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# Changes of Plant Necro Mass and Soil Faunal Composition in Wetlands Caused by Conversion of Forest to Oil Palm Plantation

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## ABSTRACT

Field research was carried out to elucidate the trajectories of the temporal changes in vegetation and soil faunal diversities in wetlands caused by conversion of forests to oil palm plantations. Soil blocks sizing 30 cm x 30 cm x 30 cm were evacuated from three oil palm fields with three different ages (i.e., 2 years, 6 years, and 10 years old), as well as in secondary forest on peat soils. Fauna found in the blocks were subjected to 70 % ethanol sterilization before hand sorter and identification. The diversity index of earthworm was calculated based on the Shannon-Wiener formula. Quadrats were employed to determine the plant structure (i.e., species abundance). A t-test was employed to assess the differences between treatments. The results showed that the ages of the oil palm cultivation affected vegetation and soil faunal structures. The diversity indexes of earthworm were 0.12, 2.49, 1.77, and 1.73 in secondary forest, 2, 6, and 10 years-old oil palm fields, respectively. Similar trends occurred on diversity of Imperata cylindrica. These findings suggested that the diversities of Imperata cylindrica and soil fauna in wetlands in the tropics increased at early development of oil palm development and decreased onwards.

Keywords: Kalimantan Island; smallholder plantation; tropical peatlands

## INTRODUCTION

In general, agricultural activities have caused significant loss of biodiversity. The impact of such activities is more severe in lowland forests and wetlands where plants are more sensitive to changes in hydrology and soil characteristics caused by farming practices (Rusdy, 2020; Childers et. al., 2003). For instance, sugarcane farming in South Florida has caused significant peat loss, and nutrient enrichment in phosphorus-limited Everglades ecosystem resulting in invasion and expansion of cattail (Typha domingensis Pers.) on the expense of native plant communities, ultimately causing loss of biodiversity (Sah et. al., 2014). Likewise in the tropical countries like Indonesia, oil palm (Elaeis guineensis Jacq.) cultivation and related activities, such as frequent fires in peatlands, has caused loss of peat soils, land use change, etc. resulting in adverse impact on biodiversity of the region (Hadi et al., 2010; Carson et al., 2013; Dariah, 2013; Asthon-Butt et al., 2018).

Oil palm (OP) is a monocotyledon plant with fibrous roots and lateral leaves attached to sheath. Oil palm can grow at elevation ranging from 0 – 500 m above sea level. This plant well adapt to environment with precipitation ranges 2,000 to 2,500 mm/year and duration of solar radiation is more than 5 hours. The optimal temperature for OP is between 24 – 28˚ C. Oil palm produces oval round fruit with black, purple, or red in color, depending on the ripening stages. The fruit of OP clusters together on a branch that appearing at every sheath (Yudhistira, 2019). Oil palm is an effective oil producing crops (Carson et al,. 2013) and the oil content increases as crop approaching rapining stage.

In Indonesia, oil palm plantations are done in 10 million ha. From this 10 m ha, Indonesia produces 43 million tons crude palm oil (CPO) annually that placed Indonesia as the biggest CPO producing country in the world (Anonymous, 2023). The CPO will then be converted to more than 100 products, including frying oil, margarine, soap, and cosmetics. Oil palm industry employs high number of work force and has made significant contribution to Indonesian economy in last two decades (Wibowo, 2010).

Cogongrass (*Imperata cylindrica*) is a widespread invasive species throughout the southern United States (US) (Lucardi et al., 2020). Imperata grassland is often serve as a starting point in plant succession prior to secondary forest establishment, but may also dominant in agricultural fields. Imperata is classified as noxious

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weed hence its presence in agriculture filed is undesirable (Rusdy, 2020). Successful invasion of Imperata is mainly due to its physiological traits, including extensive rhizome system, high adaptation to poor soils, drought tolerance, genetic plasticity, and fire adaptability (Lucardi et. al., 2020).

The presence of earthworm is frequently used to determine soil quality. It is because earthworm is present in almost all soils and has specific response to environment changes (Purwaningrum, 2012). Many scientists use earthworm to monitor environmental changes caused by human activities in the tropics (Suwandi, 2019). In other words, earthworm can function as bioindicator of environmental changes caused by human activities.

