Cattle-grazing in oil palm plantations sustainably controls understory vegetation

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Abstract

Oil palm agricultural practices need to be substantially changed in order to meet the global demand for more ethical and sustainable farming. Livestock integration is an innovative method to control understory vegetation in oil palm plantations, while reducing the need for chemical herbicides, as well as providing additional food security, ecosystem services, and habitat heterogeneity. Understory vegetation is important for faunal biodiversity in oil palm plantations, however it is often decimated by the over usage of herbicides. To determine how cattle-grazing affected the growth of understory vegetation, we collected data from 45 plantations, in Peninsular Malaysia, including those integrated with cattle and without them. Our results revealed that the plantations integrated with cattle had on average 20% more undergrowth cover, but no difference in undergrowth height, therefore, maintaining undergrowth at an acceptable height for harvesters to access oil palms. We recommend cattle-grazing as a method for oil palm stakeholders to maintain manageable undergrowth and align with sustainable palm oil certification policy by reducing their use of chemical herbicides. To promote cattle-oil palm integration, specific policies are needed to strengthen financial and technical support.

Keywords: Agricultural practice, biodiversity, ecosystem services, grazing, herbicides, livestock.

Introduction

Oil palm agriculture relies heavily on the use of chemical pesticides and herbicides to protect the crop yield from pest animals, insects, fungi, and competing weeds (Turner & Gillbanks, 1974; Choo et al., 2011; Obidzinski et al., 2012; Singh et al., 2014; Ashton-Butt et al., 2018). Undergrowth in oil palm plantations and smallholdings is controlled by using mechanical, chemical or biological methods. High undergrowth can become a problem in plantations as it obstructs harvesters from harvesting the oil palm fruit bunches and can compete with oil palms for nutrients (Bakar, 2004). Contrary to horizontal expansion of natural understory vegetation, vertical growth of the vegetation uses larger amount of soil nutrients, this may cause intense competition between oil palms and weeds in terms of nutrient uptake (Shariff & Rahman, 2008). It has been reported that the high relative abundance of grasses *Paspalum conjugatum* and *Axonopus compressus* species can be problematic in oil palm plantations, because of the perennial nature and height (Samedani et al., 2014). In addition, certain weeds such as woody and creeping weeds and speargrass, compete intensively with oil palms for water and nutrients (Woittiez et al., 2017).

Chemical herbicides have been found to have negative ecological effects in freshwater ecosystems, but are widely used by oil palm growers to control unwanted weeds (Brooker &

Edwards, 1975; Relye, 2005; Allenet al., 2015). Glufosinate ammonium and glyphosate are used to control multiple weed species in oil palm plantations (Wibawa et al., 2009). Contact herbicides are commonly utilized in immature oil palm plantations, and systemic herbicides are used in mature plantations (Nkongho et al., 2014). Negative effects on plant and animal biodiversity have been reported from the use of agricultural pesticides and the pollution of streams with pesticides is rife around oil palm plantations (Egan et al., 2014; Sánchez-Moreno et al., 2015; Jeliazkov et al., 2016). In addition, herbicide reliance can have negative socio-economic effects: herbicides are expensive, especially for oil palm smallholders who have low amounts of capital and often rely on loans to buy them (Nkongho et al., 2014).

Unlike herbicide application, which needs protective measures to reduce contamination, the use of grazing animals to suppress weeds is safer for farmers and the environment (Devendra & Thomas, 2002). To control weeds biologically, integrating managed livestock grazing (e.g. cattle, sheep and goats) with oil palm cultivation has been encouraged (Jambari et al., 2012; Purwantari et al., 2015; Zamri-Saad & Azhar, 2015). Well-managed silvopastoral systems decrease erosion and increase soil build-up, biomass, biodiversity, and water capture and storage in addition to improving the livelihoods of cattle producers through increased livestock production (Ibrahim et al., 2010; Devendra, 2011; Slade et al., 2014; Lerner et al., 2017). A major benefit of oil-palm cultivation is the availability of common weeds to grow beneath the palms; these weeds provide a large proportion of the nutritional needs of grazing animals within the plantation (Dahlan, 1993; Devendra, 2004). Both a rotational grazing system of 6-8 weekly intervals and a flexible grazing interval (to be adjusted depending upon forage availability) have been recommended for oil palm plantations (Chen & Dahlan, 1996). The recommended stocking rate for cattle ranges from 0.3/ha to 3.0/ha. Animals should be moved elsewhere after 60 % of the forage is grazed (Chen & Dahlan, 1996).

