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DISCOVERY OF A FACTOR LIMITING YIELDS IN A COCONUT PLANTATION ON PEAT: THE INSECT PEST *SUFETULA* SPP.

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SUMMARY

On a large coconut plantation planted on a deep peat soil in Sumatra, Indonesia, hybrid coconut yields are stabilizing at values well below their potential, even in plots where known production factors have been mastered since the outset: land preparation, water control, and mineral fertilization. To explain this situation, five hypotheses have been proposed. They were tested one by one in field trials. The authors have demonstrated that the main reason for stabilized yields was the Lepidoptera root pest *Sufetula* spp. and conclude by considering lines of research for controlling this pest in the context of rehabilitation and replanting.

INTRODUCTION

For several decades, the deep peat formations in Southeast Asia have been developed through oil palm and coconut cultivation (Fachri, 1998). Palm cultivation on these very particular substrates can be profitable, provided the many agronomic constraints specific to this environment are overcome: land preparation, water control, mineral fertilization, and pest control (Dolmat *et al*., 1982; Ochs *et al*., 1992; Mariau *et al*., 1992; Bonneau, 1996).

This paper describes the discovery of a new limiting factor, a Lepidoptera insect pest, *Sufetula* spp., whose larvae are destroying coconut palm roots in a plantation on a peat soil on the east coast of the island of Sumatra (Indonesia). This insect has already been described as a pest (Desmier de Chenon, 1975; Genty *et al*., 1975), but the degree of damage it can cause has only recently been suspected.

Only agronomic aspects of the problem are covered here: discovery of a factor limiting yields on a field scale, and on a plantation scale. Entomological aspects (description of the species and biology of the insect) and physiological aspects (damage on a tissue, organ and palm scale) will be covered separately. The authors point out though that two new species of the genus *Sufetula*, which differ from the species *Sufetula*

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sunidesalis, are in the process of being identified. To simplify matters for the purposes of this paper, these two species *Sufetula* sp.1 and sp.2 shall be referred to as *Sufetula* spp.

MATERIALS AND METHODS

The coconut plantation

The Pulau Burung coconut plantation is located on the east coast of the island of Sumatra (Indonesia) in Riau province approximately 100 km south of Singapore. The Riau Sakti United Plantations company (RSUP) has planted an area of 18 000 ha with dwarf × tall hybrid coconut palms, mostly PB 121 hybrids or MAWA (de Nucé de Lamothe *et al*., 1985). The basic unit is a block of 500 ha (500 × 1000 m). The palms were planted between 1987 and 1991 at a density of 180 palms ha^{-1} (8 m apart in a staggered, equilateral triangle design). The soil is a deep peat 4 to 6 m deep developed over a marine alluvial substrate (Ochs *et al*., 1992). It is a very porous, very spongy, purely organic soil with a fragile structure and is chemically poor (Bonneau, 1996).

The water table is controlled in the fields by equidistant drains (tertiary canals), which empty into peripheral canals (secondary canals) on which barges navigate. These canals empty into collectors (primary canals), which are wider and deeper and used by high-capacity tugboats. Transport (fertilizers to plots, or nuts to processing units) is exclusively by water.

The climate is highly suitable for coconut: optimum sunshine, temperature and relative humidity, abundant rainfall (2296 mm a^{-1} on average from 1991 to 2000), well distributed throughout the year.

Stagnating yields

After excellent growth during the immature period, and exceptionally early flowering (up to six months in advance of the standard on a mineral soil), the hybrid coconut palms at Pulau Burung started displaying abnormalities from the fourth year after planting: premature drying out of the lower fronds and defective fruit-setting (e.g. a series of empty bunches after a series of normal ones). This symptom, called dry bunches and leaves (DBL) became established fairly rapidly, at varying degrees of intensity, but in a steadfast way, in all the fields. Even when land preparation, water control and fertilization were ideal, the production potential of this hybrid was never reached. Figure 1 shows the production curve for two fields in relation to their potential in a commercial plantation (120 nuts $palm^{-1}$ a^{-1} on average in a block of 50 ha). The potential at Pulau Burung was estimated according to the performances of MAWA hybrid recorded by de Nucé de Lamothe *et al*. (1985) from different sites, taking in account the local soil and climatic conditions and the scale of production in an agro-industrial plantation.

