Studies on the epidemiology of spear rot in oil palm (*Elaeis guineensis* Jacq.) in Suriname

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Authors abstract

Hanny L. van de Lande, 1993. Studies on the epidemiology of spear rot in oil palm *Elaeis guineensis* Jacq.) in Suriname.

The epidemiology of spear rot, an infectious disease of unknown etiology, was studied over 10 years at three government-owned oil palm plantations in Suriname. As with other and similar diseases, amarelecimento fatal in Brazil and pudrición del cogollo in Latin America, which too show rot and yellowing, fatal to the young leaves, the affected trees die. Remission of symptoms may occur more than once during the life of a diseased palm, but is not permanent. A combination of classical and modern methods, used to analyze the temporal and spatial patterns of disease spread in the plantations, led to the conclusion that (i) there were two different patterns of dispersal, (ii) initial inoculum sources were outside the plantation, (iii) the disease was vector-transmitted (iv) disease increased logistically, and (v) dispersal was influenced by the wind. A situation where diseased trees were maintained to harvest the last bunches, led to the conclusion that blocks be abandoned at about 40% disease incidence. At that point yield was down to 50% and marginal profits from extra bunches turned to losses. Recommendations for plantation-managers and policy-makers dealt with problems of replanting, opening up new oil palm areas and prioritizing research on spear rot.

Keywords: amarelecimento fatal, critical point assessment, decision making, disease pattern, epidemiology, fatal yellowing, geostatistics, gradient, plantation management, pudrición del cogollo, remission, spatio-temporal analysis, symptomatology.

Resúmen del autor

Hanny L. van de Lande, 1993. Estudios sobre la epidemiología de la pudrición de la flecha en la palma aceitera (*Elaeis guineensis* Jacq.) en Suriname.

La epidemiología de la pudrición de la flecha, una enfermedad infecciosa de una etiología desconocida, fue estudiada durante diez años en tres plantaciones de palma aceitera que son propiedad del gobierno de Suriname. Cómo en otras enfermedades similares, tales cómo 'amarelecimento fatal' en Brazil y 'pudrición del cogollo' en la America Latina, las cuales también originan pudrición y amarillamiento, que son fatales para las hojas jovenes y finalmente producen la muerte del arbol. Remisión de los síntomas observada no era permanente. Una combinación de metodologías clasicas y modernas, usada para analizar los modelos de diseminación de la enfermedad en las plantaciones en el tiempo y en el espacio, aporto las siguientes conclusiones: (i) hay dos modelos diferentes de dispersión, (ii) las fuentes iniciales de inoculo prosedían de fuera de la plantación, (iii) la enfermedad fue transmitida por vectores, (iv) la enfermedad aumentó de manera logistica y (v) la dispersión de la enfermedad estaba enfluenciada por el viento. De una situación en que los árboles enfermos fueron mantenidos hasta la recolección de los últimos racimos, se puede concludir que las parcelas deben de abandonarse cuando la enfermedad ha afectado al 40% de los árboles. En este punto el rendimiento de la cosecha disminuye un 50% y los beneficios marginales de racimos supplementarios se convierten en pérdidas. Las recomendaciones a gerentes de plantaciónes y estrategas politicos implican problemas de replantación, apertura de nuevas áreas para el cultivo de la palma aceitera y prioridades para la investigación de la enfermedad.

Palabras clave: 'amarelecimento fatal', determinación del momento crítico, tomar deciciones, modelo de la enfermedad, epidemiología, 'fatal yellowing', la 'geostatistics', gradiente, gerencia de plantación, pudrición del cogollo, remisión, análisis en el tiempo y en el espacio, sintomatología.

Resumo do autor

Hanny L van de Lande, 1993. Estudos sobre a epidemiologia da podridão da flexa no dendê (*Elaeis guineensis* Jacq.) no Suriname.

A epidemiologia da podridão da flexa, uma doença infecçiosa de etiologia desconhecida, estudada num periodo de dez anos, em tres plantaçãos de dendê, de propiedade do governo do Suriname. Como em outras doenças similares, amarelecimento fatal no Brasil e 'pudrición del cogollo' na América Latina, que também mostram podridão e amarelecimento que são fatais para as folhas jovens, as árvores afetadas morrem. Pode ocorrer reduçao de sintomas mais de uma vez durante a vida de uma árvore doente, porém não é permanente. Uma combinação de métodos clássicos e modernos usados para analizar a desiminação da doença, no tempo e no espaco, nas plantaçãos levou a conclusão que (i) se trata de dois modelos diferentes de dispersão, (ii) as fontes iniciais de infecção eram fora da plantação, (iii) que a doença foi transmitida por vetores, (iv) a doença aumenta logísticamente e (v) a dispersão foi influenciada pelo vento. Baseado na situação onde as árvores doentes foram mantiadas para colher os ultimos cachos, pode-se concluir, que parcelas deven ser abandonadas quando a incidencia da doença chega a 40%. Neste ponto o rendimento de produção diminui ate 50% e os lucros marginais destes cachos se convertem em prejuízos. Faz-se recomendaçãos aos gerentes de plantaçãos e estrategistas politicos a respeito de problemas de replantio, aberture de novas areas para dendê e priorodade de pesquisas sobre a podridão da flexa.

Palavras chave: amarelecimento fatal, analise espaco-temporal, determinação do ponto ctitico, epidemiologia 'fatal yellowing', 'geostatistics', gerenciamento de plantação, gradiente, padrão de doença, 'pudricion del cogollo, remissão, tomada de decisão, sintomatologia.

Résumé de l'auteur

Hanny L. van de Lande, 1993. Etudes sur l' épidemiologie de la pourriture de la flèche dans le palmier d'huile (*Elaeis guineensis* Jacq.) au Suriname.

L' épidemiologie de la pourriture de la flèche, une maladie infectieuse d'étiologie inconnue, fut etudiée pendant dix ans à trois plantations au palmier d'huile apportenant au gouvernement de Suriname. Comme d'autres maladies similaires 'amarelecimento fatal' au Brésil et 'pudrición del cogollo' en Amerique hispanophone, qui ce manifestent également comme pourriture et de jaunissement les arbres affectées meurent. Rémission des symptomes ce peut passer plusieures fois pendant la vie d'une palme malade, mais elle n'est jamais permanente. Une combinaison de méthodos classiques et modernes, utilisées pour analyser le développement temporal et spatial de la maladie dans les plantations, permet de conclure que (i) il y avait deux façons differentes de dissémination, (ii) que les sources initiales de l'inoculum se trouvaient en dehors des plantations, 9iii) la maladie fut transmise par des vecteurs, (iv) la maladie progresse suivant le modèle logistique et (v) la dissémination fut influencé par le vent. Une situation permettant de maintenir les arbres malades à fin de récolter les derniers régimes laisse conclure que les parcelles doivent être abandonés une incidence de la maladie de 40%. A ce point le rendement est reduit à 50% et le profit marginal des régimes supplémentaires devient ngatif. Des récommendations ont été soumise aux gérants de plantations et aux politiciens sur les problèmes de la réplantation, du défrichage de nouveaux terrains pour la culture du palmier huile et des prioritées de recherches sur la pourriture de la flèche.

Mots-clé: 'amarelecimento fatal', analyse temporal et spatial, décisions, distribution de la maladie, épidémiologie, 'fatal yellowing', géostatistique, gradient, management de la plantation, point crtique, 'pudrición del cogollo', rémission, symptomatologie.

CONTENTS

'We shall find the real epidemic muddy and uncomfortable. And the explicit and logical analysis of our scattered observations is not less comfortable than the statement of generalities, it also puts our cards on the table for all to see. Nevertheless, we must put or shut up, striving constantly to use to the utmost the knowledge accumulated with such pain' (**Waggoner, Paul E.**, 1962. Weather, space, time and chance of infection. Phytopathology 52: 1100-1108).

1. Introduction

Importance of oil palm cultivation

African oil palm (*Elaeis guineensis* Jacq.) is one of the important oil producing crops in the world. Total world production is over 8 million tonnes of palm oil. Malaysia, the main palm oil producer, has a planted area of close to 2.0 million hectares (Anonymous, 1989a) and produces about two thirds of the world palm oil total. Oil palm is of considerable importance to South and Central America. The high market value of palm oil in the world, the need to cope with the demand of increasing populations, and the necessity to replace imported oils, to save foreign currency, contributed to a rapid establishment of large oil palm plantations. In South America, Colombia is the main producer with a planted area of over 115.000 hectares of African oil palm. Suriname, a republic since its independence, is situated in the north of South America, bordered north by the Atlantic Ocean, east by French Guiana, west and south by, respectively, Guiana and Brazil. The oil palm plantations discussed in this study are situated at about the 5th degree Northern Latitude. The climate is tropical and humid with an annual mean temperature of about 26^0 C. Four annual seasons can be distinguished, the major rain season from May to mid August, the major dry season from mid August to November, the minor rain season from December to mid February, and the minor dry season from mid February to April. In Suriname, oil palm ranks third in importance among the agricultural crops after rice and bananas. With the establishment of the oil palm industry more possibilities were created for the development of the interior and the substitution of imported edible oils.

The estimated essential fat requirement per capita is about 20 kilograms per year. With an average production of 20 tonnes of fresh fruit bunch (FFB) per hectare and an area of 3.000 hectares, it should have been possible to obtain an annual production of 60.000 tonnes of FFB. Assuming an oil extraction of 13% approximately 7.800 tonnes of crude palm oil would have been produced. Around 1981 the population of Suriname counted approximately 380.000 persons. Based on an area of 3.000 hectares the average availability of palm oil per capita was estimated to be about 20 litres per year. In order to meet the local requirements and to export part of the crude oil, the planted area was more than doubled between 1982 and 1986 (Table 1).

Table 1. Planned, planted and productive areas (in hectares) of African oil palm in Suriname between 1980 and 1992.

Plantation	Area planned	Planted area		Productive area	
		1980[a]	1986[b]	April 1991	April 1992
Victoria	1.650	1.650	1.710	700	200
Phedra	876	600	876	800	850
Patamacca	5.000	--	3.295	--	--
Smallholders	307	307	307	100	--
Total	7.833	2.557	6.188	1.600	1.050

[a] Productive area approximately 1.800 hectares.
[b] Productive area approximately 4.400 hectares.
-- Not productive.

The first commercial plantation of oil palm, Victoria, was initiated in 1969. Eight years later Phedra was started, followed by the establishment of the Patamacca plantation between 1981 and 1986. The plantations, all government-owned, are situated in the interior of Suriname in the districts of Brokopondo, Para and Marowijne, respectively. The smallholder plantings are situated next to Victoria at its southern border.
This complex of palm oil production and processing industries offered employment to over 700 persons in 1986. With the area of oil palm extending, the import of edible oil became superfluous and the possibility of establishment of other local industries such as soap factories came within reach.

In early 1992, the total planted area had shrunk from about 6.200 (in 1986) to approximately 5.100 hectares, of which only 1.050 hectares of oil palm were in production. At Victoria and Phedra, the planted area decreased to approximately 40%, primarily due to spear rot or fatal yellowing. The largest and youngest area, Patamacca, needs to be cleaned from weeds and affected trees after a 5 year period of negligence resulting from inaccessibility of the plantation (Van de Lande, 1990a) due to political problems in the interior of the country.

Occurrence of spear rot or fatal yellowing in Suriname

The most important phytosanitary problems in the cultivation of the African oil palm in Suriname are spear rot or fatal yellowing, an infectious disease of unknown etiology, Marchitez sorpresiva (Van de Lande, 1986), attributed to flagellates, and *Castnia daedalus*, an insect pest. As a result of years of research on the latter two problems, effective control possibilities are within reach (Genty, 1981; Van Slobbe, 1983). Spear rot, a fatal disease with limited control possibilities in the short run is considered the number one problem of oil palm (Van de Lande, 1986, 1990a) in Suriname, and in all of Latin America.

