Effect of paraquat dichloride application to the soil arthropods on the rice field, corn, and oil palm plantation

L Nurulalia*, N Mubin1 and Dadang1

1 Department of Plant Protection, Faculty of Agriculture, IPB University

*Email: lianurulalia@apps.ipb.ac.id

Abstract. Paraquat dichloride is a non-selective contact herbicide currently used by farmers in Indonesia to control weeds on plantations, such as palm oil, rubber, and cocoa. There are only a few studies to date on the eco-toxicological aspects of paraquat. Therefore, the research aim was to study the effect of paraquat application on soil arthropods on three commodities. The research conducted on the rice and corn fields, and oil palm plantations in two consecutive seasons. Treatments included three paraquat concentrations (4, 8, and 16 ml/l); carbendazim (2 g/l); and control, with five replicates. The number and abundance of soil arthropods observed using pitfall traps and the collection of outermost soil layers for each crop at 0, 2, 4, 8, and 12 weeks after application. The order number of soil arthropods collected from rice, oil palms, and corn in season 1 was 12, 13, and 16, respectively; and 10, 16, and 16 in season 2. The three most dominant groups of soil arthropods were collembola, mites, and ants. The population patterns of soil arthropods for those three commodities were similar. Paraquat was thought to be toxic to non-target organism, such as terrestrial arthropods. This research showed that paraquat had an effect on the presence and population of soil arthropods for certain time after application. However, after 8 to 12 weeks after application, the population increased slightly.

1. Introduction

Crop production nowadays is an agricultural sector that takes economic values into account. However, the problem of pest, disease, and weed is one of the primary concerns for achieving optimum crop production. Therefore, pest management should be taken to reduce crop losses, and the use of pesticides is one of the prevention strategies implemented. The herbicide is a pesticide widely used by farmers in Indonesia to control weeds in different crops [1]. In Indonesia, paraquat is commonly used by farmers to control weed that grows in some plantations, such as oil palm, rubber, cocoa, coconut, coffee, cloves, pepper, tea, and sugar cane. Paraquat also used in some crops, especially rice, corn, soybeans, and cassava. In addition, paraquat is sometimes used to control broad-leaf weeds in cotton and rosella [2]. Globally, paraquat dichloride has reported used in coffee, sugar cane, oil palm, banana, mangoes, and avocado [3]. Paraquat dichloride is also widely used in pineapple, banana, oil palm, rubber, and grape [4].

The IUPAC (International Union of Pure and Applied Chemistry) name of paraquat dichloride is 1,1′-dimethyl-4,4′-bipyridinium dichloride, classified as a group of bipyridilium herbicide. Paraquat generally formulated by adding two chloride molecules to form paraquat-dichloride (C12H14N2Cl2). Its solubility in water is high (62 g/100 ml at 20°C), but paraquat molecules are not soluble in organic solvents. The lethal dose50 (LD50) of paraquat ranges from 127-250 mg/kg. Based on the LD50 level, the
World Health Organization (WHO) classifies paraquat into Group II as moderately hazardous pesticides [5]. Paraquat dichloride is a non-selective and broad-spectrum contact herbicide. This herbicide is very soluble in water, and due to its ionic properties, it is readily absorbed by soil particles to become immobile [6]. The absorption of paraquat dichloride through the soil system has been affected by the soil type, soil pH, temperature, and availability of the cations that can be exchanged directly [7]. Paraquat had an impact on five species of ground beetles (carabid) by the second week following application with slightly less number of large carabids found, and these beetles did not found on the experimental area until 28 days after application [8]. There was a research reported that the abundance of macrobes in soils was slightly affected by paraquat. For low and medium concentrations of paraquat, the soil macrobial populations recovered to their peak population at the 6th week after application [9]. Therefore, this research studied the effect of paraquat dichloride on soil arthropods on three types of commodities, rice, corn, and oil palm.

2. Method
The research conducted from March 2018 to July 2019. Samples taken from the rice and corn fields, and oil palm plantation for two consecutive seasons. Specimens were collected by pitfall-trap and direct sampling of outermost soil layers at 0 (before application), 2, 4, 8, and 12 weeks after treatment (WAT) of paraquat.

