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ENVIRONMENTAL FACTORS AFFECTING THE POPULATION DENSITY OF *Oryctes rhinoceros* IN A ZERO-BURN OIL PALM REPLANT

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ABSTRACT

The environment (abiotic and biotic factors) influences the survival of an organism. This study revealed several significant relationships between the population of Oryctes rhinoceros *and the environment and physical characteristics of its habitat in an oil palm replant. Firstly, lower populations of* O. rhinoceros *occurred in areas with high cover crops over the decomposing chipped trunks. Secondly, high moisture content in the trunks was essential for the survival and satisfactory development of* O. rhinoceros. *Thirdly, there was a negative relationship between the number of developing pupae against the hardness of the trunk chips. This indicates that most of the pupae developed in the softer, decomposing chips. The larval population hastened the release of the trunk nutrients to the soil, especially K and Mg. Higher soil pH indirectly reduced the larval population of* O. rhinoceros, *possibly by promoting the growth of the entomopathogenic fungus,* Metarhizium, *which infected the larvae. This was reflected by the low number of adult beetles which emerged from the plots with high pH. Finally, rainfall induced the breeding of* O. rhinoceros *as shown by the high positive correlation between rainfall and the number of early instar larvae. Knowledge of some of these factors would enable planters to manipulate the habitat and its microclimate in order to manage the pest more effectively.*

Keywords: *Oryctes rhinoceros*, environment, cover crops, water content, *Metarhizium,* pest management.

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INTRODUCTION

The environment has a significant influence on the survival of an organism. Allee *et al*. (1949) stated that the environment comprises both abiotic (physical) and biotic factors. In general, ecologists have defined *biotic* as the living organisms and *abiotic* as the non-living factors (Smith, 1935; Nicholson, 1993).

Andrewartha and Birch (1954) defined the relationships between the four components – climate, food, pathogen and habitat – as the environment for an organism. For example, in the Brazilian *cerrado*, the insect populations fluctuated on a seasonal basis, primarily driven by the environmental factors such as rainfall, temperature and humidity. Coleoptera and other insects (Diptera, Homoptera, Hymenoptera, Lepidoptera, Orthoptera, and Psocoptera) were most abundant after rain (Diniz and Pinheiro, 2000). In a native forest, the abundance and species richness of carabid beetles were significantly affected by the pH of the soil, cover of herbs and density of their prey (Elek *et al*., 2000). In the Alps, a carabid species (genus *Nebria*) was documented as the first colonizer of new areas after glacial retreat. Comparative investigation of the distribution patterns showed that habitat selection was the major mechanism for the colonization by carabid beetles in new alpine areas.

In the oil palm ecosystem, the abundance of decomposing oil palm trunks by the zero-burning replanting technique is very attractive for *O. rhinoceros* breeding (Samsudin *et al*., 1993). Studies by Wood (1968) and Liew and Sulaiman (1993) had demonstrated that the population and attacks by *O. rhinoceros* were influenced by the cover crops, which acted as a physical barrier to the breeding sites, thereby reducing the *O. rhinoceros* breeding.

An earlier study in an oil palm replant had shown that the population of *O. rhinoceros* fluctuated

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with time, largely due to the biotic factors (Norman *et al*., 2001). Apart from the biotic factors such as disease and parasitism, the abiotic factors such as weather, soil, habitat and cultural practice can also be influential (Hinckley, 1973).

This study attempts to identify the abiotic factors such as the height of the cover crop, which could act as a physical barrier to the breeding sites; moisture content and hardness of trunk chips; soil pH, which possibly influence the development of the larval stages; and rainfall, which may influence the activity and breeding of the beetle. These factors are expected to affect either directly or indirectly to the population of *O. rhinoceros*.

Knowledge of these factors would enable planters to manipulate the habitat and microclimate of the breeding sites in order to manage the pest more effectively.

MATERIAL AND METHODS

Study Sites

A census for *O. rhinoceros* was conducted in three zero-burned replanting blocks (A, B and C) of an oil palm estate in Sepang, Selangor, Malaysia. The initiation of sampling corresponded with the availability of sites.

Block A. The area of this block was 21.6 ha. Replanting was carried out in October 1994. Three approximately 1 ha plots (Plots 1-3) were marked from the edge towards the centre of the block. Sampling was done on the heaps of oil palm trunk chips, with the first sampling at approximately one year after replanting.

