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Short- term effects of cypermethrin pesticide on nutrient levels and microbial communities in tropical soil of Uganda

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Abstract

Cypermethrin is an insecticide widely used by farmers in Uganda to control pests and diseases. The widespread use leads to biomagnification, affecting humans and the ecosystem. This study examined the short-term effects of cypermethrin on soil macronutrients (N, P, K), meso-nutrients (Ca, Mg), and microbial communities (bacteria, fungi, and actinomycetes) in tropical Ugandan soils. Soil samples treated with cypermethrin and control were collected and analysed using standard methods of flame photometry for potassium (K), atomic absorption spectroscopy for calcium and magnesium, Wet-acid oxidation for nitrogen and phosphorus, and standard plate count techniques for microbial populations. The study used a Randomized Complete Block Design (RCBD) to investigate the effects of cypermethrin on soil ecosystem in Uganda. Application of cypermethrin resulted in significant changes to soil nutrient levels and microbial communities. Nitrogen levels were similar in both control and cypermethrin treated soils, while phosphorus concentration increased by 10.5% (from 30.6 to 33.8 cmol/kg) in cypermethrin – treated soils. Across seasons, phosphorus content increased by 61.2% (from 18.1 to 46.6 cmol/kg) and 58.8% (from 19.6 to 47.7 cmol/kg) across blocks. Potassium levels increased marginal 3.7%, whereas calcium concentration remained insignificant. Magnesium content increased substantially by 65.5% across seasons. The microbial community was altered with notable increases in bacteria, fungi and actinomycetes populations in cypermethrin-treated. Analysis of variance (ANOVA) was used to compare means between control and cypermethrin-treated soils. ANOVA model was used to account for seasonal variations. The results provide insight into cypermethrin's impact on soil ecosystem balance. It further suggests that cypermethrin usage as insecticide in tropical soils can have beneficial and detrimental impacts on soil fertility

Introduction

Higher level of the world economy has brought forth enhanced agricultural production and use of pesticides (Wang et al. 2022). Pesticides are used as weapons against pests and diseases, consequently increasing crop productivity and yields (Cycon and Piotrowska-Seget 2017). About 45% of the annual crops produced globally is lost to pests and diseases (Zhang et al. 2000). One of the indicators of soil ecosystem is the measurement of the responses of microbial communities in soil to pesticide application such as cypermethrin (Banerjee and Van Heijden 2022). Research conducted in Africa demonstrated that cypermethrin can alter soil enzyme activity impacting nutrient cycling and availability (Nwankwo et al. 2022). It also inhibits the abundance of certain microorganisms such as pseudomonas and aspergillus which play critical roles in nutrient stabilization (Zhang et al. 2020, Wang et al. 2022).

Cypermethrin stimulates the growth of organotrophic bacteria by 38.3% and actinomycetes by 80.2% but inhibits fungal growth by 31.7% (Wang et al. 2022). It is used to spray insects in order to enhance crop production and yields (Bhatt et al. 2022) and their widespread use leads to biomagnification (Tang et al. 2018) affecting humans and the environment (Tang et al. 2018, Burns and Pastoor 2018, Xie et al. 2022). Responses by microbes to cypermethrin vary, however, cypermethrin promotes the reproduction of *Bacillus, Trichoderma, Proteus, Streptomyces, Fusarium* and *Rhizopus* responsible for the mineralization and availability of carbon, nitrogen and phosphorus to plants for use (Das and Murkherjee 2000). On the other hand, cypermethrin greatly inhibits the populations of certain soil microbes such as *Pseudomonas, Serratia, Staphylococcus, Norcadia* and *Micromonospora* which ensure nutrient stabilization in the soil (Sethi et al. 2013).