2.1. Research sites and treatments
The arthropods soil samples were taken from rice field at Village of Bantarjaya, Pebayuran, Bekasi (6º18′24″S, 107º13′09″W, 17 m above sea level (asl)); corn field at Village of Bojong Jengkol Cinangneng, Bogor (6º36′09″N, 106º42′35″W, 262 m asl); and oil palm plantation at PT Perkebunan Nusantara VIII, Cikasungka, Cigudeg, Bogor (6º33′08″N, 106º32′29″W, 370 m asl). The oil palm plantations used were the plantations that have produced fruit (TM).

There were three paraquat treatments: 16 ml/l = 1.6 ton of ion/ha (A), 8 ml/l = 0.8 ton of ion/ha (B), 4 ml/l = 0.4 ton of ion/ha (C); fungicide carbendazim 2 g/l as toxic standard/positive control (D), and one negative control (manual weeding without pesticide treatment) (E), with 5 replicates for each treatment. Therefore, there were 25 plots in this experiment that were arranged in a randomized complete block design. Paraquat application applied one time within each season (at week-0), so that there were two applications generated for two seasons of the experiment.

2.2. Trapping and sampling
Two sampling methods were used in this experiment, pitfall traps and soil sampling. Ground foraging arthropod was collected using pitfall traps (330 ml specimen cups, 7 cm in diameter) filled with 100 ml 4% formaldehyde to preserve fallen insects. The trap is covered with a tin roof (20 cm x 15 cm) to avoid rainfall. Pitfall traps placed on 5 points in a representative position of each plot (10 m x 10 m) for 24 hours. The samples from pitfall traps were then mixed into one plastic container. Soil arthropod was also obtained by collecting the topsoil samples (100 g) on 5 points of each plot near the pitfall traps position. Those samples from one plot then mixed into one plastic bag, so that a total of 500 g of soil samples collected from every plot.

2.3. Preservation and identification
The arthropods collected from the pitfalls transferred to insect bottles filled with 70% ethanol. In the meanwhile, litter samples first placed in the berlese funnel for three days. The arthropods collected from litters then moved to 70% ethanol-filled insect bottles. All specimens from the pitfalls and litters were counted and identified to the level of the morphospecies.

2.4. Data analysis
The arthropod population was analyzed using the general linear models (GLM) with Tukey’s advance test at confidence levels for 95%. Meanwhile, species dominance analyzed by Simpson’s biodiversity index (D).
\[ D = \sum n_i(n_i - 1)/N(N - 1) \]

Where \( n_i \) was the number of individuals in the \( i \)th species, and \( N \) was the total number of individuals.

3. **Result**

3.1. **The number of soil arthropod**

According to the number of soil arthropod order, the highest order number collected was 16 orders, which found in the corn field in both seasons and also in the oil palm in season-2 (Table 1). The least number of soil arthropod orders found in the rice fields in season-1 and season-2. There were a total of 19 soil arthropod orders from 6 classes found. The ten orders of soil arthropod present in all plantations, including Scorpionida (spider), Acari (mites), Entomobryomorpha, Poduromorpha, Symphypleona, Orthoptera, Dermaptera, Hemiptera, Diptera, and Hymenoptera. Other arthropods were relatively specific, such as Pseudoscorpionida, which is found only in the oil palm plantations; Isopoda and Scolopendromorpha, which are found in the corn and the oil palm; Isoptera in the oil palm and the rice field; Thysanoptera and Lepidoptera in the corn, and Coleoptera in the rice and the corn fields. Meanwhile, the species number collected in three commodities at season-1 was higher than in season-2. The number of soil arthropod species in the three commodities decreased by 22% in the rice field, 15% in the corn field, and 28% in the oil palm plantation. The highest number of arthropod species collected from the corn field in season-1 (125 species). On the other hand, the least number of arthropod species has found in rice fields in season-2 (58 species).

