Soil chemical properties and corn productivity as affected by application of different types of fertilizer and planting method in acid sulfate soil

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Abstract. Acid sulfate soil is use as an alternative in optimizing suboptimal land to achieve corn self-sufficiency. Balanced fertilization plays an important role in efforts to improve corn yields. This study aimed to determine the effect of planting methods and optimal dose of fertilization. This research was carried out in potential acid sulfate soils with B type overflow. This study was arranged in factorial Randomized Complete Block Design (RCBD) consist of 2 factors. The first factor was the planting method consist of Zigzag, Legowo and Conventional planting methods. The second factor was the fertilizer types comprising NPK phonska 450 kg ha⁻¹ + urea 300 kg ha⁻¹ + SP36 300 kg ha⁻¹, NPK mutiara 450 kg ha⁻¹ + urea 300 kg ha⁻¹ + SP36 300 kg ha⁻¹, Urea 450 kg ha⁻¹ + SP36 300 kg ha⁻¹ + KCl 300 kg ha⁻¹, and NPK phonska 300 kg ha⁻¹ + SP36 300 kg ha⁻¹. The results showed that the application of different types of fertilizer and planting methods could improve pH in all treatments from very acidic to acidic. pH, EC, and Eh of acid sulfate soils at 70 and 100 days after planting (dap) were not affected by the interaction between different types of fertilizer and planting methods. Total N content in Zigzag planting method was significantly lower compared to in Conventional planting methods. Meanwhile, available P increased to very high. The Exchangeable K content was only increased in the fertilizer treatment with the addition of KCl reaching a value of 0.42 cmol + kg⁻¹ at 30 dap. Zigzag planting method significantly increased corn yield to 31% higher than in Legowo planting method and 16% higher than in the Conventional planting method. The application of fertilizer with a mixture of KCl significantly increased corn yield to 26.25%. Therefore, the Zigzag planting method and fertilizer with KCl mixture are recommended for corn cultivation in acid sulfate soils.

1. Introduction

In Indonesia, corn is the main food commodity after rice having a strategic role in providing food. The demand for corn as raw material for animal feed continues to increase. According to the Ministry of Agriculture [1], it was estimated that more than 58% of domestic corn was needed. Hence, to achieve corn self-sufficiency, it is necessary to expand sub-optimal land. Increasing food production provides an opportunity to utilize sub-optimal land. The use of tidal swampland is one of the alternative efforts in utilizing sub-optimal land. Indonesia has extensive swampland, total area of swamps across Indonesia was around 33.43 million ha [1].

The soil acidity in acid sulfate soil is a major obstacle in the cultivation of food crops, especially corn, which has a growing requirement at a pH of 5.6-7.5 [2]. Increasing fertility and productivity of acid sulfate soil can be done by improving water quality and providing ameliorant and fertilizer. According to Suriadikarta [3], ameliorants that can be used are dolomite, rice straw compost, and manure. The application of urea fertilizer 200 kg ha⁻¹, SP-36 125 kg ha⁻¹, KCl 75 kg ha⁻¹, and lime 750 kg ha⁻¹ in acid sulfate soil in Barambai, South Kalimantan produced 4.4 t ha⁻¹ corn yield [4]. According to Agricultural Research and Development [5], the planting method of Zigzag combined with a high dose of fertilizer supply will reduce light and nutrient competition so that production remains optimal with an increase in the corn population around 1.8 times.

Therefore, it is necessary to conduct research in the field to determine the soil chemical properties of acid sulfate soils in the second planting season. In this study, the modified planting
method and the proper type of fertilizer applied were expected to prove that the crop index in acid sulfate soils could be improved. This study aimed to determine the effect of planting methods on corn yields and find out the appropriate type of fertilization to improve acid sulfate soils chemical properties.

2. Materials and Method

This study was conducted at the Balittra Experimental Field, acid sulfate soil with B type overflow, located in Sidomulyo Village, Tamban Catur District, Kapuas Regency, Central Kalimantan from July to November 2018. Soil analysis was carried out in the Balittra laboratory in Banjarbaru, South Kalimantan.

