IRON OXIDE PARTICLES ASSISTED PHYTOREMEDIATION OF SOIL CONTAMINATED WITH CYPERMETHRIN RESIDUE

Swe Sint[1], Phyu Phyu Myint[2], Saw Hla Myint[3]

Abstract

Cypermethrin is one of the most widely used pyrethroid insecticides against different pests, and its use causes soil contamination. The removal of 3-phenoxybenzoic acid (3-PBA), a secondary metabolite of cypermethrin, from contaminated soil by phytoremediation with four plants species: Peanut (*Arachis hypogaea* L.), Sesame (*Sesamum indicum* L.), Aster (*Callistephus chinensis* (L.) Nees) and Bermuda grass (*Cynodon dactylon* L. Pers.) was investigated in the absence and presence of iron oxide particles (0.01 g/kg of soil). The insecticide residue percent in the soil samples was determined by UV-Vis and GC-MS. The results showed that presence of iron oxide particles is important in the removal of cypermethrin. Good phytoremediation was demonstrated only by Aster and Bermuda grass (64.19 % and 96.7 % PBA removal) in 12 weeks period. Furthermore, the activities of soil urease (mg NH_4^+-N g^{-1} soil h^{-1}) and dehydrogenase (µg TPF g^{-1} soil h^{-1}) also increased in the treated soil samples as determined by phenol-hypochlorite colorimetric method and Triphenyl Tetrazolium Chloride (TTC) assay method: Aster (4.45 ± 0.17) and Bermuda grass (4.68 ± 0.04) compared to uncultivated soil (S_0) (3.74 ± 0.03), and (0.0017 ± 1.547 x 10^{-4}) and (0.0016 ± 1.516 x 10^{-4}) compared to S_0 (0.0008 ± 0.424 x 10^{-4}), respectively. The results demonstrated that Aster and Bermuda grass showed great promising potential as Phyto remediating agents.

Keywords: phytoremediation, iron oxide particles, Peanut, Sesame, Aster, Bermuda grass, insecticide-contaminated soil

Introduction

Soil pollution involves the contamination of soil by various anthropogenic activities which involve the addition of nutrients, pesticides, and sediments to soil (Srivastava *et al.,* 2019). In recent years, the phasing out of organophosphate products such as diazinon and chlorpyrifos has prompted an increased use of pyrethroid insecticides for agricultural pest control. Cypermethrin is classed as a type II pyrethroid and is commonly found in rivers, sediments, soils, and even foodstuff (Bootharaju and Pradeep, 2012). 3-PBA is a vital step for remediation of cypermethrin pollution because it is a common secondary metabolite of the synthetic pyrethroid insecticides. Cypermethrin and its metabolite 3-phenoxybenzoic acid (PBA) have exerted adverse biological impacts on the environment; therefore, it is critically important to develop different methods to enhance their degradation (Xie *et al*., 2008).

Environmental applications of nanoparticles such as cleanup of pollutants from air, water and soil have been done by various approaches, known as remediation. If living plants are involved in the remediation process, that is known as phytoremediation. Phytoremediation is the use of plants directly or indirectly to degrade contaminants from soil and water. Phytoremediation is an effective, nonintrusive and inexpensive of remediating soils (Srivastava *et al.,* 2019). Iron oxides form naturally through the weathering of Fe-containing rocks both on land and in the oceans. They have attracted much attention due to their fine magnetic properties and applications in modern science (Fernandez-Garcia and Rodriguez, 2007).

Enzymes produced by soil microorganisms are natural catalysts of many important processes that occur in soils. For this reason, enzymes may be useful in monitoring the effects of pollution on the soil environment (Malachowska-Jutsz and Matyja, 2019). A reliable assessment

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of soil quality contaminated with organic products is possible by testing the activity of lipase, dehydrogenase, catalases, and ureases. In this study, it focuses on the determination of urease and dehydrogenase activities of soil microorganisms. The aim of this research is to study the iron oxide particles assisted phytoremediation in the soil contamination by cypermethrin residues and its effect on enzymatic activities.

Materials and Methods

Soil Sample Collection

Soil sample was collected from the surface layer (0-20 cm depth) of an agricultural field located in Hpya Thee Village (21º 48' N latitude and 94º 57' E longitude), Myaing Township, Pakokku District, and Magway Region (Figure 1). This field is usually cropped with a chili and tomato rotation without treatment of any pyrethroids insecticide (including cypermethrin) for several years.

