



Research Paper

## Cadmium in Paddy Soil and Rice Crop in Indonesian Intensive Farming System

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### Abstract

Agriculture serves as a critical sector underpinning the livelihood of the Indonesian population.. Thus the implementation of this sector involves the use of fertilizers as inputs. However, A prevalent misconception among farmers is that increased fertilization invariably leads to enhanced yield. Excessive fertilization using inorganic compounds, such as phosphorous (P) can elevate levels of Cadmium (Cd), which is a potentially toxic metal for the environment and humans. Therefore, this study aimed to investigate the concentration of the heavy metal cadmium (Cd) in both soil and rice plants in Marga Cinta, Belitang Madang Raya District, East Ogan Komering Ulu Regency, South Sumatra, Indonesia. The method involved a comprehensive survey approach and spanned across 96-hectares of paddy fields, which were divided into six distinct locations. Each location comprised 16 hectares of rice fields, with five sample points drilled to a depth of 0-30 cm. The results showed that the content of Cd in paddy soil and rice plants had exceeded national food safety standards. Hence, farmers were advised to balance their use of phosphorus-rich fertilizers with organic ones, mitigating the rise in soil Cd content. This balance necessitates a reduction in the usage of other chemical fertilizers, favoring organic fertilization methods to promote phytoremediation.

### Keywords

Cadmium, Paddy Field, P Fertilizers and Rice Crop

## 1. INTRODUCTION

According to (Budianta et al., 2022), many paddy fields in Indonesia experienced a decrease in fertility in rice cultivation due to their intensive use. To address this issue and enhance soil fertility, mineral fertilization can be adopted. Inorganic fertilizers such as phosphate, nitrogen, and potassium are commonly used in rice agriculture. However, excessive application of phosphates such as SP-36 and TSP can lead to the presence of heavy metal residues such as Cd, Pb, Cr, and others in soil (Aishah et al., 2010; Smidt et al., 2011; Grant, 2011; Thomas et al., 2012; Bolan et al., 2013; Suci et al., 2022). It has been reported that Cd levels can increase from trace amounts to about 300 mg Cd kg<sup>-1</sup> of the dry product (Grant, 2011). Mineral fertilizers treatment to soil increases mobile metals such as Cd, Cu, Mn, Pb, and Zn (Czarnecki and Düring, 2015), where Cd and Pb are the highest bioavailability in paddy soil (Jalali and Hemaati, 2013). The P fertilizers contains a high concentration of heavy metals with potential toxicity (Smidt et al., 2011).

Cadmium shows the highest concentration in superphosphate, while lead, copper, and zinc are more abundant in potassium phosphate and NPK fertilizers. Phosphate minerals are found to be the major trace metal-bearing phases for cadmium, molybdenum, antimony, niobium, and palladium. Another strong correlation was found between calcium, cadmium, and sulfate (Azzi et al., 2019). According to (Sukarjo et al., 2019), cadmium has the potential to pollute soil and plants but there is limited information available on the extent of contamination in rice crop. Therefore, this study discusses the presence of cadmium in both soil and plants.

Cadmium (Cd) is a heavy metal that accumulates in soil and living organisms and can lead to severe and permanent damage. The presence in soil depends largely on the use of phosphate fertilizers (Bolan et al., 2013). Phosphorite and apatite rocks used as fertilizers contain several other minerals, including Cd. The amount of Cd incorporated depends on the type of phosphorite and apatite rocks