Block B. This block was only 4.5 ha. Replanting was done in August 1996. The block was divided into three plots (Plots 1-3) of approximately 1.5 ha each. Sampling from the palm heaps was initiated at about four months after replanting.

Block C. This block was 18.5 ha. Replanting was done in December 1996. Sampling from the palm heaps was carried out at about three months after replanting. Similarly, three approximately 1 ha plots (Plots 1-3) were arranged from the edge towards the centre of the block.

Sampling Procedures

In each block, the *O. rhinoceros* population was sampled in replicates of approximately 1 ha plots (12 x 12 palms). Within these plots, all the *O. rhinoceros* population were collected from subplots of approximately 1 m square in the heaps. The heaps were lines stacked every three palm rows. The sampling was done systematically in the heaps, adjacent to the third, sixth, ninth and 12th palms of each row. The frequency of sampling was every three months and only stopped when the mean population for the subplots within a block was less than one.

A range of 27-36 samples (at 9-12 samples per plot) were gathered per block from each sampling. During the sampling, the various abiotic parameters which have an influence on the breeding of *O. rhinoceros* were recorded, as follows: The height of the leguminous cover crop (mixtures of *Centrosema pubescens* and *Pueraria javanica*) above the decomposing trunk chips was measured using a 1 m rule. This was the physical barrier hindering the pest in its search for breeding sites.

The hardness of the trunk chips referred to their physical state in their decomposition over time. It was likely to be difficult for the *O. rhinoceros* larvae to develop in the harder tissues. The hardness was measured using a device developed specifically for this study (*Figures 1* and *2*), based on the force (F) needed to push a pointed metal rod (1 cm diameter) 3 cm into the chip. This device used a spring which compression had been calibrated with F in a linear relationship (*Figure 3*). F was therefore proportional to the hardness of the chip.

Rainfall data was taken from the weather station of the estate. Moisture in the habitat had favoured the development of the pest in the laboratory (Norman *et al*., 2001). Therefore, the moisture content of the trunk chips was estimated using a shigometer (Osmose Wood Preserving Company of America, 1980) based on the inverse relationship between electrical resistance (kOhm) and water content. The shigometer was first calibrated by taking the resistances of trunk chips with different moisture contents (*Figure 4*), and then determining their moisture contents by absolute drying in the oven (105^{o}C, for 48 hr).

The shigometer readings were regressed linearly on the moisture content. Based on the regression, the moisture contents of trunk chips could be obtained from the electrical resistance of the shigometer.

The soil pH should indicate the suitability of the habitat for development of the larvae. The mineral content of the soil should also indicate the ability of the larval stages to digest the trunk tissues and return the minerals to the soil. For this purpose, the soil was sampled under the trunk heaps for the determination of nitrogen, phosphorus, potassium, magnesium and calcium, using the analytical methods of Schinner *et al*. (1996). The *O. rhinoceros* adults collected from pheromone traps were ground into fine powder with a fruit blender machine. The powder is then analysed similarly as the soil samples for the mineral content.

The prevalence of *Metarhizium* was based on the number of colony forming units (CFU) found in the soil by the sampling technique of Ramle *et al*. (1999).

Figure 1. A device for measuring the relative hardness of decomposing oil palm trunk chips.

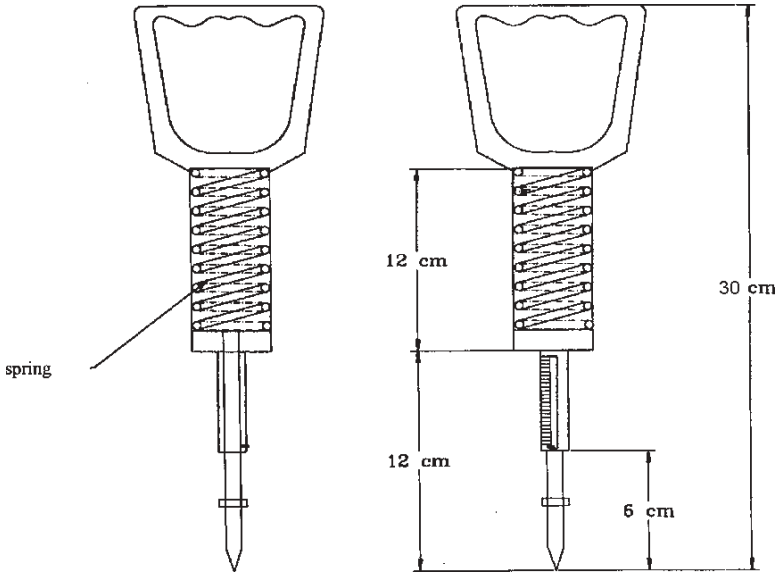

Figure 2. Side view of the wood hardness measuring device.

