JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(7), 331–344
https://doi.org/10.12911/22998993/165957
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.03.15
Accepted: 2023.05.15
Published: 2023.05.24

Evaluation of Pesticide and Heavy Metal Contamination on Soil Properties and Microbiota in Thailand's Mountainous Region

Patarapong Kroeksakul[1*], Arin Ngamniyom[1], Kun Silprasit[1], Phanom Sutthisaksopon[1], Thayat Sriyapai[1] Naphat Phowan[1], Pakjirat Singhaboot[2]

[1] Faculty of Environmental Culture and Ecotourism, Srinakharinwirot University, Bangkok, 10110 , Thailand

[2] Faculty of Agricultural Product Innovation And Technology, Srinakharinwirot University, Nakhon Nayok, 26120, Thailand

* Corresponding author's e-mail: patarapong@g.swu.ac.th

ABSTRACT

The article aims to investigate the state of soil elements in upland agriculture and the state of pesticide contamination in the environment of differing highland agricultural areas in Thailand. The number of heavy metals present was Fe > Mn > Zn > Pb > Ni > Cu > Cd, dominant pesticide contamination in the carbamate group is methomyl (0.11 mg/kg), and the organochlorine group is triazophos (0.02 mg/kg). Pesticide contamination was found to positively and significantly correlate with the soil's total N and Fe content ($p < 0.01$). In the soil microbes, the dominant genera of *Aquabacterium* were found at the highland agriculture site H1, *Massilia* at H2, and *Sphingomonas* at H3.

Keywords: mountainous region; heavy metal; pesticides; microbiota; soil properties.

INTRODUCTION

The present discourse on the impact of pesticides is strongly dominated by how they affect human health, the environment, and society (Maguire & Hardy, 2009). Pesticides are a major factor in agriculture production, so any discourse must reconcile the economic benefits of pesticide use on farmland and account for the working demands of farmers. Many farmers know and realize the side effects of pesticides on the health of farm workers and the farmland environment (Sangpakdee et al., 2014). Many decisions to use pesticides are driven by economics "if the high production effect at high income," and the ability to make it easier for farmers to control pests and weeds that interfere with crop yields (Kroeksakul & Singhaboot, 2020).

The impact of pesticides has passed into the green revolution era (Hassaan & Nemr, 2020). In 2020 the quantity of pesticide used was approximately 3.3 million tons (Sharma et al., 2019). Pesticides imported into Thailand can be broadly classified into four groups, and their respective proportions are as follows: herbicides (47.5%), insecticides (29.5%), fungicides (17.5%), and other pesticides (5.5%) (Hassaan & Nemr, 2020). In 2010, Thailand imported about 117,815 tons of pesticides, which increased to approximately 146,546 tons in 2015. However, in 2016 the imported total fell to 84,379 tons and 92,911 in 2018. In 2020, Thailand imported approximately 49,658 tons of pesticides (Office of Agricultural Regulation, 2021). Some pesticides synergize with exposure to heavy metals in the environment, such as dimethoate (DM) with $HgCl_2$ (Hg) and $NaAsO_2$ (As), and can harm health such as causing a gain in body weight. Chlorpyrifos (CPF) and nickel (Ni) may have separate molecular imprints resulting in a complex transcription profile in a mixture of the two (Singh et al., 2017), so in the area to pesticide-intensive using found to some heavy metals like a Cu, Ni, and Cd have level contaminate increase in soil (Tariq et al., 2016), so the relation of heavy metal and pesticide if contamination in the environment

seriously passivity to affect with human health together (Alengebawy et al., 2021), The aim of the research presented here was to investigate the state of soil elements and the state of pesticide contamination in upland agricultural areas within the highlands of Thailand.

The highlands of Thailand are a vital region for agricultural production—particularly for vegetables, animal feed raw materials, fruits, etc. The most important agricultural production area is near the mountainous northern region of Thailand; crops produced in this region are distributed throughout the country. In the study is environmental health monitoring and assessment process (Marković et al., 2010) to support the dynamic of agricultural production from the farmer to develop agricultural security to the environment and from the farmer to the continual consumer.

METHODOLOGY

The study sites

The sample collection area is spread across the northern region of Thailand. This study focused on individual regions within this area that have different agricultural activities: case crop production, vegetable production, and fruit production.

Site H1 – lying at latitude 17.23684, longitude 98.29257 at the boundary of the Meatan sub-district, Thasongyang district, Tak province. Site H2 – lying at the latitude 18.338775, longitude 98.072696 at the boundary of the Huayhom sub-district, Mae Lanoi district, Mae Hong Son province. Site H3 – lying at the latitude 19.438216, longitude 98352026, at the boundary of the Mae Na Toeng sub-district, Pai district, Mae Hong Son province. The location of this study site is presented in Figure 1.

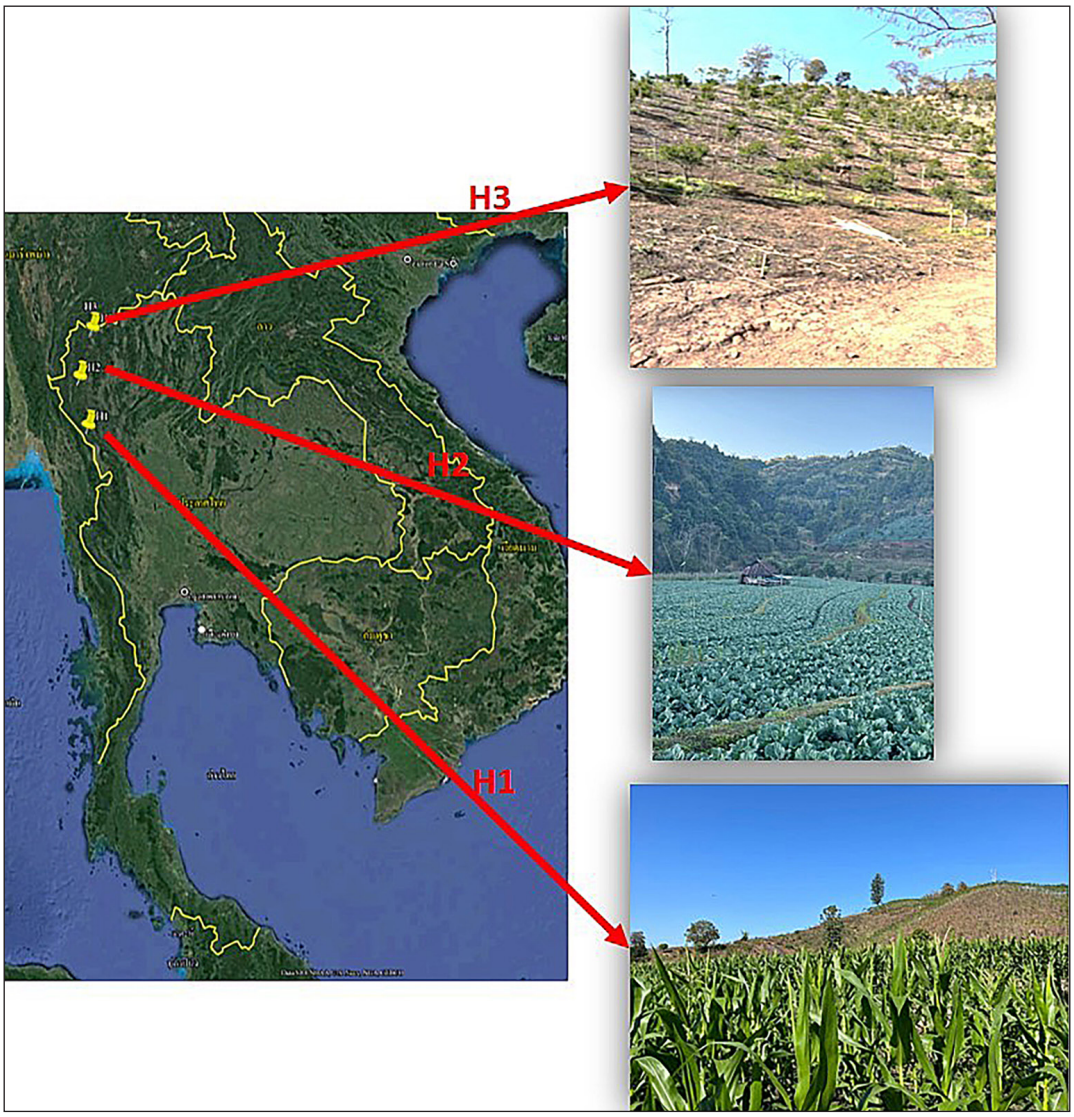

Figure 1. Study site and field plots where samples were collected

At sites H1 and H2, sediments were collected from a nearby nearly field, and the steam is space too drained of erosion flow of surface of the soil in the field for test pesticide effective transfer environmentally that in the HS1 and HS2.

