Changes in Soil Ph and Eh Of Rainfed Rice Fields With The Application of NPK Fertilizer and Rice Straw Compost

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Abstract. In Indonesia, rainfed rice fields (non-irrigated) account for only 26.5% of total rice production. The use of sub-optimal land, such as rainfed rice fields, can be used as an alternative. In general, these rainfed rice fields were infertile, they often experienced drought, and their irrigation systems depended on rain. pH and Eh soil are the main factors affecting the solubility and availability of nutrients and their transformation in the soil. Thusly, the purposes of this research were to determine the interaction effect of NPK fertilizer combined with rice straw compost on changes in soil pH and Eh in rainfed rice fields planted with rice. This research used a two-factor randomized block design (RBD). NPK fertilizer dosage (a) and composted rice straw dosage (k) made up the first and second factors, respectively. There were 3 treatments of NPK fertilizer doses, i.e. 0 (control); 150; and 300 kg ha^{-1}, while there were 6 doses of rice straw compost, 5; 7.5; 10; 12.5; 15; and 20 t ha^{-1}. Each treatment consisted of two experimental blocks, resulting in 36 experimental units. Soil observations were carried out three times, namely when the rice was 2 weeks after planting (WAP), 10 WAP, 17 WAP. Results showed the best treatment combination for lowering Eh soil at 2 WAP was a2k4 (300 kg ha^{-1} + 12.5 t ha^{-1} rice straw compost) with a value of Eh -251,2 mV. The effect of single-factor compost was best in increasing the soil pH at 2 WAP, which was 15 t ha^{-1} (k5) with a pH value of 7.28.
Keywords : Soil ph, Soil eh, Rainfed rice fields,NPK fertilizer, Rice straw compost.

1 Introduction

Rice production in Indonesia mostly comes from 60.3% of irrigated paddy fields and 26.5% of rainfed (non-irrigated) paddy fields [1]. According to the Central Statistics Agency for South Kalimantan [2], based on data series recorded in 2015–2017, a report describing the type of irrigation used, the area of paddy fields in 2017 was 549,988 ha, with 54,455 ha being used for rice fields with irrigation and 495,533 ha for non-irrigated fields of rice.

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Based on the research of Pirngadi and Makarim [3], rainfed lowland rice fields are non-irrigated land that is planted at least once a year with lowland rice on land that is always flooded and plots that are ripening, followed by an irrigation system that depends on rain. Land that is specified based on the availability of water according to rainfall is generally infertile (poor in nutrients) and often experiences drought, but the response to fertilization sometimes varies [4].

Stagnant water that is affected by rainfall will also have an impact on changes in soil chemistry. According to Wihardjaka et al. [5], the presence of erratic rainwater stagnation in rainfed rice fields will affect the decrease in oxygen levels, decrease in redox potential (Eh), and changes in soil pH. In addition, the excessive use of inorganic fertilizers also causes rainfed rice fields to become hard during the dry season, making it difficult to cultivate. Fertilizers applied to the soil, such as NPK, have volatile properties, so paddy soil is prone to cracking and even breaking [6]. According to Rep. of Indonesian Law No. 22, 2019 [7] concerning the Sustainable Agricultural Cultivation System, the use of innovations based on indigenous technology is the basic capital to encourage farmers to carry out new innovations. One example of an innovation based on sustainable agriculture was the utilization of organic waste such as rice straw as an ingredient in composting. Compost is one of the organic fertilizers used in agriculture to reduce the excessive use of inorganic fertilizers. The right type of fertilizer, the right dose, the right way, the right time, and the right method will be very important to get profitable agricultural results and maintain the health and quality of the soil.

Nutrient management in rainfed lowland rice fields by combining the application of organic matter, biological fertilizers, and NPK fertilizers has been shown to improve soil chemical properties. Based on the research of Sujana et al. [8], applied rice husk and chicken manure biochar can increase the pH of rainfed rice fields from 5.9 (slightly acidic) to neutral. The application of biological fertilizers from silkworm waste (100 mL ha-1) and NPK Pelangi fertilizer (300 kg ha-1) can increase the pH of rainfed rice fields from 5.05 to 6.74. The use of organic fertilizers should be balanced with artificial fertilizers so that the two complement each other [9]. This change in pH can affect the availability of macro and micronutrients [10].

