SHORT COMMUNICATION

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ASSESSMENT OF SUBTERRANEAN TERMITE, *Coptotermes curvignathus* (ISOPTERA: RHINOTERMITIDAE) INFESTATION SEVERITY INDEX (TISI) AND WATER TABLE ON A PEAT OIL PALM PLANTATION IN SARAWAK

MOHAMAD ROSMAN SULAIMAN[1]*; SAHARUL ABILLAH MOHAMAD[1]; MOHAMAD IZZUDDIN ANUAR[1]; SITI NURULHIDAYAH AHMAD[1] and MOHAMED MAZMIRA MOHD MASRI[1]

ABSTRACT

Growing palm in peatlands triggers the growth in the population of insect pests, and one of them is Coptotermes curvignathus*, a significant insect pest of oil palm in peatlands. Damage caused by this species can be seen in oil palm as early as 12 months after planting. The initial census is one of the methods to identify the attacks, but the index status guide for each attack by the pest needs to be fully developed. Thus, this study investigates an index of attack by* C. curvignathus *and the water table at an oil palm plantation in Sri Aman, Sarawak. The Termite Infestation Severity Index (TISI) with water table was assessed based on four parameters recorded during data collection and ground census in the field. Based on the visual symptom guide, a scale from 0 to 9 was used to rate the severity of the termite infestation in which a higher scale denotes a more progressive infestation stage than the lower scales. The study area was arranged into several task plots. Statistical analysis results revealed a significantly higher (P<0.05) average percentage of infection rates percentage from task 12 at (58.62 ± 1.99%) compared to other plots. The infestation average ranged from 7.92 ± 3.58% to 58.62 ± 1.99%. Meanwhile, on the water table level, the reading varied between 41.00 cm (task 17) and 67.50 cm (task 10) in the same area. A moderately negative correlation was found between the TISI and water table from two census sessions, notably during the first and fourth census (r = -0.432 and -0.566, respectively). Overall, correlation analysis for the entire census demonstrated a moderately inverse link (r = -0.326) between the TISI and water table. This study revealed a possible inverse relationship between TISI and water table that influences the severity of termite infestation in the field. Future studies may include additional data such as population density, precipitation and deadwood/log or stump presence in the area.*

Keywords: *Coptotermes curvignathus*, oil palm, peat, termite infestation severity index, water table.

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INTRODUCTION

Oil palm is one of Malaysia's most important crops. The estimated export earnings for the crop in 2020 was RM108.02 billion (Parveez *et al*., 2021). The area planted with oil palm, including land owned by smallholders, has reached 5.87 million hectares (MPOB, 2020). Nearly 30% of the total oil palm-planted area in Malaysia is located in Sarawak, amounting to 1.58 million hectares (Parveez *et al*., 2021). Meanwhile, roughly 37.45% of the crops grown in the state are cultivated in peatlands (Wahid *et al.*, 2010). As with any economic crop,

[1] Malaysian Palm Oil Board,
6 Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.

* *Corresponding author e-mail: mohamad.rosman@mpob.gov.my*

the productivity of oil palms grown on peat soil can be affected by continuous pest infestation, with termites being among the most significant pests. The termite problem in oil palm plantations has been documented on mineral soils and subsequently became a significant issue in oil palm planted on peatlands (Cheng *et al*., 2008; Wood, 1968).

Termites attacking oil palm, *Elaies guineensis* Jacq., were first observed in Malaysia in 1927 and were attributed to the tree-killing termites, *Coptotermes curvignathus* (Isoptera: Rhinotermitidae) (Bunting *et al.,* 1927). *Schedorhinotermes longirostris, S. malaccensis, Globitermes globosus* and *G. suplphureus* were reported as additional oil palm pests in a later publication (Harris, 1969). Despite several termite species having been linked to the oil palm attack, *C. curvignathus* appears to be the most serious threat to oil palm (Khoo *et al*., 2001). Oil palm plantations constructed on logged-over peat swamp forests in Sumatra (Sudharto *et al*., 1991) and Sarawak (Lim and Silek, 2001) have also been attacked.

The improper removal of peat swamp forests, which leaves behind timber residues and rich undecomposed material, has contributed to the abundance of *C. curvignathus* in peat soil plantations (Bunting *et al*., 1927; Rasmussen *et al*., 1982; Veloo *et al*., 2015). Furthermore, Salick and Tho (1984) and Tho (1975) highlighted that the open environment and limited termite species variety present in plantations allow *C. curvignathus* to effectively access food resources in this ecosystem. However, Kirton *et al.* (1999) discovered that wood residues have no impact on termite attack in forest plantations grown on mineral soils.

Nevertheless, the forest conversion has forced termites to adapt and respond to the situation. As a result of food scarcity, newly planted crops, especially oil palm on the site, presented the termite colonies with abundant food sources (Hasnol *et al.,* 2009). Significant loss from severe infestations were reported, especially on the logged forest estate and oil palm plantations (Yii *et al*., 2016). The infestation in oil palm trees can be observed as early as 12 months after planting, and the damage caused may lead to the death of more than 5.3% of standing palms over one year (Basri *et al*., 2003; Zulkefli, 2007). Thus, proper control strategies must be developed to reduce the infestation and prevent the attack from spreading (Khoo *et al.*, 1991; 2001; Lim and Silek 2001; Sudharto *et al*., 1991; Zulkefli *et al*., 2000).

Different species of termites may inhabit various plantations (Khoo *et al.,* 2001), and their ecology and behaviour may also vary. For management techniques to be effective, termite species must be accurately identified and verified (Kirton, 2005). Control of the termite pest population in oil palm by utilising chemicals and biological approaches in the field has been well documented (Avidlyandi *et al*., 2021; Langewald *et al*., 2003; Sulaiman *et al*., 2017). Hence, prompt and effective management practices are vital for managing termite infestations. Early termite control approaches are either repellent or fast-acting termiticides, with the application mode based on infestation and palm age phases (Zulkefli, 2007). Meiling and Goh (2008) proposed that a high water table and good water management in the planting site on peat soil can decrease the damage by *C. curvignathus*. By raising the water table, the termite population is forced to move closer to the soil surface, where they are more exposed to chemical or biological termiticides (Masijan *et al*., 2011).

