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Phytoremediation potential of sunn hemp for carbaryl-contaminated soil

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ABSTRACT: Phytoremediation of pesticide residue has been an efficient method for the removal of soil contaminants. This research examined the ability of sunn hemp to remove carbaryl residue in carbaryl-contaminated soil from the field. The sunn hemp plants were grown in soil contaminated with carbaryl that had been spiked at 73.5 and 147.25 mg/kg for 0, 4, 8, and 12 days. The results showed that in a soil pot system, sunn hemp could significantly increase shoot length (1.9-fold) and leaf number (1.9-fold) at a carbaryl concentration of 147.25 and 73.5 mg/kg, respectively, from day 4 to day 12 of cultivation. Although the plant could grow, carbaryl toxicity caused a significant decrease in the total chlorophyll (2.8-fold) and carotenoid (3.5-fold) contents when exposed to the high carbaryl concentration of 147.25 mg/kg from day 4 to day 12 of cultivation. Notably, carbaryl removal in the soil containing carbaryl at 73.5 and 147.25 mg/kg achieved residual levels of 0.0–3.8 mg/kg in the soil containing sunn hemp after cultivation for 4, 8, and 12 days. Carbaryl could be accumulated in the leaves (0.00–0.30 mg/kg) and roots (0.12–4.44 mg/kg) of sunn hemp grown in contaminated soil after 12 days of cultivation. Carbaryl could be degraded to 1-naphthol in the soil and plant. The results confirmed that sunn hemp could enhance carbaryl removal from contaminated soil based on phytoaccumulation and possible phytodegradation abilities.

KEYWORDS: carbaryl, sunn hemp, phytoremediation, rotation crop, leguminous plant

INTRODUCTION

Plant biomass, especially from leguminous plants, can be used as green manure in a crop rotation. Leguminous plants can support biological nitrogen fixation and phosphate-solubilizing bacteria. They can be alternative nitrogen sources in organic and sustainable agriculture systems. Green manure and organic fertilizer primarily produce organic matter, which improves the chemical, physical, and biological properties of soil, including the crop yield [1]. Leguminous plants that can be used as green manure include *Sesbania rostrata* (sesbania pea), *Crotalaria juncea* L. (sunn hemp), *Canavalia ensiformis* L. (jack bean), and *Vigna* spp. (mungbean). These plant species contain nitrogen (N) 2.34–2.87%, phosphorus (P) 0.22–0.54%, potassium (K) 1.11–2.46%, calcium (Ca) 0.82–1.53%, magnesium (Mg) 1.59–2.04%, and sulfur (S) 0.48–2.27% [1]. The nutrient content in green manure that can be utilized as chemical fertilizer can be determined using the nutrient content (N, P, and K), which costs in the range of USD 95–185/ha. Thus, the nutrient content in these green manure crops can be cheap and useful sources of crop macronutrients and micronutrients [1]. Among leguminous plants, sunn hemp has shown promise for use in amendment soil due to its short lifespan in a rotation period, and it has been reported to reduce arthropod pests when intercropped with vegetable plants such as zucchini [2].

Carbaryl is a chemical used for pest control on farmland to augment crop and livestock protection, including its application in residential areas for humans and their pets. Carbaryl is classified in the carbamate group of pesticides, which includes carbofuran and carbosulfan, and its chemical name is 1-naphthalenyl methyl carbamate. Carbaryl is a widely used, broad-spectrum insecticide in agriculture and horticulture on a wide range of crops, including corn, soybean, cotton, fruit, nut, vegetable crops, and rice, as well as in residential settings such as home yards and gardens,

for the control of grasshoppers, crickets, and aphids that damage grasses and other vegetation by consuming the stems and leaves, restricting plant growth (through browsing) and seed production, thus reducing grain productivity. Carbaryl has a water solubility of 36 mg/l at 20 °C [3]. It moves and transforms in the environment by processes including persistence and degradation, with mobility and migration potential to ground and surface water and plant uptake. Its half-life is in the range of 4–253 days, depending on the pH and aerated soil conditions. Carbaryl is non-persistent, and its primary degradate is 1-naphthol. Toxicity of carbaryl in acute and chronic exposure to humans is expressed via cholinesterase inhibition, a reduced enzymatic level in the blood, neurological effects, and symptoms including headache, memory loss, muscle weakness and cramps, and anorexia. The acceptable daily intake is 0–0.008 mg/kg body weight, and the standard for maximum residue limits in agricultural products is 0.02–10 mg/kg [4]. 1-Naphthol is the major degradate of carbaryl under aerobic and anaerobic conditions in soil and water. The degradation of 1-naphthol is expected to be less persistent in the field than carbaryl [3].

