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Research Article
Effect of Chemical Fertilizer on Cadmium Uptake by Sugarcane Grown in Contaminated Soil

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Abstract
Background and Objective: Heavy metal especially Cd contamination to agricultural soil is one of the most serious environmental problems globally. Sugarcane grown in the contaminated area may absorb Cd and this may be dangerous for human consumption on the long run as it may be carcinogenic. Chemical fertilizer is used to increase the crop production and its application could affect to the level of Cd accumulation in plants. Thus, this study was conducted to study the effect of chemical fertilizer application on the Cd accumulation levels in both soil and sugarcane. **Materials and Methods:** The effect of 16-16-8 NPK fertilizer on the cadmium (Cd) uptake by sugarcane grown in Cd-contaminated soil was investigated in this study. The LK92-11 sugarcane seeds were cultivated in soil containing 58.3 mg total Cd (TCd) kg^{-1} soil to which 16-16-8 NPK fertilizer was subsequently applied at 0 (control), 31.25, 62.5 and 125 g m^{-2} at 1 and 5 months of cultivation. Soil and sugarcane samples were collected for Cd analysis after 2, 4, 6 and 8 months of cultivation. After harvesting, the soil and sugarcane split into the underground stems, roots, bagasse, leaves and juice were separately analyzed for their TCd content. **Results:** The highest TCd accumulation in the soil occurred with a fertilizer application dose of 125 g m^{-2} but with the lowest available Cd concentration. In contrast, the application of fertilizer at 31.25 g m^{-2} resulted in the highest Cd accumulation level in the roots (22.61, 21.50, 20.17 and 19.01 mg kg^{-1} at 2, 4, 6 and 8 months, respectively) followed by the underground stems>bagasse>leaves>juice. **Conclusion:** This study recommends the application of 16-16-8 NPK fertilizer at 31.25 g m^{-2} to Cd-contaminated soil because this concentration resulted in the greatest reduction in the TCd level in the soil (15.0%).

Key words: Cadmium, sugarcane, contaminated soil, chemical fertilizer, nutrients, available Cd, phosphate fertilizer, cultivation time

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Heavy metal contamination in soil is at a critical level in many areas and can be divided into two groups the agricultural and industrial soils. The first is agriculture soil, which is contaminated by applying chemical fertilizer to the soil to obtain more agricultural products. This application may subsequently lead to sedimentation and accumulation of heavy metals, resulting in deterioration of the soil quality. Heavy metal contamination may also be the result of herbicide use, which can affect plants and living organisms in the soil. The second group is industrial soil, in which the level of toxic heavy metals depends on many factors, such as the raw material used in the production processes, production method and types of products obtained, which are all indicators of potential contamination. Transport of these soils into water and air may lead to subsequent environmental and health problems. Therefore, the accumulation of heavy metals in soil is inevitable and usually impacts the ecosystem, vegetation, animals and health and sanitation of humans, as well as the food chain[1]. Since 1998, the International Water Management Institute (IWMI) and Department of Agriculture have conducted research on the cadmium (Cd) contamination levels in the soils of paddy fields and rice grains in Northern Thailand, as well as on the origin of the Cd. This area is one of the most significant zinc (Zn) deposits in Thailand and is currently subjected to mining operations and mineral dressing together with surface mining and agriculture. When it rains, water washes away the surface soil, which is rich in Zn and Cd into the creek. Farmers in the area use water from the creek for agricultural activities, which subsequently causes the soil to become highly contaminated with Cd in some areas. Moreover, a high level of Cd contamination in paddy fields and rice grains may affect rice quality and is a potential health risk, which may cause cancer for the population in the area. This Cd contamination is attributed to mining and human activities, which impact human health and the food chain[2,3]. Accordingly, various preventive measures and solutions have been proposed. One preventive measure is the cultivation of non-food crops, such as fast-growing perennials or flowing plants that provide as much economic benefit as rice cultivation, including *Eucalyptus* and marigold[4].

The shortage of non-renewable fossil fuel has led to the utilization of alternative energy sources. Although food crops such as sugarcane is also a potential biofuel source because it can be used as a raw material for bioethanol production. Moreover, sugarcane is easy to cultivate and maintain and able to withstand various topological conditions. Sugarcane is also an economic crop that produces a relatively high commercial return. Sritumpawa[5] found that sugarcane can absorb Cd from contaminated soil, therefore, replacing rice farming with sugarcane cultivation is an alternative solution for heavy metal contaminated areas[6]. The application of chemical fertilizers is one factor influencing Cd mobilization but is essential in economically viable agriculture because it increases the soil fertility and consequently enhances plant growth and productivity.

