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The effect of paraquat dichloride and carbosulfan on soil conditions and population dynamic of soil microbes in a cornfield: a case study in Sumedang, West Java

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ABSTRACT

Paraquat dichloride (PC) is one of the herbicides active ingredients that is widely used by farmers to control various types of weeds, while carbosulfan (CS) is one of the insecticide's active ingredients that is widely used to control various types of insect pests. The objective of this study is to analyze the impact of pesticides for PC and CS on the chemical and physical conditions of the soil and the dynamics of fungi and soil bacteria population in a corn field in Sumedang district, West Java. The experiment took place between August and October, during the dry season, concluding just as the rainy season began. The PC concentrations used were 0 mL/L, 3.33 mL/L, 4 mL/L, 4.66 mL/L and 5.33 mL/L, while the CS concentrations used were 0 mL/L, 0.5 mL/L, 1 mL/L, 1.5 mL/L and 2 mL/L. Soil sampling was conducted before and after the application of pesticides. The total abundance of fungi and bacteria was analyzed using the total plate count (TPC) method. The application of PC to the cornfield slightly decreased soil bulk density from 1.354 g/cm^3 to 0.816 g/cm^3, while the application of CS slightly increased soil bulk density. A decrease in bulk density is considered positive for the physical conditions of the soil for plant cultivation. In general, the result indicated that the application of PC and CS did not show a significant effect on the chemical characteristics of the soil, and also it did not affect the population of fungi and bacteria. Weather conditions, i.e. dry season (June-September) and rainy season (started from October) seem to affect more on soil conditions as well soil microbial population than the application of the pesticides.

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1. Introduction

The agricultural sector plays a crucial role in the economic development and livelihoods of many Indonesians. However, several challenges, including water scarcity, climate change, and plant pests and diseases, hinder optimal agricultural production (Rozaki, 2020). Pesticides are essential for controlling these issues, but farmers often struggle with identifying and managing pests and diseases (Skevas et al., 2013; Abang et al., 2014). Agricultural practices in Indonesia heavily rely on pesticides to protect crops from pests and weeds (Joko et al., 2020; Mariyono et al., 2018).

The use of pesticides, especially herbicides, is one of the strategies to control pests and weeds in plantations, horticulture, and food crops. Weeds are a crucial problem that needs to be addressed because they can cause a 34 % decrease in plant productivity (MacLaren et al., 2020, Oerke, 2006). The use of herbicides is considered to be more effective, faster, and easier for farmers to minimize losses due to these disturbances (Sarbino and Syahputra, 2012).

One of the herbicides used in Indonesia is paraquat dichloride (PC). This herbicide is a contact herbicide that can eliminate toxic and contaminated plant tissues in living plant cells. PC offers several advantages due to its ability to target tall weeds effectively, leading to their death and allowing for immediate replanting of the land (Sarbino and Syahputra, 2012). The objective of this study is to analyze the impact of PC herbicide on the abundance of microorganisms, the dynamics of fungi and soil bacteria populations, and the physical-chemical characteristics of the soil during a planting season (dry season).

In addition to weeds, farmers in agricultural activities often encounter the issue of contamination by plant pest organisms. These pests can be present from the seed stage of the plants until they are ready for harvest, and their attacks can lead to harvest failure. To mitigate the adverse effects of pests on plant productivity, farmers use pesticides to eliminate them. The use of chemical pesticides is currently considered to be more practical, easier to obtain, and effective in dealing with pests (Ardiwinata and Nursyamsi, 2012).

One of the insecticides used in Indonesia is carbosulfan (CS) which is 2,3-dihydro-2,2-dimethylbenzofuran-7-yl (dibutylaminothio) methylcarbamate, a systemic insecticide and acaricide, acting as both a contact poison and stomach poison for pest control in plants (Giri et al, 2002). Within the insect's body, CS transforms into carbofuran (Giri et al, 2002).

The objective of this study is to analyze the impact of PC and CS applications on the chemical and physical characteristics of the soil and the dynamics of fungi and soil bacteria populations in a corn field.

