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EFFECTS OF PARAQUAT DICHLORIDE APPLICATION ON SOIL ARTHROPODS AND SOIL CHEMICAL AND PHYSICAL PROPERTIES IN OIL PALM CULTIVATION

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ABSTRACT

A field experiment was conducted to evaluate the effect of paraquat dichloride application on soil arthropods and soil physical and chemical properties in an oil palm plantation. Different rates of paraquat dichloride were applied on weeds and soil arthropods were collected by pitfall trap and soil litter collection methods. A randomized block design with one factor was set up for analysing the data. The soil samples at 0-30 cm in depth were collected before and 12 weeks after paraquat dichloride application. The results showed that paraquat dichloride application did not affect significantly the number of species and arthropod population both from pitfall trap and soil litter samples. Generally, there were no significant changes in soil properties chemically and physically after paraquat application. It suggested that application of paraquat dichloride did not affect the chemical and physical properties of the soil in an oil palm plantation.

Keywords: number of arthropod species, pitfall trap, soil litter

INTRODUCTION

In the past few years, most herbicides have been used to inhibit weed growth or to control weeds that compete with crops for space, water, nutrients and ultimately affects crop yields (Varshney et al. 2012). Many active compounds of herbicides such as glyphosate - isopropylamine salt, propanil - 3'3'-dichloropropionanile, 2, 4-D acid -2, 4-dichlorophenoxy acetic acid are categorized as persistent soil pollutants, whose effects can last for decades while degrading soil properties and biota (Shaner and Leonard 2001). However, the interaction between herbicides and soil and also with soil arthropods and microorganism depends on the type of herbicide, soil type and microorganisms that exist in the soil (Nongthombam et al. 2008).

Paraquat dichloride is classified as a contact and non-selective herbicide that is widely used to control various types of weeds in crops and plantation. In Indonesia, this active ingredient is commercialized with many trademarks. Paraquat dichloride is very soluble in water and because of its ionic properties, so it is easily adsorbed by soil particles to become immobile in the soil (Costenla et al. 1990). Based on the type of soil, soil pH, temperature and the nature of cations that can be exchanged directly, these factors affect the adsorption-desorption of paraquat dichloride through the soil system (Gevao et al. 2000). The impact of pesticide application on the environment is very important. However, there are few studies about its eco-toxicological impact on biodiversity (arthropods) and soil chemical and physical properties. Therefore, the ecotoxicology study of paraquat dichloride is very necessary. The research sought to study the impact of paraquat dichloride related to ecological aspects, such as diversity and population of arthropods, as well as soil physical and chemical properties in an oil palm plantation.

MATERIALS AND METHODS

The research was conducted in an oil palm plantation in PTPN VIII, Cimulang Site, Bogor (6º31'N; 106º42'E), from August to November 2018. Soil analysis was carried out in the Laboratory of Chemistry and Soil Fertility, Department of Soil Science and Land Resources, Faculty of Agriculture, IPB.

Pesticide application. There were five treatments used in this experiment, such as paraquat dichloride with three doses: 1.6 kg ion/ha (= 16 ml/l formulation) (A), 0.8 kg ion/ha (= 8 ml/l formulation) (B), and 0.4 kg ion/ha (= 4 ml/l formulation) (C); fungicide carbendazim (2 g/l) used as toxic standard (D); and control (E) without pesticide treatment. Each treatment was replicated 5 times. Therefore, the total experiment plots were 25 plots. A plot size was 18 m x 18 m containing 18 oil palm trees. Paraquat dichloride and carbendazim were sprayed on weeds at each plot as 0 week. The pesticides were sprayed using knapsack sprayer with spray volume was 400 l/ha.

Soil arthropods collection. Arthropod samples were collected from pitfall trap and soil litter that was taken on 0, 2, 4, 8, and 12 weeks after pesticide application.

Pitfall trap. Plastic cups (5-7 cm in diameter and 10 cm in height) were used as traps. The cups containing 100 ml of 4% formalin (in water) were buried in the ground. Formalin could killed and preserved the arthropod specimens that were trapped in cups. To prevent the trap from rain drop, a roof-like plate (20 cm x 15 cm) was placed on the trap. After 24 hours, the arthropod samples of each trap were transferred to plastic container (volume 200 ml) and the identified at laboratory.

