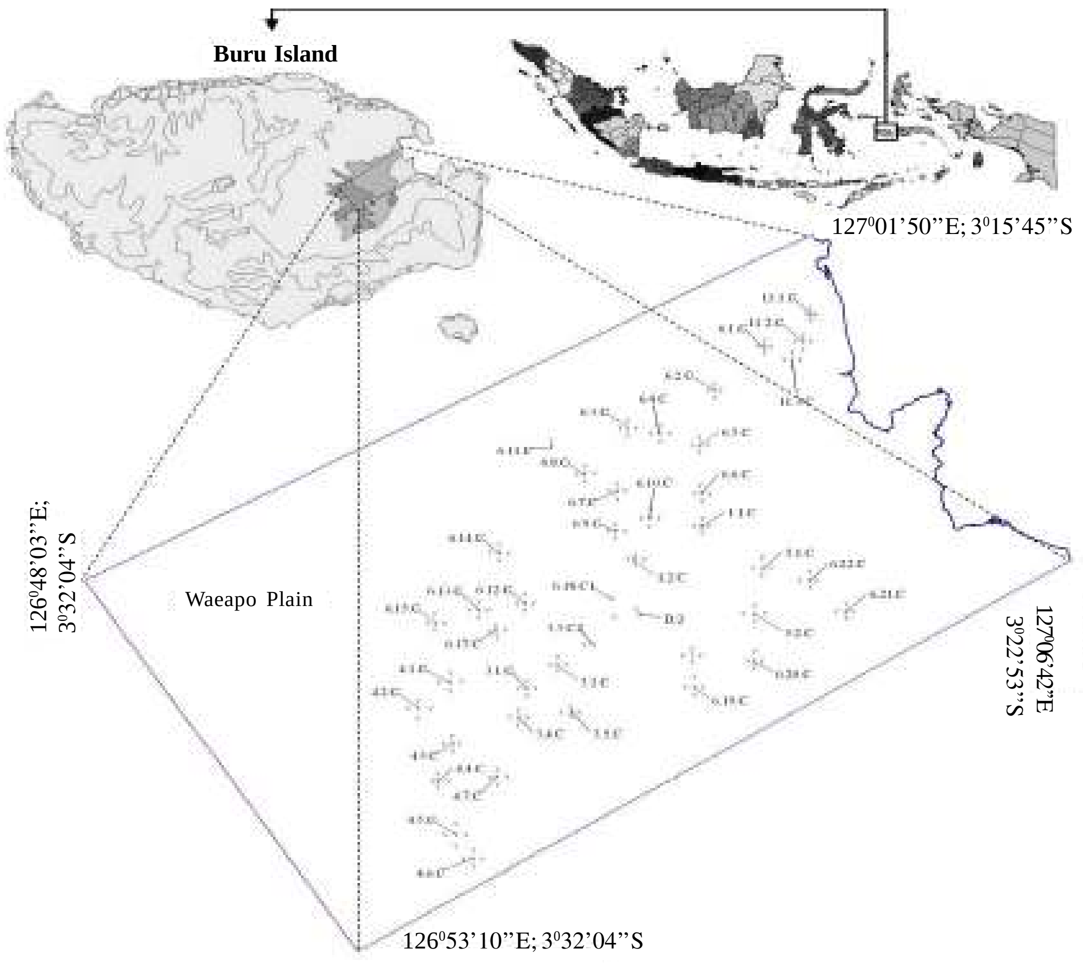

Figure 1. Research location and position of points sampling to evaluate soil fertility status of irrigation paddy at Waeapo plain, Buru regency.

of sample taken for this stage is 168. Chemical analysis to assess IP status conducted to 69 samples; represent composite result from some single sample. Point of soil sampling position presented at Figure 1.

Soil Analysis

Soil properties analysis conducted to every soil fertility samples, covering total C (Walkley & Black), total N (Kjeldahl); N-NH_4^+ (extract with KCl and titration with HCl); total P (extract with $HClO_4$ 60% and HNO_3), available P (Olsen and Bray-1), P extract HCl 25%, exchangeable of Ca, Mg, and K, CEC (extract with Ammonium acetate 1M, pH 7,0); available Si (Morgan Wolf); and Sand (pipet); accordance with guidelines from Sulaiman *et al*. 2005 and Hanudin 2000.