Sample preparation and element analysis

The samples were collected at the various sites, placed in a plastic bag, and kept in a cool box while transported from the field to the laboratory. The soil was dried at 105 °C in a hot air oven for 72 hours, then ground to a powder by grinding with mortar and pestle. A sample of 20 sifted soils was selected and maintained in a refrigerator at a temperature of 4 °C.

The soil samples used for ICP-OES analysis were divided into 2 g portions and reacted with concentrated hydrofluoric acid (HF), concentrated perchloric acid ($HClO_4$), and concentrated nitric acid (HNO_3) in a 1:1:1 ratio within a 20 ml volume. The samples were extracted at around 500 °C in a SpeedDigester K-425 BUCHI (Switzerland) until dry. Each residue was rinsed with 1% HNO_3 and sieved through filter paper. The supernatant was transferred to a 50 ml volumetric flask, and 1% HNO_3 added. Elemental analysis was performed with a PlasmaQuant 9100 series (Germany) ICP spectrometer. Nitrogen and carbon from the total nitrogen (TN) and total carbon (TC) in the samples was analyzed by a CHN-628 CHN series LECO analyzer (USA). The available soil phosphorus (P) was analyzed using the Bray II method (Bray & Kurtz, 1945), measured by spectrophotometers at a wavelength of 882 nm.

The soil fertility evaluation

This study uses the soil quality index (SQI) to determine details on elopement and soil properties via the following equation (Abdel-Fattah et al., 2021):

$$SQI = \sum_{i=1}^{N} \mathrm{Wi} * Si \quad (1)$$

Wi is the relative weight of each indicator metric with values ranging between 0 and 1, and Si is the value of each soil indicator metric (Abdel-Fattah et al., 2021). In this paper, we used the following indicator metrics: soil pH, total K, P available, total N, soil organic matter, soil organic carbon, C: N ratio, cation exchange capacity (CEC), percentage of base saturation, percentage saturation of K, percentage saturation of Mg, and percentage saturation of Ca.

Pesticide analysis

The sample for pesticide analysis used soils collected from the study sites dried at room temperature until the moisture was below 10%. Afterward, samples were winnowed from sieve No. 20 and collected at -21 °C before extraction. Producing samples via an extraction technique using a test kit (RESTEK, United States) is quick, easy, cheap, effective, rugged, and safe (QuEChERS). Sample analysis was done with a gas chromatograph mass spectrometer (GC-Ms) using a Shimadsu Corporation series GCMS-QP2020 (Japan), a combined detector with a micro electron capture detector (μ-ECD) and a flame photometric detector (FPD) in combination with post-column derivatization. The carbamate group reference was derived using an in-house method based on a liquid chromatography (LC) approach by Shimadsu Corporation series RF-20A xs (Japan).

Pesticide test

Carbamate groups are: Benzene hexachloride (BHC) is known as Hexachlorocyclohexane (HCH), Heptachlor and Heptachlor-epoxide, Aldrin and Diedrin, Dicofol, Dichlorodiphenyltrichloroethane (DDT.), Chlordane, Endosulfan, and Endrin.

Organophosphate groups are: Dichlovos, Methamidophos, Mevinphos, Omethoate, Diazinon, Dicrotophos, Monocrotophos, Dimethoate, Pirimmiphos-methyl, Chlorpyrifos, Chlorpyrifos, Parathion-methyl, Primiphos, Malathion, Fenitrothion, Parathion, Prothiofos, Methidathion, Profenofos, Ethion, Triazophos, O-ethyl O-p-nitrophenyl phenylphosphonothionate (EPN), Phosalone, and Azinphos-ethyl.

Pyrethroid groups are: Deltamethrin, Bifentrin, Permethrin, ladbda-Cyhalothrin, Cypermethrin, Cyfluthrin, and Fenvalerate.

Microbial diversity analysis

The total genomic DNA from the soil samples was extracted using Quick-DNA Fecal/Soil Microbe Miniprep Kit (Zymo Research, Irvine,

CA, USA) according to the manufacturer's protocol. The PCR mixtures for amplicon were performed using a sparQ HiFi PCR Master Mix (Quantabio, Beverly, MA, USA). Paired primers of DNA amplification for V3-V4 16S rDNA with adapters were 5'ACACTCTTTCCCTACACGACGCTCTTCCGATCTA CTCCTACGGGAGGCAGCAG -3' and 5' GACTGGAGTTCAGACGTGTGCTCTTCCGA TCTGGACTACHVGGGTWTCTAAT-3'. PCR cycles were conducted according to the following protocol: 3 min of denaturation at 94 ℃, 26 cycles of 5s at 95 ℃, 90 s of annealing at 57 ℃, 30 s of elongation at 72 ℃, and a final extension at 72 ℃ for 5 min. The DNA amplicon was purified by QIAquick Gel Extraction Kit (Qiagen, Hilden, Germany) and was monitored by a Qubit®dsDNA HS assay kit. The preparation of next-generation sequencing libraries and illumina was conducted by Genewiz Inc. (South Plainfield, NJ, USA). The amplicon generation and library preparation, in the sequencing library, was constructed using a MetaVX Library Preparation Kit (Genewiz, San Francisco, CA, USA). Finally, the library was purified with magnetic beads. The concentration was detected by an Infinite® 200 PRO microplate reader (Tecan Trading, Switzerland), and the fragment size was detected by 1% agarose gel electrophoresis, which is expected at ~400bp. Next-generation sequencing was conducted on an Illumina Miseq/Novaseq Platform (Illumina, San Diego, USA). Automated cluster generation and 250/300 paired-end sequencing with dual reads was performed according to the manufacturer's instructions. Sequences were grouped into operational taxonomic units (OTUs) using the clustering program VSEARCH (version 1.9.6) against the UNITE ITS database (https://unite.ut.ee/) pre-clustered at 97% sequence identity. The Ribosomal Database Program (RDP) classifier assigned a taxonomic category to all OTUs at a confidence threshold of 0.8. The RDP classifier uses the UNITE ITS database, with taxonomic categories predicted to the species level.

Data analysis

Data were analyzed using one-way analysis of variance (ANOVA) for variances, and differences in data were compared by posthoc Tukey's honestly significant difference (HSD) test in $p < 0.05$ between data sets. The data correlation considered the use of Pearson's correlation ($p < 0.05$). All analyses were conducted using Statistical Package for the Social Science (SPSS) v.22 and SigmaPlot 12.0.

RESULTS AND DISCUSSION

The context of the study sites

Site H1 – the region may include rice plantations in the rainy season, and after the rice harvest, farmers cultivate corn or maize. Pesticides, such as paraquat, emamectin benzoate, etc., are near the sample site. Site H2 – farmers grow arable crops, mostly cabbages, at this site. Around the fields are found pesticides such as cartap hydrochloride and abamectin. Site H3 – In the zone are orchards, principally for orange production. In the vicinity of the sample selection site are pesticides such as glyphosate.