Spear rot or fatal yellowing is a disease which is characterized by rot of spears and a gradual chlorosis, which starts in the youngest leaves and proceeds with time to the middle and older leaves. The name spear rot is the English translation of the Dutch word 'speerrot', generally accepted in Suriname. The explanatory addition of 'fatal yellowing' is used in accordance with the nomenclature by Turner (1981) to keep in line with the Spanish 'pudrición del cogollo' and to distinguish it from 'pudrición de la flecha', which is a non-fatal problem in oil palm.

The disease was found for the first time around 1976 in a 4 year old planting of Victoria. For years, spear rot only occurred incidentally in a few blocks. Six years later, in 1982, focal development of the disease was encountered in several blocks of the 1972 to 1973 and the 1980 plantings in the north of Victoria (Van de Lande, 1986). Between 1982 and 1984, diseased trees were eliminated immediately after detection during phytosanitary rounds. Meanwhile, research was started to elucidate the etiology, symptomatology and the epidemiology, and to control the disease. In spite of several phytosanitary measures disease progress was exponential in several blocks of northern Victoria. Considering that diseased trees bore normal bunches, that they had an average disease duration of two and a half to three years and that the plantings in northern Victoria were economically of high age, the management of Victoria decided to maintain most of the affected palms in the northern part of the plantation to benefit from their production as long as possible (Van de Lande, 1990a). In spite of eradication of affected trees in the initial stage of the disease, which was carried out in the southern part of Victoria between 1985 and 1990, the disease continued to spread within blocks. At the same time spear rot started to spread throughout the smallholder plantings which, since they were deprived of any phytosanitary action, probably contributed to the infection of the southern part of Victoria.

Pudrición del cogollo and amarelecimento fatal in South America

The first mention of a disease with similarities to spear rot or fatal yellowing in Suriname dates back to the early sixties from the Arenosa plantation in Turbo, Colombia (Turner, 1981). Within few years a disease, named pudrición del cogollo (PC), wiped out the entire plantation (Turner, 1981; Renard and Quillec, 1984; Anonymous, 1989b). The disease was also present in Panama and probably in Nicaragua (Van Slobbe, 1990). In the early eighties, a transition from isolated cases to focal development of a disease, named amarelicimento fatal (AF; Martins e Silva and Oliveira Freire, 1990) was observed at the Paricatuba plantation near Belém in Brazil, very similar to the spear rot situation at Victoria (Van de Lande, 1986) in Suriname. About 1983 mention was made of a comparable PC problem occurring at plantations in Ecuador (Perthuis, 1990b). The number of plantations afflicted with these respective diseases has grown steadily since.

The disease continues to spread in the affected plantations and no effective means of control are available yet. Replanting of formerly affected and cleared areas is not recommended considering the danger of infection of the newly planted areas at a young age (Anonymous, 1974; Turner, 1981; Renard and Quillec, 1984; Van de Lande, 1990b), so that investments in the layout of plantations and in corollary infrastructure are lost.

Spear rot endangering the oil palm cultivation in Suriname

In Suriname oil palm has been cultivated at a commercial scale for over 20 years now. With the growing number of diseased trees developing towards the advanced stage of spear rot, the production of bunches decreased steadily and maintenance costs increased because of weed development in areas with almost defoliated palms. The management of Victoria was left no choice but to abandon, burn down and clear the heavily affected blocks as soon as these were no longer of economical interest. The consequences are tremendous. Labour costs went up because of increased activities in the phytosanitary and maintenance section and the yield of fresh fruit bunches decreased gradually. In 1992, with the originally planted area of Victoria reduced to less than one seventh within 10 years after focal outbreaks of disease, the continuity of oil palm cultivation in Suriname and of the employment of over 400 people is endangered. An important part of the edible oil needs is met again by imports of, predominantly, soybean oil.

Research on spear rot and other fatal yellows in Suriname and elsewhere in South America

After finding focal development of the disease in 1982, the frequency of phytosanitary rounds at Victoria was increased in order to localize the affected trees earlier. Between 1982 and 1990, research efforts were focused in the fields of agronomy and pathology. Experiments were undertaken to

1. test the effect of applications of micro-nutrients (Van Slobbe, 1984),
2. evaluate the effect of surgical removal of affected parts and treatment of the wound with disinfectants (Van de Lande, Cloesen and Jubithana, unpublished),
3. isolate and test the pathogenicity of several fungi and bacteria (Van de Lande, 1984),
4. evaluate the prophylactic treatment of supposedly healthy trees with a variety of chemicals (Van Dijk and Van de Lande, 1990; Van de Lande, unpublished), and
5. eradicate the disease by cutting isolated trees and trees in foci including a border area (Van Slobbe, 1984; Van de Lande, 1990a).

In the southern part of Victoria, between 1985 and 1990, affected trees were killed immediately after their detection during phytosanitary rounds. But as a result of ongoing problems of political nature in the interior of Suriname during the same period, the day-to-day routine at the plantations suffered. Too often, phytosanitary rounds were interrupted for days or even weeks so that affected trees could be killed in an advanced stage only. Despite all actions the disease did not slow down at Victoria. At Phedra and Patamacca, affected trees were removed except for the troublesome period in the interior between 1986 and 1990 (Van de Lande, 1990a).

The fatal character and the wide occurrence of 'spear rot' in Suriname, 'amarelecimento fatal' in Brazil and 'pudrición del cogollo' in Spanish speaking countries in South and Central America urged several scientists working in the field of oil palm throughout the world to combine their research strengths (Martins e Silva and Oliveira Freire, 1990) to gain insight in the etiology, epidemiology and control of these diseases.

During the past five years research concentrated in the fields of phytopathology, entomology, virology, agronomy and breeding (Anonymous, 1989b). Preliminary results were presented at an international seminar devoted to spear and bud rot diseases, held in Paramaribo, Suriname, 1988 (Barcelos and Amblard, 1990; Celestino Filho and Lucchini, 1990; Louise, 1990; Martins e Silva and Oliveira Freire, 1990; Perthuis, 1990a, Van Dijk and Van de Lande, 1990; Van de Lande, 1990a and Van Slobbe, 1990). In the short run, no effective control means are available. In the long run, solutions are to be found in breeding for resistance which will take some twenty years more (Barcelos and Amblard, 1990).

Outline of this thesis

Studies on the epidemiology of spear rot of African oil palm in Suriname began in 1983. Chapter 1 summarizes the situation of oil palm and the detrimental effects of spear rot or fatal yellowing on this crop in Suriname, South America. In chapter 2 symptomatological and histopathological studies are reported to find indications about the etiology of the disease. In chapter 3 the symptom remission is studied to elucidate the origin of fluctuations in the occurrence of remission. In chapter 4 disease progress in time is analyzed and four mathematical models are fitted to the disease incidence data. Epidemics in the Victoria and Phedra plantations, with their different disease histories, are compared in chapter 5. Epidemic rates are related to environmental parameters. The spatial pattern of spear rot epidemics in selected blocks at Victoria and Phedra is analyzed in chapter 6 by semivariogram and gradient analysis to gain insight in the behaviour of the disease and to trace physical and biological mechanisms which may underlie the development of spatial patterns. In chapter 7 the relation between the evolution of spear rot progress and the decrease in fresh fruit bunch yield is studied to determine the critical point where bunch yield becomes limiting because of accumulating losses. The results of this study are intended to provide recommendations for optimal management of the plantations (chapter 8).

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2. Overview of spear rot or fatal yellowing of African oil palm in Suriname, South America

(Submitted, author Hanny L. van de Lande)

Abstract: For more than eight years studies were conducted on the epidemiology and symptomatology of spear rot or fatal yellowing, a disease of unknown etiology in oil palms in Suriname. The palms were studied in different developmental stages of the disease. Remission of disease occurred in individual palms but was not permanent. Symptom expression and disease duration could differ between young and adult palms. Seasonal variation in symptomatology was present. Histopathological studies carried out by light microscopy did not reveal the presence of microorganisms in association with spear rot affected tissue. Intensification of research is urgently needed to provide more insight into the epidemiology and control of this devastating disease.

Keywords: *Elaeis guineensis*, fatal yellowing, epidemiology, symptomatology, seasonal variation, histopathology.

Introduction

Spear rot or fatal yellowing (Turner, 1981) of oil palm (*Elaeis guineensis* Jacq.) was first detected in Suriname at the Victoria plantation about 1976 (Van de Lande, 1986). A disease similar to spear rot and known as pudrición del cogollo (PC) in Turbo, Colombia (Turner, 1981; Anonymous, 1989), wiped out the entire Arenosa plantation during the early seventies. The disease is also known under that name in other Spanish speaking countries in South and Central America. The most important feature of PC is chlorosis of the young leaves, accompanied by partial rot of the spear leaves. In Brazil, a disease similar to spear rot (Van de Lande, 1986) and known first as guia podre, podridâo da flecha (Van Slobbe, 1990a) and podridâo do broto final (Van de Lande, 1986) was later renamed amarelecimento fatal (AF) according to Van Slobbe (1990a). The palms affected by spear rot, amarelecimento fatal and pudrición del cogollo ultimately die (Van de Lande, 1986; Anonymous, 1989; Perthuis, 1990a; Van Slobbe, 1990b).

Spear rot or fatal yellowing of oil palm is a disease of unknown etiology (Van de Lande, 1990b). The disease has an epidemic character (Van de Lande, 1986; 1990b). In earlier studies (Van de Lande, 1984) no pathogenic fungi and bacteria could be isolated from affected spear leaves of diseased palms. The economic significance of the disease in Suriname is beyond doubt, and the exploitation policy of the plantations had to be changed radically (Van de Lande, 1990a).

This study attempts to give an overview of the epidemiology, symptomatology and histopathology of palms affected by spear rot or fatal yellowing at three plantations in Suriname.

Materials and methods

Locations and observation period. Between 1982 and 1991 more than 400 palms were examined externally and internally at plantations in Suriname; Victoria, Phedra and Patamacca (Figure 1), located in the interior in the districts of Brokopondo, Para and Marowijne, respectively. In addition, several hundreds of palms were examined for external symptoms at these plantations in dry and rainy seasons.

Layout of the plantations. The plantations are divided in blocks or subblocks. In most cases palms were planted in rows according to a triangular 9x9 m or 8.5x8.5 m design.

Disease assessment. Spear rot incidence (= proportion of diseased trees relative to the total number of trees) was assessed through frequent detection rounds by technicians of the phytosanitary departments at the respective plantations and by the author who, in an area infested by spear rot, inspected all trees for the initial symptoms of the disease. For examination of the internal symptoms, selected palms were felled and dissected by chain saw, machete and dissecting knife.

Developmental stages. The initial, advanced and final stages of the disease were assessed according to procedures reported earlier (Van de Lande, 1986). The three characteristic stages of development of the disease were: slightly affected palms with few chlorotic leaflets in one leaf, palms with up to ten chlorotic leaves, and palms with over ten chlorotic and/or broken central and middle leaves respectively. Chlorosis of central leaves is usually accompanied by rot of spear leaves.