Soil litter samples. Soil litter samples were collected from each plots (10 cm x 10 cm in plot size) by using hand shovel. The samples were placed in each labelled plastic bag, then brought to the laboratory. Each litter sample then poured into a berlese funnel for 1 to 3 days (depend on the litter humidity) to collect the arthropods. The arthropod specimens then were stored in the bottle containing ethanol 70% until identification.

Identification and diversity measurement of soil arthropods. The arthropods collected from pitfall trap and soil litters were identified until morphospecies taxonomic level using a stereo microscope. Individual number of each species of arthropod was counted and called as the population data. Furthermore, both data of morphospecies and individual number of arthropods were analyzed with Shannon and Simpson diversity index. Shannon index used to see species richness in an area, whereas Simpson index used to compare the species diversity and species domination between areas (Magurran 1988).

The equations used to calculate of Shannon and Simpson diversity indices are:

a. Shannon (H') = $-\Sigma p_i (\ln p_i)$; where p_i is the proportional abundance of the i^{th} species = (n_i/N)
b. Simpson (D) = $\Sigma n_i(n_i-1)/N(N-1)$; where n_i = the number of individuals in the i^{th} species, N = the total number of individuals

Data analysis. This experiment used a randomized block design (RBD) of one factor.Statistical analysis were conducted using SAS 9.0 and Tukey's Honestly Significant Difference (HSD) test following one-way analysis of variance (ANOVA)($\alpha = 0.05$) to describe the influence of paraquat dichloride treatments to the population of soil arthropods.

Effect of praquat dichloride to soil properties in oil palm plantation. Soil samples were taken at each treatment plot at a depth of 0-30 cm. Disturbed soil samples were taken from several subsamples with a simple random method, then composite into one sample per treatment plot. The soil samples were dried, crushed and then sieved until they passed the sieve 2-mm. After that, the soil samples were analyzed in the laboratory for analysis of soil chemical properties (pH, organic C, total N, available P, potential P and K, bases, cation exchange capacity (CEC), and base saturation (BS). The soil samples for physical properties were taken in the plot representing each of the treatment plots using a ring samples. The physical soil samples were analyzed in the laboratory for analysis of bulk density, porosity, and soil permeability. Soil sampling is carried out before and after application of herbicides.

Statistical analyses were conducted on chemical and physical properties of soil after spraying of herbicides. The data were analyzed using SAS 9.4 Software to create analyses of variance concerning effects of paraquat dichloride on the chemical and physical properties of the soil. If it was significantly different, the analysis was continued by further testing using the Duncan Multiple Range Test (DMRT) test for testing the difference of mean values with $\alpha = 0.05$.

RESULTS AND DISCUSSION

Effect on soil arthropod. The sampling results of pitfall traps showed that12 orders of arthropods were collected, including Scorpiones (spiders) and Acarina (mites) from class of Arachnida; Poduromorpha and Entomobryomorpha from class of Collembola; order/class of Diplopoda; and 7 orders from class of Insecta, such as Coleoptera (Staphylinidae), Hymenoptera (FormicidaeandScelionidae), Orthoptera (Gryllidae, Gryllacrididae, and Tetrigidae), Lepidoptera, Hemiptera (Pentatomidae and Reduviidae), Isoptera (Termitidae), and Thysanoptera. While, in the sample of soil litters, there were found 18 orders of arthropods, including Scorpiones, Pseudoscorpionides, and Acarina from class ofArachnida; Entomobryomorpha, Poduromorpha, and Symphypleona from class of Collembola;Scolopendromorpha from class of Chilopoda; order/class of Diplopoda; Isopoda; and 9 orders from class of Insecta, such as Orthoptera (Gryllidae, Gryllacrididae, and Tetrigidae), Coleoptera (Staphylinidae), Lepidoptera (Noctuidae and Psychidae), Hymenoptera (Formicidae and Scelionidae), Dermaptera (Forficulidae), Diptera, Hemiptera (Pentatomidae and Reduviidae), Isoptera (Termitidae), and Thysanoptera.