The given organic substances had an important effect on the chemical characteristics of the soil, improving soil CEC, pH, soil buffering capacity, and soil nutrients [11]. Rainfed lowland rice fields, which are relatively acidic, make it possible to find abundant microelements such as Fe, so that these microelements can be toxic to plants. Therefore, to increase the pH of slightly acidic soil, it is necessary to add organic matter. The microelement Fe can bind macroelements P, both those already in the soil and those that are given to the soil as fertilizer, so that they cannot be used by plants and tend to stunt their growth [10]. Organic matter contains organic acids, which are capable of chelating toxic elements in the soil. Organic acids are able to reduce the amount of P fixed by Fe and Al through the chelating mechanism. In addition, the reduction process in the soil due to the application of organic matter can increase soil pH, which in turn encourages an increase in nutrient solubility [1]. The addition of organic matter affects the availability of electrons for oxidation and reduction in chemical systems. Organic materials will release OH- ions so that they can reduce H+ ions (acid cations); in this case, the soil experiences oxidation and reduction activities. The Eh value will decrease if the reduction process takes place and increase if the oxidation process takes place [12].

One of the organic materials that is easy to obtain is rice straw. There are several ways to manage rice straw waste that are commonly practiced by farmers, including burning it, spreading it on the surface of the soil as mulch, and transporting the straw out of the fields.

Management by burning as above will certainly have negative impacts such as air pollution and killing beneficial soil organisms and microbes [13]. There is one management strategy that can be applied is using rice straw in agriculture as an ingredient in making compost. Research conducted by Kusumawardhani and Tyas [14] proved that composting rice straw waste can increase soil fertility. The application of crop residues such as rice straw can be returned to the soil for a minimum of 2–5 t ha-1 [15]. In addition, Kasno et al. [4] reported that applying N fertilizer with a combination of NPK fertilizers could also improve the chemical properties of rainfed rice fields by fertilizing 90 kg N, 45 kg P2O5, and 45 kg K2O ha-1 + 5 t ha-1 manure in rainfed rice fields.

Based on the discussions above, it is deemed necessary to carry out this research. In addition to increasing the potential of techno-ecologically based rainfed rice fields, this research also adds to the community's knowledge on increasing agricultural production in rainfed rice fields..

2 Material and methods

This research was carried out for five months, from May to October 2022. Located at the Subur Makmur Amali Compost House, Banjarbaru, rainfed rice fields on Gunung Kupang street, Cempaka District, Banjarbaru City, South Kalimantan, and Soil Laboratory, Department of Soils, Faculty of Agriculture, University of Lambung Mangkurat, Banjarbaru, South Kalimantan. This research method used a factorial randomized block design (RBD). The first factor was the dose of NPK fertilizer (A), and the second factor was the dose of rice straw compost (K). There were 3 treatment levels of NPK fertilizer (A), namely a0: 0 (control); a1: 150; and a2: 300 kg ha-1, while the dose of rice straw compost has 6 treatment levels, namely k1: 5; k2: 7.5; k3: 10; k4: 12.5; k5: 15; and k6: 20 t ha-1. Each treatment consisted of two experimental blocks, resulting in 36 experimental units.

Rice straw was taken and collected from paddy fields in Kunyit Village, Pelaihari, Tanah Laut, South Kalimantan (-3.771075 S. 114.782078 E). Composting rice straw waste was carried out based on the implementation method from Saputra [16]. The basic ingredients were 200 kg of chopped rice straw with a size of around 2–10 cm, 10 kg of cow manure, 10 kg of chicken manure, 3 kg of rice bran, and 15 kg of agricultural lime (dolomite). The ingredients were then combined until thoroughly mixed. To assist the decomposition process, a mixture of 300 mL of Petro Gladiator decomposer, 300 mL of molasses, and 9 L of water is added. The mixture was put into a 10 L bucket and stirred until evenly distributed. After that, the mixture of decomposers and molasses is poured over the composted material. The compost and decomposer mixture and molasses were mixed using a rake until evenly distributed. If it has been thoroughly mixed, the compost is covered using a tarpaulin and the temperature is checked for 21 days, while the mixing is carried out once every two days.

Analysis of nutrient content was carried out using the random sampling method following the Siregar [17] method by taking soil at five points with a depth of 0–20 cm, then the soil was composited, and after that, 100 g was taken to analyze pH H2O, organic C, total N, available P, exchangeable K, CEC, soluble Al, and soluble Fe. Compost analysis was carried out by taking samples of compost from the composting tub, then putting it in a plastic zip and analyzing the compost's pH, total N, organic C, C/N ratio, P2O5, and K2O in the laboratory.