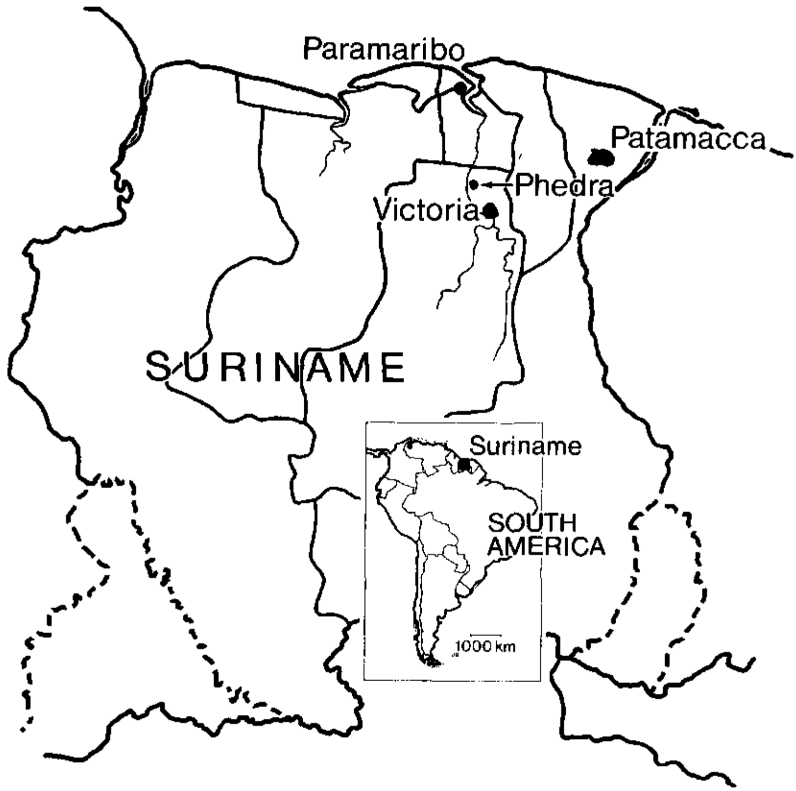

Figure 1. Situation of the Victoria, Phedra and Patamacca plantations in Suriname, South America

Disease duration. Once a palm is affected by spear rot the tree might go back and forth to a certain developmental stage of the disease (Van de Lande, 1986); the approximate period to any disease stage was assessed by calculating the time elapsed since the first detection date of initial symptoms.

Histopathological studies. From June to October, 1989, anatomical studies with light microscope were made from leaf and stem tissues of young and adult palms in varying developmental stages of spear rot at Victoria. Tissues sampled at comparable locations in green, supposedly healthy oil palms served as a check. Palms in various developmental stages of the disease were chosen at random from blocks of different planting years. The palms were felled by chain saw. Starting with approximately leaf number thirty, a palm was stripped leaf by leaf and petioles and rachis were dissected to study the symptoms of the young leaves and inflorescences. When some of the palms examined lacked the youngest unfolded leaves, samples for anatomical examination were taken generally from the petiole just below the lowermost leaflets, and from rachides of the spear leaves (numbers -1 to -7, number -1 being the oldest spear leaf and the first one to expand; the youngest expanded leaf is leaf number 1) including the young central leaves present. Trunk tissues were sampled about ten centimetres below the growing point. In green palms samples were taken from locations corresponding to those described for affected palms. Freehand longitudinal and cross sections of the fresh material were mounted in water or in a solution of cotton blue in lactophenol for examination under the light microscope.

Results

Topography of plantations. Plantations were arranged in blocks of variable sizes and shapes, depending on the topography, with areas from close to three to over 40 hectares. Blocks (at Victoria-North numbered 1 to 35) were irregular in shape due to gullies and marshy areas (Figure 2). The plantations in Suriname are surrounded and intersected by primary and/or secondary forest.

First appearances. Spear rot was found in all ages of plantings, irrespective of the provenance of the material and of soil types. At all three plantations, initially, isolated palms with spear rot were found predominantly at the border and, occasionally, in the centre of a block. The disease appeared in foci of three to four trees from 1982 onwards.

Year of first disease record. Spear rot was found for the first time about 1976 at Victoria in the 1972 plantings. The disease increased notably during 1982 in the 1972 and 1973 plantings. In a 1980 block, spear rot was observed within one year after planting. At Phedra, spear rot was seen in 1981 in the 1978 plantings; it increased steadily. Focal development occurred within three years. In young plantings of Patamacca, the disease was observed within two years after planting but it stayed at a low level.

In conclusion, early records of spear rot were made between one and four years after planting, at the three plantations in Suriname.

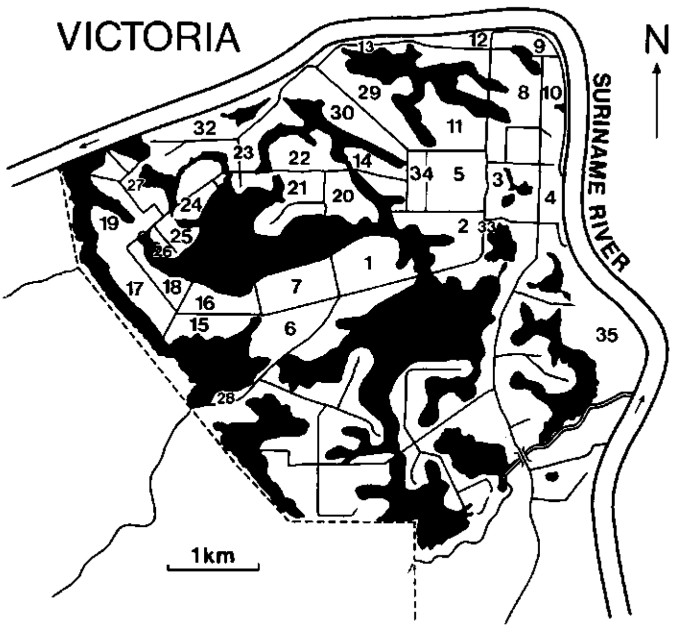

Figure 2. Situation of the Victoria plantation (Suriname), and blocks in the northern part (in black: forest, swamp area and gullies).

Disease duration. Observations of adult palms in highly infested areas at Victoria indicated an average duration of spear rot symptoms from the initial (only few leaflets of one leaf affected) to stage three (less than ten green outer leaves left) of the disease development between one and a half and two years. The shortest period from initial to final stage was ten months.

Disease situation. At Victoria, disease progress of spear rot was linear at first but by mid 1985 a transition to exponential growth was observed. By 1989 about one third of the planted area at Victoria was abandoned, mainly because of tree death due to the disease; early in 1992 less than one fifth of the area was still in production. Over 85% of the planted palms were diseased or dead. At Phedra over 10% of the palms were affected in 1992. Here, diseased and suspected palms were cut at regular intervals after detection during monthly inspection rounds, as a phytosanitary precaution. Both at Victoria and Phedra there are indications that spread of the disease is influenced by the direction of the wind. At Patamacca, up to 1986 affected palms were removed immediately after detection during phytosanitary visits at monthly intervals. Due to the political situation in the interior of Suriname there was no access to this plantation for almost 5 years. At the end of 1986 spear rot incidence at Patamacca was less than 0.001.

Control measures. Removal of affected trees in the south of Victoria between 1988 and 1990 and at Phedra between 1988 and 1991, within two days after their detection during phytosanitary rounds at approximately one month intervals, did not stop the disease spread. At both plantations disease progress was exponential. At Patamacca no phytosanitary measures were carried out between 1987 and 1991.
The hybrid of *Elaeis oleifera* and *E. guineensis* descending from crossings of Colombian and Surinamese *oleifera* and planted in a one hectare plot in north Victoria in 1978, appears to be resistant to spear rot. In all blocks surrounding this plot the majority of palms are either affected or killed by spear rot.

Histopathology. Histopathological studies were carried out at Victoria between April and November during the rainy and dry seasons of 1989. Out of 24 affected palms from the planting years 1971, 1973, 1974 and 1984, eleven trees were in the early stage of the disease and were detected less than six months before dissection. The remaining palms were in the advanced or in the remission stages of the disease and were approximately between six months and two years with spear rot symptoms. The presence of tyloses and gum-like substances was assessed in samples taken from the rachides and petioles of affected spear leaves. Only 5% of vascular bundles showed partial blockage. Parenchyma, sclerenchyma and phloem tissues generally appeared normal. Xylem and sclerenchyma displayed a brown colour when high numbers of xylem cells were blocked. One young (1974) palm showed irregularly dispersed brown spots in the trunk tissues below the apex. Here, the parenchyma showed meristematic cells and blockage of xylem cells. The majority of young male and female inflorescences, enclosed in their spathes, were brown or glossy. There were no microorganisms found in association with the phloem, xylem or parenchyma cells. Tissues from supposedly healthy palms, used as a check, showed no deformations whatsoever.

Figure 3. Spear rot or fatal yellowing in oil palm. Healthy tree (left) and diseased palm (right) with chlorosis of central leaves; note the circular form in the healthy contrasting to the flat top of the diseased tree.

Figure 4. Spear rot or fatal yellowing in oil palm. Broken spears and chlorosis (see arrow) of young leaves.

Figure 5. Spear rot or fatal yellowing in oil palm. Part of a focus with trees in the final stage of the disease.

External symptoms. Palms in the initial stage of spear rot presented necrotic patches in several leaflets of one or more spears and chlorosis of a few leaflets in unfolded leaves 1, 2 or 3. In some palms, however, chlorosis was hardly visible. The yellowish colour could be restricted to one part of a leaf or could have an irregular pattern. Young palms in the early stage of spear rot had a more pronounced drying of leaflets than adult palms. In the advanced stage (over six months) more leaves had chlorosis (Figure 3) and often one or more spears were broken (Figure 4) in the middle or near their base. With time chlorosis gradually spread from the central (usually, leaves one to ten) to the middle leaves (usually, numbers ten to twenty). In the advanced to final stages (Figure 5) all central leaves and most of the middle leaves were broken, giving the trees a flat-top appearance (generally, over one and a half years with spear rot). During the dry season young chlorotic leaves had a pronounced yellow to orange-yellow colour, as compared to the rain season when chlorosis tended more towards yellowish-light green. Breaking of spear leaves occurred during heavy rainfall, mostly at the onset of the rain season.

Irrespective of the disease stage or age of palms, bunches appeared normal in the first and second year of spear rot. They became smaller towards advanced stages of the disease, when fewer leaves were left.

Remission of the disease, indicated by the production of new green and seemingly healthy, though slightly smaller than normal, leaves occurred in individual palms irrespective of the disease stage. The remission phase could last from less than one to over six months. A single tree could pass through the remission phase more than once.

Internal symptoms. Irrespective of the external symptom expression internal symptoms could be quite variable. Whereas some palms with the initial symptoms of chlorosis and rot of spears showed no or only slight rotting of rachis and leaflets of spears, other palms with comparable external symptoms showed advanced wet rot of young enclosed spears, sometimes including the apex. Generally speaking rot of spears remained over 40 cm away from the growing point in adult palms over one year old. In young palms however apex rot occurred more frequently. Rot of the upper part of inflorescences, enclosed in their spathes, occurred more frequently in young than in adult palms. Independent of age or seasonal variation rot of spears was either watersoaked or dry.

Studies, performed on eight adult palms revealed only a few secondary roots with slight tip necrosis. In two supposedly healthy palms root tip necrosis was incidentally found.

Discussion

Occurrence of spear rot. Considering the geographical location of most early disease cases, irrespective of plantation, there seems to be a relationship between early disease incidence in the border of a block and the nearby presence of secondary or primary forest in Suriname as in Ecuador (Perthuis, 1990a).

Considerable concern arose in the early 1980's with the transition of isolated to focal incidences (Van de Lande, 1986, Van Slobbe, 1990a). A substantial increase of the disease was found in 1982 to 1983 in Surinamese plantations as well as with AF in Brazilian (Van de Lande, 1986; Van Slobbe, 1990b) and with PC in Ecuadorian plantations (Perthuis, 1990a). At most plantations in Suriname and in Brazil (Van de Lande, 1986) disease developed initially in one to four year old plantings and later in plantings of other ages.

Incubation time. Since the disease could be found within one year after planting healthy young palms in a cleared area, the incubation time must be about one year or slightly less. An incubation period of about 15 months was assumed in plantings in Ecuador (Perthuis, 1990b). In Colombia the incubation period of PC appeared to be about one year (Turner, 1981; Van de Lande, 1990b).

Age dependant susceptibility. Trees of any age may be affected and there is little evidence of an age dependant susceptibility in palms affected by spear rot or fatal yellowing. Symptom expression, however, may depend on the age of the tree. Similarly, PC and AF were found in trees of any age (Turner, 1981; Van Slobbe, 1990b).

