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Research Paper

Lead (Pb) accumulation in the Indonesian intensive farming system

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Abstract

One of the factors contributing to soil pollution in paddy fields is the presence of the heavy metal lead (Pb). Lead is not an essential element for plants, and its concentration in soil typically ranges from $0.1\,\mu g\,g^{-1}$ to $10\,\mu g\,g^{-1}$, while in various plant tissues it usually ranges from $0.5\,\mu g\,g^{-1}$ to $3.00\,\mu g\,g^{-1}$. The objective of this study was to assess the lead (Pb) content in both soil and rice plants, as well as some chemical properties of the soil in the central rice-growing area of Marga Cinta, Belitang Madang Raya District, East Ogan Komering Ulu, South Sumatra, Indonesia. The research utilized a detailed survey method with a working map scale of 1:9,000. The paddy fields under investigation covered an area of 96 hectares, which were divided into 6 locations for random sampling. Each location consisted of 5 soil drilling points, and composite samples were created from these points. Soil sampling was conducted using an auger, at a depth of 0 cm to 30 cm. The results revealed that the lead (Pb) content in the paddy soil ranged from $9.90\,\mu g\,g^{-1}$ to $12.18\,\mu g\,g^{-1}$, with an average concentration of $10.56\,\mu g\,g^{-1}$. However, the lead (Pb) content in the rice plants was below the detection limit of the analytical tool, with a value of $<0.0002\,\mu g\,g^{-1}$. In conclusion, the study found that the heavy metal lead (Pb) content in both the paddy soil and rice plants at the study site was still below the threshold level.

Keywords

Lead, Heavy Metals, Paddy Field, Rice Plant.

1. INTRODUCTION

One of the factors of soil pollution is residual containing heavy metals. Heavy metals are metal elements that have a high molecular weight and are categorized as major environmental pollution. One of the heavy metals that pollutes the soil is lead (Pb). Lead (Pb) is one of the heavy metals that are harmful to human health and other organisms derived from household activities such as soap and detergent (Agustina, 2014). The main source of soil pollution contaminated with heavy metals actually comes from the air and water that pollute the soil (Khaira, 2018).

Lead is an element that is not essential for plants, and its content ranges from $0.1\,\mu g\,g^{-1}$ to $10\,\mu g\,g^{-1}$, while its content in plants for various types normally ranges from $0.5\,\mu g\,g^{-1}$ to $3.00\,\mu g\,g^{-1}$ (Agustina, 2014). The heavy metal lead (Pb) is absorbed by plant tissues through the roots and leaves of plants, which then further goes through the food chain cycle (Agustina, 2014). Lead accumulates in body tissues and can cause poisoning in humans, animals, and plants if it exceeds the tolerance limit.

Rice (*Oryza sativa* L.) is a rice-producing food crop commodity that plays an important role in the basic needs of the Indonesian people. Based on data from the Agricultural Extension Agency of Belitang Madang Raya (2022), the level of rice production in Marga Cinta Village has experienced fluctuations over the past 5 years, namely 6.70 tons ha^{-1} in 2018, increased to 6.88 tons ha^{-1} in 2019, decreased to 5.58 tons ha^{-1} in 2020 and 2021, and then increased again to 7.98 tons ha^{-1} in 2022. Marga Cinta is a village where most people work as farmers planting rice. This village has a large paddy field of 96 hectares, but information and data on the content of the heavy metal (Pb) in the soils are still limited, which has sparked the interest of researchers to conduct research on the analysis of the heavy metal content of lead (Pb) in soil and rice crops, as well as the analysis of various soil chemical properties such as pH, Cation Exchange Capacity, and C-organic in soil.

The purpose of this study was to determine the content of the heavy metal lead (Pb) in soil and rice plants and to determine various soil chemical properties in paddy soil of Marga Cinta, Belitang Madang Raya, Ogan Komering Ulu Timur of South Sumatra, Indonesia.