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In Uganda, agriculture contributes about 20 % to the Gross National Product (GDP), 48 % to export earnings, and employs about 75 % of the population (Kaizi 2014). More than 4 million Ugandan households rely on small-scale farming for their subsistence (Kaizi 2014). Agriculture plays a crucial role in poverty reduction especially in countries like Uganda (IFAD 2019, World Bank 2020). Uganda's agricultural practices are sensitive to land use (Wasige 2014), and researchers have demonstrated that changes in rainfall patterns and soil conditions in Uganda affect crop yields, and is dependent upon changes and inadequate distribution of precipitation throughout the cropping seasons, as opposed to land use (Mubiru et al. 2015). Mubiru and Banda (2012) showed that due to frequent delays in rainfall during March – May cropping seasons close to 30 days, much of the precipitations that come later March – April is rarely available for crops. Low agricultural production in Uganda is attributed to nutrient mining, soil erosion, rainfall patterns, and temperature variations (Karltun 2013, Nkonya 2016). These factors significantly impact crop yields, but their relative importance is not well understood, hindering effective solution (Mubiru and Banda, 2012). To better understand and address these factors, research is needed to develop targeted intervention and strategies. These could involve field studies, surveys and collaboration with local farmers and stakeholders (Uganda Bureau of Statistics UBOS, 2012). Cypermethrin is an insecticide widely used by farmers in Uganda to control pests and diseases. However, it also poses significant environmental risks. It contaminates water, soil, air, and harms both target and non-target microbes, potentially entering the food chain. This disrupts soil ecosystems, affecting nutrient cycling, plant growth and development. Cypermethrin also pollutes underground water and impacts decomposers, pollinators, and pest controllers (Borowik et al. 2023). Research on its effect on soil macronutrients, mesonutrients, bacteria, fungi, and actinomycetes can inform more sustainable agricultural practices, protecting human and animal health, and improving cypermethrin management in tropic climates.

Agriculture sector in Uganda performs a critical function in the economic advancement of the country, but annually about 36 % of the agricultural produce is wasted due to pest infestation and disease attacks (UBOS 2022). This calls for extensive application of pesticides by farmers to control these pests and diseases so that farmers can enhance agricultural outputs. Cypermethrin is a synthetic pyrethroid often derived from the dried flowers of *Chrysanthemum cinerarinefolium* and *Chrysanthemum coccineum* which are known to contain natural pyrethrin and deemed as the most effective pest and disease control chemical because it even works in low concentrations and quantities (Casida and Quistad 1998). The research question which guided the study was whether cypermethrin usage in agriculture affects bacteria, fungi and actinomycetes populations, macronutrient and mesonutrient levels in humid tropical climate in Uganda. Pyrethroids are categorized on the basis of their mechanisms of biological actions as they do not share a common chemical structure. The majority of pyrethroids are derivatives of 2, 2-dimethylcyclopropane carboxylic acids. Example of pyrethroids include; aldethrin, bitenthrin, deltamethrin, cypermethrin and permethrin. However, cypermethrin has been widely used by farmers in both small and large scale crop production in Uganda (Naseer et al. 2020).

Therefore, the aim of this study was to determine the effect of cypermethrin on macronutrients and microbial communities. The study aimed at investigating the short-term effects of Cypermethrin on macro, mesonutrients, bacteria, fungi and actinomycetes in humid tropics in Uganda. The results of the study could be used as reference for future studies at similar sites. It can also help researchers, environmental engineers, entomologist, bacteriologist, and soil scientists to bridge the knowledge gap regarding the use of microorganisms for the degradation and mineralization of cypermethrin in soils.

Materials and Methods

Study area

The study was conducted at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) in Uganda. Uganda is a Sub-Saharan African country in East Africa, and is located across the humid equatorial region, the prevailing winds and water bodies bring about variations in seasons and precipitation patterns. Mean annual rainfall in the South is bimodal March – May and Sept to November and unimodal in the North (Farley and Farmer 2013). Located across equator, Uganda's climate is diverse due to the country's unique biophysical attributes influenced by large rivers, water bodies and mountain ranges to the East and West (Epule et al. 2018). Differences in sea surface temperatures in the distant tropical rainfall and Indian Ocean strongly do influence the timing of seasons and annual precipitation in Uganda.

