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# Influence of Soil Amendments on the Growth and Yield of Rice in Acidic Soil

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**Abstract:** In Malaysia, about 0.5 million ha of acid sulfate soils are found scattered over the east, west, and Sabah and Sarawak regions that can potentially be cultivated with paddy. This type of soil is acidic and not immediately suitable for crop production unless improved by applying some amendments. Thus, the current study was carried out to investigate the effects of various types of soil amendments on the growth, yield, and physiological responses of rice grown in extremely acidic conditions using ground magnesium limestone (GML), basalt, biochar, and compost as soil amendments. The acid sulfate soil with a pH of 3.76 was obtained from a paddy field in Merbok, Kedah. The plant responses were evaluated based on agronomic, physiological, and yield performance. The compost-treated rice showed the best performance in all three criteria. Compost treatment increased the soil pH up to 6.25. Physiological performances such as chlorophyll, photosynthetic rate, and water use efficiency were higher after compost treatment, while transpiration and stomatal conductance showed the highest after GML treatment. It can be concluded that the addition of compost as a soil amendment can increase soil pH and create favorable soil conditions for rice cultivation in acid sulfate soil, leading to improved rice growth performance.

**Keywords:** acid sulfate soil; plant physiology; rice growth; rice yield; soil amendment

## 1. Introduction

Malaysia's climate is categorized as an equatorial rainforest fully humid climate (Af), according to Koppen climate classification, due to its proximity to the equator [1,2]. The country is hot and humid all year round, with an average temperature of 27 °C (80.6 °F) and almost no variability in the yearly temperature. This area has tropical soil, most of which is considered as a problem soil, such as peat, sandy soil, acid sulfate soil [3], and highly weathered soil—for example Ultisols and Oxisols [4]—which need special management practices to maximize yields. Malaysia has more than 0.5 million ha of acid sulfate soil scattered over the east and west coasts of Peninsular Malaysia, Sabah and Sarawak [5]. Typically, acid sulfate soil is not suitable for crop production [6,7].

These soils are characterized by very low pH values (<3.5) and the presence of yellowish jarosite ($KFe^{3+}{}_3(OH)_6(SO_4)$) produced from pyrite exposed to the atmosphere [5]. Pyrite occurs in the soil in areas where seawater inundated the coastal plains a long time ago [8]. Under aerobic conditions, sulfate and ferric ions are reduced to sulfide and ferrous ions, which subsequently end up in the form of pyrite. As a result of pyrite oxidation, acid is released into the soil, causing the low pH and very high Al concentration. Acid sulfate soil contains high concentrations of $Al^{3+}$ and $Fe^{2+}$ in the soil environment, which can be toxic to plants [9]. The presence of excess Al and Fe can affect plant growth and hamper soil nutrient availability [6]. $Al^{3+}$ can cause the inhibition of root development as well as root retardation [10].

Currently, around 20,000 ha of acid sulfate soil is being used for rice cultivation in Peninsular Malaysia [11]. Even though rice cultivation in this soil is successful, the rice yields from each season are very low (<2 t/ha), being below the national average of 3.8 t/ha [7]. The Al toxicity in soil can be decreased by the application of amendments or liming materials. Soil amendments or liming materials are elements added to the soil to improve its capacity to support plant life [12]. It is suitable for two primary categories of problems including reducing contaminant bioavailability/phytoavailability and improving poor soil health and ecosystem function. Soil amendments restore soil quality by balancing pH, adding organic matter, increasing water holding capacity, re-establishing microbial communities, and alleviating compaction [13].

Among the methods used to ameliorate acid sulfate soil infertility are the applications of ground magnesium limestone (GML) [7], basalt [14], organic materials [15], compost [16], biofertilizers [6,11], or plant growth–promoting bacteria [17]. Besides moderating soil acidity and reducing the content of exchangeable $Al^{3+}$ and dissolved Al that result from chemical reactions in the acid sulfate soil [16], these amendments can increase the soil pH of acid sulfate soil [18,19], lead to yield increase [19,20], increase cation exchange capacity (CEC) [18], and improve the water holding capacity as well as soil structure [21]. Hence, the current study was conducted to measure the physiological growth responses of MR253 rice cultivation in acid sulfate soil using various soil amendments such as GML, basalt, biochar, and compost.