Coconut palms within a field displayed symptoms to a greater extent than did the border palms planted along the secondary canals. The latter showed the typical vegetative appearance of a healthy MAWA hybrid and a satisfactory production level with regularly set bunches. Figure 2 shows the pending production (defined as the

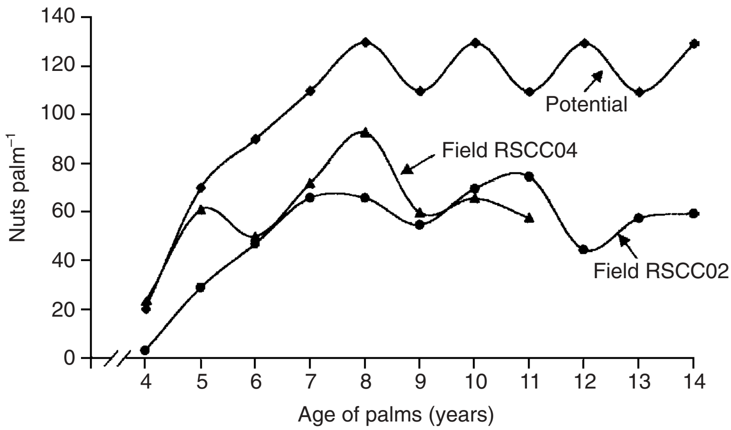

Figure 1. Production trends on two fields relative to potential nut yield.

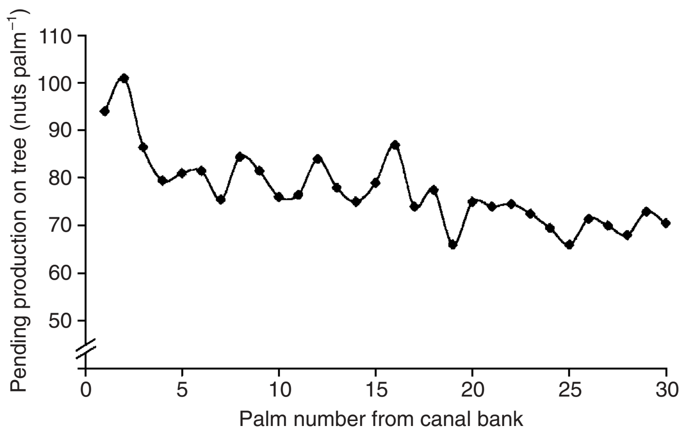

Figure 2. Yield gradient from canal bank to centre of field (mean of nine fields × eight rows).

number of nuts per palm from flowering to maturity) gradient from the outside to the inside of the fields.

The hypotheses

It was possible to rule out certain factors rapidly, through results previously obtained at this plantation. It could not be a mineral deficiency for a known nutrient: most nutrients, be they macro- or trace elements, had already been studied (Ochs *et al.*, 1993; Bonneau *et al.*, 1993). Their deficiency symptoms have been described and do not correspond to DBL. Neither could it involve a known pest, such as a leaf-eating caterpillar or termite (Mariau *et al.*, 1992), whose damage has been identified and does not correspond to DBL either. The hypothesis of a disease was also unlikely: there was no extension from a focus, instead there was a diffused and simultaneous presence.

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Based on existing knowledge, the authors put forward five hypotheses that might explain the phenomenon:

i. The action of a root pest, *Sufetula* spp., already identified at Pulau Burung, but whose impact is not known.
ii. Deficiency of a nutrient yet to be studied. Leaf analyses spanning a wide spectrum of nutrients led the authors to consider a silica (SiO_2) deficiency already suggested in an earlier article (Bonneau, 1996), or a nickel (Ni) deficiency.
iii. An excessive planting density.
iv. A water table that was too high or which fluctuated too much.
v. Highly variable land preparation from one plot to another (notably compacting of the planting rows and the existence of residual tree trunks shallowly buried by bulldozers).

Methods

Most of the results were obtained from field trials. The method described below, which has been used especially for mineral nutrition (Bonneau, 1996), proved to be appropriate for studying other production factors.

It consisted of testing the effects of different treatments on coconut palms in a plantation using a statistical design suited to the purposes of the trial. The basic unit was a plot comprising a group of coconut palms (generally between 20 and 40) of which, to minimize border effects, only the central so-called 'useful' palms were used. The variables observed palm by palm were grouped together to form plot means, which were then processed in accordance with the statistical design of the trial.

Each trial, therefore, comprised n treatments and p replicates, i.e. at least twenty or so unit plots covering a total area of several hectares. In order to isolate the factor(s) being studied, an 'all other things being equal and non-limiting' situation was created, i.e. the factors that were not being studied were controlled at uniform and non-limiting levels, so as not to interfere with those under observation.