Estimation Inherent Potentiality of Soil Fertility Status

Determination of Inherent Potentiality (IP) value by Kyuma (2004) method, early by compiling soil analysis result become eleven variable, that is X_1 (total C), X_2 (total N), X_3 (N-NH_4), X_4 (total P), X_5 (available P), X_6 (P-HCl 25%), X_7 (exchangeable [Ca + Mg]), X_8 (exchangeable K), X_9 (CEC), X_{10} (available Si) and X_{11} (sand content). Inherent potentiality of soil fertility status (IP) calculated with the following equation :

$$IP = - 0.151 (\log X_1 – 0.044)/0.297 - 0.147 (\log X_2 + 0.994)/0.282 + 0.045 (\log X_3 – 0.731)/0.425 + 0.051 (\log X_4 -1.175)/0.429 - 0.091 (\log X_5 – 0.171)/0.584 - 0.059 (\log X_6 – 0.608)/0.712 + 0.306 (\log X_7 – 0.993)/0.484 + 0.130 (\log X_8 + 0.623)/0.449 + 0.757 (\log X_9 – 1.159)/0.342 - 0.058 (\log X_{10} – 1.195)/0.515 + 0.028 (\log X_{11} – 1.314)/0.544.$$

Calculation result of every variable (X_1-X_{11}) and IP, is classified into five class that is very high (> 0.84); high (0.25 until 0.84); medium (-0.25 until 0.25); low (-0.84 until -0.25), and very low (-0.84 until – 0.25)

Mapping and Data Spatial Analysis

Whole survey data covering point sampling co-ordinate, result of soil chemistry and physical

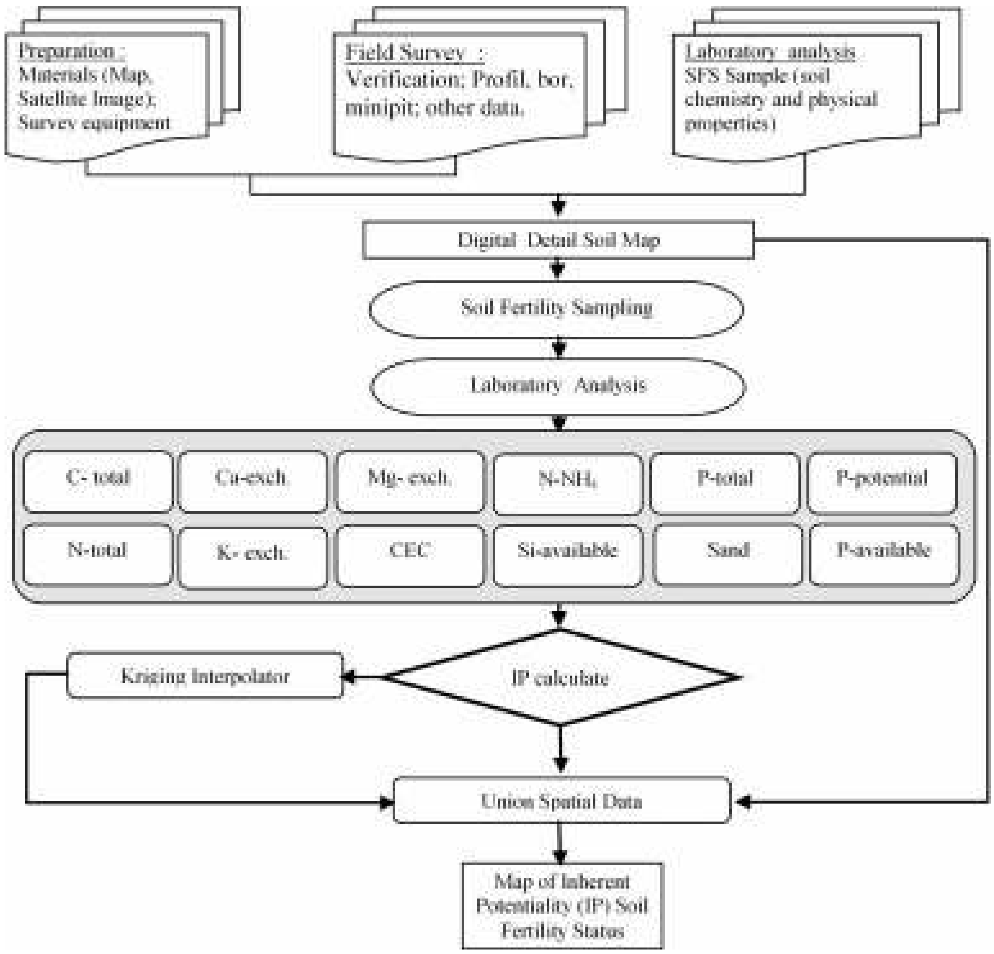

Figure 2. Flowchart research process to estimate inherent potentiality of rice soil fertility status at Waeapo plain, Buru regency.

analysis, and result of computation soil fertility status entered as data attribute which interference with polygons of SMU, and processed constructively with spatial analysis using the Kriging interpolator by software Arcview GIS version 3.3. Overall of this research process is presented in a flowchart like at Figure 2.

RESULTS AND DISCUSSION

Statistical Description and Soil Analysis

The results of statistical description of soil physical and chemical analysis are presented at Tables 1. The variability values of CEC, N-Total, $N\text{-}NH_4^+$ and [Ca+Mg]-exch. Were relatively lower compared to other elements with coefficient of variability (CV) 22.66%, 24.19%, 24.57% and 24.76%, respectively. Variability of available P was the biggest among analyzed elements that was 77.11%, this might be caused by the available of phosphate was tended to unstable which were influenced by soil reaction, organic materials content, clay mineral, and ion dynamics in soil solution. Spatial variability of P extract HCl 25% and P total were relatively lower that were 38.72% and 66.71, respectively.