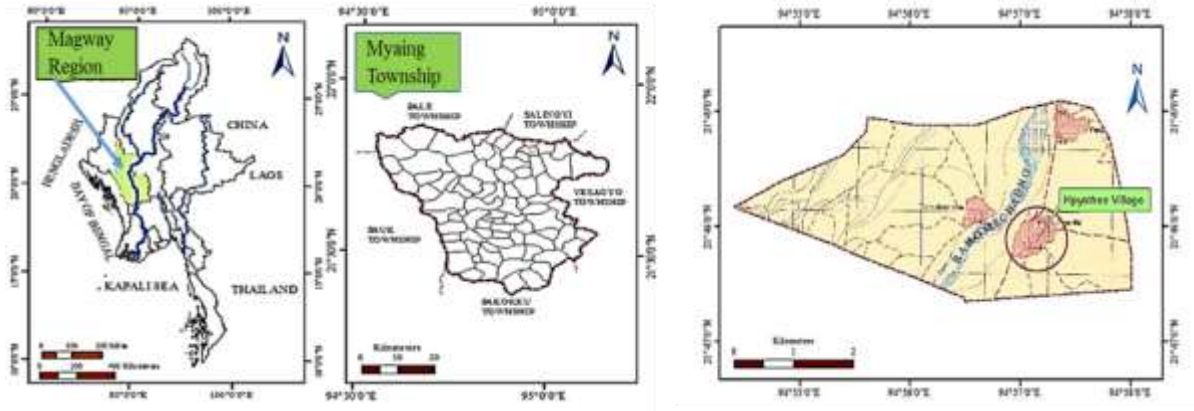


Figure 1 Sample collection site (Hpya Thee Village, Myaing Township, Magway Region)

Determination of Physicochemical Properties of Soil Sample

The moisture content of the soil sample was determined according to the oven dry method, pH value by pH meter, electrical conductivity (EC) value by electrical conductivity meter, organic matter content by Walkley and Black method based upon the oxidizable organic matter content, total nitrogen N content by Kjeldahl's method, cation exchange capacity by the method of Kappen (Jaremko and Kalembasa, 2014*)*, total phosphorus (P) content by spectrophotometric method of Olsen for neutral and alkaline soil, potassium content by ammonium acetate extraction method using flame photometer, and the elemental analysis of the soil sample by EDXRF.

Experimental Design for Determination of Insecticide Degradation in Soil

The experiment was conducted under natural light conditions. The collected soil sample (1 kg) was placed in each plastic pot. In this study, iron oxide particles were synthesized by green method, by adding 0.01 M $FeCl_3.6H_2O$ solution to the tea extract in a 1:1 volume ratio and vacuum filtered to separate the black iron oxide particles from the liquid phase. The sizes and shapes of the iron oxide particles were determined by XRD, FT IR, TG-DTA and FESEM-EDX analyses.

The experimental pots were arranged according to a random design that consists of nine treatments: (1) S_0: only cypermethrin contaminated soil, (2) S_{Fe}: cypermethrin contaminated soil with iron oxide particles (3) S_{0p}: S_0 with Peanut plant (4) S_{0s}: S_0 with Sesame plant (5) S_{0a}: S_0 with

Aster plant (6) S_{0b}: S_0 with Bermuda grass plant (7) S_{Fep}: S_{Fe} with Peanut plant (8) S_{Fes}: S_{Fe} with Sesame plant (9) S_{Fea}: S_{Fe} with Aster plant and (10) S_{Feb}: S_{Fe} with Bermuda grass plant.

For S_0, dried soil samples (10 g) and H_2O (1 mL) were placed in a 150 mL cup. For S_{Fe}, dried soil samples (10 g) and H_2O (1 mL) and 1% Fe_3O_4 (1 mL) were placed in a 150 mL cup. To each cup, 1 mL each of 0.0001 % cypermethrin solution was thoroughly mixed. In this way 45 cups each of S_0 and S_{Fe} were prepared. All the containers were covered with perforated aluminum foil to ensure gas exchange and then incubated at 25 ºC. Ninety pots were used for all treatments, each treatment has 9 pots for three different times of sample collection, at 0, 2 and 12 weeks (with three replicates for each time) from the time of exposure to determine the amount of secondary metabolite of cypermethrin (3-phenoxy- benzoic acid, 3-PBA) formed and urease and dehydrogenase enzyme activities. Thus each treatment was amended with cypermethrin insecticide concentration of 100 µg/g soil.

Extraction and Characterization of Insecticide Residue

In brief, PBA was extracted from 10 g of soil samples using methanol and dichloromethane (3:1, v/v) and placed in shaker at 150 rpm for 30 min. The supernatant liquid was centrifuged at 5000 rpm for 15 min in three times. The residual insecticide (as its metabolite 3-PBA) in extracted soil samples from the experimental plot was examined by using UV-Vis spectrophotometer and GC-MS.

Determination of the Urease Enzyme Activity

The activity of the urease enzyme (mg NH_4^+-N g^{-1} soil h^{-1}) was measured by colorimetric methods (Guo and Cai, 2012). A 10 g of fresh soil was placed in a 100 mL volumetric flask and treated with 1 mL of toluene, 10 mL buffer (pH-7) and 5 mL of 10 % urea solution (freshly prepared). After a thorough mixing, the flask was incubated for 3 h at 37 ºC in dark. After incubation, the volume was made up to 100 mL with distilled water. The ammonia released as a result of urease activity was measured by indophenol blue method with the spectrophotometer at 630 nm.