2.1. Materials

The corn cultivar used in this study was a hybrid corn cultivar (Bisi 18). The experimental field, acid sulfate soil, was given a calcification application with a dose of 2 kg per plot and amelioration with manure at a dose of 10 kg per plot. The size of the plot was 4 m x 6 m with a total number of 36 plots.

2.2. Method

This research was arranged in factorial Randomized Complete Block Design (RCBD) consisting of 2 factors. The first factor was the planting method consisting of Zigzag planting method (CT1) with a spacing of 75 cm x 25 cm x 25 cm, Legowo planting method with a spacing of 90 cm x 50 cm x 20 cm, and Conventional planting method (CT3) with a spacing of 75 cm x 25 cm. The second factor was the type of fertilizer, namely NPK Phonska 450 kg ha\(^{-1}\) + Urea 300 kg ha\(^{-1}\) + SP36 300 kg ha\(^{-1}\) (A1), NPK Mutiara 450 kg ha\(^{-1}\) + Urea 300 kg ha\(^{-1}\) + SP36 300 kg ha\(^{-1}\) (A2), Urea 450 kg ha\(^{-1}\) + SP36 300 kg ha\(^{-1}\) + KCl 300 kg ha\(^{-1}\) (A3), and NPK Phonska 300 kg ha\(^{-1}\) + SP36 300 kg ha\(^{-1}\) (A4).

Variables observed were soil chemical properties, plant height, and corn yield. The soil chemical properties observed included pH H\(_2\)O, EC, soil Eh using a Tester 35 series, total N content by the Kjeldahl method, available P using the Bray-I method, exchangeable K with NH\(_4\)OAc 1 N methods, and organic C content using the Walkley & Black method [6]. Analysis of soil chemical properties was carried out at 70 and 100 day after plant (dap). Data were analyzed with analysis of variance (ANOVA) and further tested with DMRT at \(\alpha = 5\%\) using SAS 9.3.

3. Results

A. Initial Soil Properties

Acid sulfate soil has a characteristic of soil with > 2% pyrite layer at a depth of less than 50 cm. Acid sulfate soils are divided based on the depth of the pyrite layer, soil maturity level, and soil chemical properties into two groups that are potential acid sulfate (PAS) and actual acid sulfate (AAS). The experimental field used in this study is a potential acid sulfate soil characterized by an
unoxidized pyrite layer which can be seen from the acidity level of 4.37 (Table 1). According to Subagyo [7], potential acid sulfate soil can turn into actual acid sulfate land if it is oxidized due to excessive drainage or drought.

Table 1. Initial chemical properties of the acid sulfate soil

| Chemical properties | Unit       | Value  | Criteria* |
|---------------------|------------|--------|-----------|
| pH H₂O              |           | 4.37   | Very acidic |
| pH KCl              |           | 3.68   | Very acidic |
| Organic C           | %         | 4.92   | High      |
| Total N             | %         | 0.37   | Medium    |
| Exchangeable K      | cmol kg⁻¹ | 0.31   | Low       |
| Available P         | ppm       | 12.39  | High      |

*Criteria based on Indonesian Soil Research Institute [6]

The results of acid sulfate soil analysis showed that acid sulfate soil located in Sidomulyo Village, Tamban Catur Subdistrict, Kapuas Regency, Central Kalimantan had a very acidic pH value. Total N content (0.37%), available P (12.39 ppm), and exchangeable K (0.31 cmol kg⁻¹) in acid sulfate soil varied from low, medium to high (Table 1), while the organic C content was high. This result shows that acid sulfate soil has problems with a high acidity level and low potassium content. According to Syekhfani [2], the acidity of the soil in acid sulfate soil is a major obstacle in the cultivation of food crops, especially corn, which requires a pH of 5.6-7.5 to grow. The pH value of acid sulfate soil can decrease due to drought, which is then followed by the pyrite oxidation process. The acidity level (pH) in acid sulfate soil is affected by pyrite content, organic matter, physical environment, and differences in oxidation rates [8].