with low or high Cd content. The metal is present in insoluble form and is not bioavailable to plants. However, plants can increase Cd solubility by releasing root exudates that change the pH of the rhizosphere to increase the accumulation of the metal (Ye et al., 2012; Suci et al., 2022). Continuous use of phosphate fertilizers can result in the accumulation of heavy metals in soil, which can enter crop via diffusion or osmosis mechanisms. The extent of Cd contamination in soil is influenced by various factors, including the type of clay (Ye et al., 2012). Cadmium (Cd), being a non-biodegradable element, progressively amasses in both soil and water bodies. It has the potential to be absorbed by vegetation, which can ultimately have negative impacts on human health when the availability of Cd increases in soil (Ye et al., 2012). An increase in the levels of harmful metals in soil, such as cadmium (Cd), can have detrimental effects on plants. Also, elevated Cd levels can adversely impact plant chloroplast structure, leading to the degradation of the thylakoid membrane and inhibition of photosynthetic processes. Such disruptions of photosynthetic reactions can ultimately affect the growth and development of plants (Mahfudawati et al., 2016). Excessive soil Cd of more than 1-3 mg kg<sup>-1</sup> reduces root and crop yield (Tongarlak et al., 2020)).

Intensive cultivation of paddy soil results in reduced soil productivity and declining environmental quality. The excessive use of agrochemical inputs can lead to nutrient depletion in soil, ultimately causing negative impacts on the environment. Intensive rice planting with continuous fertilization causes high residues of fertilizer and increases the availability of heavy metals. Furthermore, Cd is one of the heavy metal elements with the high potential to pollute the environment at a threshold limit of 0.5 mg kg<sup>-1</sup>. Currently, information on the levels of Cd pollution through intensive agriculture system in Indonesia is difficult to obtain. Therefore, it is crucial to study to determine the status of Cd. The results are instrumental in devising ways to remediate Cd levels, thereby minimizing its adverse impacts on human and animal health.

## 2. EXPERIMENTAL SECTION

This field study was conducted at the Rice Center of Intensification Farming system located in Belitang Madang Raya District, Ogan Komering Ulu Timur Regency, South Sumatra, Indonesia. Meanwhile, the analysis of Cd was carried out at the Basic Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, and analysis of some soil chemical properties at the Laboratory of Chemistry, Biology, and Soil Fertility, Department of Soil Science, Faculty of Agriculture, Sriwijaya University. This study was conducted from January 2022 to October 2022.

The collection of soil samples utilized a comprehensive survey approach, which involved using a working scale map of 1:9000 to cover an area of approximately 96

hectares. The determination of sampling points was conducted through the use of Randomized Sampling. At each location, a total of five sampling points were selected, and each composite soil sample was derived from six soil augerings taken at a depth of 0-30 cm from soil surface. These areas have been used for rice cultivation since 1969. For rice planting, farmers applied fertiliser consisting of Urea (N) and SP-36 (P) at the rate of 277.77 kg ha<sup>-1</sup> without application of organic matter. Rice production in 2021 was 6.22 tons ha<sup>-1</sup> and the location of soil sampling can be seen in Fig.1.

Variables observed were Cd in soil and shoot of rice extracted by wet extraction with a mixture of HNO<sub>3</sub>: HClO<sub>4</sub> (3:1, v:v) and measured using adsorption spectrophotometer system atom, CEC using NH<sub>4</sub>Oac extraction, N total (Kejdahl), C-organic (Walkey and Black), P available using Bray-I, K exchangeability with NH<sub>4</sub>OaC extraction and soil pH (electrometry 1:1).

### 2.1 Data Analysis

The data observed from laboratory analysis were analyzed using statistical method with multiple regression to know the relationship between Cd and pH, CEC, and C organic.