Determination of the Dehydrogenase Enzyme Activity

Dehydrogenase enzyme activity was assayed by modified 2,3,5 triphenyl tetrazolium chloride (TTC) reduction technique (Casida *et al.,* 1964). Five grams of soil was placed in a test tube (15 x 2 cm) and carefully mixed with 0.1 g of $CaCO_3$ and 1.5 mL of distilled water added into the mixture. Then, 1 mL of 1 % TTC solution was added and the tubes were incubated at 30 ºC for 24 h after plugging with cotton. The resulting slurry was filtered and triphenyl formazan (TPF) was extracted with successive aliquots of methanol in a 50 mL volumetric flask. The absorption of the pink colour was read out with spectrophotometer at 485 nm.

Results and Discussion

Physicochemical Properties of Soil Sample

The soil has the sandy loam texture. This research used a soil with low nitrogen, very low organic carbon, humus and electrical conductivity (EC), high K_2O and very high phosphorus (P) contents in order to scientifically investigate on the degradation of cypermethrin. The moisture content of the contaminated soil was found to be 2.34 %. The pH value of the contaminated soil was found to be 8.79, it can be considered as a moderately alkaline type of soil. The pH of the soil is important because it can alter the availability of nutrients to the plants, thereby affecting the activity of the roots and microbes. The electrical conductivity value of the contaminated soil was

found to be 0.09 mS/cm. The electrical conductivity of soil informs the ionic nature of the soluble compound to supply the needs of plants. The organic carbon content of the contaminated soil was found to be 0.36 % and humus content was 0.62 %. Humus contains every element absorbed by growing plants, but not in the same proportions as in plant. The microbes become a part of the soil humus, along with materials that have partially or entirely resisted the process of decomposition. Humus is a very important part of the ability of the soil to supply the needs to plant.

The nitrogen content of the contaminated soil was found to be the lowest value 0.13 %. Nitrogen helps plants make the proteins they need to produce new tissues. In nature, nitrogen is often in short supply, so plants have evolved to take up as much nitrogen as possible, even if it means not taking up other necessary elements. If too much nitrogen is available, the plant may grow abundant foliage but not produce fruit or flower. The cation exchangeable capacity (CEC) content of the soil was found to be 21.06 meq/100 g. The CEC is an essential measurement in agronomy and soil science to estimate the physicochemical state of a soil, which may be a good indicator of soil quality and productivity to supply the three important plant nutrients: calcium, magnesium and potassium. CEC is important for maintaining adequate quantities of plant available calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), respectively. The highest phosphorus content of the contaminated soil was found to be 45.03 ppm. Phosphorus stimulates root growth, helps the plant set buds and flowers, improves vitality and increases seed size. It does this by helping transfer energy from one part of the plant to another. Organic matter and the activity of soil organisms also increase the availability of the phosphorus.

Table 1 Characteristics of the Soil Sample

Test Parameter	**Content**
Texture	Sandy loam
Moisture (%)	2.34
pH	8.79
Electrical Conductivity (mS/cm)	0.09
Organic carbon (%)	0.36
Humus (%)	0.62
Total Nitrogen (%)	0.13
CEC (meq/100 g)	21.06
Phosphorus (ppm)	45.03
K_2O (mg/100g)	20.27
Exchangeable Ca^{2+} (meq/100 g)	19.10
Exchangeable Mg^{2+} (meq/100 g)	0.68
Exchangeable K^{+} (meq/100 g)	0.43
Exchangeable Na^{+}(meq/100 g)	0.85

The K_2O content of the contaminated soil was found to be 20.27 mg/100 g. Potassium is one of the three major fertilizer elements. In fertilizer and soil analyses, however, potash signifies the hypothetical potassium oxide although K_2O is not absorbed by plants. Plant roots absorb most of their potassium as potassium ions K^{+}. The exchangeable calcium content of the contaminated soil was found to be 19.10 meq/100 g. Calcium is used by plants in cell membranes, at their growing points and to neutralize toxic materials. In addition, calcium improves soil structure and helps to bind organic and inorganic particles together. The exchangeable magnesium content of the contaminated soil was found to be 0.68 meq/100 g. Magnesium is the only metallic component of

chlorophyll. Without it, chlorophyll cannot capture sun energy needed for photosynthesis. The exchangeable potassium content of the contaminated soil was found to be (0.43) meq/100 g. Potassium improves overall vigor of the plant. It helps the plants make carbohydrates and provides disease resistance. It also helps regulate metabolic activities. The exchangeable sodium content of the contaminated soil was found to be 0.85 meq/100 g. Sodium cations (Na^+) are not plant nutrient, so are not wanted by the plants. When exchangeable sodium is present in quantities greater than above 5% of (CEC), it makes the clay particles unstable in rainwater. This shows up as dispersion or cloudiness in water. Dispersive soils have poor water entry and drainage and set hard on drying. This study gives information about nature of soil and nutrients present in soil, so that farmer can arrange the quantity of fertilizers and nutrients needed by the soil for increased crop yield (Table 1).