2. Materials and methods

2.1. Soil sampling

The determination of pH and soil relative humidity was conducted using the soil tester DM-5 TAKEMURA on all treatment plots of T0 and T3. Bulk density determination was carried out using a core sampler, with measurements conducted on all treatment plots of T0 and T3. Soil samples were oven-baked at 150ºC for 24 hours, and bulk density was calculated by dividing the sample's dry weight by the core sampler's volume. Soil permeability determination was conducted by dropping distilled water onto the soil sample, and the time needed for all drops to reach the bottom was recorded. Soil permeability was then calculated using the following equation:

$$k = \frac{Q \, x \, L}{A \, x \, h \, x \, t}$$

Index:
Q = dropped distilled water volume (mL)
L = soil thickness / ring's height (cm)
A = soil surface area / ring's surface (cm^2)
h = Water height when soil was soaked (cm)
t = time needed until all the drops reached the bottom (minutes)

2.2. Soil microbial sampling

The research was conducted at the ITB Research Station in Haurngombong Village, Sumedang, and SITH-ITB. The experiment was conducted between August and October, during the dry season, concluding just as the rainy season began. Soil type in the Research Station is andosol with relatively high porosity. PC concentrations employed were: 0 mL/L (A2), 3.33 mL/L (B2), 4 mL/L (C2), 4.66 mL/L (D2), and 5.33 mL/L (E2), which were sprayed on the plots 35 days after planting. CS concentrations used were 0 mL/L, 0.5 mL/L, 1 mL/L, 1.5 mL/L, and 2 mL/L, and sprayed at 15 and 30 days after planting. The plot size was 5 m x 4.5 m with 5 replicates. Control plots were applied with 0 ml/L of PC and CS.

Soil sampling for microorganisms was conducted at a depth of 10 cm at three different times: T0 (original condition, before tillage), T2 (after tillage and pesticide application), and T3 (before harvesting, early rain season). Soil samples were collected from both the control and the plots with the highest concentrations of PC and CS treatments. Bacteria and fungi concentrations from all samples were then analyzed at dilutions of 10^2, 10^3, and 10^4. The grown bacteria and fungi were characterized based on the morphology of the colony. Statistical analyses were conducted using Analysis of Variance (ANOVA) with the SPSS program.

3. Results and discussion

3.1. Soil characteristics

The soil texture can be broadly classified as clay loam, with a textural composition of 8 to 9% sand, 27 to 37% silt, and 56 to 63% clay. The soil acidity content ranges from neutral pH (7), and the pH of this soil is relatively unaffected by the use of pesticides. The soil moisture at the time of application is, on average, only 15% due to the dry season, while the soil moisture after rainfall reaches 80% (Table 1).

Table 1. Soil pH and relative humidity before and after pesticide application

Treatment plots	pH		RH (%)	
	Before appl.	After appl.	Before appl.	After appl.
Paraquat dichloride	6.9	6.8	15.4	66.9
Carbosulfan	7,0	6.9	9.4	59.6

Table 2. Bulk density and soil permeability

Treatment Plots	Bulk density (g/cm³)		Permeability (cm/jam)	
	Before appl.	After appl.	Before appl.	After appl.
Paraquat dichloride	1.35	0.82	5.65	5.05
Carbosulfan	0.74	0.93	4.78	4.83

The application of PC slightly reduced the bulk density of the soil from 1.35 g/cc to 0.82 g/cc (Table 2). This decrease in bulk density has a positive effect on the physiological conditions of the soil for plant cultivation. The presence of increased plant growth, arthropod, and microbial activity can enhance porosity, organic matter, and reduce bulk density (Buckman et al., 1982). The use of pesticides did not affect soil permeability, which ranged between 5.1 and 5.6 cm/hour, classified as intermediate permeability (2 to 6.25 cm/hour) (Suripin, 2001).

It can be observed that the application of PC did not induce a significant change in soil chemical conditions (Table 3). In contrast, another report suggests that PC improves the soil's chemical properties by increasing the pH and total nitrogen content (Adnan et al., 2012). The difference in result from other experiment probably due to differences in environmental conditions.