Phytoremediation is a promising technology based on the use of plants to remove, degrade, or detoxify toxic substances such as heavy metals and pesticides [5–7]. It has been applied for soil decontamination based on phytostabilization, phytodegradation, rhizofiltration, phytovolatilization, and phytoextraction [5]. Phytoextraction and phytoaccumulation are phytoremediation processes whereby plant tissue helps to remove pollutants by direct uptake from wastewater and contaminated soil. Many plants have the ability to accumulate and tolerate high concentrations of pollutants while maintaining a rapid growth rate. Phytodegradation involves the degradation of organic contaminants directly through the release of enzymes from the roots or through metabolic activities within plant tissues, including the rhizosphere of plant roots and microbes [8]. Flowering plants and leguminous plants such as the lupine, sunflower, and morning glory have been reported to facilitate carbaryl phytoextraction and carbofuran phytodegradation [6, 7, 9]. Marigold and pot marigold have been reported to assist in the phytoremediation of heavy metals [10, 11]. Recently, sunflower (*Helianthus annuus* L.), marigold (*Tagetes erecta*), and sunn hemp (*C. juncea* L.) have been reportedly used in carbaryl phytoextraction and phytodegradation from a water-contaminated solution [12]. Thus, the objective of the present research was to investigate the phytoextraction ability of sunn hemp, a leguminous plant, for carbaryl removal in a soil pot experiment. Toxicity symptoms, plant physiology, and carbaryl accumulation in sunn hemp were determined after culture in a carbaryl-contaminated soil system.

MATERIALS AND METHODS

Sunn hemp cultivation

Sunn hemp plants were germinated for 2–3 days, then planted in a soil pot system, and watered every 2 days. The plants were grown for 36 days and then transferred to pots containing carbaryl-contaminated soil. Soil samples without and with sunn hemp plants were spiked with 0, 73.5, or 147.25 mg/kg of carbaryl into 0.1 mg/kg carbaryl-contaminated soil before collecting the plant and soil samples at 0, 4, 8, and 12 days of cultivation. The carbaryl concentrations used in the study were prepared according to the label of the product practical application of 85% carbaryl concentration of 1 g/l for the agricultural field and to the concentrations that might be left as residue in the field as well as agricultural products [3, 4]. The soil used in this study was from a carbaryl-contaminated field. Before the sunn hemp cultivation, the soil was collected and determined for its physicochemical properties (Table 1). The following determination methods were used to determine total nitrogen [13], organic matter (OM) [14], and pH and the cation exchange capacity (CEC) [15]. The size of the pot used was 4-inch pot for each 36-day-old plant cultivar. The soil was homogeneously mixed with water or carbaryl solutions, 500 g of which was added to each pot. The plant cultivar was completely randomized design when transferred to the soil pots. The plants were cultivated indoor with a light intensity of approximately 10,000 lux and daylight:darkness photoperiod of 10 h:14 h at 28 ± 2 °C. During the sunn hemp transfer and cultivation, a chemical fertilizer – Osmocote (N-P-K: 13-13-13% or N-P_2O_5-K_2O: 13-5.7-10.8%.) was added once to the soil in the pots that were watered 25 ml every 2 days for enhancing the plant growth under low nutrients N, P, and K (Table 1). The plant cultivation was conducted in triplicate.

Toxicity symptoms and plant growth

The toxicity symptoms of sunn hemp exposed to carbaryl at 0, 73.5, or 147.25 mg/kg were observed and determined on leaf, stem, and root samples for plant growth. Shoot length, root length, and leaf number were determined as well as the pigment contents in terms of the amounts of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid in shoot [16]. Samples (1.5 g each) of plant shoots cultivated for 4, 8, and 12 days were ground, and pigment extraction was performed using 7.5 ml of 80% acetone for 2 min. Each solution sample (5 ml each) was transferred and centrifuged at 3,000 rpm for 3 min, after which it was spectrophotometrically determined for its chlorophyll a, b, and carotenoid contents at wavelengths of 663, 645, and 480 nm, respectively. The amounts of pigment contents were calculated using methods from Sooksawat et al [16].

