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Essential Dynamics of Rice Cultivated Under Intensification on Acid Sulfate Soils Ameliorated with Composted Oyster Mushroom Baglog Waste

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ABSTRACT

This study examines the dynamics of essential macro-nutrients for rice cultivation in acid sulfate soils ameliorated with composted oyster mushroom baglog waste. A single factor randomized block design (RBD) was used, and the factors studied include the compost dose of oyster mushroom baglog waste, which consists of 5 treatment levels, namely 0 t ha^{-1} (control), 5 t ha^{-1}, 10 t ha^{-1}, 15 t ha^{-1}, and 20 t ha^{-1}. Furthermore, this study was carried out from May to September 2021 in the rice fields of the Faculty of Agriculture, Lambung Mangkurat University (ULM), Sungai Rangas Village, Banjar Regency, South Kalimantan. The rice plants were cultivated using an intensification technique, and the compost was applied based on the research treatment for two weeks on prepared land before planting. Also, Bartlett's test was carried out before analysis of variance, which had a significant effect of $P<0.05$, and was further tested using Duncan's Multiple Range Test (DMRT) at a 5% level. The results showed variations in the availability of macro-nutrients at five different growth stages: early planting, full vegetative, early panicle emergence, panicle filling, and harvesting phases. The highest levels of ammonium (NH_4^+) and nitrate (NH_3^-) were found in the full vegetative stage, while early planting had the lowest. Also, there was an increase in the available phosphorus (P) from the early planting to the full vegetative stage. The increase in exchangeable potassium (K) occurred at the transition of these stages. These increasing nutrients were due to the addition of the compost. The higher the NH_4^+, NO_3^-, available P, and exchangeable K in acid sulfate soils, the more nitrogen (N), P, and K uptake in rice plants. The

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provision of the compost supplied N, P, and K in available forms and reduced the amount of soluble alumunium (Al) and iron (Fe). Thereby the plant roots absorb the nutrients optimally. Additionally, the compost increased the essential macro-nutrient availability and plant uptake using the rice intensification technique from early planting to harvest.

Keywords: Acid sulfate soils, eco-friendly agriculture, rice intensification, suboptimal land

INTRODUCTION

Rice is the most important food crop in Indonesia and the main raw material for staple foods in most regions. In 2015, the consumption reached 33.3 million tons (Sulaiman et al., 2018). Currently, the largest production centers of this food crop are on the Java and Sumatra islands. During that period, production reached 17.51 million tons throughout the country (Prasetyo et al., 2021). Meanwhile, South Kalimantan could produce up to 0.67 million tons (Prasetyo et al., 2021). According to Statistics Indonesia (Badan Pusat Statistik, BPS) (2020), the population of this province which was 4.3 million, requires up to 0.4 million tons. However, rice demand will increase as the population increases, and predicting current natural conditions tends to be difficult.

Another problem arising is the increasingly limited availability of productive land in the province (Ritung, 2012). Suboptimal lands, such as peat and acid sulfate soils, require proper management when used as arable land (Nursyamsi et al., 2014). Peatland is difficult to manage because of its high environmental risk; hence, it is better to be conserved (Indonesian Agency for Agricultural Research and Development [IAARD], 2011). Meanwhile, acid sulfate soils are productive when managed with the right technology (Saputra & Sari, 2021).

The acid sulfate soils naturally occurred in coastal and inland areas when the sea level rose and immersed the land with sulfate. The sulfate from seawater blends with iron dioxides in the sediments and allows the micro-organisms to establish iron sulfides (FeS_2) under anaerobic conditions (Michael et al., 2015; Sundström et al., 2002). These conditions generate the formation of pyrite (FeS_2), which is the characteristic of acid sulfate soils. Also, land management requires improving soil drainage to provide good aeration for optimal root respiration. However, when the drainage is executed incautiously, the anaerobic condition of the pyrite layer is disturbed. As a result, the sulfide compounds present in the layer will be oxidized to form sulfuric acid and mineral jarosite, which negatively affects plant growth and depreciates macro-nutrients (Michael et al., 2017; Sudarmo, 2004; Sutandi et al., 2011). Another problem with this soil is the low availability of nutrients (Jumar et al., 2021) .

Rice plants need essential nutrients to complete growth and development. Plants that lack these nutrients will fail to germinate and grow roots, stems, leaves, and flowers (Naeem et al., 2017). The essential nutrient consists of macro-nutrients, which include carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P), and potassium (K). The secondary nutrient consists of calcium (Ca), magnesium (Mg), and sulfur (S), while micro-nutrients consist of chlorine (Cl), iron (Fe), zinc (Zn), manganese (Mn), boron (B), copper (Cu), and molybdenium (Mo) (Etienne et al., 2018). Also, essential macro-nutrients are needed by plants in large quantities; for instance, N is 100 times higher than Zn in plant tissues (Kumar et al., 2021). Rice plants require 165 kg of macro-nutrients, 19 kg of P, and 112 kg of K in one hectare of land (Dobermann & Fairhurst, 2000). In addition to soil chemical properties such as pH, nutrients, and dissolved heavy metals, acid sulfate soils have other problems which lie in their physical and biological properties (Sundström et al., 2002). The technologies to improve the soil conditions and make it productive are amelioration (Saputra & Sari, 2021) and intensification techniques (Upboff, 2008).

