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Effect of Fertilizer Type on Cyanide, Manganese, and Arsenic Phytoremediation in Tailings from Gold Mining

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Abstract

This study investigated the effects of using chemical and organic fertilizer on arsenic (As), manganese (Mn), and cyanide (CN) absorption in tailings from a gold-mining tailing storage facility (TSF) by growing plants in a nursery. The experimental sets were prepared and classified into two sets: the first set used 15-15-15 chemical fertilizer, and the second set used organic fertilizer (manure). Two groups of plants were grown; the first group was comprised of monocot species, which were *V. nemoralis* and *B. bambos*, and the second group was comprised of dicot species, which were *A. mangium* and *L. leucocephala*. Plants and tailing samples were collected every 30 days during the six-month experiment. Growth was examined, and the absorption and accumulated amounts of As, Mn, and CN in the plant parts were analyzed. The findings showed that the accumulated amounts of As, Mn, and CN decreased when the experimental period increased. The accumulated amounts of As, Mn, and CN in the parts of experimental plants at 180 days indicated that *V. nemoralis* and *A. mangium* fertilized with chemical fertilizer (mass balance calculation) had higher rates of As, Mn, and CN absorption than those in the sets fertilized with organic fertilizer. *V. nemoralis* accumulated the most As and Mn in the underground part (roots), with values of 7.07 and 17.03 mg/kg, respectively, and absorbed the most CN in the aboveground part (shoots and leaves), with a value of 6.43 mg/kg. *A. mangium* absorbed the most As and Mn in leaves, with values of 5.64 and 40.51 mg/kg, respectively, and absorbed the most CN in shoots, with a value of 0.24 mg/kg. Therefore, it could be concluded that *A. mangium* (dicot species) and *V. nemoralis* (monocot species) had a high ability and potential to absorb toxicity or reduce the accumulated amounts of heavy metal. Furthermore, *A. mangium* and *V. nemoralis* would be suitable for application per relevant guidelines to solve the problem of As, Mn, and CN contaminated soil in other regions.

Keywords: Fertilizer; Cyanide; Phytoremediation; Tailing; Gold mining

Introduction

At present, environmental problems can be found in all resources and in all countries. However, the most critical environmental problems, such as contamination from hazardous waste or heavy metals in soil, air, and water resources, affect human health and other living things. All such problems are derived from human activities, such as mining, which cause heavy metal contamination in the surrounding environment and in soil, water, and air. Minerals such as zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), chromium (Cr), cadmium (Cd), arsenic (As), and manganese (Mn) have been found to contaminate the environment (Department of Health, 2015; Mganga *et al.,* 2011). Contamination by these minerals has reached an extreme rate, which affects living things and ecology in various ways. From the random sampling of more than 600 samples of water, soil and plants from a potential source of ore in Thailand, it was found that there was an excess of CN, Mn, As, and Pb contamination above standard levels (Department of Groundwater Resources, 2015). Therefore, it is necessary to apply remediation technologies to heavy metal-contaminated soil; several methods are available, such as chemical treatment, physical treatment, and biological treatment. For the mentioned problems, one of the alternatives that has received interest and is being considered for the restoration of heavy metal-contaminated areas is the use of green plants or phytoremediation; this is the method of using plants to eliminate, remedy, and restore heavy metal-contaminated areas to restrict the expansion of contamination to the environment, which may affect human health. Phytoremediation has noncomplex steps and low expenses since it relies on the natural process by which plants absorb nutrients, as well as heavy metals and toxicity in soil. Each plant type has a mechanism for detoxification. For example, plants can store and accumulate toxins, eliminate and reduce toxicity, and change toxins into volatile substances. The most important factor is the potential of each species to absorb and endure each type of heavy metal (Sampanpanish, 2015). Therefore, the objectives of this study, which provides a comparison of the effects of the use of chemical fertilizer and organic fertilizer on As, Mn, and CN absorption in tailings from a tailing storage facility (TSF) from gold mining, were to investigate the plants that have the ability and potential to absorb heavy metals efficiently.

Materials and methods

Preparation of experimental plants

The plants used in the research were classified into two groups: 1) Monocot species: Vetiveria nemoralis (Balansa) A. Camus and *Bambusa bambos* (L.) Voss, and 2) Dicot species: *Acacia mangium* Willd. and *Leucaena leucocephala* (Lam.) de Wit. All plants in this research were selected to have the same size and weight.

Preparation of experimental sets

The plants were grown in pots prepared in a nursery (ex situ) and were grouped into two experimental sets. The first experimental set was *V. nemoralis, B. bambos, A. mangium,* and *L. leucocephala*, which were planted in pots containing 20 kg of tailings. A total of 18 pots were used, and plants were fertilized with 15-15-15 chemical fertilizer twice: the first time on the first day of growth (1 month) with an amendment of 30 g (3.25 ton/ha), and the second time on the 60 day with an amendment of 30 g. For the second experimental set, which was fertilized with organic fertilizer (manure), the same plants were grown, and the same method was applied as that used with the first experimental set. For the control set, the plants were grown in tailings but without fertilizer. Water was at 1 L/pot every day in the morning. Which, the chemical and organic fertilizer not be source of As, Mn, and CN. Moreover, the chemical fertilizer 15-15-15 was contented nitrogen (N), phosphorus (P), Potassium (K) 15%, and the organic fertilizer (cow manure) was contented N, P, and K 1.30, 0.50, and 1.70%, respectively.

Experiment period

This research was conducted within over 180 days. Plant and tailing samples were collected every 30 days throughout the experimental period: 30, 60, 90, 120, 150, and 180 days. The experiment was replicated three times.

Growth record (biomass and relative growth rate)

Throughout the experiment, the relative growth rate (RGR) was analyzed with respect to time as follows.

Relative growth rate (RGR) (Hoffmann, 2002) was calculated from formula (1):

$$RGR = ([\ln W_2 - \ln W_1])/((t_2 - t_1)) \qquad \text{..........(1)}$$

Where: t_1 is the first date of the experiment; t_2 is the last date of the experiment; W_1 is the weight of the plant at t_1 (g); W_2 is the weight of the plant at t_2 (g); and ln is the natural logarithm.