Chemical fertilizers are principally composed of the three key nutrients, nitrogen (as ammonium and nitrate salts), phosphorus (as phosphates) and potassium (K), which can be easily dissolved in water and therefore, readily released to plants. However, the drawback of certain chemical fertilizers is that they may contain heavy metals, especially most phosphate fertilizers derived from processing phosphate rock, which will be contaminated with heavy metals including Cd[7]. Continuous fertilizer application over a long period can result in the accumulation of heavy metals in both soils and plants. High levels of heavy metal contamination in soil can be toxic to plants and is hazardous for humans and other animals that consume those plants. Therefore, the major aim of this study was to determine the effect of chemical fertilizer application on the Cd accumulation level in soil and the sugarcane grown in the soil, as well as the quantity of nitrogen, phosphorus and K in the soil. This study could help optimize the level of application of chemical fertilizer that is suitable and necessary for sugarcane cultivation, including areas with Cd-contaminated soil.

MATERIALS AND METHODS

Experimental methods

Soil preparation: From the report of EHWM[8] on the distribution and bioavailability of Cd in both cultivated soil and crops in the vicinity of zinc mine, Cd-contaminated areas can be classified into three areas regarding to its total concentration. Those three areas are the area with total Cd concentrations on a dry weight basis of 0-3, 3-20 and more than 20 mg Cd kg^{-1}, respectively. This study has followed the earlier results mentioned above as the guidelines to select the study areas. Soil samples in this study had total Cd concentration higher than 37 mg kg^{-1} in which this level was also higher than the soil standard of Thailand. Soil were sampled from a depth of 30 cm depth with 10 sampling points of covering an area of 0.16 ha and the removed topsoil (total of 480 kg) was thoroughly mixed. After that, soil sample was transported to the laboratory for analysis of its texture, moisture content, pH, Cation Exchange Capacity (CEC), Electrical Conductivity (EC), Organic Matter (OM), nitrogen, available phosphorus (available P), exchangeable K and total Cd (TCd).

Plot preparation: Since, the experimental design of this present study was an *in situ* model, the plot experiment was conducted in the nursery using black plastic bags as experimental containers. A total of 10 kg of soil were placed into each bag for a total of 48 experimental containers. The containers were then covered with another layer of thick plastic to prevent heavy metals that might leach out during watering.

Plant preparation: Sugarcane, variety LK92-11 was collected from uncontaminated area and delivered to laboratory for the analysis of TCd. Upon delivery, sugarcanes were cut into pieces of similar size and weight that contained 2-3 turgid and complete nodes, grown in the nursery in sand pots with irrigation every day for about 3-4 weeks without fertilizer added. Plants were then transplanted to the experimental plots as mentioned earlier.

Fertilizer preparation: A proprietary chemical fertilizer, with a 16-16-8 NPK formula which was used in the field by farmers was applied to each soil (10 kg) container with four different concentrations including 0 (control), 31.25, 62.5 and 125 g m^{-2}. In this experiment, fertilizer was applied at the 1st and 5th month of 8 months cultivation. The experimental design used in this study was a Randomized Complete Block Design (RCBD) with three replicates (totally 48 plots)[9].

Cultivation and maintenance: The selected sugarcane pieces were planted in the experimental containers filled with 10 kg of Cd-contaminated soil with one cane piece per container. Each plot or black plastic bag was watered with 1 L every day until all the nodes had germinated and the sugarcane plants had grown strong and healthy (approximately 3-4 weeks). The 16-16-8 NPK fertilizer was applied after the 1st month of cultivation and then again at the 5th month of cultivation. The application of fertilizer during the period of cultivation was similar to the practices of fertilizer addition the farmers used in the field. The watering of each experimental container was controlled to be 1 L $plot^{-1}$ in each treatment.

Soil and plant sampling: Soil and sugarcane samples were collected after the 2nd, 4th, 6th and 8th month of sugarcane cultivation. The soil samples were mixed until each sample was homogeneous and then dried at room temperature. Next, they were analyzed to determine the soil pH (1:1 soil to water ratio) and main nutrient levels, including the total nitrogen (Kjedahl method), available P (Bray II method) and exchangeable K (1 N NH_4OAc pH 7.0). For the sugarcane sample, each sample was cleaned with tap water twice and rinsed with deionized water, dried at room temperature and then divided into the underground stem, root, bagasse, leaves and juice. Each of these parts was weighed to determine the fresh weight, then (except for the juice) oven dried at 105°C for 24-48 h and weighed again to determine the dry weight. The samples, including the soil but excluding the juice were subsequently ground and sifted through a 2 mm sieve. The soil and plant samples were then analyzed for their accumulated TCd level.