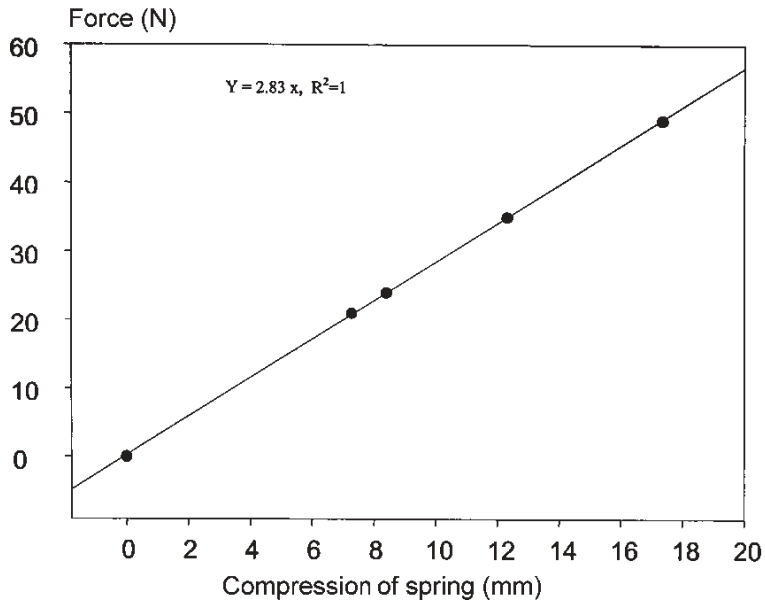

Figure 3. Linear regression to derive the force for measuring trunk chip hardness.

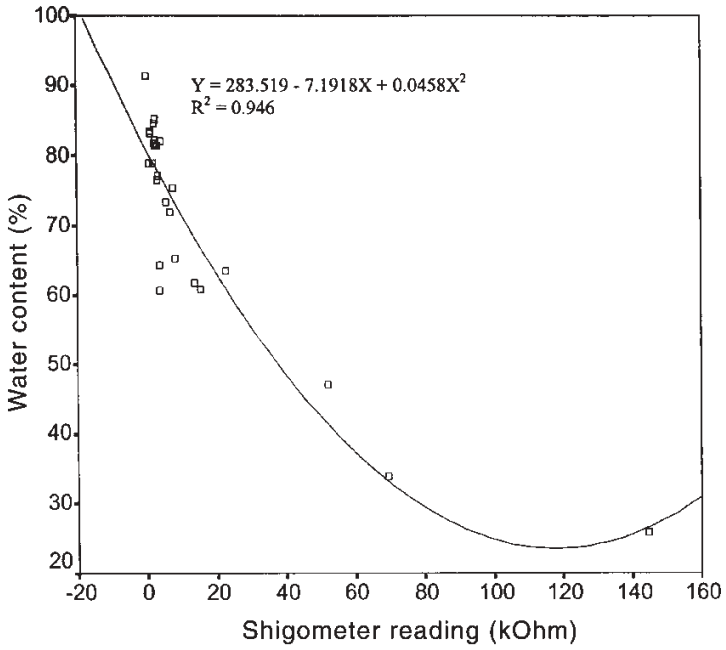

Figure 4. Calibration of water content in trunk chips and shigometer reading.

About 100 g of the top soil underneath the trunk chips were sampled and placed in individual plastic vials. The soil was then pounded into dust. One gramme was placed in a screw capped universal bottle with 10 ml sterilized distilled water added and later vortexed for 1 min at 8 revolutions per second. The soil aliquot was diluted 10 times with sterilized distilled water. Three hundred microlitres of the aliquot was then streaked onto 90 mm selective medium (modified from Mohan *et al*., 1982) plates using a sterilized L-shaped glass rod. The plates were then incubated at 28°C. The density of viable spores was estimated in numbers of CFU at seven to 10 days after incubation (Ramle *et al*., 1999).