Two methods were used to observe the roots. The first was the Voronoi pit whereby a triangle of a given volume was excavated from the base of a coconut palm. The roots exposed thus were sorted, washed, weighed and examined by category (primary, secondary and tertiary). The second method consisted of uncovering the entire length of superficial primary roots and measuring the distances between two successive attack points, thereby obtaining healthy segments, which were grouped into length categories.

HYPOTHESIS TESTING

Other hypotheses

A planting density trial, with densities up to 321 palms ha^{-1}, and a thinning trial showed that excessive planting density is not a factor. Piezometer data showed that the water table is uniform, as is expected in peat, with no relation to the irregular distribution of yields; nor do the symptoms correspond to those of either drought or water logging. The authors were unable also to establish any correlation between the standard of land preparation and symptom incidence. Trials with nickel and silicate application showed that these minerals were taken up by the coconut palms, but neither vegetative growth nor yields were improved.

Root pest hypothesis

Multiple observations showed that the root systems of coconut palms at Pulau Burung were being attacked in a continuous manner. Larvae of the pest *Sufetula* spp. (Lepidoptera: Crambidae) penetrated tender tissues (usually primary and secondary root apices), on which they fed before colonizing a new root. The larvae were highly mobile in this peat medium and could descend to a depth of 0.8 m. Tissues damaged by attack formed a scar and emitted a new root, which, in turn, would be attacked and the process would continue. There was little lateral extension of the coconut root system (it rarely exceeded 2 m from the stem, whereas healthy mature palms have primary roots over 10 m long), which was severely damaged and exhibited traces of successive reiterations right from an early age.

These observations suggested continual pest pressure on the root system, resulting in a depressive effect on overall palm functioning. It had yet to be demonstrated, though, with proof of a correlation between the presence of *Sufetula* spp. in the environment of the coconut palms, attacks on coconut palm root systems, and a reduction in the number of green fronds and amount of fruit-setting. In other words, it was necessary to determine, with all other things being equal and non-limiting, that coconut palms severely attacked by this pest developed the DBL symptom and produced significantly less yield than did healthy palms producing yields close to their potential.

Trial 1. This was planted in 1988 on cleared primary forest ground in order to compare six types of soil cover, ranging from natural re-growth (largely dominated by ferns) to bare soil (obtained by regular chemical weeding). A Fisher block design was used comprising six treatments and four replicates. Each plot comprised 48 coconut palms (four rows of 12), of which the 20 central palms were useful (two rows of 10). The treatments were initiated at planting and continued up to December 1999, i.e. for 12 years.

For the sake of clarity, only the two extreme treatments are considered here: regularly weeded soil (with dry fronds windrowed in every alternate inter-row space), and soil covered totally by ferns (apart from a circle with a 2 m radius kept clean around each coconut palm). Figure 3 shows yield trends over time. The yields of the palms on bare soil were always better than those of palms surrounded by ferns, though they still remained below their potential. Regular leaf analyses showed that this difference could not be due to better mineral nutrition: the leaf nutrient contents did not vary from one treatment to the other throughout the duration of the trial.

Table 1 shows that the coconut roots in bare soil were attacked less than those of coconut palms surrounded by ferns. Nevertheless, they were seriously affected, which explains why the palms still yielded well below their potential. Likewise, the *Sufetula*

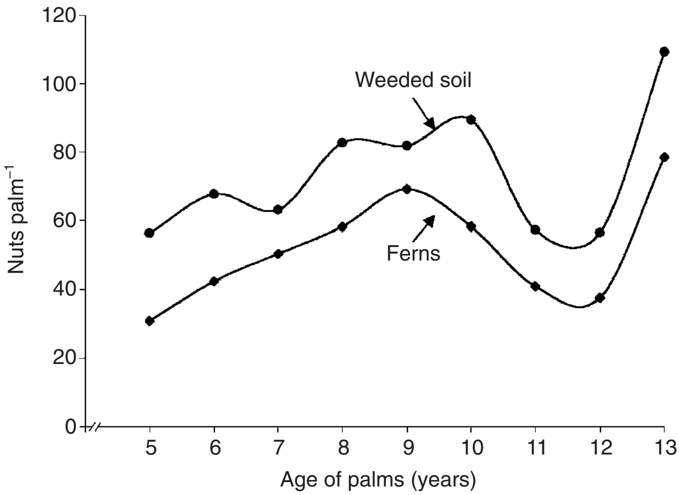

Figure 3. Effect of soil cover on yield trend over time.

