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Alley-cropping system can boost arthropod biodiversity and ecosystem functions in oil palm plantations

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ABSTRACT

Oil palm (*Elaeis guineensis*) is among the fastest expanding crops, due to high global demand for vegetable oils. Large areas of forest are converted into oil palm plantation to meet the market demand in producing countries which causes rapid decline in tropical biodiversity, including arthropods. The alley-cropping system has the potential to promote faunal biodiversity, related ecosystem services and food security in agricultural landscapes. In alley-cropping, a main crop is intercropped with a secondary crop (often a food crop), secondary crops are cultivated in the alleys in between the main crop. We compared arthropod taxonomic richness, arthropod predators and decomposers between five alley-cropping treatments (pineapple, bamboo, black pepper, cacao, bactris), where oil palm is intercropped with another species. In addition, we sampled two control treatments: monoculture oil palm, aged seven and 15 years old. A total of 50,155 arthropod individuals were recorded using pitfall trap sampling, representing 19 orders and 28 families. Fourteen orders belonging to sub-phylum Insecta, three orders from Arachnida (Araneae; Acarinae; Scorpiones) and two orders from Myriapoda (Chordeumatida; Geophilomorpha). We detected an increase in beta-diversity of oil palm production landscape. Specifically, we found that the number of arthropod orders, families and abundance were significantly greater in alley-cropping farming plots than those in monoculture plots. In addition, alley-cropping treatments contained larger numbers of predators and decomposers. Our findings suggest that the alley-cropping system can become a key management strategy to improve biodiversity and ecosystem functions within oil palm production landscapes.

1. Introduction

From initially a minor subsistence crop in West and Central Africa, oil palm has risen to become one of the world's fastest expanding and most cultivated crops (Corley and Tinker, 2003). Malaysia and Indonesia dominate the global palm oil production, providing about 80% of the world's supply (Koh and Wilcove, 2008; Fitzherbert et al., 2008; Ng et al., 2012). Due to high global demand for palm oil, large-scale land-clearing of tropical rainforest has taken place, either mechanically or with fire, during the establishment of oil palm plantations (Dislich et al., 2016). Oil palm expansion has caused major habitat destruction and deterioration in both the biotic and abiotic components of tropical ecosystems (Donald, 2004; Green et al., 2005; Fitzherbert et al., 2008; Barnes et al., 2014; Allen et al., 2015).

In comparison with tropical rainforest, oil palm production landscapes contain greatly reduced floral and faunal diversity and contain a different species composition (Meijaard and Sheil, 2013; Hawa et al., 2016; Shuhada et al., 2017). Few specialised forest species can survive in oil palm plantations due to the simplified vegetation, canopy structure and warmer understorey conditions in comparison to forest (Lucey and Hill, 2012; Livingston et al., 2013; Gray et al., 2014; Luke et al., 2014; Alonso-Rodríguez et al., 2017). These factors can interact with other environmental stressors, such as pesticide application, causing further decline of forest species (Laurance et al., 2014). A study by Senior et al. (2013), showed that species richness and abundance of birds in oil palm plantations were 43% and 18% lower compared to natural forest. Similarly, arthropods also respond negatively in terms of abundance and composition with forest conversion to oil palm plantation (Fitzherbert et al., 2008; Barnes et al., 2014; Drescher et al., 2016; Petrenko et al., 2016). Hendrickx et al. (2007) found that

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arthropod species richness in agricultural landscapes decreases with increasing management intensity of the fields and a modified landscape structure.

Landscapes that have undergone oil palm expansion have suffered biodiversity loss, however, with better oil palm farming practices, they have the potential to support a considerable floral and faunal diversity, albeit with a different species composition than natural habitat (Azhar et al., 2011; Asmah et al., 2017; Ghazali et al., 2016). Biodiversity is important in maintaining ecosystem functions and therefore the sustainability of agriculture (Foster et al., 2011; Dislich et al., 2016). Commercial growers should be required to make their existing oil palm production landscapes more compatible with enhanced biodiversity conservation (Azhar et al., 2017). The sustainable management of oil palm plantation is essential for reducing the negative effects of agricultural intensification on biodiversity. One possible method for increasing biodiversity in oil palm plantations is by incorporating alley-cropping.

