Study on Determination of Categories of Soil Quality Variable Concentrations in Brackish water Ponds of Java Island, Indonesia

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Abstract: Soil quality plays pivotal role in increasing productivity and brackish water ponds successfulness, including ponds of Java Island, Indonesia. However, the availability of data on concentration categories for soil quality variables for ponds soils in Java Island, which is volcanic-dominated soils and the largest area for ponds in Indonesia, is still scarce. This study was aimed to categories soil quality variable concentrations as an initial point in interpreting pond soils quality of Java Island. Soil samples were collected from two different soil depths of 923 sampling points representing 13 regencies/cities of West Java, Central Java, and East Java Provinces. Twenty soil quality variables were measured based on in-situ and ex-situ measurements. The t-Student and U-Mann Whitney tests were applied to analyses the differences in soils quality at each soil depth which were firstly analyzed using z-score to eliminate outlier data. The data were firstly rearranged from the smallest to the largest data prior to measuring data deciles; the deciles, as considered as the basic measurement, were used for categorizing each soil quality variable. The results of this study indicated that the pH and nutrients are higher at pond top soils, 0-0.2 m compared to that observed on the depth of 0.2-0.5 m. Concentration of soil quality variables such as $S_{KCl}$, $S_{P}$, $S_{POS}$, TPA, TAA, TSA, and pyrite relatively similar between the two depths. Data of each soil quality variable were categorized into very low, low, moderate, high, and very high to facilitate a comparison to other data of ponds soil qualities. The results of this study are not recommended for assessing the relationship between ponds soil quality and ponds productivity; yet are useful in measuring which variable of ponds soil quality is categorized as very low, low, moderate, high or very high; and also useful in making decision on pond soils quality management in Java Island.

Keywords: Concentration category; Depth; Soil quality; Brackish water pond; Indonesia

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Introduction

Indonesian government has established the President of Indonesia Instruction number 7 of 2016 on the acceleration in national fisheries industries. The Ministry of Marine Affairs and Fisheries (MMAF) is expected to increase the fisheries productions through capture and aquaculture fisheries to maintain the availability of raw materials for industry and consumption. At present, there are five aquaculture types developed in Indonesia, which are brackish water ponds, freshwater ponds, mariculture, inland open water, and rice fish. Among those five aquaculture types, brackish water ponds are the biggest aquaculture industry in Indonesia. However, mariculture is the biggest aquaculture fisheries producer that produces 9.04 million tonnes (62.95% of total aquaculture in Indonesia). In contrast, the biggest production value is provided by brackish water ponds which are IDR 42.50 trillion (33.28% of total aquaculture production value) (MMAF, 2015).

The brackish water ponds in Indonesia extend to 657,345.64 ha where most of the area is located in Java Island, which is 176,316.18 ha representing 26.82% of total pond areas in Indonesia. The ponds on Java Island are located in 6 provinces/special region capital city/special region; however, the most extended ponds areas are found in West, Central, and East Java provinces. Ponds in these three provinces mainly utilized for culturing tiger shrimp (Penaeus monodon), whiteleg shrimp (Litopenaeus vannamei), mud crabs (Scylla spp.), milkfish (Chanos chanos), and seaweed (Gracilaria verrucosa) through monoculture and polyculture under extensive, extensive plus, semi-intensive, intensive or super-intensive technologies.

Topography, tides, soil, and water qualities as well as climate are considered in enacting criteria for land suitability for ponds aquaculture, particularly for extensive and semi-intensive technologies; however, soil quality is the most dominant factor in criteria for land suitability for ponds aquaculture (Boyd, 1995; Salam et al., 2003; Giap et al., 2005; Karthik et al., 2005; Hardjowigeno and Widiatmaka, 2011; Mustafa, 2012; Mustafa et al., 2015a). Soil quality has a vital role in the successes and sustainability of ponds aquaculture. Soil quality affects water quality, biological process in ponds, and pond constructions (Sammut, 1999), it also controls transformation of nutrients, particularly performance of fertilizer (Banerjee et al., 2010). Furthermore, soil quality controls stability of pond bottom soils, pond water alkalinity, water pH and concentration of nutrients required by natural feed (Ekubo and Abowie, 2011; Caipang et al., 2012; Kumar et al., 2012; Siddique et al., 2012; Boyd and Queiroz, 2014). Soil quality and pond bottom soil processes as well as the association between ponds soil and water are important for fish or shrimp growth (Avinmelech and Ritvo, 2003; Ndome et al., 2012). The soil processes affect water quality and most problems in ponds aquaculture are associated with soil qualities (Boyd, 1992). To understand soil chemical processes and to establish decisions on land suitability for ponds aquaculture together with effective soil managements to increase ponds productivity, there is a need in understanding pond soil qualities.