Sample collection and sample analysis (plants, tailings and water)

1) Plant samples: The samples were collected after planting on days 30, 60, 90, 120, 150, and 180 using simple random sampling. They were washed with clean water 3-4 times and with distilled water one time. The first group of samples was washed, dried at room temperature for 2-3 hours, and then separated into three parts (root, shoot, and leaf) for dicot species and two parts (aboveground parts (shoot and leaf) and underground parts (root)) for monocot species. The fresh weight was measured, the samples were ground finely, and the amount of CN was analyzed by applying the in-house method OR-082-TM (Hattsu and Hatsu, 2002). For the second group of samples, after drying at room temperature, the parts were separated, the samples were oven dried at 105°C for 24-48 hours, and the dry weight was measured. The parts were ground finely, and the amounts of As and Mn were analyzed using USEPA Method 3052 with a microwave digester and

atomic absorption spectrophotometer (AAS) (USEPA, 1996).

2) Tailing samples: The samples were collected after planting by collection from the same pot as the plants at 30, 60, 90, 120, 150, and 180 days and divided into two groups. The first group was dried at 105°C for 24-48 hours, ground, and sieved to 10 mesh (2 mm) before analyzing the amount of As and Mn by microwave digestion and atomic absorption spectrophotometer (AAS) (USEPA, 1996). The second group was air dried at room temperature, ground, and sieved to 10 mesh (2 mm) before analyzing pH, electrical conductivity (EC) and oxidation-reduction potential (ORP); the amount of CN was analyzed with a UV-visible spectrophotometer.

3) Water samples: The samples used for watering during the experiments were collected twice. The basic water quality was analyzed, which included pH, dissolved oxygen (DO), EC, ORP, and the amount of As and Mn, as measured by microwave and atomic absorption spectrophotometer (AAS) (USEPA, 1998). CN was analyzed with a UV-visible spectrophotometer.

4) The growth data for the experimental plants were collected. The fresh weight and dry weight were recorded, the growth rate was calculated at 30, 60, 90, 120, 150, and 180 days, and the height was measured every week after planting.

Statistical analysis

Analysis of variance was performed on the quantitative data for As, Mn, and CN absorption and accumulation in *A. mangium*, *L. leucocephala*, *V. nemoralis*, and *B. bambos* grown in tailings in the nursery. The ANOVA results were analyzed to find the significant difference at a confidence level of 95%. If a difference was found, Duncan's new multiple range test (DMRT) was applied to test the means of the data and determine which group was different from the other groups. This statistical data analysis was performed using the Statistical Package for the Social Sciences (SPSS).

Results and Discussion

Physical and chemical quality of tailings

The tailings were collected prior to the experiment from a tailing trap in an area that potentially could be used for gold mining. The results of the analysis of the tailing properties showed that the tailings contained the following amounts of As, Mn, and CN: 50.00-51.55, 1,670.60-1,670.92, and 0.14-1.21 mg/kg, respectively. The pH value ranged from 6.3-6.7, and the electrical conductivity ranged from 1,606.13-1,937.09 µS/cm. It could be concluded that the gold-mining, tailing storage facility (TSF) was acidic and therefore the tailings could be utilized for planting. However, the necessary nutrients should also be taken into account. Regarding electrical conductivity, the tailings did not contain a salt content that would cause damage to the experiment (Faculty of Agro-Industry, 1998).

Physical and chemical quality of water for watering

The water used for watering the experimental plants met the water quality standards for the 3rd type of utilization, a water source receiving wastewater from activities containing As and Mn, with values of 0.21 and 0.31 mg/L, respectively. The pH value ranged from 6.3-6.8, and the dissolved oxygen value was 8.80 mg/L. This implied that the water was clean and had low levels of contamination. The electrical conductivity was consistent with the amount of heavy metals, which was the indicator of the total quantity of ions in the water.

Growth rate of plants

Monocot species were comprised of six experimental sets, which were 1) *V. nemoralis* (control); 2) *V. nemoralis* fertilized with chemical fertilizer; 3) *V. nemoralis* fertilized with organic fertilizer; 4) *B. bambos* (control); 5) *B. bambos* fertilized with chemical fertilizer; and 6) *B. bambos* fertilized with organic fertilizer. For dicot species, the test consisted of six experimental sets, which were 1) *A. mangium* (control); 2) *A. mangium* fertilized with chemical fertilizer; 3) *A. mangium* fertilized with organic fertilizer; 4) *L. leucocephala* (control); 5) *L. leucocephala* fertilized with chemical fertilizer; and 6) *L. leucocephala* fertilized with organic fertilizer. The details of the growth rate are as follows.

1) Biomass: It was found that the biomass of the plants in all of the experimental sets increased, and the differences showed statistical significance at the confidence level of 95% ($p \leq 0.05$) between sample collection intervals. On the first planting day (0 days), the biomass measurements of the plants in experimental sets 1-6 were 3.00, 3.09, 3.01, 2.39, 2.43, and 2.39 g, respectively. At the end of the experiment (180 days), the biomass measurements for the sets were 341.22, 643.32, 636.74, 337.30, 544.11, and 570.07 g, respectively. *V. nemoralis* fertilized with chemical fertilizer had the greatest increase in biomass at every interval of sample collection: the biomass at 0 days was 3.09 g. At the end of the experiment (180 days), the biomass was 643.32 g, as shown in Figure 1-a. The results were in line with the study of Chen *et al.* (2006), who grew wheat and added phosphate at five levels, 0, 50, 100, 200, and 400 mg/kg, before adding cadmium chloride [$(CdCl_2) \cdot 2.5H_2O$] and lead nitrate [$Pb(NO_3)_2$] at different levels in order to study the level of phosphorus the plant could uptake for utilization. The results showed that increasing phosphate levels helped to increase the dry weight of wheat. For dicot species, it was found that the biomass of the plants in the six experimental sets increased such that the difference was statistically significant at a confidence level of 95% ($p \leq 0.05$) between sample collection intervals. On the first day (0 days), the biomass measurements of the plants in sets 1-6 were 0.53, 0.54, 0.54, 3.41, 3.44, and 3.45 g, respectively. At the end of experiment, the biomass measurements were 811.99, 989.17, 690.30, 659.20, 746.47, and 727.26 g, respectively. *A. mangium* fertilized with chemical fertilizer had the greatest increase in biomass at all intervals of sample collection. That is to say, That is, on the first day (0 days), the biomass of *A. mangium* fertilized with chemical fertilizer was 0.54 g. At the end of the experiment (180 days), the biomass was 989.17 g, as shown in Figure 1-b. The results were consistent with the research of Suphachai *et al.* (2006), who discovered that fertilization with higher nitrogen levels (156-625 kg/ha) would increase the height, leaf area, fresh weight, and dry weight of kale plants at all growth intervals.