Data Analysis

There were two groups of independent variables. The first group consisted of the physical characteristics of the *O. rhinoceros* habitat - cover crop height, wood hardness and moisture content. The second group was the environmental parameters - rainfall, soil nutrients, soil pH and the prevalence of *Metarhizium*. Multiple regression analysis was performed with the two groups of parameters on five dependent variables - the populations of the first and second instars, juveniles (first to third instars), pupae, adults and total individuals (of all stages). The non-significant independent variables for each dependent variable were removed by the backward elimination procedure (SigmaStat, 1992), leaving only the most significant variables to fit the linear regression.

RESULTS

Relationship between the Physical Characteristics of the Habitat and *O. rhinoceros* Population

This was only analysed for Blocks B and C. The data for Block A could not be gathered during the early stages of replanting and therefore such incomplete data would not be able to portray the overall trends. The data for all the plots in a block were combined for an overall analysis. Subsequently, the data for Blocks B and C were combined to get overall regressions. With multiple regressions, both the cover crop height and trunk chip moisture content were found equally important in affecting the number of adults and total individuals of *O. rhinoceros* (*Table 1*). The cover crop height had a negative correlation with the total population of *O. rhinoceros* ($df = 2$, $F = 4.87$, $p<0.05$), pupae ($df = 1$, $F = 7.78$, $p<0.01$) (*Figure 5*) and adults ($df = 2$, $F = 8.59$, $p<0.01$).

However, the moisture content of the trunk chips had a positive influence on the adults ($df = 2$, $F = 9.36$, $p<0.01$) and total population ($df = 2$, $F = 5.86$, $p<0.05$) (*Table 1*). With multiple regression analysis, the hardness of the chips had no significant effects on the overall density of *O. rhinoceros*. However, a negative correlation was detected between the hardness of the chips with the pupae density ($df = 4$, $R^2 = 0.523$) (*Figure 6*).

TABLE 1. RELATIONSHIPS BETWEEN THE POPULATIONS OF *Oryctes rhinoceros* AND THE PHYSICAL CHARACTERISTICS OF THE TRUNK / HABITAT

Dependent variable	Independent variable	Regression coefficient	F	Significance (prob>F)	R^2
Pupae	Cover crop height	-0.0041	7.78	0.006	0.046
Adults	Moisture content of chips	0.0041	9.36	0.003	0.08
	Cover crop height	-0.01	8.59	0.004	-
Total individuals	Moisture content of chips	0.012	5.86	0.017	0.049
	Cover crop height	-0.0278	4.87	0.029	-

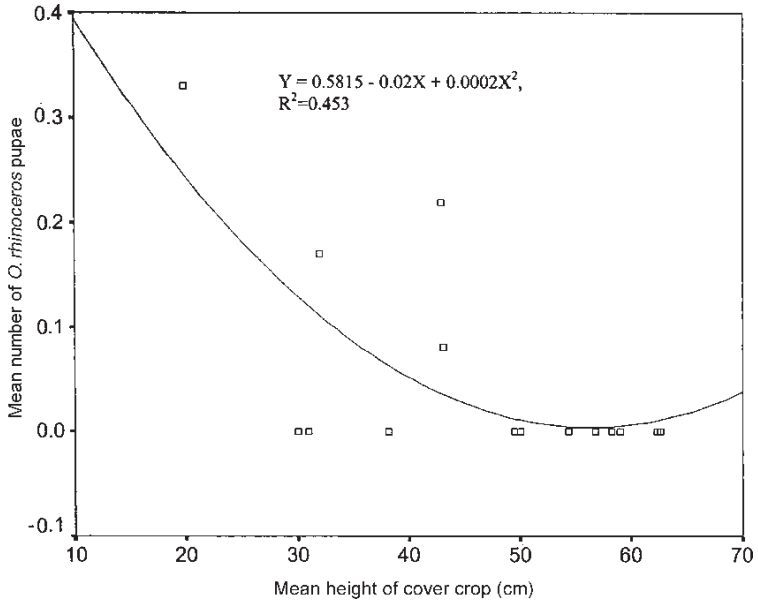

Figure 5. Relationship between cover crop height and Oryctes rhinoceros *pupae population.*

