The Role of the Palm Weevil, *Rhynchophorus palmarum*, as a Vector of Red Ring Disease of Coconuts. I. Results of Preliminary Investigations[1]

ELMER A. C. HAGLEY, *Central Experiment Station, Centeno, Arima Post Office, Trinidad, West Indies*

ABSTRACT

The incidence of red ring disease was found to be highly correlated with the seasonal abundance of the palm weevil, *Rhynchophorus palmarum* (L.) Adult insects became contaminated with fragments of diseased tissue containing large numbers of nematodes after visiting diseased palms. The main source of contamination appeared to be the frass in tunnels excavated by the larvae during feeding, but adult weevils also became contaminated by bodily contact with diseased tissue and after walking through suspensions of worms in "pockets" in diseased palms. Internal contamination of the gut and body cavity also occurred following the feeding of insects on infected tissue. Virgin insects were found to be contaminated both externally and internally prior to emergence from their cocoons. The numbers of nematodes picked up by adult weevils was found to vary with the source of contamination, the density, stage, and activity of the worms present, and the age and feeding history of the insect. Longevity of the nematodes on the body surface of the insect varied between 2–6 days and was as long as 10 days in the gut and body cavity. External and internal contamination of the field population was found to be 38.5% and 9.8%, respectively. The incidence of red ring disease was significantly reduced following the application of endrin for palm weevil control.

Ashby (1921) first suggested that the palm weevil, *Rhynchophorus palmarum* (L.), as well as scavenging insects, might act as vectors of the causative organism of red ring disease of coconuts, the nematode, *Radinaphelenchus cocophilus* (Cobb). Later (Ashby 1924), reference was made to the possible transmission of the nematode on the probosces of adult weevils in South America. In 1923, Cobb (Goodey 1933) also suggested that *R. palmarum* was a vector of red ring disease and stated that 50% of the weevils examined on coconut plantations were contaminated with nematodes. Ferreira Lima & Da Cruz (1945) after studies on the symptomatology and pathology of the disease also expressed the opinion that *R. palmarum*, as well as *Homalinotus coriaceus* Gyll. and *Rhina barbirostris* L., might act as vectors. Chaves Batista (1948), Joffily (1948), Bain & Fédon (1951), Mungia (1958), and Tidman (1959) also suggested that several species of insects including the palm weevil might play an important role in the spread of red ring disease on coconut plantations. Martyn (1953) reported that the palm weevil was an important vector of the disease in Trinidad. He noted that in areas where the population density of weevils was high the disease was more prevalent than in areas where these insects were scarce, and expressed the opinion that the nematode was carried from diseased to healthy palms in infected debris on the body of the insect. Fenwick (1957, 1958) after examining 545 field collected insects, reported that 16.3% were contaminated with nematodes, only 6.1% carrying two or more worms. He expressed the opinion that the weevil did not play an important part in the spread of the disease. However, after further investigations (Fenwick 1962), this author reported that 35% of the total weevil population examined carried nematodes externally, while internal contamination of the gut and body cavity was about 14%. The degree of external contamination of weevils from some localities was reported to be between 50%–60% while in one area 76% of the weevil population was found to be contaminated. Fenwick subsequently stated that the palm weevil should be considered as an important factor in the spread of red ring disease.

Hagley (1960, 1962a) showed that there was a high degree of correlation between red ring disease infection and palm weevil infestation. He further stated that of the field population of weevils examined, 38.5% were externally contaminated, and expressed the view that the weevil played an important role in the spread of red ring disease on coconut plantations. Further and more detailed investigations into the role of *R. palmarum* as a vector of red ring disease have been in progress over the past 2 to 3 years and the information obtained to date is presented in this paper.