## 2. Materials and Methods

### 2.1. Experimental Design

This study was conducted in a glasshouse at Rimba Ilmu, University of Malaya under temperatures ranging between 24 and 33 °C, maximum Photosynthetically Active Radiation PAR 2100 uE $m^{-2}$ $s^{-1}$, and relative humidity of 60–90%. The acid sulfate soil used was collected from paddy fields in Segantang Garam, Kota Kuala Muda, Kedah at latitude of 5°39′00.0″ N and a longitude of 100°25′12.0″ E. The soil series is an acid sulfate soil (Merbok series) which is Typic Sulfaquents [22]. The pH of the soil during collection was 3.76 and the rice variety MR253 was used as the test crop. This rice variety was chosen as it was claimed to achieve a better yield than MR219 in marginal soil and it is considered as an acid-tolerant species [23]. The air-dried soil was ground to pass through a 2-mm sieve and a total of 10 kg sieved soil was used for each treatment, placed in 16-L pots, and kept under flooded conditions.

The treatments included the following: rice grown without soil amendment (control), and with soil amendments, namely Nitrogen-Phosphorus-Potassium compound fertilizer (NPK fertilizer), NPK fertilizer + ground magnesium limestone (GML), NPK + biochar Empty Fruit Bunches (EFB), and NPK + compost (plant-based organic material), whereby each was applied separately at 4 t/ha into the soil. The experiment was arranged in a completely randomized design (CRD) with four replications. The amendments were mixed thoroughly into soil pots 15 days before transplanting and the water level was maintained at a depth of 2 cm throughout the growing season. The recommended rates of nitrogen, phosphorus, and potash were applied at 120, 30, and 60 kg/ha respectively, by using urea, triple superphosphate, and muriate of potash.

### 2.2. Preparation of Rice Seedling and Transplanting

The MR253 rice seed was soaked with water until the roots emerged, and they then sown in a germinating pot with media. Water was added daily to moisten the seed and, after 14 days, three seedlings were transplanted into each pot.

### 2.3. Data Collection

#### 2.3.1. Soil pH

Soil pH was determined fortnightly, started from 43 days after transplanting (DAT) till harvest. The soil pH readings were measured using an IQ 150 pH meter (Spectrum Laboratory Products, Inc., Gardena, CA, USA) to observe the consistency of the soil pH readings. The readings were taken in situ at a soil depth of 10 cm at three points in each pot.

#### 2.3.2. Physiological Parameters

The leaf chlorophyll content was determined using a portable chlorophyll meter (SPAD-502, Minolta Co. Ltd., Osaka, Japan), providing a rapid and non-destructive approach that enables in situ measurement. The observation was made starting at 15 days after transplanting (DAT) and continued fortnightly. It was recorded at the 2/3 position from the leaf based on the apex of a fully expanded leaf to obtain the optimum chlorophyll content [24]. The photosynthetic rate (A), stomatal conductance ($g_s$), and transpiration rate (E) of the plants were measured using a portable photosynthesis system (Li6400XT, LI-COR Environmental, Lincoln, NE, USA). The instantaneous water use efficiency (WUE) was determined as photosynthetic rate (A)/transpiration rate (E). All measurements were taken randomly between 12.00 p.m. and 1.00 p.m. with the range of PAR being 1800–2100 uE $m^{-2}$ $s^{-1}$, temperature 25–32 °C, relative humidity 60–90%, and $CO_2$ influx at 400 ppm, located at the Rimba Ilmu, University of Malaya. The readings were taken on the abaxial surface of three flag leaves for each replicate of each treatment at 48 and 88 DAT, corresponding to the stages and growth between flowering and maturing. The readings were accomplished within one hour to minimize the errors due to the diurnal pattern of photosynthesis.