The rainfed rice fields used in this study are located on Gunung Kupang street, Cempaka District, Banjarbaru City, South Kalimantan (-3.482674 S. 114.881089 E) with an area of 900 m2. Prior to use, the paddy fields were cleaned of weeds, then the soil was processed again to make it more friable using a hand rotary tractor twice and harrowing once. After that, a map is made with an area of 3 m x 3 m. The required number of plots is 36, which are divided into two trial blocks.

Application of rice straw compost, rice straw that has been composted is then applied to rainfed rice fields based on the treatment. After application, the fields were incubated for 2 weeks. The NPK fertilizer was applied after 2 weeks of incubation. The application of NPK fertilizer is done by spreading it on each trial plot unit.

Soil samples were taken again, as much as 200 g of plot-1, then put in a plastic zip and labeled. The soil samples were analyzed with two research parameters, namely soil pH and Eh. Sampling was carried out three times, namely at 2 weeks after planting (WAP), 10 WAP, and 17 WAP.

GenStat (12th edition) was used to assess the variance of the variables that were observed and the data gained from observing the impact of applied NPK fertilizer and rice straw compost on changes in the pH and Eh soil of rainfed rice fields. Prior to the analysis of variance, a homogeneity test was carried out using the Bartlett test. If the results of the analyses of variance indicated that applied rice straw compost and NPK fertilizer had an impact on the variables that were measured ($P \leq 0.05$), then the analysis continued to test the mean value using Tukey Honest Significant Difference (HSD) test at the α level of 5%. Then, variable relationships between observations will be known using correlations based on the formula Habibullah [18].

3 Result and discussion

3.1 Characteristics of rainfed rice fields

The rainfed rice fields used for the research was taken from the land belonging to one of the farmers located in ex. Cempaka Technical Implementation Unit (TIU), Gunung Kupang street, Cempaka District, Banjarbaru City, South Kalimantan (-3.482674 S. 114.881089 E). The rainfed rice fields had not been used for rice cultivation for almost five years, so there were many weeds, such as the broadleaf weed Ludwigia octovalvis, Cyperus longus weeds, the narrow-leaved weed Echinochloa colona, and other types of weeds that mostly grow and cover the land. In addition, around the land, various plants are cultivated, such as chilies, leeks, and celery. The following is a photo of the sampling location for rainfed rice fields, which can be seen in Figure 1.

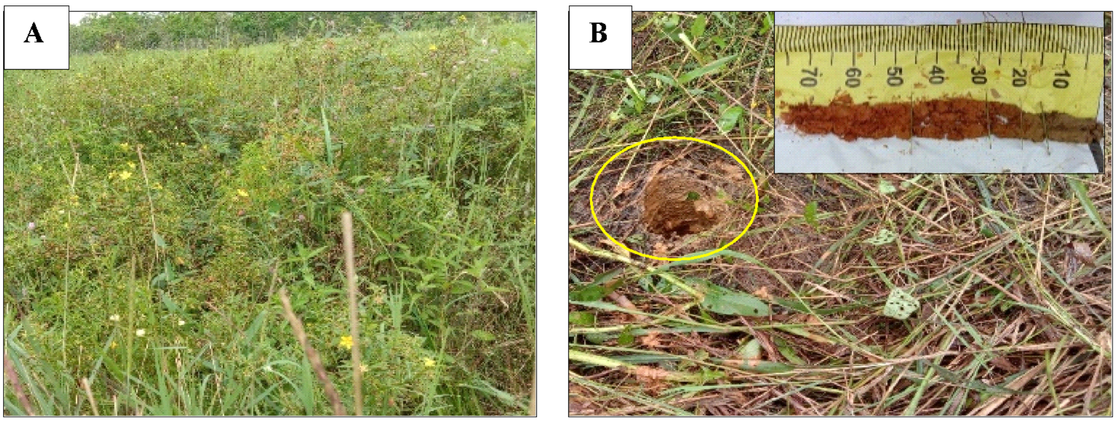


Fig. 1 (A) Rainfed rice fields vegetation and (B) characterization of rainfed rice fields.

Preliminary analysis of rainfed rice fields was carried out by taking soil samples from 0–14 cm deep (Figure 1b). This analysis were to determine the chemical characteristics of the soil, including pH, organic C, total N, available P, exchange bases, and cation exchangeable capacity (CEC) of rainfed rice fields before they were treated with NPK fertilizer and rice straw compost (Table 1).