Table 1 Physicochemical properties of carbaryl-contaminated soil from field.

Soil physicochemical property	Carbaryl-contaminated soil from field		
	0 mg/kg	73.5 mg/kg	147.25 mg/kg
Carbaryl concentration (mg/kg)	0.10	89.52	148.60
Organic matter (g/kg)	106	107	102
pH	6.5	6.6	6.7
Cation exchange capacity ($cmol_c$/kg)	26.2	26.0	23.7
Electrical conductivity (dS/m)	1.86	1.83	1.52
Total nitrogen (g/kg)	3.52	4.13	3.80
Total phosphorus (g/kg)	1.35	1.51	1.38
Total potassium (g/kg)	1.97	2.10	1.79

0 mg/kg = control soil.

Carbaryl accumulation in sunn hemp

Carbaryl and its degradate (1-naphthol) in the shoot and root samples of sunn hemp and their residues in the soil were determined using high performance liquid chromatography (HPLC) [17, 18]. The samples were tested after sunn hemp cultivation in contaminated soil with carbaryl concentrations of 0, 73.5, or 147.25 mg/kg for 0, 4, 8, and 12 days of exposure. The carbaryl and 1-naphthol were HPLC grade and purchased from Sigma-Aldrich, USA and Supelco, USA, respectively. The preparation of the standard solution and the carbaryl and 1-naphthol extracted samples from plant and soil samples followed the methods from Biswas et al and Ozhan et al [17, 18]. Plant samples were cut and separated into shoots and roots, then their respective weights were recorded. Each sample (1 g) of plant and included soil was ground and extracted for carbaryl and 1-naphthol using 3 ml of acetonitrile for 15 min at room temperature. The mixture was vortexed for 1.5 min, left for 5 min, added with 2 ml of distilled water, and vortexed again for 1 min. This mixture was centrifuged at 3,000 rpm for 15 min, after which the supernatant was collected. The sample was passed through a 0.2-μm filter and kept in a freezer before the HPLC analysis within 2 weeks. All HPLC analyses were performed on an Agilent Infinity II 1260 HPLC system (Agilent Technology, USA) connected to a photodiode array detector. Chromatographic separation was carried out in a Phenomenex Luna C18 column (250 mm × 4.6 mm; Phenomenex, Germany). An acetonitrile gradient (40–60%) was used as the mobile phase for 20 min. The back-to-initial condition was 10 min. The run time for each sample was 20 min with an injection volume of 20 μl.

Data analysis

All experimental data were determined in triplicate, and the raw data was subjected to statistical analysis using the SPSS software (SPSS Inc, USA). Analysis of Variance (ANOVA) and Tukey's honestly significant difference (HSD) were used to determine significant differences between mean values at a confidence level of 95%.

RESULTS AND DISCUSSION

Effect of carbaryl on sunn hemp growth

The physicochemical properties of the carbaryl-contaminated soil used in the experiment are shown in Table 1. The basal level of carbaryl contamination in the soil was 0.10 mg/kg, while the levels in the carbaryl-spiked soil at 73.5 and 147.25 mg/kg were 89.52 and 148.60 mg/kg, respectively. The values of OM (102–107 g/kg) and pH (6.5–6.7) among the 0, 73.5, and 147.25 mg/kg carbaryl-contaminated soils were comparable. However, the CEC and EC values of the 147.25 mg/kg carbaryl-contaminated soil (23.7 $cmol_c$/kg and 1.52 dS/m, respectively) were slightly lower than those of the 0 and 73.5 mg/kg carbaryl-contaminated soils (26.0–26.2 $cmol_c$/kg and 1.83–1.86 dS/m, respectively). The macronutrients in the 73.5 mg/kg carbaryl-contaminated contained slightly higher total N (4.13 g/kg), total P (1.51 g/kg), and total K (2.10 g/kg) than those in the 0 (3.52, 1.35, and 1.97 g/kg, respectively) and the 147.25 mg/kg (3.80, 1.38, and 1.79 g/kg, respectively) carbaryl-contaminated soils (Table 1).