In oil palms planted on peat soil, apart from regulating the subterranean termite population, good water management is vital in preventing irreversible peat drying by maintaining sufficient moisture. It also prevents flooding and controls soil water quality, reducing the risk of fire, peat subsidence and greenhouse gas (GHG) emissions (Harun *et al*., 2011). In addition, Hasnol *et al*. (2010) suggested that water management in peat soils ensures superior palm growth and high-yield production.

Conducting an early ground survey to discover the presence and damage by termites in the field is essential. Chan *et al*. (2011) identified the symptoms and mechanism of termite attack based on the palm region, but the list of symptoms lacked appropriate controls. Meanwhile, Mardji (2000) devised a method for determining the extent of termite damage to trees. The researchers also develop a method for assessing the condition of palms based on termite assaults (Mardji, 2003). Later, refinement of this technique resulted in Fernandes and Ngatiman (2015) creation of the scorecard for termite infestation. The field census is typically followed by population management techniques such as insecticide application (Chen *at al*., 2015; Huang *et al*., 2006; Lim and Silek, 2001; Manzoor *et al*., 2014; Saljoqi *et al*., 2014; Wang *et al*., 2014; Zulkefli *et al*., 2012).

Given the limited information on the ground census and its relation to the water table, it is essential to develop a termite infestation severity index (TISI) to aid planters in designing effective and practical pest control strategies in the field. For efficient pest management methods, termite treatment and extermination procedures require a severity status per location. Consequently, this study introduces TISI, a tool that can quantify the intensity of termite infestation in oil palms planted on peat and aid in developing field-based pest control methods.

MATERIALS AND METHODS

Study Site

The study site is located in Ladang Tabaruk Abadi, Sri Aman (1°14′8.73″N and 111°21′21.72″E) (*Figure 1*) that covered 6 ha of oil palm planting areas consisting of 10 year old oil palm.

The area was planted with *Dura* x *Pisifera* (DxP) planting material. The average standing palm per hectare (SPH) is 160 palm/ha. The soil type is deep peat soil, whereby non-decomposed wood is still available in the area. The study area was arranged into several task plots to facilitate termite attack symptom monitoring on each palm. Each task plot comprised four rows of planting palms separated by one collection drain. A total of 17 task plots were selected for data collection. The annual rainfall in the study area ranges between 1000 and 2000 mm without any distinct seasonal pattern. The site was reported to be solely infested by termites. The presence of other pests and diseases was not reported in the area.

Data Collection

A ground census of termite infestation was conducted in each task plot. Blanket census methods were performed on each palm to assess the damage by termites. The damage to oil palm caused by termites was arranged into TISI as depicted in *Table 1*. Meanwhile, the water table measurement reading was collected from a piezometer installed in every task plot. The study area was arranged and numbered into 17 task plots (*Figure 2*). Overall, a total of 986 palms were censused on the study plots.

Based on preliminary census and observation, the termite infestation pattern was concentrated at several spots and did not usually spread out over large areas. Therefore, the observation and census for developing the TISI in this study were performed according to the task plot arrangement. Furthermore, such arrangements are more practical and easier for future replication of the estate than sampling points or transects. The censuses were conducted based on visual symptoms on individual palms. By using a task plot, more palms can be covered as one task consisted of four rows of palm stands.

Census Incidence

The ground census was conducted based on visual observation of existing symptoms on the oil palm in the field. The index was adopted and modified from the existing *Ganoderma* Disease Severity Index (GDSI) (Idris *et al*., 2016). Meanwhile, the palm was scored based on the TISI developed on a scale of 1 to 9. After inspection,