MATERIALS AND METHODS.—Adult insects collected in the field from the leaf axils, crown region, and at the bases of the stems of individual palms, as well as from under trash and split dry husks, were examined internally and externally for the presence of worms. Individual insects were placed in separate 3″×1″ glass containers in the field and later transferred to 250 ml. conical flasks containing 50 ml. water. The flasks were placed on a horizontal shaker driven by a ¼-h.p. electric motor adjusted to give 108 strokes per minute and a thrust of about 3 ins. The insects were allowed to swim about in the water overnight and then shaken for 1 hour. The water in the flask was then passed through 100- and 250-mesh sieves, any worms present being retained on the latter. This procedure was repeated three times, the insects being kept continuously in water over the three day period. Estimates of the number of worms present were made with a Peters 1 mm. counting slide.

Adult insects to be dissected for internal examination were first killed in an acetate jar and then washed in a jet of water for 2 minutes. The weevils were subsequently immersed in 10% Lugol's solution for 30 secs., rinsed in water and mounted dry in small dissection trays. The gut, after removal, was macerated in a domestic blender for 10 secs. and allowed to soak in 300 ml. water for 15 minutes. The number of nematodes present was estimated as outlined above.

Two- to three-gram samples of larval frass and pupal cases which had been cut up into small sections were

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placed in 300 ml. water and allowed to soak for 2 hours after which the number of nematodes present was estimated.

Assessment of the number of nematodes picked up externally and internally by adult insects when feeding and when walking through larval frass was done by using virgin adult insects reared in healthy palms protected from natural infestation by means of cages consisting of a wire frame covered with plastic mesh. The insects were allowed to feed on diseased tissue or walk through larval tunnels in such tissue for varying periods of time. They were subsequently removed and examined. In longevity studies the insects after feeding were individually placed in clean dry cages and fed on nondiseased tissue protected by a wire mesh to prevent bodily contact of the insect with the tissue.

Estimates of the weevil population were made with traps consisting of large portions of diseased tissue approximately 2–3 ft. long and 1–1.5 ft. wide removed from the upper region of the stem of 3–4 year old palms.

Applications of insecticides were made with a Myers spraying unit to which were fitted two 75-ft. plastic hoses with an internal diameter of ½ in. Attached to the hoses by a "trigger" release mechanism were 9-ft. lengths of ⅝ in. diameter aluminum piping at the ends of which 1.5-ft.-long offsets were fixed at an angle of 45° to enable the spray to be directed into the leaf axils of the palm. The disk of the nozzle was removed and a 2″-diameter head was fitted over the swirl chamber to increase the volume of spray delivered in a full cone spray pattern and to reduce the degree of atomisation. The insecticides were mixed in a 1:1 proportion with "Tenac" sticker and the mixture diluted 1 part : 20 parts water. All applications were made at a pressure of 25–30 lbs. p.s.i.

RESULTS AND DISCUSSION.—*Sources of Contamination.*—Adult palm weevils became contaminated with nematodes when they visited diseased palms, particularly those in which there was a heavy larval infestation. In such palms the internal stem tissues were extensively tunnelled by the larvae both in the discolored, heavily infected red ring zone, as well as in the softer, internal stem tissues and those at the periphery of the stem external to the red ring zone. The larvae also tunnelled in the crown region of the palm and in the petiolar bases where pupation occurred. Adult insects, attracted by the decaying tissues of the palm following larval damage and subsequent invasion by secondary organisms, gained ready access into the stem through holes at the periphery made by the larvae while feeding. In palms in which the crown had fallen over and the "pop-necked" condition resulted, the weevils entered the stem through the damaged region at the bases of the petioles. Once inside the stem the insects moved around within the tunnelled and decaying regions feeding, mating, and ovipositing. As they walked about in the larval tunnels fragments of infected tissue adhered to their bodies which consequently became contaminated.

Examination of the frass removed from larval tunnels in diseased palms (table 1) has shown that living nematodes were distributed throughout the regions in which the larvae fed. In 1 gm. of frass removed from tunnels in the bases of the petioles and in the red ring zone in the stem as many as 1,258 and 880 nematodes have been recovered respectively. The density of worms was considerably lower in frass collected from the crown and stem region external to the red ring zone which did not generally become invaded by nematodes.