Table 1. RSUP Trial 1. December 1999. Effect of the pest *Sufetula* spp.on the incidence of root damage (Voronoi method) to mature coconut hybrids depending on the type of soil cover.

Variable	Treatment		*s.e.*
	Soil with fern cover	Bare soil since planting	
Primary root apexes attacked (%)	55	38	7
Root system overall attack index†	35	24	9
Pest adult population density‡	13.4	5.4	3

†Index = number of attack points/fresh root weight (g).
‡Inventory of pests collected by 'sweeping' a 28 m^2 triangle between three palms: mean of two triangles sampled per unit plot: number of adults counted per triangle.

spp. adult population density was higher around the coconut palms with ferns than around those on bare soil.

This trial showed that the most likely explanation for the difference in yields between the two treatments considered was indeed the difference in pest pressure on the root system, itself linked to the abundance of the pest in the coconut environment depending on the type of soil cover.

Trial 2. This trial was set up in 1997 on mature palms to study the effect of insecticide applications (active ingredient: chlorpyrifos) sprayed monthly onto the surface of a circle with a 2 m radius around each palm. Again a Fisher block design was used comprising six replicates of three treatments: (i) control without insecticide; (ii) insecticide at a dose of 30 ml commercial product (480 g active ingredient l^{-1} in 6 l water) per tree per month; (iii) insecticide at 30 ml commercial product in 3 l water per tree per month. Each plot comprised 25 palms (five rows of five) of which the nine central palms were useful (three rows of three).

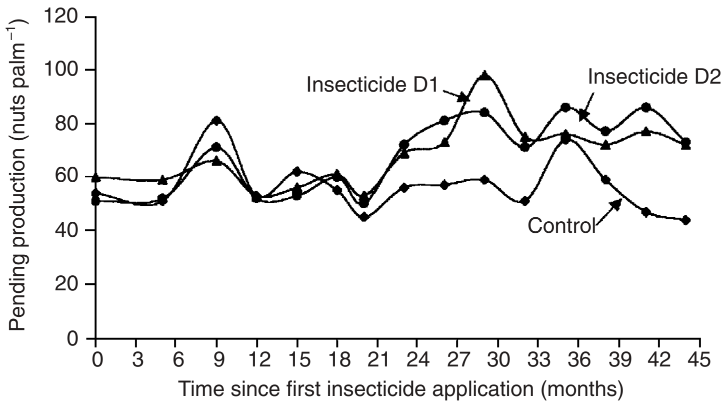

Figure 4. Effect of soil-sprayed insecticide on yield trend over time relative to control.

Table 2. RSUP Trial 2. February 2002. Effect of an insecticide treatment on the incidence of root damage (segment method) to mature coconut hybrids (two primary roots observed per palm).

	Treatment			
Variable	No insecticide	Insecticide dose 1	Insecticide dose 2	*s.e.*
Total number of attacks per root	34.2	18.3	19.2	8.6
Average length of a primary root (m)	3.75	3.78	3.85	0.24

Figure 4 shows pending production trends over time. It can be seen that the productivity of the control palms fell behind the treated palms between 18 and 24 months after the treatments were first imposed, and the trend was maintained throughout the duration of the trial. Table 2 shows that the control coconut roots were attacked more than those of the treated palms.

This trial demonstrated that when the pressure of *Sufetula* spp. attack on the root system of mature coconut palms was reduced, the nut load increased. However, it did not increase enough to reach the production potential, since a proportion of the pressure remained and the root system had been severely damaged before the trial began.

Trial 3. This trial was planted after fallow in 1997, to study the effects of soil cover together with silica fertilizer on young coconut hybrids. It was planted in a split-plot design: two main treatments (bare soil or weedy soil) and three sub-treatments (control without silica fertilizer; added alluvial clay; and added sodium silicate). The trial was replicated four times. Each plot comprised 36 coconut palms (six rows of six) of which 16 central palms were useful (four rows of four). No significant enduring effect of sub-treatments was recorded. Nor was there evidence of an interaction with the main treatments. The focus, therefore, is exclusively on the two main treatments.