Sample analysis: The TCd in the soil and the solid parts of the cultivated sugarcane (underground stem, root, bagasse and leaves) was analyzed by USEPA[10] and Jackson[11] was used to analyze the sugarcane juice. The TCd levels were quantified by Atomic Absorption Spectrometry (AAS).

Statistical analysis: Statistical analysis of variance of the TCd accumulation level in the soil and the Cd uptake in various parts of the sugarcane was performed by ANOVA and the significance of any differences was determined by Duncan's new multiple range test (DMRT) using Statistical Package for the Social Science (SPSS) software.

RESULTS AND DISCUSSION

Soil properties: The soil used in this experiment was loamy (loamy and clay loam soil was suitable to sugarcane plantation), which is suitable for cultivation of LK92-11 sugarcane. The other soil properties are summarized in Table 1, the TCd level (58.53 mg kg^{-1}) exceeded the soil quality standard (<37 mg kg^{-1}) for residential and agricultural

Table 1: Chemical and physical properties of the soil used in this experiment

Soil property	Values
Soil texture	Loam
Moisture content (%)	25.45
pH	7.31
CEC ($cmol_c$ kg^{-1})	6.05
EC (dS m^{-1})	0.167
OM (%)	2.31
N (%)	0.136
Available P (mg kg^{-1})	8
Exchangeable K (mg kg^{-1})	56
TCd (mg kg^{-1})	58.53

purposes, according to the notification of the National Environmental Committee[12]. The soil pH of 7.31 as determined in this study was within the suitable range for sugarcane growth (pH 6.05-7.53) at this pH, most of the nutrients in the soil would be dissolved, leading to maximal nutrient uptake by the sugarcane plants[5]. Based on the levels of initial total nitrogen (0.136%), available P (8 mg kg^{-1}) and exchangeable K (56 mg kg^{-1}), the experimental soil had a medium level of available P and exchangeable K, typical of the levels found in normal field soil.

Fertilizer properties: The chemical fertilizer used in this study was a granular chemical fertilizer with a 16-16-8 NPK formula. This type of fertilizer is commonly used by farmers in the study area to promote sugarcane growth. The fertilizer had low alkalinity (pH 7.35±0.02) and TCd (4.65±0.0879 mg kg^{-1}). The TCd level was in accordance with the levels reported in many types of chemical fertilizer[13-15] 0.40-56.5 mg kg^{-1}.

Soil pH: The pH of the soil after the 2nd, 4th, 6th and 8th month of cultivation increased over the culture period and with increasing concentration of applied fertilizer but these trends were only significant at the highest concentration (Table 2). This result is consistent with the study of Levi-Minzi and Petruzzelli[16] who reported that the soil pH increased from 6.4-7.7 when diammonium phosphate fertilizer was added to the soil. The decreased pH observed in the 4th month at all 16-16-8 fertilizer application levels in this study might have resulted from the rainy reason during the experimental period. The second plastic bag layer covering the cultivating containers prevented the water inside from leaking out, causing the soil to absorb a large quantity of water during the rainy season, which would consequently decrease the soil pH. Similarly, Campbell and Wansbrough[17] reported that rain affected the soil acidity through released Ca^{2+}, Mg^{2+}, K^+ and Na^+.

Nutrients in soil

Total nitrogen: The total nitrogen contents in the soil are summarized in Table 3, the accumulated nitrogen level decreased with cultivation time in all treatments, although not significantly. As expected, the accumulated nitrogen level increased as the applied fertilizer concentration increased, although not from the 4th-6th month after reapplication of the fertilizer in the 5th month.

Available P: The available P level in the soil also decreased with the cultivation time in all treatments. However, this decrease was only significant at the higher concentrations of applied fertilizer after 6 and 8 months of cultivation (Table 4)

Table 2: Effect of the chemical fertilizer application level on the soil pH

	Soil pH after cultivation for months			
Fertilizer application (g m^{-2})	2	4	6	8
0	7.39±0.06^{a}	7.33±0.04^{a}	7.42±0.08^{a}	7.46±0.06^{a}
31.25	7.43±0.07^{a}	7.41±0.02^{ab}	7.48±0.05^{ab}	7.50±0.06^{ab}
62.5	7.49±0.06^{ab}	7.46±0.04^{bc}	7.52±0.04^{ab}	7.58±0.02^{bc}
125	7.60±0.02^{b}	7.52±0.06^{c}	7.62±0.09^{b}	7.66±0.03^{c}

Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different (p<0.05, DMRT)

Table 3: Effect of chemical fertilizer application on the total nitrogen accumulation in the soil

