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Using Modified Soil Quality Index for Determining Ponds Bottom Soil Quality Status of Aquaculture Area BLUPPB Karawang West Java, Indonesia

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Abstract

The impact of aquaculture activities has led to environmental degradation, especially ponds bottom soil quality. The purpose of this study was to assess the status of the ponds bottom soil quality in different aquaculture systems (traditional and intensive) in BLUPPB Karawang region in a flexible value of soil quality index (SQI). Twenty ponds consisting of 5 traditional of milkfish (*Chanos chanos*) juvenile rearing ponds and 5 traditional polyculture ponds, 5 intensive of *Litopenaeus vannamei* shrimp ponds lined with plastic mulch and 5 intensive *L. vannamei* shrimp earthen ponds. Variables of soil quality parameters examined include physical, chemical and biological of pond bottom soil. Sediment ponds with a depth of 5-10 cm were taken for analysis. Data statistically analyzed using Anova, continued with pos hoc test HSD Tukey. The results showed the ponds soil quality (SQI) of BLUPPB Karawang area has an average of 0.38 ± 0.02 or included in low criteria. Aquaculture systems were not significant (p> 5%) to the general status of ponds soil quality. Aquaculture systems (intensive and traditional) only gave a significant different (p<5%) to the parameter of soil bulk density, c-organic, total N, C:N ratio, total S, total P and soil respiration. Stability of the ponds bottom soil chemical compositions over time make level of intensity does not significantly affect, beside routine sediment removal at the end of cycle in intensive culture.

Keywords: BLUPPB Karawang, Soil quality index, Pond bottom, Aquaculture, Traditional, Intensive

1. Introduction

The Indonesian archipelago has a coastal line reached 81,000 km, has vast potential for brackish water aquaculture activities. Until 2010, the results of Indonesian aquaculture activities accounted 3.85% of world aquaculture production, and ranks fourth worldwide , after Vietnam (FAO, 2014). Data from the Ministry of Marine Affairs and Fisheries shows that Indonesian brackish water commodity production continues to increase every year. Indonesian aquaculture shrimp production has continued to increase from 338.06 thousand tons in 2009 to 645.96 thousand tons in 2013, with an average rise reached 19.25 % , while for milkfish aquaculture production 328.3 thousand tons in 2009 to 627.3 thousand tons in 2013, with an average increase in production reached 17.16 % per year (MAF, 2014).

Aquaculture sectors as well as other sectors that also use natural resources and interact with the environment (FAO, 2000). All human activities, including aquaculture, would affect or be affected by the environmental system. Some will have a positive impact, while others will have a negative impact on the survival of natural ecosystems (Pillay, 2004). Environmental impact of aquaculture activities backfire for aquaculture itself. Various kinds of failure phenomena in brackish aquaculture lately were caused by the environmental degradation. The impact of aquaculture activities has resulted in ponds environmental degradation. The impact of environmental degradation causes the land productivity declined. Mass mortality caused by vibriosis and viral diseases outbreak on shrimp farming can be due to secondary effects of the pond environmental degradation (Funge-Smith & Briggs, 1998; Phillips, 1995). Since aquaculture activities using fertilizers in growing life feed and aquafeed has a higher in protein contains but low in feed utilization, it makes the aquaculture activities always generate waste consists of organic material and nutrients (Boyd, Lim, Queiroz, & Salie, 2005; Ronnback, 2002). Organic waste materials resulting from this activity will accumulate in the pond bottom (sediment). Accumulation of organic material on the pond bottom will be a limiting factor in the aquaculture intensification (Avnimelech & Ritvo, 2003).

Kumar et al. (2012) stated that the quality of pond sediment is one of the important factors in the success of aquaculture activities. Physical and chemical characteristics of pond water are strongly influenced by the properties of pond bottom sediment. Boyd (2003b) reported that fish farmers are widely believed that the high accumulation of organic material on the pond bottom causing a decrease in sediment quality and have a negative impact on water quality. Furthermore, it was said that the organic pond sediment layers affect water quality through the high consumption of dissolved oxygen in water, release and absorption of nutrients in the water. Pond soil is very beneficial for farms ecology as a means to hold water, store a wide variety of chemical substances, habitat for plants and animals, and the recycling of nutrients and a source of dissolved toxic substances (Boyd, 1995).