Disease duration. Disease duration in the plantations of Suriname varied from about one to two years. Similar variation was observed elsewhere (Colombia: Turner, 1981; Brazil: Van de Lande, 1986; Van Slobbe, 1990b). Typically, disease duration of PC in Amazonian Ecuador was much shorter, about two months or less (Perthuis, 1990b). Disease duration at Victoria, Suriname, seemed to be 24 to 36 months in the early years (Van de Lande, 1984, 1986). In recent years (around 1991) disease duration was about two years, or less. This shortening might be an effect of increased inoculum pressure in blocks where the affected trees were not regularly removed since 1985 (Van de Lande, 1990a). Lack of maintenance caused the continuous presence of weeds (Van de Lande, 1990a). The shortening of the disease duration might be due also to increased competition by weeds as a consequence of negligent management.

Disease situation. A transition in disease progress from linear to exponential was also observed in Brazil (Anonymous, 1989, Van Slobbe, 1990b). A wind effect on the spread of the disease (AF) was also observed in Brazil (Celestino Filho and Lucchini, 1990).

Control. So far, control of spear rot by elimination of affected trees has not been successful in Suriname. In Latin America, disease dispersal within blocks was at a higher level at locations where affected trees were not removed (Anonymous, 1989). In Brazil, there were indications that the disease slowed down after stringent measures in the eradication programme (Van Slobbe, 1990b). However, nowhere was disease brought to a halt. It is concluded that negligent management, leading to the presence of weeds or the absence of stringent eradication, can aggravate the disease situation.

Resistance of a hybrid of *E. oleifera* x *E. guineensis* to PC and AF, known in Latin America (Turner, 1981; Anonymous, 1989), was confirmed for Suriname.

Histopathology. In most palms, the rot had not yet advanced close to the base of the youngest spear leaves. Tyloses in the xylem vessels were predominantly associated with tissues in symptomatic leaves. Generally speaking, tyloses are found more frequently in affected than in healthy plants (Wood, 1967). According to Esau (1960) the formation of tyloses does not seem to be restricted to a case of infection, since they are also found in the vessels of the sapwood when conduction ceases due to wounds. According to Wood (1967) tyloses may also be a response of the plant to abnormally abundant growth promoting substances or to the presence of parasites which inhabit the xylem. Using light microscopy parasitic microbial organisms were not found in association with affected tissues. Neither in Brazil (Kastelein *et al.*, 1990) nor in Ecuador (Anonymous, 1989) were microorganisms found in association with affected tissues.

Singh *et al.* (1988) reported the presence of viroids in tissues of affected palms. Intensification of these studies is needed to assess their possible relation with spear rot, AF and PC.

Symptomatology. The present study of spear rot symptoms confirms earlier observations (Van de Lande, 1986) at Victoria in Suriname. There is no clear relationship between the external symptoms of the affected palms and the internal symptoms of the tissues of spear leaf and inflorescence. The occurrence of a remission stage, with one to several green, seemingly unaffected central leaves (Van de Lande, 1986) makes a field estimation of the life span of affected palms difficult. In adult palms there is little variation in symptoms of spear rot except for clear differences between dry and rainy seasons as to the colour of chlorotic leaves and the breaking of central leaves. No data regarding this aspect were available from other countries. Remission was also observed in palms with PC in Colombia (Turner, 1981) and AF in Brazil (Van de Lande, 1986, Van Slobbe, 1990b). Symptom expression, as regards rot of young spear leaf tissues, is more distinct in young than in adult palms, in Suriname. Perthuis (1990a) mentioned the rapid destruction of the growing point of the palm in plantings with PC in Ecuador. The shorter distance between rotting tissues and apex in young palms is probably due to the shorter length of the spear column as compared to adult palms. This could explain the more frequent occurrence in young palms of affected inflorescences, still enclosed in their spathes.

Compared to all the other locations studied, the symptomatology of PC in Ecuador was different. Rot proceeded very fast towards the apex (Perthuis, 1990a), and nearly always led to a wet rot of both spear and apex tissues. In fact, such palms never reached the final stage of PC because of rapid destruction of apex tissues in the early stage of the disease and early death of the entire tree.

Tip rot of secondary roots was sometimes found in adult palms but may be normal, since a measurable though low root rot incidence may occur in healthy palms too. Root samples of young palms were not included in the present studies. According to Perthuis (1990a) roots remain healthy in palms with PC in Amazonian Ecuador. Kastelein *et al.* (1990) mentioned the decay in tips of primary roots in the initial stage of PC and AF, but they did not mention the age of the palms dissected. Probably they used young palms with root systems not yet extended over large areas.

In conclusion, there is little variation as to the symptomatology of the three diseases in Suriname (spear rot), Brazil (AF) and Colombia (PC). In view of the frequent occurrence and rapid development of wet rot of internal spear tissues of affected palms in Amazonian Ecuador, symptomatology of PC is different from the other locations in South America.

Considering the subtle but distinct differences in the symptomatology of spear rot between adult and young palms, and the seasonal variation in symptom expression with respect to leaf colour and breaking of central leaves in spear rot palms, it can be concluded that symptomatogical studies should always be performed at regular intervals, over at least a one year period.

Spear rot, AF and PC are diseases with striking similarities in their symptomatology at several Surinamese, Brazilian and Colombian locations. The similarities in external as well as internal symptomatology of spear rot (Van de Lande, 1986,), AF (Martin e Silva and Oliveira Freire, 1990; Van Slobbe, 1990a) and PC (Turner, 1981) in these countries are as obvious as are the differences from PC in Amazonian Ecuador (Perthuis, 1990a). The main symptoms of the disease(s) in the four countries are chlorosis and necrosis, which always start in the youngest leaves and proceed to the outer leaves. One might confuse spear rot, AF and PC with the initial stage of red ring disease of oil palm (Van de Lande, 1986), which is associated with a vector-nematode complex (Schuiling and Van Dinther, 1981).
Renard and Quillec (1984) stressed the hazardous effects to the oil palm cultivation of vascular wilt disease in Africa and marchitez and spear and bud rot diseases at several plantations in South America. Vascular wilt and marchitez are wilt diseases with symptoms starting, generally, in the outermost leaves and progressing fast to the youngest leaves (Van Slobbe *et al.*, 1978, Van de Lande, 1986). In these two diseases the organisms, *Fusarium oxysporum* in vascular wilt and *Phytomonas sp.* associated with marchitez affected palms, are found in the xylem and phloem, respectively. Bunch and inflorescence rot are part of the disease syndrome in vascular wilt disease, red ring disease and marchitez, but not in spear rot, AF and PC. We may thus conclude that spear rot, AF and PC are not wilt diseases.

The vital question is whether spear rot, amarelecimento fatal and pudrición del cogollo represent three different facets of one disease, due to one unknown causal agent, or three diseases due to three different causal agents. Symptomatology cannot be decisive as the three common names of the disease(s) already indicate. Differences in symptomatology, if only one causal agent is involved in all three diseases, may be due to climatic, edaphic or genetic causes, differences in vectors, or differences between local strains of the causal agent. However, the hypothesis of three different causal agents as yet cannot be rejected.

The causal agents of spear rot, amarelecimento fatal and pudrición del cogollo have not yet been elucidated. Effective control measures are not yet available. The search for disease resistant interspecific hybrid material, suitable for commercial planting in different countries, is in progress (Anonymous, 1989), but will take some twenty years more (Barcelos and Amblard, 1990). The effects of the disease(s) on the palm oil industry in South America are disastrous. We consider spear rot or fatal yellowing, amarelecimento fatal and pudrición del cogollo of overriding importance to the palm oil industry in the world and stress the urgent need to proceed with the search for the causal organism(s) and for effective control measures.

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3. Remission of spear rot in the African oil palm at Victoria, Suriname

(Submitted, author Hanny L. van de Lande)

Abstract: Spear rot is a fatal disease of oil palm (*Elaeis guineensis* Jacq.) in Suriname. An account is given of the performance of remission of spear rot disease at the Victoria plantation in Suriname over 20 months during the years 1985 and 1986. A close relationship was found between remission fluctuations over time, indicating respectively decrease or increase in the incidence of remission and excess or deficit in total monthly precipitation over the month preceding the remission. There was no clear relationship between decrease in remission incidence, indicated by the breaking of spear leaves at the onset of the rain season, and increased wind velocities measured at the meteorological station 60 kilometres north of Victoria. Despite the relatively high incidence of the disease in individual palms, which linger on in the remitted condition over six months, the origin of the remission phenomenon remains obscure. As the infectiousness of the remitted palms is unknown, they should not be maintained but destroyed.

Keywords: *Elaeis guineensis* Jacq., epidemiology, remission.

Introduction

Spear rot disease (Van de Lande, 1986; Turner, 1981) affects the young spears and unfolded leaves of the African oil palm (*Elaeis guineensis* Jacq.) and leads to the death of the tree once the growing point is affected. Pathogenesis may take several months to three years (Perthuis, 1990; Van de Lande 1986; Van Slobbe, 1987).

Remission of the disease was observed in individual palms in some periods of the year. In such cases the diseased palms produced apparently healthy new leaves. This remission was observed irrespective of the developmental stage of the disease (Van de Lande, 1986). Ultimately, all diseased palms die, with or without remission. The remission phase may last over twelve months and may occur several times during disease progress. The production of apparently healthy new leaves with a potential of normal inflorescences is essential for bunch production (Hartley, 1977) which continues or resumes during the remission phase.

This knowledge justified a study of the proportion of palms with remission and to assess the performance of such trees in different seasons.

Materials and methods

Location and duration of study. This study was conducted at the Victoria oil palm estate in the Brokopondo district of Suriname for two years beginning 1985. Eight blocks representing five planting years were chosen for biweekly observations on the occurrence and the duration of the remission phase in the palms. The blocks, counting from 325 to 3350 trees, some 12,400 in total, were located in different sections of the plantation (Van de Lande, submitted; Table 1).

Disease appearance. Spear rot was initially found in blocks 7, 23-II, 25-I, 26 I+II and 33 about 1982. Over one year later its incidence was assessed in blocks 3, K-IV and T-II.

Disease assessment. Spear rot phases were assessed by personnel of the phytosanitary department of Victoria according to a certain protocol (Van de Lande, 1986). Palms which were marked as affected by spear rot at a previous phytosanitary visit, but which produced green leaves at the time of observation, were considered to be in the remission phase of the disease. The frequency of remission was expressed as the number of palms in the remission phase relative to the total number of spear rot affected palms in each block. During 1988 and 1989 additional symptomatological studies were made of adult palms with remission in various blocks. Apparently healthy palms of comparable age served as a comparison. Palms were dissected with the help of a chain saw.

Meteorological data. Precipitation data were obtained from Victoria. Monthly totals from two locations in the plantation were averaged. Wind velocity data were obtained from the nearest meteorological station at Zanderij airport, approximately 60 kilometres north of Victoria.

Table 1. Incidence of spear rot in eight blocks at Victoria in Suriname over 21 months during 1985 - 1986.