EDXRF Analysis

The relative abundances of some elemental contents: Si, Fe, K, Ca, Ti, Mn, Cr, Ni, Sr, Zn, Y and Rb in insecticide-contaminated soil are shown by EDXRF (Figure 2 and Table 2). The insecticide-contaminated soil contained silicon (Si) as the major constituent and iron (Fe) as the second major constituent and other trace constituents are: potassium (K), calcium (Ca), titanium (Ti), manganese (Mn), chromium (Cr), strontium (Sr), nickel (Ni), zinc (Zn), yttrium (Y) and rubidium (Rb). All of the insecticide-contaminated soil contained high amounts of Si, Fe, K, Ca, and Ti.

Table 2 Elemental Analysis of the Soil Sample

Element	Relative Abundance (%)
Silicon (Si)	54.729
Iron (Fe)	25.643
Potassium (K)	8.398
Calcium (Ca)	7.198
Titanium (Ti)	2.451
Manganese (Mn)	0.627
Chromium (Cr)	0.372
Nickel (Ni)	0.266
Strontium (Sr)	0.169
Zinc (Zn)	0.074
Yttrium (Y)	0.039
Rubidium (Rb)	0.034

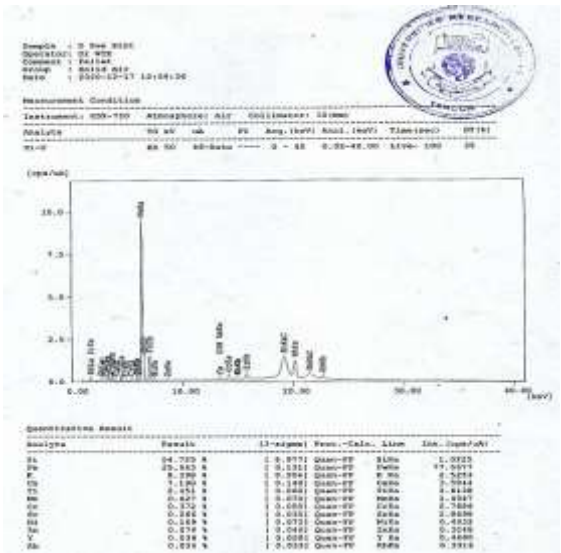


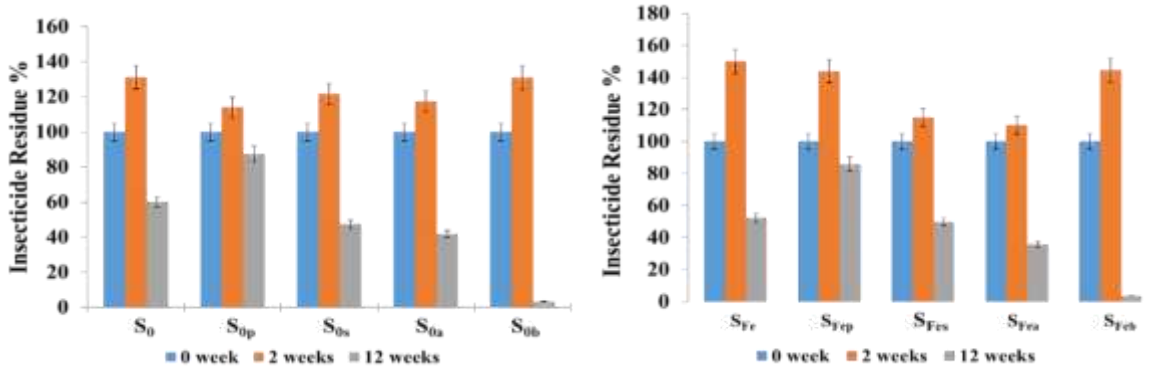
Figure 2 EDXRF spectrum of contaminated soil

The high content of Si resists the damage to crops by pathogenic microorganisms and that of other elements provide as plant nutrient. Iron (Fe) is one of the major elements present in the soil, mostly in the forms of oxide. Generally, the most dominant oxidation state is Fe^{3+} and when reducing conditions are prevailing, iron exists as Fe^{2+}. Iron oxides are very important components in most soil as they have major influence on chemical, physical, and microbial properties of soils. Because of their particles size (usually 5-200 nm), iron oxides possess large specific surface area and highly reactive surfaces. The average particle's diameter was determined to be approximately 33.423 nm. Degradation was slow in case of larger size iron oxide particles, indicating surface area dependency of the reaction. Potassium (K) is commonly supplied to the soil as farm manure and as commercial fertilizers. It is called fertilizer elements. Calcium (Ca) plays a vital role in plant growth, specifically cell wall formation, cell division and pollination. Calcium also promotes

healthy soil structure by loosening soils and stabilizing organic matter, which increases soil water-holding and nutrient-holding capacity. The more calcium is in the soil, the higher the pH of the soil can become.