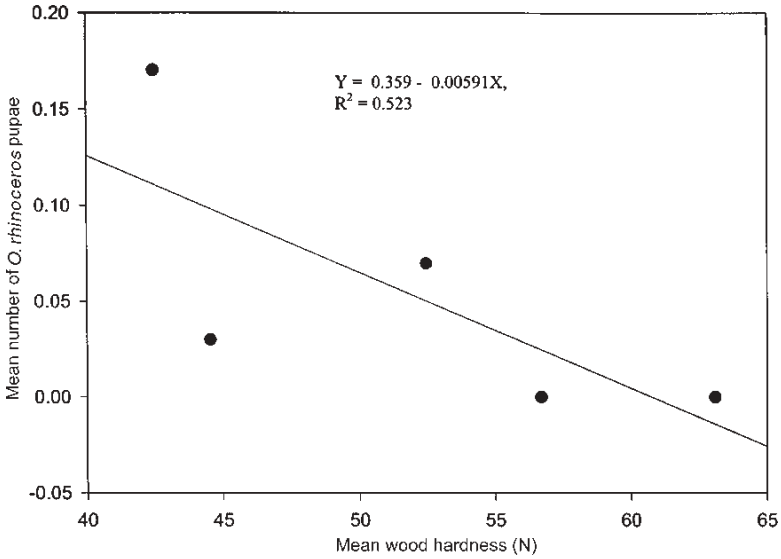

Figure 6. Relationship between trunk chip hardness and Oryctes rhinoceros *pupae populations.*

Relationship between the Soil, *Metarhizium* Colonies and Environmental Parameters and the *O. rhinoceros* population.

Only the soil K and pH had significant relationships ($p<0.05$) with the *O. rhinoceros* population (*Table 2*). Soil pH, which indicates the suitability of the breeding environment around the decomposing trunk chips, had an indirect effect on the juveniles (*Table 2*), thereby affecting the population of the pest. *Table 3* shows that there were no significant differences in densities of *O. rhinoceros* occurred in soil pH less than 4.2 (acidic) compared to those areas which were less acidic (higher than 4.2). However, it was noted that the maximum number of *O. rhinoceros* was much higher in the lower soil pH (*Table 3*).

The soil nutrients (N, P, Ca, Mg and C) had no direct relationship with the larval population. However, the density of larvae correlated positively with the soil K, suggesting a higher return of K to the soil by the chips with more larvae.

Table 4 shows comparison to the mean soil nutrient contents between the areas with and without *O. rhinoceros* larvae. The *O. rhinoceros* larvae contributed to more K and Mg in the soil, as shown by the higher concentrations of K and Mg in the soil under the trunk chips with *O. rhinoceros* larvae ($p<0.05$) than under those without them. The levels of N, C and P in the soil under the chips with *O. rhinoceros* larvae were similar to those without them (*Table 4*).

TABLE 2. RELATIONSHIPS BETWEEN THE POPULATIONS OF *Oryctes rhinoceros* WITH SOIL K AND pH

Dependent variable	Independent variable	Regression coefficient	F	Significance (prob>F)	R^2
Total individuals	K	0.195	6.80	0.010	0.051
	pH	-0.233	9.68	0.002	
Juveniles	K	0.191	6.53	0.011	0.051
	pH	-0.235	9.81	0.002	
Juveniles	K	0.173	5.31	0.022	0.046
(1st & 2nd instars)	pH	-0.228	9.21	0.003	
Pupae	K	0.079	6.44	0.012	0.029
Adults	K	0.025	4.02	0.046	0.019

TABLE 3. RELATIONSHIP BETWEEN SOIL pH AND *Oryctes rhinoceros* POPULATION

Soil pH	Sample size (n)	Mean *Oryctes* population (individuals m^{-2})	Maximum *Oryctes* population (individuals m^{-2})
< 4.2	108	4.20[a]	78
> 4.2	79	1.97[a]	17

Note: Values in the same columns with the same letters are not significantly different from each other from student's t-test ($p>0.05$).