B. Effects of different types of fertilizer and planting method on the pH, EC, and Eh of the acid sulfate soil

Data presented in Table 2 show that the values of pH, EC, and Eh are not affected by the interaction between the planting method and fertilizer types. The pH value is only affected by fertilization factors. The Conventional, Legowo and Zigzag planting methods have the same effect on the pH values. Meanwhile, A4 fertilizer (NPK Phonska 300 kg ha⁻¹ and SP 36 300 kg ha⁻¹) at 70 dap resulted in lower pH values compared to A1-A3. The types of fertilizer did not give significant effects on the pH values at 100 dap. Soil pH status was improved from very acidic (4.37) to acidic (5.16) compared to before given fertilizer treatment and modified planting method.

The pH value of the soil greatly determines the availability of elements that can be absorbed by plants. The problem commonly found in acid sulfate soil is the high soil acidity. According to Purba [9], organic acids can bind metal compounds and can increase soil pH. This is supported by the results of Tambunan's research [10] reporting that the provision of organic matter in acid sulfate soil significantly affected the soil pH, while fertilizer treatment had no significant effect on the soil pH. The status of soil pH can fluctuate, either increasing or decreasing, which is influenced by the chemical properties of fertilization, leaching, organic matter provision, and calcification.

The soil planted with the Legowo planting method had a significantly higher value of EC compared to the soil planted with the Conventional and Zigzag planting method. The types of fertilizer had no significant effect on the EC value. At 70 and 100 dap, the planting method and fertilizing type had no significant effect on the EC value. High salt content results in high EC value, which can interfere with plant growth. The main effect of dissolved salt in the soil on plants is osmotic pressure. Plants spend large amounts of energy to absorb air from soil solutions and ultimately increase plant growth and reduce plant productivity. According to Wanti [11], maize has a tolerance level to soil EC of around 1.7 dS m⁻¹ and EC in saline water between 0-3.6 dS m⁻¹.

The planting method had a significant effect on the Eh value at 70 and 100 dap. The Zigzag planting method resulted in a higher value of Eh at 70 dap and a lower Eh value at 100 dap compared. Fertilizer type gave a significant effect on the value of Eh at 70 dap. A4 fertilizer, at 70 dap, produced
a significantly higher Eh value compared to A1-A3 fertilizer. According to Syekhfanii [2], Eh will be an oxidative status if it has a value of > 400 mV and changes its status to a low reduction in the range of values of Eh 200-400 mV. The Eh value is the most important characteristic in the assessment status of elements in the soil that are related to the soil properties and plant growth. Based on the observation results (Table 2), the Eh value of > 400 mV is included in the category with oxidation status, in which the O₂ reaction in the form of oxidation is excessive and good for terrestrial plants, is not good for rice [2].

Table 2. Values of pH H₂O, EC (dS m⁻¹), and potential redox (mV) in the acid sulfate soils treated with different types of fertilizer and planting method at 70 and 100 days after planting (dap)

| Treatment | pH | EC (dS m⁻¹) | Eh (mV) |
|-----------|----|-------------|--------|
|           | 70 dap | 100 dap | 70 dap | 100 dap | 70 dap | 100 dap |
| Planting method | | | | | | |
| Conventional | 5.3a | 4.69a | 0.69a | 0.22a | 428.94ab | 467.71a |
| Legowo | 5.16a | 4.68a | 0.73a | 0.21a | 408.93b | 469.47a |
| Zigzag | 4.81a | 4.61a | 0.64a | 0.21a | 436.59a | 452.17b |
| Fertilizer type | A1 | A2 | A3 | A4 | | |
| 1 | 5.16p | 4.73p | 0.71p | 0.18p | 407.33b | 459.26p |
| 1.5 | 5.15p | 4.59p | 0.73p | 0.23p | 421.37b | 464.32p |
| 1.4 | 5.14p | 4.72p | 0.71p | 0.22p | 419.94b | 456.96p |
| 4 | 4.67q | 4.61p | 0.59p | 0.21p | 450.62a | 471.92p |

Remarks: Values followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. (–) shows there is no interaction effects between factors.