Several researchers have addressed the adverse impact on biodiversity associated with forest loss caused by plantations on uplands (Carson et al., 2013; Asthon-Butt et al., 2018). However, about 30% of oil palm plantation in Indonesia are occurs in wetlands. Most of the plantations in wetlands are established by utilizing abandoned lands and/or secondary forest. The estate development is started by constructing drainage ditches (about 1 m wide and 1 m deep) in 9 m spacing) to release excessive water.  Surjan is then constructed by digging a ditch (about 1 m wide and 1 m deep) in 9 m spacing.  The soils from ditches are spread to the land to rise the ground further (Hadi et al., 2012). Considering the cost for surjan construction and to maintain sustainably of food crops production, the government of Indonesia limits the ownership of oil palm field as maximum wide as four hectares per farmer. This type of oil palm field can be considered as small holder plantation (Anonymous, 2023).

Systematic quantitative research on biodiversity loss and its consequences on ecosystem services of oil palm with surjan system has not been well investigated. Therefore, it is important to elucidate trajectories of the changes of plant necro mass and soil faunal composition in wetlands caused by conversion of forest to oil palm plantation.

## MATERIALS AND METHODS

### Study Area

This research was carried out in Landasan Ulin village, South Kalimantan, Indonesia (3°24’36.6” S – 111°43’10.6” E; Figure 1). The area used to be covered by water but then became drier following the construction of vast irrigation facilities in 1970s. The soil is classified as Typic Tropohemist (i.e., a tropical soil that content high amount of organic matter with moderate decomposition level) (USDA, 1978). The area is considered to have climate type B according to Scmith-Fergoson climatic classification system with annual precipitation around 2,500 mm/year.The water structure was designed is using a controlled drainage model (Figure 2). Water regulation model is by using paralon pipe having goose-neck structure (L). Paralon pipe having diameter 0, 30 m (12 inch) is installed side by side (2 pipes) at 50 cm height from  canal base. This PVC pipe height is based on average high tidal water level in which high tidal water can still enter canal. The gate operation was simple as the goose-neck pipe could be removed without additional equipment. The  canal should be full so that goose-neck pipe can be installed and rain water can be detained when farmers need water. When water in  canal is full, there is no water losses in the land and root zone become saturate so that the land can be flooded when it rains. On the other hand, when rice crop require no more water, i.e. approaching harvest phase, goose-neck pipe can be uninstalled an d water in  canal decrease up to minimum limit (50 cm) of controlled drainage. Soil water can be lowered up to 20-30 cm limit if rice crop approaching harvest phase.

The Rainfed rice system depanded on  rainfall availavility. Retention option is the best way for water management in the farm level. It can provide water when the water supply from rainfall is reduced (Elnina effect).  Then the agriculture in tidal lowland can continue unaffected by climate change (Kuntiyawichai et al., 2017).

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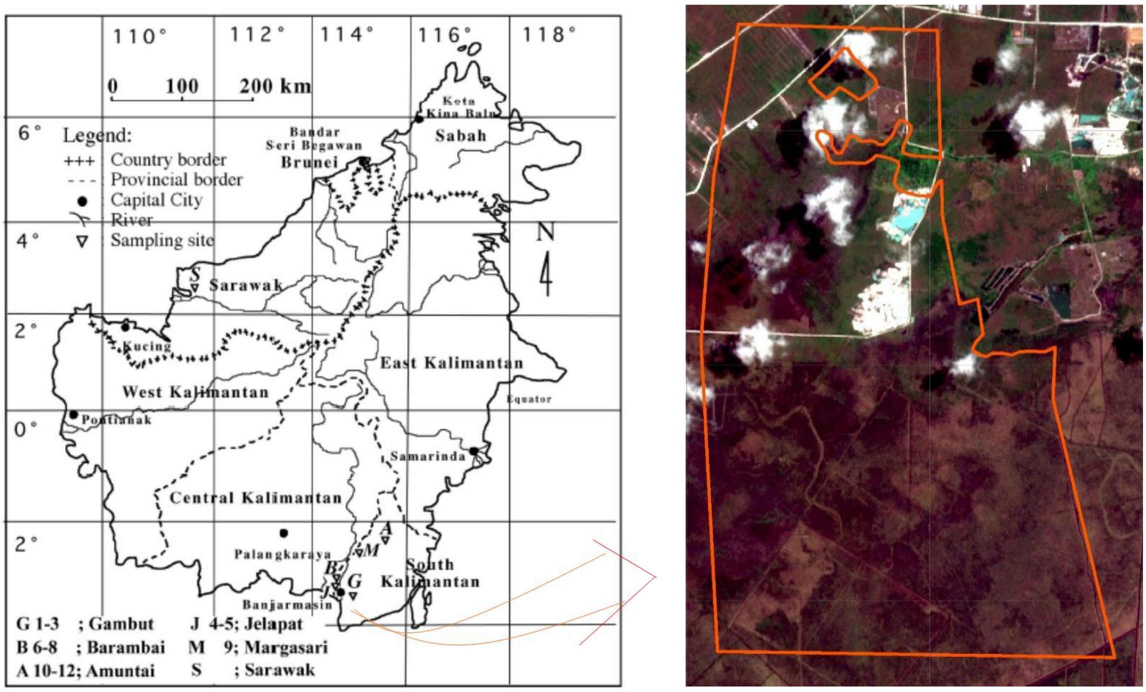