Figure 1 indicates the total of species number collected from pitfall traps and soil litter samples. At week-0 (one day before pesticide application), the number of species found was around 3-5 species per treatment plot. Generally, all pesticide treatments showed decreasing in number of arthropod species at two weeks after the pesticide application, whereas the number species in plot-E (control) was increasing. The decreasing in number of species may be caused by declining the plant species due to herbicide application, any movement of arthropods from treated plots to untreated plots or the effect of pesticide applications. At week-8 (8 weeks after pesticide application), the number of arthropod species was increasing at all pesticide applications, except at A treatment (16 ml/l). However, the number of species at A treatment increased at week 12 (12 weeks after pesticide treatment).

Effect on population of soil arthropods. The population of arthropod in all plots based on pitfall trap method were fluctuated in number (Fig. 2a). Two weeks after pesticide application (week-2), the arthropod populations in all plots were decreased, but at week-4 the population sharply increased. At week-8, the arthropod population in all plots were decreased, but at week-12 the athropod population was increased again.

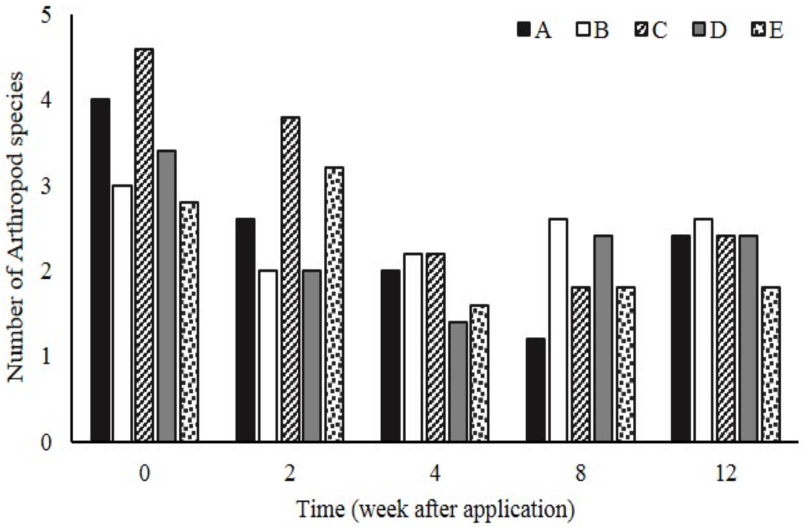

Fig. 1 Number of arthropod species collected from pitfall trap and soil litters

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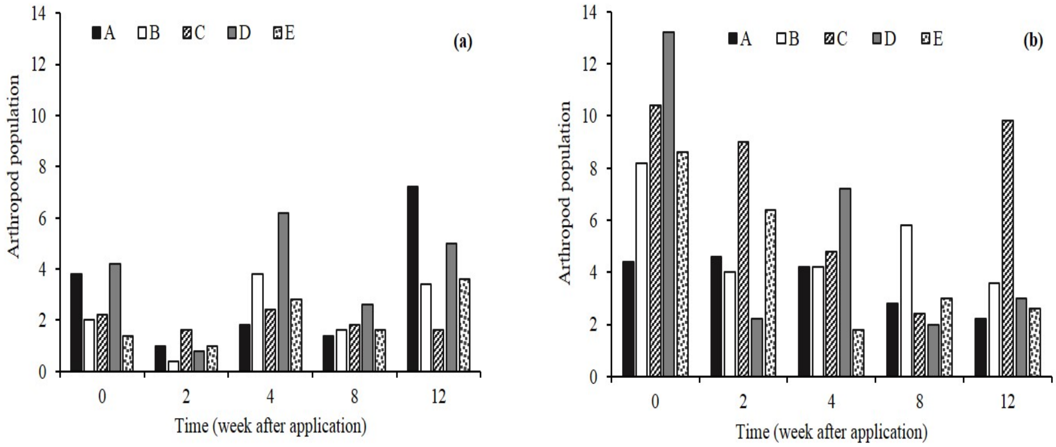

Fig. 2. Population of arthropods collected from pitfall trap (a) and soil litter (b) during five samplings.

In general, the number of arthropod species in soil litter samples was higher than from pitfall traps (Fig. 2b). The arthropod population from litter samples tend to decrease in A treatment (the highest concentration of paraquat dichloride). The similar pattern was occured in the treatment of B but in week-12, the population was increased more than three times in number. Meanwhile, the arthropod species population at other plots were fluctuated. The number of arthropod population both on pitfall trap and soil litters showed no significantly difference (Table 1).