## 3. RESULTS AND DISCUSSION

### 3.1 Characteristics of Some Soil Chemical Properties of Paddy Soil

#### 3.1.1 Soil pH

Paddy soil exhibits unique morphological and pedogenic characteristics that set it apart from dry land soil, owing to the impact of inundation that occurs for several months every year (Kurniati et al., 2016). Furthermore, the flooding condition influences some soil chemical characteristics. Puddling and drying in paddy soil can lead to the formation of concretions of rusty Fe and Mn. Soil analysis presented in Table 1 showed that the pH of intensive paddy soil ranged from 4.98 – 5.60 with an average of 5.32 ± 0.21 classified as acidic to slightly acidic, and 4.63-4.90 was found in the conventional farming system in Bogor (Sukristiyonubowo et al., 2015). Aishah et al. (2010) reported that soil pH of paddy soil in Selangor Malaysia ranged from 4.0-4.5 (moderately acidic), and 4.6 in Brahmaputra Valley of Assam (Phillips et al., 2020). A neutral pH with a value of 6.1-6.6 was obtained in Sejong Korea (Choi et al., 2018). The low pH found in this area could be due to mineral fertilization (Czarnecki and Düring, 2015; Sukristiyonubowo et al., 2015). Meanwhile, the low pH can be caused by the high annual rainfall ranging from 1,936 – 3,493 mm year<sup>-1</sup>. This is consistent with Syofiani and Oktabriana (2020), where H<sup>+</sup> ions increase in soil causing a decrease in pH and resulting in acidic conditions.

#### 3.1.2 C Organic

Table 1 showed that C organic in paddy soil ranged from 0.33 - 1.06% with an average of 0.67% ± 0.30 classified as