2) Relative growth rate (RGR): The monocot species sets illustrated that the RGRs of *V. nemoralis* fertilized with chemical fertilizer and those of sets fertilized with organic fertilizer were higher than the RGRs of other sets, with a statistically significant difference ($p \leq 0.05$). That

is, during the first 30 days, the RGRs were 0.03 and 0.05, respectively. At the end of the experiment (180 days), the RGRs decreased to 0.02 and 0.03, respectively. RGR increased from days 30-60 but decreased at the interval of 90 days. After that, it constantly decreased until the end of the experiment. This was because during the first 30-60 days, the plants grew and absorbed heavy metal normally. At day 90 of the experiment, the plants reached the point where they had too much heavy metal, so growth slowed down, signaling toxicity. After that, when the plant had adjusted to the toxicity, the RGR increased and then gradually decreased until the last day of the experiment, as shown in Figure 1-c. For dicot species, it was found that the RGR of the experimental plants decreased when the duration increased. It could be concluded that the RGRs of *A. mangium* with chemical fertilizer and those sets fertilized with organic fertilizer obviously decreased. During the first 30 days, the RGRs were 0.09 and 0.09, respectively. At every 30-day interval, the RGR decreased. Furthermore, the RGRs of *A. mangium* with chemical fertilizer and those sets fertilized with organic fertilizer had no statistical difference, even at the end of the experiment (180 days). Additionally, the RGRs decreased to 0.04 and 0.04, respectively, as shown in Figure 1-d. This result was in line with the findings of Chanjarat *et al.* (2007), who compared experimental sets with mixed fertilizer, chemical and organic fertilizer (T4, T5, T6, and T7), to an experimental set with chemical fertilizer (T3) and discovered that the plants had no statistical difference in height.

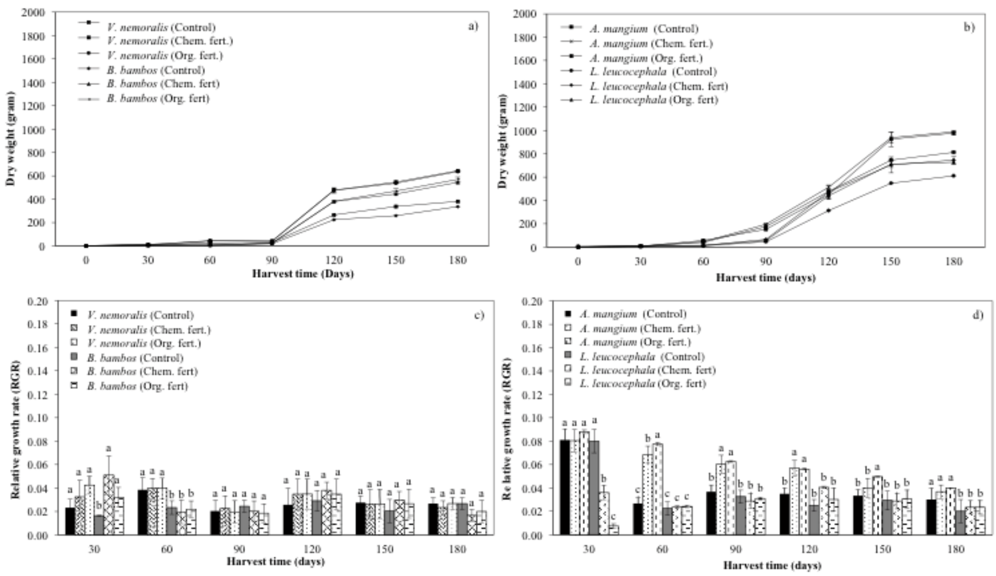

Figure 1. Dry weight of a) monocots species, and b) dicots species; Relative Growth Rate (RGR) of c) monocots species, and d) dicots species

Effects of fertilizer on As, Mn, and CN accumulation in monocot plant species

The amount of As, Mn, and CN absorption and accumulation in the aboveground parts (shoot and leaf) and underground part (root) of *V. nemoralis* and *B. bambos* during the experimental period (0-180 days) were analyzed, and the results revealed that the amounts of As, Mn, and CN absorbed and accumulated in the plants in the six experimental sets were different, with statistical significance ($p \leq 0.05$), at 180 days. The results showed that the ability to absorb and accumulate As, Mn, and CN in all experimental sets tended to increase with the increasing duration of the experiment; the details are as follows.

1) Effects of chemical and organic fertilizer on As accumulation: *V. nemoralis* at 180 days fertilized with chemical fertilizer absorbed and accumulated the most As in the aboveground parts (shoots and leaves), followed by *B. bambos* fertilized with chemical fertilizer > *B. bambos* fertilized with organic fertilizer > *V. nemoralis* fertilized with organic fertilizer > *V. nemoralis* (control) > *B. bambos* (control); the values were 6.76 > 6.39 > 4.98 > 4.79 > 3.89 > 3.78 mg/kg, respectively (as shown in Figure 2-a). This is consistent with the research of Lorenz *et al.* (1994), who reported that the increase of cations (K- and NH^{+}) in fertilizer caused an increase in heavy metal ions in the soil solution, so that the ions of heavy metals were more thoroughly absorbed. For As accumulation in the underground part (roots) at 180 days, it was shown that *B. bambos* fertilized with chemical fertilizer absorbed and accumulated the most As, followed by B. bambos with organic fertilizer > *V. nemoralis* fertilized with organic fertilizer > *V. nemoralis* fertilized with chemical fertilizer > *B. bambos* (control) > *V. nemoralis* (control); the values were 6.23, 6.03, 4.91, 4.44, 3.45, and 3.40 mg/kg, respectively (as shown in Figure 2-b).