Table 1.—The recovery of nematodes from larval frass.[a]

Region of Palm	Total No. Samples Examined	Total No. Containing Nemas	No. Containing Living Nemas	Av. No. Living Nemas /g. Frass
Crown	153	103	18	20
Stem				
(i) Outside red ring zone	131	83	34	45
(ii) Inside red ring zone	162	108	35	52
(iii) red ring zone	149	138	76	56
Petiole	161	116	49	100

[a] Samples taken from a total of 58 palms between the ages of 3–7 years.

Mature larvae and pupae removed from diseased palms were examined to determine the numbers of living worms in their alimentary systems and adult weevils were examined both externally and internally to establish the degree to which they became contaminated. The results are summarized in tables 2 and 3.

Table 2.—The recovery of nematodes from the alimentary system of larvae and pupae of *R. palmarum* collected in diseased palms.

Stage of Insect	Total No. Dissected	Total No. Carrying Nemas	No. Carrying Living Nemas	Av. No. Nemas Alive /Insect
Larvae	163	116	57	151
Pupae	202	173	98	439

As the nematodes were capable of passing through the gut of the larvae in a healthy condition, they apparently became dispersed throughout the regions of the palm in which the larvae fed. Tidman (1959) also reported the presence of *R. coccophilus* in the gut of larvae of *R. palmarum* and further observed that the nematode was expelled with the fecal pellets of the insect. The large numbers of worms recovered in the pupae probably resulted from the excavation of the pupal chamber by the mature larva in the petiolar bases which were often heavily infested with nematodes.

Adult insects removed from larval tunnels in diseased palms were also examined. The results summarised in table 3 indicate that 41% of the weevils became contami-

Table 3.—The recovery of nematodes from adult *R. palmarum* living in larval tunnels.

Examination	Total No. Insects Examined	Total No. Carrying Nemas	No. Carrying Living Nemas	Av. No. Living Nemas /Weevil
External	135	56	33	431
Internal	108	21	7	58

Table 4.—The recovery of nematodes from pupal cases and virgin adult insects recovered from diseased palms.

Total No. Pupal Cases Examined	Total No. Containing Nemas	No. Containing Living Nemas	Av. No. Living Nemas/ Cocoon	No Virgin Adults Examined		Total No. Carrying Nemas		No. Carrying Living Nemas		Av. No. Living Nemas Insect	
				Ext.	Int.	Ext.	Int.	Ext.	Int.	Ext.	Int.
173	95	11	103	57	66	14	25	8	21	88	66

nated externally with nematodes. Since as many as 20–30 adult weevils can be recovered from a single 3- to 5-year-old palm, it is likely that a large proportion of the weevil population in the field became contaminated by this means. Internal contamination as a result of the insects feeding on diseased tissue was not of great significance.

Examination of virgin adults recovered in cocoons collected from diseased palms has shown (table 4) that these insects became contaminated both externally and internally prior to emergence.

In some cases nematodes were recovered from the fibres of the cocoons but it appeared that they migrated from the diseased tissue of the palm through the cocoon wall to the adult insect. Internal contamination probably resulted through penetration of the abdominal conjunctivae of the insect by nematodes before the cuticular tissue had hardened and also as a result of insects feeding on diseased tissue by pushing the proboscis through the fibres of the cocoon wall. There is little evidence at present to suggest that the nematodes can survive the period of larval transformation in the insect in a healthy condition.

Adult weevils also became contaminated after walking through suspensions of worms when these occurred in pockets in diseased palms, particularly those in which the crown region had fallen over following heavy larval infestation. The examination of water removed from such cavities has shown that as many as 431 active worms per ml. were present.