Mean of CEC was only 8.08 cmol(+) kg^{-1}, with minimum value of 4.43; maximum value of 12.59 cmol(+) kg^{-1}. By calculation soil clay content and total C (Doberman and Fairhurst 2000), CEC clay could be estimated about 23.79 cmol(+) kg^{-1}, that was included between kaolinite and illite group. Capacities exchangeable cation kaolinite were reported very small only ranged from 1.2 – 12.5 cmol(+) kg^{-1} (Prasetyo and Gilkes 1997; Tan 1993). While CEC illite was about 25 - 40 cmol(+) kg^{-1} (Meunier 2005). Soil CEC represents important soil properties in assessing soil fertility status, because sharing direct in system transfer of ion between soil solution with crop root area.

Soil C organic value were ranged from 0.31 – 1.90% with mean 0.99% and CV 41.14%, and it was included in low until medium class (Hazelton and Murphy 2007), and represented serious limiting factor of soil fertility in Asia (Dobermann *et al*. 2003). Lowering of C organic content was always connected to low soil total N because the correlation between both elements according to Nguyen *et al.* (2004) was very strong (r = 0.97). Besides soil C organic also contributed to mobilization and immobilization element process in a complex reaction in soil solution, and crop nutrient availability (Tan 2003).

Table 1. Statistical description of soil fertility in Waeapo plain, Buru Regency.

Statistical Description	Total-C	Total-N	$N\text{-}NH_4^+$	Total-P_2O_5	Avail-P_2O_5	P_2O_5-HCl 25%	Exch-Ca+Mg	Exch-K	CEC	Avail-Si	Sand
	......%......		.........mg (100 g)$^{-1}$				.... cmol(+) kg^{-1}			mg (100 g)$^{-1}$	%
Mean	0.99	0.11	1.13	110.19	0.99	60.69	4.37	0.03	8.08	3.26	22.71
Standard Error	0.05	0.00	0.03	8.85	0.09	2.83	0.13	0.00	0.22	0.14	1.78
Median	0.97	0.10	1.14	91.60	0.76	58.83	4.17	0.02	7.92	3.13	21.54
Mode	0.79	0.10	1.14	91.60	0.46	63.52	4.10	0.02	5.45	-	-
Standard Deviation	0.41	0.03	0.28	73.50	0.77	23.50	1.08	0.02	1.83	1.12	14.81
Kurtosis	-0.41	2.89	1.13	40.80	1.41	0.26	0.60	2.17	-0.54	0.66	-0.25
Skewness	0.27	0.80	0.81	5.73	1.31	0.49	0.80	1.43	0.20	0.77	0.64
Range	1.59	0.16	1.39	595.40	3.43	114.80	5.00	0.07	8.16	5.50	65.34
Minimum	0.31	0.04	0.65	45.80	0.12	16.42	2.44	0.01	4.43	1.21	0.61
Maximum	1.90	0.20	2.04	641.20	3.54	131.22	7.44	0.08	12.59	6.72	65.95
Coef. Variance (CV)	41.13	24.19	24.57	66.71	77.11	38.72	24.76	53.58	22.66	34.42	65.22

Table 2. Value and class of IP-status for each SMU in Waeapo plain, Buru regency.

SMU	Soil Family	IP-Status		Wide	
		Value	Class	Ha	%
1	Association : - Aquic Udifluvents - Fluvaquentic Endoaquepts	-1.27	Very Low	5,358.93	20.73
3	Association: - Typic Fluvaquents - Fluvaquentic Endoaquepts	-1.08	Very Low	569.35	2.20
		-0.59	Low	859.93	3.33
4	Complex : - Fluvaquentic Endoaquepts - Typic Fluvaquents	-1.13	Very Low	1,315.44	5.09
		-0.78	Low	949.60	3.67
5	Association : - Typic Endoaquepts - Typic Epiaquepts	-1.19	Very Low	2,489.43	9.63
		-0.66	Low	635.72	2.46
6	Association : - Typic Endoaquepts - Fluvaquentic Endoaquepts	-1.16	Very Low	7,696.01	29.77
		-0.60	Low	2,687.40	10.40
11	Association : - Sulfic Endoaquepts - Sulfic Fluvaquents	-1.06	Very Low	2,123.27	8.21
		-0.69	Low	1,163.75	4.50
Total				25,848.83	100.00