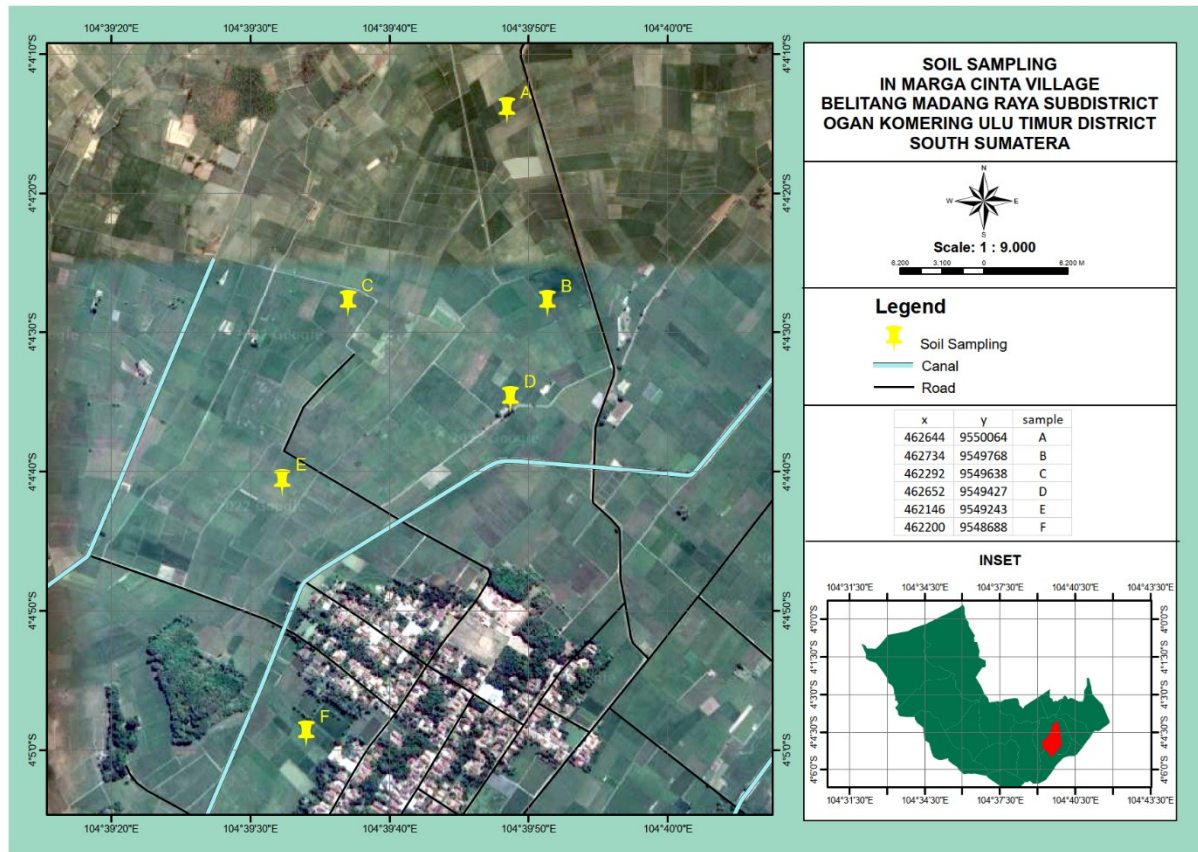


Figure 1. Soil Sampling Map

very low. C organic with a value of 0.15% - 0.29% was found in North Sulawesi (Karamoy, 2022). The study determined that the low concentration can be attributed to the absence of organic matter application in the farmers' agricultural practices. However, the organic C content can potentially be sourced from grasses and other vegetation present in farming system (Karamoy, 2022). The higher C organic paddy fields were found in Banyumas, Central Java, which was more than 1% (Firdaus et al., 2022) and found less than 1% in Serdang Bedagai, North Sumatra (Ompusunggu et al., 2015). The study showed that the Brahmaputra Valley exhibited a higher concentration of organic carbon in the arable layer, with a value of 7.30% (Phillips et al., 2020).

### 3.1.3 Cation Exchange Capacity (CEC)

Based on Table 1, the CEC of rice fields ranged from 7.5 – 10 cmol(+)kg<sup>-1</sup> with an average of 9.58 ± 1.02 Cmol(+)kg<sup>-1</sup> which was relatively low. The lower CEC value was found in Tebing Kaning, Bengkulu, ranging from 6.47 – 8.42 cmol kg<sup>-1</sup> (Wahyuni et al., 2020). Meanwhile, a high CEC value was found in Boyolali, Central Java, which was 75.41 cmol(+) kg<sup>-1</sup> (Agustian and Simanjuntak, 2018). The high and low CEC depends on soil texture, type of clay minerals, and organic matter. The secondary clay mineral content of 1:1 (kaolinite) and 2:1 (montmorillonite) had low and high

amounts of CEC (Suryani, 2014). Soil had low C organic carbon with a value of 0.67% and the clay content was dominated by kaolinite representing low CEC.

### 3.1.4 Base Saturation (BS)

Table 1 showed that base saturation ranged from 20.38 – 21.78% with an average of 21.05% ± 0.49 and was relatively low in line with soil pH. Low pH represented the low base cations, but base saturation in paddy soil was higher compared to dry soil (Kurniati et al., 2016) due to low leaching basic cations in paddy soil. Furthermore, low base saturation results were also found in Deli Serdang Regency, North Sumatra, ranging from 19.39 – 28.94% (Hutapea et al., 2018). The high value was found in Boyolali, Central Java with the highest value up to 78.58% (Agustian and Simanjuntak, 2018).

Low base saturation values were due to high soil acidification. It is closely correlated with soil pH, as a higher level is typically associated with the base saturation level. Conversely, soil pH level is proportionally associated with the base saturation level (Suarjana et al., 2015). The low pH in this study ranged from 4.98 – 5.60 and it becomes low base saturation.