The acidic condition of this soil harms productivity and the environment. Therefore, amelioration technology can reduce the impact of soil acidity (Saputra & Sari, 2021). The technology involves the augmentation of substantial materials to affect soil pH and increase nutrient availability (Michael, 2020). Nevertheless, the technique is still dominated by liming input. Although lime is effective for increasing soil pH, it tends to be expensive and unsuitable for large areas. Hence, amelioration using organic materials is recommended to overcome this issue because organic materials are available, feasible to obtain, and environmentally safe. One of these materials is oyster mushroom baglog waste. It is a post-harvest waste obtained from the media during cultivation. The material needs to go through composting to obtain a C/N ratio for macro-nutrients to be easily absorbed by plants and get rid of billions of spore contaminants in the waste (Hunaepi et al., 2018; Susilawati & Raharjo, 2010). Jumar et al. (2020) showed that composted oyster mushroom baglog waste had pH, organic C, total N, carbon to nitrogen (C/N) ratio, total P, and total K of 8.00, 14.38 mg kg^{-1}, 0.74 mg kg^{-1}, 19.43, 0.50%, and 8.08%, respectively, which is in accordance with the appropriate compost quality standard (Indonesian National Standardization Agency [Badan Standarisasi Nasional, BSN], 2004).

Research references globally point to the rice intensification cultivation technique because of its effectiveness on conventional and flooded land. This technique is famous for its rice production technology with high economic value (Hasanah et al., 2021). Furthermore, it emphasizes the management of soil, plant, and water-based on environmentally friendly activities (Upboff, 2008). Razie (2018) reported that rice production using the intensification technique in acid sulfate soils was higher than conventional cultivation with a difference of 0.78 t ha^{-1}. The technique requires a good knowledge of agronomic and environmental management because they are mutually sustainable. The use of organic matter for land amelioration, which is the compost of oyster mushroom baglog waste, is expected to maximize the potential use of the rice intensification technique in acid sulfate soil. Therefore, this study examines the dynamics of essential macronutrients for rice plants using the intensification cultivation technique on acid sulfate soils ameliorated with compost of oyster mushroom baglog waste.

MATERIALS AND METHODS

This study was carried out for four months, from May to September 2021, in the rice fields of the Faculty of Agriculture, Lambung Mangkurat University (ULM), Sungai Rangas Village, Martapura Barat District, Banjar Regency, South Kalimantan, and the Soil Laboratory, Department of Soil, Faculty of Agriculture, ULM Banjarbaru, South Kalimantan, Indonesia. Furthermore, it was conducted on a 1,000 m^2 rice field of acid sulfate soil. The fields were first cleared of weeds and plowed twice using a hand rotary tractor. Subsequently, a 4 x 4 m size plot was made and separated with a raised bed. The number of plots prepared for the study was 25, divided into five experimental blocks. A single factor randomized block design (RBD) was utilized. Also, the examined factors are the compost dose of oyster mushroom baglog waste which consists of the following five treatment levels, 0 t ha^{-1} (control), 5 t ha^{-1}, 10 t ha^{-1}, 15 t ha^{-1}, and 20 t ha^{-1}. Each treatment had five blocks; hence, 25 experimental units were obtained.

The acid sulfate soil was obtained from Sungai Rangas Village, Banjar Regency, South Kalimantan (3°20'57.5" S 114°46'02.4" E). 'Purun tikus' (*Eleocharis dulcis*) and 'papisangan' (*Ludwigia erecta*) are vegetation that grows and dominates acid sulfate soils at the time of extraction (Figure 1). The growth of these weeds covers most of the soil surface because the land has not been used for rice cultivation for almost two years.

The determination of pyrite depth in acid sulfate soils was carried out by drilling at several depths. Subsequently, the drilled soil was spread over a flat dry surface and arranged according to the depth (Figure 2). The results of observations using the Munsell soil color chart showed changes in color at a depth of 0-10 cm colored 4/2

(a)

(b)

Figure 1. (a) 'Purun tikus' (*Eleocharis dulcis*) and (b) 'papisangan' (*Ludwigia erecta*) growing at the research site

Figure 2. Acid sulfate soil depth profile 0-80 cm below the soil surface

10 yellow-red (YR) (dark grayish brown), 10-31 cm colored 4/2 5 YR (dark reddish gray), 31-46 cm colored 6/4 5 YR (light reddish brown), 46-65 cm colored 7/2 5 YR (pinkish gray), and >65 cm colored 6/3 7.5 YR (light brown).

The groundwater level in the land was found at a depth of 5 cm below the surface. Furthermore, the determination of pyrite using the rapid oxidation method in the field with 30% hydrogen peroxide (H_2O_2) solution was carried out, and the result showed that it was found at a depth of 63 cm from the ground surface.

Composting of Oyster Mushroom Baglog Waste

In the first phase of manufacturing oyster mushrooms, baglog waste obtained a total of 200 kg. Afterward, the waste was kept in the composting box with a length and width of 1.2 m long and a height of 0.8 m. The additional inputs were 10 kg of cow dung, chicken manure, and guano, as well as 3 kg of bran, which were stirred until evenly mixed.

The next phase was the addition of 300 mL of M-21 decomposer and molasses each into a 10 L bucket. Water was subsequently added until it reached 9 L, and the mixture of M-21, water, and molasses was stirred until evenly mixed and kept in the watering can. Furthermore, the mixture was poured over the composted material in the composting box, and the ingredients were stirred using a shovel until evenly mixed and covered with a burlap sack. On the next day, the temperature of the materials in the composting box was measured using a thermometer. Then, each material in the box was stirred evenly and covered again with a burlap sack.