The effect of carbaryl on the sunn hemp growth is shown in Fig. 1. The shoot length (33.7 cm) of the sunn hemp significantly increased after the carbaryl treatment at 147.25 mg/kg for 12 days compared to that (18 cm) of the untreated plants at 12 days and those (16.0–17.7 cm) of all treatments from 4 days (Fig. 1a). The root lengths of the sunn hemp plants were not affected by the carbaryl treatments at any concentration after 4, 8, and 12 days (Fig. 1b). However, the number of leaves of the sunn hemp plants was affected by carbaryl, having the same trend as the effect on shoot length. The number of leaves of the sunn hemp plants significantly increased after carbaryl treatment at 73.5 mg/kg for 12 days (17.3 leaves) compared to that of treated plants at the same concentration for 4 days (9 leaves, Fig. 1c). These results showed that the carbaryl-treated sunn hemp plants could grow in the carbaryl-contaminated soil at 73.5 and 147.25 mg/kg (Fig. 1a,b).

Carbaryl has the chemical formula $C_{12}H_{11}NO_2$. Naturally, it can be degraded through the intracellu-

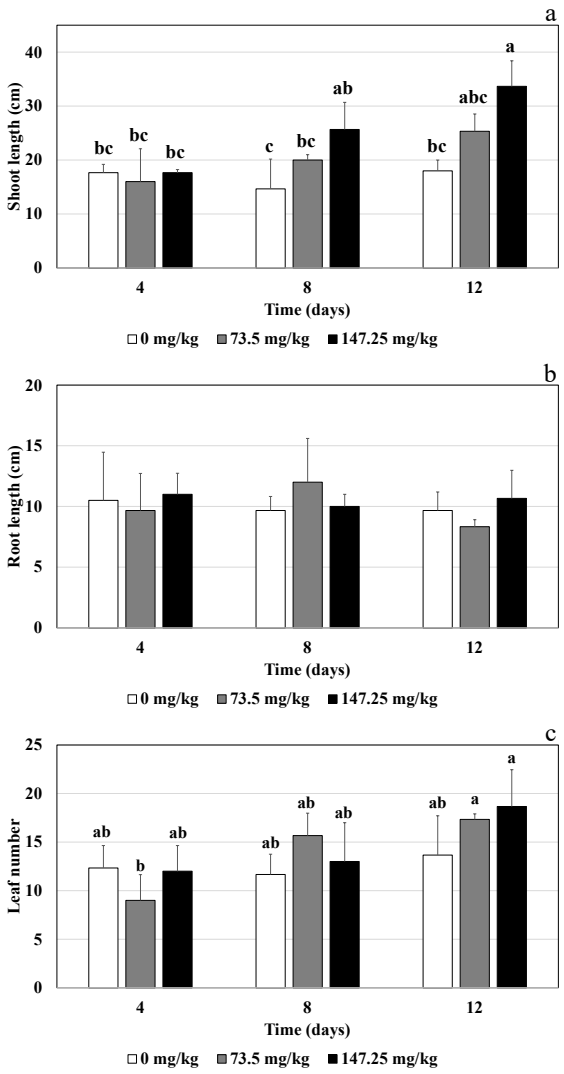

Fig. 1 Effect of carbaryl on different parts of sunn hemp after 4, 8, and 12 days of treatment in soil pots: (a), shoot length; (b), root length; and (c), leaf number. Note: a, b, and c indicate significant differences among different concentrations of carbaryl treated for different periods of cultivation.

lar metabolic pathway in microbes [19]. The *Pseudomonas* sp. strain metabolizes carbaryl (1-naphthyl-N-methylcarbamate) as a sole source of carbon and energy via 1-naphthol, 1,2-dihydroxynaphthalene, and gentisate. Gentisic acid can be metabolized further and enter the Kreb's cycle, a series of biochemical reactions that release the energy stored in nutrients through the oxidation of acetyl-CoA derived from carbohydrates, fats, and proteins, possibly including carbaryl [19]. The intracellular degradation pathway in the plant in the present study possibly utilized carbaryl as a carbon source. Thus, the plant could increase shoot length and leaf number after treatment with carbaryl for 12 days.

