Application of lime and compost on the newly established field with acid sulfate soil type in the Belandean experimental field, South Kalimantan for agricultural cultivation

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Abstract. The use of acid sulfate soils for agricultural cultivation is constrained by the oxidation process of pyrite (FeS), increasing the solubility of Al and Fe, which causes the pH to be more acidic. The specific strategy needed to utilize acid sulfate soil is through calcification technology combined with in situ organic materials. This study used lime at dose determined by the incubation method and organic materials from composted grey sedge plants, rice straw, and cow dung. The aim of this study was to determine the effect of organic matter on improving the chemical properties of acid sulfate soils. This research was arranged in a completely randomized design with four treatments and three replications. The treatments consisted of control (K0), lime without organic matter (K1), lime and organic matter (K2), and organic matter without lime (K3). The results showed that the application administration of organic matter combined with lime was able to increase the pH and available cations. The highest pH was 4.79 obtained after 14 days of incubation, and the lowest pH was observed in the control treatment, which was 3.47. The highest electrical conductivity (EC) value (76.50 µS) was observed in the K2 treatment, and the lowest EC value was observed in the K0 treatment (92.40 µS). The highest Eh value was found in the K0 treatment, reaching 274.5 mV, and the lowest was observed in K3 treatment, reaching 157.1 mV. There was a positive correlation between pH and EC and a negative correlation between pH and Eh with a value of r = 0.77 ** and r = -0.69 *, respectively.

1. Introduction
The role of tidal land with acid sulfate soil in agricultural development is becoming increasingly important due to increasing of food needs. An area of 9.53 million ha of tidal swamp land spread across the islands of Kalimantan, Sumatera, Sulawesi, Papua, and Java has the potential to be used as agricultural land [1].

In general, tidal land has number of constraints to support farming systems optimally due to the low level of soil fertility. Acid sulfate soils generally shows typical properties characterized by the presence of sulfuric horizon or sulfidic material on soil layer and soil pH <3.5 - 4.0. This sulfuric horizon containing pyrite minerals must be of particular concern in the use of acid sulfate soils. If this mineral undergoes oxidation, there will be an increase in acidity of the soil, resulting in an increase in the solution of ions such as Al³⁺, Fe³⁺ and Mn²⁺. If the solubility of Al³⁺ in the soil is high, there will be a release of large amounts of H⁺ ions because Al³⁺ ions have the ability to break down water into H⁺
and OH [2]. Furthermore, OH− ions will react with Al3+ to form Al(OH)n and H+ ions in the soil solution, decreasing pH [3]. After the decrease in soil pH, the rapid increase solubility of other toxic compounds such as Al, Fe, Mn, and SO4 will occur.

Remediation of soils containing toxic elements for plants and the environment is an effort to reduce the risk of dangerous toxic compounds and improve soil nutrition so that the soils is ready to be used as agricultural land. In general, removing toxic compounds from the soils is not a simple procedure, which caused by some portion of the toxic compounds remaining in the soils and not further degrade unlike organic molecules. However, some toxic compounds can undergo transformation and volatilization through the use of remediation materials [4].

For this reason, the use of ameliorant is needed to utilize acid sulfate soils. Ameliorant is a material that can improve soil properties physically, chemically, and biologically [5]. The main management strategy has been established to neutralize actual acidity is the use of lime. Benefits of lime in acid sulfate soils are generally to improve soil pH and to reduce in the activity of toxic elements such as Al, Fe, Mn, and SO4. Liming could reduce soil acidity and aluminium solubility [6]. This is similar to soils treated with vermicompost and the application of chemical P fertilizer either in combination or alone.

Some results of Balittra's research during the period 1984 to 2012 showed different liming requirements [7]. They concluded that potential acid sulfate soils with pH <4 need dolomite lime application at a dose of 2 - 3 t.ha−1. However, when the pH is >4, it need only 1 t.ha−1 of lime. However, the requirement of lime for potential sulfate acid soils was 3.45 t.ha−1, and for actual acid sulfate soils was 6.58 t.ha−1. The diversity of lime doses information and the high amount of lime needed causes the necessity for research to determine the appropriate dose.

In addition to lime, organic matter also can improve the fertility of acid sulfate soils. Soil organic matter is a collection of various complex compounds which are or have undergone a decomposition process, both in the form of humification and inorganic compounds resulting from mineralization [8]. Organic matter plays an important role in improving soil characteristics, not only chemically but also physically and biologically. The effects of lime with the effects of various organic amendments on cocoa productivity in acidic soils showed that organic matter was also effective as lime application, either by increasing soil pH or by reducing the availability of free aluminum ions, which were very toxic to plant roots [9].