Block number	Planting year	Observation period	Location in the plantation	Disease incidence at start
3 #	1971	02-04-'85 to 06-06-'86	NE	12.9 %
7 #	1971	19-02-'85 to 10-06-'86	NW	8.8 %
23-II	1972	04-04-'85 to 06-03-'86	NW	58.0 %
25-I	1972	02-04-'85 to 19-05-'86	NW	24.2 %
26-I+II	1972	03-04-'85 to 04-04-'86	NW	14.0 %
K-IV	1973	03-04-'85 to 09-10-'86	SE	2.6 %
T-II	1975	03-04-'85 to 31-10-'86	SE	1.3 %
33	1980	02-04-'85 to 29-10-'86	NE	15.6 %

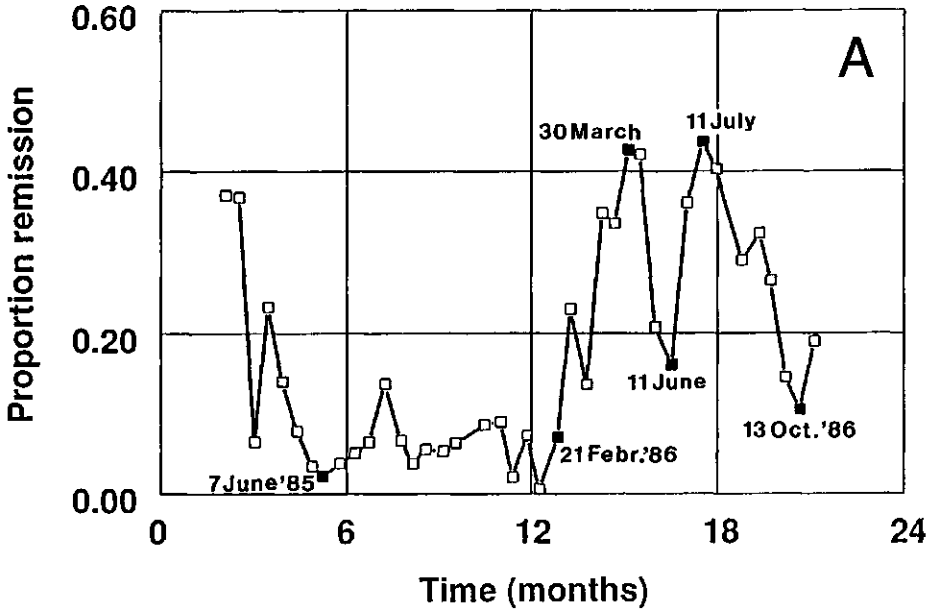
Part of block, comprising focus.
NW North West.
NE North East.
SE South East.

Results

Some observations on remission. With some exceptions, biweekly observations on disease and remission were carried out from April 1985 to October 1986. Initial disease incidence in the blocks varied from about one to over fifty-five per cent (Table 1). When spear rot incidence exceeded sixty per cent the observations were discontinued. This level was reached after approximately one year in the blocks 23-II, 25-I and 26-I+II. This study came to an end in October, 1986, when the estate was closed down due to political problems.

Palms with remission comprised trees in the early phase of the disease as well as palms which were in the advanced phase of the disease. Generally, palms in the remission phase with a short history of spear rot disease produced leaves of approximately the same length as the corresponding leaves of healthy palms. Palms with a spear rot history of over twelve months, showing advanced disease symptoms, generally produced green but relatively short leaves during remission, as compared to corresponding leaves of comparable leaf position in healthy trees. Palms never showed recovery. In studies, performed between 1988 and 1989 it was shown that in a few adult palms with over 12 apparently healthy leaves, part of the young inflorescences usually up to leaf 8, showed necrosis. In such cases the spear leaves were apparently healthy. In palms with remission symptoms, generally, inflorescences of spear and apparently healthy leaves were of approximately the same size as the corresponding leaves in apparently healthy palms. Remitted palms which relapsed into the diseased state sometimes showed breaking of the petiole or the rachis of one or more leaves. Often, the breaking was observed at the onset of the wet season with its heavy rainfall. Leaves, which had just toppled over, seldom showed wet rot of tissues. Lesions (Van de Lande, in press.) were generally present in the lower part of several leaflets or at midrib spines along the rachis of one or several affected spears. Sometimes, lesions were also found in the upper part of the leaf laminae and along the petioles. Necrotic leaflets and rachis tissues were still firm in the older spear leaves.

Proportion of remission. Figure 1 shows the number of trees with remission relative to the total number of diseased palms, counted fortnightly in blocks 3, 7, 23-II, 25-I, 26 I+II, 33, K-IV and T-II. Incidence of remission in block 3 (Figure 1A) decreased over the months of April to June 1985. Remission incidence increased in a pattern fluctuating between approximately 0.0 and 0.1, increasing faster to a proportion over 0.4 between February and the end of April, 1986.


A
Proportion remission
Time (months)
0.60
0.40
0.20
0.00
0
6
12
18
24
30 March
11 July
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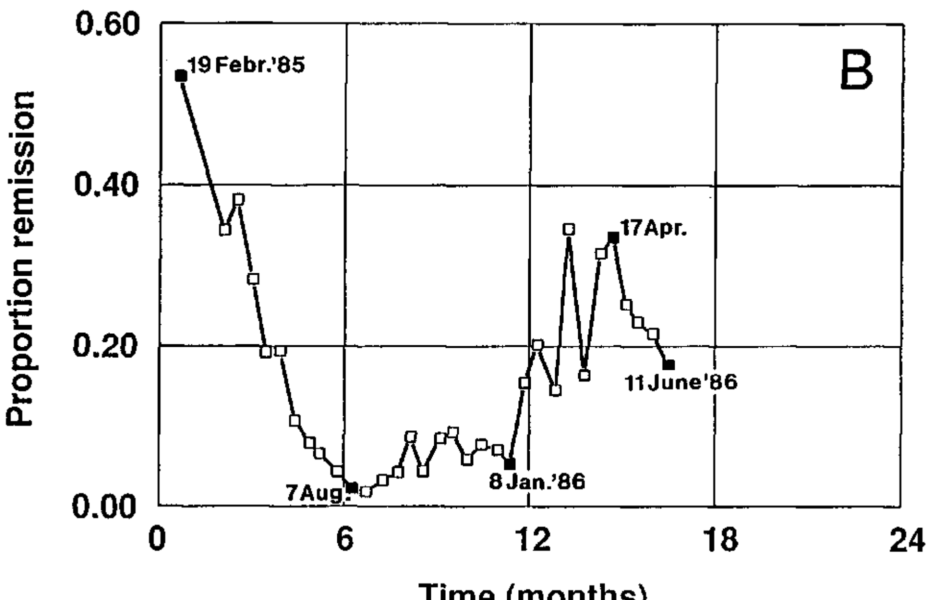
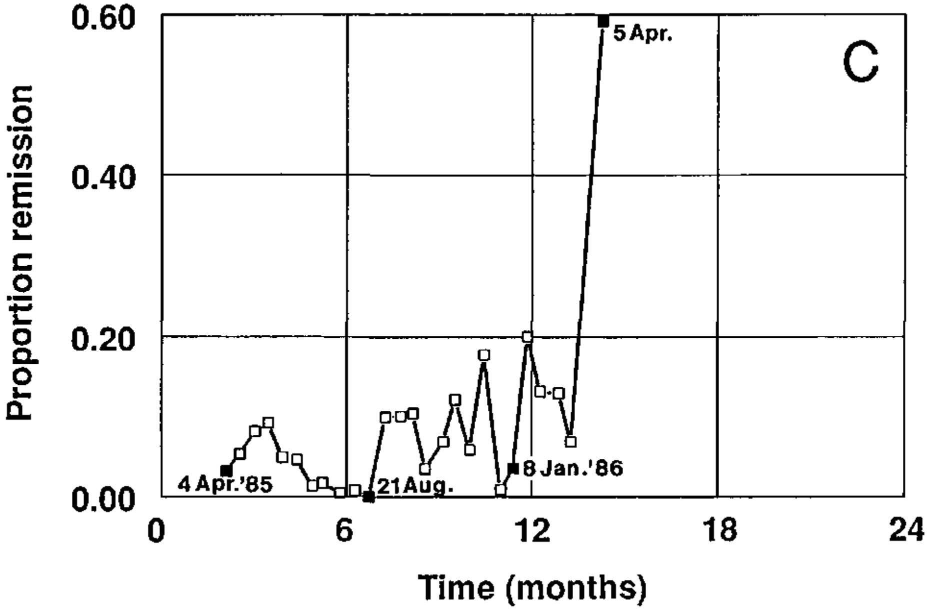
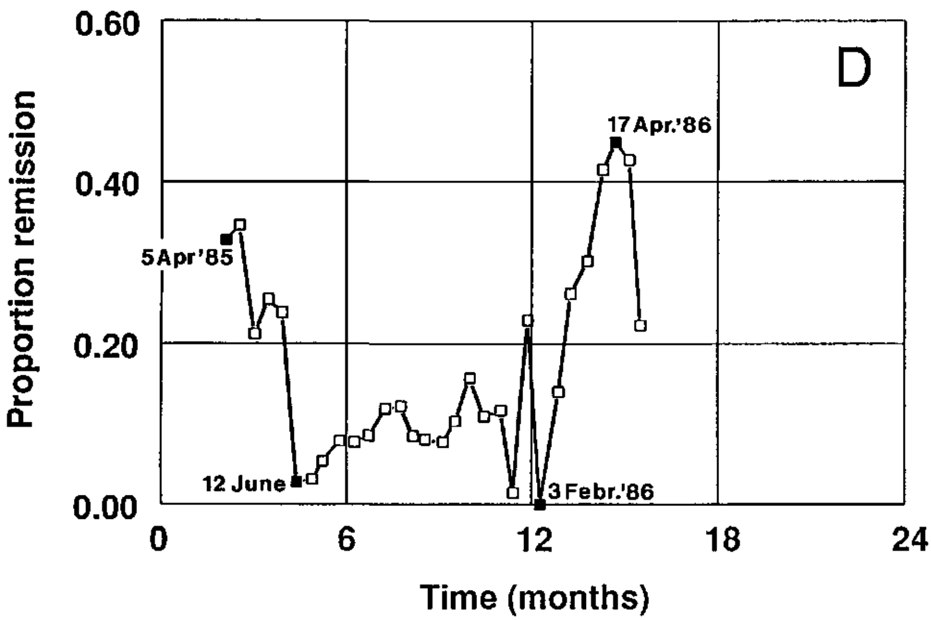
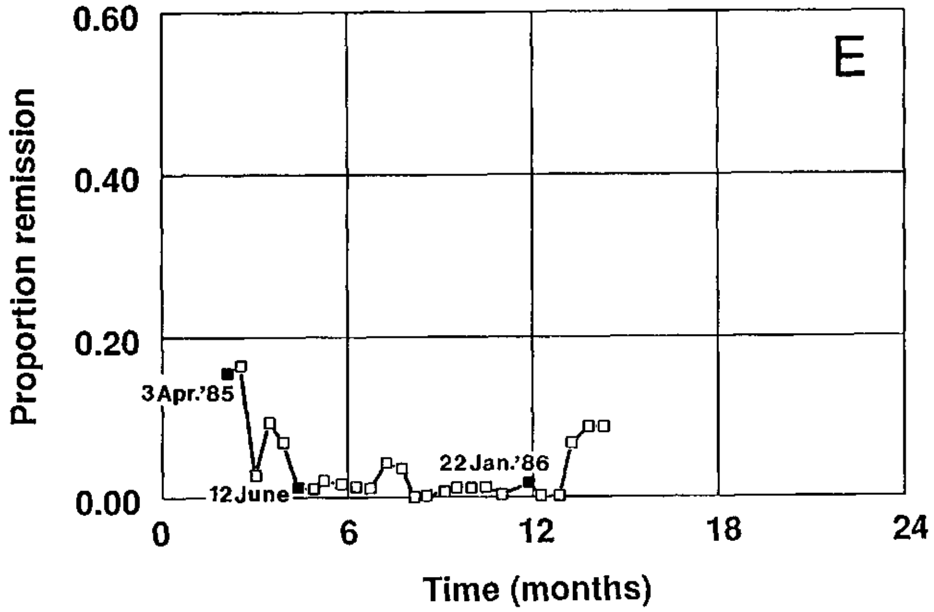
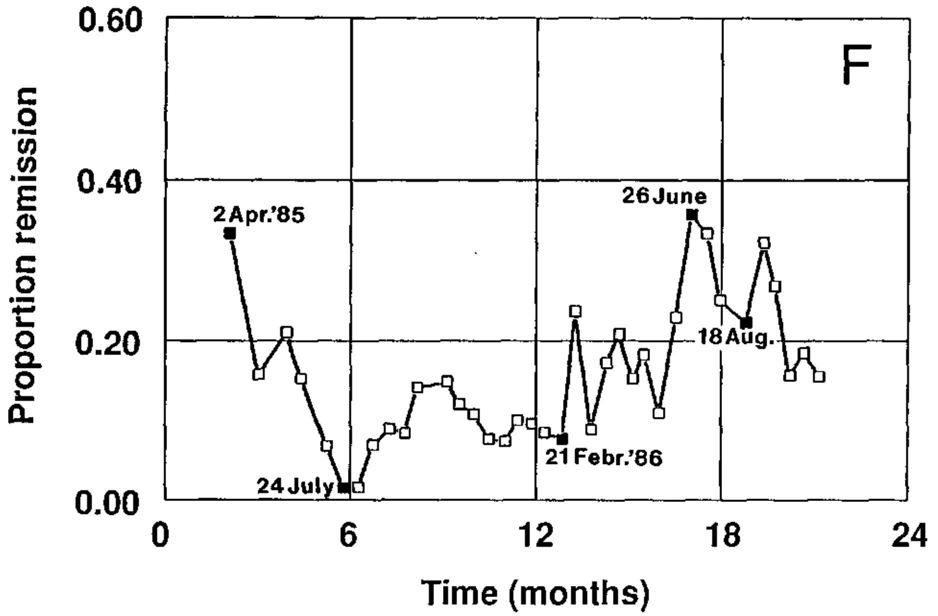
21 Febr.'86
7 June'85