The actual numbers of nematodes picked up externally by an adult insect varied with the density, stage and activity of the worms present, the age and activity of the insect and the source of contamination. An actively feeding virgin or 1–2 week old adult insect walking through larval frass containing 600–700 worms per gram, 60–70% of which were alive, a density frequently recorded for frass from larval tunnels within the discoloured red ring zone and the region of the stem immediately internal to this zone, would pick up as many as 102 nematodes within 24 hours if the latter were active pre-adult larval forms. On the other hand when walking through frass containing densities of 200–300 nematodes per gram and lower, fewer worms were picked up by adult insects even when they were active larval forms. This was most apparent when the number of living worms was below 10% of the total population present.

External contamination resulting from bodily contact of the weevil with diseased tissue during feeding was greatly influenced by the hardness of the tissue in addition to the factors previously mentioned. Adult weevils allowed to feed for 18–24 hours in diseased tissue containing 40–300 very active pre-adult larval worms per gram picked up 23–560 nematodes externally provided the tissue was removed from the upper region of the stem just below the crown of the palm. On the other hand, tissue removed from the lower stem region in which the individual cell walls had become considerably thickened containing a density of up to 4,000 nematodes per gram, 88% of which were alive, was found to be a poor source of contamination particularly when the worms were inactive larval forms.

The degree of contamination in many cases also appeared to vary considerably between individual insects reared under the same conditions. Two insects fed on tissue containing 382 worms per gram, 57% of which were active, picked up 0 and 13 worms respectively after a feed of 4 hours while two other insects fed on tissue containing 2,091 worms per gram, 13% of which were alive and active, picked up 78 and 16 worms respectively. At the very low density of 43 worms per gram, 36% of which were alive but inactive, 90 and 221 worms were picked up by two adult insects feeding for 18 hours. In the former case 25% of the worms were alive while in the latter all were dead.

Suspensions of nematodes in cavities in diseased palms were probably good sources of contamination. Eighty-seven nematodes were picked up by an adult insect walking through a suspension containing 62 worms per ml. and 231 from a suspension containing 274 worms per ml. after exposure periods of 10 seconds and 10 minutes respectively. The number of nematodes picked up by the insect was largely dependent on the activity of the worms present.

Degree of Contamination of Field Population.—It has been shown (Hagley 1962a) that 38.5% of the field population of adult weevils was externally contaminated with living nematodes, an average number of 71 worms being carried per insect. Further examination of field collected insects has shown (table 5) that the degree of internal contamination is considerably lower than that found externally. Cobb (1923) reported that 50% of field-collected

Table 5.—The recovery of nematodes from the digestive tract and body cavity of field collected adult palm weevils.

Total No. Insects Examined	Total No. Carrying Nemas	No. Carrying Living Nemas	Av. No. Living Nemas /Insect
205	42(20.5%)	20(9.8%)	116

weevils examined carried nematodes in the hairs of the mouth-parts and in the intestine. Martyn (1953) while stating that adult palm weevils were contaminated with infected debris picked up from diseased palms did not give details with regard to the percentage of the field population that became contaminated in this manner. Fenwick (1962) has found that a larger percentage of weevils, 35%