| Table 1. Soil arthropods collected in the rice field, corn, and oil palm plantation |
|------------------------|------------------|------------------|------------------|
| Class      | Order             | Rice  | Corn  | Oil palm |
|            | Season 1 | Season 2 | Season 1 | Season 2 | Season 1 | Season 2 |
| Arachnida  | Scorpionida      | √     | √     | √       | √       | √     | √     |
|            | Acari             | √     | √     | √       | √       | √     | √     |
|            | Pseudoscorpionida| x     | x     | x       | x       | x     | √     |
| Collembola | Entomobryomorpha | √     | √     | √       | √       | √     | √     |
|            | Poduromorpha     | √     | √     | √       | √       | √     | √     |
|            | Symphypleona     | √     | x     | √       | √       | √     | √     |
| Crustacea  | Isopoda          | x     | x     | √       | √       | x     | √     |
| Chilopoda  | Scolopendromorpha| x     | x     | √       | x       | x     | √     |
| Diplopoda  | Polydesmida      | x     | x     | √       | √       | √     | √     |
| Insecta    | Orthoptera       | √     | √     | √       | √       | √     | √     |
|            | Blattodea        | x     | x     | x       | x       | √     | √     |
|            | Isoptera         | √     | x     | x       | x       | √     | √     |
|            | Dermaptera       | √     | √     | √       | √       | √     | √     |
|            | Hemiptera        | √     | √     | √       | √       | √     | √     |
|            | Thysanoptera     | x     | x     | √       | √       | x     | x     |
|            | Lepidoptera      | x     | x     | √       | √       | x     | x     |
|            | Coleoptera       | √     | √     | √       | √       | x     | x     |
|            | Diptera          | √     | √     | √       | √       | √     | √     |
|            | Hymenoptera      | √     | √     | √       | √       | √     | √     |
| Σ order    | 12                | 10    | 16    | 16      | 13      | 16    |
| Σ family   | 42                | 33    | 67    | 54      | 59      | 44    |
| Σ species  | 71                | 58    | 125   | 107     | 123     | 85    |

Note: √ = present, x = absent
According to those ten orders, the collected scorpions are primarily a group of spiders that constantly move on the ground searching for prey. Mesostigmatidae and Oribatida were members of Acari that mostly found living in soil and litter [10]. Entomobryomorpha, Poduromorpha, Symphypleona were members of Class Collembola. Collembola is found predominantly in the soil and leaf litter and other decomposition habitats such as logs and dungs [11]. The insects from Order Orthoptera that have collected were Grasshoppers (Acrididae), can easily found in all terrestrial habitats; pygmy grasshoppers (Tettigidae) may inhabit a wide range of environments, but most commonly found in damp areas such as stream borders; crickets (Gryllidae) are ground-dwelling insect; cave crickets (Gryllacrididae) are nocturnal, inhabit moist location under rocks, logs, and trees, and most of them feed on seeds, leaves, and detritus, although some are a predatory insect [11]. Earwigs (Dermaptera) are insects that commonly found at ground level. Some of these insects are predators, while others are omnivores, carnivores, herbivores, and saprophagous. Many species are adapted for burrowing, while others are live under timber and stones [11]. Insect of Hemiptera that was found was Pentatomidae. The pentatomid found in the rice field was a black rice bug (Scotinophara coarctata), which is one of the pests in rice. These bugs usually move actively on the surface of wet rice fields and remain at the rice stem. True bugs found in the corn plantations were green stink bugs (Nezara viridula). Naturally, these bugs live and suck in the plant, but at the sampling time, they may have dropped to the surface of the ground and then fallen to the pitfall traps. Flies (Diptera) were mostly found in the form of larvae collected from litter, and a small number of them were small-bodied flies. Meanwhile, the vast majority of Hymenoptera found were ants (Formicidae). Another small amount of it was a small wasp from Family Diapriidae.

3.2. Arthropods species domination

In general, the three dominant arthropod groups found in the rice, corn, and oil palm were collembolan, ants, and mites (Table 2). Collembola or springtails are a group of arthropods distributed in all three plantation types and is relatively abundant in litter and topsoil. It dominated the arthropod specimens found in the rice field during sampling in both seasons. Collembola was also dominated the soil arthropod found in corn, especially in season-2. Meanwhile, Collembola’s domination in oil palm emerges only in the first season, at sampling periods of 4 and 12 weeks after application. Springtail is mostly minute, with a length of 1-5 mm. It feeds primarily on microorganisms ranging from bacteria to protozoa, while some species are herbivores and scavengers. There are almost no ecosystems without springtails. Meanwhile, in corn and oil palm plantations, the arthropods found to dominate the plots were ants and mites. During the sampling time, there was a dynamic switch in species dominance between those two groups.