TABLE 4. NUTRIENT CONTENT IN THE PALM TRUNK, SOILS UNDER THE TRUNK CHIPS WITH AND WITHOUT *Oryctes rhinoceros* POPULATION, THE ADULTS AND FAECAL PELLETS OF *Oryctes rhinoceros*

	Mean values (%)					
Nutrient	**N**	**P**	**K**	**Ca**	**Mg**	**C**
In oil palm trunks (Khalid *et al.*, 1999)	0.56	0.05	1.62	0.31	0.150	Na
Under chipped, shredded trunks without *Oryctes rhinoceros*	0.24[a]	0.007[a]	0.11[a]	0.06[a]	0.035[a]	2.69[a]
Under chipped, shredded trunks, with *Oryctes rhinoceros*	0.25[a]	0.007[a]	0.16[b]	0.07[a]	0.056[b]	3.20[a]
In adults of *Oryctes rhinoceros*	8.93	0.08	0.29	0.03	0.179	93.34
In faecal pellets of *Oryctes rhinoceros* (Norman *et al.*, 2001)	1.57	0.17	2.09	0.47	0.42	Na

Notes: Values in the same columns with the same letters (in second and third rows) are not significantly different from each other from student's t-test ($p>0.05$).
Na – data not available.

There was also a significant positive relationship between the mean rainfall over 14 days before sampling and the number of early larvae (first and second instars) (*Figure 7*).

The infection of *Metarhizium* was encountered only once during the course of this work, in March 1997. However, the infection in Blocks B and C was low, at 2.8% and 4.5% of the sampled larvae and 4.0% to 12.5% of the pupae, respectively (*Table 5*). The mean numbers of colonies of *Metarhizium* in the heaps were four and 10 CFU in Blocks B and C, respectively (*Table 5*). The mean number of *Metarhizium* colonies was negatively correlated with the mean adult beetle population in the trunk heaps (*Figure 8*).

DISCUSSION

One of the factors influencing the field population of rhinoceros beetle was the height of the cover crops. It plays a strong role in determining the population density of *O. rhinoceros* as shown by the number of pupae, adults and total individuals found in the trunk heaps under it. *O. rhinoceros* was only detected if the cover crop was less than 70 cm tall (*Figure 5*). This supports the earlier finding of Liew and Sulaiman (1993) that a cover crop of over 90 cm reduced the *O. rhinoceros* population. The cover crop apparently hinders the beetle in its search for breeding sites. The taller or denser cover crops posed a greater hindrance to the beetle, as suggested by

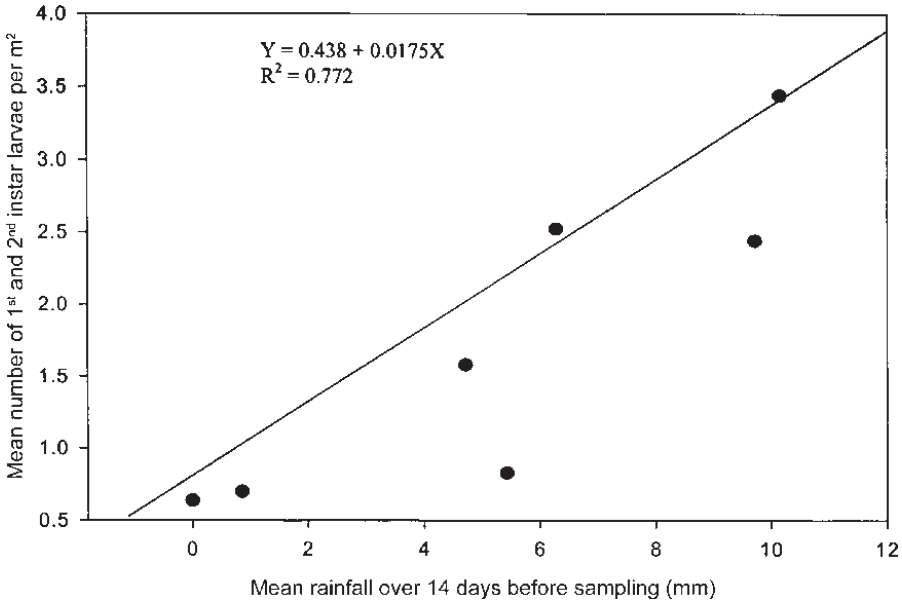

Figure 7. Relationship between mean rainfall over 14 days before sampling and population of early instar larvae of Oryctes rhinoceros.