Soil quality demonstrated the ability of soil to show its functions in land use or ecosystem, to sustain biological productivity, maintain the quality of the environment, and improve the health of the organism (Arifin, 2011). It is an important factor with regard to the concept of soil quality is measurement of soil quality should reflect both the properties of biology, chemistry, physics; processes and interactions among the three properties (Karlen, Ditzler, &

Andrews, 2003). Determination of soil quality intended to generate an understanding and awareness that soil resources is a living body with the properties of biology, chemistry and physics that are useful in ecosystem services. Measurement of soil quality indicators resulted in soil quality index (SQI). Soil quality index is an index, which is calculated based on the value and weight of each indicators of soil quality. Soil quality indicators selected from the properties that demonstrate the capacity of soil functions (Partoyo, 2005). Lee, Wu, Asio, & Chen (2006) states that the value of minimum data sets (MDS) from indicators of soil quality can be combined in an index of the soil quality, through a flexible SQI model.

BLUPPB Karawang is an aquaculture area, which located on the north coast of Karawang district, West Java, a former PP Tambak Inti Rakyat (TIR) shrimp aquaculture area of which began to be developed and operated in the mid-1980s. At this area, currently some of aquaculture commodities well developed from traditional /extensive systems to the intensive systems. Considering of long enaugh in operational time of BLUPPB Karawang region with some aquaculture technology that is developed, so the exploitation of the resources in the this region for aquaculture activities may have resulted in changes in the pond soil quality.

Studies on soil characteristics for ponds aquaculture are still rare (Boyd, 1995), therefore this study aims to assess the status of the pond bottom soil quality in the different aquaculture systems (traditional and intensive) within a value of flexible soil quality index (SQI). The information obtained can be a reference in ponds management for sustainable aquaculture, especially in the BLUPPB Karawang aquaculture area.

2. Materials and Method

This research was conducted in the area of aquaculture BLUPPB Karawang, Pusakajaya Utara village, Cilebar districts of Karawang, West Java (Figure 1) (107.430E and 6.100S) in April-May 2015. The population is restricted to the pond with brackish aquaculture commodities. Twenty ponds are used as sample, comprising 5 L. vannamei intensive shrimp ponds with lining of mulch (VnP), 5 L. vannamei intensive shrimp ponds without plastic lined (earthen pond) (VnT), 5 traditional polyculture ponds (Poly) and 5 traditional nursery ponds of milkfish juvenile (NB). Selection of ponds sampled conducted a non-randomized or non-probability sampling with purposive sampling method (intentional sample) (Siregar, 2014). Samples criteria were determined based on the representation of traditional and intensive culture systems.

Considering of each ponds bottom soil do not have a uniformity in aspects of sediment depth, texture or chemical composition, so its required soil sampling along transects from the pond with a shallow water to deep water. Pond bottom soil samples were taken at 10 points at the same distance along the transect from the tip to the middle of the pond. Soil sampling followed the pattern S (Boyd, 1995). Samples were taken using a core tube made of PVC pipe with a diameter of 5 cm and a length of 35 cm at a depth of 5-10 cm. Each pond is represented by 10 sample points are then combined to obtain a sample for each plot or area (Barua & Ghani, 2012; Brito, Costa, Antonio, & Galvez, 2007). A total of 2 Kg soil samples were taken for each pond, which is the result of merging soil of 10 sample points of each pond. Further, soil samples inserted in black plastic bags and transported to the laboratory.

Dark plastic bag labeled with the inscription date of sampling, the location and number of the ponds (Brito et al., 2007; Sonnenholzner & Boyd, 2000a).