The amount and method of processing organic matter need to be considered to get optimal results. Recently utilizing organic matters from plant residue burned by some people in South Kalimantan. This makes the ineffective use of these organic materials. Nutrient content in organic matter as rice straw includes: 0.5-0.8% N; 0.07-0.12% P; 1.2-1.7% K; 0.05-0.10% S and 4-7% Si [10]. Burning process of straw can increase the availability of nutrient K because the combustion process does not eliminate the contained K. However, by burning all N elements, 25% P and 20% K are lost. Burning will also disturb the ecosystem of the soil microorganisms. Land fires are the main cause of declining soil microorganism activity. To prevent the elements contained in the residue of the harvest from wasting, composting can be used for option [11].

Organic matters that have the potential to be used as organic fertilizer in acid sulfate swamps are rice straw, grey sedge plants, and manure. Some results of the study stated that there was an increase in soil fertility after the addition of weed compost with a dose of 6.0 t.ha−1. Changes in fertility levels were observed in nutrient availability of P from 8.8 to 43.4 ppm, K elements from 0.41 to 0.59 me/100 gr, and soil organic C content from 7.55 to 9.38%[12][13]. A combination of 30% rice straw compost coupled with 30% grey sedge weed compost and 40% cow manure compost with a leaching system was the best treatment for improving soil chemical properties and rice plant growth [14]. In addition, this treatment can reduce the solubility of Fe2+ in natural and intensive land. Composted organic matter will be a source of nutrients and hydroxyl and carboxyl sources of functional groups. This functional group will bind Al, Fe, Mn, and excessive microelements, thereby reducing the reactivity of the element [15]. A good ameliorant for tidal swamps is to have high base saturation, be able to increase
pH, improve soil structure, contain nutrients needed by plants and be able to eliminate the influence of toxic compounds, especially organic acids [16].

Increased land productivity and crop production would be better if done by maintaining nutrient balance through a combination of liming and providing organic material. The use of organic and inorganic ameliorants has often been used in intensive agricultural cultivation. However, for a newly-open land establishment, the effect of the combination of both materials has not been widely reported. For this reason, it is necessary to determine the appropriate dose of lime and the effects of the combination with compost made from potential plants in swampland.

2. Materials and Method

The study was conducted from February to March 2019 in the experimental field of Belandean, Barito Kuala Regency, and Laboratory of Soil and Water, Swampland Agricultural Research Institute, Banjarbaru Regency, South Kalimantan.

2.1. Materials

Sampling of acid sulfate soils was carried out in the newly established field. Soil samples were taken from 10-20 points at a depth of 0-20 cm with the size of the taken layer equal to the width of the soil section.

2.2. Method

This research was arranged in three stages. The first step is to determine the need for lime using the incubation method. The second step, the best dose is followed by observing the combination of lime and composted organic material. The third stage, planting is done on the best treatment of the second stage of observation. The study design used was complete random 3 non-factorial replications.

The need for lime was determined by the incubation method with agricultural lime doses of 0, 1, 2, 4, 6, 8 and 10 gr which are equivalent to 0, 2, 4, 8, 12, 16 and 20 tons of lime per ha, with the base tillage layer of 20 cm and the soil weight of 1 g.cm\(^{-3}\). The bucket was placed under the shade. Observations were made once in 2 days. The optimal lime doses obtained to increase pH and reduce Al solubility were then tested by adding organic matter followed by incubation for two weeks. The organic matter used was derived from potential plants of the tidal swamp area of the Belandean experimental field. Materials in the form of rice straw, grey sedge plants, and cow dung were composted with a ratio of 30:30:40 for one month. Variety of paddy that used as indicators in the third stage is inpara 2.

The analysis variables determined for the initial soil properties were soil texture, H\(_2\)O pH, KCl pH, organic C, potential P and K, cation exchange capacity, base saturation, and potential acidity. In soil incubation, the variables observed were pH, Eh, and EC (potentiometric method). Agronomic parameters are plant height and number of tillers.