Soil properties in the study sites

The condition of the soil at the sample sites considers four indicators: (1) soil pH soluble in water: where soil at site H2 has an average pH of 4.62 ±.035, significantly lower than ($p < 0.05$) that of H1 (5.73 ± 0.52) and H2 (6.19 ± 0.272); (2) soil moisture: determined as 19.64%, 15.13%, and 3.52% at sites H1, H2, and H3, respectively; (3) electrical conductivity: at H2 this is higher than at H3 and H1 (543, 493, and 173 µS, respectively); (4) bulk density: at H3 this is significantly high (9.95 ± 0.50 g/cm^3) compared to H2 and H1 (8.75 ± 0.84 and 8.29 ± 1.11 g/cm^3, respectively) ($p < 0.05$). The potential soil properties at sites H1 and H2 are explained by the characteristic use of the land, being employed for the short-term

Table 1. Soil condition of the mountain agriculture areas of the study sites

Parameter	H1	H2	H3
pH (in water soluble)	5.73±.520^a	4.62±.035^b	6.19±.272^a
Soil moisture (%)	19.64±1.08^a	15.13±.814^b	3.52±.485^c
EC (µS)	173±7.43^a	543±5.85^b	493±15.5^c
Bulk density (g/cm^3)	8.29±.111^a	8.75±.084^b	9.95±.050^c

production of vegetables and cash crops that require large amounts of water. This means there is a high percentage of soil moisture at these sites and the necessary water resources to support the farming process.

Fertility of farm soils

In the soil fertility in farms, we measure soil pH, total N, P available, total K, cation exchange capacity, percentage of base saturation (Ca, Mg and K), soil organic matter, soil organic carbon (Lincoln et al., 2014; Estrada-Herrera et al., 2017; Murage et al., 2000), and C:N ratio. The indicators of total N at H2 have a quantity of 1107 ± 18.5, significantly ($p < 0.05$) to that at H1 and H3. The amount of P available at H3 is significantly ($p < 0.05$) than that in soil from H1 and H2. Further details on soil fertility at the three sites are given in Table 2. Cation exchange capacity (CEC) is a

Table 2. Indicators of soil fertility in highland agriculture

Indicators	Unit	H1	H2	H3
Total N	mg/kg	503±0.643^{a}	1107±18.5^{c}	648±4.42^{b}
P available	mg/kg	0.014±0.005^{a}	0.016±0.000^{a}	0.115±0.004^{b}
Total K	mg/kg	499±0.196^{a}	461±0.424^{b}	499±0.241^{a}
CEC	meq/100 g soil	10.5±3.74^{ab}	6.66±0.425^{a}	14.37±3.26^{b}
Base saturation	meq/100 g soil	62±16.2	67.7±2.02	65.7±8.92
%Saturation of K	meq/100 g soil	23.9±17.7	26.3±2.48	14.7±6.16
%Saturation of Mg	meq/100 g soil	1.21±0.952	1.47±0.131	0.759±0.324
%Saturation of Ca	meq/100 g soil	45±33.5^{a}	19.9±1.81^{b}	38.8±16.2^{c}
Soil organic matter	mg/kg	6232±100^{a}	8744±216^{b}	10744±830^{c}
Soil organic carbon	mg/kg	180±2.91	253±6.29	311±24.07
C:N ratio	-	31.7±0.038^{a}	20±0.345^{b}	42±0.290^{c}

Note: a, b, c – the mean in row differences is significant at p-value < 0.05 level (HSD); N – nitrogen, P available – the phosphorus considers P available from potassium dihydrogen phosphate (KH2PO4); K – potassium; Mg – magnesium; Ca – calcium; CEC – cation exchange capacity; %Saturation – percentage of base saturation; meq/100 g soil – milliequivalent per 100 gram of soil; C:N ratio – carbon-to-nitrogen ratio.

Table 3. Soil quality index (SQI) of a highland farm at the three sampling sites

Parameter	H1	H2	H3
Indicate	Z-score		
Total K	0.627479	0.362129	-0.18947
P available	-0.6136	1.023515	-0.02361
Total N	-0.65743	-1.14576	1.11
Soil organic matter	0.509604	-0.86522	-0.69761
Soil organic carbon	0.509604	-0.86522	-0.69761
pH	-0.35862	1.151577	0.077868
C:N ratio	0.656391	1.146253	-1.23755
CEC	0.597373	-1.15165	0.015057
%Base saturation	0.588054	-1.15328	-0.06775
%Saturation of K	-0.58381	1.153847	0.117837
%Saturation of Mg	-0.58205	1.15427	0.117374
%Saturation of Ca	-0.58405	1.153816	0.08362
Summation	0.10894	1.96428	-1.39184
Average	0.00900787	0.1636898	-0.1159870
SD	0.60330172	1.08537958	0.57662850
SQI	-0.04356	0.131058	-0.01599

Note: N – nitrogen; P available – the phosphorus considers P available from potassium dihydrogen phosphate (KH2PO4); K – potassium; Mg – magnesium; Ca – calcium; CEC – cation exchange capacity; %Saturation – percentage of base saturation C:N ratio = carbon-to-nitrogen ratio.

helpful indicator of soil fertility because it shows the ability of the soil to provide three major nutrients: calcium, magnesium, and potassium. The CEC of H2 is significant ($p < 0.05$) compared to that of H3, and the CEC value of the area to study ranges between 6.66–14.34 meq/100 g soil. The percentage of Ca saturation between H1, H2, and H3 is significant ($p < 0.05$), and the value of the C:N ratio in all areas is significant ($p < 0.05$). However, the base saturation and percentage of K and Mg saturation are not significantly present in Table 2.

The soil quality indication (SQI) assesses the soil quality of a given site or area under different land use (Gelaw et al., 2015; Bedolla-Rivera et al., 2020). Thus, an indicator was applied from a multicomponent z-score to compare the soil quality levels of the three sample areas. The study found that H2 had an SQI of 0.131; this is higher than H3 (-0.015) and H1 (-0.043), as is shown in Table 3.

Element quantification in highland soil

Elemental quantification of soils from the three sampling sites found Fe and Ca present in the highest quantities over other measured elements. At the same time, the Cd made up the smallest quantity. The full details are presented in Table 4. The chemical elements present in the soil can be classified into two groups: a heavy metal group (Pb, Cd, Fe, Cu, Mn, Zn, and Ni) and a general element group (Ca and Mg). The number of heavy metals present in amounts where Fe > Mn > Zn > Pb > Ni > Cu > Cd, and the quantity of Fe in H2 > H3 > H1 was significant ($p < 0.05$). The quantity of Zn in soils at the sampling sites followed H3 > H1 > H2 and was significant ($p < 0.05$). The Pb level at H1 was significantly higher ($p < 0.05$) than found at H2 and H3. Ni levels in soil from H3 were significantly higher ($p < 0.05$) than those from H2 and H1, and the quantity of Cu content in H3 > H1 > H2 was significant ($p < 0.05$). The Cd content in soils from H1 and H3 was significantly higher ($p < 0.05$) than in H2. The general element group found that the quantity of Ca at H3 > H1 > H2 was significant ($p < 0.05$), and the quantity of Mg in all areas was not significant. However, the level of heavy metal contamination in the soil at the study sites is not of the standard of agricultural soil in Thailand (Pollution Control Department, 2021), so the information present in Table 4.