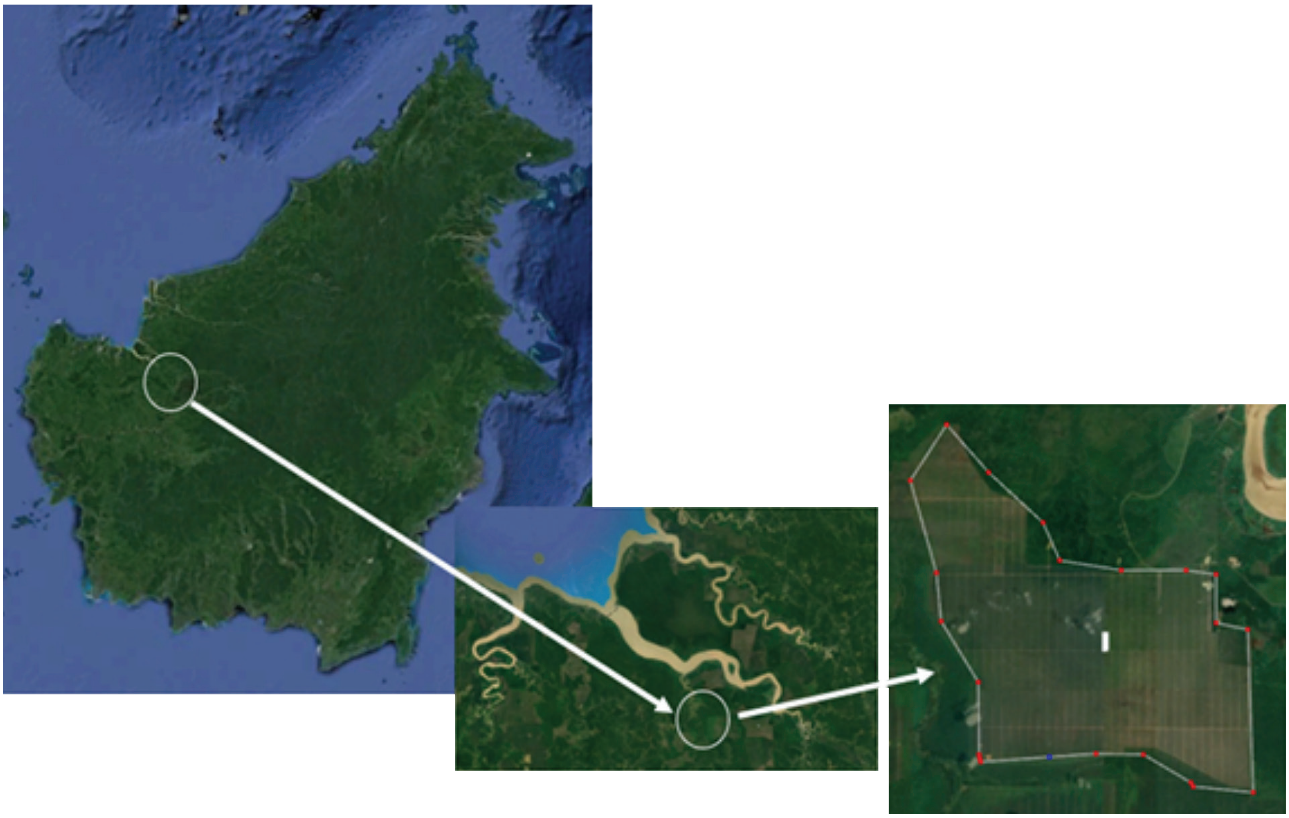


Figure 1. The study site in Ladang Tabaruk Abadi, Sri Aman, Sarawak (1°14′8.73″N and 111°21′21.72″E).

the individual oil palm was then categorised into one of the TISI. The list of the index is presented in *Table 1*.

$$\text{Termite infestation Severity index \%} = \frac{n_x}{n_t} \times 100 \quad (1)$$

where n_x is the total number of palms with TISI 1,2,3,4,5,7 and N_t is the total number of palms per task.

The visual inspection of individual oil palms in the field for TISI was conducted based on visible symptoms shown in *Figure 3(a-j).* The red circle indicates where observations for TISI were made for discoloration and the presence of mud-work while the black circle shows vacant spots mentioned in the index that were due to attack by either termites and, or unknown causes.

RESULTS AND DISCUSSION

Ground Census

Four ground census maps were prepared as shown in *Figure 4* (*a-d*). In this study, the derivation of the infested palms was according to the TISI (1, 2, 3, 4, 5 and 7), which was translated into percentage of termite infestation. The indexes were selected as they indicate the presence of termite damage. The damage pattern confirmed

TABLE 1. CLASSIFICATION OF THE GROUND FIELD CENSUS OF TERMITE INFESTATION IN OIL PALM

Index	Category	Descriptions
0	Healthy	Foliar is healthy, still green and no existence of fresh mud-work on the palm trunk due to termite infestation
1	Early	Foliar is healthy, still green and the existence of fresh mud-work on the palm trunk due to termite infestation
2	Moderate	Presence of foliar symptom <30%, foliar turn yellowish-brown of the lower fronds, the existence of mud-work on the palm trunk due to termite infestation
3	Severe	Presence of foliar symptom >30%, foliar turn yellowish-brown of the lower fronds, the existence of mud-work on the palm trunk due to termite infestation
4	DPST	Dead palm standing due to termite infestation
5	CT	Collapse due to termite infestation
6	CU	Collapse due to unknown
7	VT	Vacant due to termite infestation
8	VU	Vacant due to unknown
9	U	Presence of foliar symptoms but not due to termite infestation

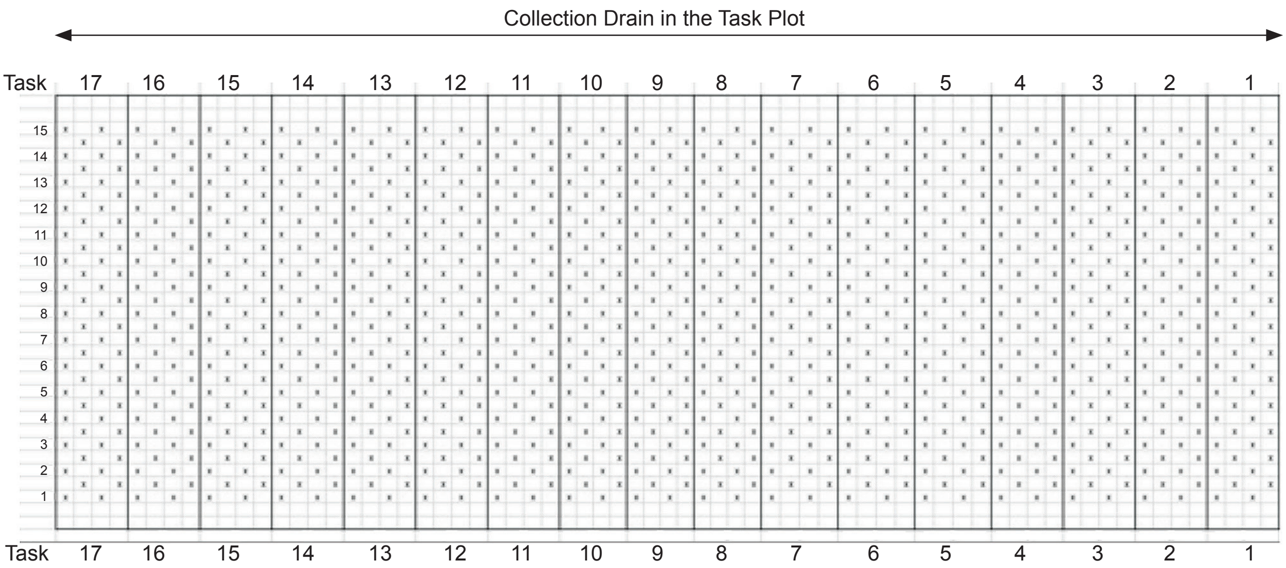


Figure 2. Arrangement of task plots in study site. The 'x' symbols represent the palm in the task plot and the collection drain is represented by the straight arrow line.