Titanium (Ti) is considered a beneficial element for plant growth. When plants experience Fe deficiency, Ti helps induce the expression of genes related to Fe acquisition, thereby enhancing Fe uptake and utilization, subsequently improving plant growth. The other nutrient elements (manganese (Mn), chromium (Cr), nickel (Ni), strontium (Sr), zinc (Zn), yttrium (Y) and rubidium (Rb) are used by higher plants in very small amounts, thereby justifying the name micronutrients or trace elements. Such a designation does not mean that they are needed in small quantities. This is due to the relatively small quantities of micronutrients in sands and organic soils and to the low availability of most of these elements under very alkaline conditions.

Insecticide Residue Percent in Contaminated Soil Samples



(a) (b)

Figure 3 Insecticide residue percent in contaminated soil treated with Peanut, Sesame, Aster and Bermuda grass (a) in the absence of iron oxide particles and (b) in the presence of iron oxide particles through 12 weeks experiments

The effect of iron oxide particles were prepared by using *Camellia sinesis* (Tea leaves) as reducing agent on phytoremediation has been investigated for phytoremediation of the residue of insecticides from contaminated soil by UV-Vis and GC-MS. Relative to S_0 in 0-week treatment, the percentages of insecticide residue in the S_0, S_{0p}, S_{0s}, S_{0a}, and S_{0b} treatments were found to be 131.28, 114.09, 121.76, 117.4 and 130.98 % PBA formed through 2 weeks experiments and 60.1, 87.46, 47.47, 41.87 and 3.4 % PBA formed through 12 weeks experiments (Figure 3-a). Relative to S_{Fe} in 0-week treatment, the percentage of insecticide residue in the S_{Fe}, S_{Fep}, S_{Fes}, S_{Fea}, and S_{Feb} treatments were observed as 149.94, 143.88, 114.98, 110.2 and 144.52 % PBA formed after 2 weeks experiments and 52.29, 86, 49.84, 35.81, and 3.3 % PBA formed through 12 weeks experiment (Figure 3-b). All treatments were found to possess phytoremediation efficiency for insecticide-contaminated soil. Among them, Aster and Bermuda grass with iron oxide particles phytoremediation had the best degradation efficiency.

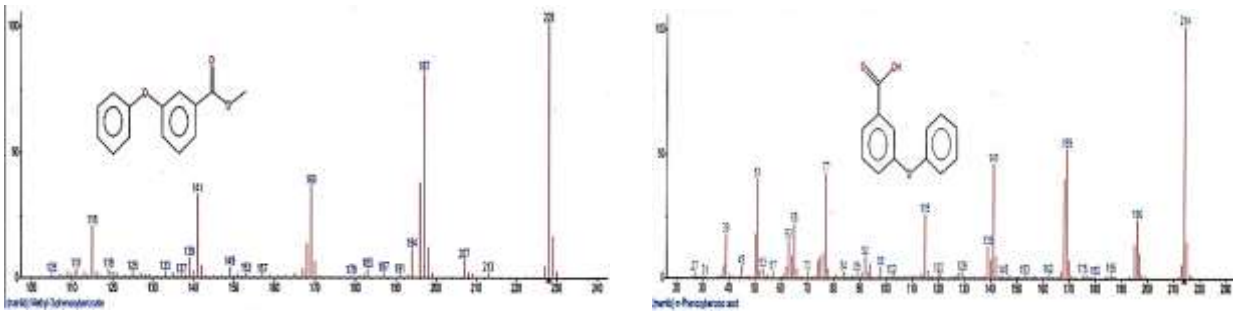
Insecticide residue was removed more quickly in the presence of iron oxide particles than by plants alone. Soil moisture also played an important role to increase ionization and activation of iron oxide particles. During cultivation, the plants were watered regularly. This may be because soil saturation with water, decreases the oxygen levels and thus prevent the oxidation of iron oxide particles. Insecticides, which are persistent in aerobic environments, are more readily degraded under reducing conditions. The results showed that the iron oxide particles played a significant role

in the degradation of insecticide residue in the soil, compared with natural degradation in soil without them.

Cypermethrin is a relatively stable to sunlight and, though it is probable that photodegradation plays a significant role in the degradation of the product, its effects in soils are limited. The most important photodegradation product is 3-phenoxybenzoic acid (PBA) and, to some extent, the amide of the intact ester, do not differ greatly from those resulting from biological degradation. Degradation in the soil occurs primarily through cleavage of the ester linkage to give PBA, and carbon dioxide. Some carbon dioxide is formed through the cleavage of both the cyclopropyl and phenyl rings under oxidative conditions. The half-life of cypermethrin in a typical fertile soil is between 2 and 4 weeks. Cypermethrin is adsorbed very strongly on soil particles, especially in soils containing large amounts of clay or organic matter.