In Malaysia, oil palm plantations with stands of seven years or older can generate 500 kg $ha^{-1}yr^{-1}$ of understorey dry matter, which is enough to warrant grazing by cattle (Latif & Mamat, 2002). One animal unit needs about 2.5 % to 3 % of its body weight in grass uptake and an animal unit that is one to two years old, uses about 3 ha of oil palm area for grazing (Latif & Mamat, 2002). Cattle-oil palm integrated production systems are considered successful and sustainable integrated agricultural production systems in Malaysia (Ismail & Wahab, 2004). Livestock integration, practiced commonly by oil palm smallholders, improves weed management, biodiversity conservation, and crop productivity (Azhar et al., 2017; Tohiran et al., 2017, 2019). Nevertheless, the integration of cattle with large-scale oil palm plantations has received limited attention from major oil palm companies (Foster et al., 2011). The lack of empirical evidence may hamper cattle integration in large-scale oil palm plantations. Besides weed control, an integrated crop–livestock system offers additional benefits such as reduced liability of raising a single farm product, increased water infiltration and resistance to soil erosion, increased soil organic carbon, and reduced fertilizer use from nutrient cycling (Lemaire et al., 2014; Wright et al., 2012). One of the limiting factors in integrating livestock with perennial crops is the damage to young trees or to the bark of adult trees (Sánchez, 1995). Hence, the size of the crop trees determines when grazing animals can be integrated into the system (Sánchez, 1995).

Undergrowth or weeds should not be simply removed from oil palm plantations or smallholdings without considering the ecosystem functions and services they provide (Ashton-Butt et al. 2018). Some commercial growers may fail to understand the ecosystem services provided by undergrowth at different scales, or when exactly the understory vegetation is competing with oil palms planted on the fields before relevant management measures (e.g. weeding) should be implemented. The use of herbicides often completely removes undergrowth; thus exposing the topsoil to erosion, removing ground cover for insect, bird and mammalian fauna and other associated ecosystem functions and services. Undergrowth delivers ecosystem services and functions by protecting the soil against erosion and providing a habitat for natural pest enemies, while interacting with the water and nutrient cycles (Woittiez, 2017). In addition, undergrowth may provide food and habitat for fauna such as farmland birds, thus improving biodiversity within oil palm plantations (Tohiran et al., 2017, 2019). Livestock grazing may be used as an alternative to adequately trim the undergrowth to an acceptable level of cover and height, allowing easy access for oil palm harvesters.

In this study, we investigate understory vegetation cover and height in oil palm plantations, with and without cattle-grazing. We pose the following research questions: (1) does cattle-grazing affect understory vegetation cover and height? (2) what are the habitat quality characteristics and agricultural practices, particularly pertaining to livestock integration that determine undergrowth coverage? (3) what factors drive undergrowth height? This study sheds new light on reconciling oil palm production with sustainable management and biodiversity enhancement by reducing herbicide application and recommends an evidence-based practice that can be applicable in any oil palm producing country, worldwide.

Materials and Methods

Study area

We undertook this study at 45 oil palm plantations located in the states of Johor, Pahang, and Negeri Sembilan in Peninsular Malaysia, comprising 79,351 ha total (Figure 1). Initially, we requested permission to collect data from 60 randomly selected plantations. However, 15 plantations declined to be surveyed. The plantations had mature oil palms (> 6 year) and comprised those that were integrated with cattle farming (30 plantations; mean plantation area ± SE = 1,643 ± 71 ha) and control plantations (15 plantations without cattle farming; mean plantation area ± SE = 2,003 ± 261 ha). The plantations were cultivated with oil palms that have a 25-year productive cycle of yielding oil palm fruit bunches, during which herbicides are commonly sprayed thrice annually.