Table 1. Population of arthropod collected from pitfall trap and soil litter during five times of sampling

Treatment	Sampling time (week after application)*				
	0	2	4	8	12
	Pitfall trap				
A	3.80 ± 4.71a	1.00 ± 1.73a	0.80 ± 0.84a	1.40 ± 2.61a	7.20 ± 2.95a
B	2.00 ± 1.58a	0.40 ± 0.55a	1.20 ± 0.84a	1.60 ± 1.82a	3.40 ± 1.82a
C	2.20 ± 1.92a	1.60 ± 1.95a	0.20 ± 0.45a	1.80 ± 2.49a	1.60 ± 1.82
D	4.20 ± 3.03a	0.80 ± 0.84a	1.00 ± 1.00a	2.60 ± 2.97a	5.00 ± 4.42a
E	1.40 ± 2.07a	1.00 ± 1.41a	1.20 ± 1.30a	1.60 ± 2.51a	3.60 ± 3.58a
	Soil litters				
A	4.40 ± 4.83a	4.60 ± 4.62a	4.20 ± 4.92a	2.80 ± 2.28a	2.20 ± 2.77a
B	8.20 ± 11.63a	41.60 ± 89.68a	4.20 ± 7.82a	5.80 ± 9.73a	3.60 ± 2.70a
C	10.40 ± 12.28a	9.00 ± 6.20a	4.80 ± 3.49a	2.40 ± 1.52a	9.80 ± 16.54a
D	2.80 ± 3.11a	2.20 ± 3.49a	2.40 ± 2.05a	2.00 ± 3.08a	3.00 ± 4.53a
E	8.60 ± 7.67a	6.20 ± 6.46a	1.80 ± 2.30a	3.00 ± 3.32a	2.60 ± 1.82a

* the number in the same column followed by the same letter is not significantly different based on Tukey's ($\alpha = 0.05$).

Species diversity and domination on the treatments of paraquat dichloride. The diversity of arthropod species was shown on Table 2. From week-0 to week-4, the highest species diversity was found in plot-C. Next, at week-8, the highest number of species found in plot-D, and at week-12 in plot-B. On the other side, there were species domination in every week of sampling. The insect from Family Formicidae (ants) dominated the arthropod species found at week-0 and 4. Meanwhile, at week-2 and 8, there was arthropod from group of Acarina (mites) that dominated the species found. Therefore, It showed that there was switching species domination between ants and mites during week-0 to week-8. Later, at week-12, group of Collembola dominated the arthropod species found.The physical properties of the soil (Table 2) on Cimulang's oil palm plantations were friable which can be seen from the relatively low bulk density, rather high porosity, and fast permeability.

Table 2. Species diversity of arthropod that collected from pitfall trap and soil litters according to Shannon and Simpson indices.

Treatment	Sampling time (week after application)*				
	0	2	4	8	12
	Shannon (H')				
A	7.95	6.01	4.65	2.72	4.70
B	5.85	1.44	4.68	5.03	5.68
C	8.68	7.25	4.82	4.39	3.72
D	6.65	4.90	3.30	5.42	5.07
E	5.85	6.33	4.02	4.21	3.77
	Simpson (D)				
A	0.08	0.08	0.12	0.24	0.21
B	0.15	0.89	1.23	0.21	0.11
C	0.06	0.11	0.16	0.11	0.52
D	0.16	0.09	0.17	0.11	0.13
E	0.10	0.12	0.10	0.14	0.23

Members of Acarina mostly found were Mesostigmata and Oribatida, and both usually found in soil. Mesostigmata is known as free-living predators. Few number feed on fungi, pollen, nectar, and plant fluids. Meanwhile the oribatid mites ingest solid foods, for example bacteria, fungi, microinvertebrates, and few are decomposting vegetation (leaf litter, lichens, and mosses).In soil, mites are contributing to the decomposition and nutrient cycling (Walter and Proctor 2013). Collembolaor springtails are also commonly found in the soil which contribute to organic material decaying. Therefore Collembola can be used as an indicator for soil fertility and disturbance. Moreover Collembola feed on fungi, and a member of Collembola (Foslomia) is known can decompose toxic material such as pesticide (Suhardjono et. al. 2012).