Table 1. Soil Chemical properties of rainfed rice fields

Chemical property	Unit	Values
Soil pH (H_2O)	-	5.73 (am)
Organic C	%	1.35 (r)
Total N	%	0.14 (r)
Available P	ppm	1.13 (sr)
Exchangeable K	cmol (+) kg^{-1}	0.04 (sr)
Exchangeable Al	cmol (+) kg^{-1}	0.35 (sr)
CEC	cmol (+) kg^{-1}	21.23 (t)
Soluble Fe	ppm	51.78 (st)

The chemical characteristics of rainfed rice fields Table 1 showed slightly acidic soil pH (pH 5.73), organic C 1.35% (low), total N 0.14% (low), available P 1.13 ppm (very low), exchangeable K 0.04 cmol (+) kg^{-1} (very low), exchangeable Al 0.35 cmol (+) kg^{-1} (very low), CEC 21.23 cmol (+) kg^{-1} (high), and soluble Fe 51.78 ppm (very high) (Table 1). Criteria for assessing chemical properties based on [19].

3.2 Characteristics of rice straw compost

The composting process that has been carried out for 21 days needs to be known for the quality of the compost before it is applied. Knowing the quality of this compost so that it can be used optimally in rainfed rice fields. The parameters tested were compost pH, total N, organic C, C/N ratio, P_2O_5, and K_2O, as presented in Table 2. The results of the rice straw compost analysis test showed that the results met the Indonesian National Standard criteria (SNI) [20]. Soil pH 7.25 according to the SNI compost criteria (6.80-7.49), 1.23% total N meets the minimum SNI compost criteria of 0.40%, 17.18% organic C meets the compost SNI criteria at a minimum of 9.80%, C/N 14.00 meets the SNI criteria (10-20), 1.16% total P meets the minimum compost SNI criteria of 0.10%, and 0.27% total K meets the SNI compost criteria minimum compost of 0.20%.

Table 2. Chemical properties of rice straw compost

Chemical property	Unit	Values
pH (H_2O)	-	7.25
Total N	%	1.23
Organic C	%	17.18
C/N ratio	-	14.00
P_2O_5	%	1.16
K_2O	%	0.27

3.3 Change of soil pH

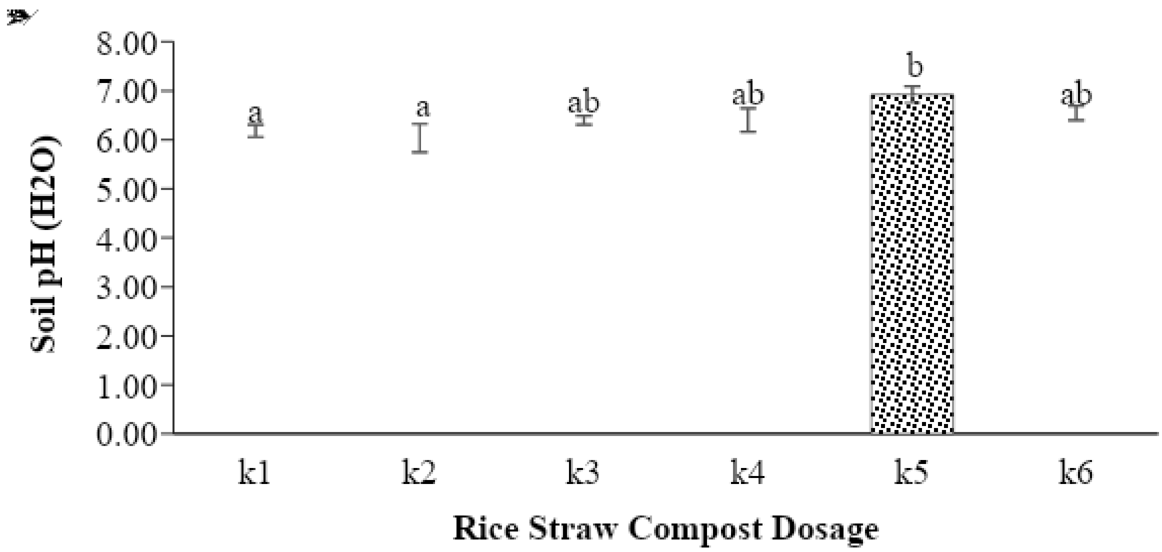
Soil reactions indicate soil acidity or alkalinity characteristics expressed by pH values. Table 3 does not show the influence of interactions between the application of NPK fertilizer and rice straw compost at each stage of observation, but there is a single factor influence on 2 WAP.