| Table 2. Soil arthropod domination at the rice field, corn, and oil palm on two consecutive seasons |
|-----------------------------------------------|
| Rice                                          |
| Season-1                                      |
| Col. ($D = 0.10$)                             |
| Col. ($D = 0.29$)                             |
| Col. ($D = 0.24$)                             |
| Col. ($D = 0.34$)                             |
| Col. ($D = 0.35$)                             |
| Season-2                                      |
| Col. ($D = 0.35$)                             |
| Col. ($D = 0.21$)                             |
| Col. ($D = 0.51$)                             |
| Col. ($D = 0.17$)                             |
| Col. ($D = 0.21$)                             |
| Corn                                          |
| Season-1                                      |
| For. ($D = 0.28$)                             |
| For. ($D = 0.37$)                             |
| Aca. ($D = 0.30$)                             |
| Aca. ($D = 0.24$)                             |
| Aca. ($D = 0.35$)                             |
| Season-2                                      |
| Aca. ($D = 0.35$)                             |
| Col. ($D = 0.41$)                             |
| Col. ($D = 0.36$)                             |
| For. ($D = 0.10$)                             |
| Col. ($D = 0.29$)                             |
| Oil palm                                      |
| Season-1                                      |
| For. ($D = 0.15$)                             |
| For. ($D = 0.34$)                             |
| Col. ($D = 0.30$)                             |
| For. ($D = 0.66$)                             |
| Col. ($D = 0.34$)                             |
| Season-2                                      |
| For. ($D = 0.34$)                             |
| For. ($D = 0.67$)                             |
| Aca. ($D = 0.18$)                             |
| Aca. ($D = 0.21$)                             |
| Aca. ($D = 0.40$)                             |

*Col.: Collembola (springtails); For.: Formicidae (ants); Aca.: Acari (mites)
3.3. The Population of soil arthropods

Population patterns of soil arthropods for three commodities were nearly similar. Generally, the population of soil arthropods decreased after pesticide application (Figure 1). On the rice field (season-1), the arthropod population decreased from 4-5 individuals per plot at 0 WAT to less than two individuals per plot at 2 WAT. At week 12, the population increased slightly at about three individuals per plot. The population pattern for season-2 was almost the same as for season-1. The increase in the arthropod population tends to happen at 8 WAT. The population of soil arthropod on corn also decreased after the application of the pesticide. At week 0 (season-1), arthropod populations were relatively similar distributed across all plots. Compared to the rice field, the rise in arthropod populations in corn has appeared to increase since 12 WAT. The population decline also occurs in oil palm plantations after pesticide application. During season-1 at week-2, 4, and 8, the arthropod population appeared to be stable in the range of 1.5-2.0 individuals per plot. Meanwhile, the population of 12 WAT began to increase to 2.5-3.0 individuals per plot. In season-2, population patterns tend to fluctuate. Population increased at week-4, then decreased at week-8, and increased again at week-12. There was also a decline in the arthropod population in the control plots because at the time of pesticide application, the control plot also indirectly affected by pesticide spraying in the nearby area. The movement of arthropods from all treatment plots to the outside of the treatment plots was likely to occur. It also may be due to the fact that soil arthropods were hiding in their tunnels and holes to protect and avoid the moderate effect of herbicide.

Figure 1. Populations of soil arthropods collected from litter and pitfall traps in rice, corn, and oil palm plantations during season-1 (S1) and season-2 (S2) (treatment A = paraquat 16 ml/l; B = paraquat 8 ml/l; C = paraquat 4 ml/l; D = fungicide carbendazim 2 g/l; and E = manual weeding (without pesticide treatment).
The population of soil arthropods collected in all treatments in the rice field only showed a significant difference in season-1 at week-0 (before pesticide application) and week-4. At week-0 (season-1), the population of soil arthropods in treatment-A (2.10 ± 0.51a) and D (1.67 ± 2.02a) was significantly different from control (E) (5.04 ± 0.85a). At week-4 (season-1), the population of soil arthropods in treatment-A (1.27 ± 0.16a), B (1.44 ± 0.11a), C (1.50 ± 0.18a), and D (1.34 ± 0.30a) was significantly different from E (2.25 ± 0.02b). In corn, there was no difference in population between treatments at all sampling times. Meanwhile, at week-0 (season-1) on oil palm, the population of soil arthropods in treatment A (2.16 ± 0.56a), B (2.31 ± 0.28a), and C (1.79 ± 0.21a) was significantly different from E (3.47 ± 0.89b).