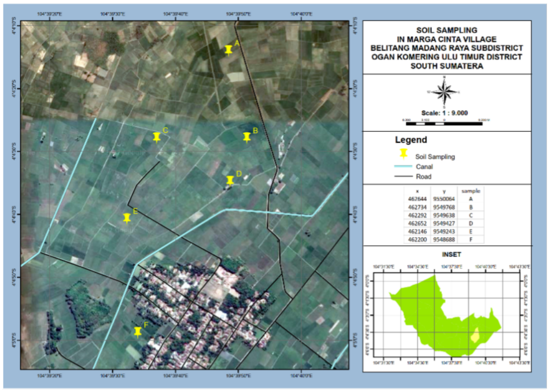

Figure 1. The map of research location

2. EXPERIMENTAL SECTION

Soil samplings were conducted in the rice center of the intensive farming system in Marga Cinta, BK 11, Belitang Madang Raya, Ogan Komering Ulu Timur of South Sumatra. The heavy metal explored was Pb and analyzed in the Basic Chemistry Laboratory, Faculty of Mathematics and Natural Sciences. The analysis of Pb in rice plants was carried out in the PT Laboratory, Global Quality Analytical. Some soil chemical properties were analyzed at the Laboratory of Soil Chemistry, Biology, and Fertility, Department of Soil, Faculty of Agriculture, Sriwijaya University. This field research was conducted from January 2022 to October 2022.

The method used in this study was the detailed survey method using a working map scale of 1:9,000 (Fig. 1). The paddy field studied covered approximately 96 hectares, divided into 6 locations, which were sampled randomly. Each location had 5 soil drilling points, which were then composited. Soil sampling was performed by augering the soil at the arable layer, at a depth of 0-30 cm. Soil samples were taken when the rice was 60 days after transplanting, and the rice variety used was Inpari 32.

2.1 Varibales Observed

The variables observed were Lead (Pb) in soil and rice plant, soil pH, soil cation Exchange Capacity and soil C-organi.

2.2 Data Analysis

To know the relationship between Pb and some soil properties was done by a multiple linear regression analysis to see the influence between soil chemical properties (pH, CEC and C-organic) and Lead (Pb) content on paddy soil at the study site, after which it was explained descriptively and will be presented in tabulation form.

3. RESULTS AND DISCUSSION

3.1 Site Description of the Research Location

The field research location was situated in a rice field at Marga Cinta, BK 11, Belitang Madang Raya, Ogan Komering Ulu Timur of South Sumatra. This village is bordered by Karang Binangun Village in the North, Tulus Ayu Village in the South, Tulus Ayu Village in the West, and Yosowinangun Village in the East. The distance from Marga Cinta Village to the district center is approximately 53 km. Marga Cinta has a total land area of 195.49 ha, and the majority of the people are engaged in rice farming. The rice fields in this village are supported by technical irrigation from the Komering river, which flows from the Musi river, with a total area of 96 hectares. The topography of these paddy fields is horizontal. The paddy fields were established around 1969. Activities related to rice cultivation are carried out 2-3 times a year. The variety used in this area is Inpari 32. Farmers typically use NPK (Phonska) compound fertilizer, single fertilizer (TSP fertilizer), and organic fertilizer (manure) to meet the nutrient requirements of rice plants.

Table 1. Analysis of Lead (Pb) in Paddy Soil and Rice crops

Treatment	Lead content	
	Paddy soil (μg g^{-1})*	Rice crop (μg g^{-1})**
A	12.18	<0.0002
B	10.45	<0.0002
C	9.97	<0.0002
D	9.90	<0.0002
E	10.02	<0.0002
F	10.83	<0.0002
Threshold	12.75	0.3
Average ($\pm$ SD)	10.56 $\pm$0.87	-

Note: Analysis Results below the method detection limit (MDL)

*) Basic Chemistry Laboratory Analysis Results, Faculty of Mathematics and Natural Sciences, Sriwijaya University (2022)

**) Laboratory Analysis Results of PT. Global Quality Analitical (2022

3.2 Lead (Pb) in Paddy Soil and Rice Crop

3.2.1 Lead in Paddy Soil

Based on the soil analysis results presented in Table 1, the paddy fields in Marga Cinta have a Lead (Pb) content ranging from 9.90 to 12.18 μg g^{-1}, with an average of 10.56 μg g^{-1} $\pm$ 0.87. The Lead content at the study site is still below the threshold set by the Soil Research Center (2002). According to Novandi et al. (2014), Lead pollution can arise from the use of phosphate fertilizers in agricultural land as well as industrial activities. Farmers in the irrigated paddy fields of Marga Cinta generally fertilize paddy rice with chemical fertilizers and manure. One of the chemical fertilizers used is TSP fertilizer. Table 2 shows that the Pb content in TSP fertilizer is 10.83 μg g^{-1}. It can be concluded that the use of chemical fertilizers is one of the main causes of heavy metal pollution in rice fields.