	Total nitrogen level (%) after cultivation for months			
Fertilizer application (g m^{-2})	2	4	6	8
0	0.131±0.001^{a}	0.130±0.001^{a}	0.126±0.004^{a}	0.124±0.004^{a}
31.25	0.141±0.001^{b}	0.137±0.004^{b}	0.136±0.003^{a}	0.1310±0.001^{a}
62.5	0.142±0.004^{b}	0.138±0.005^{b}	0.136±0.006^{a}	0.1250±0.005^{a}
125	0.144±0.004^{b}	0.139±0.003^{b}	0.138±0.010^{a}	0.129±0.007^{a}

Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different (p<0.05, DMRT)

Table 4: Effect of chemical fertilizer application on the available P level in the soil

	Available P (mg kg^{-1}) after cultivation for months			
Fertilizer application (g m^{-2})	2	4	6	8
0	6.33±0.58^{a}	5.33±1.15^{a}	3.67±0.58^{a}	3.00±1.00^{a}
31.25	7.00±1.00^{a}	5.00±1.00^{a}	5.00±1.00^{ab}	4.67±0.58^{ab}
62.5	7.67±0.58^{a}	5.67±0.58^{a}	6.00±1.00^{b}	5.67±2.08^{ab}
125	9.67±0.58^{b}	7.33±0.58^{b}	7.67±0.58^{c}	7.00±1.73^{b}

Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different (p<0.05, DMRT) likely because sugarcane utilizes phosphorus for growth. As expected, the available P level in the soil increased with an increasing concentration of applied fertilizer, even in the 6th month of cultivation after the second fertilizer application at 5 months. Phosphorus, an essential nutrient for sugarcane, is required for fast growth of the roots and shoots and to strengthen the sugarcane stem. Therefore, chemical fertilizer application is necessary to provide a sufficient level of available P for sugarcane growth[18].

Exchangeable K: Potassium plays an important role in photosynthesis and sugar transport and increases the amount of sugar in sugarcane juice. Therefore, a sufficient level of potassium in the soil leads to good quality sugarcane. The exchangeable K level in the soil decreased with the cultivation time in all treatments, although the decrease was not significant in the control (no fertilizer application) soil (Table 5). Note that the increased available K in the 6th month of cultivation reflects the reapplication of fertilizer in the 5th month.

Soil TCd levels: The TCd levels in the soil are summarized in Fig. 1 and results showed that the TCd level increased with increasing concentration of the initially applied 16-16-8 NPK fertilizer but not after the second application. However, the slight decrease in the TCd level with increasing cultivation time was not significant in any of the treatments. This is consistent with Lambert *et al.*[7] who reported that the TCd level in the soil also increased when phosphate fertilizer was applied at 0, 31.25, 62.5 and 125 g m^{-2}. However, the present study found that the TCd level in the soil decreased as the sugarcane cultivation time increased.

The level of TCd in the soil decreased in all treatments as the cultivation period increased to 8 months, the percentage reduction compared to the initial level decreased with an increasing concentration of applied fertilizer (Table 6). Higher fertilizer concentration provided a higher amount of available nitrogen, P and K nutrients in the soil and resulted in more sugarcane growth. This, in turn led to higher nutrient uptake from the soil, including Cd, decreasing the soil TCd level by approximately 8-20%[19].

Available Cd level in the soil: John and Leventhal[20] stated that the availability or bioavailability of metals is the proportion of total metals available for incorporation into biota or taken up by plants. Therefore, the available soil Cd concentration is the concentration of the Cd form that plants can easily take up and accumulate. In order to investigate the available Cd concentration, an extraction method with diethylene triamine pentaacetic acid was used in this study. The available Cd in the soil tended to decrease as the concentration of the applied 16-16-8 NPK fertilizer increased (Fig. 2). The lowest concentration of available Cd in the soil was observed at an applied fertilizer concentration of 125 g m^{-2} but increased slightly with the cultivation time from 14.24 mg kg^{-1} in the soil after 2 months of cultivation to 17.14 mg kg^{-1} after 8 months. The reason that the lowest available Cd concentration was detected in soil applied with the highest concentration of fertilizer might have been due to the higher soil pH resulting from greater fertilizer application. Similarly, Levi-Minzi and Petruzzelli[16] reported that the addition of diammonium phosphate fertilizer to soil increased the soil pH from 6.4-7.7 and decreased the soluble Cd level in the soil. Adriano[21] also reported that increasing the soil pH above 7.0 decreased the availability of Zn for plant uptake.