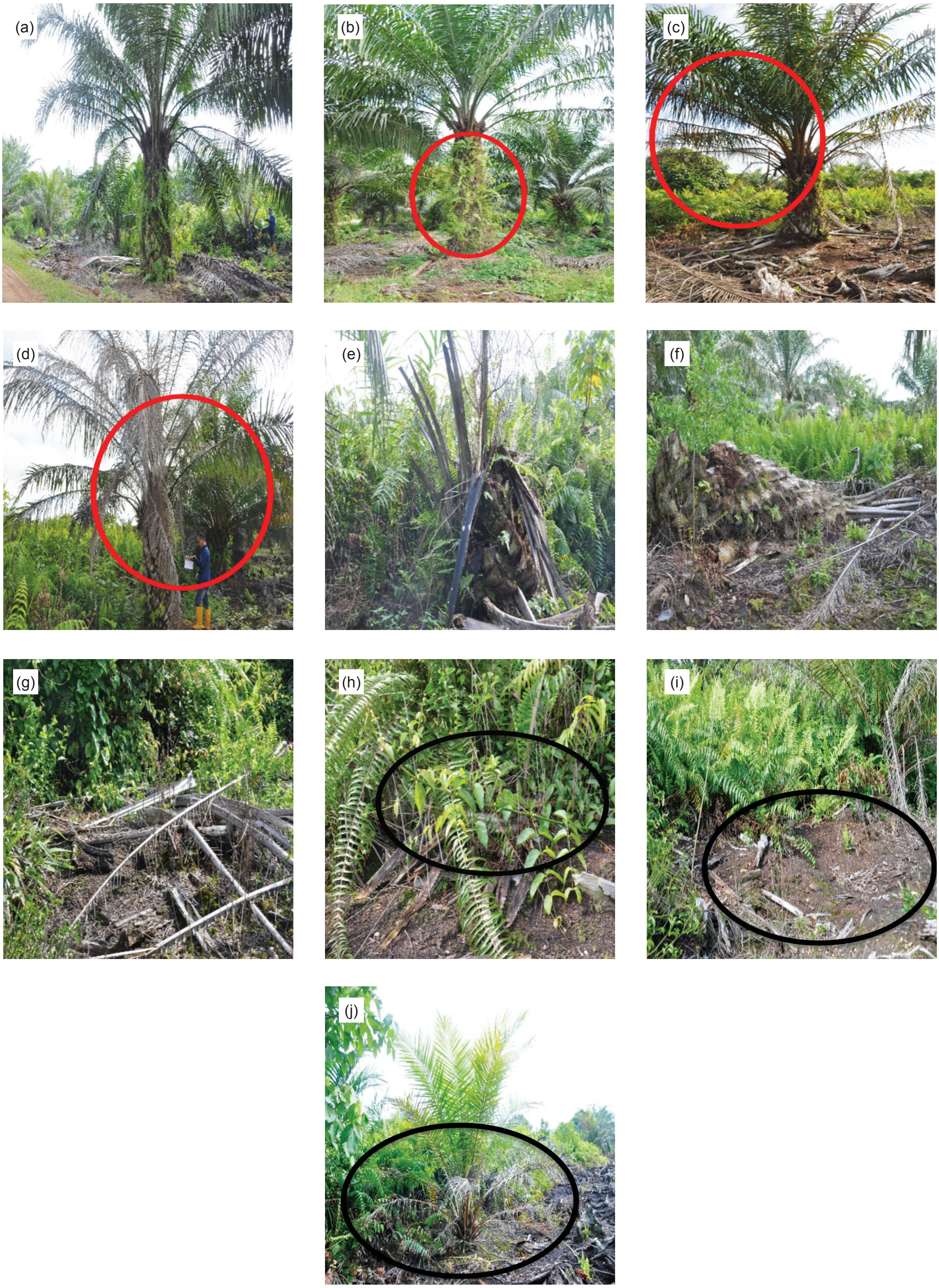


Figure 3. Visual description of Termite Infestation Severity Index for (a) healthy-0, (b) early-1, (c) moderate -2, (d) severe-3, (e) standing dead palm due to termite infestation-4, (f) collapsed palm due to termite infestation-5, (g) collapsed palm due to unknown reasons-6, (h) vacant spot due to termite infestation-7, (i) vacant spot due to unknown reasons-8, and (j) unknown cause effecting palm-9.

the preliminary observation that the pattern of the termite infestation in the study area is concentrated on specific spots, as the occurrences of termite colonies/damages at some tasks are minimal.

As illustrated in the first round of the map census (*Figure 4a*), 698 healthy palms were recorded as healthy out of the possible 986 palms. Fresh and old termite infestation was observed on a total of 197 palms within the 6 ha study area, which translates into 3.3% infestation rate per hectare. In the first month of the census, four task plots were found to be free of termite infestation. In the second round of the census, the number of healthy palms was reduced by 10, as the infested palms increased by 204. During the third and fourth rounds of the census, the healthy palms kept declining to 668 and 645 palms, and the infestation trend escalated to 238 and 263 palms, respectively. Moreover, the trend of increasing infestation over time was observed from the first round until the last round of the census. The scenario was due to the incremental new infestation index of 1, 3, 4 and 5 recorded, especially during the third and fourth rounds. However, no data on the infestation of the termites were recorded on the study task plot 6.

Termite Infestation and Water Table

The census was conducted on each palm within the study site. The termite infestation was determined through the infestation severity index suggested by Sulaiman *et al.* (2017). Each collapsed palm was examined to confirm the termite's presence inside the trunk. The primary criterion used in detecting termite presence was the appearance of the mud-work. The mud-work was easily visible on most of the mature palms. Overall, the water table measurement computes the distance from the soil surface to the subsoil water bodies. A low reading indicates a shorter distance from the soil surface to subsoil water and vice versa. *Figure 5* depicts the concept of water table measurements used in this study.