Effect of carbaryl on pigment content of sunn hemp

The plant morphology was observed after cultivation of sunn hemp in soil pots with 0, 73.5, or 147.25 mg/kg for 4, 8, and 12 days. The results showed that carbaryl could induce pale-to-white spots on the sunn hemp leaves. The chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid contents in the leave are shown in Fig. 2. The different concentrations of carbaryl did not clearly reduce the total chlorophyll and carotenoid contents in the leaves of sunn hemp; however, all the treated concentrations significantly decreased the chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid contents after 4, 8, or 12 days of treatment (Fig. 2). Thus, a longer time after the treatment exposure to carbaryl caused toxicity symptoms and reduced the pigment contents in the sunn hemp leaves.

Carbaryl and 1-naphthol removal from carbaryl-contaminated soil

The carbaryl and 1-naphthol concentrations left in the soil cultivated with sunn hemp after treatments of the spiked concentrations of carbaryl for 4, 8, and 12 days are shown in Table 2. The soil used to grow sunn hemp had significant reductions in the carbaryl and 1-naphthol concentrations after various treatment times (Table 2). After growing the sunn hemp for 4–12 days, there were significantly reduced carbaryl levels in the ranges of 0.00–1.54 and 0.04–3.78 mg/kg from the soil contaminated with 73.5 and 147.25 mg/kg of carbaryl, respectively. Carbaryl could be degraded to 1-naphthol in the soil with the 1-naphthol being detected in the beginning (day 0) from the soil contaminated with 73.5 and 147.25 mg/kg of carbaryl at levels as high as 0.50 and 0.68 mg/kg, respectively. After growing the sunn hemp for 4 days, there was a significantly reduced 1-naphthol concentration to 0 mg/kg in the soil contaminated with 73.5 mg/kg of carbaryl. At the higher concentration of carbaryl contamination (147.25 mg/kg), the soil growing the sunn hemp had a significant reduction in the 1-naphthol level to 0.00–0.08 mg/kg after 12 days of cultivation. Notably, the soil with no sunn hemp plant had reduced carbaryl levels to 0.06 and 0.78 mg/kg from the original contamination with 73.5 and 147.25 mg/kg, respectively, after 12 days of cultivation, as well as a reduction in 1-naphthol to 0.00 mg/kg in the soils contaminated at all concentrations of carbaryl treated (data not shown). The results suggested that the soil may have microbial activity from the rhizosphere of the sunn hemp, a leguminous plant, that may play a role in carbaryl and 1-naphthol degradation, so that the sun hemp might also support the degradation and removal of these substances in the soil.

Rhizobial bacteria (such as *Rhizobium leguminosarum*) nodulating with sunn hemp have been reported to have high antagonistic potential against

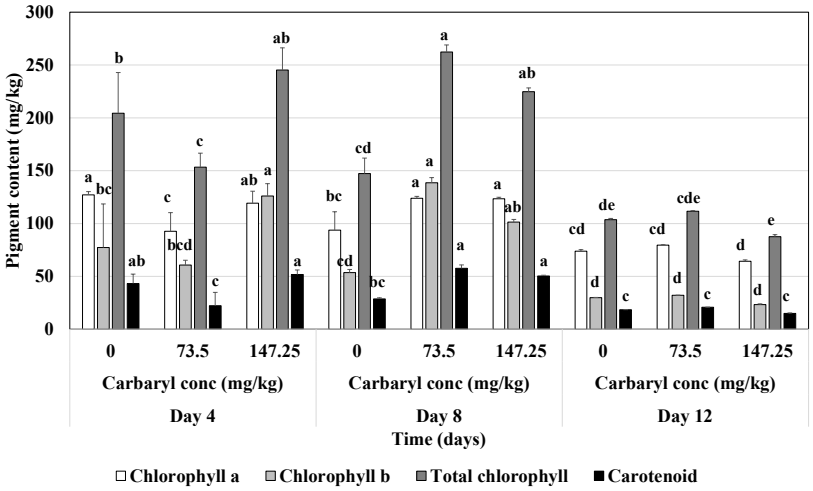

Fig. 2 Effect of carbaryl on pigment contents of sunn hemp after 4, 8 and 12 days of cultivation for carbaryl treatments at 0, 73.5, or 147.25 mg/kg. Note: a, b, c, d, and e indicate significant differences among different concentrations of carbaryl treated for different periods of cultivation.