C. Nutrient content of N, P, and K in the acid sulfate soil after treated with different types of fertilizer and planting method

Table 3 shows that the content of N, P, and K is not affected by the interaction between fertilizer types and planting methods. Total N content at 70 dap in the soil treated with Conventional planting method was significantly higher than in the soil treated with Legowo and Zigzag, but at 100 dap, it was not significantly different from Legowo planting method. Different types of fertilizer had the same effect on the total N content in the soil. The results showed that there was no change in the nutrient status of N in the milk and harvest stage, which was categorized in the medium criteria. At 70 and 100 dap, total N content in the soil decreased 27% compared to total N content before treated.

Table 3. Content of total N, available P, and Exch. K in the acid sulfate soil treated with different types of fertilizer and planting method at 30, 70, and 100 days after planting (dap)

| Treatment | Total N (%) | Available P (ppm) | Exchangeable K (cmol+ kg⁻¹) |
|-----------|-------------|------------------|-----------------------------|
|           | 70 dap | 100 dap | 70 dap | 100 dap | 70 dap | 100 dap |
| Planting method | | | | | | |
| Conventional | 0.34a | 0.33a | 12.29a | 27.49a | 0.31a | 0.28a |
| Legowo | 0.27b | 0.29ab | 6.2a | 15.16b | 0.28ab | 0.27a |
| Zigzag | 0.27b | 0.27b | 9.78a | 16.26b | 0.24b | 0.29a |
| Fertilizer type | A1 | A2 | A3 | A4 | | |
| 1 | 0.29p | 0.29p | 6.98p | 23.34p | 0.28p | 0.28p |
| 2 | 0.29p | 0.29p | 11.00p | 17.97p | 0.29p | 0.29p |
| 3 | 0.28p | 0.31p | 11.93p | 18.85p | 0.26p | 0.27p |
| 4 | 0.29p | 0.29p | 8.48p | 18.39p | 0.28p | 0.28p |

Remarks: Values followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. (-) shows there is no interaction effects between factors.

The content of available P on the acid sulfate soil was not significantly affected by the interaction between factors. At 70 dap, the soil treated with Conventional planting method had a significantly higher value of available P compared to the soil treated with Legowo and Zigzag planting
Phosphorus content in the soil can be affected by the differences in the number of plant populations in each planting method. As shown in the observation results at 100 dap, the available P was only affected by the planting method. The P available content in the soil treated with Conventional planting method was significantly higher than in the soil treated with Legowo and Zigzag. Fertilization factor at 70 dap and 100 dap give the same effect on available P content. The available P content at 100 dap has increased to very high with different fertilization and planting methods.

The exchangeable K values at 70 and 100 dap were not significantly affected by the interaction between fertilizer types and planting methods. The Conventional planting method, at 70 dap, significantly produced higher exchangeable K value compared to Legowo and Zigzag. Meanwhile, the fertilization type didn't give any significant effects on the exchangeable K value.

According to Sirappa [12], nutrient elements of N, P, and K are absorbed by plants in the vegetative growth stage. The nutrient uptake occurs very rapidly during the vegetative growth and seed filling stage. In corn plants, elements of N and P are continuously absorbed by plants until they are approaching maturity, while K elements are especially needed when silking. This supports the results of this study that at 100 dap, the elements of N and K are in low-moderate status, while the P element is in very high status (Table 3) because it is mostly absorbed in the soil. According to Zin [13], P element forms a strong chemical bond with the soil and is not mobile like N elements. The P content is highly correlated with pH. A low value of pH will assist the reaction of P with Fe and Al to form complex bonds that are not taken by plants but remain in the soil.