The temperature measurement and mixing of materials in each composting box were carried out until the 21st day when the compost had matured. The maturity indicators of the composted material are: (1) there was a change in the original smell, as the compost emitted an odor like molasses (or no longer smells), (2) there was a change in the original color with blackish brown, and (3) the temperature was in the range of 28–35°C. Subsequently, the compost was kept in an airtight bag and stored for application in the field.

Fertilization

The compost was applied for two weeks based on the research treatment on prepared land before planting. The additional fertilizers were mineral fertilizers such as urea (Pupuk Indonesia, Indonesia) for N fertilizer with a dose of 100 kg ha^{-1}, super phosphate ($Ca(H_2PO_4)$), namely 'SP-36', Petrokimia Gresik, Indonesia) for P fertilizer 25 kg ha^{-1}, and potassium chloride (KCl, Petrokimia Gresik, Indonesia) for K fertilizer 25 kg ha^{-1} (50% of the recommendation for rice fertilization). The urea fertilizer was given two times, 50 kg ha^{-1} each, during the planting and when the rice was four weeks after planting (WAP). Meanwhile, the SP-36 and KCl fertilizers were applied literally at the planting time. Recommendations for N, P, and K fertilization were sourced from the Ministry of Agriculture Number 40 of 2007 in West Martapura District (Ministry of Agriculture Republic Indonesia [MoA], 2007).

Seeds Preparation

The preparation of rice seeds (Inpara 10) was based on Permatasari et al. (2018). Ten (10) Inpara seeds were soaked in a salt solution prepared by incrementally adding salt to the water containing chicken eggs until they floated. The seeds that floated under this condition were discarded because they indicated an open grain, while the sinking ones were selected as they indicated to be full grain.

Chemical Properties of Acid Sulfate Soil and Compost of Oyster Mushroom Baglog Waste

The chemicals in the acid sulfate soils include pH, redox potential (Eh), organic C, N-mineral (NH_4^+, NO_3^-), available P, exchangeable K, Soluble Al, and Fe. In contrast, the chemical properties of the assessed compost and the reference for testing methods include pH, organic C, total N, C/N ratio, total P, total K, total Al, and Fe. The determination of selected soil chemical characteristics was conducted in moist conditions for approaching the field requirements. The methods are presented in Table 1.

There were various pH values in each sampled depth, but they were all very acidic. For example, organic C content at a depth of 0–10 cm and 10–31 cm of acid sulfate soils was classified as moderate, while at a depth of 31–45 cm, 45–65 cm, and >65 cm, it was classified as low (Eviati & Sulaeman, 2009). The chemical properties are presented in Table 2.

The content of NH_4^+ and NO_3^- at all sampled depths was classified as very low, while available P at 0–10 cm depths was classified as moderate, and available P at other soil sampled depths was classified as very low. The concentration of soluble Al and Fe at all sampled depths was very high, which is a characteristic of acid sulfate land. These criteria for classifying soil characteristics in this study were based on Eviati and Sulaeman's (2009) requirements for assessing soil properties.

The content of organic C, total N, C/N Ratio, P, K, Ca, Mg, Al, and Fe compost is in accordance with Indonesian National Standard [Standar Nasional Indonesia (SNI)] No.19-7030-2004. However, the results of pH measurement on the compost did not meet SNI because the pH value was higher than the maximum according to the standard value. The results are presented in Table 3.

Although the pH did not meet the quality, the compost fulfilled the condition as being mature. It is supported by Meena et al. (2021), which stated that organic acids would neutralize their acid during the composting process, and the compost will mature with a pH usually between 6–8. In addition, a high pH has advantages in improving acidity, especially in South Kalimantan, which has acid sulfate soils and high acidity, where high compost pH can increase the pH of the soil. According

Table 1
Methods of chemical analysis of oyster mushroom baglog waste compost and acid sulfate soil

Chemical property	Method	Sample	Reference
pH (H_2O)	pH Electrode	Soil, compost	Neves et al. (2021)
Organic C	Walkley and Black	Soil, compost	Shamshuddin et al. (1994)
Total N	Micro-Kjeldahl	Soil, compost, plant tissue	Miller and Horneck (1997)
Total P	Ascorbic acid	Soil, compost, plant tissue	Raun et al. (1987)
Total K	Flame Photometry	Soil, compost, plant tissue	Juo (1978)
Al	Colorimetric (aluminon plus ascorbic acid)	Soil, compost	Abreu Jr. et al. (2003)
Fe	Ammonium acetate extracts	Soil, compost	Ure et al. (1993)
Eh	Eh electrodes	Soil	Rabenhorst et al. (2009)
N-mineral (NH_4^+, NO_3^-)	Morgan-Wolf Extract	Soil	Eviati and Sulaeman (2009)
Available P	Bray-I	Soil	Gutiérrez Boem et al. (2011)
Exchangeable K	Percolation	Soil	Matthews and Smith (1957)

Table 2
Chemical properties of acid sulfate soil at various depths (cm)