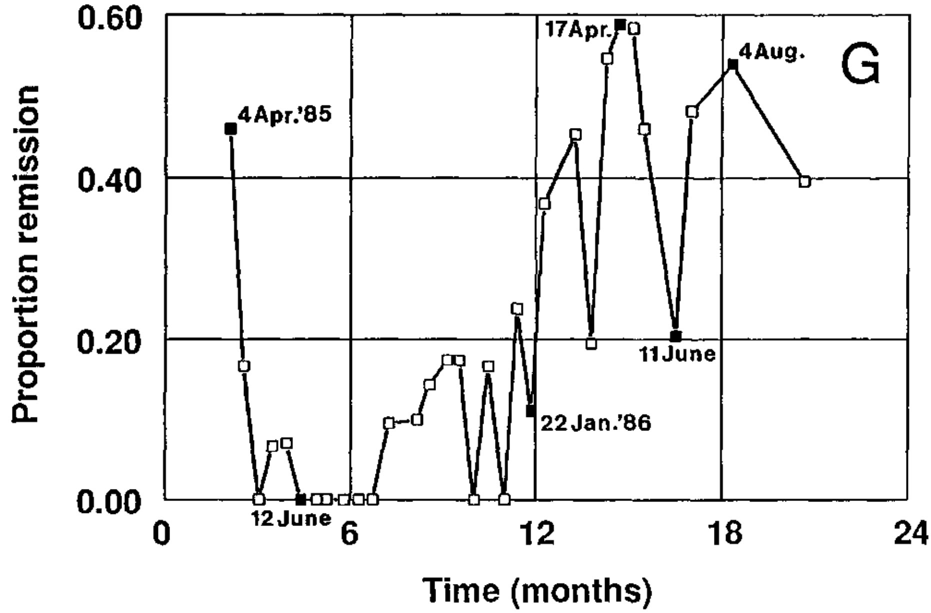

B
Proportion remission
Time (months)
0.60
0.40
0.20
0.00
0
6
12
18
24
19 Febr.'85
17 Apr.
11 June'86
8 Jan.'86
7 Aug.


C
0.60
0.40
0.20
0.00
Proportion remission
0
6
12
18
24
Time (months)
5 Apr.
8 Jan.'86
4 Apr.'85
21 Aug.


D
0.60
0.40
0.20
0.00
Proportion remission
0
6
12
18
24
Time (months)
17 Apr.'86
5Apr'85
12 June
3 Febr.'86


E
Proportion remission
0.60
0.40
0.20
0.00
3 Apr.'85
12 June
22 Jan.'86
0
6
12
18
24
Time (months)


F
Proportion remission
0.60
0.40
0.20
0.00
2 Apr.'85
24 July
21 Febr.'86
26 June
18 Aug.
0
6
12
18
24
Time (months)



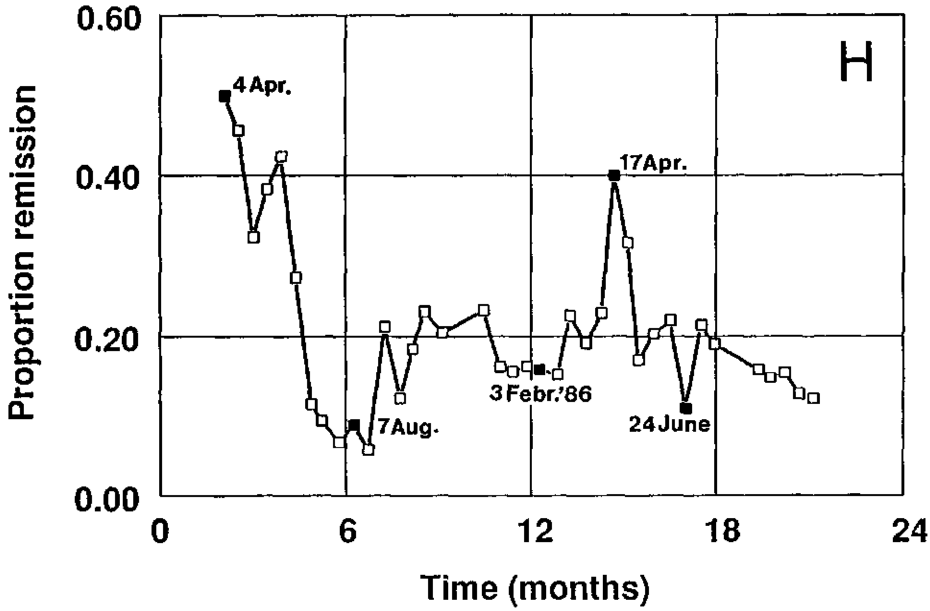


Figure 1. Incidence of remission of spear rot in eight blocks at the Victoria plantation in Suriname between 1985 and 1986.
A (Block 3), B (Block 7), C (Block 23-II), D (block 25-I, E (Block 26-I+II), F (block 33), G (Block K-IV), H (Block T-II).

Except for a sharp drop to less than 0.2 at 11 June, followed by an increase to over 0.4 in mid July, 1986, remission incidence decreased again to around 0.1 in the second week of October 1986.

Remission incidence in block 7 (Figure 1B) decreased over the months of February to July, 1985. Between 7 August and 8 January, 1986, remission incidence slightly increased in a pattern fluctuating between 0.0 and 0.1, reaching values over 0.3 in early March and in mid of April 1986. From mid April, remission incidence decreased again.

In block 23-II (Figure 1C) remission incidence fluctuated from 4 April 1985 to 8 January, 1986, about approximately 0.07, rising to 0.60 on 5 April, 1986.

Remission incidence in block 25-I (Figure 1D) decreased from 5 April to mid June, 1985. Between June, 1985 and 8 January, 1986, proportion of remission increased in a pattern fluctuating between 0.0 and 0.1 and increased sharply to over 0.4 in mid April, 1986. Later, incidence decreased again.

Block 26 I+II (Figure 1E) showed a comparable pattern of decrease of remission incidence from April to 12 June, 1985. A pattern was observed fluctuating around an average of about 0.01 between mid June, 1985, and mid January, 1986, with a tendency to increase in February.

The incidence of remission in block 33 (Figure 1F) decreased from over 0.3 to close to 0.0 between April and mid July, 1985. Then, remission incidence slightly increased in a fluctuating pattern to nearly 0.1 in the third week of February, 1986. The proportion rose to higher values with fluctuations up to 26 June and decreased from July to October, 1986.

In block K-IV (Figure 1G) remission incidence decreased over April to almost 0.0 in mid June. Remission incidence increased in a fluctuating pattern up to the end of December 1985, rising to values over 0.5 in April, 1986, and decreased to 0.2 at 11 June. From that date on remission incidence increased until early August, 1986, with a tendency to decrease after that date.

In block T-II (Figure 1H) remission incidence decreased from 4 April (0.5) to mid August, 1985, (approximately 0.1). Remission increased in a fluctuating pattern to 0.4 around mid April, 1986, and decreased again with fluctuations from the end of April to October, 1986.

The remission data of the eight blocks were pooled by weighted means (Figure 2). The peak of month 1 (February, 1985) refers to block 7 only. The peak of months 17 to 19 (July to September, 1986) refers to blocks 33, K-IV, and T-II. In the 8 blocks studied remission incidence tended to decrease between February and July,

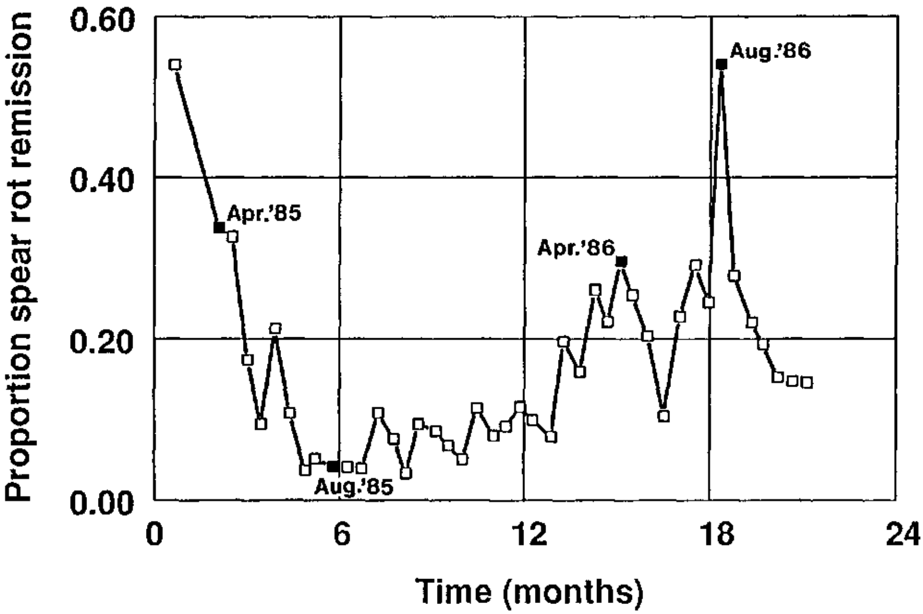


Figure 2. Remission incidence of spear rot in eight blocks at Victoria. Weighted mean of proportion remission over the years 1985 and 1986.

1985. The level of remission increased slowly in a fluctuating pattern between July, 1985 (less than 0.05), and February, 1986 (about 0.1), increasing from about 0.2 to 0.3 over the months March to April, 1986. The level of remission incidence was slightly higher in blocks K-IV and T-II than in the remaining six blocks. In most blocks remission incidence dropped to values about half the peak reached in mid June, 1986, and then increased again over July, reaching a second peak about mid August, decreasing during the months of August to October, 1986.

Weather factors. The monthly precipitation of September 1982 to October 1986 (Figure 3) show a generalized pattern of low monthly precipitation values from September to November (generally, the big dry season), a small peak in December or January (small rain season), low precipitation values in February-March (small dry season) and, high monthly precipitation values, generally over 300 mm in May-June (big rain season).