2) Effects of chemical and organic fertilizer on Mn accumulation: At 180 days, *V. nemoralis* fertilized with organic fertilizer accumulated the most Mn in the aboveground parts, followed by *V. nemoralis* with chemical fertilizer > *B. bambos* with organic fertilizer > *B. bambos* with chemical fertilizer > *V. nemoralis* (control) > *B. bambos* (control); the values were 308.90 > 256.26 > 180.12 > 172.82 > 114.70 > 110.45 mg/kg, respectively (as shown in Figure 2-c). Regarding the amount of Mn absorbed in the underground part, *V. nemoralis* fertilized with chemical fertilizer absorbed and accumulated the most Mn, followed by *V. nemoralis* (control) > B. bambos with chemical fertilizer > *V. nemoralis* with organic fertilizer > *B. bambos* (control) > *B. bambos* with organic fertilizer; the values were 531.88 > 456.78 > 416.51 > 354.53 > 300.01 > 281.12 mg/kg, respectively (as shown in Figure 2-d). These results corresponded with the research of Sampampanish *et al.* (2008a) and Sampanpanish *et al.* (2008b), who studied the effect of phosphorus in fertilizer on the levels of cadmium and zinc that plants could absorb and examined accumulation in sugarcane. The study was conducted in actual areas (in situ) that applied 16-16-8 chemical fertilizer. The findings revealed that the concentrations of cadmium and zinc tended to increase, which resulted in higher amounts of Cd and Zn than could be absorbed by the sugarcane and soil.

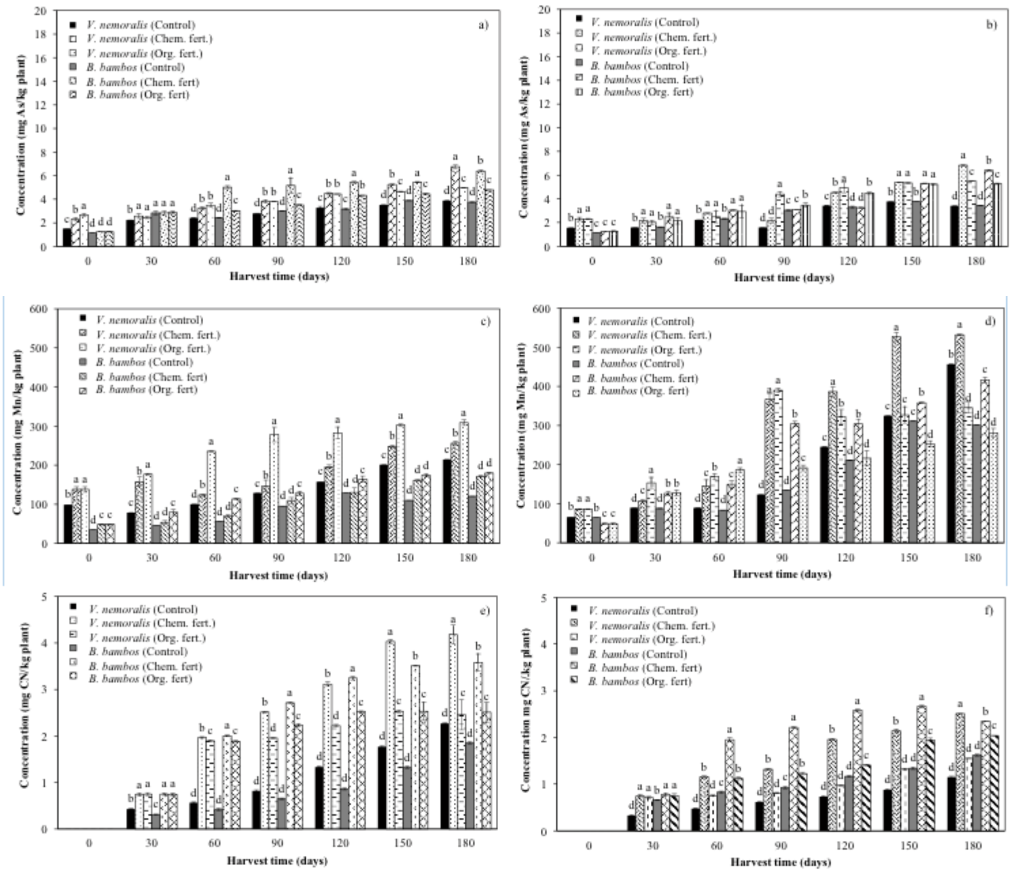

Figure 2. Effects of fertilizer on As, Mn, and CN accumulation in monocot species; a) As in aboveground part (shoots and leaves), b) As in underground part (roots), c) Mn in aboveground part (shoots and leaves), d) Mn in underground part (roots), e) CN in aboveground part (shoots and leaves), and f) CN in underground part (roots)

3) Effects of chemical and organic fertilizer on CN accumulation: At the end of the experiment (180 days), it was found that *V. nemoralis* fertilized with chemical fertilizer absorbed and accumulated the most CN, followed by B. bambos with chemical fertilizer > *V. nemoralis* (control) > *V. nemoralis* with organic fertilizer > *B. bambos* with organic fertilizer > *B. bambos* (control); the values were 4.45 > 3.79 > 3.39 > 2.76 > 2.71 > 2.65 mg/kg, respectively (as shown in Figure 2-e). With regard to CN accumulation in the underground part, *V. nemoralis* fertilized with chemical fertilizer absorbed and accumulated the most CN, followed by B. bambos with chemical fertilizer > *B. bambos* with organic fertilizer > *B. bambos* (control) > *V. nemoralis* (control) > *V. nemoralis* with organic fertilizer; the values were 2.51 > 2.35 > 2.04 > 1.97 > 1.61 > 1.55 mg/kg, respectively (as shown in Figure 2-f).

Furthermore, it was found that the experimental sets fertilized with chemical fertilizer stimulated the plants to better absorb CN than the plants in those sets fertilized with organic fertilizer, as the addition of organic fertilizer retained CN in the tailings, meaning the plants were unable to absorb CN from the tailings.