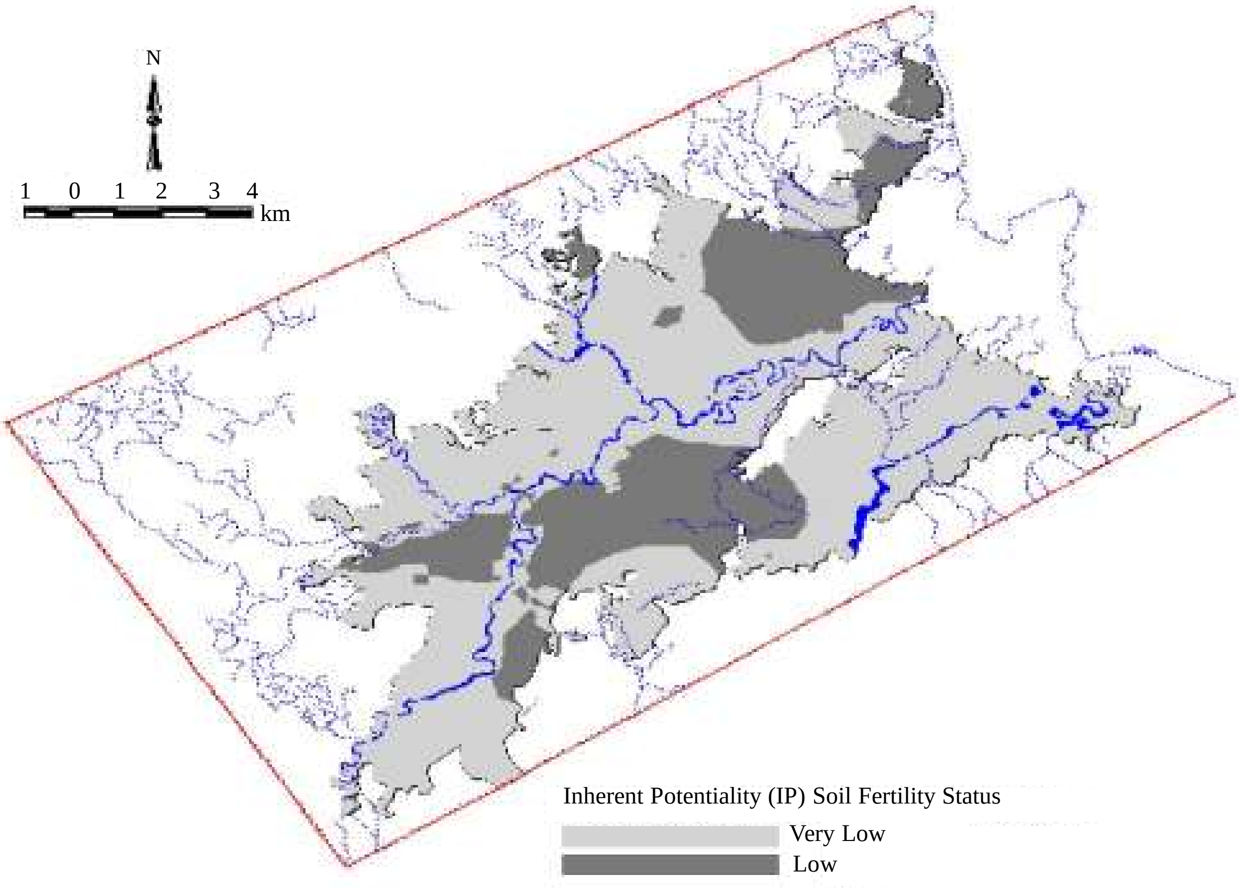

Figure 3. Map of inherent potentiality (IP) of soil fertility status with Kyuma (2004) method in rice field at Waeapo plain, Buru regency.

Inherent Potentiality of Soil Fertility Status (IP-status)

Tesfahunegn *et al.* (2011) stated that the delineation of soil properties with spatial analysis could improve the land use accuracy for farming. Spatial soil properties mapped based on kriging interpolation are more accurate than the catchment average value (classical statistics) for site-specific management decisions. Result of evaluation IP-status with kriging interpolation showed that from totalizing area 25,848.83 ha, about 19,552.44 ha (75.64%) had IP-status very low class and 6,296.39 ha (24.36%) is low class. Detail calculation about value and class IP-status for each SMU are presented at Tables 2.

Results of spatial data analysis that are union between SMU with IP-status boundary are presented in the map like at Figure 3. Part of SMU with low class IP-status spreaded around Savana Jaya village, Waekasar, Waenetat, Unit of X, XI, Waelo and Parbulu, and the rest area was come into very low class IP-status (Figure 3).

Relationship between Chemical Soil Properties with IP-Status

Statistical analysis to determine correlation between soil properties with IP-status are presented at Tables 3. Very significant positive correlation is shown by relation between IP-status with CEC (r = 0.77), [Ca+Mg]-exch. (0.69), available Si (r = 0.51), K-exch. (0.36); while sand had very significant negative correlation to IP-status (r = -0.44) and CEC (r = -0.66). Strong correlation between CEC with IP-status is evidence that CEC play important role in determining soil fertility. Hazelton and Murphy (2007) suggested that CEC is the capacity of the soil to hold and exchange cations. It provides a buffering effect to changes in pH, available nutrients, calcium levels and soil structural changes. As such, it is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and the soil's reaction to fertilizers and other ameliorants. A low CEC means the soil has a low resistance to changes in soil chemistry that is caused by land use.