Pesticide contamination in soil

Analysis of pesticides in soil sampled from H1, H2, and H3, includes sediments near H1 and H2. In the result of the analysis of pesticides at one contaminated site, the pesticide is in zone H2, and the result of pesticide detection is shown in Table 5. The soil at H2 was found with pesticide contamination from several groups; methomyl in the carbamate group and triazophos was present from the organochlorin group. The insecticides have performant in killing nematodes, snails, and caterpillars. Triazophos is a pesticide in the organophosphate group; they are used mainly in controlling and killing *Sogatella furcifera* (Horvath), green rice leafhopper, rice armyworm

Table 4. The elemental composition of the soils of highland farms at the three sampled sites

Elements	H1	H2	H3
Heavy metal group			
Pb	8.11±0.087^{a}	6.13±0.116^{b}	6.2±0.027^{b}
Cd	0.019±0.001^{a}	0.009±0.000^{b}	0.025±0.003^{a}
Fe	406±0.088^{a}	410±0.076^{b}	408±0.033^{c}
Cu	4.19±0.061^{b}	2.11±0.062^{a}	10.83±0.076^{c}
Mn	59.9±17.4	37.2±0.349	53±0.026
Zn	12.3±0.294^{b}	7.29±0.278^{a}	18.6±0.311^{c}
Ni	4.43±0.472^{a}	4.56±0.208^{a}	10.7±0.237^{b}
General group			
Ca	485±4.88^{b}	177.8±8.34^{a}	677±0.351^{c}
Mg	7.64±0.310	7.97±0.053	7.93±0.071

Note: a, b, c – the mean in row differences is significant at *p*-value < 0.05 level (HSD); Mg – magnesium; Ca – calcium; Pb – lead; Cd – cadmium; Fe – iron; Cu – copper; Mn – manganese; Zn – zinc; Ni – nickel. NA – No control announcement.; * Standard limit refences from Pollution Control Department of Thailand (2021).

Table 5. Results of pesticide detection at the study sites

Group	Pesticide	H1	H2	H3	H1S	H2S
		mg/kg as dry basic				
Carbamate						
Carbaryl		ND	ND	ND	ND	ND
Isoprocarb		ND	ND	ND	ND	ND
Fenobucarb		ND	ND	ND	ND	ND
Promecarb		ND	ND	ND	ND	ND
Carbofuran		ND	ND	ND	ND	ND
Methiocarb		ND	ND	ND	ND	ND
Methomyl		ND	0.11	ND	ND	ND
Aldicarb		ND	ND	ND	ND	ND
Oxamyl		ND	ND	ND	ND	ND
Metolcarb		ND	ND	ND	ND	ND
Organochlorine						
BHC(HCH)		ND	ND	ND	ND	ND
Heptachlor&Heptachlor-epoxide		ND	ND	ND	ND	ND
Aldrin(HHDN)&Dieldrin (HEOD)		ND	ND	ND	ND	ND
Dicofol		ND	ND	ND	ND	ND
DDT		ND	ND	ND	ND	ND
Chlordane		ND	ND	ND	ND	ND
Endosulfan		ND	ND	ND	ND	ND
Endrin		ND	ND	ND	ND	ND
Organophosphate						
Dichlovos (DDVP)		ND	ND	ND	ND	ND
Methamidophos		ND	ND	ND	ND	ND
Mevinphos		ND	ND	ND	ND	ND
Omethoate		ND	ND	ND	ND	ND
Diazinon		ND	ND	ND	ND	ND
Dicrotophos		ND	ND	ND	ND	ND
Dimethoate		ND	ND	ND	ND	ND
Pirimiphos-methyl		ND	ND	ND	ND	ND
Chlorpyrifos		ND	ND	ND	ND	ND
Parathion-methyl		ND	ND	ND	ND	ND
Pirimiphos		ND	ND	ND	ND	ND
Malathion		ND	ND	ND	ND	ND
Fenitrothion		ND	ND	ND	ND	ND
Parathion		ND	ND	ND	ND	ND
Prothiofos		ND	ND	ND	ND	ND
Methidathion		ND	ND	ND	ND	ND
Profenofos		ND	ND	ND	ND	ND
Ethion		ND	ND	ND	ND	ND
Trizophos		ND	0.02	ND	ND	ND
EPN		ND	ND	ND	ND	ND
Phosalone		ND	ND	ND	ND	ND
Azinphos-ethyl		ND	ND	ND	ND	ND
Pyrethroid						
Deltamethrin		ND	ND	ND	ND	ND
Bifenthrin		ND	ND	ND	ND	ND
Permethrin		ND	ND	ND	ND	ND
Lambda-Cyhalothrin		ND	ND	ND	ND	ND
Cypermethrin		ND	ND	ND	ND	ND
Cyfluthrin		ND	ND	ND	ND	ND
Fenvalerate		ND	ND	ND	ND	ND

Note: The limit of detection (LOD) is 0.01 mg/kg, ND = not detected.

(*Mythimna separata*) (Walker), etc., insecticides use the pest almost to a greater extent in vegetables than in cash crops or orchards.

Methomyl contaminates the H2 soil sample with around 0.11 mg per 1 kg dry weight of soil. The oral LD50 for methomyl is between 17 and 24 mg/kg for rats and 10 mg/kg for mice, and 15 mg/kg for guinea pigs (American Crop Protection Association, 1995). Methomyl will be decomposed in soil and groundwater with a half-life of about 14 days. It will decompose in water with a half-life of 6 days and groundwater over approximately 25 weeks. After being applied to the plants, this half-life is approximately 3–5 days (Extension Toxicology Network, 1996). The methomyl rapidly degrades in the environment through action from microbes such as *aminobacter, pracoccus, bacillus*, etc. (Zhang et al., 2017; Mohamed, 2009; Lin et al., 2020) and light (Tomasevic et al., 2009). The soil pH and the temperature in the environment influence the microbial activity and determine the rate of methomyl degradation. At present, the Methomyl has not defined maximum residue level (MRL.) in the Thailand.

Triazophos contaminated the H2 soil sample with 0.02 mg to 1 kg dry weight in the soil. Triazophos is chemically stable against sunlight, and the oral LD50 is high to 31 mg/kg of body weight of a male mouse, and 29 mg/kg of body weight of a female mouse, or 68 mg/kg of body weight of a male rat, 82 mg/kg of body weight of female rat (Hollander & Weigand, 1977a), 26 mg/kg of body weight of male guinea pig, and 35 mg/kg of body weight of female rat guinea pig (Scholz & Weigand, 1973). Triazophos can decompose in river water (condition pH 7.3 and 22 °C) with a half-life of around 41 days (National Center for Biotechnology Information, 2022). Its degradation half-life in soil was 7.93 days and had a dissipation rate of 90% over 21 days. The half-life in the wheat plains was 5.22 days and had a dissipation rate of 90% over 14 days (Li et al., 2008). Triazophos will degrade by environmental microbial action (Wang et al., 2005; Ambreen & Yasmin, 2020; Zhang et al., 2020). However, the Triazophost has not defined maximum residue level (MRL.) in the Thailand.

In an actual world situation, farmers may often use higher levels of pesticide than recommended. This is because the farmer often has better experience of how much pesticide is necessary on particular land to control pests or weeds adequately. This study did not find pesticide contamination in the sediment in the steam nearly farm (H1S and H2S in Table 5). This may be because the volume of pesticides applied to the land was lower than that recommended by manufacturers or the level was below what the instruments could detect.