**Table 1.** Some soil chemical properties of paddy soil

Sample	Observation Parameters						
	pH H <sub>2</sub> O	C Organic (%)	CEC (cmol(+) kg <sup>-1</sup> )	BS (%)	N total (%)	P available (mg kg <sup>-1</sup> )	K exch (cmol(+) kg <sup>-1</sup> )
A	5.6 <sup>Sa</sup>	0.48 <sup>VL</sup>	10 <sup>L</sup>	21.78 <sup>L</sup>	0.2 <sup>M</sup>	1.25 <sup>VL</sup>	0.19 <sup>L</sup>
B	5.3 <sup>a</sup>	0.33 <sup>VL</sup>	10 <sup>L</sup>	20.87 <sup>L</sup>	0.05 <sup>VL</sup>	0.31 <sup>VL</sup>	0.19 <sup>L</sup>
C	5.25 <sup>a</sup>	1.06 <sup>L</sup>	10 <sup>L</sup>	20.38 <sup>L</sup>	0.06 <sup>VL</sup>	4.84 <sup>VL</sup>	0.19 <sup>L</sup>
D	5.35 <sup>a</sup>	0.70 <sup>VL</sup>	10 <sup>L</sup>	20.78 <sup>L</sup>	0.08 <sup>L</sup>	3.12 <sup>VL</sup>	0.19 <sup>L</sup>
E	5.45 <sup>a</sup>	0.45 <sup>VL</sup>	7.5 <sup>L</sup>	21.09 <sup>L</sup>	0.05 <sup>VL</sup>	0.78 <sup>VL</sup>	0.26 <sup>L</sup>
F	4.98 <sup>a</sup>	0.97 <sup>VL</sup>	10 <sup>L</sup>	21.38 <sup>L</sup>	0.15 <sup>VL</sup>	0.94 <sup>VL</sup>	0.19 <sup>L</sup>
Mean (± std. deviation)	5.32 ± 0.21	0.67 ± 0.30	9.58 ± 1.02	21.05 ± 0.49	0.10 ± 0.07	1.87 ± 1.75	0.20 ± 0.03

Note: Sa (slightly acidic = 5.5-6.5); an (acidic = 4.5-5.5) ; VL (very low = < 1% for C organic and N total, < 10 mg kg<sup>-1</sup> for available P); L (low = 5-16 cmol(+)kg<sup>-1</sup> for CEC, 20-35% for BS), M (medium = 0.21-0.50% for N total)

### 3.1.5 N Total

From Table 1, the N total at the study site ranged from 0.05 - 0.21% with an average of 0.10% ± 0.07 which was classified as very low to moderate. An almost similar result was found in paddy soil of Bolaang Mongondow Noth Sulawesi with a value of 0.16-0.23% (Karamoy, 2022). In addition, the N present in soil was highly susceptible to loss, as it could be easily washed away by water or evaporated and absorbed by plants. This process led to an overall reduction in the average amount of nitrogen found within soil (Benauli, 2021). Agustina et al. (2020) reported low levels of N in irrigated paddy fields ranging from 0.08% to 0.18%. Furthermore, the low content could be attributed to the land use system utilized, which involved continuous flooding throughout the planting season, making it difficult for N-fixing bacteria to thrive.

The interview results indicated that farmers applied fertilizers by spreading them, and did not engage in any immersion treatment. According to Sakti et al. (2011), this method was found to be inefficient, as fertilizers applied did not penetrate soil reduction layer where NH<sub>4</sub><sup>+</sup> could dissolve in the puddle through oxidation. Due to the hygroscopic nature of urea, it transformed into NH<sub>3</sub><sup>+</sup>, which subsequently evaporated into the air. To address this issue, it is recommended to immerse fertilizers in soil at a depth of 15 to 20 cm (Sakti et al., 2011).

### 3.1.6 P Availability

Based on the results of laboratory analysis in Table 1, soil P-available ranged from 0.31 – 4.84 mg kg<sup>-1</sup> with an average of 1.87 mg kg<sup>-1</sup> ± 1.75 which was classified as very low. Meanwhile, low P in paddy soil cultivated in the long term was due to P adsorption phenomena in paddy soil (Hua et al., 2023). Soil pH was closely related to the availability of P in soil. According to Firnia (2018), the maximum P availability was found in the range of 5.5 – 7.0 mg kg<sup>-1</sup>. Available P decreased when soil pH was lower than 5.5 or

higher than 7. The low availability of P was also attributed to the practice of farmers discarding hay after harvest. Staw, which is a source of organic matter and P was inappropriately applied. This finding was consistent with Sari et al. (2022), where organic acids formed chelation bonds with Al and Fe ions, leading to a decrease in the solubility of these ions. In addition, organic acids resulted from the decomposition of matter to release absorbed P.