TABLE 5. INFECTION RATES IN *Oryctes rhinoceros* BY THE NUMBER OF *Metarhizium* COLONIES IN THE SOIL

Location	Infection rate by *Metarhizium* (%)		Mean colonies of *Metarhizium* in the soil (CFU)
	Instar 3	Pupa	
Block B (March 1997)	2.83	4.00	3.64
Block C (March 1997)	4.55	12.50	9.87

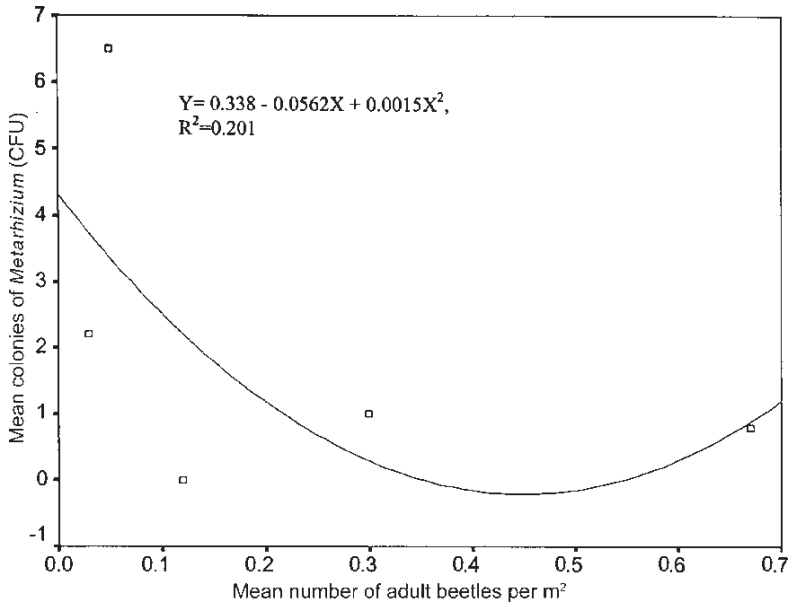

Figure 8. Relationship between the number of Metarhizium *colonies in the soil and the population of* Oryctes rhinoceros *adults.*

Wood (1968). However, this may not hold in areas with a high immigration pressure of *O. rhinoceros* (Chung, per. comm, 1997).

Apart from ground cover, the moisture content of the decomposing trunk tissue also played a role in determining population density of the pest, especially for the satisfactory development of the *O. rhinoceros* larvae in them. More larvae were found at higher levels of moisture content, even up to 80%-100%. Assuming that all the adults were new emergent, the relationship of moisture content with the number of adults suggests that the larvae needed a high moisture content to develop successfully into adults. An earlier laboratory study indicated that a moisture content of over 77% was needed for the satisfactory development of *O. rhinoceros* (Norman *et al*., 2001). This also supports an earlier observation by Catley (1969) that low moisture content was detrimental to the larvae. A dry microclimate and low nutritional conditions generally delayed the development of *O. rhinoceros* and resulted in smaller adults (Catley, 1969).

Pupation is likely to occur in the semi-decayed region of the trunk chips, as most of the pupae were only found in the softer areas. Hinckley (1973) had reported this phenomenon, where *O. rhinoceros* cannot breed in living plant tissues, nor can it develop well in substrates that are too hard or too decomposed. Breeding was reported only on partly decayed plant materials (Zelazny and Alfiler, 1991; Samsudin *et al*., 1993). However, these authors did not measure the hardness of their substrates which could be related to their state of decomposition. In this study, a device was specifically developed for measuring the hardness of the trunk chips.

There was a significant positive correlation between the larval density and soil K (*Table 2*). As the larvae were mostly found in softer tissues, the chips having more larvae tend to degrade more rapidly, thus releasing more of the trunk nutrients to the soil. Interestingly, the concentration of Mg was also correspondingly high in the soil underneath trunk chips with a high number of larvae (*Table 4*).

The trunk contained considerably more K (Khalid, 1999) than can be absorbed by the insect, therefore, most of it was excreted and returned to the soil more quickly than by normal decomposition of the tissue alone. This is in accordance with the earlier laboratory finding that the larval faecal pellets contained high K (Norman *et al*., 2001). However,

the adult beetle has a much higher concentration of N (*Table 4*). This indicates that N, being a building block for protein, is essential to form its hard cuticular structure.