Alley-cropping is an agricultural practise in which more than one species of tree, grass and/or shrubs are grown with the main commercial crop within an agricultural mosaic (Gold and Garrett, 2009). Alley-cropping can have important roles in preserving biodiversity by providing complementary habitats and improved ecosystem services (Williams-Guillén et al., 2008; Quinkenstein et al., 2009; Jose, 2012). Through alley-cropping, floristic and faunal diversity can be improved within the plantation. For example, a greater number and richness of bird and bat species have been recorded in cacao and banana agroforestry alley-cropping systems compared to monocultures (Harvey and Villalobos, 2007). Harvey et al. (2006) also recorded higher levels of dung beetle and terrestrial mammal biodiversity in cacao and banana alley-cropping system compared to plantain monoculture system. This suggests that agroforestry, alley-cropping system have positive impacts on biodiversity for insect, mammal and avian communities, providing habitats for both specialised and generalist species (Tsonkova et al., 2012).

Conversion of forest habitat to oil palm plantation reduces arthropod diversity due to changes in habitat landscape, absence of microhabitat, lack of resource availability and increased fluctuations in microclimate (Pfeiffer et al., 2008; Brühl and Eltz, 2010; Fayle et al., 2010). Alley cropping may have the potential to ameliorate some of these issues. Alley cropping may improve vegetation structure attributes including canopy level or understory level within agricultural landscape that can promote better arthropod diversity (Perfecto and Vandermeer, 2008; Jose, 2012; Asmah et al., 2017; Ghazali et al., 2016; Novais et al., 2016).

While current evidence highlights alley-cropping as a potentially successful strategy in improving biodiversity within agricultural farmland, few studies have investigated the effects of intercropping within large-scale oil palm plantations (Asmah et al., 2017; Ghazali et al., 2016). Ghazali et al. (2016) suggest that polyculture farming, together with management for in situ habitat complexity, may be a useful strategy in supporting biodiversity within in oil palm plantations. However, Asmah et al. (2017) found that polyculture farming failed to increase fruit-feeding butterfly diversity as a result of a limited number of crop species in oil palm smallholdings.

The present study attempts to determine if alley-cropping can improve biodiversity, particularly beta-diversity in large-scale oil palm plantations. This study addresses the following research questions: (1) Does terrestrial arthropod abundance, number of orders, number of families, and functional composition of arthropods differ between alley-cropping oil palm and monoculture oil palm systems? We predicted that terrestrial arthropod abundance, number of orders, number of families, predator and decomposer arthropod abundance are higher in alley-cropping oil palm plantations when compared to monoculture oil palm systems. (2) What are the orders that constitute arthropod composition in alley-cropping oil palm and monoculture oil palm systems? We predicted that both systems are characterized by different arthropod compositions. The findings from the study will advance our knowledge of how to improve agricultural practices in oil palm, with regards to sustainability and biodiversity conservation.

2. Materials and methods

2.1. Study area

The study was conducted on experimental plots in an oil palm plantation (607 ha) operated by Malaysian Palm Oil Board situated in Kratong, Pahang, Peninsular Malaysia (2°47′1″N, 102° 55′22″E). The plantation was located between 0 and 10 m above sea level with no notable differences in elevation. The experimental plots were grouped into two monoculture farming systems solely planted with oil palm crops and alley-cropping farming systems that intercropped oil palm with other crop plants that include pineapple (*Ananas* spp.), bamboo (*Gigantochloa albociliata*), bactris (*Bactris* spp.), black pepper (*Piper nigrum*) and cacao (*Theobroma cacao*).

The alley-cropping system was implemented by the Division of Integration Research and Extension of MPOB in 2006. The system followed a double-row avenue planting (Ismail et al., 2009) which was originally introduced to increase the income of oil palm growers. The planting system is recommended for lowland areas and those characterized by undulating terrain (less than 6°). The system consists of 30–35% of the land planted with crops other than oil palm, arranged parallel to each other in strips or alleys with a length of 70–100 m and width of 15.2 m on the harvesting path. The secondary crops and oil palm were managed in accordance with Good Agricultural Practises in terms of fertilization and pest/disease control (Ismail et al., 2009; MPOB, 2018). The planting distance between oil palms was 6.1 m and 9.1 m within and between rows, respectively. The oil palm density in the double-row avenue planting was 136 palms ha-1, similar to the conventional triangular planting. Planting rows were designed in an east-west orientation to permit sunlight to reach the intercropping areas between avenues. There were 58–65 oil palm planted in each row. Double-row avenue planting and conventional triangular planting produce a similar amount of fresh fruit bunches.