Chemical property	Unit	The amount by depths (cm)				
		0-10	10-31	31-45	45-65	>65
pH (H_2O)		4.75	4.67	4.61	4.60	4.06
Eh	mV	147.50	149.10	153.20	153.70	186.90
Organic C	mg kg^{-1}	3.09	2.89	1.64	1.44	1.32
NH_4^+	mg kg^{-1}	1.30	1.21	1.72	0.94	0.41
NO_3^-	mg kg^{-1}	1.43	1.40	1.43	1.38	1.28
Available P	mg kg^{-1}	9.30	4.95	2.19	2.26	2.16
Exchangeable K	cmol (+) kg^{-1}	0.16	0.15	0.16	0.14	0.16
Soluble Al	mg kg^{-1}	272.24	339.33	300.09	317.90	381.56
Soluble Fe	mg kg^{-1}	306.68	339.92	364.79	341.25	432.57

Table 3
Chemical properties of oyster mushroom baglog waste compost

Chemical property	Unit	Amount
pH (H_2O)		9.80
Organic C	mg kg^{-1}	21.95
Total N	mg kg^{-1}	1.10
C/N ratio		19.96
P_2O_5	mg kg^{-1}	1.99
Potassium oxide (K_2O)	mg kg^{-1}	0.35
Ca	mg kg^{-1}	4.44
Mg	mg kg^{-1}	0.30
Al	mg kg^{-1}	0.0017
Fe	mg kg^{-1}	0.0038

to Saputra and Sari (2021), applying an ameliorant with a pH of 8.4 can increase the pH of peat and tidal swamp soils because they contain Ca and Mg. These elements will replace the H^+ position on the colloidal surface to neutralize acidity.

Planting

The rice seedlings were transplanted to experimental plots after 12 days in the nursery with as much as one seed per planting hole (single planting), shallow, and the root position forming the letter L. Planting was carried out with a spacing of 30 x 30 cm and the water treatment in the rice fields was in a saturated condition with water layer of 3 cm above the soil surface (*macak-macak*).

Observation

Observations were made five times, at the early stage of 0 weeks after planting (0 WAP) or before applying urea, SP-36, or KCl fertilizer, full vegetative phase (8 WAP), early panicle emergence (9 WAP), filling panicles (12 WAP), and harvest phase (15 WAP). Also, soil sampling was conducted in every growth stage with purposive sampling. Each experimental unit obtained 250 g and was analyzed in the laboratory. Determination of the ammonium (NH_4^+) and nitrate (NO_3^-) levels using a Morgan Wolf extract was measured with a wavelength of 636 nm and 494 nm (Eviati & Sulaeman, 2009). Meanwhile, the determination of available P utilized Bray-I methods (Gutiérrez Boem et al., 2011) and the exchangeable K content used percolation (Matthews & Smith, 1957).

The observation of nutrient uptake was carried out at the harvest phase (15 WAP). The Kjeldahl method was only applicable to plant tissue to digest N contents (Miller & Horneck, 1997). Digestion in plant tissue of P contents was carried out using mixture of nitric acid and perchloric acid (HNO_3-$HClO_4$) digest and orthophosphate as phosphorus (PO_4-P) in a dilute acid extract (DAEP), and the contents of P in digested solution were determined using the ascorbic acid method (Raun et al., 1987). K contents were divided using HNO_3-$HClO_4$ acid digest, and the contents of K in digested solution were determined using the flame photometry method (Juo, 1978).

Sampling Data Processing

Variance analysis was carried out on the observed variables using the GenStat (12th edition) application to examine the effect of the application of oyster mushroom baglog waste on changes in soil N, P, K nutrient availability and uptake. Prior to this analysis, the homogeneity of variance was tested. When the analysis showed that the compost application significantly affected the observed variables ($P<0.05$), a different treatment test was subsequently carried out. The different treatment tests need to be taken using Duncan's Multiple Range Test (DMRT) at a level of 5% (Duncan, 1955).

RESULTS AND DISCUSSION

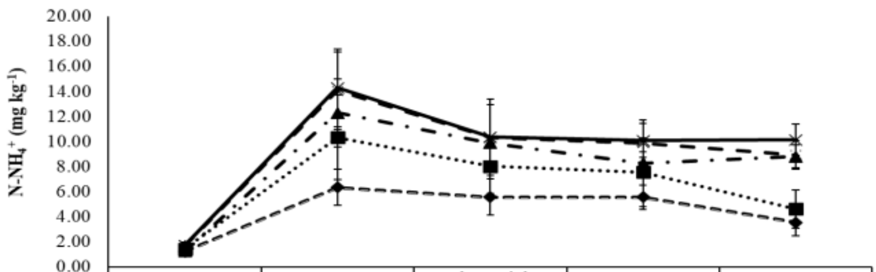
The Dynamics of NH_4^+ and NO_3^-

The observations made at five different growth stages of early planting, full vegetative, early panicle emergence, panicle filling, and harvesting showed variation in the availability of NH_4^+ and NO_3^- in acid sulfate soils. The results for the amount of NH_4^+ and NO_3^- are presented in Figures 3a and 3b.

The compost with a dose of 20 t ha^{-1} could improve the highest N-mineral (NH_4^+ and NO_3^-) contents in acid sulfate soils. This result is in line with Jumar et al. (2021), which stated that utilization of *Pleurotus ostreatus* substrates compost with a dose of 20 t ha^{-1} improved the chemical properties in terms of N-mineral in acid sulfate soils. Furthermore, Burhan and Proyogo (2019) claimed that the greater dose of baglog applied to the planting media enhanced the fertility and developed better plant growth of *Allium ascalonicum* L. The compost of baglog waste dose that significantly raised the plant growth ranged from 10-30 t ha^{-1} (Prabowo et al., 2020; Saputra & Sari, 2021). Moreover, Bonanomi et al. (2020) showed that organic amelioration enhanced fertility and improved a beneficial soil microbiota equipped for supporting high plant yield under an intensive agricultural system.