3.2. Abundance of microorganisms

3.2.1. Population dynamic of fungi

The number of fungi in the samples taken before the corn was harvested (T3) was generally higher than the number of fungi at the time before tillage (T0) (Fig. 1 and 2). This observation is linked to the environmental conditions of the soil during sampling. Generally, during the sampling at T0, the soil in the planting area was dry

Table 3. Chemical properties of the soil in Haurngombong village, Sumedang.

Parameters	Plots PC		Plots CS	
	Before Appl.	After Appl.	Before Appl.	After Appl.
C-organic (%)	1.33 ± 0.20	1.510 ± 0.16	1.65 ± 0.32	1.57 ± 0,13
N-total (%)	0.18 ± 0.03	0.17 ± 0.02	0.20 ± 0.02	0.20 ± 0.01
C/N	7.67 ± 1.16	9.33 ± 1.53	8.33 ± 1.16	7.67 ± 0.58
P_2O_5 HCl 25% (mg/100g)	250.34 ± 13.54	225.57 ± 48.61	252.25 ± 25.93	266.11 ± 16.57
P_2O_5 (Bray) (ppm P)	53.42 ± 27.89	22.09 ± 11.49	30.62 ± 6.32	22.12 ± 10.27
K_2O HCl 25% (mg/100 g)	55.00 ± 26.13	35.93 ± 29.29	27.04 ± 19.67	32.80 ± 12.82
CEC (cmol/kg)	18.37 ± 0.69	17.51 ± 0.47	19.57 ± 2.34	16.96 ± 7.24

In samples taken after spraying with PC and CS, almost all treatments led to a decrease in the number of fungi, except in treatment C1 (1 mL/L CS) and C2 (4 mL/L PC), where it appears that the number of fungi increased, although statistically not significantly.

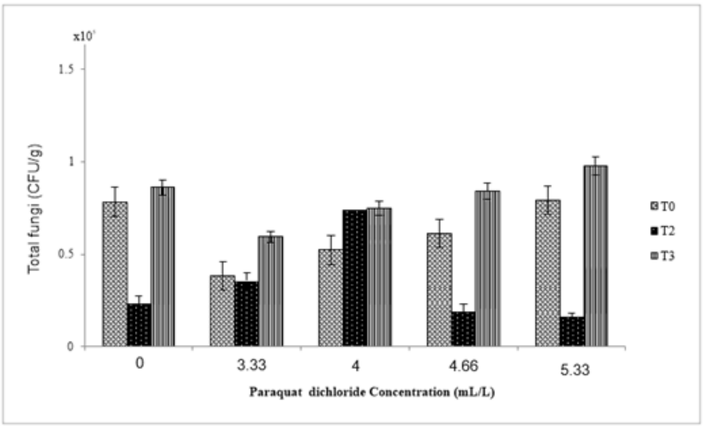

Fig. 1. Fungi abundance in PC Plots at Time Before Tillage and Pesticide Application (T0), After Pesticide Application (T2) and Before Harvesting (T3).

A similar trend is also observed in both PC and CS treatments in general. This trend is likely attributed to the influence of environmental factors, such as air temperature and soil moisture. Based on the observation results, it was found that environmental factors have a far greater impact on the dynamics of the fungi population than PC pesticides and CS.

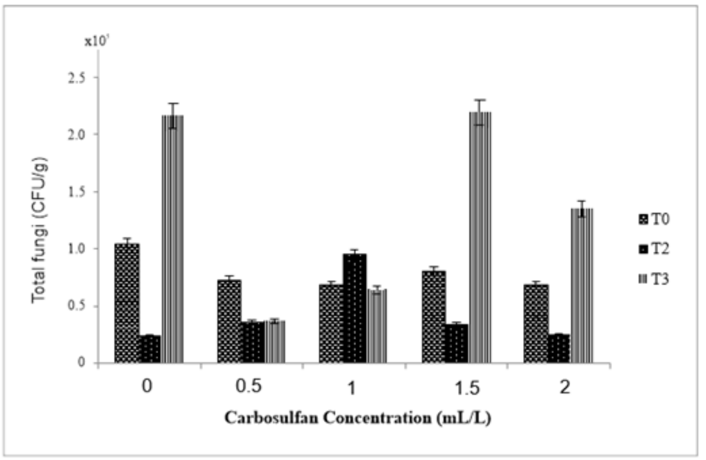

Fig. 2. Fungi abundance in CS Plots at Time Before Tillage and Pesticide Application (T0), After Pesticide Application (T2) and Before Harvesting (T3).