The surface sediment of pond has the biggest impact on quality of pond environment, such as water quality. Although water quality management is considered as a crucial factor in the success of ponds, some evidences show that soil quality and the materials exchanges between soil and water affect pond water quality (Boyd, 1995; Siddique et al., 2012). Anaerobic surface pond soil is particularly harmful for cultured shrimp because the shrimp lives on pond soils surface. The direct contact between tiger shrimp and pond bottom soils through aqueous phase is the cause of low survival rate of shrimp cultured in sulfate acid soil-affected ponds (Mustafa, 2007). However, deeper soil characteristics need to be measured because the pond soil is sometimes excavated during pond establishment and management either to meet pond depth requirement or to have a new pond soil surface that has different quality. The new established pond areas are usually cleared from vegetation and about 0.25 to 0.75 m of surface soils are usually removed to establish pond dykes (Boyd and Queiroz, 2014). The characteristics of soil may vary following the differences of soil depths (Boyd, 1976; Mustafa et al., 2015b; Perryman et al., 2017). The surface soils usually have different characteristics to the deeper soils (Sartohadi et al., 2012).

A “tool” in aquaculture management that rarely utilized and developed is soil analysis. Data of pond soil quality collected through soil analyses are scarcely applied by most decision makers, including aquaculture managers; however low soil quality is frequently the suspect when they cannot explain low growth and survival rate of cultured organism resulted by diseases outbreaks, low feed quality, extreme season, low water quality, incorrect pond management or other main causes. Information on category of concentration soil quality variables is a crucial aspect in understanding the status of pond soil quality. The category of concentration soil quality variables had been established in ponds of Thailand, Philippines, Ecuador, and Venezuela (Boyd et al., 1994); however, these categories were based on limited soil quality variables. Mustafa et al. (2015a) also have established category of concentration soil quality variables in pond soils in South Sulawesi where the soils is swamp land consisted of alluvial acid sulfate, peat and alluvial non-acid sulfate soils, including saline soil. The soils in Java Island, especially in northern and eastern coasts are dominated by volcanic soil (Supriyo et al., 1992; Jensen, 1993; Devnita et al., 2010; Erfandi and Rachman, 2011; Widiatmaka et al., 2016) that has specific characters; therefore the soils show particular character and different from soils outside Java Island. In addition, some studies conducted in shrimp ponds of Java Island only assessed land suitability for shrimp pond (Utojo et al., 2012; Utojo et al., 2013a; Utojo et al., 2013b; Utojo et al., 2013c; Suhaemi et al., 2013; Utojo et al., 2014); spatial distribution of soil variables (Asaad and Mustafa, 2011; Kamariah et al., 2014); influence of water and soil qualities on shrimp production (Mustafa and Athirah, 2014), traditional shrimp pond management (Mustafa et al., 2015c) and feasibility of silvofishery (Taranamulia et al., 2015). This study was aimed to provide information on categories of soil quality variable concentrations at two different soil depths of pond soils in Java Island. This activity was as the initial categorization to interpret soil quality variables in categorizing soil quality variable concentrations as very low,
low, moderate, high, or very high and for making decision in pond soils management.

Materials and Methods

Soil samples

Pond soil samples were collected at the Regencies/Cities of Subang, Indramayu, Cirebon (West Java), Brebes, Pekalongan, Demak, Pati (Central Java), Tuban, Lamongan, Gresik, Sidoarjo, Pasuruan, and Probolinggo (East Java), Indonesia (Figure 1). These areas were selected by the MMAF as the minapolitan and aquaculture revitalization areas based on the Ministry of MMAF decree number KEP.32/MEN/2010 on the determination of minapolitan areas. In addition to the MMAF, the general director of aquaculture issued a degree number Kep.240/DJ-PB/2012 to determination 87 locations of aquaculture production centre as the pilot area for minapolitan. Samples of soils were collected using bore soil sampler with a diameter of 0.05 m. The number of sampling points was 923 points extended in those 13 regencies/cities where the sampling points were chosen based land use and topography (Rayes 2007; Hazelton and Murphy, 2009). The collections of soil samples were conducted during 2010 to 2015.