TCd levels in sugarcane: The level of Cd uptake in sugarcane, as the TCd was evaluated separately for the roots, bagasse,

Table 5: Effect of chemical fertilizer application on the exchangeable K accumulation in the soil

	Exchangeable K (mg kg^{-1}) after cultivation for months			
Fertilizer application (g m^{-2})	2	4	6	8
0	54.33±0.58^{a}	52.00±1.00^{a}	51.00±1.73^{a}	49.67±0.58^{a}
31.25	58.00±0.00^{b}	51.00±2.00^{a}	61.00±5.00^{b}	55.33±1.53^{ab}
62.5	58.33±1.15^{b}	50.00±4.58^{a}	63.67±3.21^{b}	58.00±5.20^{b}
125	59.00±1.73^{b}	53.00±2.65^{a}	64.33±4.04^{b}	58.00±3.46^{b}

Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different (p<0.05, DMRT)

Table 6: Reduction in soil TCd levels after 8 months of sugarcane cultivation

Fertilizer application (g m^{-2})	TCd level in soil after 8 months (mg kg^{-1})	Reduction in TCd in soil (%)
0	46.33±1.61	20.84
31.25	49.77±3.41	14.97
62.5	52.94±2.52	9.55
125	53.54±2.56	8.53

Initial TCd level in the soil was 58.53 mg kg^{-1} in all treatments. Data are shown as the Mean±1 SD, derived from three independent replicates

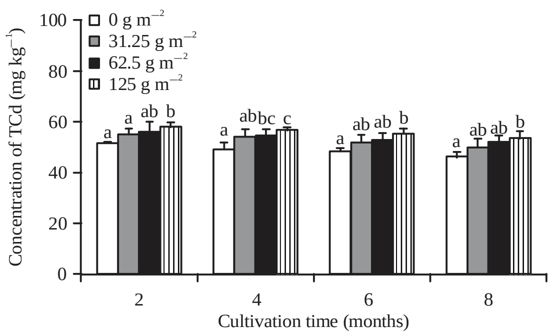

Fig. 1: Effect of the chemical fertilizer application rate on the TCd level in the soil. Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different ($p<0.05$, DMRT)

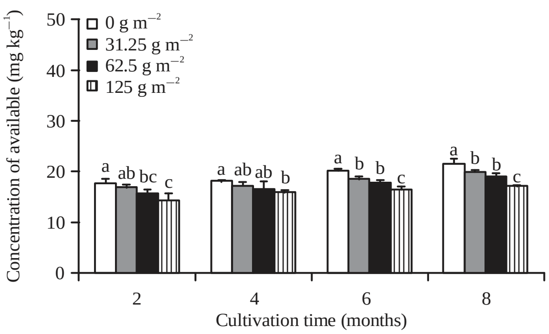

Fig. 2: Effect of the chemical fertilizer application rate on the available soil Cd level. Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different ($p<0.05$, DMRT)

leaves, underground stems and juice with the results summarized in Fig. 3.

The highest TCd level was found in sugarcane roots followed by the underground stems, bagasse, leaves and juice. Suminarti *et al.*[18] reported that heavy metals, such as Cd, Cr, Cu, Hg, Mn, Pb and Zn accumulated in various parts of sugarcane. These researchers detected the lowest level of all these metals, except Cd in the leaves and found that Cd accumulated most in the roots, followed by bagasse and leaves at 0.23, 0.20 and 0.13 mg kg^{-1}, respectively[22]. Azimi *et al.*[23] studied the Cd uptake in legumes growing in wastewater contaminated with 65 mg Cd L^{-1} and found that Cd accumulated to the highest level in roots (70 mg L^{-1}), compared to 12-16 mg L^{-1} in the other parts of the legume. Chen *et al.*[1] reported that the Cd uptake in wheat grass growing in Cd-contaminated soil with different concentrations of applied phosphate fertilizer was highest in the roots, followed by the stem, chaff and grain, respectively. Khamla and Pantawat[24] showed that arsenic (As) accumulation in roots was significantly higher than in stems and leaves ($p<0.05$) and was maximal after 120 days of cultivation, at which point the As concentration reached 29.71 mg As kg^{-1} in the roots compared to 6.32 mg As kg^{-1} in the stem and leaves. The average As accumulation in all parts of the plant over 4 months was 2.71-36.03 mg As kg^{-1} plant.