2.2. Sampling design

The study used a systematic sampling design with a random starting point adopted from Morrison et al. (2008) where the first sampling point was established at any location and the following points were systematically distanced from the starting point. This design ensures randomization (Krebs, 1989). There were five treatments under the alley-cropping system and two monoculture treatments as control plots. The treatments for the alley-cropping system were oil palm intercropped with: (i) pineapple aged one-year old, (ii) bactris (fruit producing, spiny palms) aged six-year old, (iii) bamboo aged two-year old, (iv) black pepper aged four-year old, and (v) cacao aged six-year old (Fig. 1). The other two treatments were monoculture system oil palm plants that aged (vi) seven-year old and (vii) 15-year old (Fig. 1). Each treatment had three replicates, represented by three alleys (100 m each), where 10 pitfall traps were set up at each alley. The distance between different alley-cropping plots as well as between the monoculture and alley-cropping plots was at least 300 m apart.

2.3. Arthropod sampling

Arthropod sampling was conducted from July to November 2017 by using pitfall traps. A total of 840 pitfall traps (30 traps treatment^{-1} month^{-1} × seven treatments × four months) were placed randomly on the harvesting path, 5 m apart from each other and at least 5 m from the edge of the cropping lane at each treatment. Each pitfall trap was moved to a new location on a monthly basis. At a time, 210 pitfall traps were set up simultaneously. The pitfall traps consisted of

Fig. 1. Alley-cropping system designed with seven treatment levels. Oil palm plants were intercropped with cacao (A), black pepper (B), pineapple (C), bactris (D), and bamboo (E). Two conventional oil palm monoculture stands characterized by seven- (F) and 15- (G) year old crops were used as control plots.

open plastic containers (8 cm in diameter, 12 cm deep) and were buried into the ground with the lip of the container at the same level with the ground surface. The pitfall traps were covered by suspended plates to prevent disturbance from other animals and flooding by rainwater (Gibb and Oseto, 2006). The traps were filled with a mixture of water and detergent to kill and keep the arthropods at the bottom of container. Salt was added into the mixture as a preservative agent. The traps were emptied after seven days. We identified arthropod based on the key morphological characteristics to family level using several identification guides (Romoser and Stoffolano, 1998; Bland and Jaques, 2010; Capinera, 2011; Chapman and Douglas, 2013; Coleman et al., 2017). Arthropods were then further categorised according to feeding guild using the guides.

2.4. Local-scale habitat quality measurement

A total of eight vegetation characteristics were measured at each arthropod sampling point (Table 1): (i) % grass cover in a 1 m × 1 m

Table 1
Summary statistics of vegetation, microclimate and soil characteristics.

Attribute	Mean ± SD	Min	Max
Grass cover (%) within 1 m^2	46.15 ± 16.62	10	95
Grass cover (%) within 10 m^2	47.29 ± 16.08	8	93
Non-grass cover (%) within 1 m^2	23.35 ± 11.01	2	75
Non-grass cover (%) within 10 m^2	24.43 ± 10.44	3	74
Height of grass (cm) within 1 m^2	5.823 ± 2.071	1	15
Height of grass (cm) within 10 m^2	8.598 ± 2.429	2	17
Height of non-grass (cm) within 1 m^2	7.663 ± 2.675	2	21
Height of non-grass (cm) within 10 m^2	10.96 ± 3.364	4	32
Light intensity (Lux)	409.7 ± 322.2	25	1292
Air temperature (°C)	34.75 ± 3.360	28.17	45.1
Relative humidity (%)	58.38 ± 6.645	37.7	69.9
Wind speed (m/s)	1.692 ± 11.43	0	185.8
Soil moisture	2.218 ± 0.904	1	8
Soil pH	6.989 ± 0.290	5	8
Soil surface temperature (°C)	34.84 ± 4.420	27.06	48.2

quadrat, (ii) % grass cover in a 2 m × 5 m quadrat, iii) % non-grass in a 1 m x 1 m quadrat, iv) % non-grass in a 2 m × 5 m quadrat (v) height of grass cover in a 1 m × 1 m quadrat, vi) height of grass cover in a 2 m × 5 m quadrat, vii) height of non-grass cover in a 1 m × 1 m quadrat, and (viii) height of non-grass cover% non-grass in a 2 m × 5 m quadrat. All these characteristics were measured at north, east and west directions (1 m from the sampling point). Lastly, (ix) distance of the pitfall traps to the nearest crops was measured.