Table 3. Interaction of NPK fertilizer and rice straw compost on soil pH

NPK	Rice straw compost	pH (H_2O 1:5)		
		2 WAP^{Tn}	10 WAP^{Tn}	17 WAP^{Tn}
a0	k1	6.45 ± 0.04	6.25 ± 0.11	6.20 ± 0.14
a0	k2	5.45 ± 0.53	5.25 ± 0.11	5.25 ± 0.11
a0	k3	6.45 ± 0.11	6.40 ± 0.21	6.30 ± 0.21
a0	k4	5.85 ± 0.04	5.10 ± 0.35	5.68 ± 0.23
a0	k5	6.60 ± 0.14	6.60 ± 0.14	6.78 ± 0.12
a0	k6	6.68 ± 0.30	6.35 ± 0.32	6.35 ± 0.39
a1	k1	6.15 ± 0.11	5.70 ± 0.78	5.25 ± 0.32
a1	k2	6.60 ± 0.07	6.25 ± 0.11	6.55 ± 0.25
a1	k3	6.20 ± 0.35	6.23 ± 0.30	6.05 ± 0.25
a1	k4	6.65 ± 0.18	6.40 ± 0.21	5.15 ± 0.11
a1	k5	7.28 ± 0.16	5.65 ± 0.04	5.45 ± 0.25
a1	k6	6.20 ± 0.07	5.85 ± 0.11	6.05 ± 0.25
a2	k1	5.95 ± 0.04	6.10 ± 0.21	5.10 ± 0.07
a2	k2	6.05 ± 0.25	5.75 ± 0.11	5.75 ± 0.53
a2	k3	6.55 ± 0.25	5.80 ± 0.42	6.25 ± 0.32
a2	k4	6.70 ± 0.07	6.50 ± 0.28	5.95 ± 0.32
a2	k5	6.90 ± 0.07	5.90 ± 0.07	5.65 ± 0.46
a2	k6	6.75 ± 0.04	5.45 ± 0.04	5.15 ± 0.04

Note: a0: 0 (control); a1: 150; and a2: 300 kg ha^{-1} of NPK fertilizer, k1: 5; k2: 7.5; k3: 10; k4: 12.5; k5: 15; and k6: 20 t ha^{-1} of rice straw compost. Significant Influence (*), Very Significant Influence (**), No Influence (Tn). The number in front of the ± sign is the standard error of the treatment (n=2). Based on the Tukey Honest Significant Difference (HSD) test at the α level of 5%, a similar letter denotes that there is no difference between the treatment's effects

The application of rice straw compost to rainfed rice fields gave different results between treatments for changes in soil pH. Figure 2 shows the soil pH of 2 WAP with the application of 15 t ha^{-1} rice straw compost, obtaining a pH value of 7.28 for rainfed rice fields. This pH value corresponded to the criteria for a neutral pH value according to Eviati & Sulaeman [19], namely a range of 6.6–7.5, and when compared with the initial soil pH value of 5.73, the pH value at 2 WAP after the application of 15 t ha^{-1} rice straw compost higher than when 20 t ha^{-1} rice straw compost applied. The figure shows that the best treatment of rice straw compost is 15 t ha^{-1}, which can significantly increase the pH of rainfed rice fields.



Note: k1: 5; k2: 7.5; k3: 10; k4: 12.5; k5: 15; and k6: 20 t ha^{-1} of rice straw compost. The line above the bar diagram is a standard error. The same letter above the bar diagram indicates that the treatment has no different effects based on Tukey Honest Significant Difference (HSD) test at the α level of 5%

Fig. 2 Changes in the pH of rainfed rice fields due to the application of rice straw compost 2 WAP

According to the initial analysis, the pH of rainfed rice fields is slightly acidic at 5.73. Soil acidity can indicate the availability of nutrients in the soil, making it one of the most important indicators of soil fertility. When 2 WAP was applied, rice straw compost at a dose of 10 t ha^{-1} was able to increase the pH of rainfed rice fields compared to the control treatment. According to Mulyadi & Wihardjaka [21], root respiration in rice plants occurs optimally when pH is 6–8. The application of rice straw compost can increase soil pH, from 5.73 to 7.25. The addition of dolomite lime contained in compost can also help overcome soil acidity problems because it inhibits H^+ activity and increases the pH value [22].

Applied rice straw compost can release H^+ ions as a result of the decomposition of organic matter in rice straw, accelerating the weathering of minerals that contain a lot of bases and resulting in the formation of water-soluble nutrients and secondary minerals such as clay minerals and iron and aluminum oxides [10]. The application of rice straw compost (15 t ha^{-1}) gave a higher pH value than the application of rice straw compost (20 t ha^{-1}). This is likely due to the rate of supply of organic matter nutrients, which is influenced by the C/N ratio. Based on the results of the characteristics of rice straw compost presented in Table 2, the C/N ratio of rice straw compost of 14.00 complies with SNI standards. However, if organic matter is applied in large quantities, it will also affect the process of decomposition and mineralization by the soil because the nutrients contained in organic matter are slowly released. The thing that needs to be considered is the rate of mineralization or the amount of nutrient supply to the soil due to the decomposition process organic [23].

