Journal of Experimental Agriculture International

44(3): 29-37, 2022; Article no.JEAI.85253
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

The Applications of Compost and Ca $(OH)_2$ to Overcome Cadmium (Cd) Contamination in Inceptisols

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2022/v44i330806

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/85253

Original Research Article

Received 20 January 2022
Accepted 28 March 2022
Published 01 April 2022

ABSTRACT

Heavy metals contribute to soil contamination and can decrease soil productivity. Compost and $Ca(OH)_2$ can restore heavy metal contaminated soil. The purpose of this study was to examine the effectiveness of compost and $Ca(OH)_2$ in reducing cadmium (Cd) contamination in Inceptisols. The study was carried out between February and April of 2021. The study used a completely randomized design (CRD) with treatments of control (0), $Ca(OH)_2$ at a dose of 1 ton/ha, 2 tons/ha, 3 tons/ha, and compost at a dose of 10 tons/ha, 20 tons/ha and 30 tons/ha. Each treatment was repeated three times. The results showed that the treatment had a significant effect on soil pH, organic C, N-total, and soluble Cd in the soil. The highest dose of compost and $Ca(OH)_2$ is equally effective to lower the concentration of Cd in contaminated Inceptisols. This finding is significant in the restoration of Cd contaminated soils.

Keywords: $Ca(OH)_2$; cadmium; compost.

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1. INTRODUCTION

Soil and environmental pollution can be associated with the accumulation of heavy metals in the soil [1]. Heavy metal pollutants are found in nature, such as from rock and rainwater and in the air nearby industrial activities and emissions from motor vehicle [2]. It was reported that cadmium (Cd) generated by metal industrial activity contaminated the air, soil and plants [3]. Phosphate fertilizers, sewage sludge, and a mixture of zinc (0.2% Cd as an impurity material) are also sources of Cd in the soil. The textile industry is also a source of Cd pollutants generated by the drying process [4].

The primary source of Cd pollution of agricultural soils is phosphate fertilizers. Phosphate fertilizer application on agricultural land leaves Cd residue in the soil [5]. The natural content of phosphate fertilizer raw materials from rock phosphate is the source of Cd in the fertilizer. Rock phosphate also contains other heavy metal as by-products such as Pb, Cr, Co, Hg, Ni, and As. Study by [6] noted that Cd was a harmful by-products of phosphate fertilizer. The environmental impact of Cd pollution is related to its reactivity, solubility, and mobility [7].

Among others, Cd uptake by plants is influenced by the content of Cd and Zn in the soil, soil pH, and plant species. The high Zn content can minimize Cd absorption. Cadmium is hazardous to health due to the element's severe acute toxic [8]. Cadmium (Cd) is also a heavy metal pollutant that causes chlorosis, necrosis, wilting, and impaired photosynthesis and transpiration, inhibiting plant growth. Cadmium contamination in Inceptisols originates from various sources, and the presence of organic matter can reduce the solubility of heavy metals in soil.

Compost is known as mature organic material that has undergone a decomposition process by bacteria and other microbes to produce humic substance. This substance can reduce high concentration of heavy metals. The process of heavy metal removal by humic substance is by the formation of complex compounds and chelates, causing lower release of the metal to the environment. In situ stabilization of heavy metals can be carried out by the application soil amendments such as lime and compost to reduce the bioavailability of metals and minimize their uptake by plants [9].

Limestones are the most abundant alkaline earth element in the planet's crust. The first chemical reaction used by humankind was burning limestone to generate lime [10]. Precipitation of Cd can be carried out by adding carbonate, phosphate, sulfide, or hydroxide compounds to form a precipitate of cadmium carbonate, cadmium phosphate, cadmium sulfide, or cadmium hydroxide, which is insoluble or has minimal solubility [11]. As hydroxide substance, calcium hydroxide ($CaOH_2$) can reduce the solubility of Cd in soil.

Calcium hydroxide is a colorless crystal produced by the reaction of calcium oxide (CaO) with water and by mixing a solution of calcium chloride ($CaCl_2$) with a solution of sodium hydroxide (NaOH). Calcium hydroxide is a strong base because it is completely ionized; however, this base has a lower solubility than NaOH [10]. The solution interacts aggressively with various acids, which react with several metals and water. The purpose of this study was to determine the effectiveness of the application of compost and $Ca(OH)_2$ in reducing cadmium (Cd) contamination in Inceptisols.