Study site

The Makerere University Agricultural Research Institute Kabanyolo (MUARIK) is located at 0 ° 29 °N, 32 ° 27' E, it is about 1,200 m above sea level in Wakiso District, central region of Uganda. Kabanyolo is 19 kms North-West of Kampala, the capital city of Uganda, and lies within the humid tropical climate in Uganda. Humid tropical climate has the characteristics of; length of crop growing period is 270 to 365 days; soils are moderate to poor in crop productivity, temperature of greater than 20 °C all year round, and the area has hot climate with rainfall of > 1000 mm with one or more extended dry periods per year. The soil texture of the area is sandy, loam 66%, 0.05-2.0 mm, silt 15% 0.002-0.005 mm and clay < 0.002 mm 20% and drainage is adequate. The vegetation is savannah woodland, and the mean diurnal maximum temperature range is between 18 °C and 35 °C, while the minimum diurnal temperature range is 8 °C and 25 °C. There are two wet seasons running from April to May and September to November. Kabanyolo's humid tropical location, with two rainy and dry seasons, provide ideal condition for studying microorganisms, macronutrients, and mesonutrients. It offers access to research facilities and equipment. Being fenced and not disturbed by animals, Kabanyolo was an ideal location for this study.

Study design

The study used a randomized block design with 16 blocks, each containing cypermethrin-treated and control. Two treatments in a completely randomized block design

replicated three times was employed. Cypermethrin was obtained from local agro-dealers in container village in Kampala, the capital city of Uganda. Cypermethrin 50% active ingredient was applied at the recommended field rate of 50 g/L. Treatments included control, and cypermethrin treated soils. This application rate was selected to minimize the effect of adsorption of Cypermethrin on soil microbes following the method of Goswami et al. (2013).

The design allowed for comparison of treatment effects while controlling for block-to-block variability. The design helps in the reduction of biases within treatment groups by categorizing similar experimental units, it enhances precision of treatment effect estimates, and allows researchers to generalize findings to other similar populations and nutrients levels elsewhere. The outcome of the study was to determine the short-term effects of cypermethrin on microorganisms, macro and mesonutrients. Short-term effect of cypermethrin in the study is defined as the time period between 2018–2020. The population change of microorganisms, macro and mesonutrient levels were measured.

Two variables considered in the study were; independent variables such as macro and mesonutrients, as they could be manipulated or controlled by researcher to study their effects on microbial population. The dependent variables considered were bacteria, fungi and actinomycetes as they are affected by levels of macro and meso-nutrients in the soil, soil type and properties, and finally cypermethrin levels applied. The control variable was temperature at which the experiment was conducted, pH of soil which can affect microorganisms count in the soil. These variables helped in the isolation of effects of cypermethrin on soil bacteria, fungi, actinomycetes and soil macro and meso-nutrients.

Collection of soil samples and preparation for laboratory analysis

A one-kilogram soil sample was collected from Makerere University Agricultural Research Institute Kabanyolo in Wakiso District, central region of Uganda. A hand auger of diameter 2-3 cm and length of 15-20 cm was employed. Soil was collected at a depth of 0-15 cm. Samples were placed in clean, air-tight polythene bags and transported to microbiology laboratory in Makerere University for analysis. Samples were air-dried on a clean piece of paper, ground using a mortar and pestle, sieved through a 0.2 mm mesh. The samples were incubated in the dark at 30 ºC for one week then stored at 4 ºC to slow down biochemical reaction and ensure accurate results. Soil properties vary with seasons due to factors such as rainfall, temperature and plant growth. The sampling was done during peak wet and dry seasons for consistent results. Multiple surface soil samples were collected at a depth of 0-15 cm. The soil samples were analysed for nutrient fluctuation and seasonal changes in nutrient availability.

Soil analysis

Determination of pH, organic matter, macro and mesonutrients in soil samples

Soil pH was measured in a 1:2.5 soil to water suspension using glass electrode method (McLean 1982). The electrode was dipped in the soil water solution. Hydrogen ions (H^+) from the solution interacted with the glass membrane caused change in the membrane potential. The potential difference between the internal reference electrode and the glass membrane was measured and it was proportional to the pH of the solution.

In phosphorus analysis, soil of 2.5 g was weighed and added into a 125 ml Erlenmeyer flask and 50 ml of $NaHa_3$ was added into it. The flask was shaken for 30 minutes at 25 ºC. The solution was filtered through Whatman No. 42 filter paper. Ammonium molybdate and ascorbic acid were added to the extract to develop a blue colour. The absorbance was measured at 882 nm using a spectophotomer.