The samples of pond bottom soils were collected at two sampling points of each pond bottom then composited to represent one sampling point. The samples of pond soils were collected at two depths, which were 0-0.2 and 0.2-0.5 m for each sampling point. The sampling activities were mostly conducted at ongoing farming ponds for various fisheries commodities; therefore most samples were collected from watering ponds. The vegetation debris, gravels, shells, and other contaminants attached in the soil samples were removed manually by hands then the samples were filled in plastic bags and stored in ice box (Ahern et al., 2004) and eventually transported to the Soil Laboratory belongs to Research Institute for Coastal Aquaculture and Fisheries Extension, previously known as Research Institute for Coastal Aquaculture.

Soil analyses

$\text{pH}_F$ of soil samples were measured under in-situ measurements using a pH meter based on electrometric method (Ahern and Rayment, 1998; Watling et al., 2004), whereas and $\text{pH}_{\text{ox}}$ (pH of oxidized soils using 30% of hydrogen peroxide ($\text{H}_2\text{O}_2$)) of soil samples were measured also using a pH meter based on electrometric method (Ahern and Rayment, 1998; Watling et al., 2004; Hazelton and Murphy, 2009). In the laboratory, the acid sulfate soil samples were dried in an oven under 80-85°C.

Figure 1: Study locations in brackishwater ponds of 13 regencies/cities in Java Island, Indonesia.
for 48 hours (Ahern and Blunden, 1998). The non-acid sulfate soils samples were air dried in a special and contaminant free  

rack that was protected from sunlight. The dried samples were then ground using porcelain mortar and pestle then sieved on a 2.0 mm mesh size. The samples were then re-grounded using porcelain mortar and pestle then re-sieved on a 0.5 mm mesh size to obtain soil particle size less than 0.5 mm.

The soil quality variables analyses in the laboratory consisted of \( \text{pH}_{\text{H}_{2}O} \) (pH of soils extracted by \( \text{H}_{2}O \)), \( \text{pH}_{\text{KCl}} \) (pH of soils extracted by 30% of \( \text{H}_{2}O \)) based on electrometric method (McElnea and Ahern, 2004a,b), \( S_p \) (sulphur extracted by 30% of \( \text{H}_{2}O \)) based on spectrophotometric method (McElnea and Ahern, 2004c), \( S_{\text{KCl}} \) (sulphur extracted by \( \text{KCl} \)) based on spectrophotometric method (McElnea and Ahern, 2004d), Titratable Peroxide Acidity (TPA), previously known as Total Potential Acidity based on titrimetric method (McElnea and Ahern, 2004b), Titratable Actua acidity (TAA), previously known as Total Actuality based on titrimetric method (McElnea and Ahern, 2004a), Titratable Sulfidic Acidity (TSA), also known as Total Sulfidic Acidity (TATA) (McElnea and Ahern, 2004b), pyrite (FeS\(_2\)) through titrimetric method (Ahern et al., 1998a,b), organic carbon by titrimetric under method of Walkley and Black (Sulaeman et al., 2005; Eviati and Sulaeman, 2009), total Nitrogen by titrimetric using Kjedhal method (Sulaeman et al., 2005; Eviati and Sulaeman, 2009), \( \text{PO}_4 \) and \( \text{P}_{2} \text{O}_5 \) measured using titrimetric under Bray or Olsen method (Sulaeman et al., 2005; Eviati and Sulaeman, 2009), Iron (Fe) and aluminium (Al) using spectrophotometric technique (Menon, 1973) through a GENESYS 10S UV-Vis spectrophotometer.

Quality control by a duplo measurement and controlled sample (Kantasubrata, 2012) was applied on selected soil quality variables and soil samples. Re-analyses on the selected variables and soil samples were conducted during field works; whereas controlled samples were conducted on soil quality variables analysed in the laboratory as a part of the laboratory quality control.

Data analyses

Data of this study were then compiled from studies collecting data of soil quality variables through the studied area, Subang Regency (Tanunamulia et al., 2015), Indramayu Regency (Utojo et al., 2013b), Brebes Regency (Suhaemi et al., 2013), Pekalongan (Asaad and Mustafa, 2011), Demak Regency and Athirah, 2014), Pati Regency (Mustafa et al., 2015c), Tuban Regency (Utojo et al., 2014), Lamongan Regency by Utojo et al., 2012), Gresik Regency (Utojo et al., 2013a), Pasuruan Regency (Utojo et al., 2013c), and Regency and City of Probolinggo (Kamariah et al., 2014).