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Design

The research was conducted from February 2021-April 2021 at the Soil Science Laboratory, Faculty of Agriculture, Bengkulu University, Indonesia. The soil sample used in this study was collected from Air Nipis District, South Bengkulu Regency, Indonesia at 4^o23’47.0” S, 103^o04’05.6” E. Soil were compositely sampled from 5 sites at depths of 0 to 20 cm. The soil sample was then air-dried and sieved with a 2 mm screen. A portion of sample was sieved with 0.5 mm screen and analyzed for organic-C, total-N, exchangeable Ca, soluble Cd, texture, Cation Exchange Capacity (CEC), and soil pH as initial characteristics of Inceptisols. The initial characteristic of soil sample was 53.34% sand, 10.52% clay, 36.13 silt, 2.1% organic-C, 0.17% total-N, 0.13 cmol/kg exchangeable Ca, 13.44 cmol/kg CEC, 0.1 ppm soluble Cd, 0.26 dS/m EC, and pH of 4.36. Moreover, the compost has 26.3% C, 1.01% N with C/N ratio of 26.0 and pH of 6.7. A completely randomized design (CRD) was assigned in the study. The treatments included a control (P0), $Ca(OH)_2$ at doses of 1 ton/ha (A1), 2 tons/ha (A2), and 3 tons/ha (A3), and leaf compost at doses of 10 tons/ha (B1), 20 tons/ha (B2), and 30 tons/ha (B3). Each treatment was repeated three times, totaling of 21 experimental units.

2.2 Laboratorium Experiment

A total of 300 g of soil sample was put into an incubation jar and added with 100 ppm Cd using $Cd(NO_3)$ solution. The sample then mixed with $Ca(OH)_2$ or compost according to the treatment dose. The soil in the incubation jar is then added with distilled water until achieving 40% of the field capacity. Each sample was labeled and placed randomly in the laboratory at room temperature and incubated for two months. Soil moisture was checked daily during the incubation and distilled water was added to maintain it at 40 % field capacity. During the incubation, soil temperature and pH were measured every week. After the incubation period of 2 months, the soil was air-dried and sieved using a 0.5 mm sieve for analysis. The sample was analyzed for Electrical Conductivity (EC), organic-C, total-N, and DTPA extracted (soluble) Cd. Soil pH and EC was analyzed using pH meter at ratio of soil and distilled of 1:1 [12]. Soil temperature was measured using soil thermometer at the depth of 5-10 cm. Soluble Ca was assessed using DTPA extraction and detected with AAS (Atomic Absorption Spectrometer) [12]. Soil organic carbon was analyzed using Walky and Black Method [12]. Likewise, total soil N was measured using the Kjeldahl method.

2.3 Data Analysis

The data were statistically analyzed using Analysis of Variance (ANOVA) at 95% confidence level. The variables that had a significant effect were further tested with the DMRT test at the 5% level

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance (ANOVA)

The result of data analysis is presented in Table 1. The results showed that the treatment ($Ca(OH)_2$ and compost) had no significant effect on electrical conductivity and soil temperature. However, both treatments significantly affected soil pH, organic-C, total-N, and soluble Cd.

3.2 Soil pH

The initial soil pH measurement showed a low pH of 4.3, classified as acidic. Acidic soil pH will reduce the availability of nutrients for plants, especially macro elements, and increase microelements that can be toxic to plants. Changes in soil pH during the incubation period are presented in Table 2.

The presence of heavy metals in the soil lowers plant productivity and nutrient availability. Soil pH decreased after the treatment of cadmium as indicated in control treatment. This result is attributed to the Cd hydrolysis, producing proton (H^+). The results of this study are in line with that reported by [13] where the decrease in soil pH is due to the hydrolysis process of heavy metals, increasing H^+ in the system. Table 2 also shows that the pH of the soil changed during incubation. In general, application of both $Ca(OH)_2$ and compost increases the pH.

Organic acids produced by the decomposition of organic matter can chelate heavy metals while lime reaction leads to an increase in OH^-. Compost is an ameliorant that, through chelating formation, can reduce the availability of heavy metals in the soil. Compost decomposes into humus, which contains organic acids (humic acid, humin, and fulvic acid). Organic acids have a functional group – COOH forming complexes/chelates with metal metals, and COOH can be deprotonated, which decreases the formation of H^+ and increases the formation of OH^-. [14] concluded that lower soil pH resulted from Cd binding by humic substance from the decomposition of the organic material, which inhibits hydrolysis and hydrogen production.