3. Results

3.1. Initial soil properties

The analysis of the initial soil properties indicates that the soil texture is silty clay, which means that the soil has a fairly good water holding capacity. In addition, the soil with a silty clay texture implied a large surface area, so that it can effectively come into contact with water, energy or other materials. This fine soil texture also contributes to a high value of cation exchange (35.37 cmol\((+)\). kg\(^{-1}\)). The CEC value is influenced by the levels of clay, organic C, and the type of clay minerals. The effect of clay content on the CEC is quite significant, while the influence of organic C is less significant due to low organic C content in the soil [17].
Table 1. Soil properties of the newly established field of acid sulfate soils.

| Soil properties                  | Unit | Value   | Class [18] |
|----------------------------------|------|---------|------------|
| Physical properties:             |      |         |            |
| Texture                          |      | Silty clay |           |
| - Sand fraction                  | %    | 4.24    |            |
| - Silt fraction                  | %    | 48.93   |            |
| - Clay fraction                  | %    | 46.83   |            |
| Chemical properties:             |      |         |            |
| - pH H$_2$O                      |      | 3.79    | Very acidic|
| - pH KCl                         |      | 2.2     | Very acidic|
| - Organic C                      | %    | 7.017   | Very high  |
| - Al saturation                  | %    | 48.27   | High       |
| - Base saturation                | %    | 19.92   | Very low   |
| - EC                             | μS   | 119.2   | Very low   |
| - Al$^{3+}$                      | cmol(+).kg$^{-1}$ | 8.03 | Very high  |
| - Fe$^{2+}$                      | mg.g$^{-1}$ | 248.85 | Very high  |
| - H$^+$                          | cmol(+).kg$^{-1}$ | 1.558 | -          |
| - SO$_4^{2-}$                    | mg.g$^{-1}$ | 295.38 | Very high  |

Soil reaction (pH H$_2$O) is very acidic causing a high solubility of toxic compounds such as Al and Fe. The Al saturation is high indicated by a very high exch-Al. This is also followed by the high value of exch-Fe (248.85 mg.g$^{-1}$). The absorption sites complex which was dominated by Al$^{3+}$ and H$^+$ has caused a low value of base saturation. According to Table 1, the soil organic matter content is very high. Organic matter can affect the physical, chemical, and biological properties of the soil. Physically, organic matter has an effect on granulation and decreased cohesion as well as on the ability to hold water. Meanwhile, chemically, organic matter can affect the availability of nutrients (N, P, and S in the organic form) and CEC. In addition, this soil type also has a very high SO$_4^{2-}$ content, which is equal to 295.38 mg.g$^{-1}$. In soils with high organic matter, sulfur is present in two main forms, namely sulfur compounds which bind to carbon and sulfur which bind to the ester group. The transformation of sulfur in the soil is complex and fast because of the redox influence of the soil.

3.2. Changes in soil pH, exch-Al and exch-H

Soil amelioration that has frequently been implemented is calcification. Changes in soil pH value will occur with the addition of lime at certain doses. Soil neutralization process takes some time after liming. The length of the incubation period depends on the type and size of the lime particles used.
Figure 1. Changes in pH, exch-Al and exch-H of the soil at the end of observation.

The increase in soil pH values occurred ten days after the incubation period in each treatment due to the reaction between lime and soil particles. On the 30th day of the observation, the pH value decreased except in the highest lime dose treatment (20 t.ha⁻¹). The results of the exch-Al test (Figure 1) showed that soils treated with lime at doses of 12 t.ha⁻¹, 16 t.ha⁻¹, and 20 t.ha⁻¹ had exch-Al values of 0 cmol(+). kg⁻¹. However, the soils treated with control treatment and lime at doses of 4 t.ha⁻¹ and 8 t.ha⁻¹ had high, medium, and low exch-Al values. This might be due to a lack of lime dose to neutralize soil hydrogen ions so that Al solubility still occurs. Liming treatment at doses of 12 t.ha⁻¹, 16 t.ha⁻¹ and 20 t.ha⁻¹ caused changes in pH (Figure 1) which were followed by the decrease in Al³⁺ concentration. However, at a dose of 12 t.ha⁻¹, the pH value after 30 days of observation was 4.6. The low pH value at the end of the observation period was due to the influence of watering using river water. The source of soil acidity was hydrogen ions. Hydrogen ions can increase or disappear from an ecosystem or can be produced and used in reactions in ecosystems [5].

3.3. Remediation of acid sulfate soils using lime and organic matter

The results of the observations showed the combination treatment of lime and organic matter had a pH value of 4.79 after 14 days of incubation (Table 2). Meanwhile, the lowest pH value (3.47) was observed in the control treatment. The highest EC value (176.50 µS) was found in the K2 treatment, while the lowest was in the K0 treatment, which only reached 92.40 µS. The highest Eh value was found in treatment K0, reaching 274.5 mV, while the lowest was observed in K3, reaching 157.1 mV.