Each plantation was located at least 1 km apart. There was a total of 20,329 heads cattle kept in the plantations. Kedah-Kelantan cross was the cattle breed used for integration with oil palm farming at our study areas, which is native to Peninsular Malaysia. Cattle grazing was not allowed in fields planted with young oil palm stands (less than five years). Within mature oil palm areas, light penetration allows undergrowth or weeds to grow and there are more than 50 species of plant already identified (Ayob & Kabul, 2009) [34]. None of the plantations are mechanical weeded.

Survey design

Using a nested survey design, we established three study plots per plantation for a total of 135 study plots at 45 plantations. These study plots were treated as fully independent. Even though the plots were on the same plantations, each plot was in different planting blocks. Each study plot was surveyed twice during the study (Figure 1; Supplementary table). Each point was located at least 500 m apart to ensure sampling independence. We used a handheld Global Positioning System (GPS) to geo-reference each plot (latitude and longitude). Sampling was conducted between November 2014 and March 2016.

Habitat quality measurements and livestock management

At each study plot, we collected the following data from within four 1 m^2 square-quadrats on harvesting paths in, or adjacent to the study plot: 1) visually estimated percentage of undergrowth coverage (grass and non-grasses). The non-grasses include broadleaf weeds, brush weeds, creepers, sedges and ferns; 2) mean-height of undergrowth; 3) mean-height of three oil palms using a laser rangefinder; 4) percentage of canopy cover using a GRS densitometer; and 5) altitude (Table 1). The vegetation structure measurements were taken twice over the study period. We interviewed plantation managers to collect additional information related to livestock management (i.e. the number of cattle) and undergrowth management (i.e. the numbers of circular and selective herbicide spraying per year). Circular spraying was conducted within 2 m radius from palm, whereas selective spraying was targeted at woody shrubs. We reported the season we conducted sampling in as either wet (March – April and October – December) or dry (January – February and May – September) season.

Data analysis

To compare understory vegetation cover and height between the plantations with cattle-grazing and those without cattle-grazing, we performed unbalanced ANOVA. We used generalized linear models (GLMs) to examine the relationships between ground vegetation coverage, habitat quality characteristics and agricultural practices. Normal distribution and identity-link function were used in the modelling process. To select the final model, the best model was selected from a subset of explanatory variables according to goodness-of-fit criteria. The coefficient of determination, R^2 of the final model was reported. We repeated the same procedures to analyse height of undergrowth. We log-transformed both response variables when the regression function was not linear and the error terms were not normal. We conducted correlation tests to detect multicollinearity among explanatory variables. Strongly correlated variables ($|r| > 0.7$) were dropped to avoid distortion in model estimation (Dormann et al. 2013). Only one variable from the correlated pair with lowest Wald statistic value was removed from the modelling process of each model (undergrowth coverage or height of undergrowth). Nine explanatory variables were tested in these analyses. These include: canopy cover; stand age; oil palm stand height; number of circular spraying annually; number of selective spraying annually; altitude; number of cattle in each plantation; plantation area; and season (wet or dry). Height of oil palm stand was excluded in the weed coverage model ($r = -0.889$) and in the weed height model ($r = -0.889$) because of multicollinearity. To compare undergrowth coverage and height between different seasons (i.e. wet and dry), we performed unbalanced design ANOVA. All analyses were performed in GenStat version 12 (VSN International, Hemel Hempstead, UK).

Results

Undergrowth coverage

We found that undergrowth coverage was 20% greater (df = 1; F = 29.51; $p < 0.001$) in the plantations integrated with cattle (mean = 75.69 %) compared to those without the livestock animals (mean = 55.68 %). Five of the eight explanatory variables explained 18.26 % of the variation in ground vegetation coverage. We found that log-transformed undergrowth coverage significantly increased with the number of grazing cattle (Figure 2a; slope = 3.192 x 10^{-4}; Wald = 12.04; $p < 0.001$), whereas it significantly decreased with number of circular herbicide spraying (Figure 2b; slope = -0.1865; Wald = 4.67; p = 0.032). Log-transformed undergrowth coverage also increased with age of oil palm stand (Figure 2c; slope = 2.750 x 10^{-2}; Wald = 12.68; $p < 0.001$) and altitude (Figure 2d; slope = 6.32 x 10^{-3}; Wald = 11.07; p = 0.001). However, log-transformed undergrowth coverage decreased with the oil palm canopy cover (Figure 2e; slope = -8.29 x 10^{-3}; Wald = 9.02; p = 0.003). We did not detect any significant effects from the number of selective herbicide spraying, size of grazing area, and season. There was no significant difference in undergrowth coverage ($p > 0.05$) between wet (mean = 55.59 %) and dry (mean = 59.56 %) season.