Effects of fertilizer on As, Mn, and CN accumulation in dicot plant species

1) Effects of chemical and organic fertilizer on As accumulation: At the end of the experiment at 180 days, the root part of A. mangium fertilized with chemical fertilizer absorbed the most As, followed by *L. leucocephala* with organic fertilizer > *L. leucocephala* with chemical fertilizer > *A. mangium* (control) > *A. mangium* with organic fertilizer > *L. leucocephala* (control); the values were 7.06 > 6.13 > 5.33 > 5.30 > 4.79 > 3.01 mg/kg, respectively (as shown in Figure 3-a). It was found that the shoots of *A. mangium* fertilized with chemical fertilizer absorbed and accumulated the most As, followed by *L. leucocephala* fertilized with organic fertilizer > *A. mangium* with organic fertilizer > *L. leucocephala* with organic fertilizer > *A. mangium* (control) > *L. leucocephala* (control); the values were 6.29 > 5.30 > 5.12 > 4.89 > 3.07 > 3.02 mg/kg, respectively (as shown in Figure 3-a). For As absorption in the leaves, *A. mangium* fertilized with chemical fertilizer absorbed and accumulated the most As, followed by A. mangium fertilized with organic fertilizer > *L. leucocephala* with chemical fertilizer > *A. mangium* (control) > *L. leucocephala* with organic fertilizer > *L. leucocephala* (control); the values were 5.50 > 4.70 > 3.95 > 2.98 > 2.87 > 2.73 mg/kg, respectively (as shown in Figure 3-a

2) Effects of chemical and organic fertilizer on Mn accumulation: The accumulation in the root at 180 days was compared; *A. mangium* fertilized with chemical fertilizer absorbed and accumulated the most Mn, followed by *A. mangium* fertilized with organic fertilizer > *L. leucocephala* with chemical fertilizer > *L. leucocephala* with organic fertilizer > *A. mangium* (control) > *L. leucocephala* (control); the values were 165.95 > 160.51 > 158.45 > 148.24 > 101.01 > 98.99 mg/kg, respectively (as shown in Figure 3-b). With regard to Mn accumulation in the shoots, *A. mangium* fertilized with chemical fertilizer absorbed the most Mn, followed by *A. mangium* (control) > *L. leucocephala* fertilized with chemical fertilizer > *L. leucocephala* with organic fertilizer > *A. mangium* with organic fertilizer > *L. leucocephala* (control); the values were 175.62 > 120.45 > 78.52 > 77.52 > 73.85 > 67.80 mg/kg, respectively (as shown in Figure 3-b). The leaves of *L. leucocephala* fertilized with chemical fertilizer accumulated the most Mn, followed by *L. leucocephala* fertilized with organic fertilizer > *A. mangium* with chemical fertilizer > *A. mangium* with organic fertilizer > *L. leucocephala* (control) > *A. mangium* (control); the values were 209.67 > 190.09 > 169.85 > 155.14 > 120.04 > 100.90 mg/kg, respectively (as shown in Figure 3-b).

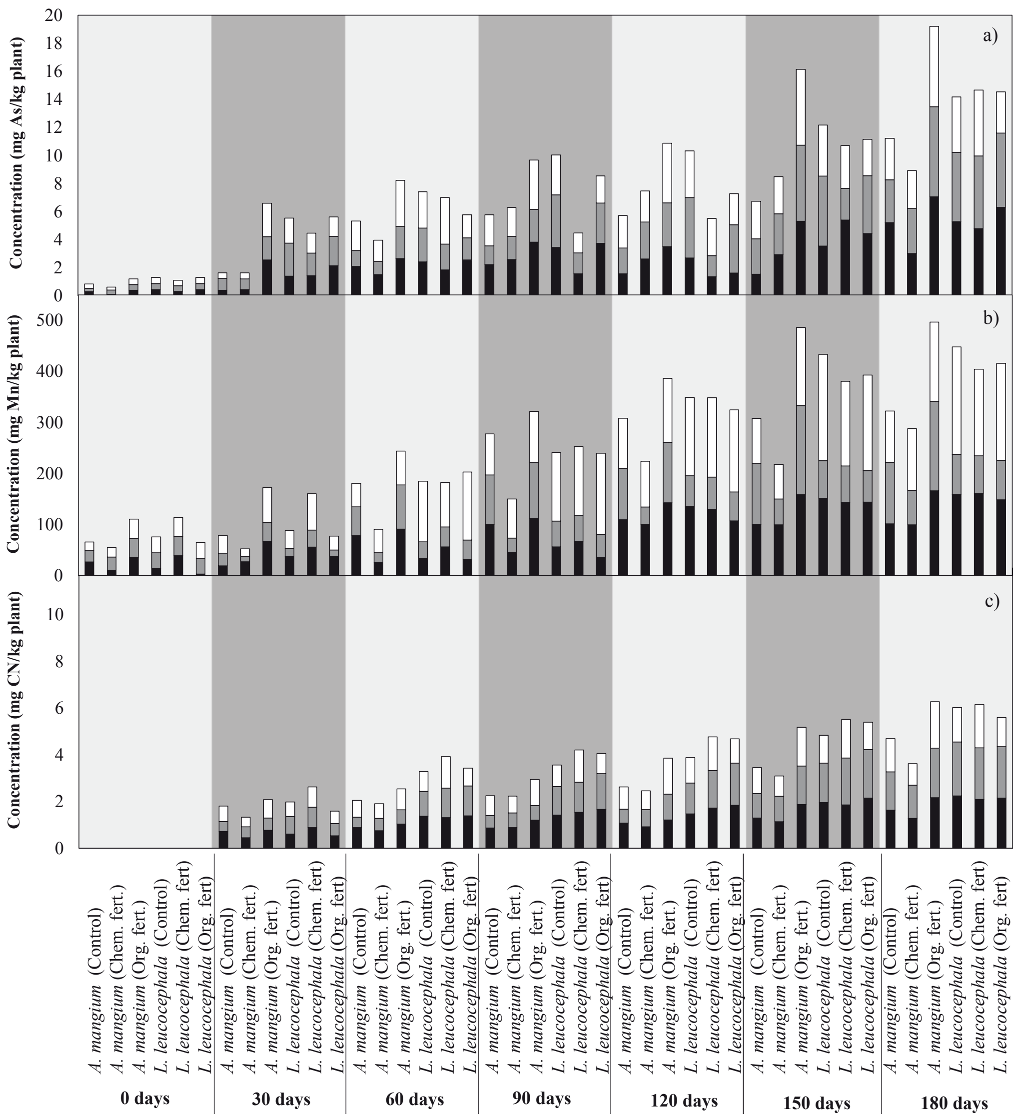

Figure 3. Effects of fertilizer on As, Mn, and CN accumulation in dicot species; a) As in roots, shoots, and leaves, b) Mn in roots, shoots, and leaves, and c) CN in roots, shoots, and leaves