Data analyses were initialed by determining outlier data of each soil quality variable using standard score (Z-Score). Levene’s test was conducted to measure the equality of variance of a variable in two data populations (0-0.2 and 0.2-0.5 m depths). Data of \( \text{pH}_{\text{KCl}}, \text{pH}_{\text{SO}_4}, \text{pH}_{\text{H}_{2}O}, \text{Fe}, \text{TPA}, \text{TSA}, \text{Pyrite}, \text{S}_{\text{KCl}}, \text{S}_{\text{PO}_4}, \text{S}_{\text{H}_{2}O}, \text{S}_{\text{Fe}}, \text{Fe}, \text{Al} \) were directly analyzed using t-Student test as these data meet the requirement for parametrical analysis; whereas data of redox were transformed by \( \log_{10} \) (X+3); C:N ratios, \( \text{PO}_4 \) and \( \text{P}_{2} \text{O}_5 \) were transformed by \( \log_{10} \) (X+1) prior to t-Student tests since the variance of these data were not equal. In contrast, data of \( \text{pH}_{\text{KCl}}, \text{pH}_{\text{PO}_4}, \text{pH}_{\text{Fe}}, \text{pH}_{\text{H}_{2}O}, \text{pH}_{\text{KCl}} \), total N, and TAA did not meet requirement for parametrical analyses then analyzed using non-parametrical analyses by Mann-Whitney (U-tests). The acceptance degree for each statistical analyses were 95% (\( \alpha=0.05 \)). The quantitative measurements on soil quality variables were presented as average \( \pm \) standard deviation. The deciles measurements were conducted by re-arranging the data from the lowest to the highest. The deciles of soil quality variables then categorized in to five concentration categorizes, which were: very low (1st decile), low (2nd and 3rd deciles), moderate (4th to 7th deciles), high (8th and 9th deciles), and very high (10th decile) based on Boyd et al. (1994). Data analyses were conducted using IBM®SPSS® (Statistical Product and Service Solution) software, version 24.

Results and Discussion

Volcanic soils are also known as andosols or andisols on a various soil classification systems (Hardjowigeno, 2003). Most of volcanic soils in Indonesia distributed in Sumatera, Java, Bali, and Lombok Islands. Van Ranst et al. (2002) reported that Java has a various types of soils, yet dominated by volcanic soils. Volcanic soils were formed through a weathering of volcanic dusts; this soil type is also distributed to the low land of Java by wind transport. However, alluvial, which are acid sulfate soils and non-acid sulfate soils also found on pond soils in a small specific area of Java Island (Asaad and Mustafa, 2011; Mustafa and Athirah, 2014; Mustafa et al., 2015c). The characteristics of pond soils at two different depths are presented on Tables 1-3.

Table 1: Descriptive statistics of soil quality variables at different depths in brackish water ponds of Java Island, Indonesia.

| Variables | 0-0.2 | 0.2-0.5 |
|-----------|-------|---------|
| \( \text{pH}_{\text{H}_{2}O} \) | 7.22 ± 0.37* | 7.15 ± 0.40* |
| \( \text{pH}_{\text{KCl}} \) | 6.68 ± 1.05* | 6.64 ± 1.19* |
| \( \Delta \text{pH} \) | 0.77 ± 0.74* | 0.58 ± 0.91* |
| \( \text{pH}_{\text{SO}_4} \) | 8.00 ± 0.28* | 7.94 ± 0.28* |
| \( \text{pH}_{\text{KCl}} \) | 7.46 ± 0.39* | 7.33 ± 0.59* |
| \( \text{pH}_{\text{KCl}} \) | 4.55 ± 1.56* | 4.42 ± 2.08* |
| \( \text{S}_{\text{KCl}} \) (%) | 0.2859 ± 0.2922* | 0.2626 ± 0.2669* |
| \( \text{S}_{\text{KCl}} \) (%) | 6.1589 ± 8.2845* | 6.5865 ± 8.8647* |
| \( \text{S}_{\text{PO}_4} \) (%) | 5.3990 ± 4.5590* | 6.0798 ± 7.8080* |
| TPA (mole H+/l) | 86.55 ± 126.76* | 90.37 ± 143.50* |
| TAA (mole H+/l) | 0.02 ± 0.19* | 0.06 ± 0.30* |
| TSA (mole H+/l) | 86.53 ± 126.76* | 90.37 ± 143.50* |
| Pyrite (%) | 0.3862 ± 0.5659* | 0.4019 ± 0.6393* |
| Fe (ppm) | 531.64 ± 521.22* | 485.16 ± 502.10* |
| Al (ppm) | 113.56 ± 96.92* | 92.08 ± 88.59* |
| Organic C (%) | 1.4723 ± 0.7528* | 1.4201 ± 0.7811* |
| Total N (%) | 0.0979 ± 0.0558* | 0.0888 ± 0.0508* |
| C:N ratio | 16.16 ± 8.31* | 17.49 ± 8.97* |
| \( \text{PO}_4 \) (ppm) | 62.70 ± 54.15* | 43.57 ± 41.75* |
| \( \text{P}_{2} \text{O}_5 \) (ppm) | 46.86 ± 40.47* | 32.56 ± 31.20* |
Soil acidity