The aim was to compare two growth environments for young coconut palms: one in which the pest was not controlled and could exert its maximum pressure, and the

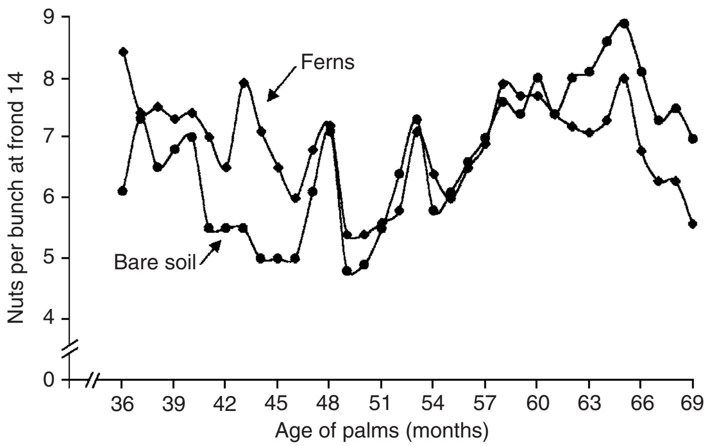

Figure 5. Effect of soil cover on fruit set at frond 14 of young hybrids.

other in which it was controlled at as low a level as possible so as to exert minimum pressure. In the first case, natural fern re-growth was left (apart from a cleared circle with a 2 m radius each coconut palm), no insecticide was applied and coconut residues (dry fronds and husks) were windrowed on site. In the second case, the soil was clean weeded, an insecticide was sprayed at various frequencies on the soil surface, and coconut residues were burnt in place. The purpose was to have a soil with no shelter for adult *Sufetula* spp.

Figure 5 and Table 3 show that there has yet to be any enduring effect of the main treatments with respect to growth (except at the end of the emergence phase within a non-limiting range of values), sex differentiation, fruit-setting (although in Figure 5 the beginning of a trend indicating an advantage of the bare soil treatment, became apparent from month 62), or the initial coconut yields. There was, however, an often-significant difference in pest pressure on the root systems of the young palms.

It happened that the coconut palms were planted after several years of fallow, far enough away (> 500 m) from an adult coconut planting infested with *Sufetula* spp., so that the pest was not present at the time of planting. Regular observations on the root system of the young palms showed that the pest remained absent for almost a year, and that it then took a long time to colonize the plot and reach a high population level. Table 3 shows that it was only at the end of the fourth year that the *Sufetula* spp. adult population level increased substantially. In the meantime, the young palms were able to establish a largely healthy root system, as they were generally subjected to low pest pressure, even though a significant difference could often be detected between the two treatments. To date, even in the treatment assumed to be more favourable for the pest, the pressure has been too low to limit the growth of the young palms. For the time being, it is as though there is no limiting factor, allowing an excellent preparation for bearing in all the palms in the trial.

It is worth continuing this trial therefore, while maintaining as great a difference as possible in *Sufetula* spp. pressure between the two main treatments, bearing in mind

Table 3. RSUP Trial 3. Effect of soil cover on young coconut hybrids in a new field.

Variable		Palm age (months)	Main treatments: Palms with weeds, no insecticide	Main treatments: Palms with bare soil, with insecticide	*s.e.* main treatments
Collar girth (mm)		12	375	422	87
		24	1303	1397	116
		36	1515	1537	14
		42	1547	1572	21
Sexually differentiated palms (%)		24	7.0	7.5	3.8
		30	35.4	34.3	6.6
		36	78.1	82.6	6.2
		42	90.7	95.7	5.8
		48	97.9	100	4.2
Yield (nuts palm^{-1} a^{1})		36–47 (4th year)	31.8	26.8	11.4
		48–59 (5th year)	78.4	78.9	9.5
Voronoi method. Primary root apexes attacked (%)		24	10.6	2.6	6.4
		30	18.3	3.6	16.5
		36	28.8	11.2	20.3
		42	27.3	6.7	18.5
Voronoi method. Overall attack index†		24	11.1	5.4	6.8
		30	10.0	3.4	8.1
		36	9.2	5.6	5.4
		42	11.0	2.9	5.7
Segments method. Number of healthy primary root segments of given length	0.01 – 0.1 m	54	22.5	6.9	20.4
		60	29.4	17.5	8.5
	0.1 – 0.5 m	54	23.9	8.8	12.1
		60	29.8	15.3	8.6
	2 – 5 m	54	4.9	5.1	2.1
		60	1.3	3.1	1.2
	> 5 m	54	0.1	1.7	1.2
		60	0	0.2	0.3
Distance of first attack from stem (m)		54	1.53	2.71	1.42
		60	0.88	1.56	0.41
Pest adult population density (adults per 28 m^2 triangle)		42	1.5	0.5	1.9
		48	11.1	6.9	6.1
		54	19.2	22.3	7.2
		60	6.6	2.4	6.3

†number of attack points/fresh root weight (g).

that, due to contamination from neighbouring weedy plots, it is impossible to have a zero level in the bare soil treatment. It could then be seen when, and at what level of pressure, the pest has a depressive effect on coconut yields.