The initial soil properties. Soil characteristics (soil physical and chemical properties) prior to herbicide application on each experimental treatment on oil palm plantations are presented on Tables 3 and 4. Table 4 shows that the soil pH at the experimental site were a very acidic category except in the experimental plot E classified as acid, low C-organic content (trial plots A, B, C, and D) while in the E trial plots were classified as moderate, N-total of the plots were low to moderate, P-available were low in all experimental plots, and P-total in all trial plots were very high. The basic cations in the experimental treatments were very low to low (Ca) and low to medium (Mg) while the K and Na were very low, the cation exchange capacity (CEC) was classified as moderate except for the A treatment was low, and base saturation (BS) classified as very low (trial plots of B and C) to low (trial plots of A, D, and E).

Table 3. Initial physical properties of the each treatment before pesticide application.

Treatment	Bulk Density (g/cm^3)	Porosity (%)	Permeability (cm/hour)
A	0.98	63.0	8.97
B	0.95	64.2	9.67
C	1.02	61.6	7.04
D	1.01	61.9	7.53
E (control)	1.00	62.4	11.0

Effect on chemical and physical properties of Cimulang oil palm plantation soil. Paraquat dichloride application did not significantly affect the chemical properties of the soil, except soil pH total N. Paraquat dichloride had a significant effect on pH. The pH in experimental plots which were sprayed with paraquat dichloride at 4 ml/l (C) and carbendazim 2 g/l (D) were significantly higher than the experimental plots applied with paraquat dichloride at 8 and 16 ml/l (A and B). However, pH in the experimental plots C and D were not significantly different from controls (E). The total N-content in the control experimental plot (E) was significantly higher than the experimental plots which were sprayed with herbicides (Table 5).

Analyses of variance showed that paraquat dichloride did not significantly affect the bulk density and porosity but affected significantly the permeability of the soil. In paraquat dichloride treatment the concentration of 8 ml/l (experimental plot B) soil permeability was significantly higher than the treatment plot C, D, and E, but not different from the paraquat dichloride treatment concentration of 16 ml/l (Table 6).

Table 4. Initial soil chemical properties of the each treatment (before pesticide application).

Treatment	pH 1:5	Walkley & Black	Kjeldahl	Bray I	HCl25%		NNH4OAc pH 7.0					BS
	H_2O	Org-C	Total N	P	P	K	Ca	Mg	K	Na	CEC	
		..(%)..	..(%)..	……...(ppm)………			……..…...(cmol(+)/kg)……….					..(%)..
A	4.35	1.60	0.25	5.25	180	58.7	1.73	0.61	0.07	0.11	12.5	20.6
B	4.26	1.73	0.28	4.68	240	56.8	1,58	0.53	0.09	0.09	16.1	14.2
C	4.30	1.70	0.15	4.76	280	54.3	1.64	0.54	0.06	0.08	17.7	13.6
D	4.45	1.79	0.13	6.16	418	77.5	2.57	1.15	0,06	0.08	18.5	20.8
E (Control)	4.51	2.09	0.18	5.06	388	69.3	3.59	1.11	0.07	0.10	18.6	25.0

Table 5. Chemical soil properties of the each treatment after pesticide application.

Treatments	pH 1:5	Walkley & Black	Kjeldahl	Bray I	HCl25%		NNH_4OAc pH 7.0					BS
	H_2O	C-org	N-Total	P	P	K	Ca	Mg	K	Na	CEC	
		.(%).	..(%)..	……..(ppm)……			…………(cmol(+)/kg)…………					.(%).
A	4.39 a	1.66	0.25 a	3.64	208	188	2.71	1.15	0.40	0.06	15.4	27.5
B	4.32 a	2.11	0.22 ab	4.02	215	42.6	2.22	0.89	0.08	0.05	16.2	20.1
C	4.90 b	1.73	0.21 ab	3.76	215	76.8	3.65	1.51	0.16	0.04	15.3	35.1
D	4.79 b	1.83	0.19 b	3.67	282	34.7	3.35	1.48	0.08	0.04	16.2	31.4
E (control)	5.04 b	1.91	0.31 c	4.01	265	41.7	3.99	1.35	0.10	0.04	15.7	34.6

Means followed by the same letter within a column show no significant difference (DMRT $P < 0.05$)

Table 6. Physical soil properties of each treatment after pesticide application.