Table 2. Correlation analysis between soil pH, Eh and EC.

|       | pH    | Eh (mV) | EC (µS) |
|-------|-------|---------|---------|
| pH    | 1.00  | -0.69   | 0.77    |
| Eh (mV)| -0.69 | 1.00    | -0.84   |
|       | P = 0.0125* | P = 0.0035** | P = 0.007** |
| EC (µS)| 0.77  | -0.84   | 1.00    |
|       | P = 0.004** | P = 0.007** |

Remarks: *significant **highly significant

Remediation of contaminated soils could be done in three mitigation measures, namely in situ remediation, ex-situ remediation, and combination of in-situ and ex-situ remediation steps [19]. Implementation of two or more combined mitigation measures will be effective and efficient to
accelerate soil remediation process. This has been proved by the pH and EC charts (Figure 2). The increase in soil pH value was also followed by the increase in the EC value, with a coefficient of correlation of 0.77.

The results of the soil analysis after harvest (Table 3) showed that the values of organic C, Fe, and SO_4\(^{2-}\) of the soil in each treatment were not significantly different. Meanwhile, the values of exch-Al and exch-H between treatments were significantly different. The lowest values of exch-Al and exch-H were found in the soil treated with organic matters combined with lime, while the highest values were observed in the soil treated with organic matter without lime. This was because of decomposition process of soil organic matter will decrease soil pH. Therefore, the soils without calcification treatment will increase the solubility of Al\(^{3+}\) [5].

**Table 3. The results of soil analysis after harvest.**

| Treatment                        | Organic C | exch-Al | exch-H | Fe\(^{2+}\) | SO_4\(^{2-}\) |
|----------------------------------|-----------|---------|--------|-------------|-------------|
| Control                          | 7.970\(^{a}\) | 2.227\(^{b}\) | 3.049\(^{ab}\) | 706.9\(^{a}\) | 213.53\(^{a}\) |
| Lime without organic matter      | 7.607\(^{a}\) | 0.423\(^{b}\) | 1.29\(^{b}\) | 468.6\(^{a}\) | 235.23\(^{a}\) |
| Lime and organic matter          | 8.130\(^{a}\) | 0.000\(^{b}\) | 0.873\(^{b}\) | 462\(^{a}\) | 282.17\(^{a}\) |
| Organic matter without lime      | 6.937\(^{a}\) | 7.353\(^{a}\) | 4.62\(^{b}\) | 600.1\(^{a}\) | 254.84\(^{a}\) |

Remarks: \(^{a}\)significant \(^{b}\)highly significant

**4. Discussion**

The results of the soil incubation method showed that a dose of 12 t ha\(^{-1}\) was the best dose, because the influence of aluminum has reduced. Applying lime to acid soils not only increases pH, but significantly increases base cations and reduces the concentration of dissolved Al in the soil [20].

Increased pH and reduced influence of aluminum can be offset by the provision of organic matter. This is useful for maintaining the balance of nutrients that were needed by plants. The results of the second stage of observation showed that liming followed by the addition of organic matter was the best treatment.

The treatment of liming with adding organic matter can increase the electrical conductivity of the soil, reaching 176.50 µS. In addition, there is a very significant positive correlation between the pH value and EC and a significant negative correlation between the pH value and Eh. The use of lime in agricultural land causes roots to grow well, so that it can absorb nutrients optimally [5]. However, liming without adding of organic matter did not increase the biomass planted in acid soils [21]. Liming has been shown to increase the concentration of calcium and cation exchange capacity but the plants appear stunted.

Soil properties can change based on the use of ameliorants. Concentration and solubility of the elements that are very sensitive to changes in soil redox conditions, such as iron, will be determined by the redox capacity of the ameliorant materials. Ameliorants such as rice straw, having a large reduction capacity, can cause higher concentrations of Fe\(^{2+}\) compared to ameliorants such as manure. Rice straw has a higher C/N compared to manure, leading to better reduction capacity and chelation ability [22]. In addition to rice straw, the weed in swampland is potentially used as soil organic matter. The production of weed biomass in acid sulfate soils ranged from 3.0 to 3.5 tons of dry matter ha\(^{-1}\) [13]. This biomass contains macro and micro nutrients that can be used to substitute nutrients needed by plants. Organic fertilizers from grey sedge plants contained N (3.36%), P (0.43%), K (2.02%), Ca (0.26%), Mg (0, 42%), and other micro elements [23]. Furthermore, the provision of compost based on 91.91% grey sedge and 9.09% chicken manure could increase rice production in pot experiments by 16.2 gr pot\(^{-1}\) [24].
5. Conclusion
Liming and adding composted organic matter can increase soil pH and nutrient availability and reduce the concentration of Aluminum. Liming without adding composted organic matters was not effective to remediate the newly established land. This is because of an imbalance in soil nutrient content.

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