There are some reports, however, that mention a decrease in the number of genera of fungi isolated, from 29 in organic soybean to 20 in conventional soybean (Stuart et al., 2018). In another case, the herbicide 2,4-D led to a significant increase in the population of total bacteria (up to 21.1%) and fungi (33.7%) (Paul et al., 2013). It was also reported that Flusilazole (Punch 400 EC), Amitraz (Mitac 20 EC), and phosalone (Zolone 350 EC) were toxic to *Hirsutella nodulosa*, *H. brownorum*, *H. kirchneri*, and *H. necatrix* (Tkaczuk and Miętkiewski, 2004).

3.2.2. Population dynamics of bacteria

The application of PC and CS did not have a significant effect on the population number of bacteria. The difference in the quantity between the time before and after the application appears to be more influenced by environmental conditions, namely, the dry conditions at T0 and T2, and rainfall at T3 (Fig. 3 and 4).

Microbial variety and uniformity were consistently greater in untreated and herbicide (atrazine, glyphosate) treated groups compared to those treated with insecticides (malathion, carbaryl, permethrin) or a combination of insecticide and herbicide, according to Muturi et al. (2017). These effects were notably intensified by day 7, with the highest diversity and evenness observed in untreated and herbicide-treated groups, intermediate levels in insecticide-treated groups, and the lowest levels in groups treated with a combination of insecticide and herbicide. Another study using permethrin, malathion, atrazine, and glyphosate pesticides found that they influenced microbial communities in aquatic environments (Muturi et al., 2013).

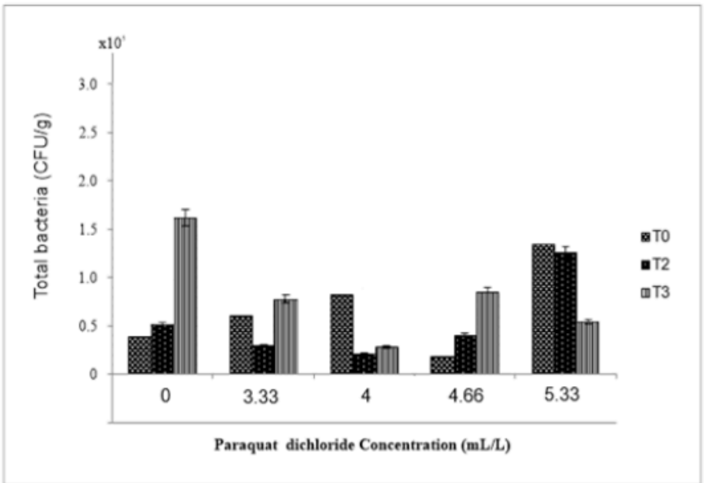

Fig. 3. Abundance of bacteria in PC Plots at Time Before Tillage and Pesticide Application (T0), After Pesticide Application (T2) and Before Harvesting (T3).

In the case of CS, these results are consistent with those reported by Sarnaik et al. (2006), who found that CS does not have a significant impact on the overall abundance of bacteria in the soil. The dynamics of bacterial populations coincide with changes in weather and the second application of pesticides. Some bacteria, such as nitrogen-fixing aerobic bacteria like *Azospirillum*, and carbosulfan-degrading bacteria such as *Pseudomonas sp.*, can have their growth induced by the presence of CS pesticides (Sharif and Mollick, 2013).