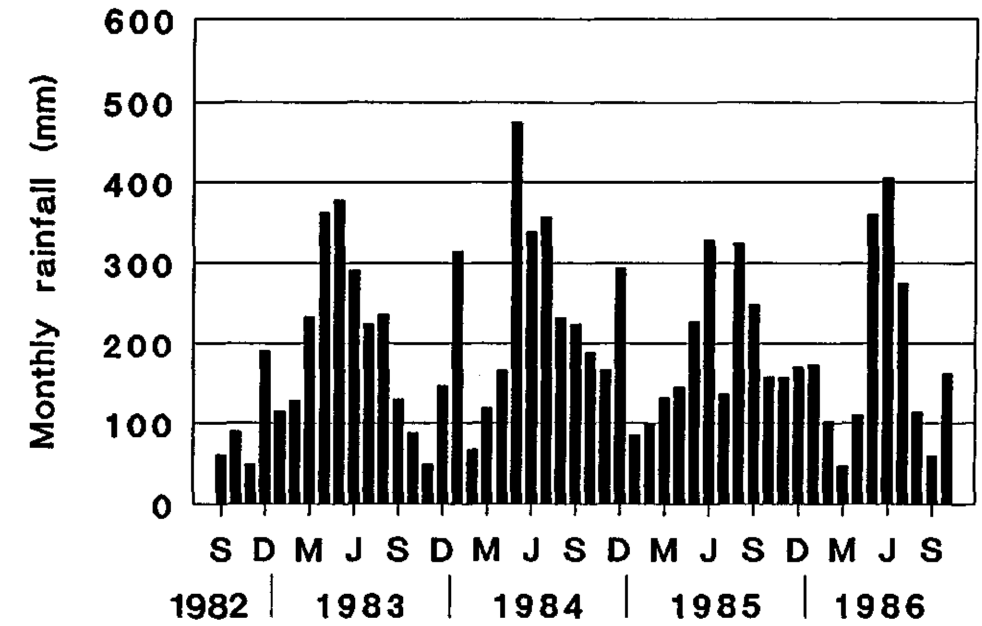


Figure 3. Monthly totals of precipitation at Victoria, measured between September 1982 and October 1986.

The monthly precipitation was significantly negatively related to remission incidence for the September 1982 to May 1984 precipitation period (r= -0.52, p= 0.95). Correlation values of the inverse relationship between remission incidence and monthly precipitation were high but not significant for precipitation periods with starting dates September 1983 (r= -0.43), February 1984 (r= -0.50) and January 1985 (r= -0.53). The months of September, February and January are generally marked by a sharp drop of the monthly precipitation values compared to the preceding month, following a short or long rainy season. Figure 4 shows the relation between remission incidence per month and the total monthly precipitation measured over the month preceding the one of remission incidence, during the January 1985 to September 1986 period. Except for one datum (encircled), remission incidence seems to be inversely related to precipitation.

The 1985 data on wind velocity at Zanderij airport were analyzed. Wind velocities of 3.1 to 4.0 m/s were registered on average during 32% and 29% of daytime (from 6.00 to 18.00 hours) respectively, measured during February to May, and from September to October, 1985 (Table 2). These velocities coincided

Table 2. Percentage of time in wind velocity ranges at Zanderij, daytime (06.00 - 18.00 hrs.), 1985.

1985	Wind velocity ranges (m/s)							
	0.0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0
Jan.	6	15	4	27	2	11	5	1
Feb.	4	13	3	33	2	10	4	2
Mar.	3	14	4	33	3	15	1	1
Apr.	3	15	7	31	3	11	3	0
May	3	19	4	33	5	9	2	0
Jun.	7	16	6	26	1	3	1	1
Jul.	6	17	5	24	1	7	2	1
Aug.	4	15	3	21	1	12	4	1
Sep.	5	18	4	28	2	10	3	0
Oct.	7	17	8	29	0	10	2	0
Nov.	7	16	7	30	2	8	2	1
Dec.	4	15	6	26	2	10	3	0
Mean	5	16	5	28	2	10	3	1

(Source: Meteorological Service, Paramaribo).

with Beaufort scales 2 to 3 (a light to moderate breeze). In the (February to May) period, on average 11% of the time, wind velocities between 5.1 and 6.0 m/s (Beaufort scales 3 to 4, comparable to gentle to moderate breezes) were registered (between 6.00 and 18.00 hours.). Breezes over 8 m/s (Beaufort scale 5 or higher) were not registered and moderate breezes (6.1 to 7.0 m/s) were registered with a mean monthly frequency of 3% of time over the entire year.

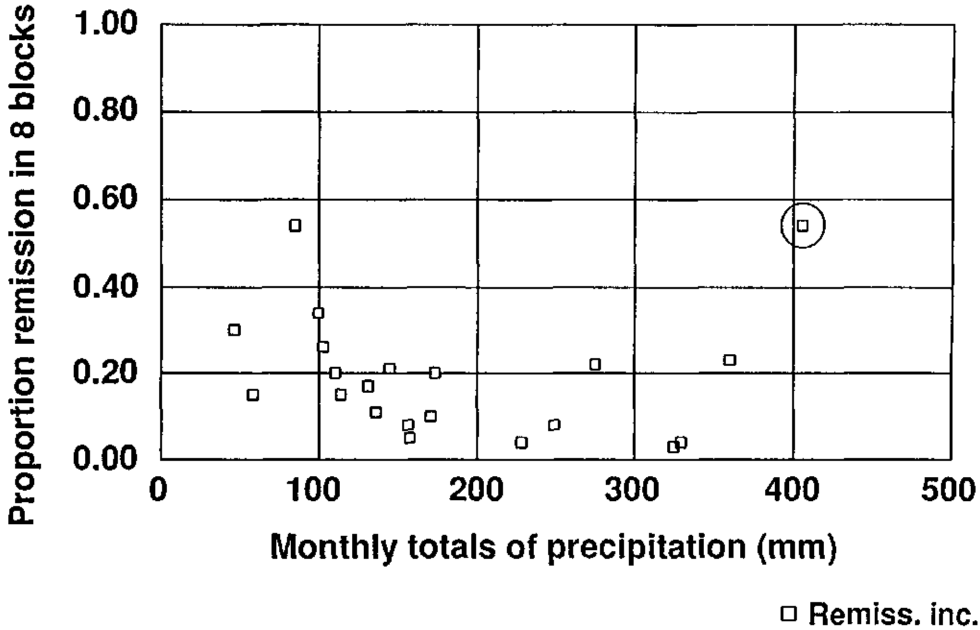


Figure 4. The relation between remission incidence per month (February 1985 to October 1986 period) and total monthly precipitation (January 1985 to September 1986 period) measured over the month preceding remission data collection at Victoria (The encircled datum can be considered an outlier).

Discussion

Symptomatology. Turner (1981) mentioned the occurrence of spontaneous recovery at Turbo (Colombia). A prolonged condition of temporal recovery from the diseased state was observed in coconut palms with symptoms of lethal yellowing disease in Jamaica (Harries, 1974). Remission of lethal yellowing was observed by Mc. Coy (1972) in coconut palms treated with tetracycline antibiotics. No explanation was given for the occurrence of the symptom remission. In the spear rot syndrome remission occurs intermittently for different time periods during the diseased state of the palm. Hunt et al. (1973) in an experiment in Jamaica, stressed that, in coconut palms with remission resulting from a tetracycline treatment, it would be difficult to distinguish between loss of remission and reinfection should symptoms reappear since the disease was still active at the experiment site.

Within the spear rot syndrome, the decline of remission implies that spear and unfolded leaves have become affected again. In spite of the presence of lesions at various locations of the rachis, generally, the spears had not toppled over at these locations. In earlier studies (Van de Lande, 1984) the presence of pathogenic microorganisms, associated with affected leaf parts in spear rot palms, could not be demonstrated. Studies, performed in 1989 (Van de Lande, submitted), confirmed that dry or wet rot of tissues in the unfolded leaves was part of the spear rot syndrome. The incidence of rotting lesions was not related to the stage of the disease. According to Hartley (1977) and others the rate of opening of leaflets in the dry season is slower than in the rainy period. When the wet season sets in the majority of the spears will open. It is possible that this increase in physiological activity puts an extra strain on the tissues in the young leaves of a diseased palm.

The necrosis of inflorescences of young unfolded leaves of a few palms in a prolonged remission stage does not necessarily have to be an effect of the spear rot disease. Corley (1976) and Breure (1987) observed that rot is specifically apt to occur at the start of rapid expansion of the inflorescences about leaf number 7.

The pattern of remission incidence. The fluctuating pattern of remission is rather similar in the eight blocks. The average level of remission incidence, slightly higher in the blocks K-IV and T-II than in the other six blocks, may be an effect of the block location in the plantation. These 2 blocks are located in the southern and least affected area of Victoria. The generally low level of remission incidence in blocks 23-II and 26 I+II may be an effect of high level of disease in these blocks at the start of this study and their location in the highly affected area in the plantation.

Remission and weather factors. Decrease of remission incidence, which set in during April, 1985, and dropped off to a level of approximately 0.1 between May and July of that year seemed to be related to an increase in total monthly rainfall (Figure 4). The relatively high, although not significant correlation coefficients indicate relationship between an increase in remission and a decrease in precipitation. The developmental period of leaf formation from initiation to the production of the oldest spear leaf is about two years (Hartley, 1977). The significant correlation measured between the September 1982 to March 1984 precipitation period and the February 1985 to October 1986 remission period, about 30 months, is therefore highly questionable. The increase of remission incidence, which set in during August, 1985, sharply increasing in March, 1986, was probably related to a deficit in monthly precipitation of July, 1985, relative to the preceding month, and the deficit in February, 1986, relative to January, 1986. The drop in remission of May, 1986, was related to the excess of monthly precipitation in April, 1986, relative to the preceding month. Accordingly, there appeared to be a relationship between the sharp increase of remission incidence of July, 1986, and the rainfall deficit in July as compared to the preceding month.

The Victoria estate, located 60 km south of the Zanderij meteorological station, must be less influenced by the coastal wind currents. We consider wind velocities of Beaufort 3 to 4 of minor importance as a possible mechanical aid in the breaking of spears and young unfolded leaves. From January to April, 1985, and from August to October, 1985, a relatively high percentage of time was registered in the 5.1 to 6.0 m/s wind velocity range. The peaks mark the beginning and the end of the rain season of 1985. This is not quite consistent with our general observation of leaves breaking mainly at the onset of the rain season. We hypothesize that spears and young leaves break by sudden, brief but strong wind gusts which accompany the onset of the rains in the interior of Suriname. Zanderij airport is the closest by meteorological station to Victoria. It is questionable whether wind velocities at 60 km distance may serve for interpretation at the Victoria estate. Gusts and squalls are quite likely to have occurred but have not been registered.
We cannot draw conclusions on the relationship between increased wind velocities and the decreased remission incidence.

The causal agent of the spear rot syndrome has not yet been identified. The palms which showed a succession of symptomatic and asymptomatic new leaves must be regarded as affected. They may serve as sources of inoculum. This risk should be avoided and palms with remission symptoms, even if bearing harvestable fruit, should be eliminated.

Acknowledgements

The Directorate of 'De Gemeenschappelijke Plantaardige Olieën en Vetten Bedrijven N.V. (G.P.O.V.)', the Oil Palm Companies in Suriname is thanked for permission to publish this work. I am indebted to personnel of the phytosanitary department at Victoria and to the Misses S.M. Van Dijk, K. Burke and, L. Jubithana from the University of Suriname for assistance in field work. The critical comments on the manuscript by Professor. Dr. J.C. Zadoks are deeply acknowledged. I thank the Wageningen Agricultural University, The Netherlands, and the State University of Gent, Belgium, for opportunities provided to finalize the manuscript.

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4. Disease progress curves of spear rot in oil palm at Victoria, Suriname

(Submitted, author Hanny L. van de Lande)

Abstract: The exponential, monomolecular, logistic and Gompertz model are discussed in relation to observed disease progress curves of spear rot of oil palm at the Victoria plantation in Suriname. The change in disease proportion *y* between successive months divided by the change in time *t* showed an inflection point between $y = 0.43$ and 0.57 after approximately 42 months, suggesting that the disease progress curve is almost symmetrical. The simple logistic model gave the best description of the data when the full range of disease incidence with low initial and high final disease assessment (over 0.40) was considered (R^2 of 0.92 to 0.99). These results suggest that the disease is polycyclic.

Keywords: epidemic analysis.