Table 1. Summary of Analysis of Variance (ANOVA)

Variables	F-calc.	F-table 5%	CV (%)
EC	2.59 ns	2.85	9.22
Soil pH (8 WAT)	3.10*	2.85	3.17
Soil temperature	0.11 ns	2.85	3.45
Soluble Cd	3.37 *	2.85	7.22
Organic-C	4.69*	2.85	8.56
Total-N	7.83*	2.85	13.68

Table 2. Changes in soil pH during incubation

Treatments	Soil pH (week after treatment)							
	1	2	3	4	5	6	7	8
A1	5.11	5.14	5.31	5.66	5.40	5.37	5.20	5.10
A2	5.54	5.80	5.54	5.92	5.66	5.64	5.30	5.18
A3	6.16	6.33	5.95	6.24	5.88	5.54	5.50	5.46
B1	4.88	4.65	5.22	5.50	5.16	5.21	5.37	5.06
B2	4.96	4.93	5.36	5.57	5.24	5.29	5.45	5.20
B3	4.93	4.95	5.45	5.63	5.26	5.30	5.27	5.25
P0	4.22	4.32	4.88	5.51	5.17	5.09	5.20	4.63

Note: A1= $Ca(OH)_2$ 1 ton/ha, A2= $Ca(OH)_2$ 2 ton/ha, A3= $Ca(OH)_2$ 3 ton/ha, B1= compost 10 ton/ha, B2= compost 20 ton/ha, B3= compost 30 ton/ha, P0= control

Another study showed that the addition of organic matter increased soil pH [15]. Lime application has also been shown to raise soil pH. $Ca(OH)_2$ in the soil is ionized to form Ca^{2+} and $2OH^-$. H^+ ions present in the soil will react with OH^- ions so that the soil pH will increase. Metals can settle and get deactivated when soil pH rises.

Fig. 1 shows that application of both compost and $Ca(OH)_2$ increases soil pH as compared to control (without treatment). Treatment with $Ca(OH)_2$ at a dose of 3 tons/ha (A3) increased soil pH by 0.53 units (4.93 to 5.46) and the maximum dose of compost (30 tons/ha (B3) increased soil pH by 0.32 units as compared to no treatment. The treatment of the highest dose of $Ca(OH)_2$ (A3) was effective in increasing soil pH, followed by the highest dose of compost (B3). The application of $Ca(OH)_2$ directly affects increasing the pH. However, the compost has a slower effect on increasing the pH due to the decomposition process of the compost. According to [16], the addition of $Ca(OH)_2$ can accelerate the precipitation of metals and act as a coprecipitate.

3.3 Electrical Conductivity

Electrical conductivity (EC) refers to the soil capability to conduct electric current and is a measurement of ion content in the solution. Soil EC influences plant growth as EC affects soil salinity. According to [17] EC affects salinity, pH, nutrients and is determine soil fertility. High salt content in soil will decrease the availability of cations such as Ca^{2+}, Mg^{2+}, and K^+. However, high salinity minimizes the amount of heavy metals in the soil. High heavy metal content in soil inhibits plant growth and nutrient absorption [18].

Soil salinity affects the heavy metal content in the soil; increasing soil salinity may reduce heavy metal toxicity. Research by [19] indicated that dissolved Cd cations would interact with ions present in the soil to form inorganic or organic complexes, thereby reducing the presence of free Cd ions.

The result of this study showed that the treatment did not influence EC. Electrical conductivity of soil ranged from 0.28 dS/m–0.22 dS/m. Highest dose of $Ca(OH)_2$ (3 ton/ha) tended to have the greatest EC, followed by compost at the dose of 30 tons/ha, whereas the lowest EC appeared in control (0.22 dS/m). According to [20], decreasing salinity will increase the toxicity of heavy metals. Still, the treatment would balance the availability of K, Ca, Mg, N, and P in the soil so that it was expected to improve the availability of soil nutrients.

3.4 Soil Temperature

Soil temperature can influence plant growth, humidity, microbial activity, and nutrient availability. The temperature was measured weekly with a soil thermometer during the study. Fig. 3 shows soil temperature changes during incubation.