Figure 1. Map of study area

Development of oil palm in the area has started following land scape arrangement carried out by Indonesian central government in early 2010es. Oil palm transplanting was performed by digging planting holes on the risen part of surjan 9.3 m apart one to another with triangle formation. Planting generally spent several years, depending on the ability of farmer to invest (Sayuti, 2023, Personal Communication). At the time of experiment, there were 10 years old oil palm. 6 years oil palm, and 2 years oil palm fields. Small portion of forest also existed near by the oil palm fields.

### Apparatus and Experimental Design

The main apparatus for field sampling was 1 x 1 m2 quadrat (referred as big quadrat hereafter), 0.5 x 0.5 m2 quadrat (referred as small quadrat hereafter), shovel, and 50-m-length measure tape. The quadrats were made of polyvinyl carbon (PVC) pipe purchased from home center store. The PVC pipe was cut into eight peace, but then reinstalled to accommodate four T-share pipe connectors and four L-form connectors to form a quadrat. Ten cm length PVC pipe cut were finally connected to other edges of T-shape pipe connector and function as leg of the quadrat (Figure 2).

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Figure 2. Quadrat and other apparatus used for understory necro mass and diversity.

Sixteen random plots, sizing 9.3 x 37.2 m2 each, were established in secondary forest, 2 years old oil palm field, 6 years old oil palm field, and 10 years old oil palm field (i.e., four treatments with four replication). The treatments were arranged to follow randomized block design (Figure 3). All plots start and end at the furrow of the oil palm plants, covering eight oil palm plants. A measuring tape was stretched in between the plant trunk and the edge of the plot to indicate 9.3 m distance and to ensure stretch placement of the quadrats.