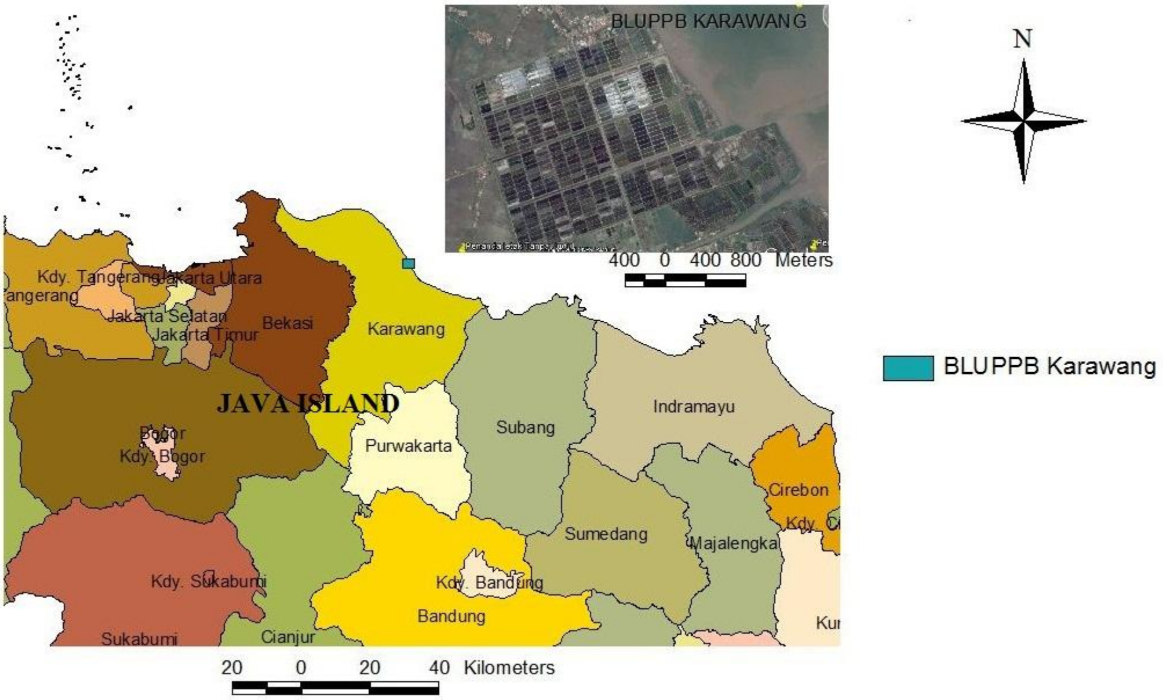

Figure 1. Map of The Study Site

Analysis of soil pH and potential redox performed insitu using ORP meter. Bulk density analysis carried out by the procedure described by Boyd (1995). Total nitrogen were analyzed using dry combustion method (Wright & Bailey, 2001). Soil texture is analyzed using pipette method. Organic materials were analyzed using Walkey and Black for carbon organic. The cation exchange capacity (CEC) was determined by saturation with 1 M NH4OAc at pH 7.0. Total phosphorus, total sulfur, calcium, magnesium and iron extracted using HNO3 (Eviati & Sulaeman, 2009). Soil bacteria were analyzed using total plate count method (Lipşa et al., 2012; Nimrat, Suksawat, Maleeweach, & Vuthiphandchai, 2008). Analysis of soil respiration conducted in the laboratory, using the methods described and used by (BBPPSLP, 2007).

Status of ponds soil quality done by analyzing descriptively the data of soil quality indicators results of measurement into a quantitative value of Soil Quality Index (SQI). Calculations to determine the SQI refers to methods performed by Lee et al.(2006) and Partoyo (2005) with the modification and development for aquaculture. Representation of the physico, chemical and biological soil quality parameters considered in this study.

The equation used to determine the value of Soil Quality Index (SQI) is as follows :

$$SQI = \Sigma (Si \times Wi) \quad (1)$$

Where Si is score of the soil quality indicators and Wi is the weight index of each soil quality indicators which the scores equal to weight 1 x weight 2. Si and Wi standardized value from 0 to 1 and therefore SQI values were also calculated with a range of values from 0 to 1. The method of scoring or weighting of each parameter adjusted to the importance of the function in supporting living of aquaculture organisms.