The findings indicated that the dicot species in all six experimental sets accumulated the most Mn in the leaves, followed by the shoots and roots. This result was in line with the study of Hao and Jiang (2015), who investigated the concentration of heavy metals in soil and plants in a manganese mining in Chongqing, China. They studied the plants and soil from five zones in the area and analyzed the concentrations of Mn, Cd, Cu, Pb, and Zn using 37 plant species. The results showed that Miscanthus sinensis and Stenoloma chusanum accumulated Mn in the leave at 323-8,434 mg/kg

3) Effects of chemical and organic fertilizer on CN accumulation: At the end of the experiment at 180 days, the root of *L. leucocephala* fertilized

with chemical fertilizer accumulated the most CN, followed by *L. leucocephala* fertilized with chemical fertilizer > *A. mangium* with chemical fertilizer > *A. mangium* with organic fertilizer > *A. mangium* (control) > *L. leucocephala* (control); the values were 2.22 > 2.18 > 2.17 > 2.09 > 1.67 > 1.29 mg/kg, respectively, as shown in Figure 3-c. This was consistent with the study of Chen *et al.* (2004) on cadmium absorption by wheat with the addition of phosphorus at various levels. The results showed that the root of wheat accumulated the most cadmium, followed by the stem > shoots > grain. For CN absorption and accumulation in the shoot, *L. leucocephala* fertilized with chemical fertilizer absorbed the most CN, followed by *L. leucocephala* fertilized with chemical fertilizer > *A. mangium* with chemical fertilizer > *A. mangium* with organic fertilizer > *A. mangium* (control) > *L. leucocephala* (control); the values were 2.39 > 2.29 > 2.28 > 2.10 > 1.69 > 1.45 mg/kg, respectively (as shown in Figure 3-c). With regard to CN accumulation in the leaves, *A. mangium* fertilized with chemical fertilizer absorbed the most CN, followed by *A. mangium* fertilized with organic fertilizer > *L. leucocephala* with chemical fertilizer > *A. mangium* (control) > *A. mangium* with chemical fertilizer > *L. leucocephala* (control); the values were 1.99 > 1.80 > 1.45 > 1.44 > 1.2 > 0.91 mg/kg, respectively (as shown in Figure 3-c). Additionally, the experimental sets fertilized with organic fertilizer caused the retention of heavy metals in the soil, which resulted in a lower ability to absorb CN compared to that of the sets fertilized with chemical fertilizer.

The effects of chemical and organic fertilizer on As, Mn, and CN accumulation in plants showed that the plants in the experimental sets fertilized with chemical fertilizer absorbed more As, Mn, and CN than the sets fertilized with organic fertilizer because adding chemical fertilizer enhanced metal absorption from the tailings.

As, Mn, and CN accumulation in tailings from the tailing storage facility (TSF)

The evaluation of the amounts of As, Mn, and CN in the tailings during the experimental period from 0-180 days showed that As, Mn, and CN tended to decrease as the duration of the experiment increased.

The amount of As accumulated in the tailings based on the plots of monocot species from 0-180 days was 48.12-40.05 mg/kg. It was found that on the 180th day, the experimental set of *V. nemoralis* fertilized with chemical fertilizer had the lowest As accumulation in the tailings with a value of 40.05 mg/kg, as shown in Table 1. For dicot species, the amount was 40.32-39.01 mg/kg. On the 180th day, the experimental set of *A. mangium* fertilized with chemical fertilizer had the lowest As accumulation in the tailings with a value of 39.01 mg/kg, as shown in Table 2. With regard to the amount of Mn in the tailings of monocot species samples, the accumulation from 0-180 days was 1,480.80-1,436.08 mg/kg. On the 180th day, the experimental set of *V. nemoralis* fertilized with organic fertilizer had the lowest Mn accumulation in the tailings with a value of 1,436.08 mg/kg, as shown in Table 1. For the dicot species, the amount was 1,199.23-1,170.45 mg/kg. On the 180th day, the experimental set of *V. nemoralis* fertilized with chemical fertilizer had the lowest Mn accumulation in the tailings with a value of 1,170.45 mg/kg, as shown in Table 2. CN accumulation in the tailings of the monocots from 0-180 days was 1.43-0.78 mg/kg. On the 180^{th} day, the experimental set of *V. nemoralis* fertilized with chemical fertilizer had the lowest CN accumulation in the tailings with a value of 0.78 mg/kg, as shown in Table 1. For the dicot species, CN accumulation was 1.20-1.03 mg/kg. On the 180th day, the experimental set of *V. nemoralis* fertilized with chemical fertilizer had the lowest CN accumulation with a value of 1.03 mg/kg, as shown in Table 2. The results illustrated that As, Mn, and CN accumulation in the experimental sets with chemical fertilizer was likely to decrease more than that in the sets fertilized with organic fertilizer. This is in line with the research of Sampanpanish and Wanapan (2016) who examined the effects of phosphorus fertilizer on the absorption and accumulation of Cd and Zn by sugarcane. The experiment was divided into two portions: 1) a field study that collected samples of soil and sugarcane from a contaminated area in Mae Sot, Tak Province, and 2) a nursery study using soil from Mae Sot, Tak Province. The findings showed that the experiment in the nursery using the soil from Mae Sot, Tak Province, which included added phosphorus fertilizer, yielded a reduced level of Cd and Zn accumulation in the soil.