This study showed that the Cd accumulation in the roots of sugarcane (Fig. 3a) decreased as the sugarcane growth (cultivation time) increased and when 16-16-8 NPK fertilizer was applied. The Cd accumulation level was highest in sugarcane samples collected in the 2nd month of cultivation. Ruangkhum[25] reported the effect of the addition of phosphate fertilizer at 0, 31.25, 62.5 and 125 g m^{-2} on Cd uptake by sugarcane with Cd levels of 5.74, 4.04, 3.59 and 2.46 mg kg^{-1}, respectively, after 6 months of cultivation. In this study, the Cd accumulation levels in the sugarcane bagasse and leaves (Fig. 3b, c) significantly increased ($p<0.05$) with increasing concentration of the applied 16-16-8 NPK fertilizer, reaching the highest Cd accumulation in the bagasse and leaves of 8.25 and 8.24 mg kg^{-1}, respectively. However, the sugarcane accumulated higher levels of Cd in the 2nd, 4th and 6th month of cultivation and lower levels in the samples cultivated for 8 months, which means that the physical growth rate of sugarcane decreased as the sugarcane started to accumulate sugar. Figure 3d shows that the Cd accumulation in the underground stems increased with increasing concentrations of applied fertilizer after the 2nd, 4th and 6th month of cultivation but gradually decreased by the 8th month. This trend reflects the role that the underground stems initially play in water and nutrient uptake to promote sugarcane growth but with longer cultivation times, the underground stems are functionally replaced by new roots and gradually deteriorate by the 6th month of sugarcane cultivation[5].

With respect to the Cd accumulation in the sugarcane juice (Fig. 3e), the juice had the lowest Cd accumulation level compared to the other parts of the sugarcane. However, the concentration in the juice increased with increasing cultivation time with the highest level (0.24 mg kg^{-1}) detected in samples after 8 months of cultivation without any added fertilizer. The Cd accumulation level in the juice from sugarcane applied with 31.25 g m^{-2} fertilizer was less than that at 0, 62.5 and 125 g m^{-2}. Note that the Cd accumulation in the juice at the 2nd and 4th month of cultivation could not be analyzed because the sugarcane was changing from the tillering phase to the elongation phase and there was no sugar accumulation during this