Treatments	Bulk Density (g/cm^3)	Porosity (%)	Permeability (cm/h)
A	1.05	60.33	5.13 a
B	1.02	61.46	6.18 a
C	1.05	60.26	1.82 b
D	1.13	57.36	0.66 b
E (control)	1,06	60,08	1,55 b

Means followed by the same letter within a column show no significant difference (DMRT P < 0.05)

Comparison of soil properties before and after paraquat spraying. After paraquat application, there were changes in soil chemical properties (Figures 3, 4, and 5). These changes showed an increase in pH, from very acidic to acidic (experimental plots C, D, and E), but no changes were noted in trial plots A and B. The soil C-organic content is relatively higher after spraying herbicides and fungicides except in the control experimental plot (E), where weeding was done manually. An increase in soil organic-C on herbicide-treated land can be associated with faster herbicide decomposition by microbial activity that helps decompose organic matter and weeds die faster (Ayansina and Oso 2006). Decomposition of organic matter and weeds that die due to herbicide treatment can indirectly increase nutrient content and soil organic matter (Faqihhudin et al. 2013). The highest increase in C-organic content was seen in the treatment which was sprayed with paraquat dichloride concentration of 8 ml/l (Treatment B).

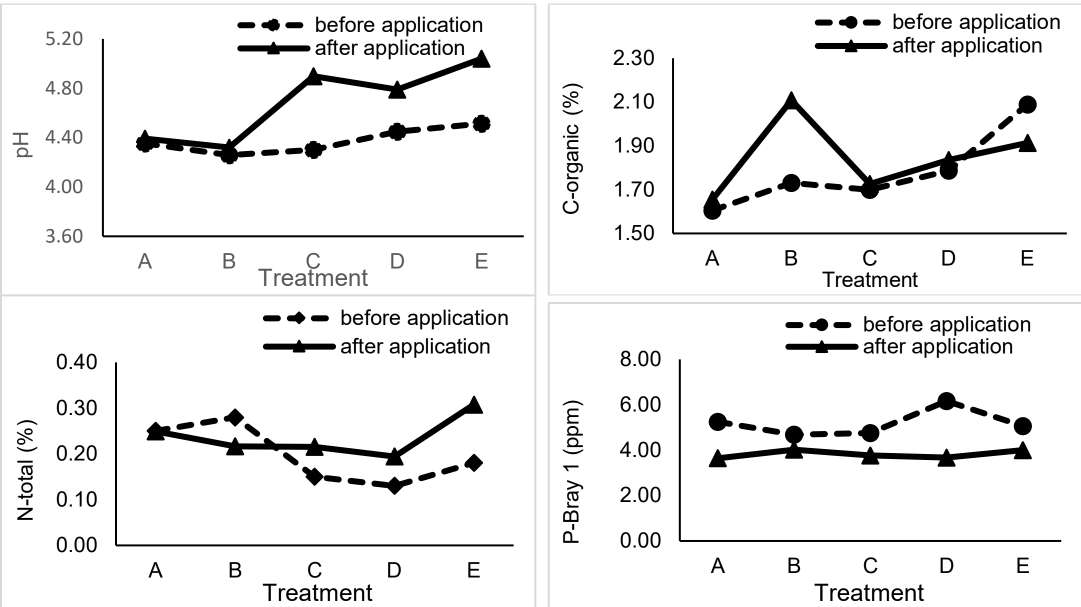

Fig. 3. The comparison of soil pH, organic C, total N, and Bray 1 P before and after paraquat dichloride application

Ca content after application of paraquat dichloride and carbendazim has increased from very low before application into a low category. The Mg content in the paraquat dichloride and carbendazim application plots is slightly increased towards the medium category. The K content in the experimental plot after application paraquat dichloride 16 ml/L increased from very low to the medium category. The Na content decreases after application pesticides. In the There was a significant reduction in Na concentration after herbicide application compared to controls (Sebiomo et al. 2012). Decreasing Na concentration occurs as a result of nutrient washing in soil solutions and herbicide degradation by soil microbes.

CEC in experimental plots after herbicides application is relatively similar to before application, although there is a slight decrease. This is likely to occur because when paraquat dichloride comes into contact with the soil, cationic (positive) / paraquat herbicides are quickly and strongly absorbed by negatively charged soil particles (Raeder et al. 2015) which results in decreased CEC after administration of herbicides. Base saturation in the B and C trial plots increased from very low category to low, but trial plots A, D, and E were still in the same category as before application herbicides and fungicides. . After application of paraquat dichloride , there was a relative increase in bulk density, decreased porosity and permeability of the soil. The differences between before and after application of paraquat dichloride were more due to the differences in spatial of the soil samples.