For potassium, 5g of soil sample was weighed and added into 125 ml Erlenmeyer flask. 50 ml of 1M NH_4OAC solution was aslo added. The flask was shaken for 30 minutes in room temperature (25 ºC). The extract was filtered through Whatman No. 42 filter paper. The concentration of potassium was determined using flame photometer at wave length of 766 nm.

For calcium, 5 g of soil sample were weighed and added into a 125 ml Erlenmeyer flask. 50 ml of 1M NH_4OAC (pH 7) was added. The flask was shaken for 30 minutes at room temperature (25 ºC). The extract was filtered through Whatman No. 42 filter paper. The concentration of calcium in the extract was measured using Atomic Absorption Spectrophotmer.

For magnesium, into a 5 ml 1M NH_4OAC (pH 7), 5g of soil was added and shaken for 30 minutes. The solution was filtered using Whatman No. 42 filter paper. Magnesium concentration was measured at wave length of 285.2 nm using AAS.

Determination of microbial communities

The collected soil samples were stored in a cool place at 4 ºC to prevent over growth of fast-growing bacterial species and minimize changes in microbial composition and viability. Soil samples were serially diluted (10^{-3} – 10^{-6}). Onto the diluted samples, 0.1 ml was spread onto potato dextrose agar (PDA). The mixture was plated on the agar and incubated at temperatures of 28 – 37 ºC for 2 – 7 days. The bacterial colonies that developed were converted and calculated in colony forming units (cfu/g). For fungal analysis, the collected soil samples (0 – 15 cm depth) were stored in a sterile bag. The sample was plated on PDA and selective media like Rose Bengal agar was added. This was incubated at 28 ºC for 3 – 7 days.

The soil samples were serially diluted (10^{-3} – 10^{-6}). 0.1 ml of agar was spread into the diluted solution and incubated at 28 – 30 ºC for 5 – 14 days. Streptomycin was used to suppress fungi and bacteria. The period allowed for visible colony growth since actinomycetes are slow growing (Klinger et al. 1962, Williams and Davis 1965). The colony forming units (cfu/g) were counted.

Data analysis

Statistical package SPSS was used to analyse data collected from both baseline (2016 - 2019) and experimental study. The results from both were used to compare means of three replicates for Least Significant Difference LSD at $P \leq 0.05$. For macronutrient concentrations of N, P, K, Ca, and Mg, SPSS was used to determine the mean. Standard Deviation SD for nutrient levels and P values for comparing effects of cypermethrin on both nutrient levels and microbial populations. Baseline or reference point was established to measure

variations in independent and dependent variables over time after cypermethrin intervention.

Results

The results of pH, organic matter, macro and mesonutrients are presented in Table 1. The study examined the parameters in the soil before cypermethrin application. The mean baseline parameters were pH 6.8, organic matter 3.51%, Nitrogen N 0.4%, phosphorus P 52.6 cmol/kg, potassium K 0.65 cmol/kg, and mesonutrients; calcium Ca 6.03 cmol/kg, and magnesium 1.91 Cmol/kg (Table 1).

Table 1: Results of baseline analysis of physicochemical properties of the soil before cypermethrin application

		Macronutrients			**Mesonutrients**	
pH	OM %	% Nitrogen (N)	Phosphorus (P) Cmol kg^{-1}	Potassium (K) Cmol kg^{-1}	Calcium (Ca) Cmol kg^{-1}	Magnesium (Mg) Cmol kg^{-1}
6.4	3.75	0.19	47.15	0.65	6.1	1.93
6.5	3.50	0.18	52.9	0.56	6.2	2.15
6.7	3.65	0.16	74.6	0.45	7.0	1.25
6.5	3.02	0.14	42.8	0.49	4.5	2.54
6.4	3.65	0.18	34.7	0.50	6.6	1.25
6.3	4.03	0.15	32.4	0.68	5.8	3.24
6.5	4.13	0.20	41.1	0.74	5.9	1.45
6.7	4.91	0.24	64.2	0.85	4.8	1.25
6.5	3.78	0.25	82.5	0.65	5.1	2.35
5.9	3.66	0.27	30.8	0.66	6.8	1.54
6.5	3.53	0.26	36.3	0.68	6.5	2.22
6.0	3.63	0.21	41.9	0.74	6.1	1.32
6.8	3.70	0.16	39.2	0.65	5.9	2.21
6.5	3.55	0.19	30.6	0.80	6.4	1.45
5.4	4.15	0.21	32.8	0.67	5.6	2.35
6.6	3.66	0.20	64.1	0.65	6.8	2.46
6.8	3.51	0.14	52.6	0.65	6.03	1.91