Height of natural undergrowth

No significant difference in undergrowth height ($p > 0.05$) was detected between the plantations integrated with cattle (mean = 13.44 cm) and those without the livestock animals (mean = 13.60 cm). Similar to undergrowth coverage, five of the eight explanatory variables explained 18.42 % of the variation in weed height. Our results revealed that number of cattle decreased the log-transformed height of undergrowth (Figure 3a; slope = -2.148 x 10^{-4}; Wald = 6.67; p = 0.010), showing the cattle's effectiveness in maintaining a viable undergrowth height for harvesting. Log-transformed height of undergrowth also increased with the age of oil palm stand (Figure 3b; slope = 3.163 x 10^{-2}; Wald = 20.53; $p < 0.001$), altitude (Figure 3c; slope = 4.62 x 10^{-3}; Wald = 7.23; p = 0.008) and plantation area size (Figure 3d; slope = 1.168 x 10^{-4}; Wald = 6.08; p = 0.014). In contrast, log-transformed height of undergrowth decreased with the oil palm canopy cover (Figure 3e; slope = -0.128; Wald = 20.68; $p < 0.001$). No significant effect from the number of selective herbicide spraying, number of circular herbicide spraying and season was detected. No significant difference in weed height ($p > 0.05$) was found between wet (mean = 10.92 cm) and dry (mean = 10.82 cm) season.

Discussion

Here, we show that the management of understory vegetation with conventional herbicides in large-scale oil palm plantations can be substituted with cattle grazing. This is because cattle can cause local effects on understory vegetation in their habitat through grazing and grooming behaviour (Feucht, 2010). Our findings show that cattle grazing as opposed to herbicide spraying maintains beneficial undergrowth coverage while controlling the height of the undergrowth (Figure 4). The regular movement and grazing behaviour of cattle are likely to determine weed distribution in the plantations. Large-scale cattle grazing (allowed rotationally or continuously in some plantations) and congregation near shade and water influence nutrient accumulation (Dubeux et al., 2006).

The positive relationship between cattle grazing and undergrowth coverage could be caused by more fertilization by cattle droppings, which increase soil organic carbon storage and total nitrogen content (Abdalla et al., 2018). Cattle absorb nutrients contained in forages and return most of them to the soil in their waste in the form of manure and urine (Dubeux et al., 2006). Oil palm producers would benefit from the improved flow of soil nutrients from manure produced from cattle grazing. This means that cattle-oil palm integration allows the reduction of synthetic fertilizers applied in the plantations by recycling nutrients.

In addition, cattle discriminately grazing on understory vegetation rather than the indiscriminate removal of undergrowth vegetation by herbicides including those considered as beneficial plants for biodiversity. Extensive high undergrowth is untenable in oil palm plantations due to the problems it causes for harvesting; making it difficult for harvesters to access the fruit bunches and find them when they have been harvested (Turner & Gillbanks, 1974). However, undergrowth coverage can provide important ecosystem functions and services to the oil palm plantation which are lost when there is an extensive use of herbicides (Foster et al. 2011; El Kateb et al., 2013; Huang et al., 2014). The integration of livestock into oil palm plantations could reduce the use of herbicides by 80 % (Chen & Dahlan, 1996).

Maintenance of undergrowth coverage benefits oil palm cultivation

Our study suggests that cattle grazing can manage understory vegetation coverage in oil palm plantations better than those without cattle and relying on herbicide application. Undergrowth maintains soil moisture, recycles soil nutrients, mitigates soil erosion, and provides habitat for farmland biodiversity (Azhar et al., 2013; El Kateb et al., 2013; Huang et al., 2014; Bergholm et al., 2015). Without vegetation cover, bare soils experience depletion of the soil food web, reducing bacterial and fungal-mediated decomposition (Allen et al., 2015), in addition to reducing macroinvertebrate abundance and diversity (Giller, 1996). Undergrowth coverage is extensive, particularly at higher altitudes and steeper slopes as access to the plantations by either cattle or for manual herbicide application is limited. Furthermore, cattle grazing on gentle topography and relatively homogeneous vegetation occurs more frequently than cattle grazing pastures with more rugged topography and more heterogeneous vegetation (Bailey et al., 2015). Cattle graze mostly in the valleys with higher forage quality and quantity (Bailey, 2005). They are less likely to climb hills and graze along the way because of physical limitations. This spares perfectly good forage on hillsides from grazing.