Soil acidity or soil pH is a crucial variable in managing pond productivity since this variable controls chemical reactions and ponds environment. Thus, as the acid sulfate soils also present in Java Island, there is a need to measure soil pH such as pH_{F}, pH_{FOX}, pH_{KCl}, pH_{OX} which are commonly measured.
for acid sulfate soils. The results of pH measurements indicated that in general, pond soils of 0-0.2 m depth were significantly higher compared to that measured on soils at 0.2-0.5 m depths (Table 1). The higher soil pH at 0-0.2 m depths is as a result of pond soils remediation removing acid compounds on pond soils surface. Liming to increase soils pH during pond preparation and shrimp farming is another cause of higher pond soil pH. However, the lime does not penetrate soil depth until 0.2-0.5; therefore the liming does not elevate soils pH at the depth greater than 0.2 m. In fact, lime particles only penetrate until the depth of 0.04 m (Coneyers et al., 2003) and 0.05 m (Queiroz et al., 2004) and 0.05 m (Coneyers et al., 2003).

The values of soils pH (pH$_{H+}$, pH$_{FOX}$, ΔpH, pH$_{H_{2}O}$, pH$_{KCl}$, and pH$_{KCl}$) at the depth of 0-0.2 (7.22 ± 0.37; 6.58 ± 1.05; 0.77 ± 0.74; 8.00 ± 0.28; 7.46 ± 0.39 and 4.55 ± 1.56, respectively) and 0.2 to 0.5 m (7.15 ± 0.40; 6.64 ± 1.19; 0.58 ± 0.91; 7.94 ± 0.28; 7.33 ± 0.59 and 4.42 ± 2.08, respectively) of Java Island are higher compared to soils pH of ponds in South Sulawesi Province. Mustafa et al. (2015b) reported that pH$_{p}$, pH$_{FOX}$, pH$_{KCl}$, and pH$_{OX}$ of pond soils in South Sulawesi at the depth of 0-0.2 m are 6.90 ± 0.51; 3.28 ± 2.06; 6.41 ± 1.25; and 3.47 ± 2.10, respectively; whereas at the depth of 0.2-0.5 m are 6.79 ± 0.47; 2.92 ± 2.08; 5.77 ± 1.59; and 3.13 ± 2.20, respectively. These findings indicated that based on soils pH, the soils of Java Island is preferred for shrimp ponds compared to South Sulawesi. At neutral pH (6.6-7.3), the availability of macro nutrients in soils is relatively high, and in contrary, the available of toxic compounds are low; in which provides preferable environment for both natural feed and aquaculture commodities. Mustafa et al. (2015b) reported that pond soils in South Sulawesi are mostly built on swamp land dominated by acid sulfate soils and peat soils indicated by low soils pH and high potential acidity. In contrast, volcanic soils dominating soils of Java Island have higher pH (Qafoku et al., 2004; Van Ranst et al., 2008).

pH$_{p}$ is pH measured during the field work where the soils are still wet or commonly called as fresh soils. The pH$_{p}$ is applied as a rapid assessment on the present of and acid sulfate soils severity. However, the pH measurement using a pH-meter should be conducted in-situ on wet soils to prevent pyrite oxidation (common compounds in acid sulfate soils) to acid sulfate that eventually reduces the actual soil pH (English et al., 1997). pH$_{FOX}$, in contrast to pH$_{p}$, is the measurement of soils pH after the addition of hydrogen peroxides (30% H$_{2}$O$_{2}$) during field works. The additional 30% of H$_{2}$O$_{2}$ during pH$_{FOX}$ measurement is aimed to oxidizes all acidity potential compounds in the brackishwater ponds soils. Thus, the measured pH$_{FOX}$ becomes lower compared to pH$_{p}$ at these two soil depths. The ΔpH might be applied as an indicator of the value of acidity potential on acid sulfate soils; then based on Table 2, the acid soils potential on brackishwater pond soils at 0-0.2 m depths of Java Island are significantly (P<0.05) higher compared to the soils at 0.2-0.5 m of depths. However, this observed ΔpH is relatively lower compared to soils dominated with acid sulfate soils and peat soils at the same depths (0-0.2 m) in brackishwater pond soils established in South Sulawesi, which are 3.62 ± 2.08 (Mustafa et al., 2015b). Thus, the acidity potentials of pond soils in Java Island are lower.