The results on microorganisms (bacteria, fungi and actinomycetes) in the soil are presented in Table 2. The results of soil microorganisms in the study site showed that; Bacteria population varied from 50.5 x 10^7 to 89.5 x 10^7 cfu/g, fungal count varied between 26.4 x 104 to 51.0 x 10^4 and actinomycete population ranged from 33.5 x 10^6 to 120.5 x 10^6 cfu/g (Table 2).

Table 2: Results of baseline analysis of soil microbes before cypermethrin application

Bacteria x 10^7/g dry weight soil	**Fungi x 10^4/g dry weight soil**	**Actinomycetes x 10^6/g dry weight soil**
89.5	51.0	120.5
73.0	38.0	185.5
63.5	49.5	38.5
64.5	51.0	88.5
60.0	40.5	48.5
87.0	32.0	57.5
50.5	30.5	83.0
60.5	46.2	61.5
48.0	31.5	33.5
87.4	26.4	29.4
58.5	30.5	39.5
67.0	51.5	40.0
66.5	44.0	38.5
50.8	26.4	38.0
80.1	29.2	33.5
78.2	30.9	27.5

The results on the effect of cypermethrin treated soils on macronutrients are shown in Table 3. Nitrogen levels were similar in control and cypermethrin treated soils (0.22%). Among blocks, the levels of nitrogen ranged from 0.19% - 0.24% at ($P \leq 0.05$). In control soil, the level of phosphorous was 30.6 cmol/kg and in cypermethrin – treated soil, it was 33.8 cmol/kg. Among blocks, phosphorus content ranged from 19.6 cmol/kg (lowest) to

47.7 cmol/kg (highest) at ($P \leq 0.05$). Control soil had potassium concentration of 0.56 cmol/kg and cypermethrin treated soil had 0.54 cmol/kg. Within blocks, potassium levels were 0.50 cmol/kg (lowest) to 0.57 cmol/kg (highest) at ($P \leq 0.05$).

Table 3: Effect of Cypermethrin treated soils on macronutrient levels (Nitrogen, Phosphorus and Potassium)

Nitrogen			
Variables	**Category**	**Mean of Nitrogen N %**	**Standard SE**
Pesticide	Control (TC)	0.22	0.02
	Cypermethrin (CP)	0.22	0.02
Blocks	A	0.23	0.03
	B	0.19	0.03
	C	0.24	0.03
	D	0.20	0.02
Phosphorus			
Pesticide	Control (TC)	30.6	4.21
	Cypermethrin (CP)	33.8	5.11
Blocks	A	30.6	4.11
	B	39.8	6.89
	C	47.7	7.21
	D	19.6	2.51
Potassium			
Pesticide	Control(TC)	0.54	0.06
	Cypermethrin (CP)	0.56	0.03
Blocks	A	0.57	0.04
	B	0.52	0.03
	C	0.56	0.05
	D	0.50	0.06

The results of the effect of cypermethrin treated soils on mesonutrients are shown in Table 4.

Calcium level in control soil was 5.80 cmol/kg and in cypermethrin – treated soil it was 5.96 cmol/kg. Across blocks, concentration of calcium varied from 4.7 cmol/kg (lowest) - 7.51 cmol/kg (highest) at ($P \leq 0.05$).

Magnesium level in control soil was 1.93 cmol/kg and cypermethrin – treated soil was 1.97 cmol/kg. Within blocks, magnesium content varied from 1.96 cmol/kg (lowest) - 2.24 cmol/kg (highest) at ($P \leq 0.05$).