The excellent performance of functionalized iron oxide particles in nanomaterial and biomedical applications often relies on achieving the attachment of ligands to the iron oxide surface both in sufficient number and with proper orientation (Korpany *et al*., 2017). The results of this study could be due to relationships between the ligand chemical structure and surface binding on magnetic iron oxide particles (~30 nm) for a series of related benzoic acid derivatives. The structure of the resultant ligand-surface complex was primarily influenced by the relative positioning of hydroxyl and carboxylic acid groups within the ligand. The chemical structure of benzoic acid derivatives enables fast and stable covalent binding on the surface of magnetite (Fe_3O_4) particles, which act as catchers and carriers for magnetic removal. The results of studies have shown that, when iron oxide particles are applied, the levels of cypermethrin as its secondary metabolite PBA can be effectively lowered.

GC-MS Analysis of Cypermethrin and Its Metabolites



(a) **(b)**

Figure 4 MS spectra of (a) Methyl 3-Phenoxybenzoate observed sample and (b) 3-PBA (library spectrum)

Gas chromatograph-mass spectrometry (GC-MS), is a sophisticated method for identification of molecular structure of the insecticides present in the samples. Confirmatory methods for organic residues or contaminants shall provide information on the chemical structure of analyte. Figures 4 (a) and (b) are mass spectra corresponding to the observed sample Methyl 3-Phenoxybenzoate and the standard 3-PBA.GC-MS had been successfully applied for determining metabolites of cypermethrin in soil. Appearance of cypermethrin breakdown product 3-PBA was evident after 12 weeks application. GC-MS analysis of extracted solution consisting of the target compounds, was carried out and a library matching was done with the obtained mass spectrum and library spectrum. PBA was eluted at a GC retention time of 8.06 min (Figures 5 and 6) and identified by its mass spectrum (Figure 4). The percentages of insecticide residue PBA are calculated based on the peak area in gas chromatograms (Figure 3).

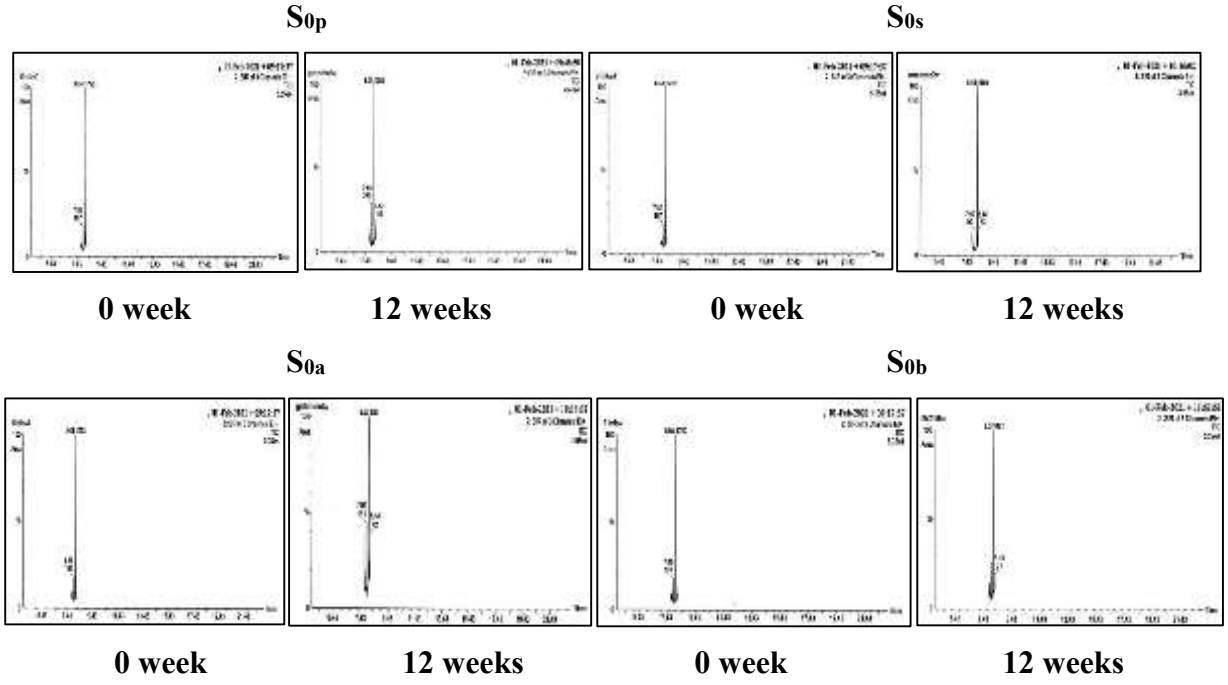


Figure 5 Gas chromatograms for insecticide residue in contaminated soil samples (S_0, S_{0p}, S_{0s}, S_{0a}, S_{0b})