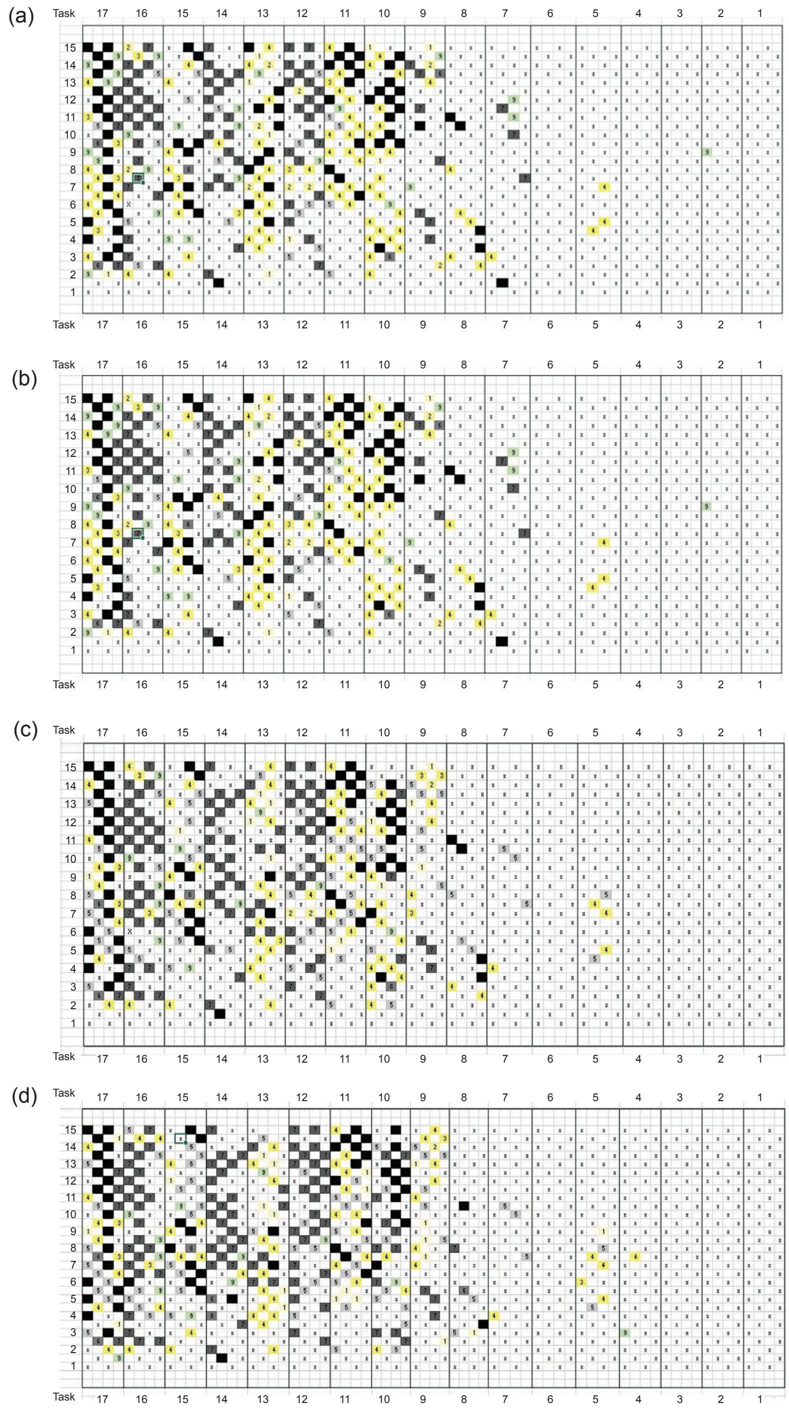
The infestation rate was observed to be lower in task plots 5 and 7. Based on the census conducted, the mean infestation rate was 7.92% to 8.19%, respectively. A high mean rate of infestations throughout each census was observed on the subsequent tasks, ranging from 25.00% to 58.62% (task plot 9 onwards). Notably, no infestation was detected in task plots no. 1, 2, 3, 4, and 6. One of the possible factors is due to the high-water table reading (deep) as compared to the low prevalence of infestation (task 5 = 46.75 cm, task 7 = 56.75 cm). This probably led to a reduced termite foraging activity in these task plots. In addition, rotten logged stumps might also influence the rate of infestation, especially in task plot 7, as seen during the ground census, although the water table reading is considered high. *Rhinotermitidae*, the family from which *C. curvigathus* hails, is known to be a wood feeder. So the presence of tree stumps, roots, dead logs, and branches may harbour termite colonies beneath the soil surface (Hidayat *et al.*, 2018). From the total tasks surveyed, task plots no. 12 ($\bar{x}$ = 58.62%) and no. 16 ($\bar{x}$ = 54.74%) consistently recorded a significantly higher rate of termite infestations compared to other task plots (*Figure 6a*). Both task plots have a water table measurement of less than 60 cm (*Figure 6b*).

On the other hand, water table reading fluctuated at each session; some task plots recorded minor changes between sessions of the four census, while others recorded heavy fluctuation, reflected by a relatively significant standard deviation. The water table in the study area ranged between 41.0-67.5 cm (*Figure 6b*). As explained earlier, a higher groundwater table valuer indicates a greater distance between the soil surface and underground soil water level and vice versa. The fluctuation in the groundwater table is influenced by environmental factors, such as rainfall, a good drainage network system, and water management within the estate.

In *Figure 7a*, there is a pattern in the level of termite infestation and the water table fluctuation across the overall period of the census. As shown in the graph, a pattern for best management or practice in plantations to manage their water table is to keep it, approximately at 50-70 cm (Hasnol *et al.*, 2010). This result reflects the possible connection between termite infestation and water table. For example, task plot 12 recorded the highest and lowest values in terms of infestation and water table, respectively. This is in contrast to task plot 10 with the highest water table readings but considerably low termite infestations. This trend was also observed in task plots 6 and 8.