Correlation of soil elements and pesticides

There was a positive correlation between the level of pesticide contamination with the chemical composition of soils from highland farms,

Table 6. Correlation of soil components in highland agricultural land in Thailand

Parameter	Area	Pb	Fe	Cu	Cd	K	P	Ca
Area	1	-.848**	0.456	.729*	0.362	0.017	.869**	0.381
Pb	-.848**	1	-.847**	-0.26	0.158	0.51	-0.479	0.16
Fe	0.456	-.847**	1	-0.265	-0.621	-.864**	-0.029	-0.632
Cu	.729*	-0.26	-0.265	1	.869**	.696*	.969**	.910**
Cd	0.362	0.158	-0.621	.869**	1	.884**	.759*	.950**
K	0.017	0.51	-.864**	.696*	.884**	1	0.504	.930**
P	.869**	-0.479	-0.029	.969**	.759*	0.504	1	.783*
Ca	0.381	0.16	-0.632	.910**	.950**	.930**	.783*	1
Mg	0.559	-0.652	0.599	0.139	-0.017	-0.394	0.329	-0.161
Mn	-0.225	0.544	-.690*	0.331	0.55	.721*	0.137	0.59
Zn	0.557	-0.038	-0.463	.973**	.922**	.839**	.888**	.978**
Ni	.871**	-0.482	-0.022	.965**	.734*	0.497	.996**	.776*
N	0.225	-.699*	.954**	-0.502	-.776*	-.969**	-0.281	-.815**
SOM	.974**	-.865**	0.527	0.665	0.242	-0.047	.812**	0.314
SOC	.974**	-.865**	0.527	0.665	0.242	-0.047	.812**	0.314
C	.994**	-.899**	0.546	0.653	0.267	-0.089	.812**	0.281
Soil moistures	-.958**	0.663	-0.19	-.892**	-0.601	-0.298	-.973**	-0.626

Table 6. Cont. Correlation of soil components in highland agricultural land in Thailand

Bulk density	.822**	-0.487	0.034	.873**	0.655	0.409	.926**	.685*
EC	.795*	-.990**	.889**	0.167	-0.254	-0.59	0.394	-0.255
pH	0.264	0.246	-.681*	.797*	.896**	.888**	.672*	.913**
C:N ratio	0.488	0.042	-0.54	.953**	.947**	.881**	.852**	.993**
CEC	0.355	0.061	-0.455	.745*	0.611	.726*	0.62	.801**
%Base Saturation	0.164	-0.271	0.264	-0.028	-0.333	-0.194	-0.02	-0.121
%saturation of K	-0.368	0.168	0.104	-0.481	-0.247	-0.333	-0.423	-0.44
%saturation of Mg	-0.331	0.09	0.198	-0.514	-0.315	-0.42	-0.435	-0.507
%saturation of Ca	-0.124	0.397	-0.506	0.263	0.583	0.499	0.195	0.417
Pesticide	0	-0.524	.873**	-.684*	-.878**	-1.000**	-0.489	-.924**
	Mg	Mn	Zn	Ni	N	SOM	SOC	C
Area	0.559	-0.225	0.557	.871**	0.225	.974**	.974**	.994**
Pb	-0.652	0.544	-0.038	-0.482	-.699*	-.865**	-.865**	-.899**
Fe	0.599	-.690*	-0.463	-0.022	.954**	0.527	0.527	0.546
Cu	0.139	0.331	.973**	.965**	-0.502	0.665	0.665	0.653
Cd	-0.017	0.55	.922**	.734*	-.776*	0.242	0.242	0.267
K	-0.394	.721*	.839**	0.497	-.969**	-0.047	-0.047	-0.089
P	0.329	0.137	.888**	.996**	-0.281	.812**	.812**	.812**
Ca	-0.161	0.59	.978**	.776*	-.815**	0.314	0.314	0.281
Mg	1	-0.591	-0.037	0.321	0.52	0.527	0.527	0.598
Mn	-0.591	1	0.492	0.104	-.755*	-0.249	-0.249	-0.3
Zn	-0.037	0.492	1	.885**	-.681*	0.495	0.495	0.466
Ni	0.321	0.104	.885**	1	-0.272	.822**	.822**	.815**
N	0.52	-.755*	-.681*	-0.272	1	0.281	0.281	0.327
SOM	0.527	-0.249	0.495	.822**	0.281	1	1.000**	.976**
SOC	0.527	-0.249	0.495	.822**	0.281	1.000**	1	.976**
C	0.598	-0.3	0.466	.815**	0.327	.976**	.976**	1
Soil moisture	-0.444	0.021	-.767*	-.972**	0.059	-.913**	-.913**	-.923**
Bulk density	0.454	-0.05	.777*	.923**	-0.208	.796*	.796*	.775*
EC	.683*	-0.629	-0.058	0.405	.767*	.820**	.820**	.855**
pH	-0.206	0.38	.870**	.673*	-.802**	0.168	0.168	0.169
C:N ratio	-0.078	0.522	.994**	.845**	-.741*	0.418	0.418	0.393
CEC	-0.44	0.602	.810**	0.639	-0.616	0.36	0.36	0.277
%Base Saturation	-0.455	0.109	-0.047	0.011	0.239	0.246	0.246	0.184
%saturation of K	0.512	-0.427	-0.498	-0.44	0.226	-0.385	-0.385	-0.332
%saturation of Mg	0.555	-0.49	-0.549	-0.451	0.32	-0.341	-0.341	-0.285
%saturation of Ca	0.301	0.133	0.326	0.168	-0.523	-0.215	-0.215	-0.177
Pesticide	0.401	-.723*	-.829**	-0.482	.974**	0.064	0.064	0.106
	Soil moisture	Bulk density	EC	pH	C:N ratio	CEC	%base saturation	%saturation of K
Area	-.958**	.822**	.795*	0.264	0.488	0.355	0.164	-0.368
Pb	0.663	-0.487	-.990**	0.246	0.042	0.061	-0.271	0.168
Fe	-0.19	0.034	.889**	-.681*	-0.54	-0.455	0.264	0.104
Cu	-.892**	.873**	0.167	.797*	.953**	.745*	-0.028	-0.481
Cd	-0.601	0.655	-0.254	.896**	.947**	0.611	-0.333	-0.247
K	-0.298	0.409	-0.59	.888**	.881**	.726*	-0.194	-0.333
P	-.973**	.926**	0.394	.672*	.852**	0.62	-0.02	-0.423
Ca	-0.626	.685*	-0.255	.913**	.993**	.801**	-0.121	-0.44
Mg	-0.444	0.454	.683*	-0.206	-0.078	-0.44	-0.455	0.512
Mn	0.021	-0.05	-0.629	0.38	0.522	0.602	0.109	-0.427

Table 6. Cont. Correlation of soil components in highland agricultural land in Thailand