The method used in weighting of soil quality parameters is a modification from Amacher, Neill, Perry, & Service (2007); Lee et al. (2006); Partoyo (2005) adjusted for aquaculture interest. Standard values (0-1) soil quality indicators are given specific weight and then combined into a single simply value called SQI. The total value of the weight of all indicators is 1. Therefore, SQI values are in the range of 0 and 1. The weighting given subjectively. Physico, chemical and biological properties are given almost the same weight, considering among the three indicators have the same importance functionality (Weight 1). Each indicator is given a factor, called sub-factor weights or sub-weight (Weight 2). The weight assessment can be different for each person depending on the emphasis on the role of the individual from the soil property. Weighting models used in this study can be seen in Table 1.

Table 1. Model weight (w) and the index weighting (W) for each soil quality parameters

Parameters	**Weigth (w1)**	**Indicators**	**Unit**	**weight 2 (w2)**	**Weight Index (Wi) (w1xw2)**
Physical	0.33	Bulk density	g/cc	0.50	0.17
		Clay content	%	0.50	0.17
Chemical	0.34	Soil pH		0.12	0.04
		C-organik	%	0.12	0.04
		CEC	mEq/100g	0.09	0.03
		Total N	%	0.12	0.04
		Sulphur	%	0.09	0.03
		C:N ratio		0.12	0.04
		Redox potential	mV	0.09	0.03
		phosphorus	ppm	0.06	0.02
		Potassium	ppm	0.06	0.02
		Magnesium	ppm	0.06	0.02
		Calcium	ppm	0.06	0.02
		Besi	ppm	0.03	0.01
Biological	0.33	Total bacteria	CFU	0.50	0.17
		Soil Respiration	$mgCO_2/g/d$	0.50	0.17
Total	**1.00**				**1.00**

Assessment or scoring (Si) the quality of soil indicators are performed by dividing into three-assessment system by using the term scoring function (SF). The third SF are SF3, SF5 and SF 9 (Figure 2). SF3 to assess the soil quality indicators, which the higher values give the better. SF5 to assess indicators of soil quality, which have a range of optimum values. SF9 to assess indicators of soil quality, which the lower values are better quality soil. Table 2 is indicators of soil quality with SF specific value as the computation of soil quality index (SQI). Soil quality status assessment criteria conducted based on Arifin (2011) as shown in Table 3.

Determination effect of the aquaculture systems to the status of ponds soil quality were done statistically by analysis of variance (Anova) and if there give a significant effect ($p<5\%$) continued with pos hoc test to compare means using HSD (Honestly Significant Different) Tukey test. Statistical analysis helped using the software Xlstat Pro.

Table 2. Selected indicators of soil quality and SF models for soil quality parameters

Indicators	Unit	SF	Lower threshold	Base line	Upper threshold	Lower baseline	Opt. level	Upper baseline
Physical properties								
Bulk density	g/cc	5	0.17		>1.55	0.55	0.92	1.24
Clay content	%	5	10		35	15	20	25
Chemical properties								
Soil pH		5	<5.5		>9	6.5	7	7.5
C-organic	%	5	<0.5		>4	1	2	3
CEC	mEq/100g	5	<5		>40	16	20	30
Total N	%	5	<0.15		>0.5	0.25	0.325	0.4
Sulphur	%	5	<0.05		>1.5	0.075	0.3	1
C:N ratio		5	<5		>25	8	12	20
Redox potential	mV	3	<-250	(-200)-(-250)	>(-100)			
Phosphorus	ppm	5	<20		>400	30	150	300
Potassium	ppm	5	<100		>1700	250	800	1450
Magnesium	ppm	5	<700		>4000	1100	2250	3500
Calcium	ppm	5	<1000		>8000	1500	3000	6000
Iron	ppm	5	<60		>1200	200	475	750
Biological properties								
Total bacteria	CFU	3	10^3	10^5	10^7			
Soil respiration	mgCO2/g /day		<0.043		>0.286	0.071	0.143	0.214

Sources: Amacher et al. (2007); Avnimelech & Ritvo (2003); Banerjea (1967); Boyd, Tanner, Madkour, & Masuda (1994); Boyd, Wood, & Thunjai (2002); Boyd (1995); Eviati & Sulaeman (2009); Lee et al. (2006); Silapajarn, Boyd, & Silapajarn (2004); USDA-NRCS, (2001); Waksman & Starkey (1931)