In this study, termite infestation indexed from 1 to 5, and 7 required additional mitigation as they indicate the possible presence of an active termite colony/colonies. Depending on the severity index, immediate intervention may be necessary to suppress the outbreaks. *Figure 7b* illustrated the details of the number of infestations categorised into severity levels of 1 to 5 and 7 in the study task plots throughout the census period. Temporally, a trend of increasing infestation was evident in the studied area. Corresponding to TISI, all categories were interrelated as the affected palms will degrade over time if no immediate control is taken and possible changes occur in the TISI.

The study revealed a correlation between TISI and the water table data collected during all four rounds of census. Correlation analysis between the TISI and the groundwater table measurements (*Figure 8a, 8d*) revealed that only two of the four censuses presented a moderate negative correlation



Map Legend

Index	Category	Description
x	Healthy	Follar is healthy, still green and no existence of fresh mud-work on the palm trunk due to termite infestation
1	Early	Follar is healthy, still green and no existence of fresh mud-work on the palm trunk due to termite infestation
2	Moderate	Presence of foliar symptom <30%, foliar turn yellowish-brown of the lower frond, the existence of mud-work on the palm trunk due to termite infestation
3	Severe	Presence of foliar symptom >30%, foliar turn yellowish-brown of the lower frond, the existence of mud-work on the palm trunk due to termite infestation
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9	U	Presence of foliar symptom but not due to termite infestation

Figure 4. The Ground Census Map for (a) first census, (b) second census, (c) third census, and (d) fourth census.

between the measured variables, namely during the first and the fourth census (r = -0.432 and r = -0.566, respectively). The overall correlation analysis revealed a moderate inverse relationship between the two variables upon combining all the readings from the four census sessions (r = -0.326).

This work elucidates the development of TISI to facilitate subterranean termite field census. The ground census only focused on *C. curvignathus* species as it was the only species found at the study site. The practical technique functions as a constant ground inspection, allowing fast management of a specific termite-infested area. The description may be complicated, but it is a vital tool for those with necessary training and on-the-ground experience. In addition, we attempted to correlate the termite infestation with other variables in the present study, such as the water table. The assemblage structure of termites may varysignificantly among areas, even in the same ecosystem, depending on the degree of exposure to anthropogenic disturbance. The palm damage occurred primarily on peat soils and was caused by two *Coptotermes* spp., *C. sepangensis* and *C. travians*. Both species were only capable of forming localised infestations and small nests in mature palms, which did not result in the death of the oil palm. *Coptotermes curvignathus* was the only species of termite that could kill young or mature living oil palms, and the event was observed only in peat soils (Cheng *et al.*, 2008).

Moreover, the uniform availability of a susceptible host species appears to be the primary factor contributing to the high incidence of attack

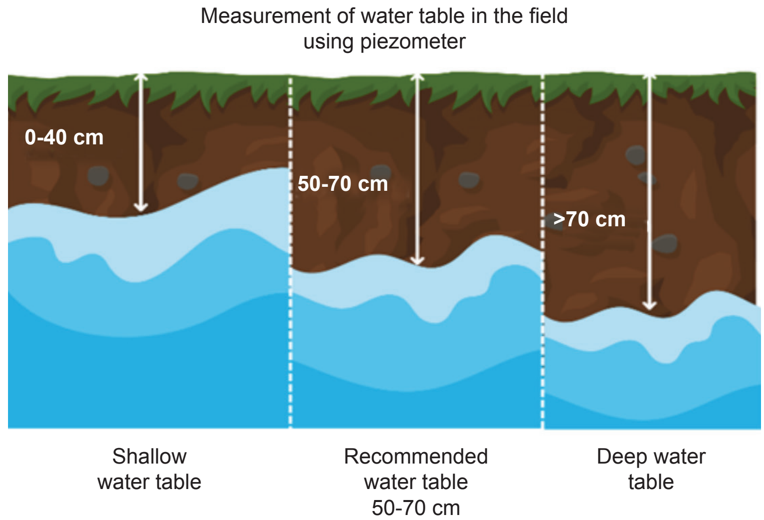

Figure 5. Interpretation of the water table at the study task plot.

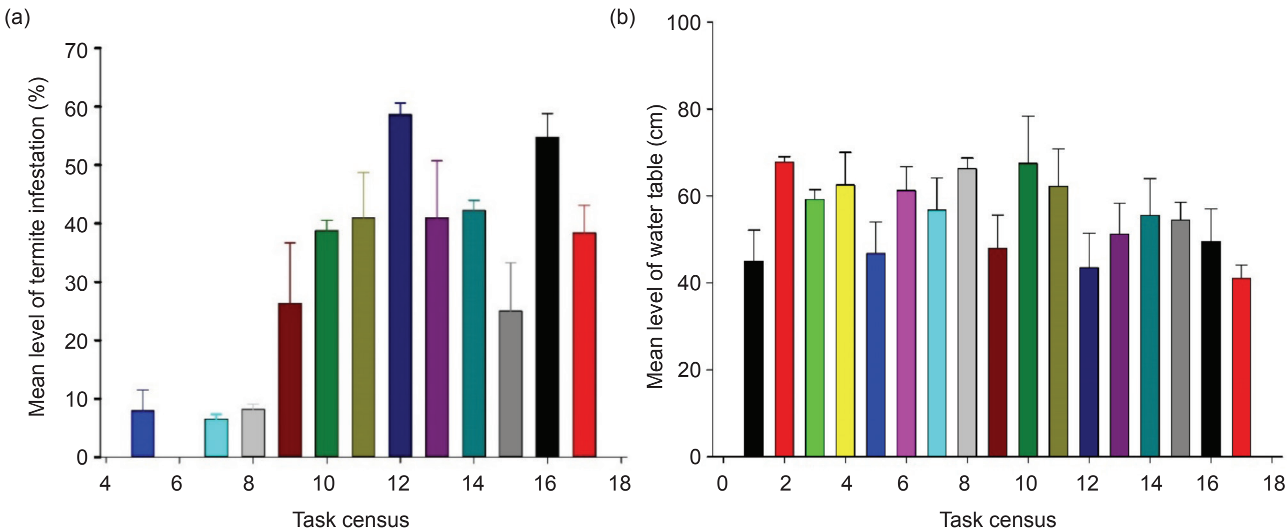

Figure 6. (a) The mean level of termite infestation at task plots. (b) The mean level of water table at the respective task plots.