#### 2.3.3. Yield Components

At harvest, several yield components were determined (panicle number, panicle length, number of grains per panicle, grain filling percentage, 1000 grain weight, plant biomass, and harvest index). The samples were washed, then oven-dried for 48 h at 65 °C. The grain yield was determined from all plants in each experimental plot.

### 2.4. Data Analysis

Statistical analysis was performed using (IBM SPSS Statistic 20 software, (IBM Corporation, Armonk, NY, USA) One-way ANOVA was applied to evaluate the significant differences among the means. Means were tested by Tukey's test at a 5% level of confidence. Pearson's correlation was used to analyze the relationship between physiological parameters in all treatments. All diagrams were drawn using Microsoft Excel 2010 (Microsoft Corporation, Redmond, Washington, DC, USA).

## 3. Results

### 3.1. Effect of GML, Basalt, Biochar, and Compost on Acid Sulfate Soil pH, Plant Height, and Number of Tillers

The application of soil amendments increased the soil pH from 3.7 to 6.2. Significantly ($p < 0.05$) high soil pH changes were observed after 57 DAT for GML, basalt, biochar, and compost, and the reading continuously increased until harvest. Based on the results, all treatments showed significant differences in soil pH at 99 DAT. Compared to other treatments with the application of soil amendments, the soil pH of the basalt treatment increased at the lowest rate and gave the lowest reading of soil pH at 99 days (Figure 1a). Plant height increased in all treatments with time until it reached the maturity stage at 85 DAT (Figure 1b). At 99 DAT, the application of soil amendments showed significantly higher plant height compared to the treatment without soil amendments (NPK and control). Active tillering started after 29 DAT and continued until 85 DAT in all treatments (Figure 1c).