The results of pH$_{KCl}$ showed the pH of soils after H$^{+}$ in an adsorption complex was pressured to enter and leave soil solution by another cation, therefore, pH$_{KCl}$ also known as soil pH potential. The pH$_{KCl}$ commonly measured to compare the value of soils pH measured extracted by H$_{2}$O (pH$_{H_{2}O}$). Based on Table 1, the values of pH$_{KCl}$ at 0.2-0.5 m are higher compared to the value of pH$_{H_{2}O}$. The value of pH$_{KCl}$ is greater than 0.5 unit compared to the value of pH$_{H_{2}O}$ indicates that a sum of exchangeable aluminium (Al) are found in the soil. The aluminium hydrolysis which then replaced by K results in pH decreasing of soils extracted by KCl (Hardjowigéno, 2003), in which this process is supported by the present of Al in brackish water ponds soils of Java Island (Table 1).

The values of pH$_{p}$, pH$_{FOX}$, pH$_{H_{2}O}$, pH$_{KCl}$, and pH$_{OX}$ at the depths of 0-0.2 m (7.20–7.52; 6.61–7.34; 7.96–8.21; 7.47–7.70; and 3.47–6.54, respectively) and 0.2-0.5 m (7.14–7.48; 6.70–7.54; 7.92–8.15; 7.38–7.75; and 3.42–6.76, respectively) (Table 2) are categorized as moderate. In general, the values of these soils pH are higher at the depth of 0.0-0.2 m compared to that measured at the depth of 0.2-0.5 m, which is as the results of more intensive natural remediation processes at the surface pond soils and the liming which are effectively just at the upper pond soils as previously discussed. The values of soils pH measured in this study, are higher compared to that found in pond soils of South Sulawesi as reported by Mustafa et al. (2015b) where the values of pH$_{p}$, pH$_{FOX}$, pH$_{KCl}$, and pH$_{OX}$ at soil depths of 0-0.2 m (6.70–7.20; 1.65–4.80; 6.10–7.20; and 1.90–4.35, respectively) which are also categorized as moderate. The moderate values of pH$_{H_{2}O}$ in this study also relatively higher compared to that reported by Boyd et al. (1994) measured in pond soils of Thailand, Philippines, Ecuador, and Venezuela which are 6.0-7.0 at the soil depths of 0-0.5 m. Different categorizations of soils based on pH$_{H_{2}O}$ have been established by Pusat Penelitian Tanah (1993 in Hardjowigéno and Widiatmaka, 2011) which are very acid, acid, moderately acid, neutral, moderately alkaline and alkaline at the values of <4.5; 4.5–5.5; 5.6–6.5; 6.6–7.5; 7.6–8.5; and >8.5.

Sources of acidity

As stated earlier, that the volcanic soils are dominating soil type in Java Island; however acid sulfate soils also found in this island. Pyrite is a specific characteristic of acid sulfate soils which one of its main sources is sulphur. Oxidized pyrite results acid sulfate and ferrosulfate which release ferry sulfate when react with water and then results sulfate acid when it re-oxidized. Concentration among sulphur extracted by some extractors (S$_{KCl}$, S$_{p}$, and S$_{FOX}$) were no significantly (P>0.05) different between these two soil depths (Table 1), however, concentration of S$_{p}$ and S$_{POS}$ at 0.2-0.5 m of depths relatively higher compared to that observed at depth of 0-0.2 m. The similar findings are also reported by Tanikawa et al. (2013) that higher concentration of sulphur are higher at depth 0.2-0.5 compared to depth of 0-0.2 m in volcanic soils of Japan which is resulted by abundance of pedogenic minerals at the depths of 0.2-0.5 m. As the main source of acidity in acid sulfate soils, data of S$_{POS}$ were considered by Ahern et al. (1999b) in determining concentration of sulphur in which to calculate lime requirement for acid sulfate soils. The concentration of sulphur in the mountain regions adjacent to coastal areas where the elevation is low and have high rainfall tend to increase (Bern et al., 2015).
TPA, TAA, and TSA, variables of soil quality indicating soil acidity have similar pattern to sulphur (S$_{org}$, S$_{S}$, and S$_{T}$). The concentration of TPA, TAA, and TSA at the depths of 0-0.2 m and 0.2-0.5 m are no significantly different (P>0.05). McElnea et al. (2004a, b) stated that there is a correlation between TSA and S$_{org}$ in acid sulfate soils containing low concentration of organic matters. In addition, Noor (2004) reported that in acid sulfate soils, TSA and pyrite are linearly correlated. Thus, based on Table 1, concentration of pyrite between those two depths are no significantly different (P>0.05). The higher concentration of pyrite have been reported by Subagyo (2006) in actual acid sulfate soils of Kalimantan Island where concentration of pyrite ranged from 0.85 to 1.07% which were found at the surface and deeper soils. High concentration of pyrite in pond soils also reported by Mustafa et al. (2015b) in ponds of South Sulawesi where concentration of pyrite were 1.3713% at 0.2 m of depth and 1.7846% at depth of 0.2-0.5 m.