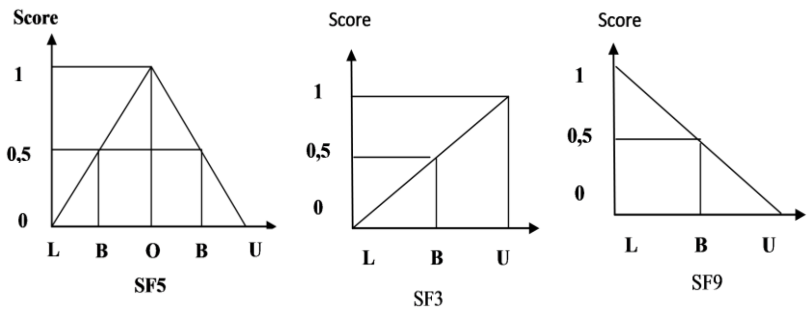

Figure 2. The General Form Scoring Function (SF) for The Evaluation of Soil Quality. SF3: Indicates The Higher Value/Large Will be Better, SF5 Indicates The Optimum Value Would be Better, and SF9 Indicates That the Smaller Value, The Better. (1) Score SF3: l (Lower Threshold) = 0, B (Baseline) = 0.5; and U (Upper Threshold) = 1; (2) Score SF5: l (Lower Threshold) = 0, B1 (Lower Baseline) = 0.5, O (optimum) = 1, B2 (Upper Baseline) = 0.5; and U (Upper Threshold) = 0; and (3) Score SF9 = l (Lower Threshold) = 1, B (Baseline) = 0.5; and U (Upper Threshold)= 0

Table 3. Criteria for soil quality based on soil quality index (SQI) values

No	Class of SQI values	Criteria of soil quality
1	0.80 – 1.00	Very good
2	0.60 – 0.79	Good
3	0.40 – 0.59	Moderate
4	0.20 – 0.39	Low
5	0.00 – 0.10	Very low
5	0.00 – 0.10	Very low

3. Results and Discussion

3.1 Soil Quality Index (SQI)

The result showed the value of soil quality index (SQI) ranging from 0.24 to 0.48 with an average 0.38 ± 0.017 as can be seen in Figure 2. Based on Arifin (2011), the status of the ponds bottom soil quality in the BLUPPB Karawang area included in the quality criteria for low to moderate. Results of analysis of variance showed that the different aquaculture systems did not affect significantly (p>5%) to the status of soil quality. There is evidence of a decline in the quality of the pond bottom soil , because of the accumulation of waste and the development of anaerobic conditions in the ponds bottom soil (Avnimelech & Ritvo, 2003). Characteristic chemical parameters of pond bottom soil on traditional systems and semi intensive showed only slight differences (Caipang, Fos, & Golez, 2012). Ponds bottom sediments removal are able to change the pond bottom soil quality, and the concentration of some soil parameters different from the situation without the sediment removal (Yuvanatemiya & Boyd, 2006).