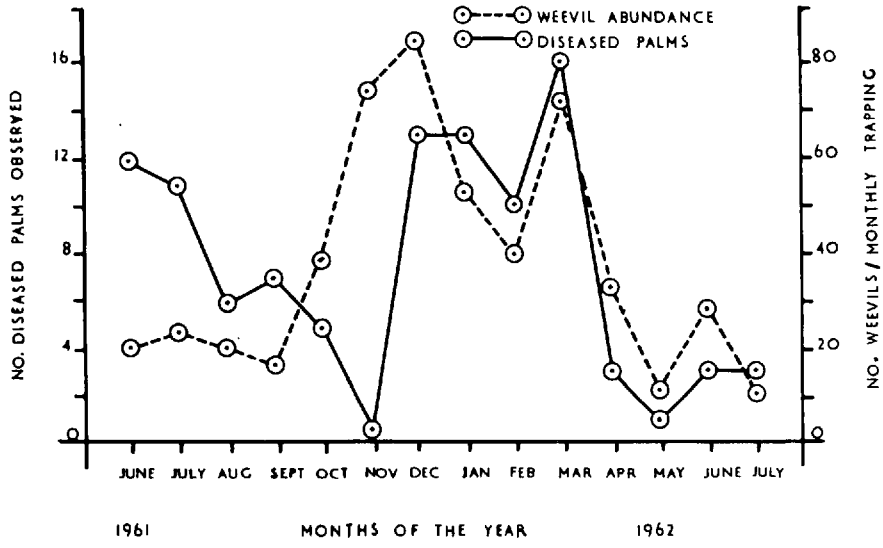

FIG. 1.—Correlation between weevil population density and red ring disease incidence. (r=0.65 at 0.02 level of probability).

externally and 14% internally, became contaminated than originally stated (Fenwick 1957). However, in his later examinations Fenwick apparently trap-collected field weevils by using cut-logs of coconut tissue and although the insects were subsequently examined individually little consideration appears to have been given to cross-infestation occurring between contaminated and "clean" insects attracted to the same log. This might have influenced to a greater or smaller degree the high percentages of contamination obtained in some cases.

The results of laboratory tests in which adult weevils were confined in a specially designed cage (Hagley 1962b) and fed tissue containing known densities of nematodes have shown that the hardness of the diseased tissue, the density and activity of worms present and the feeding history of the insect were important factors influencing the uptake of nematodes during feeding and hence to a large extent the degree of internal contamination.

A virgin insect fed on soft stem tissue containing 314 inactive pre-adult larval worms per gram had 290 living nematodes in its alimentary canal after a period of 7 days feeding. Another virgin insect, however, when fed for 7 days on non-diseased tissue prior to being fed on the same tissue for a similar period of time showed no internal contamination with living worms. Similarly tissue containing up to 1,100 nematodes per gram was not a good source of contamination if the insect had been previously fed for a period of 12–14 days. As many as 337 nematodes were however ingested by virgin insects given their first meal on soft stem tissue containing 1,200–2,000 active pre-adult larvae per gram. In the case of hard stem tissue as few as 10–20 worms were ingested at densities of 600–2,000 per

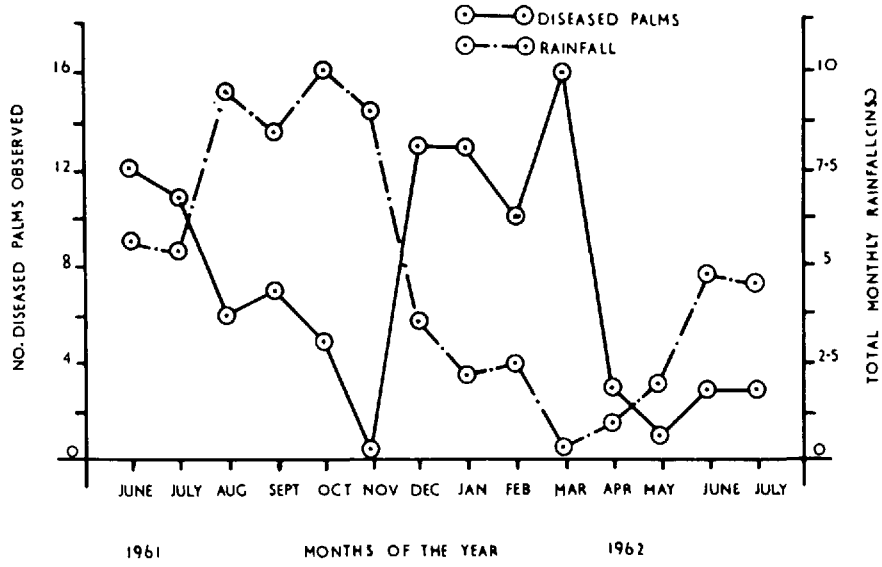

FIG. 2.—Seasonal incidence of red ring disease.