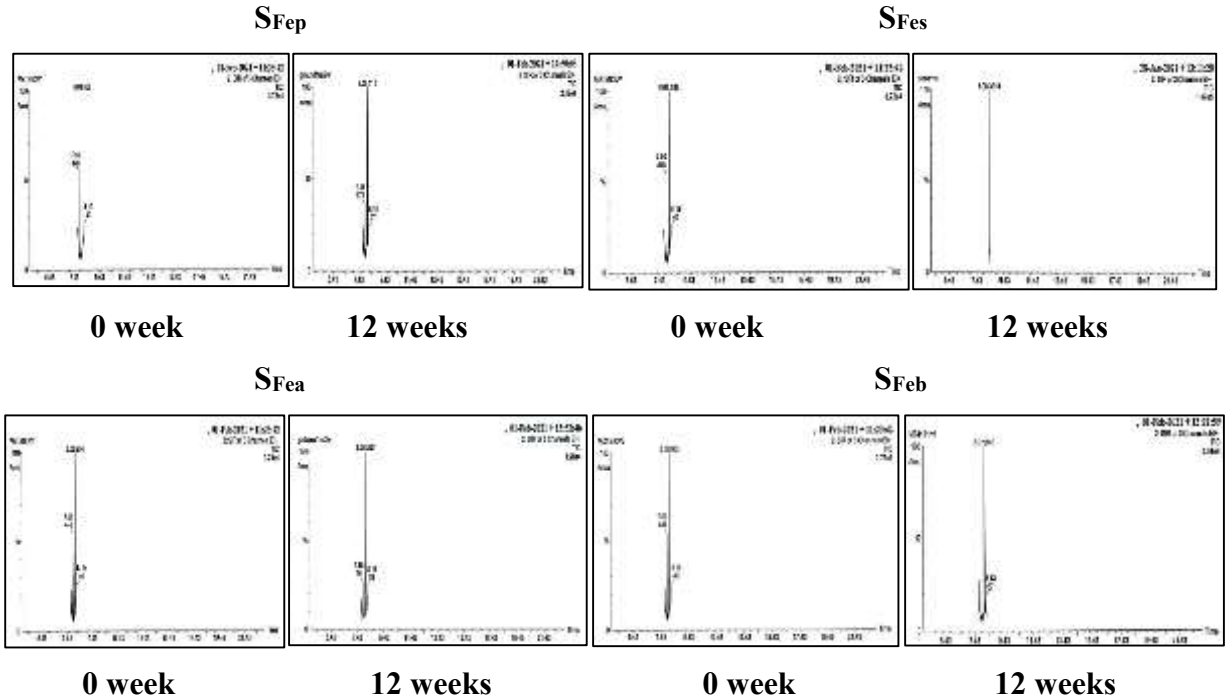


Figure 6 Gas chromatograms for insecticide residue in contaminated soil samples (S_{Fe}, S_{Fep}, S_{Fes}, S_{Fea}, S_{Feb})

Enhancement of Urease and Dehydrogenase Enzyme Activities

The effects of iron oxide particles on increasing urease and dehydrogenase activities were found to be maximum during the incubation periods (12 weeks). According to figure, the changes of urease and dehydrogenase activities depend on dosage of iron oxide particles. The degradation of cypermethrin in soil is mostly attributed to microorganisms. Urease and dehydrogenase activities are appropriate substitute biomarker of general microbial activities in soils.