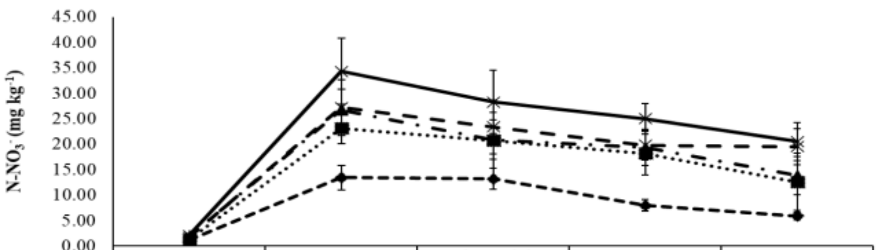
The availability of the minerals (NH_4^+ than NO_3^-) is due to the stimulating effect of N fertilizer (urea) and organic matter application under the rice intensification technique. The greater availability of NH_4^+ than NO_3^- was due to the chemical reactions catalyzed by enzymatic activity, which occurs after the fertilizer contact with the soil. Nitrogen in soil is converted to NH_3 and shortly after that to NH_4^+ (Marchezan et al., 2020). The process of transforming urea into NH_4^+ was influenced by the soil organic matter, as its high content quickens the transformation process. Therefore, the improvement of the matter could enhance the ammonification process that changes organic N to NH_4^+ (Saidy, 2018). This study also supported the compost of baglog oyster mushroom waste at a dose of 20 t ha^{-1}, which had the highest dose with more NH_4^+ content of 14.28 mg kg^{-1}. Therefore, the formation speed of the minerals was certainly good as the soil could meet the N needs of rice plants.

The levels of NH_4^+ were lower than NO_3^- due to the absorption of N by rice plants and nitrification (transformation of NH_4^+ to NO_3^-) processes. According to Figure 3, the NO_3^- the amount in the plants was higher than NH_4^+ because the rice cultivation in this study used an intensification technique, causing the paddy soils to be more aerobic. The nitrification process cannot be separated from the aerobic condition of the soil, which allows



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	1.21 a	6.34 a	5.57 a	5.55 a	3.55 a
5 t ha-1	1.42 ab	10.34 a	8.04 a	7.54 a	4.62 a
10 t ha-1	1.24 a	12.29 a	9.87 a	8.27 a	8.81 b
15 t ha-1	1.67 b	14.06 a	10.32 a	9.89 a	8.93 b
20 t ha-1	1.70 b	14.28 a	10.36 a	10.09 a	10.15 b

(a)



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	1.20 a	13.43 a	13.21 a	7.96 a	5.89 a
5 t ha-1	1.32 ab	23.14 ab	20.73 ab	18.21 b	12.57 ab
10 t ha-1	1.85 ab	26.80 b	20.87 ab	19.36 b	13.88 ab
15 t ha-1	1.71 ab	27.20 b	23.42 ab	19.82 b	19.56 b
20 t ha-1	2.13 b	34.30 b	28.32 b	25.00 b	20.51 b

(b)

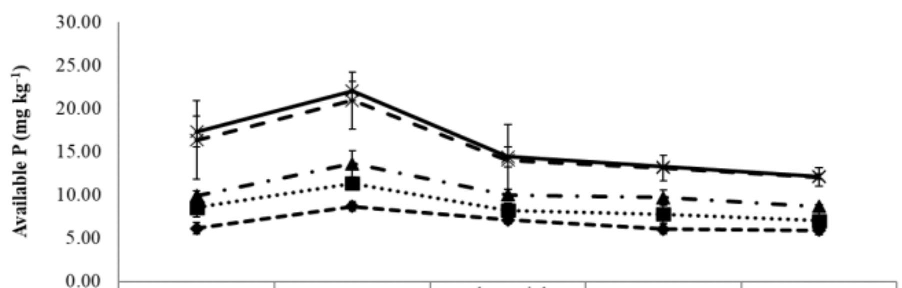
Figure 3. The dynamics of (a) NH_4^+ and (b) NO_3^- in several rice stadia cultivated under rice intensification and ameliorated by the compost of oyster mushroom baglog waste

Note. The line above the diagram is the standard error of the treatment (n = 5). Numbers followed by the same letter at the same rice stadia indicate that the treatment has a no different effect based on Duncan's Multiple Range Test (DMRT) at the level of 5%

nitrifying bacteria to function properly and increase the amount of NO_3^- than NH_4^+ (Khotimah et al., 2020; Sugiarta, 2016). The alternate wetting and drying treatment on the rice plants (as an intensification technique) improved soil NO_3^- content, nitrification processes, N absorption, and accumulation (Chunmei et al., 2020). Improving soil oxygen (O_2) (more aerobic) conditions aid the conversion of soil N cycling and contributes to enhancing the N absorption and accumulation by rice plants in paddy fields. The key to the intensification technique is intermittent periodical irrigation of keeping shallow water depths (*macak-macak*) and intense application of composted organic amendment (Arif et al., 2019). This technique aims to alter the condition of paddy soils to be more aerobic and control the nitrification balance.