Zn	-.767*	.777*	-0.058	.870**	.994**	.810**	-0.047	-0.498
Ni	-.972**	.923**	0.405	.673*	.845**	0.639	0.011	-0.44
N	0.059	-0.208	.767*	-.802**	-.741*	-0.616	0.239	0.226
SOM	-.913**	.796*	.820**	0.168	0.418	0.36	0.246	-0.385
SOC	-.913**	.796*	.820**	0.168	0.418	0.36	0.246	-0.385
C	-.923**	.775*	.855**	0.169	0.393	0.277	0.184	-0.332
Soil moisture	1	-.911**	-0.591	-0.505	-.714*	-0.528	-0.074	0.421
Bulk density	-.911**	1	0.415	0.61	.751*	0.455	-0.18	-0.201
EC	-0.591	0.415	1	-0.324	-0.139	-0.137	0.266	-0.105
pH	-0.505	0.61	-0.324	1	.902**	0.641	-0.242	-0.311
C:N ratio	-.714*	.751*	-0.139	.902**	1	.795*	-0.103	-0.456
CEC	-0.528	0.455	-0.137	0.641	.795*	1	0.478	-.845**
%Base Saturation	-0.074	-0.18	0.266	-0.242	-0.103	0.478	1	-.825**
%saturation of K	0.421	-0.201	-0.105	-0.311	-0.456	-.845**	-.825**	1
%saturation of Mg	0.41	-0.212	-0.022	-0.383	-0.515	-.882**	-.780*	.995**
%saturation of Ca	-0.048	0.311	-0.415	0.498	0.385	-0.173	-.944**	0.62
Pesticide	0.282	-0.399	0.604	-.883**	-.873**	-.719*	0.201	0.323
	%saturation of Mg	%saturation of Ca	Pesticide					
Area	-0.331	-0.124	0					
Pb	0.09	0.397	-0.524					
Fe	0.198	-0.506	.873**					
Cu	-0.514	0.263	-.684*					
Cd	-0.315	0.583	-.878**					
K	-0.42	0.499	-1.000**					
P	-0.435	0.195	-0.489					
Ca	-0.507	0.417	-.924**					
Mg	0.555	0.301	0.401					
Mn	-0.49	0.133	-.723*					
Zn	-0.549	0.326	-.829**					
Ni	-0.451	0.168	-0.482					
N	0.32	-0.523	.974**					
SOM	-0.341	-0.215	0.064					
SOC	-0.341	-0.215	0.064					
C	-0.285	-0.177	0.106					
Soil moisture	0.41	-0.048	0.282					
Bulk density	-0.212	0.311	-0.399					
EC	-0.022	-0.415	0.604					
pH	-0.383	0.498	-.883**					
C:N ratio	-0.515	0.385	-.873**					
C.E.C	-.882**	-0.173	-.719*					
%Base Saturation	-.780*	-.944**	0.201					
%saturation of K	.995**	0.62	0.323					
%saturation of Mg	1	0.552	0.41					
%saturation of Ca	0.552	1	-0.505					
Pesticide	0.41	-0.505	1					

Note: *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); N – nitrogen, P available – phosphorus available from potassium dihydrogen phosphate (KH2PO4); K – potassium; Mg – magnesium; Ca – calcium; CEC – cation exchange capacity; %Saturation – percentage of base saturation; C:N ratio – carbon-to-nitrogen ratio; Mg – magnesium; Pb – lead; Cd – cadmium; Fe – iron; Cu – copper; Mn – manganese; Zn – zinc; Ni – nickel.

with total N (r = 0.974, p < 0.01) and Fe (r = 0.873, p < 0.01) content in the soil. There was a negative correlation between total K (r = -1.00, p = 0.01), Ca (r = -0.924, p = 0.01), soil pH (r = -0.883, p = 0.01), Cd (r = -0.878, p = 0.01), C:N ratio (r = -0.873, p = 0.01), Zn (r = -0.829, p = 0.01), Mn (r = -0.723, p = 0.05), and CEC (r = -0.883, p < 0.05). The correlations are shown in Figure 2, and the other chemical components are presented in Table 6. The possibility of contaminating the soil with pesticides is linked to other factors, such as organic matter (Kuisi, 2014; Barchanska et al., 2020), soil type, and soil salinity (Rasool et al., 2022). These factors are closely related to the level of microbial activity involved in pesticide degradation. The level of Fe and Al oxides in the soil is indirectly related to soil pH almost are dynamic in soil to support microbial activity (Meftaul et al., 2022).

The relationship between pesticides and soil composition may explain the condition of soil found on highland farms. Many factors will affect the level of contamination overall, such as frequency of pesticide use, the timing of pesticide application, pesticide type, and volume, which offer many interesting avenues for future research.

Microbial communities in the soil of highland agriculture

In the biodiversity index of the microbial community, as well as the abundance and diversity of species, so index to estimation form OUT in the community. However, in estimating biodiversity in highland agriculture farms in northern Thailand, use the ACE diversity index, Chao1 diversity index, Shanon diversity index, Simson diversity index, and goods_coverage diversity index to explain biodiversity in the study site. However, the three indicates are ACE. Chao1 and Shannon have biodiversity H3 > H2 > H1, and Goods_coverage has H3 > H1 = H2, but in the Simson index present to H3 > H1 > H2, as present in Table 7.

For the classification of OUT, the Venn diagram represent microbial data in a different area in Figure 3A. The number of OTUs is unique, and the circle difference color of the H1 that founds OTUs unique is 883, H2 is 1487, and H3 is 2533. Moreover, the intersection between H1 and H2 shows 1322 OTUs, and the intersection of H1 between H3 has 549 OTUs. H2 intersection has 349 OTUs, and H1 union H2 and have 184 OTUs. However, all microbes are similar to H1, H2, and H3 detected OTU at 1184.

For the relative abundance of microbial genera, *Aquabacterium* is the predominant family of *Comamonadaceae* in the soil sample from H1, and *Massilia* of Oxalobacteraceae is high in H2. In contracts, *Sphingomonas* belonging to *Sphingomonadaceae* are dominated by the soil sample from H3 (Figure 3B). In addition, bacterial communities from soil samples in H1 are similar to H2 but not the sample from H3 (Figure 3C).

The microflora biodiversity at the study sites provides the major mechanism for pesticide contamination degradation in soil, especially

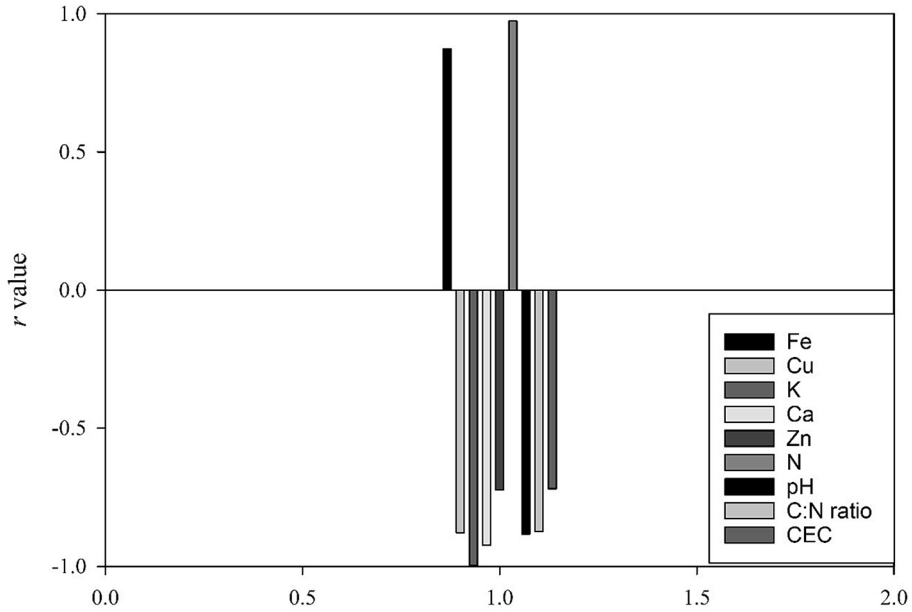

Figure 2. Correlation of pesticide contamination, soil element, and soil properties in a highland farm