Table 2 Carbaryl and 1-naphthol concentrations in soil growing sunn hemp after 4, 8, and 12 days of carbaryl treatments at different concentrations in soil pot system, where values (mean ± SD) with different lowercase superscripts in rows are significantly ($p < 0.05$) different.

Time (days)	Carbaryl concentration (mg/kg)			1-Naphthol at carbaryl concentration (mg/kg)		
	0	73.5	147.25	0	73.5	147.25
Control (0 day)	0.10 ± 0.03^{b}	89.52 ± 29.02^{a}	148.60 ± 11.37^{a}	0.00 ± 0.00^{b}	0.50 ± 0.40^{a}	0.68 ± 0.12^{a}
4	0.10 ± 0.17^{b}	1.54 ± 1.34^{b}	3.78 ± 5.26^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
8	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.04 ± 0.07^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.06 ± 0.10^{b}
12	0.00 ± 0.00^{b}	0.04 ± 0.07^{b}	1.10 ± 0.82^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.08 ± 0.14^{b}

0 mg/kg = control soil.

Macrophomina phaseolina, a plant pathogen that causes stem and root rot on many plant species such as soybean, sorghum, and groundnut [20, 21]. *R. leguminosarum* was reported to have grown well in the temperature range of 10–40 °C and pH range of 5.5–9.0, as well as survived when exposed to 3.0% salt stress and had plant growth promotion characteristics such as phosphate solubilization, indole-3-acetic acid (IAA) production, siderophore production, and hydrogen cyanide production, being a macronutrient, a plant hormone, a micronutrient, and a biocontrol compound, for promoting crop growth and crop yield [20]. In the present study, the carbaryl-contaminated soil grown with and without sunn hemp plants had not been sterilized and may have contained a microbial community transferred from the field soil. This soil could remove carbaryl, which had possibly been degraded by physico-chemical, biological, and environmental conditions [3]. Through the process of rhizodegradation, the rhizosphere promotes biodegradation by soil microbes, and the process is facilitated by root exudates (organic molecules) from the plant that sustain populations of soil microbes [8].

Carbaryl and 1-naphthol accumulation in sunn hemp

To determine the accumulation and degradation abilities of sunn hemp, leaf and root samples of the plant were examined. The results showed that after 4 days of soil carbaryl contamination at 0, 73.5, or 147.25 mg/kg, the sunn hemp leaves showed levels of carbaryl accumulation of 0.18, 0.00, and 0.30 mg/kg, respectively, whereas the roots showed levels of carbaryl accumulation of 4.44, 0.12, and 0.36 mg/kg, respectively (Table 3). These results suggested that sunn hemp could accumulate carbaryl in the roots more than in the leaves, as it has been reported in another research. For example, sunn hemp grown in carbaryl-contaminated solutions (5 and 10 mg/l) in a hydroponic system showed root accumulation of carbaryl at a higher level from the solution contaminated with 10 mg/l of carbaryl than with 5 mg/l of carbaryl [12]. The uptake of toxic or mineral substances such as Mg has been recently reported on its different distribution throughout plant parts depending on the substance concentrations [22]. In the present study,

Table 3 Carbaryl degradation in shoots and roots of sunn hemp after 4, 8, and 12 days of carbaryl treatments in soil pot system.

Time (days)	Plant part	Carbaryl concentration (mg/kg)			1-naphthol concentration (mg/kg)		
		0	73.5	147.25	0	73.5	147.25
0	Soil without plant	0.10	89.52	148.60	–	0.50	0.68
4	leaf	0.18	0.00	0.30	–	–	–
	root	4.44	0.12	0.36	–	–	–
8	leaf	–	–	0.12	–	–	–
	root	–	–	–	–	–	–
12	leaf	–	–	–	–	–	–
	root	–	–	–	–	–	–

0 mg/kg = control soil; and – mg/kg is under detectable level.