Generally, CN and As are highly toxic to humans and the environment. CN is also toxic when inhaled from the air. CN is not persistent in water or soil. Long-term exposure to moderate levels may result in breathing difficulties, heart pain, vomiting, blood changes, headaches, convulsions and thyroid problems. Exposure to extremely high levels might result in damage to the brain or heart and cause coma or even death. As also persists in the environment and accumulates in living organisms. Exposure to extremely high levels of arsenic is fatal. Direct contact with the skin can cause burning and irritation. Long-term exposure to some arsenic compounds has been linked to skin and lung cancers. Mn is naturally distributed in the environment and, at normal levels, will not harm humans or the environment. Generally, trace amounts of Mn are actually essential to plants and animals. Mn is not a pollutant and has no such effects on the global environment (SEPA, 2018).

Table 1 Amount of As, Mn, and CN accumulation in tailing storage facility (TSF) in monocot species plots

Monocot Plots	Heavy metal	Days						
		0	30	60	90	120	150	180
V. nemoralis (Control)	As	56.77±0.00	54.89±0.08	53.10±0.02	52.32±0.02	51.05±0.01	49.32±0.01	48.11±0.01
	Mn	1530.76±0.22	1525.08±0.59	1520.82±0.18	1500.58±0.08	1488.75±1.01	1480.82±1.22	1473.86±2.95
	CN	1.41±0.01	1.39±0.01	1.21±0.01	1.18±0.01	1.17±0.01	1.01±0.02	0.94±0.02
B. bambos (Control)	As	45.01±0.01	44.21±0.03	43.21±0.00	43.12±0.02	42.07±0.01	42.02±0.01	41.94±0.04
	Mn	1531.11±0.01	1526.17±0.06	1522.08±0.45	1516.22±0.58	1500.37±0.53	1496.08±0.46	1481.25±0.41
	CN	1.49±0.01	1.41±0.02	1.34±0.01	1.21±0.01	1.18±0.01	1.21±0.01	0.98±0.01
V. nemoralis (Chem. fert.)	As	49.87±0.01	49.33±2.08	48.31±0.04	48.10±0.05	48.01±0.02	47.98±0.04	40.05±0.04
	Mn	1521.39±0.92	1510.79±0.60	1500.69±0.58	1464.09±7.76	1461.26±0.66	1460.80±1.06	1458.88±0.00
	CN	1.43±0.00	1.30±0.02	1.19±0.02	1.09±0.02	0.95±0.04	0.86±0.06	0.77±0.01
B. bambos (Chem. fert.)	As	41.64±1.32	41.02±0.70	41.19±0.28	41.06±0.44	40.95±0.54	40.90±0.50	41.52±0.59
	Mn	1525.56±0.00	1509.66±5.13	1503.95±0.44	1495.68±5.76	1489.67±5.76	1481.71±3.16	1475.72±5.79
	CN	1.44±0.00	1.32±0.02	1.20±0.02	1.18±0.02	0.99±0.05	0.90±0.08	0.88±0.01
V. nemoralis (Org. fert.)	As	47.70±0.05	43.33±0.03	41.71±0.02	46.37±0.02	45.07±0.02	43.90±0.01	42.11±0.02
	Mn	1528.96±0.05	1519.66±0.91	1506.39±3.60	1501.73±2.86	1494.41±3.92	1459.24±5.41	1436.06±0.04
	CN	1.42±0.00	1.37±0.02	1.21±0.02	1.19±0.02	1.05±0.10	0.96±0.02	0.93±0.01
B. bambos (Org. fert.)	As	49.50±0.54	47.42±0.63	48.23±0.44	45.29±0.63	42.69±2.21	43.23±0.97	43.12±0.91
	Mn	1522.20±0.01	1519.72±0.72	1510.89±0.97	1506.18±3.78	1492.60±5.62	1464.60±2.11	1456.41±0.31
	CN	1.46±0.00	1.39±0.01	1.22±0.03	1.18±0.01	1.12±0.02	0.99±0.11	0.95±0.01

Table 2 Amount of As, Mn, and CN accumulation in tailing storage facility (TSF) in dicot species plots

Dicot Plots	Heavy metal	Days						
		0	30	60	90	120	150	180
A. mangium (Control)	As	46.61±0.01	44.13±0.02	43.09±0.01	42.61±0.05	41.22±0.02	41.22±0.57	40.32±0.03
	Mn	1580.54±0.23	1568.35±0.52	1390.79±0.20	1399.17±0.50	1240.51±0.03	1230.78±0.45	1198.93±0.52
	CN	1.41±0.01	1.38±0.01	1.21±0.02	1.18±0.01	1.15±0.03	1.17±0.01	1.15±0.02
L. leucocephala (Control)	As	45.01±0.01	45.20±0.01	42.89±0.10	41.83±0.05	41.02±0.02	40.53±0.03	40.13±0.02
	Mn	1599.08±0.80	1590.36±057	1402.76±0.64	1257.38±0.44	1237.23±0.58	1230.58±0.42	1200.06±0.04
	CN	1.42±0.02	1.32±0.02	1.32±0.03	1.32±0.03	1.24±0.01	1.22±0.02	1.20±0.01
A. mangium (Chem. fert.)	As	49.83±0.03	43.13±0.10	40.86±0.55	40.27±0.87	39.16±0.17	39.08±0.01	39.01±0.00
	Mn	1540.33±0.00	1510.57±0.42	1336.34±11.27	1233.25±2.91	1217.21±6.13	1211.87±3.22	1170.43±0.03
	CN	1.42±0.01	1.32±0.02	1.21±0.02	1.11±0.03	1.09±0.06	1.06±0.06	1.04±0.02
L. leucocephala (Chem. fert.)	As	42.40±0.00	43.93±0.52	42.21±0.86	41.16±0.71	40.27±0.44	39.80±0.66	39.77±0.00
	Mn	1570.45±0.00	1540.67±0.58	1386.74±5.26	1236.89±5.18	1226.28±7.40	1215.77±6.62	1181.12±0.01
	CN	1.46±0.00	1.32±0.02	1.28±0.02	1.18±0.02	1.16±0.01	1.15±0.02	1.14±0.01
A. mangium (Org. fert.)	As	48.50±0.59	45.00±0.56	43.01±0.76	41.82±0.51	41.85±0.00	40.12±0.00	39.89±0.00
	Mn	1578.11±0.01	1559.00±2.48	1424.07±3.24	1374.96±6.22	1266.87±9.58	1230.38±5.46	1190.56±0.01
	CN	1.42±0.00	1.34±0.02	1.23±0.02	1.19±0.02	1.18±0.02	1.17±0.00	1.16±0.01
L. leucocephala (Org. fert.)	As	46.78±0.67	46.39±0.52	42.80±0.55	41.56±1.25	41.41±0.58	40.63±0.56	39.92±0.60
	Mn	1588.75±0.05	1547.78±5.69	1476.58±3.98	1386.78±5.13	1265.34±4.21	1232.05±5.92	1182.74±0.06
	CN	1.47±0.01	1.38±0.01	1.23±0.03	1.19±0.02	1.18±0.02	1.15±0.00	1.14±0.01