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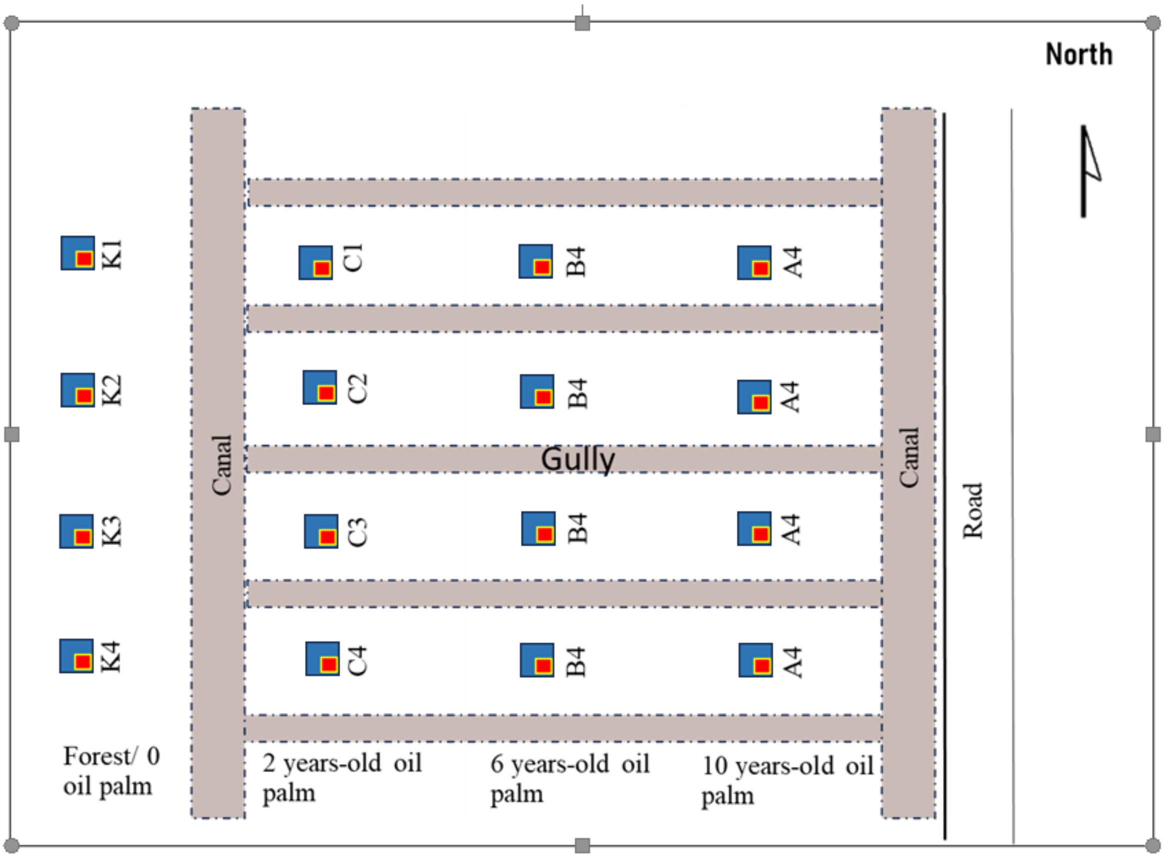


Figure 3. Arrangement of experimental units and placement of quadrat. : big quadrat; small quadrat.

## Measurements

### Understory Necro Mass and Diversity

Four big quadrats were placed at every 9.3 m in each four treatments. Species of understory plants found in 1 x 1 m2 square were identified. The species identification was carried out by scanning the plant on lens application (by google) in the field. Representative plant sample of each species was brought to the laboratory and compared to their description found in Flora untuk Sekolah di Indonesia book (Steenis, 2003).

A small quadrat was placed at corner of each big quadrat. The plants in the small quadrats were harvested exactly at ground surface. The plants were weighted in the field (considered as understory fresh weight hereafter). The plants were placed in a paper envelope and brought to laboratory for determination of dry necro mass after being sub-sampled (to have less than 200 g in the envelope). In the lab, the plants were dried in an oven at 70°C for 48 hours and then weighted. The mass of fresh- and oven dried- plants were calculated to follow formula below (Hairiah et. al., 2004):

Necro mass (g) =DW sub-sample/FW sub-sumple
Total FW

Where: DW = dry weight; FW = fresh weight

### Earthworm Diversity

Four soil blocks of 30 cm x 30 cm x 30 cm were excavated from each of the three oil palm fields with three different ages (i.e., 2 years, 6 years, and 10 years old), as well as in secondary forest on peat soils. Macro fauna found in the blocks were subjected to 70 % ethanol sterilization prior to hand sorter and identification. Identification of macro fauna was done following procedures described by Jumar (2000). Diversity index of earthworm was calculated based on the Shannon-Wiener formula:

$$H' = -\sum pi \ln pi$$

$$pi = \frac{ni}{N}$$

where:

H' = Shannon-Wiener index

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pi = proportion of ith spesies
ln = logaritm natural
ni = number of ith spesies
N = total number of individuals

### Data Analyses

All data obtained in this research were subjected to normality test described by Barlet. Additional logarithmic transformation was performed to data that were not normally distributed. Analysis of variance and least significant difference tests were conducted to assess the effect of treatment on measured parameter (Mahbub, 2023).

## RESULTS AND DISCUSSION

### Description of Site Location

The conversion of forest to oil palm field affected soil carbon and fiber contents. The carbon content of the soil ranged from 8.98% to 23.06% with the highest in forest, followed by 2 years old, and 6 years old oil palm field. The lowest soil C content was observed in 10 years old oil palm field. Simar pattern was shown by soil fiber content (Table 1).