We recorded four microclimate and three soil characteristics at each arthropod sampling point, at the same visit to the site (Table 1). For microclimate characteristics, three measurements of (i) air temperature, (ii) wind speed, (iii) relative humidity and (iv) light intensity were recorded and averaged. Readings of wind speed and light intensity were taken ten times per measurement and averaged whereas the air humidity and the air temperature were recorded only once per measurement. Air temperature, wind speed and relative humidity were measured using a digital anemometer-thermometer-hygrometer (Skywatch-Atmos series) while light intensity was measured using a photometer from ISO-TECH ILM 1332A. All these microclimatic measurements were conducted at solar noon time (between 1 p.m. and 2.30 p.m.). For soil characteristics, a multi-meter thermometer was used to measure (v) soil moisture and (vi) soil pH, both readings were taken three times and averaged. The (vii) soil surface temperature was taken by using a Fluke IR thermometer approximately one meter from each pitfall. All measurements were recorded on monthly basis.

2.5. Data analysis

To compare the abundance, number of orders and families between conventional monoculture oil palm and alley-cropping plots, we performed one-way analysis of variance (ANOVA). In addition, ANOVA was performed to compare the abundance of predators and decomposers between conventional monoculture and alley-cropping plots. Sampling weeks were included as experimental block in this analysis. The response variables, including abundance, number of order and number of families were tested with Shapiro-Wilk test to detect deviation from normality. All response variables were square-root transformed to improve the linearity of the data. Tukey's method was used to create confidence intervals for all pairwise differences between the response variables. In addition, we contrasted habitat quality characteristics between treatments by repeating the ANOVA procedures. Analyses were performed using Genstat version 15 software (VSNI, Hemel, Hempstead, UK).

To assess differences in arthropod composition between treatments, we used analysis of similarity (ANOSIM) to compare arthropod order composition between conventional monoculture and alley cropping systems. SIMPER analysis was used to determine the contribution of each arthropod order in arthropod composition. Bray-Curtis distance was used to compute the resemblance metric between each treatment. We used PRIMER version 6 (PRIMER-E Ltd, Plymouth) to perform all multivariate analyses.

Table 2
Total abundance of arthropod order collected from all treatment levels.

Order	Family	Trophic guild	Abundance	Total
Trombidiformes	Trombidiidae	Predator	68	68
Araneae	Araneidae	Predator	424	2503
	Gnaphosidae	Predator	2079	
Blattodea	Corydidae	Decomposer	1023	1023
Spirobolida	Trigoniulidae	Decomposer	550	550
Coleoptera	Scarabidae	Decomposer	10290	11253
	Carabidae	Predator	871	
	Lucanidae	Decomposer	92	
Dermaptera	Forficulidae	Decomposer	121	121
Diptera	Muscidae	Decomposer	2112	2479
	Culicidae	Decomposer	142	
	Calliphoridae	Decomposer	225	
Geophilomorpha	Geophilidae	Predator	16	16
Hemiptera	Coreidae	Predator	55	55
Homoptera	Cicadellidae	Predator	230	230
Hymenoptera	Formicidae	Predator	21211	21216
	Vespidae	Predator	5	
Isoptera	Termitidae	Decomposer	880	880
Lepidoptera	Unidentified caterpillar	Predator	25	25
Mantodea	Mantidae	Predator	29	29
Microcoryphia	Meinertellidae	Decomposer	407	407
Neuroptera	Myrmeleontidae	Predator	23	23
Orthoptera	Acrididae	Predator	674	9142
	Gryllidae	Decomposer	8439	
	Tettigonidae	Predator	29	
Scorpiones	Buthidae	Predator	10	10
Thysanura	Lepismatidae	Decomposer	125	125

3. Results

3.1. General patterns of arthropod biodiversity

We collected a total of 50,155 arthropod individuals belonging to 19 orders and 28 families (Table 2). Fourteen orders belonged to subphylum Insecta, three orders from Arachnida (Araneae; Acarinae; Scorpiones) and two orders from Microcoryphia (Chordeumatida; Geophilomorpha). Hymenoptera were the most abundant order with 21,216 individuals followed by Coleoptera (11, 253 individuals) and Orthoptera (9142 individuals). The lowest number of recorded individuals belongs to the order Scorpiones with only 10 individuals sampled. With respect to habitat quality, only one (i.e. height of non-grass within 10 m^2 quadrat) of fifteen characteristics were not significantly different between alley-cropping and conventional plots (Supplementary Table 1).