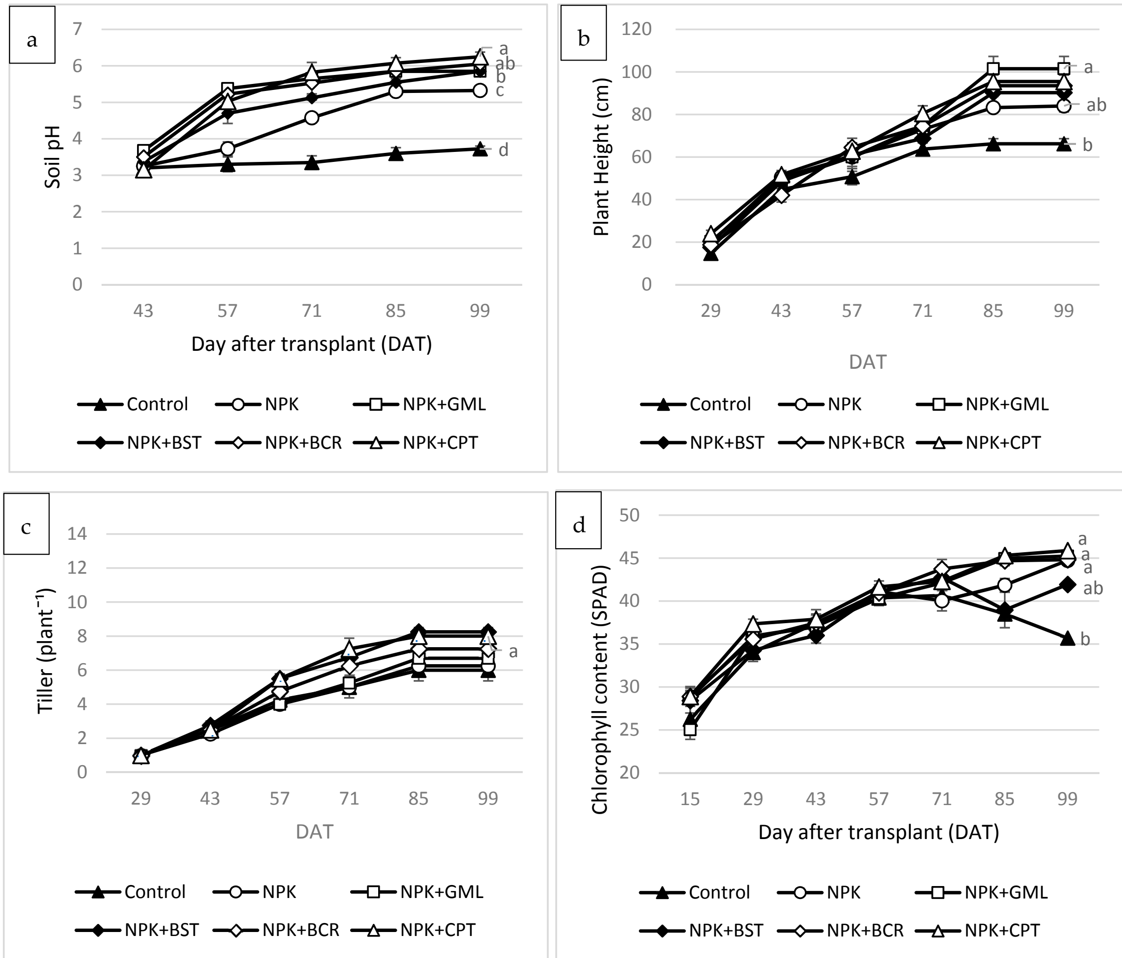


**Figure 1.** Effect of different amendments on (**a**) soil pH, (**b**) plant height, (**c**) tiller number, and (**d**) chlorophyll content during the entire cycle of rice growth. Vertical bars indicate the standard errors of the means ($n$ = 4). Different letters indicate a significant difference ($p < 0.05$).

The total chlorophyll content showed an increasing value throughout the entire cycle of rice growth in all treatments except for basalt and the control, which showed a fluctuation between 75 and 99 DAT and a significant decrease at 71 DAT, respectively. At 71 DAT, certain treatments (control, NPK, and basalt) reached the maximum chlorophyll content and the readings started to decline. The other three treatments (GML, biochar, and compost) reached their maximum chlorophyll content at 85 DAT before becoming constant (Figure 1d). During the last data collection, the chlorophyll content in compost, biochar, and GML treatments showed significantly higher readings compared to the other treatments.

### 3.2. Physiological Response

The photosynthetic rate, stomatal conductance, and transpiration rate of plant between flowering and maturing stage showed differences between the different treatments. The photosynthetic rate of MR253 showed a significant difference between flowering and maturing stages. At the flowering stage, there was no significant difference in the photosynthetic rate amongst treatments. Meanwhile, at the maturing stage, a significantly higher photosynthetic rate was observed in compost (36 µmol $m^{-2}$ $s^{-1}$) compared to the other treatments. Overall, the photosynthetic rates of treatments were significantly higher compared to the control at both stages (Figure 2a).