The Dynamics of Available P

The observations made at the five different growth stages of early planting, full vegetative, early panicle emergence, panicle filling, and harvesting showed fluctuations of available P in acid sulfate soils. The results are presented in Figure 4. The compost with a dose of 20 t ha^{-1} could improve the highest available P. This result is in line with Jumar et al. (2021), which stated that the use of *Pleurotus ostreatus* substrates compost with a dose of 20 t ha^{-1} improved the chemical properties in term of available P in acid sulfate soils. Phuong et al. (2020b) also claimed that compost in these soils successfully improved available P by magnifying labile P contents with 100% and 200% doses of 10 g kg^{-1} and 20 g kg^{-1}. In addition, the compost of baglog waste mixed with wood biochar could increase



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	6.13 a	8.69 a	7.12 a	6.06 a	5.90 a
5 t ha-1	8.54 a	11.37 ab	8.23 a	7.79 ab	7.04 ab
10 t ha-1	9.92 a	13.60 b	10.00 ab	9.70 b	8.68 b
15 t ha-1	16.36 b	20.91 c	14.04 b	13.13 c	12.09 c
20 t ha-1	17.34 b	22.04 c	14.41 b	13.26 c	12.17 c

Figure 4. The dynamics of available P in several rice stadia using rice intensification technique given compost of oyster mushroom baglog waste

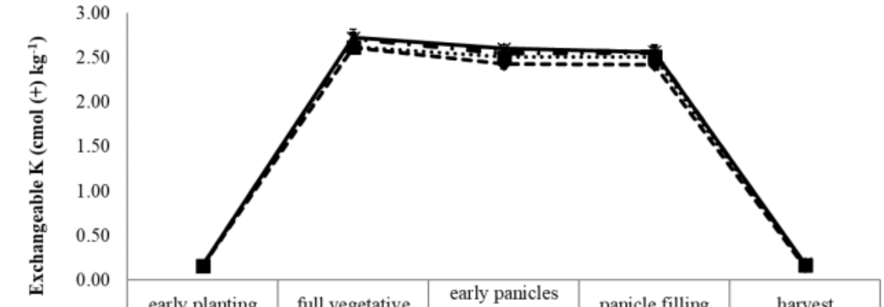
Note. The line above the diagram is the standard error of the treatment (n = 5). Numbers followed by the same letter at the same rice stadia indicate that the treatment has a no different effect based on Duncan's Multiple Range Test (DMRT) at the level of 5%

the photosynthetic rate and plant growth performance (Seehausen et al., 2017).

The increase of available P is due to the addition of the compost combination of oyster mushroom baglog waste and SP-36 fertilizer. The combination of phosphorus pentoxide (P_2O_5) from SP-36 fertilizer directly increased available P, but the main problem in acid sulfate soils is the high solubility of Fe and Al (Jumar et al., 2021). In accordance with the data in Table 2, the content of dissolved Fe and Al was categorized as very high. Therefore, the organic matter from the compost was very important in order not to disturb the available P in the soil. Furthermore, according to Eusterhues et al. (2005), the application of organic matter, such as compost, can reduce Fe^{3+} to Fe^{2+}, which is highly reactive to organic matter. Therefore, the material given in the form of compost could cover the toxicity of Fe, which binds important nutrients to the soil. Likewise, soluble Al could be neutralized by adding organic matter to the soil due to the binding of Al^{3+} by organic acid functional groups, such as humic acid. Therefore, the plants demanded available P to accelerate the flowering process and panicle filling. Moreover, Zhang et al. (2012) confirmed that this chemical is important because it accelerates the maturity of panicle filling, thereby improving the quality of the rice.

The Dynamics of Exchangeable K

The variations in the availability of exchangeable K in acid sulfate soils are shown in Figure 5. The compost with a dose of 20 t ha^{-1} showed that the exchangeable K content was effectively available. Hanifa



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	0.15 a	2.62 a	2.43 a	2.42 a	0.15 a
5 t ha-1	0.16 a	2.62 a	2.51 a	2.51 ab	0.17 ab
10 t ha-1	0.15 a	2.72 a	2.55 a	2.55 ab	0.17 ab
15 t ha-1	0.16 a	2.72 a	2.59 a	2.57 b	0.18 ab
20 t ha-1	0.16 a	2.73 a	2.60 a	2.56 b	0.19 b

Figure 5. The dynamics of exchangeable K in several rice stadia using rice intensification technique given compost of oyster mushroom baglog waste

Note. The line above the diagram is the standard error of the treatment (n = 5). Numbers followed by the same letter at the same rice stadia indicate that the treatment has a no different effect based on Duncan's Multiple Range Test (DMRT) at the level of 5%

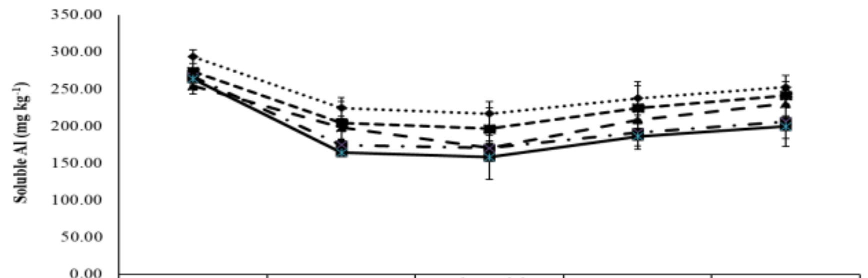
et al. (2019) stated that plants consistently consumed N-mineral and available P until they developed towards maturity, while exchangeable K contents are particularly required in the reproductive growth stages of corn plants. Phuong et al. (2020a) affirmed that the higher application dose of compost in acid sulfate soils could precisely magnify K^+ elements, bringing about higher exchangeable K than in unameliorated soils. Therefore, the compost amendment by 20% could give nutrients fitting to establish plant growth and meet the fertilizer prerequisites of commercial seedlings (Meng et al., 2019).