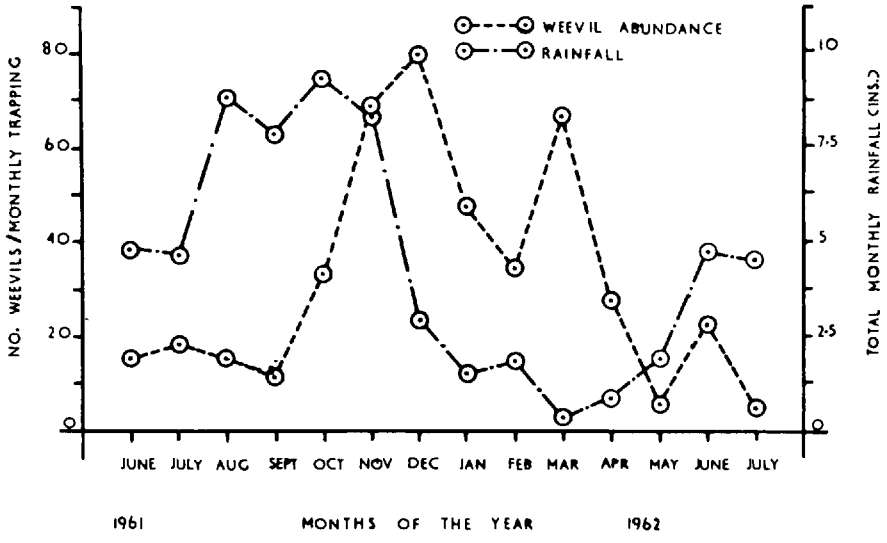

FIG. 3.—Seasonal abundance of adult palm weevils.

gram. A similarly low degree of internal contamination was found when insects, fed continuously for 16–18 days on diseased tissue containing 1,300–1,400 nematodes per gram, were examined. The low degree of contamination occurred even when the worms were active pre-adult larvae and in the case of hard stem tissue probably resulted from the inability of the insect to feed extensively on the tissue as well as the scraping action of the mandibles during feeding. Portions of nematodes were often recovered in the gut of insects fed on such tissue suggesting that the worms were destroyed when the insects attempted to feed. In insects fed continuously on non-diseased tissue for varying periods of time before being given a meal on diseased tissue or fed continuously on diseased tissue alone it appeared that the survival of the nematodes was adversely affected during passage through the alimentary canal. In many insects fed in this manner 200–300 dead worms were often recovered in the gut.

The Longevity of Nematodes in and on Adult Weevils.—The longevity of nematodes on the external body surface of adult weevils was found to vary according to the source of contamination. Hagley (1962a) has stated that nematodes picked up by adult weevils in fragments of diseased tissue remained alive for 2–3 days. The longevity of worms picked up from a suspension was 6–7 days. In the latter case the nematodes became attached to the hairs on the body surface of the insect surrounded by a film of