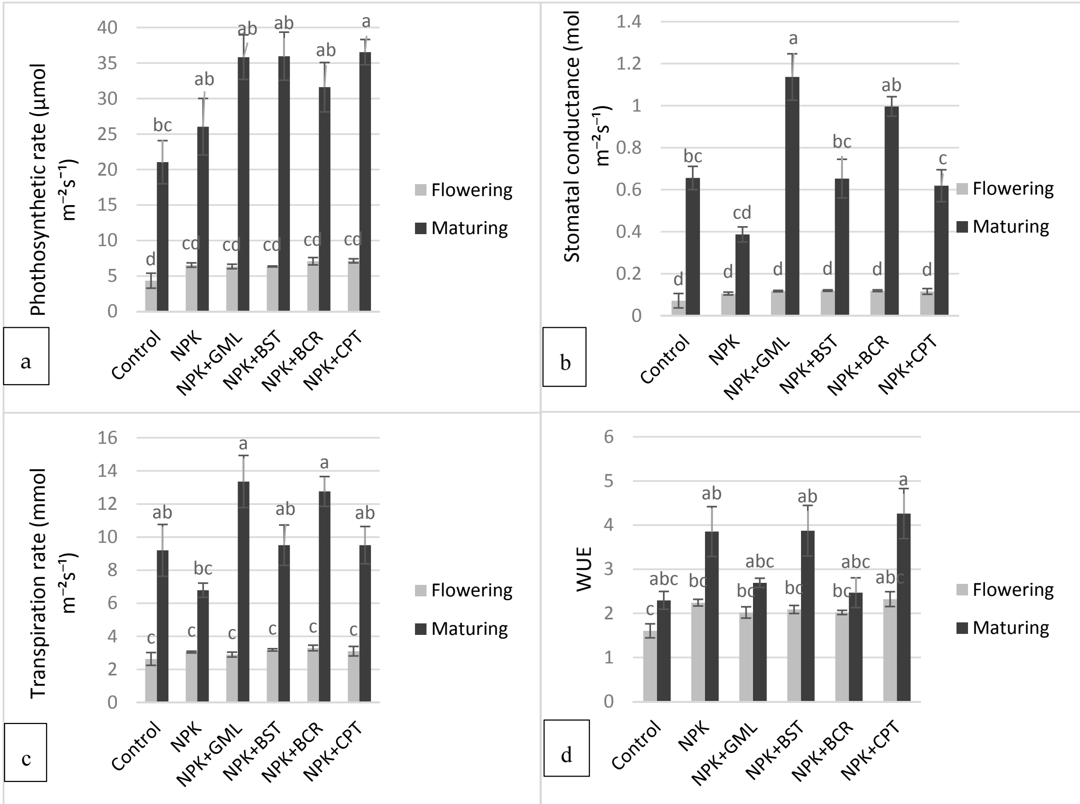


**Figure 2.** Figure indicates the (**a**) photosynthetic rate, (**b**) stomatal conductance, (**c**) transpiration rate, and (**d**) water use efficiency (WUE) at both the flowering and maturing stages of rice. Each data item represents the mean of replicates and the vertical bar represents the standard error of the mean ($n$ = 3). Different letters indicate a significant difference ($p < 0.05$). NPK = NPK fertilizer, GML = ground magnesium limestone, BST = basalt, BCR = biochar, CPT = compost.

In general, stomatal conductance and transpiration rate at both stages showed a similar trend of treatment response. At the flowering stage, there were no significant differences between treatments observed in the stomatal conductance and transpiration rate. Meanwhile, at the maturing stage, the GML plants lost the greatest amount of water through significantly high transpiration and stomatal conductance, followed by biochar and basalt (Figure 2b,c). The results indicate that at both stages, a significantly higher water use efficiency (WUE) was found in the compost treatment group while the lowest reading was recorded for the control. WUE was a response between the photosynthetic and transpiration rates, where a high WUE was indicated by a high photosynthetic and a low transpiration rate (Figure 2d).

There was a weak positive correlation ($r^2$ = 0.17) between the photosynthetic rate and stomatal conductance (Figure 3a), implying that non-stomatal regulation might contribute to the higher photosynthetic rate. A similar trend was observed in the correlation between the stomatal conductance and transpiration rate (Figure 3b), in which both parameters were directly related ($r^2$ = 0.98).