Observations in commercial plantings

A certain number of observations in commercial plantings backed up this root-pest hypothesis. Of course, they have no statistical value and cannot be used for demonstration purposes, but they can be taken into account simply as additional indicators to back up statistically validated trials.

i. An examination of the root system of certain coconut palms (on a canal bank), which had a better nut load than those inside the plots (see Figure 2), showed that their roots were less severely attacked. Healthy primary root segments were visible up to 1 m at least, before a new attack occurred. The attacks, therefore, did not have the continuous and repetitive nature usually found inside plots. Moreover, the *Sufetula* spp. adult population level was lower on the edge of the canal, where more light reached ground level resulting in a higher temperature, and where there were fewer ferns and erect grasses to harbour adults.
ii. When the roots of germinated nuts were examined in plots of adult coconut palms severely infested by *Sufetula* spp., it was found that the first primary roots emitted were relentlessly attacked as soon as they emerged from the nut, usually within the first 200 mm. On the other hand, one plot of a former seed garden in which upkeep had been good from the outset had no weeds, there were very few coconut residues left on the ground, and a blanket of moss in which *Sufetula* spp. adults could not find shelter largely covered the ground. In that plot, the primary roots of germinated nuts were healthy over a length of at least 0.5 m. At the same time, the yields of the dwarf coconut palms in the same field were good and uniform throughout the time the field was exploited.

DISCUSSION

Once the limiting factor had been identified, its true impact on yields remained to be determined. Notably, this was the purpose of trial 3 for which results still need to be collected for a few more seasons before the data can be presented. Nevertheless, with particular reference to the comparisons made between the yields from coconut palms on a canal bank and those inside plots, it can be estimated that the depressive effect of the pest corresponds to a 30–50 % reduction compared with the potential yield.

The next stage consists in eliminating, or at least considerably reducing, pest pressure at Pulau Burung. To this aim, two lines of research have begun:

i. Rehabilitation of the existing adult plantation; and
ii. Replanting a second generation of hybrid coconut palms.

Regarding rehabilitation, the question arises: does the additional productivity generated by the pest control techniques warrant the cost of their implementation? The two control methods described earlier had been tested on small experimental areas for demonstration purposes. It is obviously difficult to implement them over an area of 18 000 ha, not to mention the cost of application for a result that is still uncertain on such a scale. Indeed, it is not certain that all the rehabilitated adult palms will be able to achieve their production potential and, in the light of the first experiments, it is even highly likely that the productivity gain will be limited. In order to control this pest in a mature plantation covering several thousand hectares, at a cost vindicated by the increase in productivity, it will probably be necessary to combine several techniques: chemical control, cultural control with bare soil, and biological control. This last is still at the research stage.

With respect to replanting, it is known already that replanting immediately after felling old coconut palms in an environment infested by *Sufetula* spp. is not advisable: the roots of replanted young coconut palms are immediately and repeatedly attacked (Bonneau *et al*., unpublished). On the other hand, when planting is carried out in an environment that is free of *Sufetula* spp. at the outset, young coconut palms are able to establish a healthy root system, and thereby guarantee a good start to production, provided, of course, the other limiting factors are controlled. The question will therefore be whether to delay as long as possible, or completely prevent, the establishment of *Sufetula* spp. in new fields.

Research at RSUP has shown that pineapple grown in a monoculture does not attract *Sufetula* spp. (Philippe *et al*., unpublished). Given that pineapple is grown at RSUP both as a monoculture, and under mature coconut palms, it could be used in farming systems with young palms. For example, one or two cycles of pineapple could be grown after old coconuts have been felled, until *Sufetula* spp. has been eliminated from the environment. Thereafter young coconut palms could be replanted with a pineapple intercrop.

The problem with coconut replanting on peat is not limited to controlling the pest *Sufetula* spp. It also involves controlling *Oryctes* and other variables linked to the nature of the soil (Mukesh Sharma *et al*., 2000). Re-compacting the peat or adopting new systems with intercrops (pineapple in this case) are considerations.

CONCLUSION

Sufetula spp. insects constitute a very serious pest in coconut plantations on peat. It is the most plausible factor responsible for stagnating hybrid coconut yields at levels well below what they could potentially reach in plantations. Ways of controlling the insect by rehabilitation and/or replanting are being developed and will be covered in a future paper.

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