The concentration of pyrite categorized as very low, low, moderate, high, and very high at depths of 0-0.2 m in pond soils of Java Island are <0.0001; 0.0001–<0.0100; 0.0100–0.6900; >0.6900–1.3800 and >1.3800%, respectively. Whereas concentration of pyrite in the same categories at the same depths in pond soils of South Sulawesi are <0.0005; 0.0005–<0.0670; 0.0670–1.7590; >1.7590–3.7945 and >3.7945%, respectively (Mustafa et al., 2015b). Higher concentration of pyrite found in ponds of South Sulawesi is resulted from domination of acid sulfate soils where the soils or sediments rich of pyrite or ferric sulphide.

**Nutrients**

Fe has important role in basic biological processes such as photosynthesis, respiration, fixation, and assimilation of nitrogen (Boyd, 1995). However, Fe in high concentration might be toxic to aquatic organism. Concentration of Fe in pond soils at depths of 0-0.2 and 0.2-0.5 m in this study are no significantly different (P>0.05). In this study, concentration of Fe categorized as moderate are 225.56-910.00 ppm are relatively higher compared to that reported by Boyd et al. (1994) measured in pond soils of Thailand, Philippines, Ecuador, and Venezuela which were 200-750 ppm. As discussed earlier that the volcanic soils have high capacity in retaining phosphate because this type of soil contains more Al and Fe which resulted in low P availability for plants and algae. In this study, the concentration of Fe in pond soils at depths of 0-0.2 m in this study are significantly (P<0.05) higher compared to that measured at soil depth of 0.2-0.5 m which categorized as moderate are 2.60-2.0200 and 1.900-1.9700%, respectively (Tables 2 and 3). The concentration of organic C in this category is similar to that reported in ponds soils of Thailand, Philippines, Ecuador and Venezuela which are 1.0-2.5% Boyd et al. (1994). However, concentration of organic C in this category measured in this study are relatively lower compared to that reported by (Mustafa et al., 2015b) in pond soils of South Sulawesi which are 1.6855–5.6050%. The concentration of organic C measured in this study also relatively low compared to concentration of organic C categorized as moderate, which are 2.0-3.0%, for agricultural plants in Indonesia (Pusat Penelitian Tanah, 1993 in Hardjowigeno and Widiatmaka, 2011). Concentration of organic C ranged between 1.00 to 1.80% are categorized as moderate in relating to soil physical fertility by Charman and Roper (2007) and 1.00-1.59% based on assessment of soils condition Hazelton and Murphy (2009). Low concentration of organic C in brackishwater pond soils of Java Island is caused by the absent of peat soils; whereas Boyd et al. (2002) reported that concentration of organic C in peat soils commonly greater than 15%.

Organic matters produce C and nutrients such as nitrogen. Concentration of total N in soils describes the amount of N in soils which mostly in an-organic forms that is no instantly available for plants and algae. N is macro nutrient in ponds aquaculture and has important role in measuring pond soils fertility. Concentration of total N in pond soils at 0-0.2 m depth in this study are significantly (P<0.05) higher compared to that measured at soil depth of 0.2-0.5 m. Higher concentration of total N at the depth of 0.2 m is a result of application of N fertilizers such as Urea and ZA (Zwavelzuur Ammonium or Ammonium Sulfate) through pond soils initial fertilization and or contaminant fertilizations. Concentration of total N in pond soils of Java Island in various categories at soil depths of 0-0.2 and 0.2-0.5 m are presented on Tables 2 and 3, respectively. Concentration of total N measured in this study is similar to concentration of total N within each category as reported by previous studies in Thailand, Philippines, Ecuador, and Venezuela where the concentration of total N in categories of very low, low, moderate, high, and very high are <0.15; 0.15–0.25; 0.25–0.40; 0.40–0.50; and >0.50%, respectively (Boyd et al., 1994). Whereas, concentration of total N
in those categories are <0.0600; 0.0600–<0.0700; 0.0700–0.1300; >0.1300–0.1700; and >0.1700%, respectively in South Sulawesi (Mustafa et al., 2015b). In addition, Pusat Penelitian Tanah (1993 in Hardjowigeno and Widiatmaka 2011) reported a series of concentration of total N in these consecutive categories are <0.10; 0.10–0.20; 0.20–0.50; 0.50–0.75; and >0.75%, respectively; whereas Bruce and Raymond (1982) distributed concentration of total N <0.05; 0.05–0.15; 0.15–0.25; 0.25–0.50; and >0.50%, respectively on those series categories.