Table 4: Effect of Cypermethrin treated soils on mesonutrients (Calcium and Magnesium)

Calcium			
Variables	**Category**	**Mean of Calcium (Ca) Cmol kg^{-1}**	**Standard (SE)**
Pesticide	Control(TC)	5.80	0.81
	Cypermethrin (CP)	5.96	0.72
Blocks	A	5.81	0.49
	B	7.51	1.25
	C	6.21	0.67
	D	4.70	0.37
Magnesium			
Pesticide	Control(TC)	1.93	0.13
	Cypermethrin (CP)	1.97	0.15
Blocks	A	1.96	0.27
	B	2.24	0.24
	C	1.96	0.16
	D	2.04	0.18

Microbial Communities

In control soil, bacterial count was 7.5 x 108 cfu/g and cypermethrin-treated soil had 16.0 x 108 cfu/g, whereas, the fungal count was 5.2 x 105 cfu/g in control soils and cypermethrin-treated soil had 2.0 x 105 cfu/g.

Discussion

The nitrogen levels in both cypermethrin – treated and control were below the lower and upper limits of the sufficiency range of 0.17–0.34% (Table 3). Similar results were reported by Van Bruggea and Semenov (2000). This low nitrogen level limits plant growth and productivity (Marschner 2012) suggesting that nitrogen might be a limiting factor for crop growth, regardless of

cypermethrin application in the study area. The consistent nitrogen levels in control and cypermethrin-treated soils (0.22%) suggests minimal impact of cypermethrin on soil nitrogen in tropical climate in the short-term.

Block level variations (0.19-0.24%) indicate soil heterogeneity and potential opportunities for soil management. During dry seasons, reduced soil moisture minimizes nitrogen leaching, but also decreases microbial activity leading to reduced nitrogen mineralization, and immobilization, potentially limiting plant nitrogen availability in soils. In contrast, rainy seasons can exacerbate nitrogen leaching, reducing soil nitrogen availability for plants, as excess water facilitates nitrogen loss from the soil profile (Cameron et al. 2013).

Organic matter in before cypermethrin application was 3.50–4.91% (Table 1), the maximum soil organic content of the world is 5% but some soils contain between 2–10% organic matter (Lal 2004, Six et al. 2002). Increase in soil pH due to pesticide use increases the solubility of organic matter by increasing the dissolution of acid functional groups (Anderson et al. 2000, Evans et al. 2012).

Organic matter can exchange calcium and magnesium for hydrogen ions, this leads to increased soil acidity in the tropics (Van et al. 1983, Binkley and Richer 1987). However, small increase in organic matter can lead to a large increase in pesticide sorption thereby increasing the level of pesticides in the soil (Adeyeye and Ademuliyi 2017, Atsushi and Shibata 2018, FAO 2018). Contrary to this finding, Kumar et al (2012) reported increase in soil organic matter in cypermethrin-treated over control soils in tomato cultivation in India.

High rainfall and organic matter decomposition lead to acidic soil conditions (Sparks 2003, Kochian et al. 2004). This highlights the importance of soil management practices like no-till, cover cropping and organic amendments to mitigate acidity and maintain soil health by enhancing soil structure, increasing infiltration and water-holding capacity within the tropics (Barrios 2007).

Cypermethrin – treated soils can alter phosphorus levels by impacting microbial communities and enzyme activities, potentially reducing phosphorus availability by inhibiting phosphorus- mineralizing microorganisms (Singh and Singh 2005). Phosphorus levels saw variations but overall, they were within a range that supports crop growth. The slight difference between control and cypermethrin treated soils might not be significant, considering the block-level variations. Sufficient phosphorus levels in soil boosts the soil's disease-suppressive capacity through beneficial plant-microbe interactions (Marschner and Timonen 2005). Previous studies have shown that phosphorus boosts microbial biomass, obtained through organic matter decomposition and animal manure (He and Zhu 2013, Chen and Jiao 2015). These microbes compete with plants for phosphorus, absorbing and storing it, then releasing it upon death.