There was an increase in exchangeable K because of the compost combination of oyster mushroom baglog waste and KCl fertilizer. The treatment of 20 t ha^{-1} of the waste in this research succeeded increasing the exchangeable K in acid sulfate soils. The provision of KCl in the rice intensification system plays a very important role in increasing the exchangeable K. This is in accordance with Isnaini (2005), which stated there was a positive correlation in soil between total N and NH_4^+, where the content of the latter is more significant in the provision of exchangeable K. The increased of exchangeable K in maize plants by the application of organic amendments was strongly influenced by soil moisture mechanism (Manolikaki & Diamadopoulos, 2019; Rogovska et al., 2014). Organic amendments could improve the porosity of soils, which could generate the rearrangement of pore-size distribution and aggregation in soils, thereby contributing to higher soil water retention (Guo et al., 2020).

The Dynamics of Soluble Al and Fe

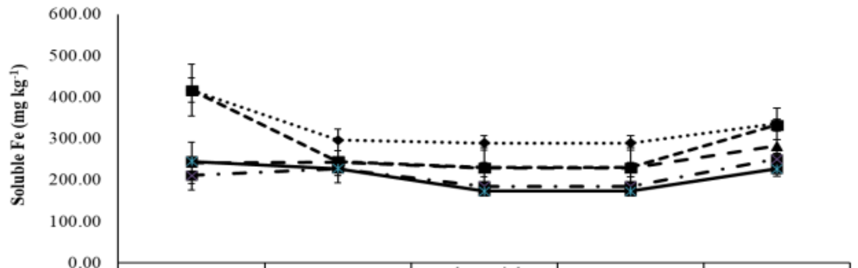
The observation results showed a fluctuation in Soluble Al and Fe levels at five different growth stages. The results are presented in Figures 6a and 6b. The compost as an organic matter plays an important role in managing the solubility of some metals. The more organic matter dissolved in soils, the less amount of soluble Al in plants because the dissolved organic matter (DOM) will buffer the free state of Al and Fe with DOM-metal bound (Stirling et al., 2020; Watmough & Orlovskaya, 2015). Zanin et al. (2019) further stated that organic matters are referred to as redox reactive, which can reduce metal ionic compounds, including Fe^{3+}. In addition, it has been verified that they can accelerate the reduction of Fe (III)-oxide in sediments and bioreduction of Fe (III) minerals in the soil in a dissolved and stable state.

The main source of dissolved organic carbon (DOC) in soil usually originated from root exudates. Rice growth promotes extra photosynthesized (newly-derived) C into soil C pools compared to unplanted land, reflecting the discharge of root exudates from rice roots (Ge et al., 2012). The previous studies stated that within higher soil N, the release of C from the roots is elevated since N uptake through rice flora is stronger in the prophase of the growth degree (Ge et al., 2015). Said-Pullicino et al. (2016) affirmed that the soil-derived DOC should stimulate the reductive dissolution of Fe (hydr)oxides by presenting electrons from organic matter degradation to Fe-lowering micro-organisms. Therefore, the



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	293.75 b	224.54 b	216.89 a	237.67 a	252.33 a
5 t ha-1	273.74 ab	204.51 ab	196.64 a	224.66 a	241.30 a
10 t ha-1	254.10 a	198.11 ab	170.55 a	208.51 a	230.36 a
15 t ha-1	266.63 ab	174.75 a	170.37 a	191.58 a	206.25 a
20 t ha-1	263.50 ab	164.24 a	158.06 a	186.18 a	199.53 a

(a)



	early planting	full vegetative	early panicles appeared	panicle filling	harvest
0 t ha-1	417.23 b	296.97 b	289.88 c	289.88 c	336.20 b
5 t ha-1	417.13 b	245.45 a	230.52 b	230.52 b	333.01 b
10 t ha-1	242.26 a	243.91 a	228.40 b	228.40 b	282.81 ab
15 t ha-1	211.02 a	228.18 a	184.91 a	184.91 a	250.81 a
20 t ha-1	245.33 a	228.05 a	173.02 a	173.02 a	227.39 a

(b)

Figure 6. The dynamics of (a) soluble Al and (b) Fe in several rice stadia cultivated under rice intensification and ameliorated by the compost of oyster mushroom baglog waste
Note. The line above the diagram is the standard error of the treatment (n = 5). Numbers followed by the same letter at the same rice stadia indicate that the treatment has a no different effect based on Duncan's Multiple Range Test (DMRT) at 5%

application of the compost, which provides N uptake availability, increased the root exudates and consequently reduced soluble Fe and Al uptake by promoting more DOC in paddy soils.

The dynamic levels of P availability also influenced the availability of soluble Al and Fe in rice plants. The regular concept stated that the reduction of Fe (III) within the soil could solubilize P, likely through desorption approaches mediated by using subsequent biological assimilation, precipitation, and resorption by Fe (III) species (Peretyazhko & Sposito, 2005). Powerful decreasing conditions with the regular augmentation of organic matter amelioration are required to increase P solubility in these Fe-rich tropical soils (Lin et al., 2018). Also, Khan et al. (2019) showed microbial-mediated Fe (III) reduction was intensified through labile organic C compounds, which acted as energy resources and electron donors. The discharge of available P through Fe reduction followed the way of Fe (III) peaks, DOC, or pH, and was observed through a decrease in iron-bound P (Fe-P). It indicated that Fe-P is the main supply of P in the paddy soils. Therefore, the application of oyster mushroom baglog waste compost in this study, which provides the P availability, reduced the soluble Al and Fe levels in paddy fields as the level of available P improved.