The increased at 2 WAP was also suspected to be due to environmental factors, namely rain, which caused inundation. According to data reported by Climatology and Geophysics Agency, 2022 [24], at the beginning of August, the rain in Banjarbaru City at that time reached 99%, namely with above-normal rainfall (AN) of > 200 mm. As a result of the high rainfall, the research location was flooded, resulting in high inundation in the rice fields. According to Cyio [12], the soil pH value will increase with increasing inundation height, and will increase with the addition of organic matter. When it is flooded, the soil will release OH^- ions due to a reduction process. The presence of Fe^{3+} ions in the reduced soil will change to Fe^{2+} so that it has the opportunity to release OH^-.

3.4 Yield and Production

Table 4 shows the effect of the interaction between the application of NPK fertilizer and rice straw compost on changes in soil Eh. Observations of soil Eh at 2 WAP and 17 WAP showed that there was an interaction. The results of the BNJ test with a level of 5% and the application of NPK fertilizer and rice straw compost to soil Eh at 2, 10, and 17 WAP can be seen in Table 4.

Table 4. Interaction of NPK fertilizer and rice straw compost on soil Eh

NPK	Rice straw compost	Eh (mV)		
		2 WAP**	10 WAP[Tn]	17 WAP*
a0	k1	211.90 ± 6.29[a]	247.75 ± 3.57	288.20 ± 2.26[abcd]
a0	k2	226.80 ± 5.44[a]	282.00 ± 4.10	317.10 ± 6.15[ab]
a0	k3	213.20 ± 35.43[a]	215.35 ± 38.93	280.55 ± 6.26[abcde]
a0	k4	220.00 ± 1.63[a]	282.00 ± 18.38	302.00 ± 5.66[abcd]
a0	k5	87.75 ± 13.26[ab]	241.20 ± 9.12	227.65 ± 18.49[de]
a0	k6	247.85 ± 6.12[a]	229.90 ± 9.40	244.50 ± 41.37[bcde]
a1	k1	204.50 ± 11.60[a]	245.55 ± 8.17	294.50 ± 10.75[abcd]
a1	k2	96.45 ± 25.14[ab]	243.00 ± 2.97	214.25 ± 10.01[e]
a1	k3	163.55 ± 86.30[a]	223.75 ± 9.79	274.95 ± 12.55[abcde]
a1	k4	-239.28 ± 65.21[c]	235.55 ± 14.04	288.90 ± 4.24[abcd]
a1	k5	126.00 ± 48.72[a]	293.55 ± 3.71	339.30 ± 6.72[a]
a1	k6	112.05 ± 10.36[ab]	245.00 ± 14.00	236.40 ± 27.37[cde]
a2	k1	234.35 ± 9.16[a]	250.70 ± 47.87	313.15 ± 1.24[ab]
a2	k2	196.10 ± 29.13[a]	191.05 ± 50.03	308.65 ± 13.19[abc]
a2	k3	152.30 ± 7.92[a]	258.45 ± 24.93	301.45 ± 5.34[abcd]
a2	k4	-251.15 ± 19.83[c]	187.70 ±19.09	296.60 ± 1.98[abcd]

a2	k5	-221.10 ± 14.85^{c}	221.20 ± 47.73	275.90 ± 16.69^{abcde}
a2	k6	-33.30 ± 21.78^{b}	284.45 ± 11.56	299.40 ± 13.86^{abcd}

Note: a0: 0 (control); a1: 150; and a2: 300 kg ha^{-1} of NPK fertilizer, k1: 5; k2: 7.5; k3: 10; k4: 12.5; k5: 15; and k6: 20 t ha^{-1} of rice straw compost. Significant Influence (*), Very Significant Influence (**), No Influence (Tn). The number in front of the ± sign is the standard error of the treatment (n=2). Based on the Tukey Honest Significant Difference (HSD) test at the α level of 5%, a similar letter denotes that there is no difference between the treatment's effects

The change of condition from reductive to oxidative causes a change in the load of the redox elements. The content of the elements ferro (Fe^{2+}), and manganese (Mn^{2+}) transformed into more stable ferri (Fe^{3+}) and mango (Mn^{4+}), binding hydroxide ions (OH^-) and releasing hydrogen ions, as well as the transformation of sulfide (S^{2-}) into sulfate (SO_4^{2-}), which gave the effect of soil saturation [25]. The condition of the reductive (Eh) soil will decrease, while the condition of the dry (oxidative) Eh soil will increase. The decrease in the Eh value that occurs indicates the soil condition becomes more reductive due to the occurrence of $Fe(OH)_3$ reduction [26].