Table 1. Soil C and ash contents in oil palm plantation of three different ages (2, 6 & 10 years) and in secondary forest.

| Site | Soil pH | Organic C (%) | Ash content (%) |
|---|---|---|---|
| Secondary forest | 4.89[c] | 23.06[a] | 13 |
| 2 years old oil palm field | 5.20[bc] | 15.25[ab] | 47 |
| 6 years old oil palm field | 5.36[ab] | 12.26[bc] | 51 |
| 10 years old oil palm field | 5.75[a] | 8.98[c] | 56 |

Peat soils are composed by organic C and minerals like clay. The organic C content of 12% w/w is the minimum requirement of soil to be considered as peat soil. The organic C content should be 18% w/w or more if the clay content of the soil is 60% or more (USDA, 1977). The organic C content of 10 years oil palm field (8.8%) is below the minimum requirement of peat soil. This suggests that organic C has been removed from soil following the conversion of forest to oil palm fields. The organic matter can be mineralized by soil biota to form $CO_2$. The $CO_2$ will further escape to the atmosphere (Wouwmen, 1998; Hadi et al., 2010) or in water and flowed to follow drainage path ways (Inubushi et al., 1998). Upon the C releases the minerals will also be released lead to increase the percentage of ash. The increase in ash content leads to increase in soil pH (Table 1).

The conversion of forest to oil palm field also affected soil pH. The highest soil pH was observed in 10 years old oil palm field, followed by 6 years oil palm field, and 2 years oil palm field. The lowest pH was observed in forest (Table 1). The changes in soil pH probably as consequences of increase in $OH^-$ contents and/or decrease in H+ content. The decrease in $H^+$ was due to the lime applied by farmer, while the increase in OH- content was due to mineralization of organic matters. As explained earlier that C contents decreased along with the oil palm ages. Upon the organic matter was decomposed to simpler organic matter and/or $CO_2$. With water, dissolved $CO_2$ will form $H_2CO_3$ through chemical reaction:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

### Understory Necro Mass and Diversity

The results showed that the ages of the oil palm cultivation affected the understory necro mass and structure. Necro mass of understory plants in forest, and 2-, 6-, and 10-years old oil palm fields were 6.3 $\pm$ 0.1, 3.4 $\pm$ 2.1, 1.5 $\pm$ 0.1, and 1.3 $\pm$ 0.7 ton $ha^{-1}$, respectively. Imperata cylindrica was found in forest, as well as in oil palm fields with the abundance in 2 years old oil palm field> forest>6 years old oil palm field>10 years old oil palm field in this order. *Acacia* and *Stenochlaera* were present in forest but were absent in oil palm fields, while *Boreria* and *Ageratum* present in oil palm fields but were absent in forest. Sevent plant species were found in forest and 2 years old oil palm field. Eight and nine plant species were found in 6- and 10-years old oil palm fields, respectively (Table 2).



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Table 2. Plant species and their abundances

| Plant name | Abundance (%) | | | |
|---|---|---|---|---|
| | Forest | OP 2 years | OP 6 years | OP 10 years |
| Imperata cylindrica | 34.3 | 62.5 | 5 | 0.2 |
| Cyperus rotundus | 8.3 | | | 54 |
| Pasifera foetida | 30.3 | | | 1 |
| Stenochlaera sp. | 6.7 | | | |
| Naphrolepis sp. | 2.8 | 7.5 | 33.3 | 13.3 |
| Acacia sp. | 2.5 | | | |
| Mimosa pudica | 24.0 | | 36.7 | 1 |
| Alcholaea sp. | | 1 | 0.7 | |
| Ageratum sp. | | 11.5 | 0.7 | 3.3 |
| Mischantus sinensis | | 7.5 | | 21.7 |
| Caladium sp. | | 7.5 | | |
| Boreria sp. | | 2.5 | 1.7 | 4.5 |
| Rhodomyrtustam tomentosa | | | 0.3 | 1 |
| Urera caracasana | | | 18.3 | |
| Musa sp. | | | 3.3 | |
| Dieranopteris sp. | | | | 0.3 |

The use of herbicide seemed to be the most important factor affecting the understory plant in this area. According to the farm owner, herbicides are regularly applied in productive oil palm fields (i.e., 6- and 10- years old oil palm fields). This has led to the reduction in understory necro mass in these fields to about one fourth of forest and half of newly established oil palm field (i.e., 2 years old oil palm field).