Relationship Between Nutrient Availability and Nutrient Absorbed by Rice Plants

The relationship between nutrient availability at the harvest phase and rice plant uptake was determined using a

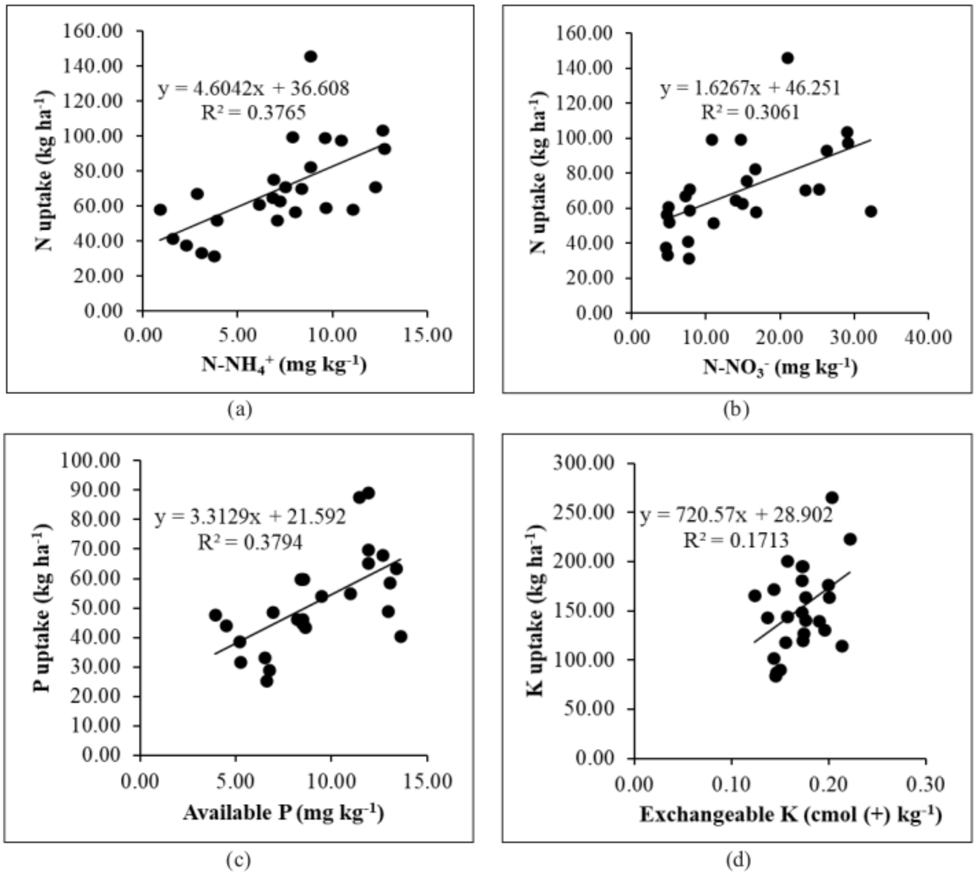


Figure 7. Correlation between: (a) NH_4^+ and N uptake; (b) NO_3^- and N uptake; (c) Available P and P uptake, and (d) exchangeable K and K uptake of rice

correlation test. The uptake illustrates the number of nutrients absorbed by plants, obtained by multiplying the dry weight of nutrient concentrations in the plant tissue. Figure 6 shows the correlation between the availability of N, P, and K and their nutrient uptake in rice plants.

There was a positive correlation between the availability of NH_4^+ in acid sulfate soils at the harvest stage and the N uptake using the intensification technique with a correlation coefficient value (*r*) of 0.6136 (Figure 7a). Likewise, the availability of NO_3^- at the harvest stage and the N uptake with a coefficient value (*r*) of 0.5533 (Figure 7b) indicated a moderate level of close relationship (Schober et al., 2018). Furthermore, a moderate level of a close relationship with a positive correlation coefficient value (*r*) of 0.6160 was found in the available P with the uptake (Figure 7c). Moreover, the exchangeable K with the K uptake of rice had a coefficient value (*r*) of 0.4139 (Figure 7d) which indicated the criteria of moderate relationship closeness (Schober et al., 2018).

The higher the NH_4^+, NO_3^-, available P, and exchangeable K, the more N, P, and K uptake using the intensification technique. The compost provision of oyster mushroom baglog waste provided N, P, and K in available forms. Hence, the roots can optimally absorb these nutrients. It is supported by the data presented in Figures 3 to 5 that the dose of compost given increased with the availability of N (NH_4^+ and NO_3^-), P, and K at all stages using the intensification technique. Furthermore, Sopha et al. (2015) stated that tissue analysis results increased with the growth and production of plants.

CONCLUSION

The compost supplied N, P, and K in available forms and reduced the amount of soluble Al and Fe; hence, the roots can absorb these nutrients optimally. Also, the compost increased the availability of essential macro-nutrients and uptake in plants under the rice intensification technique from early planting stages to the harvest phase.

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