3.2. Comparison of arthropod order, family and abundance between alley-cropping and monoculture systems

The number of arthropod orders (ANOVA: df = 6; F = 33.56; $p < 0.001$) and families (ANOVA: df = 6; F = 38.60; $p < 0.001$) were significantly greater in the alley-cropping systems compared to the conventional monoculture system. Cacao treatment had the highest numbers of orders and families compared to other treatments (Fig. 2). The lowest number of orders and families were recorded in oil palm monoculture aged seven-years (Fig. 2). Arthropod abundance was significantly greater (ANOVA: df = 6; F = 41.16; $p < 0.001$) in the alley-cropping system than conventional monoculture systems. Bamboo had the highest abundance, whereas the lowest abundance was recorded in oil palm monoculture aged seven-years (Fig. 2). A post hoc Tukey test showed that both oil palm monoculture stands aged seven-years and 15-years differed significantly in the number of arthropod orders,

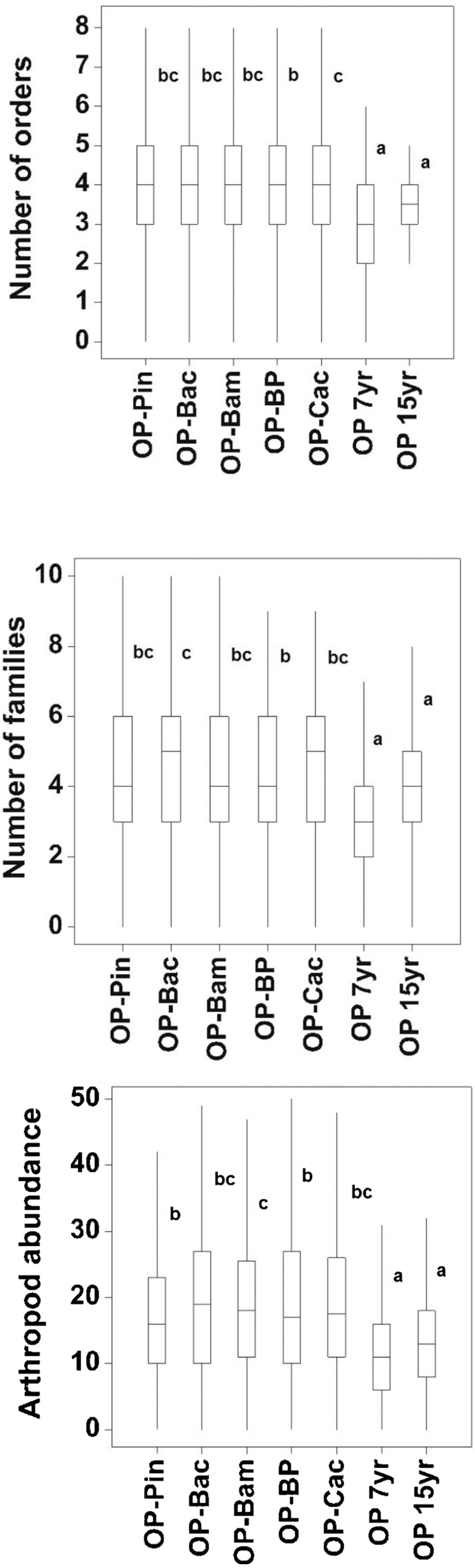

Fig. 2. The number of arthropod orders, families and abundance in seven treatment levels of control (oil palm monoculture aged seven-year and 15-year) and alley-cropping (oil palm intercropped with pineapple denoted by OP-Pin, black pepper denoted by OP-BP, cacao denoted by OP-Cac, bactris denoted by OP-Bac and bamboo denoted by OP-Bam) treatments. Each treatment had three replicates.