4. Discussion
The pesticide application influenced the presence of soil arthropods in the three plantations. Population decline may occur due to mortality or movement of arthropods from inside to the outside of treatment plots (emigration). It is related to the statement that changes in population density may be related to mortality and, or emigration [12].

The three dominant groups of soil arthropods are springtails (Collembola), mites (Acari), and ants (Hymenoptera: Formicidae). Collembolan commonly found in soils that contribute to the degradation of organic material. It catalyze the decomposition of organic matter and plant nutrients’s circulation. Collembolan used as an indicator of soil fertility and disturbance. Low levels of pesticides can contribute to a rapid increase in the number of collemobolans, as many collemobolans tolerate these chemicals while their predators killed. Also, collemobolan feed on fungi, and a collemobola member, Folsomia, reported decompose toxic materials such as pesticide [13]. The majority of Acari members found in soil were Mesostigmata and Oribatida. Mesostigmata classified as a free-living predator. Few numbers feed on fungi, seeds, nectar, and plant fluids. A meanwhile, oribatid mites are ingesting solid foods such as bacteria, fungi, microinvertebrates, and few are decomposing leaves, litters, lichens, and mosses). In soil, mites contribute to decomposition and nutrient cycling [14]. Meanwhile, ants are one of the most common and important insect groups. Ants have diverse diets, from predators and scavengers to plant-eaters, fungus eaters, and other specialties or combinations of these. Ant nests are typically found in the ground. Still, they can also be found in trees and between the silk-joined leaves in the green ants of the tree [11]. The ants collected in this research include Iridomyrmex, Anoplolepis, Tapinoma, Paratrechina, Monomorium, Pachycondyla, Hypoponera, Leptogenys, and several other species of ants that are actively moving on the ground.

Herbicide paraquat can react and poison plants by acting on chloroplasts and causing a decrease in chlorophyll quantities. It is dependent on research that shows that there is very limited photo-degradation of paraquat on the surface of the leaf. Still, there is no metabolism of paraquat in plant tissue [15]. In the meantime, about 99.9% of paraquat molecules can be absorbed very strongly by soil particles [16]. The remaining 0.01% of paraquat molecules that are not absorbed by soil particles will be completely degraded to NH₄, CO₂, and H₂O by photo-degradation and soil microbial degradation processes. Paraquat and other degraded compounds do not have adverse environmental effects, especially in the soil environment. Paraquat molecules absorbed by soil particles can also undergo photo-degradation due to high temperatures and solar radiation. After three months of application, only 25% of paraquat remained [17]. A same study also mentioned that the process of desorption could also occur as much as 0.17-5.83% of the paraquat molecules absorbed by the soil will release.

Based on previous studies, there have been changes in soil chemical properties following application of paraquat herbicides, such as an increase in soil pH from very acidic to acidic, and an increase in soil C-organic, which correlated with weed decomposition through microbial activity, and then indirectly increase the nutrient content and soil organic matter. The content of Ca after herbicide application has increased from a very low to low category. The content of Mg also increased slightly to a medium category, as similar to the K content increased from a very low to a medium category. In contrast, the Na content decreased after the application of pesticides. Decreasing Na concentration occurs due to nutrient rinse in soil solutions and herbicide degradation by soil microbes. The CEC (Cation Exchange Capacity) was also slightly reduced. It is likely to occur because when paraquat dichloride comes into contact with soil, positive cations rapidly and strongly absorbed by soil particles [18].
5. Conclusion
Paraquat herbicide application affected species composition, dominance, and population of soil arthropods in the rice fields, corn, and oil palm plantations. The soil arthropods population declined after paraquat application, but steadily increased in the 8 to 12 weeks after application.