Statistical analysis shows that during the incubation, the treatment has no significant effect on soil temperature. Fig. 3 shows the changes in soil temperature during the incubation. Average soil temperature ranged from 25°C to 30.7°C. At the first 4 weeks, the soil temperature was around 26-27^{o}C and slightly increased at week 6 and lowering back afterward. The highest dose of compost (30 tons/ha) tended to have highest soil temperature. This might be associated with higher microbial activity which uses C as source of their energy. This result is in line with that found by [21] where higher the soil temperature led to faster the decomposition process of soil organic matter. This finding shows that soil temperature is a non-significant factor during the chemical process in the tropical environment.

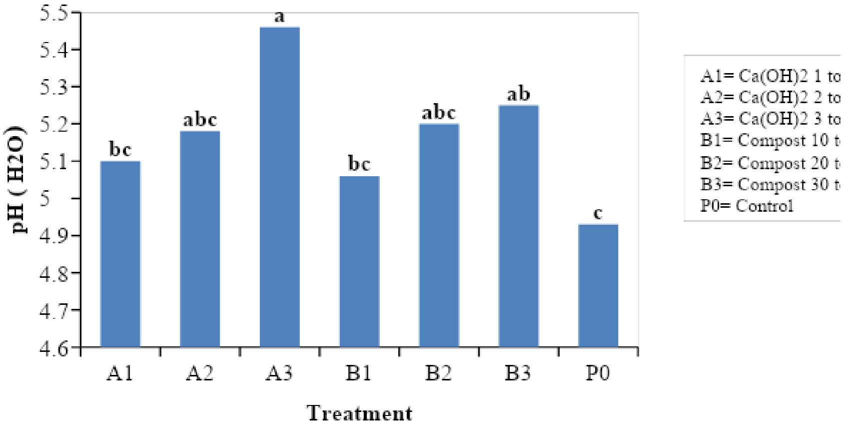

Fig. 1. Effect of compost and $Ca(OH)_2$ on soil pH at week 8

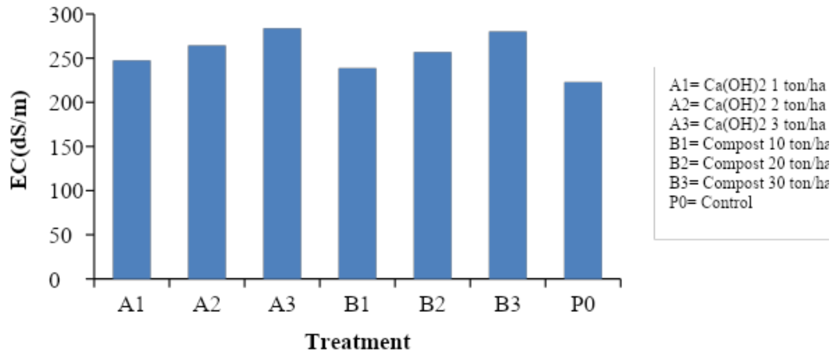

Fig. 2. Soil electrical conductivity during incubation

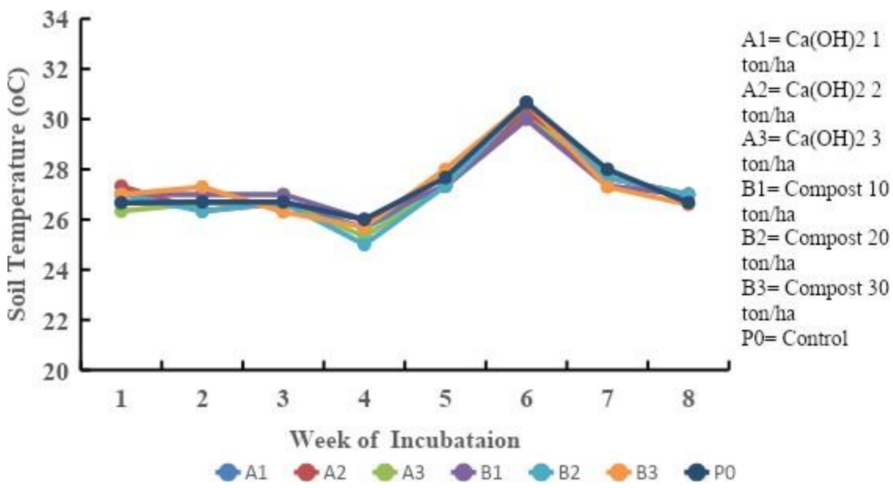

Fig. 3. Temperature changes during incubation

3.5 Organic Matter

Compost increases organic matter as indicated by the content of soil organic carbon in soil. Fig. 4 shows the C-organic content in soil at the end of the incubation.