The changes in plant structure seemed to also be caused by introduction of some horticulture crops by farmers. *Caladium* is a tuber plant of which tuber, stem, and rhizome that can be consumed as vegetable. *Musa* is an important fruit that can be consumed freshly or is cooked to varies kinds of cakes. These two horticulture crops were grown while the oil palm canopies allow sun light to reach the ground (i.e., 2- and 6- years old oil palm). As the oil palm grows densely (i.e., 10 years old), the horticulture crops disappeared. Typical farmyard plant (Rhodomyrtustam tomentosa) started to appear in 10 years old oil palm field (Table 2).

The fact that the understory diversity increased upon development of oil palm indicated that the development of oil palm can be recommended. Oil palm maintenance done by farmer that was proven to reduce the dominance of *Imperata* may also indicate the bright future of restoration of plant diversity. Similar results have been reported by Usmadi et al. (2020) in Bogor's grasslands. The reduction in *Imperata* abundance was mainly because it is being utilized by farmers for making rope and mulching vegetable crops cultivated nearby oil palm fields. The firm root system of mature oil palm probably eliminates the invasion of *Imperata* in this area.

## Soil Faunal Diversity

The results showed that the ages of the oil palm cultivation affected soil faunal structures. Secondary forest retained 397 macro fauna per 0.009 m3 soil block, comprised of eight earthworm (*Dichogaster* sp.), 382 ant (*Myrmicinae*), 6 scorpion (*Chilopoda*) and 1 larva of *Scarabaeiform*, and being the highest among the treatments studied. Forty-four macro fauna were observed in 2 years old oil palm field, which comprised of 29 earthworm, 8 ant, 5 scorpion and 2 larvas of *Scarabaeiform*. Eighteen and sixteen macro fauna were found in 6- and 10-years old oil palm fields, respectively (Table 3).



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The diversity indexes of soil macro faunal were 0.26, 0.45, 0.69, and 0.42 in secondary forest, 2, 6, and 10 years-old oil palm fields, respectively (Table 3). The diversity indices indicated that oil palm field are favorable for divers' soil macro fauna. This probably due to the nutrient enrichment caused by organic matter mineralization and/or fertilizer application along with the maintenance of oil palm plant. Degraded forest was favorable only for particular fauna (i.e., ant) but not for others.

Smallholder oil palm plantation promoted by Indonesian government can be encouraged by scientific society. The invasion of Imperata occurred of natural ecosystems Indonesia (Rusdy, 2020) or did not occur in small holder oil palm plantation studied. An area of maximum four hectare per farmer family regulated by Indonesian government (Anonymous, 2023) seems to be in reach of farmer for responsible maintenance. Manual weeding and optimal introduction of agricultural crop will help in maintenance of the soil faunal diversity and/or event increase understory plant diversity.

## CONCLUSIONS AND SUGGESTIONS

1. The diversity indexes of earthworm were 0.12, 2.49, 1.77, and 1.73 in secondary forest, 2, 6, and 10 years-old oil palm fields, respectively.
2. Abundance of Imperata cylindrica was the highest in the 2 years-old oil palm field, and followed by 6, and 10 years-old oil palm fields.
3. These findings suggested that the necro mass and soil fauna in wetlands increased at early development of oil palm development and decreased onwards.
4. Minimizing the use of chemicals and encouraging mechanical techniques in weed control should may maintain the plant and soil faunal diversities.

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Table 3. Numbers and diversities of soil fauna as affected by land use conversion.

| Treatments | Earthworm | Ant | Others | Total | H' |
|---|---|---|---|---|---|
| Secondary forest | 8 | 382 | 7 | 397 | 0.26 |
| 2 years old oil palm field | 29 | 8 | 7 | 44 | 0.45 |
| 6 years old oil palm field | 11 | 1 | 6 | 18 | 0.69 |
| 10 years old oil palm field | 10 | 1 | 5 | 16 | 0.42 |

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