Applied straw compost and NPK fertilizer had no interaction effect on soil Eh changes at 10 WAP, as demonstrated in Table 4. The interaction occurred at 2 WAP and 17 WAP Eh of soil. Soil Eh at 2 WAP showed that the application of 300 kg ha^{-1} NPK fertilizer + 12.5 t ha^{-1} rice straw compost significantly reduced the soil Eh value by -251.2 mV. According to Tan [27], The Eh value will fluctuate lower if the reduction process occurs and up if the oxidation process occurs. Compost made from rice straw and NPK fertilizer can lower Eh's value. Cyio [12] reported that organic matter can release OH^- ions, which will later undergo a reduction process, thereby reducing the Eh value of the soil. The presence of Fe^{3+} in reduced soil will change to Fe^{2+}, which will produce OH^-. According to Asfianti *et al.* [28], NPK fertilizer will release nitrate, phosphate, and potassium ions during the reduction process, where these ions can be immediately available and absorbed by plants after the fertilizer is applied to the soil.

pH decreased when there was an increase in Eh. Since the number of electrons is directly proportional to the redox potential, a drop in the amount of electrons will consequently lower the value of Eh. This decrease also resulted in a decrease in the number of electrons in the soil solution [12]. The Eh value of the soil obtained at 2 WAP was -251.2 mV, these results indicate that the Eh value in the soil experienced a strong reduction due to flooding. It is possible that this was due to the fact that the research area had been flooded, causing a decrease in O_2 in the soil followed by a decrease in Eh. According to Mulyadi & Nurcholis [29], the longer a soil is inundated, the lower the O_2 content, even up to an Eh value of -350 mV.

At 17 WAP (harvest), the application of 150 kg ha^{-1} NPK + 7.5 t ha^{-1} rice straw compost was able to significantly reduce the Eh value to 214.25 mV. When compared with the Eh value at 2 WAP, the Eh value at 17 WAP has increased. It is suspected that at 17 WAP (harvest), the condition of the paddy soil was not inundated (mixed conditions), including moderately reduced, so that the Eh value increased compared to Eh at 2 WAP with flooded conditions. According to Husson [30], Eh values can generally change between -300 mV and can even reach 900 mV, for plant growth, the Eh value range is ±100 and ±400 mV. If the Eh value is > 450 – 500 mV, it is considered unfavorable for the plant because it will experience mineral deficiencies (P, Mn, Fe) and heavy metal toxicity (Cd, Pb). According to

Virzelina et al. [31], soil Eh will decrease and reach a negative value after oxygen in the soil is used up due to aerobic microbial activity that requires it. The availability of oxygen, nitrate, iron, manganese, and sulfate will affect the oxidation capacity as the main electron acceptor [30].

3.5 Relationship between soil pH and Eh

The data obtained from the observations tested the level of closeness between the observation variables using the correlation test to find out whether the observed variables are independent from one another or have a relationship between the two variables. The results of calculating the relationship between the observed variables can be seen in Figure 3 and Table 5.

Table 5 shows the relationship between the observed variables and the criteria for closeness values on the variables pH 10 WAP and Eh 10 WAP (moderate correlation), pH 2 WAP and Eh 2 WAP (moderate correlation), and pH 17 WAP and Eh 17 WAP (moderate correlation). The correlation between pH and Eh parameters at each observation stage has a negative correlation value, which means it has the opposite relationship. When the pH value increases, Eh decreases. This is in line with the statement of Cyio [12] that changes in soil from dry to flooded conditions affect oxidative to reductive changes, such as involving soil microbial activity in stimulating the process of reducing Fe3+ to Fe2+ so that it can increase pH and reduce Eh.