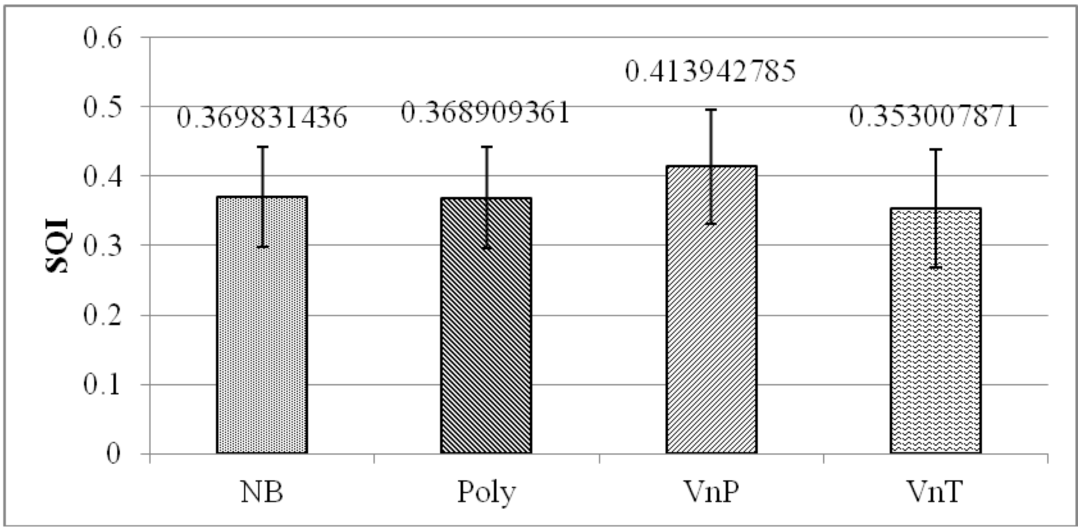

Figure 2. Soil Quality Index (SQI) of Some Aquaculture Systems (NB: Nursery Milkfish, Poly: Polyculture, VNP: Vanamei Intensive Plastic Lined and VNT: Vanamei Intensive Earthen Ponds)

Status ponds soil quality in the research area cannot be separated from the ponds age, which has a relatively old and the accumulation of nutrients at the end of the culture cycle. The absence of differences in the status of soil quality in different aquaculture systems is probably caused by the stability of the chemical composition of the pond bottom soil over time so it is not significantly affected by the level of intensity of the systems. The higher nutrient input in the intensive systems than in traditional, does not give a different effect, considering the better ponds preparation in the intensive system includes routine sediment removal. This treatment may able to maintain the quality of the pond bottom soil in intensive pond, beside intensive ponds with plastic lined.

3.2 Physical and Chemical Indicators

Data of ponds soil physical and chemical indicators taken from paper reported by Prihutomo, Anggoro, & Dewi (2016). As can be seen in Table 4 and Table 5

Table 4. The soil texture of pond bottom soil in BLUPPB Karawang

Aquaculture Systems	Sand	Silt	Clay	Texture Type
	%	%	%	
NB	1.80±0.84	29.20±7.40	69.00±6.96	Clay
Poly	2.00±0.71	25.20±1.79	72.80±2.28	Clay
VnP	2.40±1.95	24.20±3.35	73.40±5.13	Clay
VnT	3.00±3.46	25.00±4.30	72.00±6.67	Clay

Source: Prihutomo, Anggoro, & Dewi (2016)

Table 5. Ponds soil chemical properties in different aquaculture systems of BLUPPB

Karawang (Prihutomo et al., 2016)

Parameters	Aquaculture Systems			
	Traditional		Intensive	
	NB	Poly	VnP	VnT
Bulk density (g/cc)	0.67 ±0.09[ab]	0.55 ±0.12[a]	0.82 ±0.22[b]	0.83 ±0.16[b]
pH	6.91 ±0.46[a]	7.048 ±0.36[a]	5.74 ±0.07[a]	6.72 ±0.27[a]
C-org (%)	0.526 ±0.08[a]	0.746 ±0.06[a]	0.45 ±0.21[ab]	0.41 ±0.06[b]
tot. N (%)	0.42 ±0.04[ab]	0.451 ±0.02[a]	0.30 ±0.06[b]	0.37 ±0.02[b]
C:N ratio	1.28 ±0.25[ab]	1.66 ±0.14[a]	1.21 ±0.33[ab]	1.11 ±0.15[b]
S (%)	0.44 ±0.32[ab]	0.82 ±0.18[a]	0.20 ±0.33[b]	0.08 ±0.16[b]
CEC (mEq/100g)	17.95 ±1.51[a]	18.16 ±0.96[a]	14.30 ±1.11[a]	17.88 ±0.88[a]
Redox (mV)	0.40 ±27.07[a]	-7.28 ±21.12[a]	1.35 ±3.71[a]	6.6 ±8.47[a]
P (ppm)	3 640 ±477[b]	2 680 ±487[b]	10 280 ±6 069[a]	9 000 ±3 977[ab]
Fe (ppm)	50 400 ± 6 177[a]	50 520 ±3 474[a]	50 060 ±4 714[a]	50 220 ±2 340[a]
Ca (ppm)	6 920 ±4 103[a]	9 020 ±3 401[a]	16 640 ±9 721[a]	17 760 ±8 336[a]
K (ppm)	9 660 ±1 532[a]	8 300 ±894[a]	7 800 ±1 350[a]	9 600 ±447[a]
Mg (ppm)	11 140 ±2 669[a]	9 780 ±1 045[a]	7 600 ±901[a]	8 800 ±418[a]