Very significant negative correlation between sand content with IP-status causes sand do not play important role in soil buffering capasity system and have the character of inert. Source of negative charge at CEC is determining by clay mineral and primarily dictated by the abundance and types of phyllosilicates that are present (Esington, 2003). So that correlation between sand content and CEC was negative (r = -0.66). CEC could explain 60% IP-status in research location (Figure 4).

Positive correlation among IP with available Si (r = 0.51), caused rice was silicolous crop. Amount of Si taken up by rice per ha ranged from 890 – 1,018 kg. Silica nutrient is needed to improve resistance of rice to pest and disease attack through physical hardness crop tissue. Besides Si is also tighten paddy leaf structure so that improve photosynthesis and root oxidation, reduce absorption of Fe and Mn, and increase efficiency of N fertilization (Yoshida 1981). Water usage efficiency will reduce if Si insufficiency in rice, because water will loss by transpiracy (Fairhurst *et al.* 2007).

Table 3. Matrix correlation of soil properties and inherent potentiality of soil fertility status in irrigation rice field at Waeapo plain, Buru regency.

	C-total	N-total	$N\text{-}NH_4$	P_2O_5-total	P_2O_5-available	P_2O_5-HCl 25%	[Ca+Mg]-exch.	K-exch.	KPK	Si-available	Sand
N-total	0.38^{**}	-									
$N\text{-}NH_4$	0.05^{ns}	0.17^{ns}	-								
P_2O_5-total	-0.07^{ns}	0.20^{ns}	0.24^{ns}	-							
P_2O_5-available	0.11^{ns}	-0.18^{ns}	-0.18^{ns}	-0.01^{ns}	-						
P_2O_5-HCl 25%	-0.01^{ns}	0.04^{ns}	0.17^{ns}	0.14^{ns}	0.20^{ns}	-					
Ca+Mg-exch.	-0.02^{ns}	0.10^{ns}	0.08^{ns}	0.28^{ns}	0.03^{ns}	0.51^{**}	-				
K-exch.	-0.13^{ns}	-0.06^{ns}	0.23^{ns}	-0.05^{ns}	0.07^{ns}	0.08^{ns}	0.22^{ns}	-			
KPK	0.16^{ns}	0.58^{**}	0.13^{ns}	0.28^{ns}	-0.31^{*}	0.32^{*}	0.60^{**}	0.03^{ns}	-		
Si-available	-0.09^{ns}	0.08^{ns}	0.38^{**}	0.16^{ns}	-0.11^{ns}	0.28^{ns}	0.33^{**}	0.24^{ns}	0.47^{**}	-	
Sand	-0.06^{ns}	-0.53^{**}	-0.12^{ns}	-0.27^{ns}	0.35^{**}	-0.18^{ns}	-0.26^{ns}	0.03^{ns}	-0.66^{**}	-0.37^{**}	-
IP-Status	0.33^{**}	0.15^{ns}	0.16^{ns}	0.28^{ns}	-0.34^{**}	0.33^{**}	0.69^{**}	0.36^{**}	0.77^{**}	0.51^{**}	-0.44^{**}

*significantly different at level $\alpha = 1\%$; **very significantly different at level $\alpha = 1\%$; ns = no significantly different

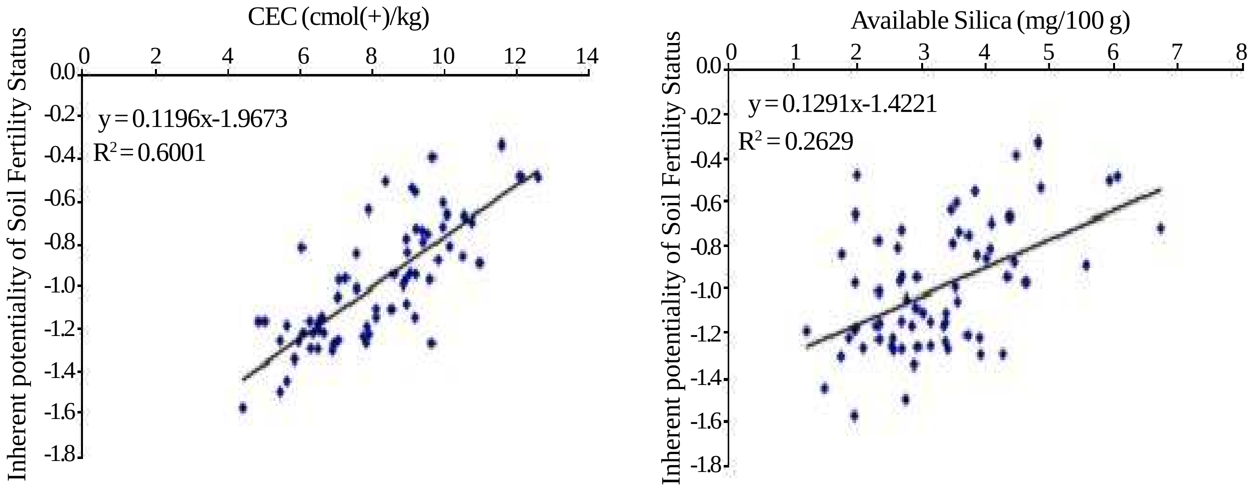

Figure 4. Relationship between CEC and available Si with IP-status in Waeapo plain, Buru.