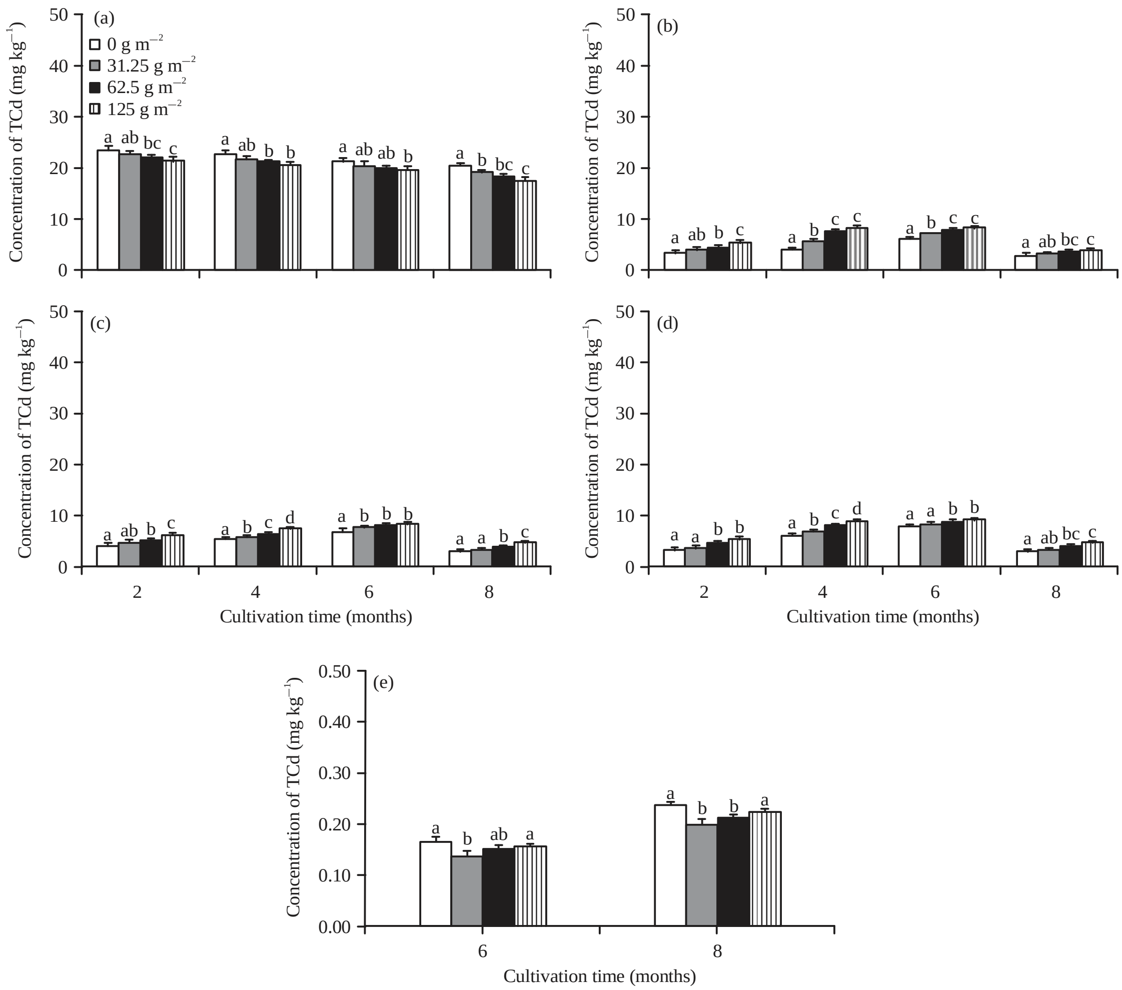

Fig. 3(a-e): Concentration of TCd in the (a) Roots, (b) Bagasse, (c) Leaves, (d) Underground stems and (e) Juice of sugarcane after cultivation in Cd-contaminated soils with different concentrations of applied fertilizer. Data are shown as the Mean±1 SD, derived from three independent replicates. Means with different lowercase letters are significantly different (p<0.05, DMRT)

period[26]. Pantawat and Natthakan[27] previously reported that the application of 1 mmol EDTA kg^{-1} soil resulted in the highest Cd accumulation in sugarcane roots, reaching 21.87, 44.68, 57.52 and 41.97 mg kg^{-1} after the 2nd, 4th, 6th and 8th month of cultivation, respectively. Furthermore, the sugarcane roots exhibited the most efficient Cd uptake, followed by the underground stems>bagasse>leaves>juice.

Based on all results obtained, it can be concluded that the optimum fertilizer application which could result benefit farmers in terms of cost effectiveness, agricultural yield and risk management was 31.25 g m^{-2}. This level of fertilizer application leads to the lowest total Cd accumulation in sugarcane and thus, could cause some advantages to the public health and food safety issues concerning Cd contamination along the food chain.

CONCLUSION

Analysis of the effect of the chemical fertilizer application concentration (0, 31.25, 62.5 and 125 g m^{-2}) on Cd uptake by sugarcane after 2, 4, 6 and 8 months of cultivation revealed that the TCd level in the soil increased when the rate of fertilizer application increased and that the TCd level in the soil decreased with increasing cultivation time. The highest Cd accumulation in sugarcane was found in the roots, followed by the underground stems>bagasse>leaves>juice. The most appropriate level of 16-16-8 NPK fertilizer addition was 31.25 g m^{-2} because this concentration resulted in the lowest soil TCd level and provided the lowest available Cd accumulation in various parts of the sugarcane plant. Furthermore, this level of fertilizer application resulted in the greatest Cd reduction in the soil (15.0%).

SIGNIFICANT STATEMENTS

- Concentrations of Cd generally decreased as the cultivation period increased. However, concentrations of Cd were found to increase when the application rate of fertilizer increased
- No significant reduction in Cd uptake among different application rates of chemical fertilizer
- Highest and lowest Cd concentrations were found in the roots and juice of sugarcane, respectively
- The optimum fertilizer application which could result in both cost effectiveness of fertilizer application and lowest total Cd concentrations in soil and sugarcane was 31.25 g m^{-2}
- Results obtained could be used to promote public health and food safety issues concerning Cd contamination along the food chain