Conclusion

The study of the effects of fertilizer use on As, Mn, and CN accumulation in monocot and dicot species concluded that the dry weight of the experimental plants (monocot and dicot species) increased for all intervals of the experiment. Regarding the effects of fertilizer type on As, Mn, and CN absorption by the plants in tailings from the tailing storage facility (TSF), it was shown that *V. nemoralis* and *A. mangium* in the experimental sets fertilized with chemical fertilizer had a higher ability to absorb As, Mn, and CN than that in the sets fertilized with organic fertilizer. Furthermore, the results indicated that *V. nemoralis* absorbed and accumulated the most As and Mn in the underground part (root), while absorbing and accumulating the most CN in the aboveground parts (shoot, leaf). *A. mangium* absorbed and accumulated the most As and Mn in the leaves, whereas it absorbed and accumulated the most CN in the shoots. Therefore, the study area (which was the tailing storage facility (TSF)) should allow for the growth of *A. mangium* (dicot) and *V. nemoralis* (monocot) and enhance the efficiency of As, Mn, and CN absorption and accumulation by adding chemical fertilizer. The most appropriate growing duration was 120 days, which was sufficient to reduce contamination. These plants had excellent potential to absorb toxins or were able to reduce the amounts of heavy metals. Moreover, *A. mangium* and *V. nemoralis* are native plants, which could be applied as a solution to the problem of As, Mn, and CN contamination in soil.

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References

Chanjarat W, Arunsiri K, Wanna P. Emission effects of nitrogen from livestock release on growth rate and yield product of brassica plants. Journal of Plant Conservation and Research Center. Kasetsart University 2007; 1(1): 12.

Chen Y, Shen Z, Li X. The use of vetiver grass (*Vetiveria zizanioides*) in the phytoremediation of soils contaminated with heavy metals. Applied Geochemistry 2004; 19(10): 1553-1565. doi.org/10.1016/j.apgeochem.2004.02.003.

Chen YP, Rekha PD, Arun AB, Shen FT, Lai WA, Young CC. Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities. Applied Soil Ecology 2006; 34(1): 33-41. doi.org/10.1016/j.apsoil.2005.12.002

Department of Groundwater Resources. The study of groundwater contamination and the monitoring network from toxic in the area of the Tab khoa, Wang Sai poon districts, Phichit Province and Wang Pong district, Phetchabun Province. Ministry of Natural Resources and Environment, Thailand. 2015.

Department of Health. Monitoring guidelines for risk areas: case study for gold mining. Department of Health, Ministry of Public Health, Thailand. 2015.

Faculty of Agro-Industry. Basic soil science. Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok: Kasetsart University Press, Thailand. 1998.

Hao Q, Jiang C. Heavy metal concentrations in soils and plants in Rongxi Manganese Mine of Chongqing, Southwest of China. Acta Ecologica Sinica 2015; 35(1): 46-51. doi.org/10.1016/j.chnaes.2015.01.002.

Hattsu, Hatsu. In-house method OR-082-TM. Shoku-Ki-Hattsu/Shoku-Kan-Hatsu No. 1121002. Labour and Welfare, Japan Ministry of Health. 2002.

Hoffmann WA, Poorter H. Avoiding bias in calculations of relative growth rate. Annals of Botany 2002; 90(1): 37-42.

Lorenz SE, Hamon RE, Mcgrath SP, Holm PE, Christensen TH. Application of fertilizer cations affect cadmium and zinc concentrations in soil solutions and uptake by plants. European journal of soil science 1994; 45(2), 159–165. doi.org/10.1111/j.1365-2389.1994.tb00497.x

Mganga N, Manoko M, Rulangaranga ZK. Classification of plants according to their heavy metal content around North Mara gold mine, Tanzania: Implication for phytoremediation. Tanzania Journal of Science 2011; 37(1): 109-119.

Sampampanish P, Suchera R, Chantra Tongcumpou. Effect of phosphorus in commercial fertilizers on phytoavailability cadmium and zinc uptake by sugarcane. Proceeding of the Fourth International Conference on Waste Management and the Environment (Waste Management 2008), Granada University; 2-4 June 2008a, pp. 739-749, Spain

Sampanpanish P, Chaengcharoen W, Tongcumpou C. Heavy metals removal from contaminated soil by siam weed *(Chromoleana odorata)* and vetiver grass *(Vetiveria zizanoides)*. Research journal of chemistry and environment 2008b; 12: 23-33.

Sampanpanish P. *Phytoremediation*, 1st ed. Thailand: Chulalongkorn University Press, Thailand. 2015.

Sampanpanish P, Wanapan P. Effect of Chemical Fertilizer on Cadmium Uptake by Sugarcane Grown in Contaminated Soil. International Journal of Agricultural Research 2016; 11(4): 126-134. doi.org/10.3923/ijar.2016.126.134.

SEPA, Cyanide (CN), Arsenic (AS), Manganese (Mn). Scottish Environment Protection Agency, Online available: http://apps.sepa.org. uk/spripa/Pages/SubstanceInformation. aspx?pid=6 [Accessed, June 12, 2018]

Suphachai A, Takagaki M, Chaireag S, Sutevee S, Inubushi K. Effect of amount of nitrogen fertilizer on early growth of leafy vegetables in Thailand. Japanese Journal of Tropical Agriculture 2006; 50(3): 127-132.

USEPA. Microwave assisted acid digestion of siliceous and organically based matrices. Method. 3052, Washington D.C., USA. 1996.

USEPA. Microwave Assisted Acid Digestion of Aqueous Samples and Extracts. Method. 3051A, Washington D.C., USA. 1998.