Both plantations integrated with and without cattle are similar with respect to understory vegetation height. Properly managed, overgrazing in oil palm plantations can be avoided by deploying semi-free range cattle, using a rotational grazing system. Increased light penetration because of shrub suppression by cattle trampling, supported by increased fertility from cattle faeces and urine deposition, can facilitate recovery of undergrowth (Pittarello et al., 2016). Ruminants such as cattle, provide manure for the maintenance and improvement of soil fertility (Devendra & Thomas, 2002). As manure is rich with organic materials, if applied in large amounts, it can improve soil texture, promote better absorption of moisture, minimize run-off and deter crusting of the soil surface (Devendra & Thomas, 2002). Surprisingly, circular spraying of herbicides reduced undergrowth coverage, but not undergrowth height and selective spraying of herbicides did not control undergrowth coverage or height. This indicates that both of these methods are inadequate in order to sufficiently control understory vegetation in oil palm plantations.

Stocking rate is critical in weed control in oil palm plantations. Cattle-oil palm integration operations should be carried out in the manner of rotational stocking to control unwanted weeds (Tohiran et al., 2017). However, continuous grazing system is prevalent in some plantations where livestock animals are left in the field without any control over where the animals go and how long they graze. This may cause shrub and herbaceous species, in mosaic distribution and consequently maintain biodiversity and increase productivity as long as overgrazing occurs at low level. Even though oil palm growers consider understory vegetation as a competing weed, this misconception of undergrowth should be revised due to its benefit to ecosystem services and functions. Biological control of weeds in oil palm plantations through cattle grazing is a management option that can balance the demand for agricultural products (e.g. vegetable oil and beef) with environmental protection. Similar to other silvopastoral systems, cattle grazing in oil palm production landscapes should be managed appropriately to prevent overgrazing that may deteriorate the environment.

Conclusions

Our findings show cattle grazing can be a sustainable agricultural practice, used to promote undergrowth coverage and suppress unwanted vertical growth of weeds. This practice can maintain soil moisture and mitigate soil erosion, important for improved crop productivity (Sánchez-Moreno et al., 2015). In addition, livestock integration with oil palm cultivation has positive benefits in terms of environmental protection by reducing the use of chemical herbicides, as well as improving food security, by optimizing agricultural land for beef and vegetable oil production. Cattle-oil palm integration may likely result in lower production costs and increase profits (Latif & Mamat, 2002; Tohiran et al., 2017).

Livestock grazing in oil palm plantations fits well under principles and criteria of sustainable palm oil certifications (e.g. Roundtable on Sustainable Palm Oil and Malaysian Sustainable Palm Oil) because it is a non-chemical strategy for controlling weeds. We recommend oil palm stakeholders, including commercial growers and certification bodies consider livestock grazing within existing oil palm production landscapes. To promote cattle-oil palm integration in producing countries, specific policies are needed to strengthen financial and technical support, in order for farmers to integrate cattle successfully. Further research should be conducted to determine the appropriate cattle density for oil palm plantations under different oil palm management systems (i.e. large-scale plantation or smallholding).

Acknowledgements

We thank all plantation managers who granted us access to collect data in the field. We are also grateful to the Director General of the Malaysian Palm Oil Board (MPOB) and the Director of Integration Research and Extension Division of MPOB. This research project was funded by MPOB and KAT is financially supported by MPOB's scholarship.

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Table 1. Summary statistics of response and explanatory (e.g. habitat quality/livestock management) variables.

