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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