### 3.1.7 K Exchangeable

The K exchangeability in Table 1 illustrates that the K exchangeability ranged from 0.19 – 0.26 cmol(+)kg<sup>-1</sup> with a relatively low average of 0.20 cmol(+)kg<sup>-1</sup> ± 0.03. The low value was caused by soil's potassium input capacity, insufficient application of potash fertilizers causing low levels of K in irrigation water and low efficiency of absorption (Agustina et al., 2020). Meanwhile, very high potassium was reported in Manggis, Bali (Suarjana et al., 2015).

The low K exchangeable was also attributed to the low CEC, as it caused K to leach out of soil more easily. This finding was consistent with Suarjana et al. (2015), where a higher CEC influenced soil solution to slow the release of K and reduce the leaching rate of K. The transportation of harvested hay from the field without any return also contributed to the low soil K nutrient content, as straw contains high amounts of K. This finding was supported by a previous study, where the removal of plant residues, including straw, reduced the amount of K available in soil. (Karamoy, 2022). In fact the amount of K transported in grain was more than 20% absorbed and about 80% of K is in hay (Asmin and Karimuna, 2014).

## 3.2 Characterization of Phosphate fertilizers Cadmium (Cd) in Phosphate Fertilizers

Fertilizers played a crucial role in ensuring sustainable food production, particularly in developing countries with low fertility paddy soil. Due to the prevalence of infertile soil,

rice yields in these regions were low. As a result, fertilizers such as Urea, KCl, and TSP/SP-36 were commonly applied to enhance rice yield. The application of P fertilizers resulted in heavy metal contamination of soil. Table 2 highlighted that TSP and SP-36 fertilizers contains Cd at a concentration of  $4.90 \text{ mg kg}^{-1}$  and  $10.43 \text{ mg kg}^{-1}$  Cd. Higher content of Cd in certified P fertilizers was found in Brazil with a value of  $20.3 + 0.9 \text{ mg kg}^{-1}$  (Guilherme et al., 2019) and  $16 \text{ mg kg}^{-1}$  (Smidt et al., 2011). Furthermore, small amounts of P fertilizers ranged from 1-5% absorbed by crops and became toxic. Plants that were often fertilized with phosphates (SP-36 and NPK) over a long time triggered the accumulation of Cd in soil (Tresnawati et al., 2014).

**Table 2.** The Cd Content in P Fertilizers

Fertilizers	Cadmium ( $\text{mg kg}^{-1}$ )
TSP	4.90
SP-36	10.43

## 4. CADMIUM (Cd) PADDY SOIL AND SHOOT OF RICE

### 4.1 Cadmium in Paddy Soil

Table 3 presented the results that analyzed the Cd heavy metal content in soil samples collected from paddy fields and used for rice cultivation since 1969. The data indicated that the Cd content in paddy soil ranged from 0.47 to  $1.47 \text{ mg kg}^{-1}$ , with an average of  $0.86 \pm 0.34 \text{ mg kg}^{-1}$ . The study showed that the location surpassed the threshold of  $0.50 \text{ mg kg}^{-1}$  based on the Ministry of State for Population and Environmental of Indonesia, and Dalhousie, University Canada (1992) and the Regulation of the Minister of Health of the Republic of Indonesia number 492/MENKES/PER/IV/2010. This confirmed that long-term rice cultivation produced heavy metal residues (Czarnecki and Düring, 2015).

Inorganic fertilizers, including NPK and P, have been identified as one of the causes of heavy metal contamination. For instance, NPK fertilizers contains 15% phosphate, which can indirectly lead to the presence of Cd in soil. Herero and Martin (1993), as cited in Syachroni (2017), reported that the heavy metal was easily absorbed by soil and was typically present in phosphate or P fertilizers. This was in line with the findings of S. et al. (1995), where the content of heavy metal Cd in paddy fields in the North Coast area of West Java was high, exceeding  $1 \text{ mg kg}^{-1}$ . In addition, this was due to the continuous use of TSP fertilizers, which tended to accumulate heavy metals. Syachroni (2017) found that the low content of Cd in paddy fields in Palembang City was attributed to the farmers' use of manure instead of phosphate fertilizers. Manure contained