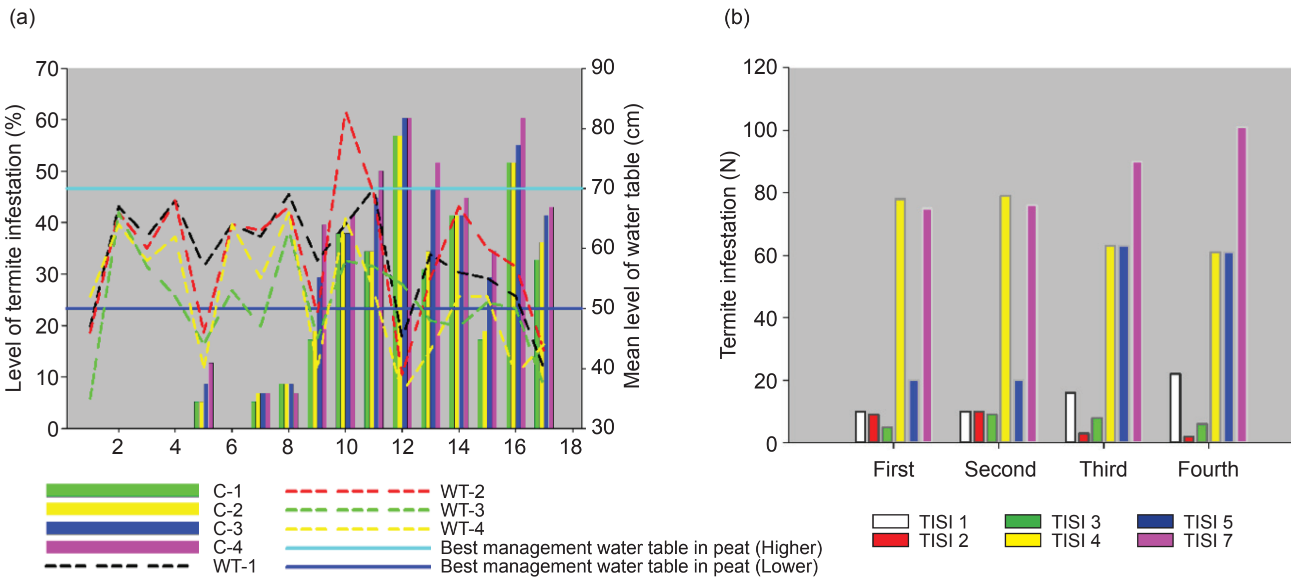

Figure 7. (a) Overlay of the termite level of infestation and water table at task plots, and (b) termite infestation number according to the TISI.

by this tree-killing termite species in oil palm cultivated on ex-peat swamps (Cheng *et al*., 2008). The current study demonstrated the relationship between the rate of termite infestation and water table measurements. As suggested by a previous study by (Zulkefli and Norman, 2011), a moderately inverse relationship between the variables was observed. The subterranean termite population can be controlled by reducing the ability of the termite colonies to thrive underground by raising the water table (Zulkefli and Norman, 2011). In oil palm plantations in peat, the water level can be regulated using the water gate (Hasnol *et al.*, 2011) and sandbags (Zulkefli and Norman, 2011). As a result, water level management can be a vital tool in controlling the population of subterranean termites, especially in peat soils.

A moderate inverse relationship between the infestation rate and the groundwater table measurements was also observed in the present study. As reported in previous studies (Zulkefli, 2007; Zulkefli and Norman, 2011), water table variations indirectly affect termite activity, particularly in deep peat. Water table variation is also among the basic approaches that encourage the termite colony to shift upward and thus, easier to control (Hasnol *et al*. 2010; Zulkefli *et al*. 2012). Following the earlier idea proposed by Zulkefli *et al*. (2012) and Hasnol *et al*. (2009), the population level of termites can be decreased by increasing the water table, which is by reducing the distance between the soil surface and underground water. In contrast, subterranean termite colonies thrive in areas with a higher water table. As a result, it is challenging to apply chemical treatments since the population is profoundly rooted in peat soil.

The field census indicates the pattern of the subterranean termite infestation in the studied area. The infestation was absent in the first few tasks before becoming more frequent in the subsequent tasks, reaching nearly 60% of infestation in the affected task plot. Subterranean termites are among the most abundant but cryptic animals, making behavioural studies very difficult. Consequently, little is known about their foraging behaviour or general activity patterns (Araujo, 1970; Eggleton *et al*., 1996; Emerson, 1955; Wood and Johnson, 1986). The real underlying factor behind this observation is thus challenging to single out. Nevertheless, based on the observation in the field, one of the possible factors influencing the termite infestation rate is the abundance of food sources in the area. Subterranean termites search for food in the soil by constructing underground tunnels. Once the food is discovered, it is transferred by individual termites moving within the existing tunnels that lead to multiple current food sources (Manzoor *et al*, 2013). Another possible factor that could play a role in termite foraging behaviour is temperature. Apart from seasonal fluctuations, daily fluctuations in temperature also influence termite activity. Termites do not live in soils characterised by an extremely hot or cold top layer, rather they move deeper into the soil (Puche and Su, 2001).