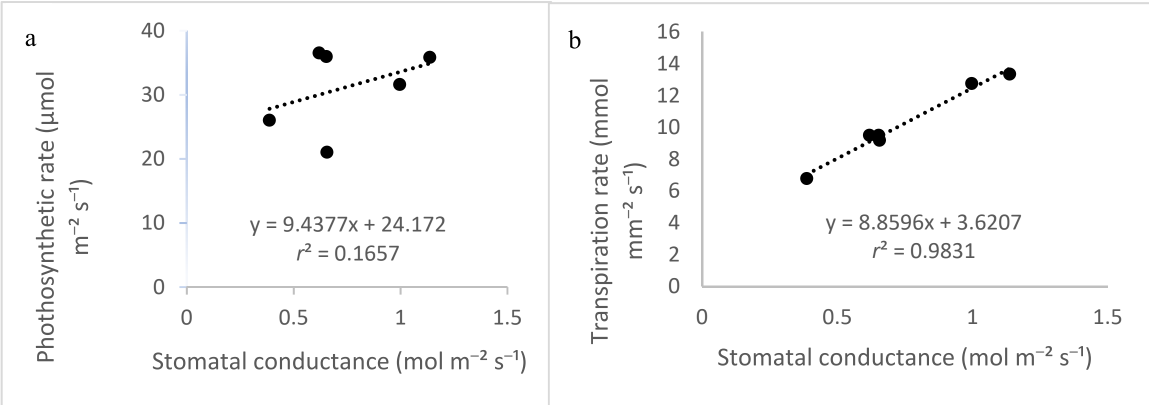


**Figure 3.** Correlations between the photosynthetic rate (**a**) and transpiration (**b**) against stomatal conductance at the maturing stage.

The results also showed that the photosynthetic rate, stomatal conductance, and transpiration rate are positively correlated with each other (Table 1). Water use efficiency was only significantly correlated with stomatal conductance and transpiration rate when the stomata open, transpiration occurs, and water is released to the atmosphere.

**Table 1.** Relationship between physiological parameters in rice treatment using Pearson's correlation.

| Parameter | A | $g_s$ | E | WUE |
|---|---|---|---|---|
| A | - | 0.869 ** | 0.893 ** | 0.668 ** |
| $g_s$ | | - | 0.980 ** | 0.274 |
| E | | | - | 0.297 |
| WUE | | | | - |

** $p = 0.01$.

### 3.3. Effect of Soil Amendments on Rice Growth

The application of soil amendments positively affected the growth of rice. From Table 2, GML treatment showed the highest reading in plant height and root length (104.75 and 21.00 cm), while compost treatment gave the highest in number of tillers plant$^{-1}$ (8), number of panicles plant$^{-1}$ (8), and size of panicles (22.19 cm). Apart from number of tillers, the growth in plant height, root length, number of panicles, and size of panicles significantly improved with the addition of fertilizer and soil amendments compared to the control.

**Table 2.** Effect of soil amendments on the growth of rice plants.

| Treatment | Plant Height (cm) | Root Length (cm) | Number of Tillers (plant$^{-1}$) | Number of Panicles (plant$^{-1}$) | Size of Panicles (cm) |
|---|---|---|---|---|---|
| Control | 86.50 $^{b}$ | 15.50 $^{c}$ | 5 $^{a}$ | 4 $^{b}$ | 16.16 $^{b}$ |
| NPK | 92.5 $^{ab}$ | 17.50 $^{b}$ | 4 $^{a}$ | 6 $^{ab}$ | 20.18 $^{ab}$ |
| NPK + GML | 104.75 $^{a}$ | 21.00 $^{a}$ | 6 $^{a}$ | 7 $^{ab}$ | 18.16 $^{ab}$ |
| NPK + BST | 93.25 $^{ab}$ | 19.50 $^{ab}$ | 7 $^{a}$ | 7 $^{ab}$ | 20.85 $^{ab}$ |
| NPK + BCR | 99.75 $^{ab}$ | 18.00 $^{abc}$ | 7 $^{a}$ | 8 $^{ab}$ | 21.22 $^{ab}$ |
| NPK + CPT | 95.50 $^{ab}$ | 20.75 $^{ab}$ | 8 $^{a}$ | 8 $^{a}$ | 22.19 $^{a}$ |

NPK = NPK fertilizer, GML = ground magnesium limestone, BST = basalt, BCR = biochar, CPT = compost. Means followed by the same letter within a column are not significantly different ($p < 0.05$).

### 3.4. Effect of Soil Amendment on Yield and Yield-Contributing Characteristics of Rice

The application of soil amendments significantly increased the number of 1000 grain weight and the harvest index for all treatments compared to the control (Table 3). Among the treatments, the application of compost alone gave the highest reading in grain number per panicle (121), percentage of filled grain (83.40%), 1000 grain weight (23.30 g), and harvest index (88.71%). Table 2 also shows that there were differences in yield components for different treatments. A high number of grains per panicle and percentage of filled grain were observed in compost, basalt, and GML applications. The highest aboveground biomass (53.10 g) was observed in GML application, followed by basalt (47.17 g), biochar (45.10 g), and compost (44.54 g). In the overall observation of the harvest index (HI), the application of basalt, biochar, and compost doubled the percentage of the index of the control treatment with readings of 70.25%, 55.62%, and 88.71%, respectively.