**Table 3.** Cadmium (Cd) in Paddy Fields and Rice Crop

Sample	Cadmium Contents	
	Paddy Field ( $\text{mg kg}^{-1}$ )	Shoot ( $\text{mg kg}^{-1}$ )
A	0.70	0.58
B	0.85	0.48
C	0.92	0.58
D	0.73	0.62
E	0.47	0.65
F	1.47	0.66
Threshold	0.50	0.10
Average ( $\pm$ std. deviation)	$0.86 \pm 0.34$	$0.60 \pm 0.07$

the necessary nutrients for plants, improved soil fertility, and reduced toxic heavy metals in soil and plants (Simanungkalit et al., 2006).

### 4.2 Cadmium in the Shoot of Rice

Cadmium heavy metal content in rice plant samples from paddy fields located in Marga Cinta Village, Belitang Madang Raya District, Ogan Komering Ulu Timur Sumatra Selatan, was analyzed using the study methodology.

Table 3. shows the analysis of the heavy metal content of Cd in rice plants ranged from 0.48-0.66  $\text{mg kg}^{-1}$ . The analysis indicated that in Marga Cinta village, Belitang Madang Raya District, Ogan Komering Ulu Timur, the rice crop in the region exceeded the threshold, with an average value of  $0.60 \text{ mg kg}^{-1} \pm 0.07$ . According to the Indonesian National Standardization Agency (2009), the threshold for cadmium heavy metal contamination is  $0.10 \text{ mg kg}^{-1}$ .

One of the factors contributing to high levels of heavy metals in Marga Cinta village, Belitang Madang Raya District, Ogan Komering Ulu Timur, is the continuous use of chemical fertilizers. Table 4 shows that one of the chemical fertilizers used is TSP, which contains a high level of heavy metal Cd at  $4.90 \text{ mg kg}^{-1}$ . In addition to fertilizer usage, several other factors contribute to the pollution of irrigation water in the rice field area of Marga Cinta village. These included an industrial zone and densely populated residential areas where waste was often disposed of in the nearby rivers. Consequently, the irrigation canals that flowed through these areas became heavily contaminated with various heavy metals, particularly Cadmium (Cd). Rice plants have the potential to be exposed to these heavy metals, which pose a significant risk to both human health and the environment.

## 5. RELATIONSHIP BETWEEN pH, CEC, C-ORGANIC, AND SOIL Cd

To understand the relationship between Cd and various chemical properties of soil, multiple linear regression analysis was employed. The results of the data analysis using SPSS indicated a strong correlation of 0.9357 between soil chemical properties and Cd. Meanwhile, the value of the coefficient of determination was 0.6889 or 68.89% and the remaining 31.11% was influenced by other factors. The equation obtained was  $Y = 6.49578 + (-1.25344) \text{pH} + 0.10602 \text{CEC} + 0.02284 \text{C-Organic}$  ( $R^2 0.8755$ ). Meanwhile, the constant ( $\alpha$ ) had a value of 6.49578 meaning that when the variable pH, CEC, and C-Organic were considered zero, there was an increase in heavy metal Cd (Y) of 6.49578. There was a decrease in Cd by -1.25344 when pH had a value of -1.25344. The CEC also had a regression coefficient of 0.10602, meaning that the variable is directly proportional to heavy metal Cd (Y) by 0.10602. The C-Organic has a regression coefficient of 0.02284 meaning that the variable is directly related to Cd by 0.02284.

## 6. CONCLUSION

In conclusion, the level of Cd in the soil has surpassed the threshold, and the content present in rice plants also exceeds the threshold, with a value greater than 0.10 mg  $\text{kg}^{-1}$ . Furthermore, the paddy fields are classified as acidic with an average Soil pH value of 5.32. Soil CEC and C-Organic are also classified as low and very low with values of 9.58  $\text{cmol kg}^{-1}$  and 0.67% respectively. The relationship between soil chemical properties (pH, C-Organic, CEC) and Cd has a strong correlation with the value of 0.9357.

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