References
[1] Dadang, Kurniadi D, Sriyani N, Budiawan, Andayani L S and Perdana T. 2020. Profil Kemanan dan Penggunaan Herbisida Parakuat Diklorida di Indonesia (Bogor: IPB Press) p 27-52
[2] Direktorat Pupuk dan Pesticida. 2020. Sistem Informasi Pesticida: Rekap Izin Pesticida berdasarkan Merek Dagang. Online. http://pestisida.id/simpes_app/. Accessed: 25 August 2020
[3] Wesseling C, Joode B V, Ruepert C, Leon C, Monge P, Hermosillo H and Partenan T J. 2001. Paraquat in developing countries. Int. J. Occup Environ Health. 7(4):275-286
[4] Bromillow R H. 2003. Paraquat and sustainable agriculture. Pest Management Science. 60:340-359
[5] PubChem. 2020. Compound Summary: Paraquat dichloride. National Library of Medicine – National Center for Biotechnology Information. https://pubchem.ncbi.nlm.nih.gov/compound/Paraquat-dichloride#section=Uses. Accessed: 25 August 2020
[6] Constena M A, Riley D, Kennedy S H, Rojas C E, Mora L E and Stevens J E B. 1990. Paraquat behavior in Costa Rican soils and residues in coffee. J. Agric Food Chem. 38:1985-1988
[7] Gevao B, Semple K T and Jones K C. 2000. Bound pesticide residues in soils: a review. Environmental pollution. 108(1):3-14
[8] Brust G E. 1990. Direct and indirect effects of four herbicides on the activity of carabid beetles (Coleoptera: Carabidae). Pesticide Science. 30(3):309-320. https://onlinelibrary.wiley.com/doi/abs/10.1002/ps.2780300308. Accessed: 20 November 2020
[9] Frimpong J O, Ofori E S K, Yeboah S, Marri D, Ofife B K, Apaatah F, Sintim J O, Ofori-Ayeh E, Osae M. Evaluating the impact of synthetic herbicides on soil dwelling macrobes and the physical state of soil in an agro-ecosystem. Ecotoxicoloy and Environmental Safety. 156:205-215. https://reader.elsevier.com/reader/sd/pii/S0147651318302239?token=66AE8D7A50D157475763FD9299B93AF2CC4B10E985C5CA0F1706F17B5D9AA8500B0FCDBC8BB641B31C4EA12B75EB361E. Accessed: 20 November 2020.
[10] Kumarasinghe L, Voice D, O’Donnel M, Gunawardana D, Bennet S, Fan Q H, Jones D, George S. 2015. Pest Identification Workshop – Workshop Manual 2 Part 1 (New Zealand: Plant Health and Environment Laboratory).
[11] Zborowski P and Storey R. 2017. A Field Guide to Insects in Australia. 4th ed. (Sydney: Reed New Holland Publishers)
[12] Tarumingkeng R C. 1992. Dinamika Pertumbuhan Populasi Serangga (Bogor: IPB Press) p 26
[13] Suhardjono Y R, Deharveng L and Bedos A. 2012. Biologi, Ekologi, Klasifikasi Collembola (Ekor Pegas) (Bogor: Vegamedia)
[14] Walter D E and Proctor H C. 2013. Mites: Ecology, Evolution, and Behavior: Life at A Microscale, 2nd ed. (New York: Springer Science and Business Media). https://doi.org/10.1007/978-94-007-7164-2
[15] Slade P. 1966. The Fate of Paraquat Applied to Plants. https://onlinelibrary.wiley.com/doi/pdf. Accessed: 25 August 2020
[16] Roberts T R, Dyson J S, Lane M C G. 2002. Deactivation of the biological activity of paraquat in the soil environment: a review of long-term environmental fate. J. Agricultural and Food Chemistry. 50(13):3623-3631
[17] Amondham W, Parkpian P, Popprasert C, Deulaene R D and Jugsujinda A. 2006. Paraquat adsorption, degradation, and remobilization in tropical soils of Thailand. J. Environmental Science and Health Part B. 41(5):486-507
[18] Dadang, Hartono A, Nurulalia A, and Soekarno B P W. 2019. Effects of paraquat dichloride application on soil arthropods and soil chemicals and physical properties in oil palm cultivation. *J ISSAAS*. **25**(2): 174-184