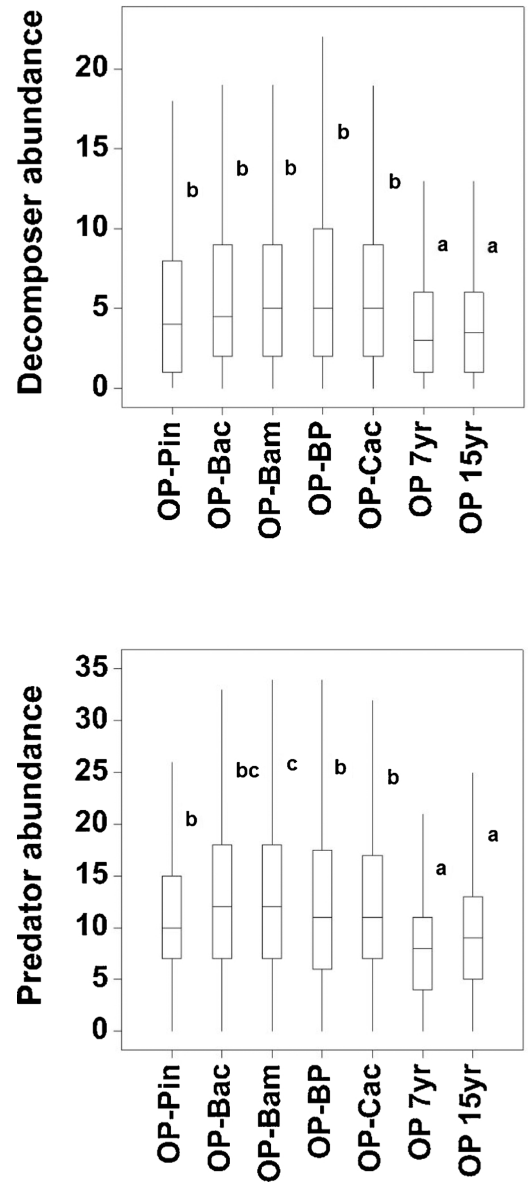

Fig. 3. Arthropod abundance in terms of feeding guild in seven treatment levels of control (oil palm monoculture aged seven-year and 15-year) and alley-cropping (oil palm intercropped with pineapple denoted by OP-Pin, black pepper denoted by OP-BP, cacao denoted by OP-Cac, bactris denoted by OP-Bac and bamboo denoted by OP-Bam) treatments. Each treatment had three replicates.

families and abundance from all alley cropping treatments (Fig. 2).

3.3. Comparison of arthropod abundance grouped into predator and decomposer feeding guilds between alley-cropping and monoculture systems

Decomposer abundance (ANOVA: df = 6; F = 20.20; $p < 0.001$) and predator abundance (ANOVA: df = 6; F = 30.08; $p < 0.001$) were significantly greater in the alley-cropping system compared to conventional monoculture system (Fig. 3). A post hoc Tukey test showed that the cacao treatment contained the highest abundance of decomposers with the lowest abundance recorded in oil palm monoculture aged seven-year. For predator abundance, post-hoc Tukey tests identified the bamboo treatment as having the highest abundance of predators, and oil palm monoculture of seven years as having the lowest predator abundance.

Table 3
Pairwise comparison in order composition of seven treatment levels of control (oil palm monoculture aged seven-year and 15-year) and alley-cropping (oil palm intercropped with pineapple, black pepper, cacao, bactris and bamboo) treatments.

Groups observed	p value
Oil palm + pineapple/oil palm + bactris	0.012
Oil palm + pineapple/oil palm + bamboo	0.001
Oil palm + pineapple/oil palm + black pepper	0.004
Oil palm + pineapple/oil palm + cacao	0.003
Oil palm + pineapple/oil palm monoculture aged seven-year	0.001
Oil palm + pineapple/oil palm monoculture aged 15-year	0.001
Oil palm + bactris/oil palm + bamboo	0.011
Oil palm + bactris/oil palm + black pepper	0.687
Oil palm + bactris/oil palm + cacao	0.114
Oil palm + bactris/oil palm monoculture aged seven-year	0.001
Oil palm + bactris/oil palm monoculture aged 15-year	0.001
Oil palm + bamboo/oil palm + black pepper	0.013
Oil palm + bamboo/oil palm + cacao	0.008
Oil palm + bamboo/oil palm monoculture aged seven-year	0.001
Oil palm + bamboo/oil palm monoculture aged 15-year	0.001
Oil palm + black pepper/cacao	0.611
Oil palm + black pepper/oil palm monoculture aged seven-year	0.001
Oil palm + black pepper/oil palm monoculture aged 15-year	0.001
Oil palm + cacao/oil palm monoculture aged seven-year	0.001
Oil palm + cacao/oil palm monoculture aged 15-year	0.001
Oil palm monoculture aged seven-year/oil palm monoculture aged 15-year	0.002