The soil pH had indirectly affected the population of *O. rhinoceros*. Generally, *O. rhinoceros* larvae were found in the decomposing chips just above the soil. Higher maximum number of larvae was found in the acidic (pH < 4.2) than alkaline soils (pH > 4.2) (*Table 3*). A pH value of lower than 4.2 could have retarded the growth of soil microbes such as *Metarhizium*. For example, a low pH (4.2) had reduced the germination of the soil fungus, *Beauveria bassiana*, while a higher pH (5.1-6.7) increased it (Groden and Dunn, 1996). Therefore, it is suggested that the plots with pH > 4.2 had higher spore germination of *Metarhizium*, causing higher mortality to the larvae and subsequently reducing the population of *O. rhinoceros* in the trunk chips. A previous work has shown that liming to make the soil more alkaline is good for the control of cockchafers (Lim, per. comm., 2000). It has also been suggested that high lime deposits would also form an olfactory or tactile repellent to the females, inhibiting oviposition rather than directly affecting the larvae, in the case of the Japanese beetle or European chafer (Vittum and Tashiro, 1980). It is also therefore possible that higher soil pH repels the female *O. rhinoceros* from ovipositing in the trunk beneath it.

The effect of *Metarhizium* is greater on the third instar larvae (Ramle *et al*., 1999). This instar has the longest developmental period and thereby facilitates longer exposure of fungal infection. It was also evident that the chance of infection by *Metarhizium* is related to the number of colonies in the soil. The infection occurs mainly in the later stages of development - at the third instar and pupal stages (*Table 5*) as observed in the field by Ramle *et al.* (1999). The negative correlation between the number of *Metarhizium* colonies in the soil and the population of adult beetles in the trunk chips likely indicates this phenomenon.

Rainfall had a direct effect on the breeding of *O. rhinoceros*. There was a highly significant positive correlation ($p<0.05$) between mean rainfall over the last 14 days and the population of first and second instar larvae (*Figure 7*). The occurrence of these early instars should indicate that breeding activities are prevalent during the wet season (Norman *et al*., 2001). Similar results were gathered from an earlier study (Norman *et al*., 1999), in which adult *O. rhinoceros* were found actively flying about in the wet season, likely foraging for breeding sites. In New Britain, Bedford (1975) reported that low nightly rainfall increased captures in coconut log traps, indicating that the coconut log acts as a suitable breeding substrate. The relationship between rainfall and fecundity is perhaps a survival instinct of the insect, to ensure success and survivorship of the subsequent generation. The palm leaf miner, *Coelanomenodera minuta*, has also shown increased fecundity during high rainfall periods (Mariau, 1999).

With this information, planters can manipulate the microclimates within the habitats of the beetle, to be less conducive for the breeding of *O. rhinoceros.* The chipped oil palm trunks should be placed in a single layer covering all the inter-rows. This would facilitate their drying, rendering them unsuitable as breeding sites. Leguminous cover crops should be planted early, as soon as replanting starts, so as to hinder the foraging of the adults for breeding sites. *Metarhizium* can also be augmented during replanting, *e.g*. by inoculating the soil during the chipping process. Lime can be incorporated in the soil during the trunk chipping to induce growth of the fungus for early infection of the pest, or to repel the female beetles from oviposition.

CONCLUSION

This study has shown some significant relationships between the population of *O. rhinoceros* with the environment and physical characteristics of its habitat. The cover crop influenced the density of *O. rhinoceros* in the trunk heaps. A high moisture content in the chips was essential for the survival and development of *O. rhinoceros*. There was a significant relationship between the mean pupal density with the mean chip hardness, indicating that the pupa preferentially developed in the softer decomposing chips. The larval population caused a more rapid decomposition of the chips, releasing more K to the soil. The soil pH may have an indirect effect on the population of *O. rhinoceros*. A higher pH may have induced the growth of *Metarhizium*, inflicting higher mortality on the larvae. On the other hand, rainfall directly affected the breeding of *O. rhinoceros*, as shown by a high positive correlation between rainfall and the population of the early instar larvae. These information would be useful for planters to manage their fields, especially in zero-burn replanting, to make them as unconducive as possible to the breeding of this pest.

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