Fig. 4 shows that the compost at a rate of 30 tons/ha (B3) had the highest organic C content. This result is related to the addition of carbon from compost as discussed previously. According to [22], the application of compost leads to the release of C, which is used as an energy source, and the proliferation of soil microbes, resulting in an increase in organic C in the soil. Other study by [23] also concluded that the addition of organic matter could activate the decomposition of soil organic matter, increasing the organic matter content in the soil and providing plant nutrients. The highest dose of compost increased 3.62% organic-C in comparison to control, while $Ca(OH)_2$ increased organic-C by 3.23%.

The application of $Ca(OH)_2$ also enhanced the soil-organic-C, although not as much as the compost. The addition of lime plays a role in several processes in the soil, such as the production of N_2O in the soil, increasing C-organic and total-N related to the activity of soil microorganisms [24]. The increase in soil organic-C from compost is greater than that of the lime, due to the direct effect of compost addition rather than lime. The results of this study are in line with [25], the application of compost increases the C-organic content in the soil. Compost also releases humic substance which exhibits cation and anion exchanges and forms organic metal complex [26].

Nitrogen in the soil has an essential role for microorganism activity. Microorganisms for their growth and development require nitrogen. Fig. 5 shows the influence of $Ca(OH)_2$ and compost on total-N-of the soil.

Fig. 5 shows that 30 tons/ha (B3) compost application resulted in the highest total N, 0.35 %. According to [27], the increase in total N was achieved through the addition and mineralization of organic matter. Compost application can accelerate the breakdown of organic materials, increasing the amount of nutrients in the soil. According to [28], increasing soil nutrients will optimize the proliferation of microorganisms in the soil. Organic matter increases soil total-N through the mineralization process [29]. Compost application can increase soil N and plant growth [30]. According to the findings of [31], the addition of organic matter could increase the soil total-N, but the increase was not remarkable. Our study revealed that higher compost dose resulted in the higher total-N in the soil. This result is associated to the higher amount of N release to the soil from compost, as previously mentioned that the compost contained 1.01% N. In addition, lime application can accelerate the N mineralization process, increasing N_2O. Lime applied to acid soils raises the content of NH_4 and NO_3, enhancing nitrification and denitrification processes. The lime application can raise the pH of the soil. As a result, lime regulates soil processes such as organic matter mineralization, nitrification, and denitrification.

3.6 Cadmium (Cd)

Addition of both $Ca(OH)_2$ and compost reduced the soluble Cd in soil and the accumulation of Cd in the soil is dependent on soil acidity. This study showed that $Ca(OH)_2$ and compost significantly lower soluble Cd the soil (Fig. 6).

$Ca(OH)_2$ decreased soluble Cd by 13.19% as compared to control (Fig. 6). The decline might be associated with an increase in pH and Cd precipitation. Higher dose of $Ca(OH)_2$ reduced higher soluble Cd. Likewise, compost also lowered soluble Cd by 13.48 % as compared to control. The decrease in soluble Cd was due to the organic acid content in the decomposed compost, resulting in the chelation of metal ions. The highest compost and $Ca(OH)_2$ doses were equally effective in decreasing Cd in the soil. Fig. 6 shows that among 7 (seven) treatments, the most effective Cd reduction was the $Ca(OH)_2$ at a dose of 3 tons/ha, reducing 7.44 ppm and compost 30 tons/ha, lowering7.6 ppm as compared to control.

Compost increases organic matter content, releasing humic acid and fulvic acid during the decomposition process. These organic acids will interact with Cd to form chelation/complex bonds that influence metal reactivity and toxicity. According to [32], using organic matter as a source of organic acids can overcome heavy metal solubility in the soil and chelate heavy metals. Metal ion complexation influences metal pollutant retention and mobility in soil. Metal ions are coordinated by the organic functional group (-COOH) to form chelation and bind metal ions from retention complexing cations [33].