Available of Si could explain 26% IP-status in research location (Figure 4).

Identify of Limiting Factor and IP-Status Management Alternative

Davatgar *et al*. (2012) reported that delineation limiting factors of soil fertility can determinate precisely inputs to improve the success of farming. The average values of soil nutrients in each zone can be used as a reference for variable-rate fertilization. Identify limiting factor of IP-status is meant to assess hard level of influence of each element in determining value of IP-status. Result identified this majored for IP-status, because to assess limiting factor of N and P separate calculation by calculating of organic matter and N status (OM) and availability of phosphate status (AP) is needed which is not discussed in this article.

According to calculation result of variable value of X_1 - X_{11} (Table 1) and its value could be grouped in class as did class of IP, hence could be determined that C-Total, N-Total, N-NH_4, Total P_2O_5, P_2O_5 extract HCl 25%, available of P_2O_5 and available Si did not become special limiting factor of IP-status. Four special elements which limiting factor of IP-status were medium class sand content and also [Ca+Mg]-exch., K-exch., and CEC with very low until low class. Sand proportions had negative correlation with CEC and IP-status. But management of soil texture was related to change of physical soil properties which relative difficult to be done.

Spatial distribution of combination limiting factor of IP-status is presented at Figure 5. Increasing CEC could be done by adding organic materials or other ameliorant like zeolite. Zeolite 40 mesh have CEC about 48.65 ± 2.05 cmol (+) kg^{-1} and probably can improve CEC and decrease reactivity of soil Fe (Poerwadi and Masduqi 2004). Al-Jabri (2008), also expressed that zeolite with CEC ranged from 83 - 193 cmol (+) kg^{-1} can be used for ameliorant in degraded agriculture land.

Deficiency of exchangeable Ca and Mg can improved with giving of calcite and dolomite; Doberman and Fairhurst (2000), suggested to apply lime ($CaCO_3$) with 40% Ca to increase Ca in soil with acid reaction. To increase soil Ca quickly without increase of soil pH calcium chloride ($CaCl_2.6H_2O$) with about 18% Ca can be used. Dolomite ($MgCO_3$+$CaCO_3$) with 13% Mg and 21% Ca can be given to simultaneously increase soil Ca and Mg slowly.

Increase of exchangeable K can be done by returning straw to rice field. More than 80% K rice are in straw, so that straw represents of important source K and must be calculated in requirement of K fertilizer that is applied (Doberman and Fairhurst 2000). Straw is the only major organic material available to most rice farmers. According to Witt, *et al*. (2007), nutrient sources such as straw should be used in combination with mineral fertilizers to satisfy part of the rice crop's requirement for nutrients and to sustain soil quality in the long run. About 40% of the N, 80–85% of the K, 30–35% of the P, and 40–50% of the S absorbed by rice remains in vegetative plant parts at crop maturity.

Besides, amount of Ca, Mg, K and CEC ratio in rice field represent important matter that must be paid attention. Fairhurst *et al*. (2007) expressed that soil with high K content, but high (Ca+Mg)/K ratio too,