at the high level of carbaryl contamination in the soil (147.25 mg/kg), there was detectable carbaryl in the leaves of sunn hemp at the lower level of 0.12 mg/kg after cultivation for 8 days, whereas there was no detectable carbaryl concentration in the roots, suggesting that carbaryl might be able to be translocated from the roots to the shoots and leaves of the sunn hemp plant. The plant has the ability to detoxify carbaryl since there was no detectable carbaryl after 8 and 12 days of cultivation. In addition, there was no detectable 1-naphthol in the leaves and roots of the sunn hemp after 4, 8, and 12 days of cultivation. One possible mechanism by which the plant could detoxify carbaryl toxicity is via the degradation to 1-naphthol and then to other substances in the plant. Thus, sunn hemp could grow in soil contaminated with 73.5 or 147.25 mg/kg with increases in the shoot length and leaf number after 12 days of cultivation (Fig. 1a,c). Although the high carbaryl level (147.25 mg/kg) caused reductions in the total chlorophyll and carotenoid contents in sunn hemp leaves (Fig. 2), the plant could accumulate carbaryl in leaves and roots and could remove carbaryl and 1-naphthol down to levels of 1.10 and 0.08 mg/kg from the original spiking at 73.5 and 147.25 mg/kg, respectively (Table 2).

Sunn hemp response by carbaryl accumulation and degradation

A hypothetical model of the plant response to carbaryl accumulation by sunn hemp has been reported [12]. There may be a detoxifying mechanism via reactive oxygen species (ROS), and plant response with internal hormone might get involved to remove carbaryl and 1-naphthol. Gibberellic acid (GA) and IAA may play a role in sunn hemp root elongation when treated with carbaryl in a hydroponic system. Carbaryl and 1-naphthol could be taken up by the elongated root and be translocated to the shoot, while 1-naphthol in the shoot and root of sunn hemp could be degraded inside the plant [12]. The sunn hemp in the present study performed well as a phytoremediator. Carbaryl could be uptake and had been toxic to sunn hemp by reducing the total chlorophyll and carotenoid contents when grown in 147.25 mg/kg contaminated soil for 12 days compared to those for 4 days (Fig. 2); however, the plant had the longest shoot length when cultivated in this soil with 147.25 mg/kg carbaryl (Fig. 1a). The plant seemed to detoxify the toxic carbaryl by root uptake and accumulation, root degradation to 1-naphthol, translocation carbaryl from root to shoot, and finally carbaryl accumulation and degradation to 1-naphthol in shoot in hydroponic system [12]. In soil system, such an attribute could further assist with the production of phytohormones and plant growth-promoting bacteria, including arbuscular mycorrhiza fungal inoculation, to ameliorate the efficacy of the sunn hemp plant for toxic substance decontamination [5]. The soil microbe, for example, the *Pseudomonas* sp. strain metabolizes carbaryl as a sole source of carbon and stores energy via Kreb's cycle pathway [19]. Thus, the soil without sunn hemp could degrade and remove carbaryl within 12 days. In addition, the intracellular degradation pathway in the plant in the present study possibly metabolized and utilized carbaryl as a carbon source, thus shoot growing very well in 12 days exposed to the high level of carbaryl (147.25 mg/kg) and removing carbaryl from the contaminated soil rather soon within 4 days. The present study confirmed that sunn hemp is a good phytoremediator for carbaryl-contaminated soil. The mechanism of plant response in soil system and further additional technique to improve carbaryl removal from soil such as microbe-assisted technique has been needed to be clarified.

CONCLUSION

The present study used carbaryl-contaminated soil from the field to study carbaryl removal by growing sunn hemp, a leguminous plant in a soil pot system. The results showed that sunn hemp showed reduction in pigment contents but could grow well when exposed to carbaryl for long period of 12 days. The shoot length increased when exposed to a high level of carbaryl after being treated with carbaryl compared to non-spiked

soil. Sunn hemp could accumulate more carbaryl in the roots than in the leaves after 4 days of cultivation. The soil with the plant could had a significantly decreased carbaryl concentration and could remove 1-naphthol to a non-detectable level within 4 days. In conclusion, sunn hemp could grow and also efficiently remove a high level carbaryl from carbaryl-contaminated soil within 4 days. Thus, the plant has great phytoremediation potential for use in carbaryl removal from contaminated agricultural soil.

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