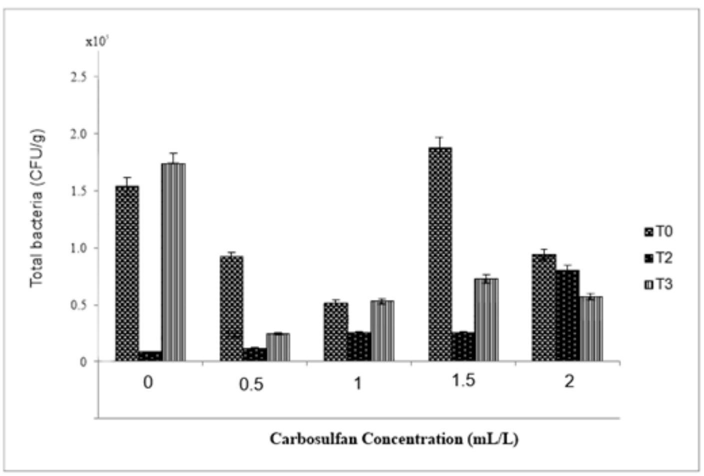

Fig. 4. Abundance of bacteria in CS Plots at Time Before Tillage and Pesticide Application (T0), After Pesticide Application (T2) and Before Harvesting (T3).

Increasing soil moisture supports microbial abundance because it is related to water content and the presence of organic and inorganic materials dissolved in the soil, which in turn fosters microbial growth, including both fungi and bacteria. This is further supported by the conditions of neutral soil pH (7 ± 0.2) and soil temperature (30 ± 0.6), which are conducive to the growth of mesophilic bacteria such as *Bacillus sp* and *Clostridium sp* (Madigan et al., 2014). At neutral pH, the majority of microbes that thrive are neutrophilic, including bacteria, actinomycetes, and fungi capable of degrading inorganic and organic matter, thus maintaining the pH level close to normal (Rousk, 2010).

In other studies, the weight loss of leaves, faster losses of Ca and Mg, and promoted higher densities of microfloral-grazing microarthropods than untreated controls. The rate of nutrient loss from the litter occurs through microbial and microarthropod activity (Hendrix, 1985).

The herbicide PC was found to have no significant effect on soil arthropods according to Anggraeni et al. (2020). Similarly, Martono et al. (2021) reported that PC application in rice paddy soil did not greatly impact soil fauna, including arthropods and earthworms. Dadang et al. (2019) observed no significant effects on the chemical and physical properties of soil in oil palm plantations following PC application. However, Nurulalia et al. (2021) reported different findings, indicating that PC application affected the species composition, dominance, and population of soil arthropods in rice fields, corn fields, and oil palm plantations, with steady increases observed 8 to 12 weeks after application.

Herbicides had a greater impact on soil microorganisms and their functions compared to fungicides or insecticides when tested in laboratory. However, when used at the recommended doses in soil, the effects typically reversed within 1-3 weeks (Subhani et al., 2000). This finding supports the idea that pesticides, when applied correctly, are usually not harmful to helpful microorganisms and their functions (Subhani et al., 2000, Wainwright, 1978). Furthermore, applying herbicides once at the recommended rates did not consistently or significantly impact the soil's microbial biomass or bacterial diversity. However, changes in the microbial community structures were occasionally observed even when there were no differences in microbial biomass and diversity (Lupwayi et al., 2003).

4. Conclusion

The application of paraquat dichloride (PC) to the cornfield slightly decreased soil bulk density from 1.354 g/cm^3 to 0.816 g/cm^3, while the application of carbosulfan (CS) slightly increased soil bulk density. A decrease in bulk density is considered positive for the physical conditions of the soil for plant cultivation. In general, the application of PC and CS did not have a significant effect on the physical and chemical properties of the soil.

Furthermore, the application of PC and CS did not significantly impact the community of bacteria and fungi in the soil in terms of changes in their population dynamics. The population dynamics of bacteria and fungi appear to be more influenced by environmental factors, such as drought conditions at the beginning of planting and the onset of rainfall at the end of the experiment, compared to the application of pesticides. Applying the two pesticides at recommended doses and within the planting season did not have any adverse effects on soil microorganisms.

To enhance future studies, we suggest commencing the experiment at the onset of the rainy season to reduce the impact of varying weather conditions in the experimental field.

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Conflict of interest

The authors declare there is no conflict of interest in this paper.

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