3.2.2 Lead in Rice Plants

Based on the soil analysis results listed in Table 1, the Lead (Pb) content in rice crops has a value of <0.0002 μg g^{-1}, which is still below the threshold. The limit for Pb content in food crops (cereals) is 0.3 μg g^{-1} (National Standardization Agency, 2009), so the Pb content in this location is relatively low. The low value of heavy metal Pb in plants can be influenced by the content of soil chemical properties. As explained by Suastawan et al. (2016), the low value of heavy metal Pb is influenced by the low content of cation exchange capacity (CEC) and soil organic matter. Based on the analysis results, the average value of soil CEC was 9.58 mg kg^{-1}, which is relatively low, and the average value of soil C-Organic was 0.67%, which is classified as very low.

3.3 Lead (Pb) content in TSP Fertilizer

Based on the Pb analysis results presented in Table 2, the Lead (Pb) content in TSP Fertilizer is 10.83 μg g^{-1}. TSP fertilizers are used by farmers to accelerate root growth, increase plant resistance, and promote seed formation. However, the continuous use of phosphate fertilizers can be a source of lead heavy metal pollution in agricultural land. According to Khaira (2018), the use of phosphate fertilizers commonly used by farmers in Indonesia has a lead metal content ranging from 5-156 μg g^{-1}. If fertilization continues, the lead content in the soil will continue to increase.

Table 2. Heavy Metals Pb on TSP Fertilizer

Sample	Lead in TSP Fertilizer ($\pm$g g^{-1})*
Fertilizer P	10.83

*) Basic Chemistry Laboratory Analysis Results, Faculty of Mathematics and Natural Sciences, Sriwijaya University (2022)

3.4 Characteristics of Some Soil Chemical Properties

3.4.1 Soil pH

Based on the soil analysis results presented in Table 1, the soil acidity at the study site has a pH ranging from 4.98 to 5.6, with an average of 5.32 $\pm$ 0.21. These results indicate that the soil acidity criteria at the study site are in an acidic to slightly acidic condition. These results are consistent with the findings of Maintang et al. (2022) who reported that the pH of irrigated paddy fields in Barru regency, South Sulawesi, ranges from 4.5 to 5 (acidic). This result is also similar to the average pH of 4.86 (acidic) in irrigated rice fields in Gugut village, Rambipuji district, Jember, as reported by Siswanto (2019). Soil acidification can be caused by several factors, including the excessive use of inorganic fertilizers. Additionally, the low content of organic matter can also contribute to soil acidification. According to Prabowo and Subantoro (2011), organic matter affects the water absorption process in the soil. When the soil water content increases, more H^+ ions are released, leading to soil acidity. Based on surveys and interviews conducted at the research site, it was found that farmers tend not to use harvested straw as organic fertilizer due to the potential for straw accumulation becoming a nesting site for rat pests. Instead, straw is used as animal feed or burned.

3.4.2 C-Organic

Based on the soil analysis results listed in Table 1, the C-organic value at the study site ranged from 0.33% to 1.06%, with an average of 0.67 $\pm$ 0.30. These values indicate that the C-organic content at the study site is at the low to very low criteria. This result is lower than the C-organic value of 1.35% reported by Wunangkolu et al. (2019) for irrigated paddy fields in Duampanua district, Pinrang Regency, South Sulawesi. The low C-organic content of the soil can affect the low value of heavy metal Pb (Suastawan et al., 2016). The low content of C-organic can be attributed to the continuous use of chemical fertilizers without the application of organic fertilizers (compost, manure). This finding is consistent with interviews conducted with farmers, who mentioned the practice of burning straw after the harvest period. According to Kemala et al. (2017), the use of harvested straw in paddy fields can contribute to organic matter, while burning straw in paddy fields can lead to a reduction in organic matter and the loss of nutrients C, N, P, K, S, Ca, Mg, and microelements needed by plants.