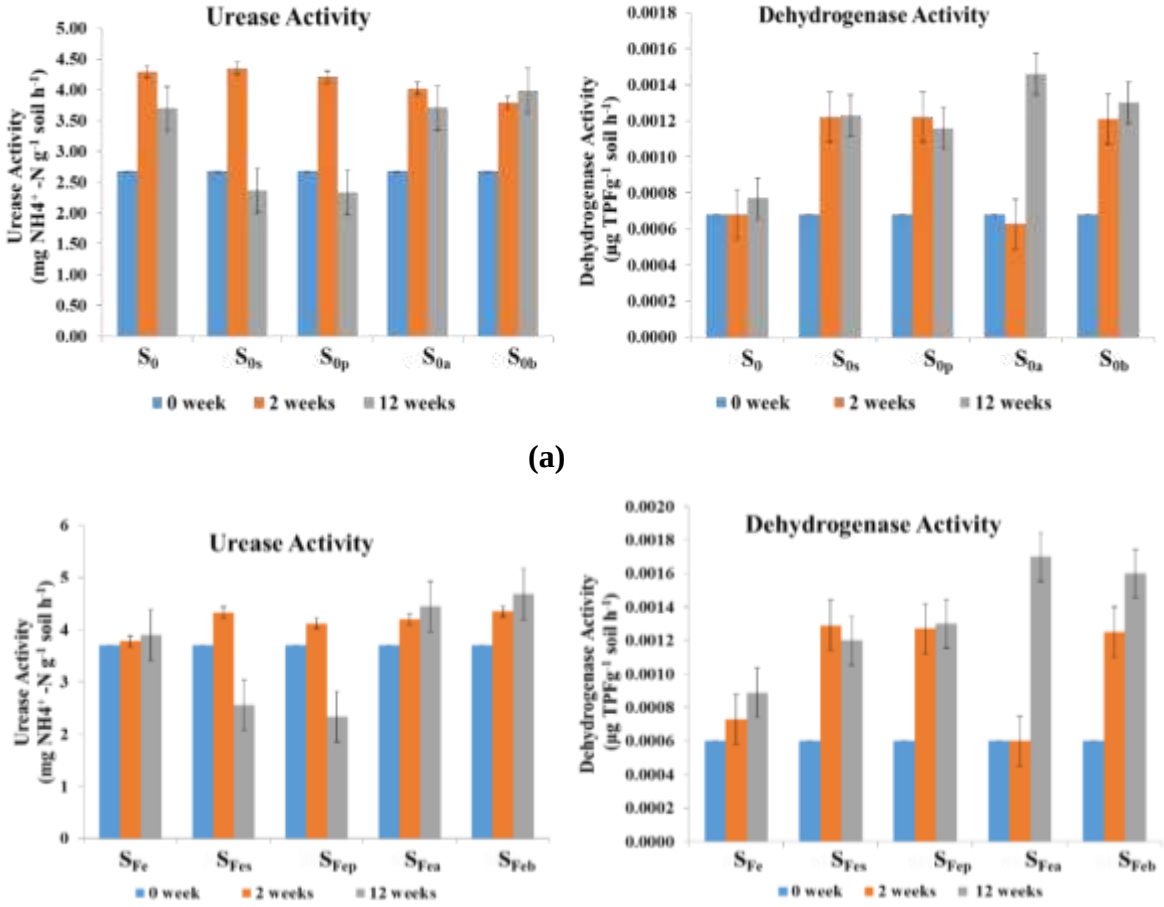


Figure 7 Soil urease and dehydrogenase activities in insecticide contaminated soil treated with Peanut, Sesame, Aster and Bermuda grass (a) in the absence and, (b) in the presence of iron oxide particles

After 12 weeks, the urease and dehydrogenase activities in the controls (or treated soil in the absence of iron oxide particles-S_0), were found to reach 3.74 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0008 µg TPF g^{-1} soil h^{-1}, whereas 2.364 mg NH_4^+-N g^{-1} soil h^{-1} and 0.0012 µg TPFg^{-1} soil h^{-1} in Peanut plant (S_{0p}), 2.33 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0012 µg TPF g^{-1} soil h^{-1} in Sesame plant (S_{0s}), 3.71 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0015 µg TPF g^{-1} soil h^{-1} in Aster (S_{0a}) and 3.7 mg NH_4^+-N g^{-1} soil h^{-1} and 0.0013 µg TPF g^{-1} soil h^{-1} in Bermuda grass (S_{0b}) (Figure 7-a). The percentage of urease and dehydrogenase activities increased to 63.20 and 33.33 % plant (S_{0p}), to 62.30 and 44.44 % in Sesame plant (S_{0s}), to 65.38 and 55 % in Aster (S_{0a}), and to 77.78 and 62.5 % in Bermuda grass (S_{0b}) relative to controls (assumed as 100 %) through 12 weeks.

After 12 weeks, the urease and dehydrogenase activities in the presence of iron oxide particles (S_{Fe}) were found to reach 3.9 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0009 µg TPF g^{-1} soil h^{-1}, 2.55 mg NH_4^+-N g^{-1} soil h^{-1} and 0.0012 µg TPF g^{-1} soil h^{-1} in Peanut plant (S_{Fep}), 2.342 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0013 µg TPF g^{-1} soil h^{-1} in Sesame plant (S_{Fes}), 4.45 mg NH_4^+-N g^{-1} soil h^{-1} and 0.0017 µg TPF g^{-1} soil h^{-1} in Aster (S_{Fea}) and 4.68 mg NH_4^+-N g^{-1} soil $h^{-1}$and 0.0016 µg TPF g^{-1} soil h^{-1} in Bermuda grass (S_{Feb}) (Figure 7-b). The percentage of urease and dehydrogenase activities increased to 65.38 and 50 % in Peanut plant (S_{Fep}), to 60 and 50 % in Sesame plant (S_{Fes}), to

99.14 and 87.5 % in Aster (S_{Fea}) and to 98.93 and 78 % in Bermuda grass (S_{Feb}) relative to S_{Fe} (assumed as 100 %) through 12 weeks.

The present study showed that urease and dehydrogenase enzyme quantities were improved by the addition of proper iron oxide particles, showing the usefulness of iron oxide particles in phytoremediation.

Conclusion

The possibility of iron oxide particles assisted phytoremediation of four plants (Peanut, Sesame, Aster, and Bermuda grass) to remediate soil contaminated with cypermethrin was determined in this study. The results of this study suggest that addition of iron oxide particles of an adequate amount could enhance degradation of cypermethrin and its most persistent metabolite, PBA. Thus, in agricultural practice, adequate application of iron oxide particles is an efficient method to reduce the accumulation of cypermethrin and PBA in soil and significantly decrease environmental risks. Aster and Bermuda grass with iron oxide particles phytoremediation had the best degradation efficiency. The two plants also had affected on the soil microbial and biochemical properties, reflected by the increase in enzyme activity.

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