Variable	Mean ± SD	Min	Max
Response			
Undergrowth coverage (%)	69± 30	0	100
Undergrowth height (cm)	13 ± 9	0	51
Explanatory			
Oil palm height (m)	8 ± 3	1.5	14
Canopy cover (%)	63 ± 17	10	100
Oil palm age (year)	19 ± 7	6	32
Number of cattle	452 ± 554	0	2500
Planted area (ha)	1763 ± 975	135	3924
Circle spraying	3 ± 1	1	4
Selective spraying	2 ± 1	0	3
Altitude (m)	58 ± 28	7	114

Figure 1. Map of study areas encompassing 45 oil palm plantations located in the central (a) and southern (b) regions of Peninsular Malaysia.

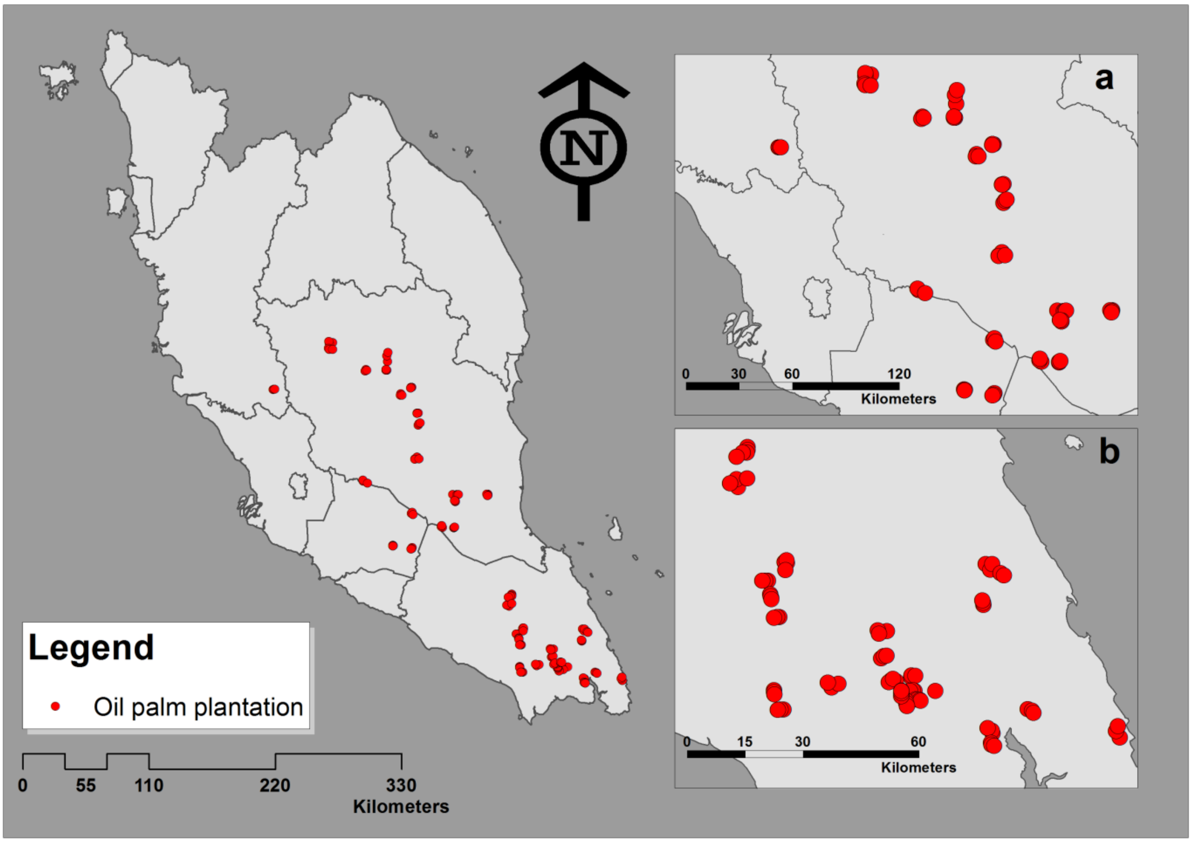
Legend
Oil palm plantation
0
55
110
220
330
Kilometers
N
a
0
30
60
120
Kilometers
b
0
15
30
60
Kilometers

Figure 2. Scatterplots with 95% confidence intervals (dashed) on the regression (solid) line showing the relationships between the undergrowth coverage and habitat quality/livestock management characteristics (a-e).