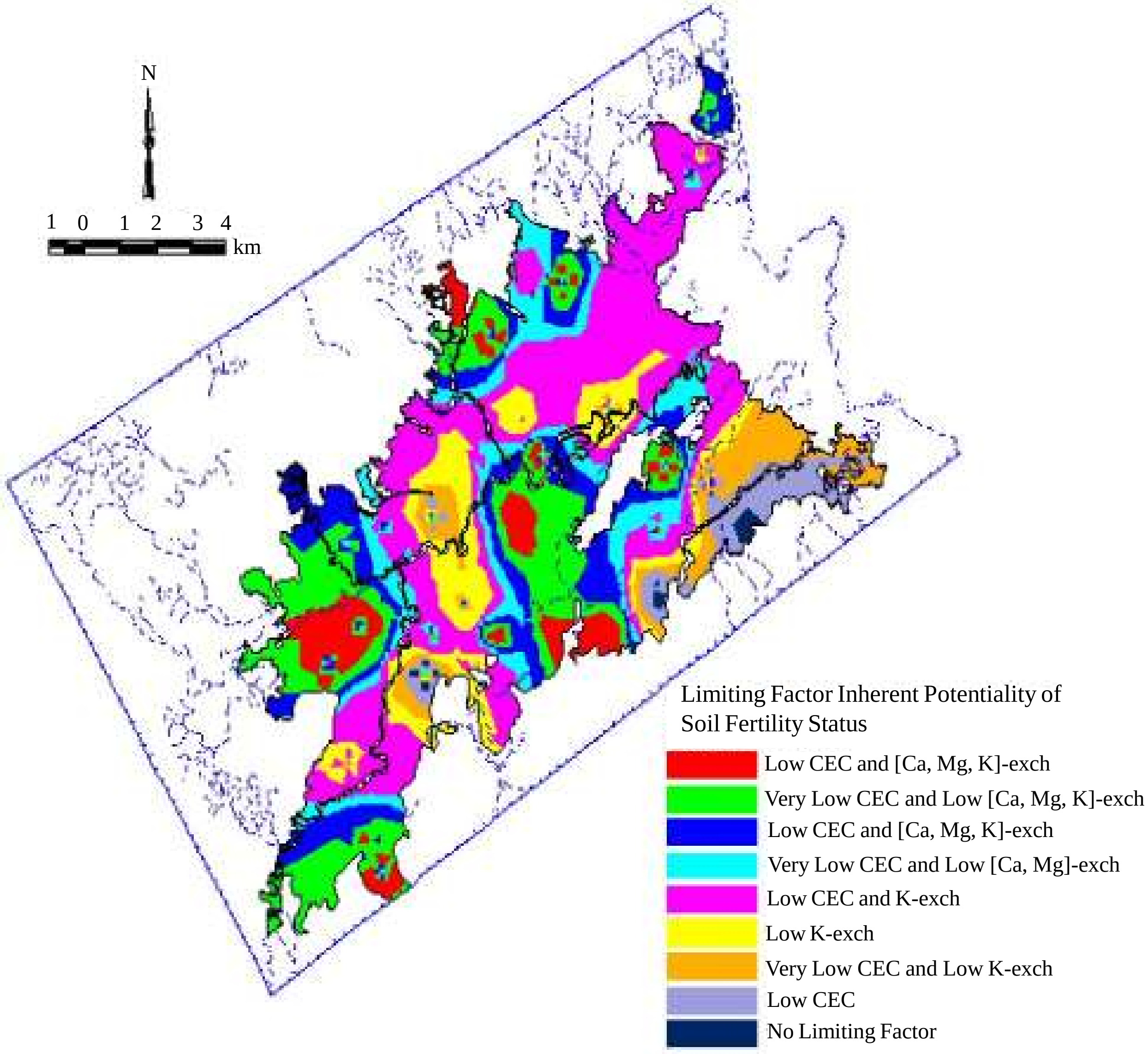

Figure 5. Map of limiting factor soil inherent potentiality fertility status in rice field at Waeapo plain, Buru regency.

can cause deficiency of rice K. Therefore, when saturation of Ca < 8% from CEC, rice will be deficiency of Ca although amount of soil exchangeable Ca is in enough category. Optimum growth of rice can be reached by exchangeable Ca/Mg ratio is>3/1 in soil solution. Deficiency of Mg will be happened if ratio of exchangeable K with Mg > 1/1.

Spatial data Analysis with kriging interpolator proved that it is able to map of plant growth limiting factor from soil properties. This map is needed to improve the accuracy of site-specific nutrient management. Wei *et al*. (2009) stated that the mapping of the variability of soil chemical properties with particular sampling strategies can be used easily to improve efficiency and effectiveness of fertilizer based on site-specific nutrient management concept.

CONCLUSIONS

Spatial variability of available P at rice field in Waeapo plain was high about 77.11%, whereas P extract HCl 25% and total P were lower than available P that were 38.72% and 66.71%, respectively. Coefficient variances (CV) of CEC, N-Total, N-NH_4 and [Ca+Mg]-exch.Were relative lower compared to other elements which were 22.66%, 24.19%, 24.57% and 24.76%, respectively. Wide of area with IP-status very low class was about 19.552,44 ha (75.64%), and low class was about 6.296,39 ha (24.36%).

IP-status had positive correlation with CEC (r=0.77), [Ca+Mg]-exch. (r=0.69), available Si (r=0.51), and K-exch. (r=0.36); while sand content had negative correlation with IP-status (r=-0.44) and

CEC (r=-0.66). Total C, N-total, N-NH_4, total P_2O_5, P_2O_5 extract HCl 25%, available of P_2O_5 and available Si did not become especial limiting factor of IP-status. Four special elements with limiting factor of IP-status were medium class sand content and also [Ca+Mg]-exch., K-exch., and CEC with very low until low class. Strategy management of IP instructed to increase CEC by adding ameliorant (organic materials, calcite, zeolite and dolomite) and improving the availability of K by returning of straw compost (not burned).

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REFERENCES

Al-Jabri M. 2008. Kajian metode penetapan kapasitas tukar kation zeolit sebagai pembenah tanah untuk lahan pertanian terdegradasi. *J Standardisasi* 10: 56-63 (in Indonesian).

Davatgar N, Neishabouri MR, Sepaskhah AR. 2012. Delineation of site specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. *Geoderma* 173: 111-118.

Doberman A and T Fairhurst. 2000. *Rice: Nutrient disorders and nutrient management*. International Rice Research Institute (IRRI). Philippines. 191p.

Dobermann A, C Witt, S Abdulrachman, HC Gines, R Nagarajan, TT Son, PS Tan, GH Wang, NV Chien, VTK Thoa, CV Phung, P Stalin, P Muthukrishnan, V Ravi, M Babu, GC Simbahan and MAA Adviento. 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of asia. *Agron J* 95: 913-923.