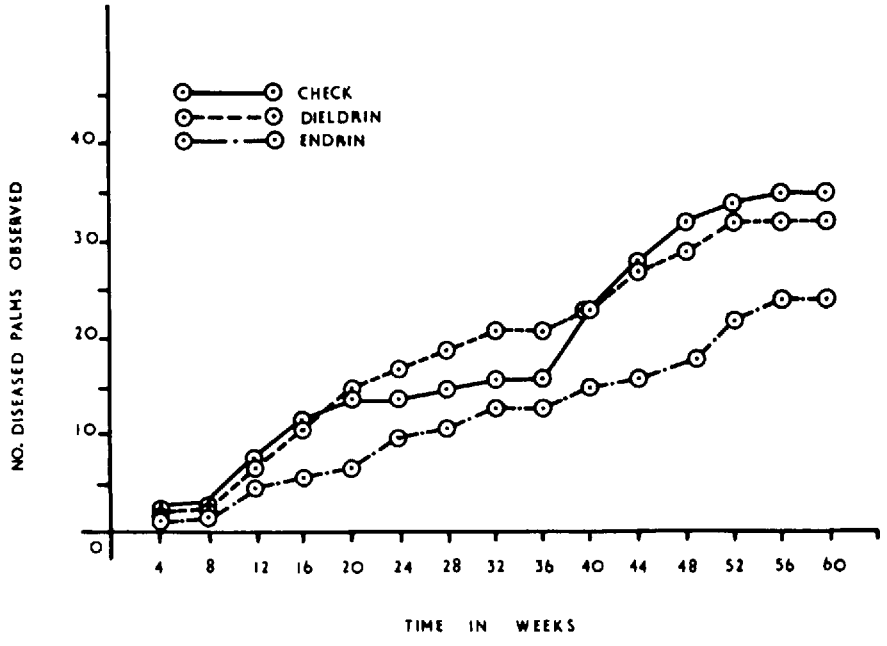

FIG. 4.—The effect of insecticidal control of the palm weevil on red ring disease incidence.

moisture and as a result death from desiccation was considerably delayed.

Longevity of worms within the digestive tract and body cavity of the insect was as long as 10 days (Hagley 1962a).

Correlation Between Red Ring Disease Incidence, Palm Weevil Abundance, and Rainfall.—The incidence of red ring disease and the fluctuation in palm weevil population density were recorded in 6 observation plots, totalling 600 palms between the ages of 3–7 years. The total monthly rainfall was also recorded for the area in which these plots were located. The results are summarized in figures 1, 2, and 3. The heaviest losses due to red ring disease occurred at the end of the wet season and in the first 2–3 months of the dry season, i.e., between December and March. The weevil population began increasing towards the end of October reaching a peak in December and falling in January and February. In March the population again increased thereafter falling considerably throughout the latter part of the dry season and early rainy season. As the records of the incidence of the disease were based on the first appearance of external symptoms, which became manifest 6–8 weeks after initial inoculation of the palm, the actual period of highest disease incidence corresponded with the time of greatest weevil abundance.

In early October and November the field population would be comprised largely of active 2 to 4-week-old insects which would have a greater vector potential at that age than when 6–8 weeks old in December and early January at which age individual activity was greatly reduced. Consequently the spread of the disease should be greatest in October and November, this being shown in the appearance of external symptoms in December and January. Similarly, although the weevil population dropped in January and February, the individual insects present at that time would be young and active representing the progency of adults which emerged in late October and November. These insects would disseminate the disease extensively resulting in a rise in the incidence in March. From figure 1, it can further be ascertained that during the six month period June–November the average monthly loss of palms to red ring disease was 7 while between December and March this figure had risen to 13.

The increase in weevil abundance in March, like that in December, would represent a population comprised largely of 6 to 8-week-old individuals which would not be very active vectors, and the disease incidence consequently dropped in April and remained at a low level as did the weevil population throughout the remainder of the dry season and early wet season.

Effect of Palm Weevil Control on Red Ring Disease Incidence.—Mungia (1958) has reported a reduction in the annual incidence of red ring disease from 10% to 1% in several regions in Mexico following the large scale application of "Palmarol" insecticide (19.5% endrin+coumarone) to the leaf axils of healthy palms.

The results of preliminary field experiments on the control of the palm weevil using dieldrin and endrin are shown in figure 4. The incidence of red ring disease was significantly lowered (31.4%) following applications of endrin but was not affected by dieldrin. The insecticides were applied on the basis of weather conditions, at 50- and 70-day intervals in the rainy and dry season respectively. It is now apparent that better results might be obtained with more frequent applications towards the end of the rainy season and at the beginning of the dry season when the weevil population reaches its maximum density. Further field studies are currently in progress in this regard and the results will be reported in the future.

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