During the field observation, task plots 12 and 16 were spotted with accumulated improperly cleared logged stumps adjacent to the palms. It is hypothesised that the uncleared stumps still contained active meristem tissues rich in cellulose,

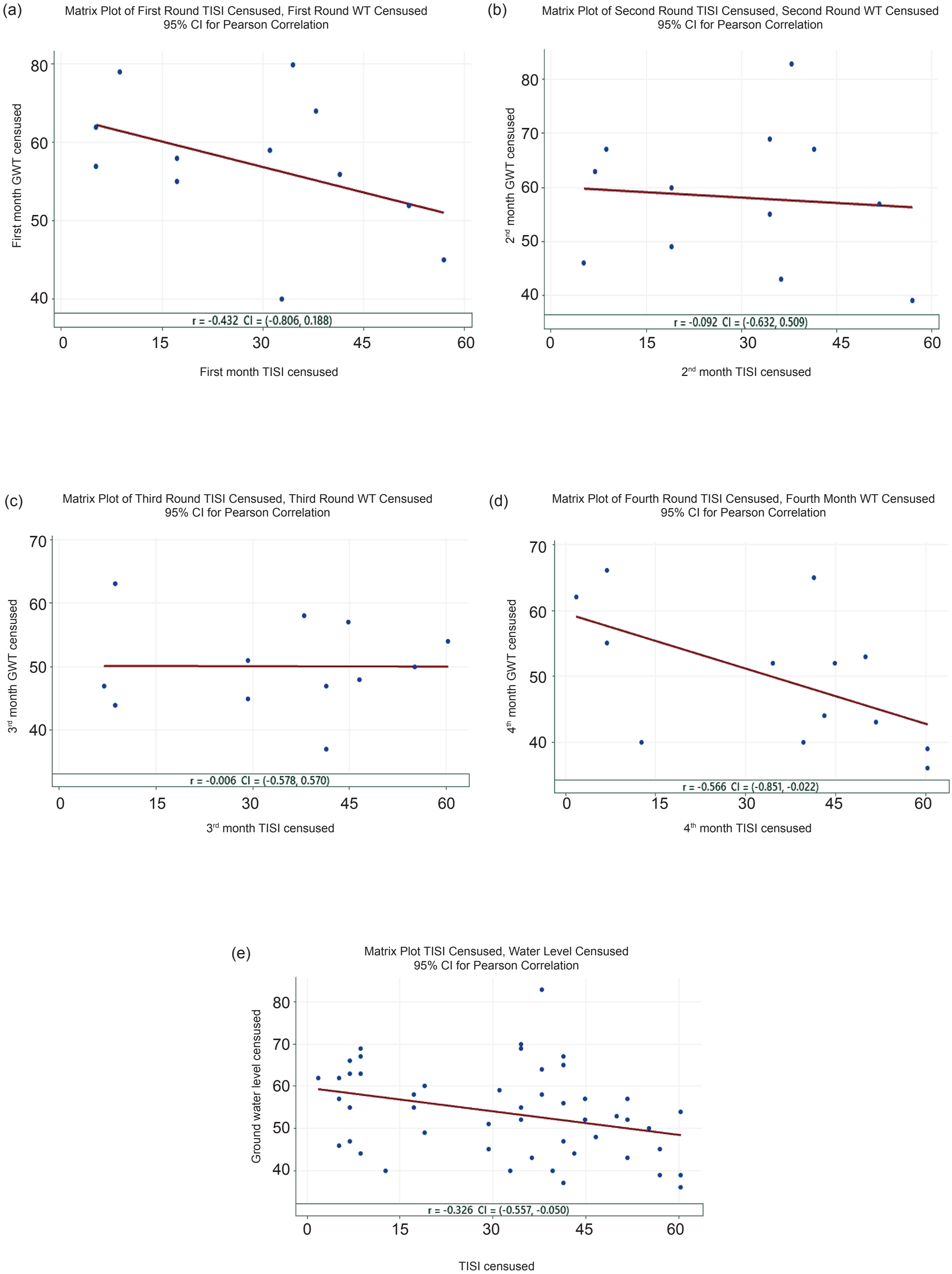

Figure 8. (a-e). Correlation between the Termite Infestation Severity Index (TISI) and Water table (WT).

which is essential to the termite diet as an energy source. Wood-feeding subterranean termites prefer to feed on cellulose matrix with additives (Rojas and Morales-Ramos, 2001). Subsequent studies by Munizaga and Araya (2018) and Suiter *et al.* (2009) detailed the source of cellulose and the subterranean termite feeding preferences in the field. As illustrated in the results section, the infestation has increased from one point of the census to the other. During the study, different task plots in the estate produced a different number of infestations over time. A palm might be indexed differently in separate census. Several palms were indexed with different severity throughout the study, indicating the dynamics of the visual symptoms exhibited as the palm continued to degrade due to the uncontrolled infestation. For example, TISI 1 increased as the number of palms infested increased. Climatic factors such as rainfall, which influence the water table may reduce the soil temperature and increase the peat's moisture content, thereby affecting the foraging pattern and activity of the subterranean termites. A study by Jin *et al.* (2020) reported an association between clay materials and moisture levels on habitat preference and survivorship of subterranean termites. Davies *et al.* (1997) stated that moisture stress of micro-environments, the structure of ground cover vegetation, and environmental factors (temperature, relative humidity, and precipitation) play an essential role in termite distribution in a tropical area. Supported by Sattar *et al*. (2013), environmental factors also impact the population dynamics, density, and foraging activities of termite communities in the respective areas, explaining the increase and decrease in our study site.

CONCLUSION

Frequent monitoring of pest presence is one of the cornerstones of the Integrated Pest Management (IPM) system. Regular termite census in the oil palm plantation environment is a time-consuming activity depending on the scale of the infestation area. Census errors are expensive and may expose the plantation to a higher incidence of termite infestation; thus, standardizing the infestation through the index is crucial. Therefore, with a practical and standardized TISI, the task can be less laborious, more efficient and more dependable. The overall correlation analysis for the entire census revealed a moderately inverse link, reflecting a possible inverse relationship between TISI and the water table that influences the severity of termite infestation in the field. In addition, future studies may focus on the occurrences of termite assemblages in different types of peat soils.

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