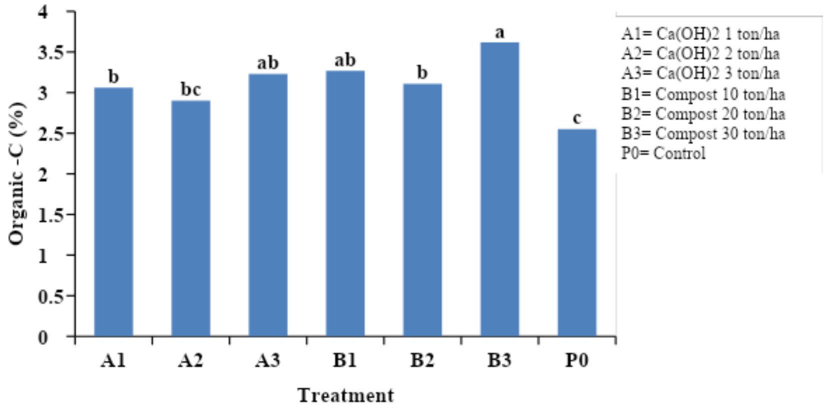

Fig. 4. Effect of $Ca(OH)_2$ and compost on soil organic C

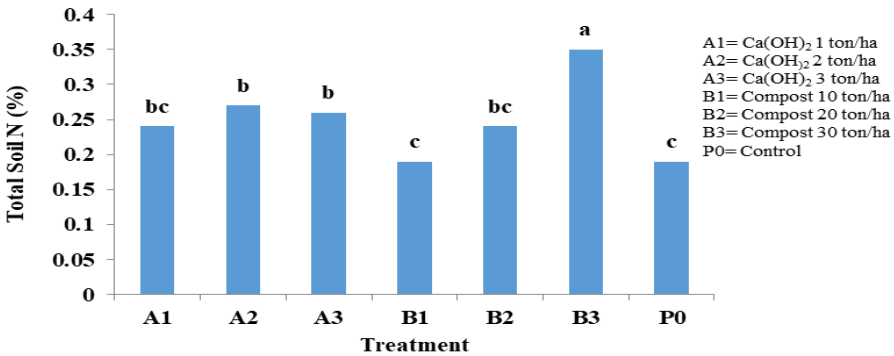

Fig. 5. Effect of $Ca(OH)_2$ and Compost on total soil N

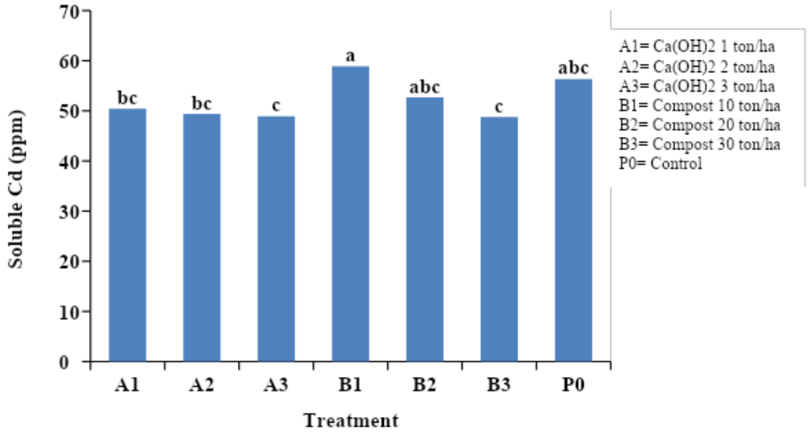

Fig. 6. Effect of Ca(OH)2 and compost on Cd

Likewise, the Cd solubility is dependent on pH and organic matter in the soil. Cadmium will dissolve easily at low pH. Application of $Ca(OH)_2$ can increase soil pH. $Ca(OH)_2$ will be ionized into Ca^{2+} and OH^-. An increase in soil pH can cause metal ions (Cd^{2+}) to precipitate into $Cd(OH)_2$, decreasing soluble Cd in soil solution. Previous study indicated that lime increase soil pH and reduced heavy metal concentration in soil solution [34]. Our study shows that compost and $Ca(OH)_2$ have similar effectiveness on the reduction of soluble Cd in Inceptisols.

4. CONCLUSION

A $Ca(OH)_2$ at dose of 3 tons/ha and a compost dose of 30 tons/ha reduced soluble Cd by 13.19% and 13.48%, respectively, compared to control, indicating that both have similar effectiveness in the reduction of soluble Cd. The application of $Ca(OH)_2$ and compost improved key soil chemical properties indicated by the increase in organic-C, total soil-N, and soil pH. This finding is significant in improving Cd contaminated Inceptisols and its fertility.

ACKNOWLEDGEMENTS

Authors highly appreciate laboratory technician at Soil Science Lab, Faculty of Agriculture, University of Bengkulu for assistance on soil chemical analysis and providing space for this study

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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