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REFERENCES

1. Chen, S., T.H. Sun, L.N. Sun, Q.X. Zhou and L. Chao, 2006. Influences of phosphate nutritional level on the phytoavailability and speciation distribution of cadmium and lead in soil. J. Environ. Sci. (China), 18: 1247-1253.
2. Luc, K., E.A. Patrick, A. Lucien, H.S. Armelle and E. Bernadin, 2012. Threat of the health quality of garden produces linked to pollution by toxic metals on some gardening sites of Benin. Am. J. Environ. Sci., 8: 248-252.
3. Sarma, H., 2011. Metal hyperaccumulation in plants: A review focusing on phytoremediation technology. J. Environ. Sci. Technol., 4: 118-138.
4. DPIM., 2006. Research report causes of cadmium contaminated in soil. Mae sot District, Tak Province, Bangkok, Thailand.
5. Sritumpawa, W., 2007. Cadmium uptake by sugarcane grown in contaminated soil. Master Thesis, Environmental Science (Interdisciplinary Program), Graduate School, Chulalongkorn University.
6. Tananonchai, A. and P. Sampanpanish, 2014. Effect of EDTA and DTPA on cadmium removal from contaminated soil with water hyacinth. Applied Environ. Res., 36: 65-76.
7. Lambert, R., C. Grant and S. Sauve, 2007. Cadmium and zinc in soil solution extracts following the application of phosphate fertilizers. Sci. Total Environ., 378: 293-305.
8. EHWM., 2009. Sugarcane cultivation in former cadmium contaminated paddy soil. Environmental and Hazardous Waste Management, Chulalongkorn University, Bangkok.
9. Hussain, S., M. Anwar-ul-Haq, S. Hussain, Z. Akram, M. Afzal and I. Shabbir, 2015. Best suited timing schedule of inorganic NPK fertilizers and its effect on qualitative and quantitative attributes of spring sown sugarcane (*Saccharum officinarum* L.). J. Saudi Soc. Agric. Sci., (In Press). 10.1016/j.jssas.2015.02.004
10. USEPA., 1996. EPA Method 3052, Microwave assisted acid digestion of siliceous and organically based matrices. US Environmental Protection Agency, Research Triangle Park, NC.
11. Jackson, M.L., 1973. Soil Chemical Analysis. 2nd Edn., Prentice Hall of India Pvt. Ltd., New Delhi, India.
12. National Environmental Committee, 2004. Issue 25 (B.E. 2547) on soil quality standards. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.
13. MDoA., 2007. Heavy metal analysis in fertilizers distributed in Minnesota. Minnesota Department of Agriculture, University of Minnesota, December 2007. http://www.mda.state.mn.us/chemicals/fertilizers/heavymetals.aspx
14. Mariano, E., J.M. Leite, M.X. Vieira-Megda, I.A. Ciampitti and A.C. Vitti *et al*., 2016. Biomass and nutrient content by sugarcane as affected by fertilizer nitrogen sources. Crop Sci., 56: 1234-1244.
15. Leite, J.M., I.A. Ciampitti, E. Mariano, M.X. Vieira-Megda and P.C.O. Trivelin, 2016. Nutrient partitioning and stoichiometry in unburnt sugarcane ratoon at varying yield levels. Front. Plant Sci., 7: 466-466.
16. Levi-Minzi, R. and G. Petruzzelli, 1984. The influence of phosphate fertilizers on Cd solubility in soil. Water Air Soil Pollut., 23: 423-429.
17. Campbell, A. and H. Wansbrough, 2005. Soil acidity and liming. http://www.nzic.org.nz/ChemProcesses/soils/2C.pdf.
18. Suminarti, N.E., Ariffin, B. Guritno and M.L. Rayes, 2016. Effect of fertilizer application and plant density on physiological aspect and yield of Taro (*Colocasia esculenta* (L.) *Schott* var. *Antiquorum*). Int. J. Agric. Res., 11: 32-39.
19. Mensah, E., H.E. Allen, R. Shoji, S.N. Odai, N. Kyei-Baffour, E. Ofori and D. Mezler, 2008. Cadmium (Cd) and lead (Pb) concentrations effects on yields of some vegetables due to uptake from irrigation water in Ghana. Int. J. Agric. Res., 3: 243-251.

20. John, D.A. and J.S. Leventhal, 1995. Bioavailability of Metals. In: Preliminary Compilation of Descriptive Geoenvironmental Mineral Deposit Models, Du Bay, E.A. (Ed.). Chapter 2, U.S. Department of the Interior, U.S. Geological Survey, Denver, CO., USA., pp: 10-18.
21. Adriano, D.C., 2001. Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals. 2nd Edn., Springer, New York, USA., ISBN-13: 9780387986784, Pages: 867.
22. Segura-Munoz, S.I., A. da Silva Oliveira, M. Nikaido, T.M.B. Trevilato, A. Bocio, A.M.M. Takayanagui and J.L. Domingo, 2006. Metal levels in sugar cane (*Saccharum* spp.) samples from an area under the influence of a municipal landfill and a medical waste treatment system in Brazil. Environ. Int., 32: 52-57.
23. Azimi, A., T.N. Daneshmand and A. Pardakhti, 2006. Cadmium absorption and accumulation in different parts of kidney beans, radishes and pumpkins. Int. J. Environ. Sci. Technol., 3: 177-180.
24. Khamla, N. and S. Pantawat, 2015. Effect of NTA and EDTA on arsenic uptake from contaminated soil by *Mimosa pudica*. Mod. Applied Sci., 9: 280-291.
25. Ruangkhum, S., 2007. Effect of phosphorus in fertilizer on available cadmium and zinc uptake by sugarcane. Master's Thesis, Environmental Management, Graduate School, Chulalongkorn University, Bangkok.
26. Vered, E. and V.P. Rao, 2007. Crop growth phases. Netafim's Agriculture Department. http://www.sugarcanecrops. com/crop_growth_phases/.
27. Pantawat, S. and T. Natthakan, 2015. Effect of EDTA on cadmium and zinc uptake by sugarcane grown in contaminated soil. Am. J. Environ. Sci., 11: 167-174.