Table 3. Soil pH, C-Organic, and Soil CEC in Paddy soil

Sample	pH H_2O	C-Organic (%)	CEC (cmol kg^{-1})
A	5.6SL	0.48VL	10L
B	5.3A	0.33VL	10L
C	5.25A	1.06L	10L
D	5.35A	0.70VL	10L
E	5.45A	0.45VL	7.5L
F	4.98A	0.97VL	10L
Average ($\pm$SD)	5.32 $\pm$ 0.21	0.67 $\pm$ 0.30	9.58 $\pm$ 1.02

SL(slightly acidic); A (acidic); VL (very Low); L (Low), M (Medium); Assesment Criteria for soil chemical properties based on LPT (1983)

3.4.3 Soil Cation Exchange Capacity (CEC)

Based on the soil analysis results presented in Table 1, the CEC value at the study site ranged from 7.5 cmol kg^{-1} to 10 cmol kg^{-1}, with an average of 9.58 $\pm$ 1.02. These values indicate that the soil CEC results at the study site are in the low-value range. This result is lower than the average CEC value of 59.9 cmol kg^{-1} reported by Wunangkolu et al. (2019) for irrigated paddy fields in Duampanua District, Pinrang Regency, South Sulawesi, and the CEC range of 25-40 cmol kg^{-1} reported by Syachroni (2019) for paddy fields in Palembang. The low CEC content of the soil can affect the low value of heavy metal Pb (Suastawan et al., 2016). The low content of CEC in the soil can be attributed to various factors, including the organic matter content. Based on the analysis results of C-organic content at the study site (Table 1), it is classified as low to very low, with an average of 0.67%. According to Nugroho et al. (2013), organic matter is a factor that influences the increase and decrease in CEC. Higher clay and organic matter content in the soil contribute to higher CEC content, and vice versa. Additionally, according to Maintang et al. (2022), a low CEC value is also associated with a low soil pH value.

3.5 Relationship between pH, CEC, C-Organic with Pb in Soil

The data observed in this study were analyzed using multiple regression analysis. Multiple linear regression analysis is a statistical method used to explain the influence of independent variables on dependent variables (Marcus et al., 2012). In this study, multiple linear regression analysis was conducted to determine the influence of soil chemical properties (pH, C-Organic, CEC) on the lead (Pb) content in the soil. Based on the output results obtained using SPSS, the correlation value between X1, X2, X3, and Y is 0.5647, which falls into the medium category. The coefficient of determination is -0.7025 or -70.25%, indicating that X1, X2, and X3 explain 70.25% of the variation in Y, while the remaining variation is influenced by other factors. The significance value is 0.8198, indicating that the significance value is > α = 0.05. Therefore, it can be concluded that there is no significant influence of X1, X2, and X3 on Y, where X1 = pH, X2 = C-organic, X3 = CEC, and Y = soil Pb. Based on the multiple regression analysis, the equation obtained is Y = -1.5488 + 1.6062 pH + (-0.4815) C-Organic + 0.4068 CEC (R^2 = 0.3190). The interpretation of the multiple linear regression equation is as follows: The constant (α) has a regression value of -1.5488, indicating that when the variables pH (X1), CEC (X2), and C-Organic (X3) are considered zero, there is a decrease in the heavy metal Pb (Y) by -1.5488. The pH (X1) has a regression coefficient of 1.6062, indicating that a one-unit increase in pH results in a 1.6062-unit increase in heavy metal Pb (Y). The C-Organic (X3) has a regression coefficient of -0.4815, indicating that a one-unit increase in C-Organic results in a -0.4815-unit decrease in heavy metal Pb. The CEC (X2) has a regression coefficient of 0.4068, indicating that a one-unit increase in CEC results in a 0.4068-unit increase in heavy metal Pb (Y).

4. CONCLUSIONS

The conclusions obtained from this study are the heavy metal content of Lead (Pb) in paddy fields and rice plants in Marga Cinta, Belitang Madang Raya, Ogan Komering Ulu Timur is classified as having not reached the threshold value set with a soil Pb content of 10.56 μg g^{-1} and a Pb content of rice plants of $<$0.0002 μg g^{-1} (still below the method detection limit). This shows that the rice plants at the study site did not accumulate lead the heavy metal contamination, either from soil media or from the environment so that they were safe for consumption. The relationship between chemical properties (pH, C-Organic, CEC) to Lead (Pb) in soil has a correlation value between X1, X2, X3 and Y is 0.5647 which belongs to the moderate category while the significance value $> \alpha$= 0.05 so it can be concluded that there is no significant influence between X1, X2 and X3 on Y.

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