D. Organic C content in the acid sulfate soil after treated with different types of fertilizer and planting method

Table 4 shows the content of organic C at 70 and 100 dap after the treatment of different types of fertilizer and planting methods. The content of organic C at 70 dap was not significantly affected by the interaction between fertilizer types and planting methods. Organic C content in the soil treated with the Conventional planting method at 70 dap was significantly higher than in the soil treated with Legowo and Zigzag planting methods. Meanwhile, the different types of fertilizer didn't give any significant effects on the organic C content.

| Observation time | Planting method | Fertilizer type | Mean     |
|------------------|----------------|----------------|----------|
|                  |                | A1             | A2       | A3       | A4       |          |
| 70 dap           | Conventional   | 6.83           | 5.25     | 4.85     | 5.48     | 5.61a    |
|                  | Legowo         | 5.21           | 5.52     | 5.34     | 4.62     | 5.17a    |
|                  | Zigzag         | 4.50           | 4.93     | 5.12     | 4.76     | 4.82a    |
|                  | Mean           | 5.51p          | 5.23p    | 5.10p    | 4.95p    | (-)      |
|                  | CV (%)         | 26.64          |          |          |          |          |
| 100 dap          | Conventional   | 5.78a          | 4.77b    | 4.58b    | 4.97ab   | 5.03     |
|                  | Legowo         | 4.29b          | 5.81a    | 4.39b    | 4.02b    | 4.63     |
|                  | Zig-Zag        | 4.44b          | 4.34b    | 4.25b    | 4.36b    | 4.35     |
|                  | Mean           | 4.84           | 4.97     | 4.41     | 4.45     | (+)      |
|                  | CV (%)         | 11.36          |          |          |          |          |

Remarks: Values followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. (-) shows there is no interaction effects between factors.

At 100 dap, there was an interaction effect between fertilizer types and planting methods on the organic C content. The Conventional planting method combined with A1 fertilizer significantly increased organic C content compared to if combined with A2, A3, and A4 fertilizers. Meanwhile, the Legowo planting method combined with A2 fertilizer significantly increased organic C content.
compared to if combined with A1, A3, and A4 fertilizers. However, all fertilizer types combined with
the Zigzag planting method didn't give significant effects on the organic C content.

According to Zin [13], organic C is an important source in soil due to its ameliorative effects on
the nutrients supply, moisture content, nutritional retention, and its function in the formation of soil
structures. The content of organic matter in soil has an important role to prevent iron and aluminum
poisoning in the soils reacting acidly. It can also increase the availability of phosphate in the soil [9].

E. Plant height of the corn plants in the acid sulfate soil after treated with different types of
fertilizer and planting method

The growth of the corn plants at the end of observation (60 dap) was not affected by the
interaction between fertilizer types and planting methods. The results showed that the Zigzag planting method
gave better effect on the plant height compared to the Conventional and Legowo planting
methods. The plants treated with Zigzag planting method were 9% taller than the plants treated with
Legowo planting method and 5% taller than the plants treated with Conventional planting method. A4
fertilizer produced significantly lower plants compared to A1, A2, and A3. The highest value of plant
height was observed in the treatment of A3 fertilizer composed of Urea + SP36 + KCl.

Table 5. Plant height of the corn plants (cm) in the acid sulfate soil treated with different types of fertilizer and
planting method at 60 days after planting (dap)

| Planting method | Fertilizer type | Mean   |
|-----------------|----------------|--------|
|                 | A1             | A2     | A3     | A4     |       |
| Conventional (C3) | 227.17         | 243.23 | 243.50 | 225.83 | 234.93b |
| Legowo (C2)     | 235.00         | 231.67 | 231.87 | 203.53 | 225.52b |
| Zig-Zag (C1)    | 261.03         | 250.30 | 255.53 | 224.10 | 247.74a |
| Mean            | 241.07p        | 241.73p| 243.63p| 217.82q|       |
| CV (%)          | 4.97           |        |        |        |        |

Remarks: Values followed by the same lowercase letters in the same column are not significantly different
according to DMRT 5%. (-) shows there is no interaction effects between factors.