Esington ME. 2003. *Soil and Water Chemistry. An Integrative Approach*. CRC Press. Boca Raton - Florida. 523p.

Fairhurst T, A Dobermann, AG Quijano and V Balasubramanian. 2007. Kahat dan Keracunan Mineral dalam Padi: Panduan Praktis Pengelolaan Hara, *In* : Fairhurst, C. Witt, RJ. Buresh, and A. Dobermann (*Eds.*). *International Rice Research Institute (IRRI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI)*. Diterjemahkan oleh Adi Wiyono. Badan Litbang Pertanian. Jakarta. 91p + A-46p (in Indonesian).

Haefele SM and MCS Wopereis. 2005. Spatial variability of indigenous supplies for N, P and K and its impact on fertilizer strategies for irrigated rice in West Africa. *Plant Soil* 270: 57-72.

Haefele SM, DE Johnson, S Diallo, MCS Wopereis and I Janin. 2000. Improved soil fertility and weed management is profitable for irrigated rice farmers in the Sahel. *Field Crops Res* 66: 101-113.

Hanudin E. 2000. *Pedoman Analisis Kimia Tanah. Jurusan Tanah*. Fakultas Pertanian. Universitas Gadjah Mada. Yogyakarta (in Indonesian).

Hazelton P and B Murphy. 2007. *Interpreting Soil Test Results. What Do All The Numbers Mean?*. CSIRO Publishing. Australia. 152p.

Kyuma K. 2004. *Paddy Soil Science*. Kyoto University Press and Trans Pacific Press. 290p.

Mc Bratney AB and MJ Pringle. 1997. Spatial variability in soil-implication for precision agriculture. In: JV Stafford (ed.) *Precision Agriculture '97. Vol. I.* Bioss Scientific Publ. Ltd., Oxford, United Kingdom, pp.3-31.

Meunier A. 2005. *Clays*. Springer-Verlag Berlin Heidelberg. Germany. 467p.

N Davatgar, MR Neishabouri and AR Sepaskhah. 2012. Delineation of site specific nutrient management zones for a paddy cultivated area based on soil fertility using fuzzy clustering. *Geoderma* 173-174: 111-118.

Nguyen BV, DC Olk and KG Cassman. 2004. Characterization of Humic Acid Fractions Improves Estimates of Nitrogen Mineralization Kinetics for Lowland Rice. *Soils. Soil Sci. Soc. Am. J.* 68: 1266-1277.

Poerwadi AD and A Masduqi. 2004. Penurunan Kadar Besi oleh Media Zeolit Alam Ponorogo Secara Kontinyu. *JPurifikasi* 5: 169-174 (in Indonesian).

Prasetyo BH and RJ Gilkes. 1997. Properties of Kaolinit from Oxisol and Alfisols in West Java. *Agrivita* 20: 220 - 227.

Sirappa MP, AN Susanto, AJ Rieuwpassa, ED Waas and S Bustaman. 2005. Karakteristik, Jenis Tanah dan Penyebarannya Pada Wilayah Dataran Waeapo, Pulau Buru. *Agriplus* 15(1): 20-32 (in Indonesian).

Sulaeman, Suprapto dan Eviati. 2005. *Analisis Kimia Tanah, Tanaman, Air dan Pupuk*. Edisi Pertama. Balai Penelitian Tanah. Bogor. 136p (in Indonesian).

Syam T. 2010. Spatial Variability of Soil Nutrients Content Related to Rice Yield. *J. Trop Soils* 15: 153-157.

Tan KH. 2003. *Humic Matter in Soil and The Environment. Principles and Controversies*. Marcel Dekker, Inc. New York. 370p.

Tan KH. 1993. *Principles of Soil Chemistry, 2nd ed.* Marcel Deckker Inc., New York. 376p.

Tesfahunegn GB, L Tamene and PLG Vlek. 2011. Catchment-scale spatial variability of soil properties and implications on site-specific soil management in northern Ethiopia. *Soil Till Res* 117: 124-139.

WEI, Yi-chang, You-lu BAI, Ji-yun JIN, Fang ZHANG, Li-ping ZHANG, Xiao-qiang LIU. 2009. Spatial Variability of Soil Chemical Properties in the Reclaiming Marine Foreland to Yellow Sea of China. *Agric Sci China* 8: 1103-1111.

Witt C, BT Yen, VM Quyet, TM Thu, JM Pasuquin, RJ Buresh and A Dobermann. 2007. Spatially Variable Soil Fertility in Intensive Cropping Areas of North Vietnam and Its Implications for Fertilizer Needs. *Better Crops* 91: 28-31.

Yesrebi J, M Saffari, H Fathi, N Karimian, M Moazallahi and R Gazni. 2009. Evaluation and Comparison of Ordinary Kriging and Inverse Distance Weighting Methods for Prediction of Spatial Variability of Some Soil Chemical Parameters. *Res J Biol Sci* 4: 93-102.

Yoshida S. 1981. *Fundamentals of Rice Crop Science*. IRRI. Los Banos, Philippines. 269p.