3.4. Arthropod composition in alley-cropping and monoculture systems

Our results revealed that individuals from four orders (i.e. Hymenoptera, Orthoptera, Coleopteran and Araneae) were the most common in all the treatments with the exception of oil palm monoculture aged seven-year; in which Araneae was not one of the most common orders (Supplementary Table 2). In all treatments, Hymenoptera had the highest contribution with an average of 41% followed by Orthoptera (26%), Coleoptera (19%) and lastly Araneae (6%). Out of 19 orders, those four orders represented 92% of the arthropod composition in the alley-cropping system and the other 15 orders constituted 8%. ANOSIM analysis revealed a significant difference between arthropod composition in all the treatments (number of permutations = 999; Global $R = 0.015$; $p = 0.001$). Both oil palm monoculture stands aged seven-year and 15-year differed significantly in arthropod composition from other treatments (Supplementary Table 2). The pairwise comparisons of bactris/black pepper and black pepper/cacao were not significant (Table 3).

4. Discussion

Alley-cropping system can increase beta-diversity in monoculture landscapes. We found that the number of arthropod orders, families, and abundance were greater in the alley-cropping system compared to the monoculture system. This result is in line with findings from Ghazali et al. (2016) and Azhar et al. (2014) showing that practising polyculture farming in oil palm agriculture contributes positively to biodiversity. A possible explanation for this might be that alley-cropping systems incorporate a diversity of crop plants, trees and livestock in an agricultural landscape thus increasing habitat heterogeneity, soil fertility, water quality, carbon and nutrient cycling (Williams-Guillén et al., 2008; Fahrig et al., 2011; Torralba et al., 2016). In contrast, oil palm monocultures have very little floral diversity and undergrowth is restricted by herbicides and lack of light, particularly, during the mature phase of monoculture plantations (Ismail et al., 2009).

Alley-cropping systems can enhance arthropod habitat by increasing the structural, vegetation complexity of the agricultural area and providing variation in microhabitats (Lawton, 1983; Jose, 2009). Diversified microhabitats can provide different food resources such as pollen and nectar (Brandle et al., 2004). In addition, structural, vegetation complexity also provides nesting habitat and breeding opportunities that promote variation of species richness within the environment (Hendrickx et al., 2007; Jose, 2009; Stein et al., 2014). Similarly, Ghazali et al. (2016) reported that key habitat characteristics such as number of crop species, height of the oil palm crop and number of immature oil palms support greater richness of arthropods in banana-oil palm systems.

The number of arthropod orders and families were highest in the cacao treatment. This may due to cacao's wider canopy cover providing shelter from direct sunlight, thereby maintaining a lower understory temperature (Perfecto and Vandermeer, 1996). Furthermore, an alley cropping system using cacao provides a layer of diverse organic material below the shade providing nesting and feeding areas and cover for arthropods (Power, 1996; Philpott and Foster, 2005). The alley-cropping system likely provides a more optimal microclimatic condition for arthropods compared to monoculture farming that is drier and has reduced shelter (Turner and Foster, 2006; Quinkenstein et al., 2009; Luke et al., 2014). Changes in temperature can influence arthropod populations due to their short life cycle (Bale et al., 2002). Within an area, changes in air temperature can influence the physiological conditions of arthropods, in particular, for specialist species, preventing them from colonization (Cornelissen, 2011; Kingsolver et al., 2011; Wilson and Maclean, 2011). Tropical insect species experience high sensitivity to temperature variation (Robinet and Roques, 2010, Cornelissen, 2011; Kingsolver et al., 2011).