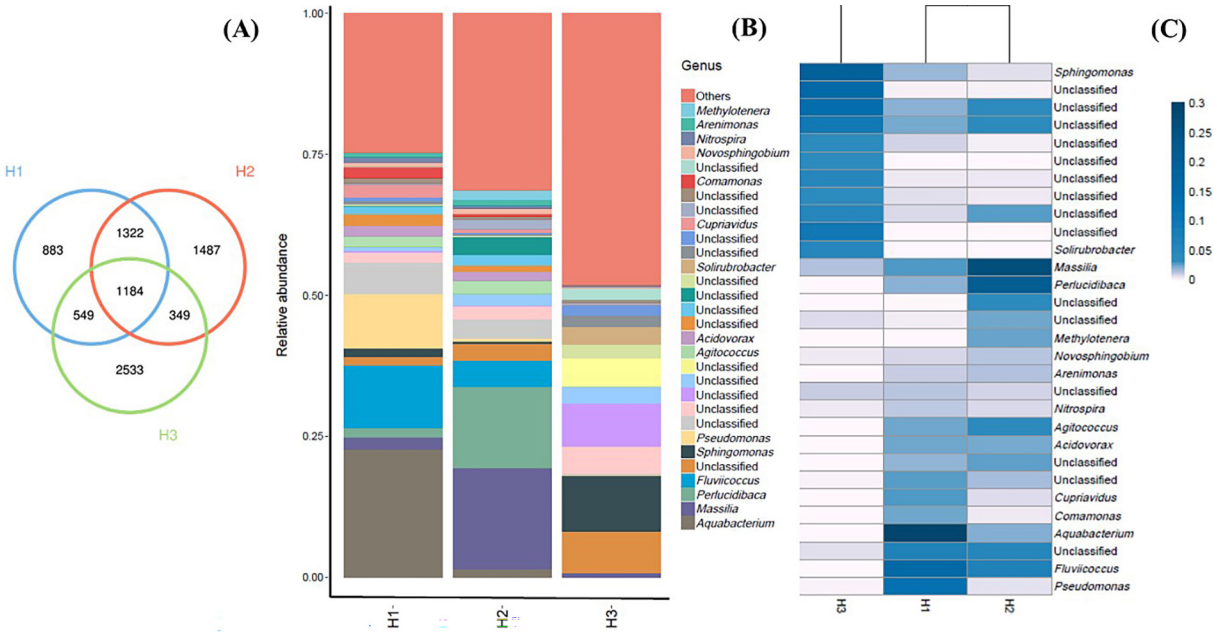

Figure 3. OTU Venn diagram (A) relative abundance of bacterial genera (B) and heatmap of microbial diversities (C) from soil samples in H1, H2, and H3

Table 7. Biodiversity of microbial community index

Site	ACE	Chao1	Shannon	Simpson	Goods_coverage
H1	4242.655	4201.942	7.211	0.962	0.997
H2	4679.222	4633.672	7.477	0.946	0.997
H3	4738.217	4662.435	9.815	0.996	0.999

Note: ACE – abundance-based coverage estimator.

Pseudomonas genus (Doolotel dieva et al., 2017) and *Aquabacterium* genus (Karolina et al., 2020; Dahal et al., 2021). The bacterial group will be specific to the soil environment and governed by factors such as pH, moisture, organic matter, or organic carbon (Zhang et al., 2015). Jia et al. (2019) reported that in China's Huixian Karst Wetland region, *Aquabacterium* was the dominant genera in paddy fields, and *Sphingomonas* was prevalent on dry land. It is known that *Massilia* is a major group of the plant rhizosphere and root colonizing microbe (Ofek et al., 2012). Microbes have also been isolated from soil, air, and water samples (Vikram et al., 2017). As a result, the microbiota in this study may be the main bacteria in the agricultural area's soil sample, and the characteristics of the microorganisms also alter when farmers use chemicals.

CONCLUSIONS

Highland soils were sampled at three different sites. Soil at site H2 had a pH of 4.62, lower than at H1 and H3 (5.73 and 6.19, respectively). The soil moisture percentage at H3 was lower than at H2 and H1 (3.52, 15.13, 19.64, respectively). The bulk density of the soil at H3 (9.95) was higher than at H2 and H1 (8.75 and 8.29 g/cm^3, respectively). Soil fertility was considered using 12 indicators, and it was found that soil from H2 was of better quality than soil from H3 or H1. There were a number of heavy metals present in all sampled soils, in amounts Fe > Mn > Zn > Pb > Ni > Cu > Cd. Pesticides were checked at five sites, and, at H2, soil contamination by methomyl (0.11 mg/kg) and triazophos (0.02 mg/kg) was found. The level of contamination standard does not meet the standard of agricultural soil in Thailand. However, the level of contamination lies below LD50. Pesticides encountered in the soil content were positively correlated with the total N and Fe ($p < 0.01$) but negatively correlated with soil total K, Ca, soil pH, Cd, C:N ratio, Zn ($p < 0.01$), Mn, and CEC ($p < 0.05$). This research showed a direct connection between soil minerals and chemical and microbial residues so the microbial data in highland agriculture displays the specific communities of bacteria that may relate

to characteristics of soils, agricultural patterns, and chemical profiles. The relationship between pesticide contamination and a soil's chemical and microbial makeup is a function of soil fertility and agricultural activity and a consequence of farmers' decisions to use pesticides for conservation the microbial in soil, and in this study found microbes in the highland farmland, which are important for soil quality. Future studies should look into how these bacteria can breakdown soil chemicals and increase soil fertility.

Acknowledgments

This research was supported by a generous scholarship from Thailand Science Research and Innovation (TSRI) transfers to Srinakharinwirot University (Code; 016/2565 and 021/2565). In addition, I would like to thank the Faculty of Environmental Culture and Ecotourism for the instrumental support for the data analysis.

REFERENCES

1. Abdel-Fattah, M.K., Mohamed, E.S., Wagdi, E.M., Shahin, S.A., Aldosari, A.A., Lasaponara, R., Alnaimy, M.A. 2012. Quantitative Evaluation of Soil Quality Using Principal Component Analysis: The Case Study of El-Fayoum Depression Egypt. Sustainability, 13(4), 1824.
2. Alengebawy, A., Abdelkhalek, S.T., Qureshi, S.R., Wang, M.Q. 2021. Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. Toxics, 9(3), 42.
3. Ambreen, S., Yasmin, A. 2020. Novel metabolites of triazophos formed during degradation by bacterial strains Pseudomonas kilonensis MB490, Pseudomonas kilonensis MB498 and pseudomonas sp. MB504 isolated from cotton fields. Journal of environmental science and health. Part. B, Pesticides, food contaminants, and agricultural wastes, 55(12), 1106–1113.
4. American Crop Protection Association. 1995. Pesticides production: Total gained in 1993, despite fungicides decline. Chem.Engin. News, 73(44), 3–4.
5. Anderson, T. 2003. Microbial eco-physiological indicators to asses soil quality. Agriculture, Ecosytems&Environment, 98(1–3), 285–293.
6. Barchanska, H., Czaplicka, M., Kyziol-Komosinska, J. 2020. Interaction of selected pesticides with mineral and organic soil components. Archives of Environmental Protection, 46(3), 80–91.
7. Bedolla-Rivera, H.I., Xochilt Negrete-Rodríguez, M.L., Medina-Herrera, M.R., Gámez-Vázquez, F.P., Álvarez-Bernal, D., Samaniego-Hernández, M., Gámez-Vázquez, A.J., Conde-Barajas, E. 2020. Development of a Soil Quality Index for Soils under Different Agricultural Management Conditions in the Central Lowlands of Mexico: Physicochemical, Biological and Ecophysiological Indicators. Sustainability, 12(22), 9754.
8. Dahal, R.H., Han, J.Y., Lee, H., Chaudhary, D.K., Kim, D.U. 2021. *Aquabacterium terrae* sp. nov., isolated from soil. Archives of microbiology, 203(6), 3183–3189.
9. Doolotkeldieva, T., Konurbaeva, M., Bobusheva, S. 2017. Microbial communities in pesticide-contaminated soils in Kyrgyzstan and bioremediation possibilities. Environ Sci Pollut Res, 25, 31848–31862.
10. Estrada-Herrera, I.R., Hidalgo-Moreno, C., Guzman-Plazola, R., Suáres, J.J.A., Novarro-Garza, H., Etchevers-Barra, J.D. 2017. Soil quality indicators to evaluate soil fertility. Agrociencia, 51(8), 813–831.
11. Extension toxicology network. 1996. Methomyl. http://extoxnet.orst.edu/pips/methomyl.htm
12. Gelaw, A.M., Singh, B.R., Lal, R. 2015. Soil Quality Indices for Evaluating Smallholder Agricultural Land Uses in Northern Ethiopia. Sustainability,7(3), 2322–2337.
13. Hassaan, M.A., Nemr, A.E. 2020. Pesticides pollution: Classifications, human health impact, extraction and treatment techniques. The Egyptian Journal of Aquatic Research, 46(3), 207–220.
14. Hollander, H., Weigand, W. 1977. Acute oral toxicity to the male SPF-NMRI mouse. Unpublished report No. 362/77 from Hoechst AG, Pharma Research Toxicology, Frankfurt am Main, Germany, 15 April 1977. Aventis document A12522. Submitted to WHO by Aventis CropScience, Frankfurt am Main, Germany.
15. Jia, Y.H., Jin, Z.J., Yuan, W., Cheng, Y.Y., Qiu, J.M., Liang, J.T., Pan, F.J., Liu, D.S. 2019. Comparison of Soil Bacterial Community Structure Between Paddy Fields and Dry Land in the Huixian Karst Wetland, China. Huan Jing Ke Xue, 40(7), 3313–3323.
16. Karolina, F., Jorostaw, G., Anna, G., Jacek, N. 2020. Prevalence of unclassified bacteria in the soil bacterial community from floodplain meadows (fluvisols) under simulated flood conditions revealed by a metataxonomic approaches. CATENA, 188, 104448.
17. Kroeksakul, P., Singhaboot, P. 2020. Factors which encourage farmers to use pesticides for vegetable agriculture in Thailand. Journal of Community Mobilization and Sustainable Development, 15(2), 289–298.
18. Kuisi, M.A. 2014. Adsorption of dimethoate and 2,4-D on Jordan Valley soils and their environmental impacts. Environmental Geology, 42, 66–671.