[a,b] The same letters in different column showed no significant differences (p > 5 %) between aquaculture systems; NB: Milk fish nursery ponds; Poly: Polyculture ponds; VnP: Intensive vanamei plastic lined ponds; VnT: Intensive vanamei earthen ponds

3.3 Biological Indicators

3.3.1 Soil Respiration

Ponds soil respiration obtained ranged from 0.001 to 0.37 mgCO2/g/day with an average range was 0.177 ± 0.023 mgCO2 /g/day. Results of analysis of variance shows that aquaculture systems do not affect significantly (p>5%) to the level of soil respiration, but as seen in Figure 3 intensive aquaculture systems show higher level of soil respiration than traditionals. Activity of microorganisms based on the soil respiration values in the pond samples ranged from very low to very high, according to the criteria USDA-NRCS, (2001). Several factors contribute to the high rate of soil respiration are sufficient levels of soil moisture (Boyd, 1995; Gupta et al., 2004; Pepper, Gerba, & Brusseau, 2006; Ria Azizah, Subagyo, & Rosanti, 2007), soil neutral pH to near the base (Boyd & Pippopinyo, 1994; Boyd, 1995), plowing of ponds bottom soil to increase soil oxygen content (Boyd & Pippopinyo, 1994; Boyd, 1995; Pepper et al., 2006), suficient concentration of soil organic matter (Sonnenholzner & Boyd, 2000b; Xinglong & Boyd, 2006) and nitrogen fertilization (Boyd & Pippopinyo, 1994; Boyd, 1995). The high input of organic materials containing nitrogen in intensive aquaculture resulted in a low C:N ratio and this condition triggering decomposition of organic matter more quickly (Boyd, 1995). This conditions are characterized by high levels of soil respiration in intensive system.