**Table 3.** Effect of soil amendment on rice yield and its components.

| Treatment | Grains/Panicle | Filled Grain (%) | 1000 Grain Weight (g) | Aboveground Biomass (g) | Harvest Index (g) |
|---|---|---|---|---|---|
| Control | 66.00 $^{ab}$ | 59.69 $^{ab}$ | 16.14 $^{b}$ | 40.46 $^{ab}$ | 35.01 $^{a}$ |
| NPK | 83.00 $^{ab}$ | 58.83 $^{b}$ | 20.48 $^{ab}$ | 33.75 $^{b}$ | 42.05 $^{a}$ |
| NPK + GML | 87.00 $^{ab}$ | 67.10 $^{ab}$ | 21.00 $^{ab}$ | 53.10 $^{a}$ | 47.08 $^{a}$ |
| NPK + BST | 104.00 $^{ab}$ | 65.52 $^{ab}$ | 19.43 $^{ab}$ | 47.17 $^{ab}$ | 70.25 $^{a}$ |
| NPK + BCR | 64.00 $^{b}$ | 57.54 $^{b}$ | 19.42 $^{ab}$ | 45.10 $^{ab}$ | 55.62 $^{a}$ |
| NPK + CPT | 121.00 $^{a}$ | 83.40 $^{a}$ | 23.30 $^{a}$ | 44.54 $^{ab}$ | 88.71 $^{a}$ |

NPK = NPK fertilizer, GML = ground magnesium limestone, BST = basalt, BCR = biochar, CPT = compost. Means followed by the same letter within a column are not significantly different ($p < 0.05$).

## 4. Discussion

This study found that the acid sulfate soil used had a very low pH (3.76), which was not suitable for rice cultivation. The suitable soil pH for rice cultivation is at pH 6 [22], which is uncommon in acid sulfate soil [5]. Acid sulfate soil contains high concentrations of $Al^{3+}$ and $Fe^{2+}$ in an environment which can be toxic to plants [9]. This type of soil needs to be treated and the aluminum toxicity in the soil should be decreased by the application of amendments or liming materials. However, the application of amendments does not increase the soil pH immediately, but rather gradually increases the pH over time. In this study, significant differences in soil pH after 99 days were observed in all treatments, as compared to Reference [25]. The application of 6 t $ha^{-1}$ of GML can increase the soil pH in three weeks, while liquid lime under submerged conditions can increase the soil pH in six weeks. After all, results from other studies have shown that the application of these amendments can increase the soil pH of acid sulfate soil [7,14,15,18,20].

Leaf chlorophyll content (SPAD values) readings in plants can be affected by the treatments, where higher values can be indicators of a higher yield [26] and photosynthetic rate [27]. It is also one of the most important biochemical indicators for plants [28]. During this study, a rapid increase of chlorophyll was observed at the early growing stage (15–29 DAT). The chlorophyll content of rice subjected to the compost treatment was significantly higher followed, by those plants applied with biochar and GML. This significant increase may be due to the improvement of the nutritional condition of soil, which can reflect the growth of the plant and the chlorophyll content [6,29].

Plant height and tiller counts are among the basic characteristics observed when assessing rice crops, where plants tend to grow to a certain height in each stage [30]. In rice crops, more tillers generally indicates a greater yield [31]. In the rice crop growing stage, tillers will appear when the rice crop is self-supporting [32]. When the first tiller appears, it signifies the start of the tillering stage. The tiller with the longest leaf would be the height of the plant [33]. In this study, the plant height development and tillering process reached its maximum rate at the grain filling stage (85 DAT)

(Figure 1b,c). From the results in this study, soil amendment treatments showed significantly higher readings of plant height compared to the untreated groups (NPK and control).