According to Subekti [14], the optimum vegetative growth stage occurs when plants are
between 33-50 days after germination. Plants grow quickly, and the accumulation of dry matter also
increases rapidly. Nutrient and water requirements are relatively very high to support plant growth
rates. All plants in various treatments developed following the growth pattern of corn plants in
general. The highest growth rate at the end of the observation was in the treatment of Zigzag planting method combined with fertilizer types of NPK Phonska 450 kg/ha + Urea 300 kg/ha + SP36 300
kg/ha and the lowest was observed in Legowo planting method combined with fertilizer types of NPK Phonska 300 kg/ha + SP36 300 Kg/ha. In this stage, maximum biomass from the vegetative part of the
plant is produced, which is about 50% of the total plant dry weight. The absorption of N, P, and K by
plants is 60-70%, 50%, and 80-90%, respectively [14].

F. Productivity of the corn plants in the acid sulfate soil after treated with different types of
fertilizer and planting method

Table 6 shows that the productivity of corn plants in the acid sulfate soil was not affected by the
interaction between fertilizer types and planting methods. The Zigzag planting method significantly
increased the productivity of corn plants compared to the Conventional and Legowo planting methods.

Table 6. Productivity of the corn plants (t/ha) in the acid sulfate soil treated with different types of fertilizer and
planting method at 60 days after planting (dap)

| Planting method | A1     | A2     | A3     | A4     | Mean   |
|-----------------|--------|--------|--------|--------|--------|
| Conventional (C3) | 227.17 | 239.23 | 233.50 | 225.83 | 234.93b |
| Legowo (C2)     | 235.00 | 231.67 | 231.87 | 203.53 | 225.52b |
| Zig-Zag (C1)    | 261.03 | 250.30 | 255.53 | 224.10 | 247.74a |
| Mean            | 241.07p| 241.73p| 243.63p| 217.82q|       |

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Table 6. Productivity of the corn plants (ton ha\(^{-1}\)) in the acid sulfate soil treated with different types of fertilizer and planting method

| Planting method  | Fertilizer types | A1  | A2  | A3  | A4  | Mean   |
|------------------|------------------|-----|-----|-----|-----|--------|
| Conventional (C3)|                 | 6.82| 7.72| 9.18| 7.01| 7.68ab |
| Legowo (C2)      |                 | 6.70| 6.64| 6.78| 5.11| 6.31b  |
| Zig-Zag (C1)     |                 | 10.44| 8.61| 10.33| 7.25| 9.16a  |
| Mean             |                 | 7.99pq| 7.66pq| 8.76p | 6.46q| (-)    |
| CV (%)           |                 | 24.75|

Remarks: Values followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. (-) shows there is no interaction effects between factors.

According to Hatta [15], if the inorganic fertilizers are given proportionally, the nutrients of N, P, and K can be utilized by corn plants resulting in better growth and higher yield. Fertilization recommendations for corn cultivation on tidal swampland are the provision of lime and manure before planting and fertilization of urea 350 kg ha\(^{-1}\), SP 36 250 kg ha\(^{-1}\), and KCl 150 kg ha\(^{-1}\). The response of plants to fertilizer given depends on the type of fertilizer and the level of soil fertility. Therefore, the fertilizer dose is different for each location. N, P, and K are nutrients needed by corn plants to grow and produce yield. The corn plant requires 27.4 kg N, 4.8 kg P, and 18.4 kg K [12].

Conclusion
Cultivation of corn plants in acid sulfate soil with high acidity can produce optimal corn productivity with a treatment combination of Zigzag planting method and balanced fertilization. The Zigzag planting method significantly increased up to 10.44 ton ha\(^{-1}\) corn yield. The application of fertilizer with a mixture of KCl fertilizer significantly increased up to 8.76 ton ha\(^{-1}\) corn yield. Thus, the combination of Zigzag planting method and fertilizer with KCl mixture is recommended for corn cultivation in acid sulfate soil.

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