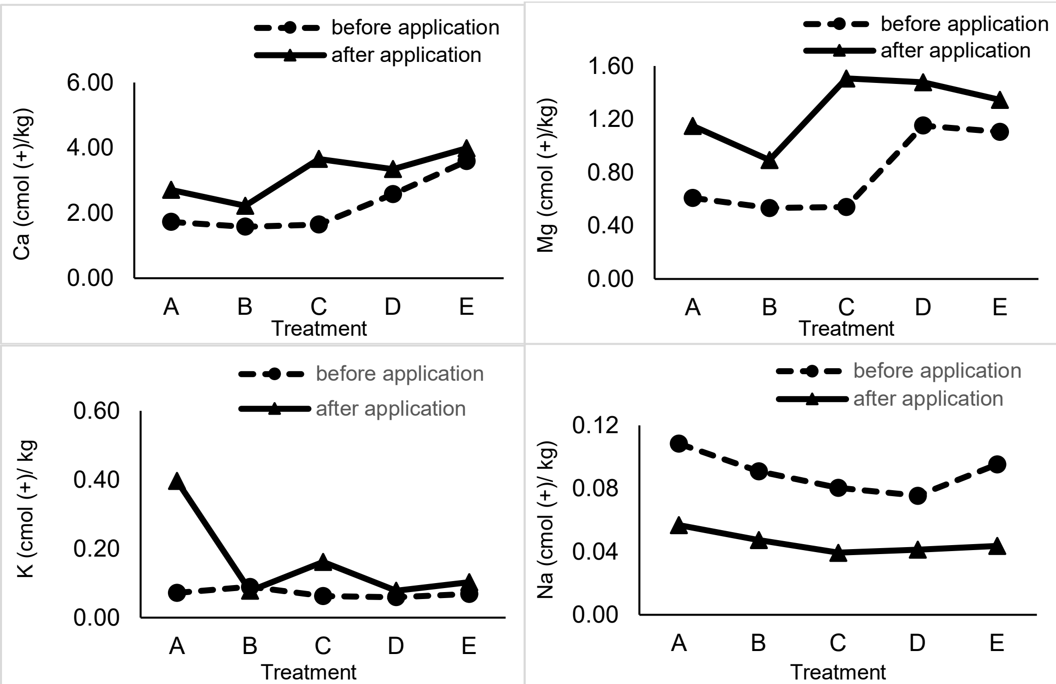

Fig. 4 . Comparison of basic cations before and after paraquat dichloride application

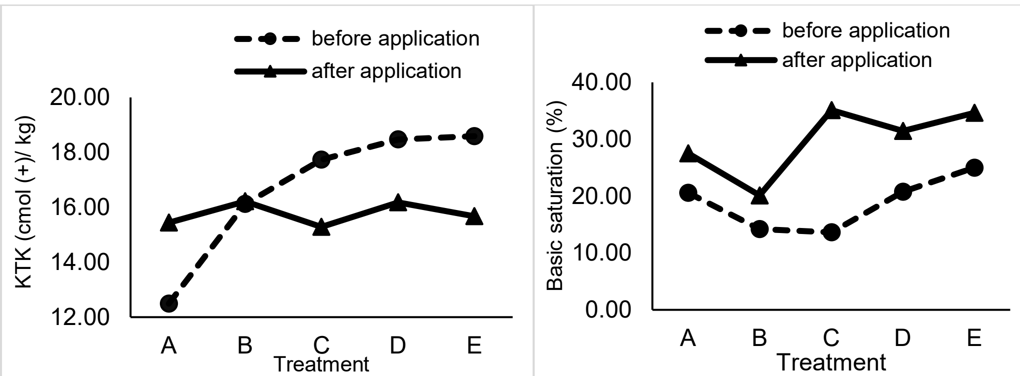

Fig. 5. Comparison of CEC and BS before and after paraquat dichloride application

CONCLUSION

Paraquat dichloride application did not affect significantly the number of species and arthropod populations. The application of paraquat in oil palm plantations did not have a significant effect in general on the soil physical and chemical properties. The application of paraquat significantly increased soil porosity compared to controls.

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