The soil C:N ratios affect soil microbial activities in mineralizing organic matters to release an-organic nutrients (Boyd, 1995). Relatively similar concentration of organic C at both pond soil depths, yet lower concentration of total N at soil depth of 0.2-0.5 m result in significantly (P<0.05) higher C:N ratios at pond soils depth at 0.2-0.5 m compared to that measured at pond soils depth of 0-0.2 m. Lower C:N ratio at surface soils compared to deeper soils (25 vs. 39) also reported by Subagyo (2006) in actual acid sulfate soils in Kalimantan Island. C:N ratio of 8.35-16.70 is categorized as moderate in pond soils of South Sulawesi (Mustafa et al., 2015b), whereas C:N ratios of 11-15 is categorized as moderate for agricultural soils in Indonesia (Pusat Penelitian Tanah, 1993 in Hardjowigeno and Widiatmaka, 2011). According to Hazelton and Murphy (2009), C:N ratio of 15-25 are categorized as moderate and in these ratio, the rate of soil organic matters decomposition is low.

Phosphorus (P) is highly required by natural feed in ponds-main food sources of brackish water commodities cultured under traditional technology. P is limited factor for primary productivity in ponds where the roles of P are crucial in photosynthesis, respiration, storage and transfer of energy, cell division, cell growth, and some other processes (Price, 2006). Concentration of PO₄ and PO₅ in soils at depth of 0-0.2 m measured in this study are significantly (P<0.05) higher compared to that measured at pond soils depth of 0.2-0.5 m. The application of fertilizers such as SP-36 containing PO₄ and PO₅ at the soil surfaces as pond soils initial fertilizations and at ponds water column as continual fertilization during farming, and eventually settle on pond bottoms. The relatively similar results have been reported by Subagyo (2006) that concentration of available P (P_05-Bray) is higher at surface soils (19.3 ppm) compared to that measured at deeper soils (12.6 ppm) at actual acid sulfate soils in Kalimantan Island. Concentration of PO₄ as much as 13.2845–67.3450 ppm are categorized as moderate in pond soils of South Sulawesi at depth of 0-0.2 m (Mustafa et al., 2015b). Concentration of PO₅-Bray as much as 16.0–25.00 ppm and PO₄-Bray between 11.60 and 22.80 ppm are categorized as moderate by Pusat Penelitian Tanah (1993 in Hardjowigeno and Widiatmaka 2011) for agricultural soils in Indonesia.

**Implications**

Tiger shrimp, whiteleg shrimp, milkfish, nile fish, mud crab, and seaweed are common commodities cultured in this studied ponds. However, data of pond productions from each studied ponds are scarce; therefore, the assessment to measure optimum concentration of each soil variable based on this study is not possible. Wide range of data measured from this study indicate wide distribution of each soil quality variable, however ponds with these wide ranged value of soil quality variables are still acceptable for culturing shrimp, fish and seaweed which their productions are also varies. Therefore, the result of this study is not recommended in measuring association between pond soils quality and ponds productivity. The data measured in this study, however, have a role as initial information in interpreting variables of pond soils quality of Java Island, Indonesia particularly in categorizing soil quality variable concentrations whether very low, low, moderate, high or very high and also in making decisions on pond soils management.

**Conclusion and recommendation**

The results of study indicate that volcanic soils are dominant soil type in brackish water ponds of Java Island, Indonesia. In general, the soil pH and nutrients at soil depths of 0-0.2 m are higher compared to that measured at soil depths of 0.2-0.5 m. The soil quality variables such as S_05, S_04, S_03, TPA, TAA, TSA, and pyrite were relatively similar between soil depths of 0-0.2 and 0.2-0.5 m. Data of soil quality variables have been arranged in tp concentration categories (very low, low, moderate, high and very high) to facilitate a comparison to other data on soil quality of brackish water ponds. The results of this study is not recommended for assessing the association between soil quality and brackish water ponds productivity, yet can be applied as a basic measurement in determining whether the soil quality variables are in the category of very low, low, moderate, high or very high and to facilitate decision in improving pond soils quality of Java Island.

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