In addition, our results show that the alley-cropping system has the potential to boost biodiversity related ecosystem functions services as it sustains greater numbers of predatory and decomposing arthropods. Predatory arthropods can provide biological control services as an alternative to chemical usage in agricultural systems (Jamian et al., 2017) and help maintain stable arthropod communities (Finke and Snyder, 2010, Tylianakis et al., 2010). Generally, in monoculture oil palm plantations, pest herbivore species are generally controlled by targeted application of pesticides (Wood, 2002). A study conducted by Nurdiansyah et al. (2016) found that predation rates and occurrence were higher in plantation areas bordered by various natural and different vegetation cover compared to monoculture oil palm plantation. This suggests that with greater vegetation diversity and habitat complexity within oil palm plantations, alley-cropping system can attract potential predators to control oil palm pests or support higher numbers of existing predators. This claim is supported by Jamian et al. (2017) who found that the abundance of predatory bugs (*Cosmolestes picticeps* and *Sycanus dichotomus*) increases with the presence of beneficial plants and ground vegetation cover in oil palm plantations.

With regard to arthropod decomposers, the alley-cropping system has the potential to maintain a greater decomposer arthropod population compared to the monoculture agricultural system. Decomposers are important for breaking down plant detritus and thereby increasing access to microbes, modifying soil particles and influencing water availability and integration of organic matter in the soil (Ebeling et al., 2014). Schmidt et al. (2015) showed that decomposer invertebrates are crucial in increasing soil fertility in agricultural landscapes. The ground litter was more abundant in the alley-cropping system compared to monoculture oil palm plantation, which often contains only sparse bushes and dry soil (Jose, 2009). Ground litter can be important in providing food for decomposers and supporting a stable temperature and humidity (Moço et al., 2010).

Arthropod diversity was higher in the alley-cropping systems than in oil palm monocultures. These results contradict those of Ghazali et al. (2016), who compared polyculture and monoculture smallholdings and found no difference in insect composition between the two. Of all the arthropod orders recorded, Hymenoptera (family: Formicidae) had the highest abundance followed by Coleoptera (family: Carabidae) and Orthoptera (family: Gryllidae). Oil palm plantations support a greater number of ant species, but most of these are non-native species that are not found in primary forest (Fayle et al., 2010).

Hymenoptera are among the greatest insect component of tropical biodiversity due to their adaptive strategies to various habitat modifications (Luke et al., 2014). Arboreal ant species gain benefits with increasing nesting and foraging sites while open ground species benefit from availability of open terrain with lack of tree cover (Ribas et al., 2003; Lassau and Hochuli, 2004). This indicates that ant species can adapt to almost any condition and survive even in hostile area such as oil palm agroecosystems compared to the other arthropods. Similarly, a study conducted by Bos et al. (2007) recorded that 75% of forest ant species were found in agroforestry system showing that ant has high survival rate from habitat modification.

The more dense and diverse vegetation structure found in the alley-cropping systems may provide habitat for ground beetles and crickets and increase their abundance (Karindah et al., 2011). The presence of grasses and bushes in hedgerows also provide similar functions maintaining food and shelter for ground beetles (Burel, 1989). Our results imply that the alley-cropping system can introduce greater habitat heterogeneity that will increase biodiversity in oil palm production landscapes (Azhar et al., 2015). The findings from this study can guide certification bodies such as Roundtable on Sustainable Palm Oil (RSPO), Malaysian Sustainable Palm Oil (MSPO), and Indonesian Sustainable Palm Oil (ISPO) to promote oil palm production landscapes that are managed more sustainably.

5. Conclusions

The findings of this study indicate that alley cropping system can maintain greater arthropod biodiversity compared to the monoculture system. Oil palm growers should be encouraged to practise the alley-cropping system or systematic polyculture farming as an alternative production strategy as it increases the floristic composition and structural complexity aiding arthropod and avian biodiversity (Yahya et al., 2017). The alley-cropping system can also provide additional source of revenue as well as making the plantation more hospitable to biodiversity and increasing ecosystem functions, potentially improving yields of both crops. Future experiments should look at the potential of using the alley-cropping systems along with other sustainable management practices such as the reduction of herbicides and pesticides, which could lead to further environmental benefits than alley-cropping alone. In addition, the potential ecosystem services provided by the biodiversity increases that alley-cropping provides, should be tested directly. To improve the sustainability of oil palm agriculture, it is imperative that commercial growers alter the present management of oil palms (Azhar et al., 2017; Yahya et al., 2017). Our findings provide an essential guide for policy makers and certification bodies to promote oil palm production landscapes that will safeguard farmland biodiversity.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.agee.2018.03.017.

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