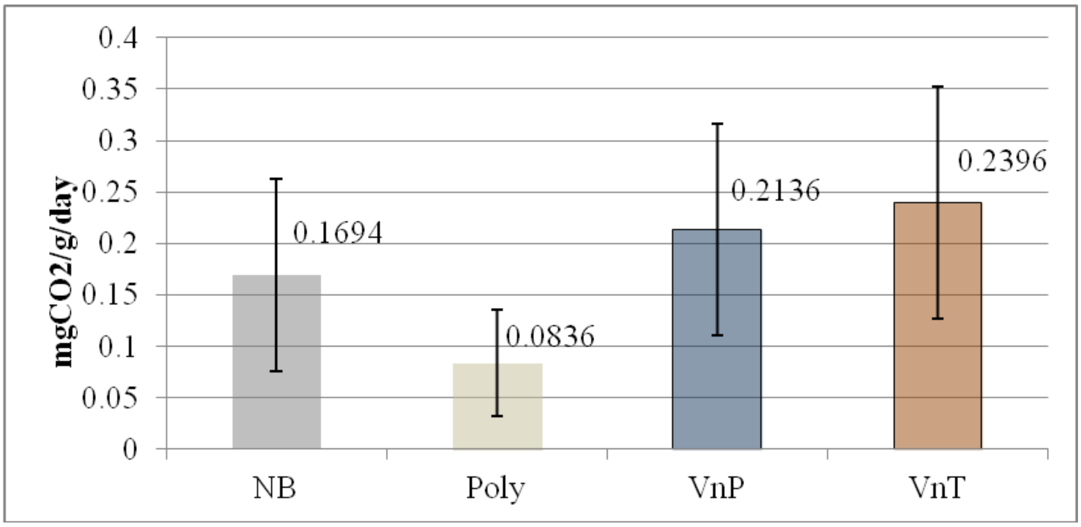

Figure 3. Pond Bottom Soil Respiration in Some Aquaculture Systems

3.3.2 Total Bacteria

Total soil bacteria abundance can be seen in Figure 4. Range of total bacteria in the ponds soil samples 7 000-181 900 CFU/g with an average was 46 600 ± 8 553 CFU/g. Results analysis of variance total soil bacteria abundance can not show any significant differences ($p > 5\ \%$) of different aquaculture systems. The average total bacterial abundance of these ponds can be said to have a fairly low when viewing reports of Devaraja, Yusoff, & Shariff, (2002) and Anand Ganesh, Das, Chandrasekar, Arun, & Balamurugan (2010). Waksman & Starkey, (1931) stated on the plate count method total amount of bacteria are vary from 10 000 CFU / gram in the desert soil, up to 50 million CFU / gram are often found in soil fertilized and well treated. The low population of bacteria in the ponds soil acquired during study the possibility soil samples located in the ayer of transition zone, so growth of aerobic bacteria limited by the lack of oxygen, only a facultative bacteria are able to survive, as reported Husson (2013). He reported that each type of organisms able to adapt on specific potential redox (Eh) conditions, and characterized by the ability to thrive in a wide range of Eh or more narrow and anaerobic bacteria can thrive only in the range of very low Eh values. Inglett et al. (2005) stated that the soil under saturation conditions supporting microbial population that is able to adapt the anaerobic environment. Aerobic microbial populations restricted to zones where oxygen is still available. Most aerobic organisms be silent or dead, and a new habitat are mostly facultative and obligate bacteria take over. Low soil organic carbon concentration of the ponds sample may also be a factor causing low total abundance of pond soil bacteria. As reported Das (2012) who states that the c-organic is the most significant factors that regulate the concentration of total soil microbial population.

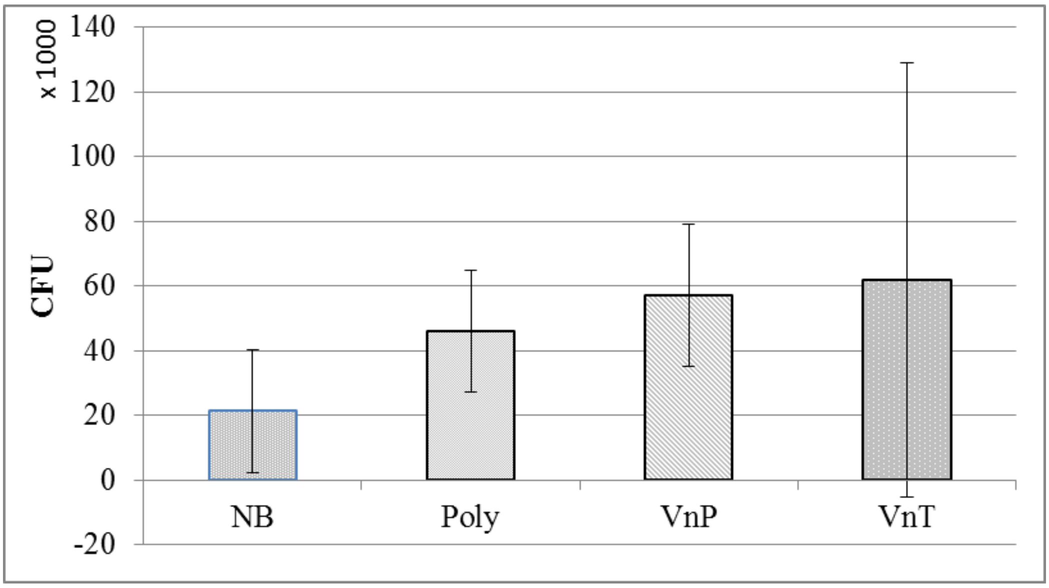

Figure 4. Total Bacteria of Pond Bottom Soil Some Aquaculture Systems

4. Conclusions

Ponds bottom soil quality status of BLUPPB Karawang area included in the low-quality criteria. Different aquaculture systems generally do not affect significantly (p>5%) to the status of ponds soil quality. Different aquaculture systems (intensive and traditional) just only significant different (p<5%) to the soil parameters content of bulk density, c-organic, total N, C:N ratio, total S, total P and soil respiration.

Considering the soil quality index value is relative, it is necessary to iterate the model to get pond soil quality index values more representative to the real condition of ponds bottom soil. Ponds management, need to be addressed to improve ponds bottom soil quality conditions.

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