A significant difference in the photosynthetic rate between the flowering and maturing stages was found as the plant grew; at the maturing stage, the photosynthetic rate was significantly higher (Figure 2a). Based on Hidayanti et al., the rates of photosynthesis at the vegetative, flowering, grain filling, and mature grain phases were significantly different from each other [34]. At the grain maturing stage, a higher photosynthetic rate may be caused by the high amount of leaves and chlorophyll content. In the overall treatment at both stages, rice plants with the application of compost showed the highest photosynthetic rate, while the control showed the lowest. Therefore, a high photosynthesis reading implies that the plant is more likely to grow faster [35].

Based on the results in this study, the stomatal conductance and transpiration rates at both stages showed similar trends, where basalt, biochar, and GML treatments showed the highest readings. The transpiration rate was significantly higher at the maturing stage, caused by the high amount of water used to translocate photosynthate from the source to the sink. In this case, panicles (spikelet) became a strong sink to fill the grain. Moreover, the water that was being absorbed by the plant roots was not totally used to produce dry matter because less than 5% of water absorbed remains in plant for growth and storage, while the rest is lost via transpiration [36]. The high value of WUE in the compost treatment group, especially at the maturing stage, was attained by the high photosynthesis rate and the reduction of the transpiration rate. A high WUE is a good indicator, showing that the compost treatment has the ability to cope with soil water deficit and holds greater promise to increase both grain yield and WUE [37].

In monitoring the growth performance of rice plants, several growth characteristics were observed including plant height, root length, number of tillers, number of panicles, and size of panicles for each plant [6,11,22]. The highest readings of plant height and root length was observed in the GML treatment, while the compost treatment gave the highest reading in number of tillers, number of panicles, and size of panicles. Rice grain yield is highly dependent on the number of panicle-bearing tillers produced per plant [38]. The compost treatment rice plant grew rapidly at the tillering stage and underwent slow growth at the reproduction stage until harvest. According to Tao et al. [39], the number of tillers per hill is an important morpho-physiological trait of grain yield in rice since the number of tillers per hill is closely related to the number of panicles per hill.

Basically, grain yield was attributed to number of grains per panicle, percentage of filled grain, grain weight density, aboveground biomass, and harvest index [40,41]. Amongst the treatments, the application of compost alone gave the highest reading in grain number per panicle, percentage of filled grain, 1000 grain weight, and harvest index. The treatments responded differently in the development of dry matter. The GML treatment had the highest reading in plant aboveground biomasses, shown by the record of the highest plant height. However, theoretically, aboveground biomass is contributed by the number of panicles, number of grains, and grain weight density [40,42,43]. A shorter plant has a lower number of tillers and panicles, which leads to a lower aboveground biomass as well as a reduced harvest index, as represented by the rice plants without soil amendments (control and NPK) in this study. Based on other research, the application of GML combined with JITU (bio-organic fertilizer) improved soil fertility as well as the rice growth and yield parameters grown in acid sulfate soils. In addition, it also had a residual effect for two seasons [23]. Furthermore, the application of bio-organic fertilizer along with beneficial microbes improved rice growth and yield in acid sulfate soils [6,17].

## 5. Conclusions

The addition of soil amendments to acid sulfate soil can alleviate the soil acidity problem and improve rice growth and yield. In this study, compost-treated rice plants showed the best reading in increasing the soil pH and plant performance including the highest reading of chlorophyll content, photosynthetic rate, WUE, number of tillers, number of panicles, size of panicles, number of grains per panicle, percentage of filled grains, 1000 grain weight, and percentage of harvest index. This lead to the conclusion that the best treatment for soil amendment used for rice plant cultivation in acid sulfate soil is compost, followed by biochar.

**Author Contributions:** Conceptualization N.S.A.H., R.A., Q.A.P. and C.F.I.; Data Curation, N.S.A.H.; Formal Analysis, N.S.A.H., R.A., N.O. and S.A.K.; Methodology, N.S.A.H., R.A., Q.A.P., N.O. and C.F.I.; Supervision, R.A. and S.A.K.; Writing—Original Draft Preparation, N.S.A.H., R.A., Writing—Review and Editing, S.A.K., N.O., Q.A.P. and C.F.I.

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