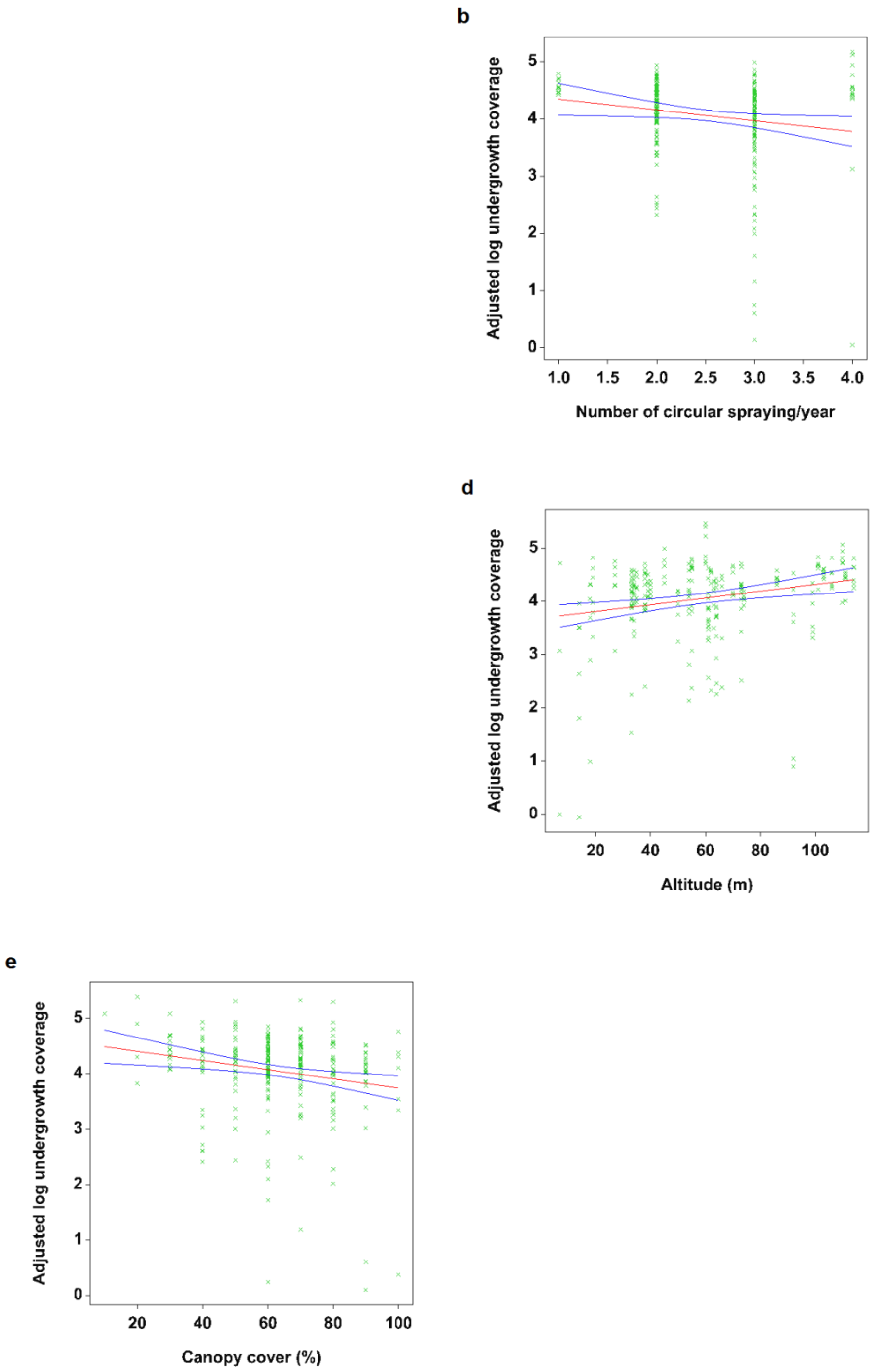

Figure 3. Scatterplots with 95% confidence intervals (dashed) on the regression (solid) line showing the relationships between the height of undergrowth and habitat quality/livestock management characteristics (a-e).

Figure 4. Condition of oil palm undergrowth; before (a) and after (b) cattle grazing took place for one whole day.


a
b