19. Li, W., Qiu, S.P., Wu, Y.J. 2008. Triazophos residues and dissipation rates in wheat crops and soil. Ecotoxicology and environmental safety, 69(2), 312–316.
20. Lin, Z., Zhang, W., Pang, S., Huang, Y., Mistra, S. Bhatt, P., Chen, S. 2020. Current approaches to and future perspectives on Methomyl degradation in contaminated soil/water environment. Molecules, 25(3), 738. https://doi.org/10.3390/molecules25030738
21. Lincoln, N., Chadwick, O., Vitousek, P. 2014. Indicators of soil fertility and opportunities for precontact agriculture in Kona, Hawai'i. Ecosphere, 5(4), 42.
22. Maguire, S., Hardy, C. 2009. Discourse and Deinstitutionalization: The Decline of DDT. The Academy of Management Journal, 52(1), 148–178. http://www.jstor.org/stable/40390280
23. Marage, E.W., Karanja, N.K., Smithson, P.C., Woomer, P.L. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. Agriculture, Ecosystems & Environment,79(1), 1–8.
24. Marković, M., Cupać, S., Durović, R., Milinović, J., Kljajić, P. 2010. Assessment of heavy metal and pesticide levels in soil and plant products form agricultural area of Belgrade, Serbia. Archives of Environmental Contamination and Toxicology, 58, 341–351.
25. Mohamed, M.S. 2009. Degradation of methomyl by the novel bacterial strain Stenotrophomonas maltophilia M1. Electron. J. Biotechnol., 12(4), 6–7.
26. National Center for Biotechnology Information. 2022. PubChem Compound Summary for CID 32184, Triazophos. https://pubchem.ncbi.nlm.nih.gov/compound/Triazophos
27. Ofek, M., Hadar, Y., Minz, D. 2012. Ecology of root colonizing Massilia (Oxalobacteraceae). PLoS One.,7(7), e40117.
28. Office of Agricultural Regulation. 2021, January 20. Information with hazardous to registers. Department of Agriculture. https://www.doa.go.th/ard/?page_id=386
29. O'Halloran, D.M., Uriagereka-Herburger, I., Bode, K. 2017. STITCHER 2.0: primer design for overlapping PCR applications. Sci Rep., 30(7), 45349.
30. Pollution Control Department. 2021. Nation environmental committee declaration: soil quality control. Ministry of Natural Resources and Environment, Thailand.
31. Rasool, S., Rasool, T., Gani, K.M. 2022. A review of interactions of pesticides within various interfaces of intrinsic and organic residue amended soil environment. Chemical Engineering Journal Advances, 11, 100301.
32. Sangpakdee, K., Silprasit, K., Peangthai, D., Khwaiphan, W., Siriyan, S., Kroeksakul, P. 2014. A study of chemical use behaviors of farmers in Ongkharak district, Nakhon Nayok province, Thailand. Khon Kean Agriculture Journal, 42(3), 375–384.
33. Schloter, M., Nannipieri, P., Sørensen, S.J., van Elsas, J.D. 2017. Microbail indicators for soil quality. Biology and Fertility Soil, 54, 1–10.
34. Scholz, J., Weigand, W. 1973. Acute oral toxicity of triazophos Hoe 02960 O I to the female Perbright guinea pig. Unpublished report from Hoechst AG, Pharma Research Toxicology, Frankfurt am Main, Germany, 5 November 1973. Aventis document A29549. Submitted to WHO by Aventis CropScience, Frankfurt am Main, Germany.
35. Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G.P.S., Handa, N., Kohli, S.K., Yadav, P., Bali, A.S., Parihar, R.D., Dar, O.I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., Thukral, A.K. 2019. Worldwide pesticide usage and its impacts on ecosystem. SN Appl. Sci., 1, 1446.
36. Singh, N., Gupta, V.K., Kumar, A., Sharma, B. 2017. Synergistic effects of heavy meatal and pesticides in living systems. Frontiers in Chemistry, 5, 70.
37. Tariq, S.R., Shafiq, M., Chotana, G.A. 2016. Distribution of heavy metals in the soils associated with the commonly used pesticides in cotton fields. Scientifica, 7575239.
38. Tomasevic, A., Daja, J., Petrovic, S., Kiss, E.E., Mijin, D.Z. 2009. A study of the photocatalytic degradation of methomyl by UV light. Chemical Industry & Chemical Engineering Quarterly, 15(1), 17−19.
39. Trivedi, P., Delgado-Baquerizo, M., Aderson, I.C., Singh, B.K. 2016. Response of soil properties and microbial communities to agriculture: implications for primary productivity and soil health indicators. Frontiers in Plant Science, 7, 990.
40. Vikram, S., Govender, N., Kabwe, M.H., Bezuidt, O., Makhalanyane, T.P. 2017. Draft genome sequence of Massilia sp. KIM isolated from South African grassland biome soils. Genom Data, 13, 24–26.
41. Wang, L., Zhang, L., Chen, H., Tian, Q., Zhu, G. 2005. Isolation of a triazophos-degrading strain Klebsiella sp. E6 effectively utilizing triazophos as sole nitrogen source. FEMS Microbiology Letters, 253(2), 259–265.
42. Zhang, C., Jin, Y.W., Wang, X., Zhang, Y., Zhu, S., Yu, X., Hu, G., Hong, Q. 2017. Degradation of methomyl by the combination of *Aminobacter* sp. MDW-2 and *Afipia* sp. MDW-3. Letters in Applied Microbiology, 64(4), 289–296.
43. Zhang, S.Y., Xiao, W., Xia, Y.S., Wang, Y.X., Cui, X.L., Zhang, N.M. 2015. Arenimonas taoyuanensis sp. nov., a novel bacterium isolated from rice-field soil in China. Antonie van Leeuwenhoek, 107(5), 1181–1187.
44. Zhang, Y., Xu, Z., Chen, Z., Wang, G. 2020. Simultaneous degradation of triazophos, methamidophos and carbofuran pesticides in wastewater using an Enterobacter bacterial bioreactor and analysis of toxicity and biosafety. Chemosphere, 261, 128054.