The potassium levels indicate minimal difference between control and cypermethrin-treated soils showing little impact of cypermethrin on soil potassium on tropical soil of Uganda within the short-term (Table 3). Potassium uptake is optimized when soil levels are within the optimal range (Adeyeye and Ademuliyi 2017). However, potassium is depleted through crop removal, erosion, and leaking leading to declining levels if not replenished. The role of potassium in stress tolerance and physiological processed is well documented by Ejaz et al. (2011) and Mengel and Kirby (2000) highlighting the importance of potassium in plant growth and development in tropical climates.

Calcium concentrations in the control soil and cypermethrin-treated soils were relatively consistent suggesting that control soil has stable calcium levels indicating relatively homogenous soil conditions. These values can serve as a baseline to compare the effects of cypermethrin treatment or other interactions. Seasonally, factors such as rainfall and temperature influence calcium availability in the soil. The factors influencing calcium variability in soil are precipitation, temperature, and microbial activity in the area (Likens and Bormann 2014). Calcium is very available to plants in soils with pH 6–7 (Brady and Weil 2002). The critical deficiency levels for exchangeable calcium vary among plant species, but is reported to be in the range of 0.5 – 1.5 $cmolkg^{-1}$ (Kopittke et al. 2016). The finding agrees with Ozgen and Palta (2005), who reported that calcium is considered to play a role in mediating stress responses during injury, recovery from injury and acclimatization to stress.

Magnesium concentrations in soil show minimal difference between control and cypermethrin-treated soil, indicating little impact of cypermethrin on soil magnesium. The block level variations suggest some fluctuations but overall magnesium levels seem adequate for crops within the short-term. The dry conditions reduce microbial activity slowing magnesium cycling leading to its accumulation in the soil (Wang et al. 2018). Magnesium level in the tropics is 4-6 cmol/kg, for better crop growth and development. Magnesium requirement and its availability in tropical soils are; 6–8 cmol/kg in acidic soils, and generally ranges from 4-6 cmol/kg (Thomas 1996). The factors influencing magnesium availability in soils are; soil pH, which decreases in acidic soils, soil type, weathering and organic matter.

and Increased temperatures (18.6– 26.4 $^{\circ}C$) and low rainfall 8.16 mm to 42.59 mm in the dry season reduced bacterial population in the soil. Initial decline in population were due to toxicity. Rapid recovery of bacteria exceeding control levels were due to reduced competition, utilization of deal cell debris as energy source by the bacteria. Cypermethrin is claimed to be environmentally friendly compared to other chemicals (Bashir et al. 2007, Bhatt et al. 2020, 2021). However, its wide agricultural use leads to accumulation in soil affecting crop yields (Suresh Juma 2013, Duran et al. 2015, Birolli et al, 2022).

In control soils, fungal population was higher at 5.2 x 10^5 cfu/g, compared to cypermethrin – treated soil 2.0 x 10^5 cfu/g. Both control and treated soils showed reduced fungal population. The possible degradation of cypermethrin by fungal species as a carbon source hence increased their populations in the soil. Cypermethrin might have stimulated fungal growth in the treated soils. In the control soil, fungal growth might have been limited by limited nutrients and insufficient organic matter in the soil. The toxic nature of cypermethrin reduced fungal population in treated soils. Low fungal population in control soils suggest cypermethrin was used an as energy

source. Persistence of cypermethrin in soil leads to long-term effects on soil microbe. In addition, cypermethrin had negative effect on actinomycetes population, the possible explanation could be due to the toxicity of cypermethrin that inhibited actinomycetes germination, growth and development and soil. In general, cypermethrin affects soil fertility by altering populations of soil organisms (Ortiz – Hernandes et al, 2013).

Conclusion

The study revealed significant effects of cypermethrin on soil macronutrients, meso-nutrients, bacteria, fungi, and actinomycetes in tropical soils in Uganda. Major findings indicate; Soil nitrogen concentration was similar in control and cypermethrin treated soils. Phosphorus levels were higher in cypermethrin treated soils than control soils. Potassium level increased slightly in cypermethrin treated soil.

Microbial populations decreased in all the soil types. It is recommended that farmers use integrated pest management practices in tropical climate of Uganda as well as organic fertilizers to enhance soil fertility and microorganism activity.

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Competing Interests

Authors declares no competing interests.

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