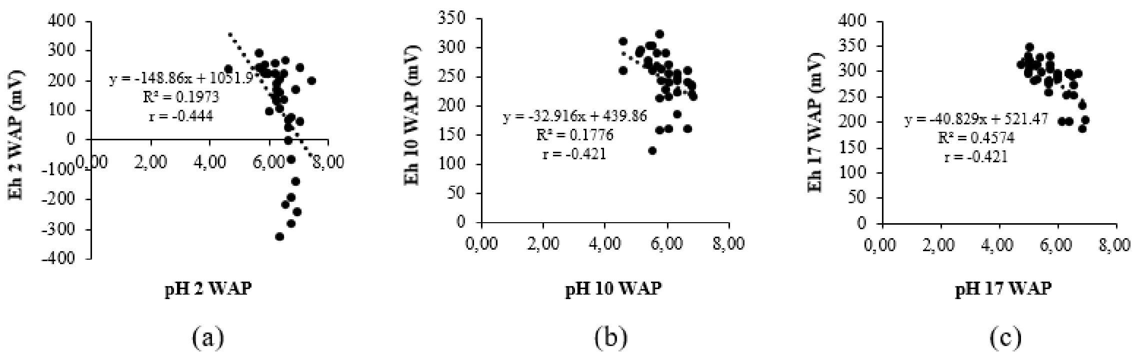


Fig. 3 Relationship between (a) pH 2 WAP and Eh 2 WAP; (b) pH 10 WAP and Eh 10 WAP; (c) pH 17 WAP and Eh 17 WAP

Table 5. Relationship between observation variables

	pH 2 WAP	pH 10 WAP	pH 17 WAP	Eh 2 WAP	Eh 10 WAP	Eh 17 WAP
pH 2 WAP						
pH 10 WAP						
pH 17 WAP						
Eh 2 WAP	-0.444					
Eh 10 WAP		-0.421				
Eh 17 WAP			-0.676			

Note: If the correlation coefficient is <0.1, the relationship between the two variables is not close. Otherwise, > 0.9 indicates that the relationship between the two variables is very close. Criteria for closeness value [32]: 0.10 – 0.39 = weak correlation; 0.40 – 0.69 = moderate correlation; 0.70 – 0.89 = strong correlation; 0.90 – 1.00 = very strong correlation.

Eh and pH are significant parameters for biological activity. Eh significantly affects the development of microorganisms, each group of microorganisms also adapts to a certain pH range where outside of this pH range, they cannot live. Figure 3 illustrates the relationship between soil pH 2 WAP and soil Eh 2 WAP (Figure 3a). Soil pH 2 WAP and soil Eh 2 WAP had a moderate correlation with a correlation value of -0.444. The relationship shown is negative, so the two have the opposite relationship. When the soil pH value increases, the soil Eh decreases. This is also thought to be due to inundation, the increase in pH increases with increasing inundation, and this increase also increases when organic matter is applied, while the Eh of the soil decreases.

As stated by Wiranti [33], these alterations came about through the addition of both hydroxyl groups and other carboxyl compounds to the soil solution, which can balance the activity of H+ ions and result in a drop in their concentration. This decrease will also encourage a decrease in the number of electrons because the number of electrons is directly proportional to the redox potential. This also happened to the relationship between pH 10 WAP and Eh 10 WAP and the relationship between pH 17 WAP and Eh 17 WAP, so that Figures 3b and 3c show that the correlation value is negative (not close) or has the opposite relationship.

Organic substance in the form of rice straw bokashi can increase soil pH. The decomposition process of bokashi produces alkaline cations such as Ca^{2+}, K^{+}, Na^{+}, and Mg^{2+}, which can neutralize the negative charge on the soil [11]. Several factors can affect soil pH and Eh, namely precipitation and flooding. Rainfed rice fields whose soil is inundated by rainwater are thought to affect the erratic changes in soil pH and Eh. In rainwater that passes through the soil, alkaline cations such as Ca and Mg will be leached. The lost alkaline cations in the soil will be replaced by acid cations such as Al, H, and Mn, so that soils formed on land with high rainfall will usually be more acidic than soil on dry or arid land [34].

4 Conclusions

The results suggested that applied NPK fertilizer and rice straw compost in rainfed rice fields could reduce soil Eh, and there was no interaction with changes in soil pH. The best treatment combination for reducing soil Eh at 2 WAP was a2k4 (300 kg ha^{-1} NPK + 12.5 t ha^{-1} rice straw compost) with an Eh value of -251.2 mV. The best dose of NPK fertilizer, namely 300 kg ha^{-1} at 2 WAP and 150 kg ha^{-1} at 17 WAP, can reduce soil Eh. The best dose of rice straw compost, namely 15 t ha^{-1}, was able to increase soil pH at 2 WAP, and the best dose of rice straw compost, 12.5 at 2 WAP and 7.5 t ha^{-1} at 17 WAP, was able to reduce soil Eh.

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