Introduction

Spear rot is an important disease of oil palm (*Elaeis guineensis* Jacq.) in Suriname (Van de Lande, 1986). The causal organism is not yet known. The disease has a distinct symptomatology (Van de Lande, submitted). It affects the spear and young unfolded leaves resulting in chlorosis and necrosis, which progressively develop to the older leaves. Once the growing point is affected, the palm can no longer produce new inflorescences. The production of new bunches will cease and ultimately the palm will die.

The first record of spear rot from Suriname dates back to about 1976 when it was observed in one block in the northern part of the Victoria oil palm plantation. The disease remained at a low level until 1982, when the number of affected trees began to increase in blocks of different years of planting, at various soil types (Van de Lande, 1990). During 1982 and 1983, palms affected by spear rot had been removed by cutting with a chain saw. Despite several phytosanitary measures the disease continued to expand. The company decided to maintain spear rot affected palms in the northern part of the plantation to benefit from their production as long as possible. In 1990, over 60% of the oil palms at Victoria were affected or dead. This paper analyses the disease records over a period of years to assess the nature of the disease progress.

Materials and Methods

Location of study. This study was performed in blocks 1 to 34 (Van de Lande, submitted: Figure 1) in the initially affected part in the north of the Victoria oil palm plantation, between 01-01-1984 and 31-12-1988. Victoria is located in the district of Brokopondo, approximately 100 km south of the capital Paramaribo, in the interior of Suriname, in South America.

Field layout. The Victoria plantation comprised 1,710 hectares of african oil palm. The layout of the plantation was largely defined by the topography of the area, resulting in blocks of different shapes and sizes. The palms had been planted according to a 9x9 m triangular design.

Year of planting and origin. The oldest plantings, 1970 to 1973, one block of 1974 and all plantings of 1980 and 1983 to 1986 are situated in the northern part of the plantation. The remaining plantings of the years 1973 to 1974 and a few blocks of 1975 and 1978 are situated in the southern part. The planting material at Victoria was locally made from *Deli-Dura* crossings with pollen partly imported from abroad (Papua New Guinea). Only three areas (such as block 34) totalling 73 hectares were planted with material imported from Papua New Guinea or West Africa.

Disease Assessment. Every tree in each block was inspected visually by trained observers during phytosanitary surveys and checked systematically for the presence of diseases, pests and disorders. Phytosanitary surveys were started in 1983. In this study, the disease ratings between 01-01-1984 and 31-12-1988 were considered. Epidemics in blocks were studied during 2 to 4 years depending on the start date of the epidemic. The progress of the disease was monitored every 3 to 4 months. From about 1986 the sampling interval was about 1.5 to 2 months. The total number of observations per block varied between 16 and 26. Disease was recorded as disease incidence (proportion of trees expressing symptoms of spear rot relative to the total number of trees in a block). This study was carried out in blocks of the planting years 1970 to 1973 and 1980, which comprised the affected area, where the epidemic initially began.

Analyses. Disease progress models were tested per block over the full length of the available period of records. Blocks were selected with a wide range of observations over time and a final disease level over 0.50 (to evaluate inflection points). The disease increase was evaluated at 6-months intervals to reduce short term periodicity due to cycling and seasonality (Butt and Royle, 1990). The inflection points of these disease incidence curves were estimated by plotting the disease increment with time $\Delta y/\Delta t$ (Δt = approximately 6 months) and reading the highest value from the graph.

The course of disease incidence over time, transformed according to the exponential, monomolecular, logistic and Gompertz models, was examined by linear regression analysis. The differential equations of these models are $dy/dt = ry$, $dy/dt = r(1-y)$, $dy/dt = ry(1-y)$ and $dy/dt = ry(-\ln(y))$ respectively. Here y is disease incidence, t is time, and r is a proportionality constant (a disease progress rate). These models are linearized to $\ln(y_t) = \ln(y_o) + rt$ for the exponential model, $\ln(1/(1-y_t)) = 1/(1-y_o) + rt$ for the monomolecular model, $\ln(y_t/(1-y_t)) = \ln(y_o/(1-y_o)) + rt$ for the logistic model and $-\ln(-\ln y_t) = -\ln(B) + rt$ for the Gompertz model (Madden, 1980). In these equations y_o represents the initial disease level and y_t the variable level of disease incidence at time t, r is the growth parameter, t the time in days, and B is a constant of integration in the Gompertz model.

The exponential model is only appropriate when growth is unlimited (Zadoks and Schein, 1979; Madden, 1980); it has no inflection point. With monomolecular growth the fastest rate occurs early in the epidemic, when y is close to zero. There is no inflection point. The logistic curve here has its maximum derivative at $y = 0.50$ (Madden, 1980). When y approaches 1.00 the disease progress rate declines to zero. With the Gompertz model, the maximum value of the derivative occurs at $y = 0.37$. Accordingly, the curve of the derivative is skewed to the right (Berger, 1981).

The linearised models were fitted to the data using regression. The appropriateness of each regression model was evaluated by examining the determination coefficient (R^2) and the standard error of the y estimate $\{Sy't)$. ($Sy't = \sqrt{(\text{sum of squares error}/ (n - 2))}\}$. Models with high R^2 and low $Sy't$ values were considered good (Draper and Smith, 1966).

Results

Thirty blocks in the northern part of Victoria were evaluated over the full range of observation dates. Since phytosanitary inspection was not regular before 1983, the exact date of first infection in some blocks was not available. Through reports from harvesters the approximate period of first incidence of spear rot could be assessed. When this study was finalized five blocks had a final disease (y_f) below 0.20, four blocks had a final disease incidence between 0.20 and 0.40, and the remaining 21 blocks had a final disease incidence over 0.40 (Table 1).

In most blocks the plots of disease incidence, the cumulative proportion of affected trees, versus time resulted in exponential curves. This is illustrated by the epidemic in block 15 (Figure 1). Only 6 blocks (2, 19, 22, 25, 26 and 34) out of 10 (Table 1) had a final disease incidence over 0.50. Four of these blocks had a low initial incidence, wide range and high number of observations at 6-month intervals. In blocks which almost reached the final stage of the disease, the disease progress curves were almost sigmoidal in shape. This is demonstrated in Figure 2A to D. The curves of the change in disease incidence in these blocks, when observations at approximately 6-months intervals were plotted, showed an inflection point (highest (y_i - y_{i-1} / t_i - t_{i-1}) as shown in Figure 2A to D) between 0.43 and 0.57. In blocks 2, 19, 22 and 34, where disease incidence at the earliest date of assessment (y_0) was around 0.005, the observed inflection point (y_{inf}) was reached after 42 months on average (Table 2). In blocks 25 and 26 the time to reach the inflection point was 28 months on average. Here, the disease incidence at y_0 was much higher and within the range of observation few observations were available compared to the four other blocks. The logistic infection rate (r) varied between 0.003 and 0.005 (day^{-1}) in all six blocks, which had their first disease records between 1982 and 1984.

In figure 3 the estimated standard error of y_t is plotted in relation to final incidence y_f for each block. *Sy't* values for the exponential model are high at low incidence range (Table 2A, Figure 3A), decrease at medium incidence range (Table 1B) and increase slightly at full incidence range (Table 1C). *Sy't* values for the monomolecular model increase drastically from low (Table 1A) to full incidence range (Table 1C). *Sy't* values for the logistic model are high at low (Table 1A) and low at medium and full (Table 1C) incidence range (Figure 3B). *Sy't* values for the Gompertz model are fairly stable over the ranges with some increase at full incidence range (Table 1C, Figure 3A). Note that *Sy't* values cannot be compared between models except for the exponential and logistic model at low incidence levels (y below 0.05). Only in the monomolecular model *Sy't* values show a sharp

Table 1. Spear rot epidemics in oil palms. Four different mathematical models were fitted to disease incidence (proportion trees diseased).

Block number	T_0	y_0	y_f	Exponent -ial model		Mono- molecular model		Logistic model		Gompertz model	
				Sy't	R^2	*Sy't*	R^2	*Sy't*	R^2	*Sy't*	R^2
A. Final incidence < 0.2											
8	9/84	.0010	.154	.30	.97	.02	.82	.30	.97	.07	.97
9	3/84	.0020	.117	.78	.87	.02	.77	.79	.87	.17	.88
12	10/84	.0002	.168	.62	.95	.03	.64	.62	.95	.17	.91
13	10/84	.0007	.149	.46	.94	.03	.67	.48	.94	.15	.90
28	4/84	.0005	.032	.53	.76	.01	.48	.53	.76	.10	.75
B. Final incidence between 0.2 and 0.4											
16	5/84	.0042	.345	.18	.98	.05	.81	.17	.99	.09	.97
20	3/85	.0016	.343	.27	.98	.07	.79	.29	.98	.15	.95
29	5/84	.0014	.347	.23	.99	.07	.81	.20	.99	.12	.97
32	4/84	.0030	.275	.37	.94	.06	.67	.40	.93	.16	.88
C. Final incidence above 0.4											
1	4/84	.0006	.510	.40	.96	.12	.74	.32	.98	.14	.97
2	3/84	.0025	.659	.32	.97	.16	.78	.19	.99	.17	.96
3	6/84	.0734	.780	.12	.96	.20	.69	.24	.94	.22	.85
5	3/84	.0063	.556	.18	.98	.14	.70	.21	.98	.18	.92
6	5/84	.0004	.765	.41	.97	.24	.57	.36	.98	.30	.90
7	5/84	.0217	.490	.23	.95	.11	.65	.33	.92	.21	.83
11	4/84	.0033	.441	.26	.98	.10	.74	.32	.97	.19	.92
14	4/84	.0003	.414	.53	.94	.09	.56	.57	.94	.23	.87
15	5/84	.0016	.396	.31	.98	.07	.76	.34	.98	.17	.94
17	5/84	.0016	.473	.51	.95	.11	.73	.48	.96	.18	.94
18	5/84	.0020	.517	.74	.89	.09	.89	.69	.92	.17	.96
19	5/84	.0031	.559	.47	.94	.12	.84	.38	.97	.10	.98

21	4/84	.0007	.486	.30	.98	.12	.72	.27	.99	.16	.95
22	4/84	.0007	.731	.30	.96	.18	.79	.19	.99	.17	.96
23	3/84	.0275	.557	.14	.98	.09	.85	.13	.99	.11	.06
24	5/84	.062	.607	.25	.90	.05	.97	.25	.94	.10	.97
25	5/84	.1065	.698	.14	.96	.13	.87	.20	.97	.16	.94
26	4/84	.0397	.728	.14	.98	.15	.87	.14	.99	.16	.96
27	4/84	.0084	.294	.27	.95	.06	.89	.24	.97	.07	.98
30	5/84	.0003	.429	.31	.98	.10	.71	.40	.93	.18	.95
34	4/84	.0047	.901	.42	.96	.34	.76	.32	.99	.35	.92

T_0 Date spear rot was first assessed in this block at a phytosanitary inspection round.
y_0 Initial disease incidence.
y_f Final disease incidence.
$Sy't$ Standard error of the y_t estimate.
R^2 Coefficient of determination.

Table 2. Spear rot epidemics in oil palm. Characteristic data from blocks with a disease range over 0.50.

Block	Area (ha)	y_0	y_{inf}	T_{inf}	T_0	r_d	r_y	Number of diseased palms in 1984
2	47.7	.0025	.43	43.0	1983	.0043	1.56	17
19	18.0	.0031	.47	42.8	1984	.0047	1.68	8
22	28.8	.0066	.54	42.9	1983	.0037	1.32	27
25	9.4	.1065	.57	29.1	1982	.0030	1.08	143
26	23.8	.0397	.57	27.8	1982	.0043	1.56	135
34	10.4	.0047	.57	41.1	1984	.0050	1.80	7

y_0 Disease incidence at first disease assessment (19840.
y_{inf} Disease incidence at the inflection point in Figure 3A to D.
T_{inf} Time elapsed in months between first observation date and date of y_{inf}.
T_0 Year of disease occurrence.
r_d Logistic infection rate, per day.
r_y Logistic infection rate, per year.

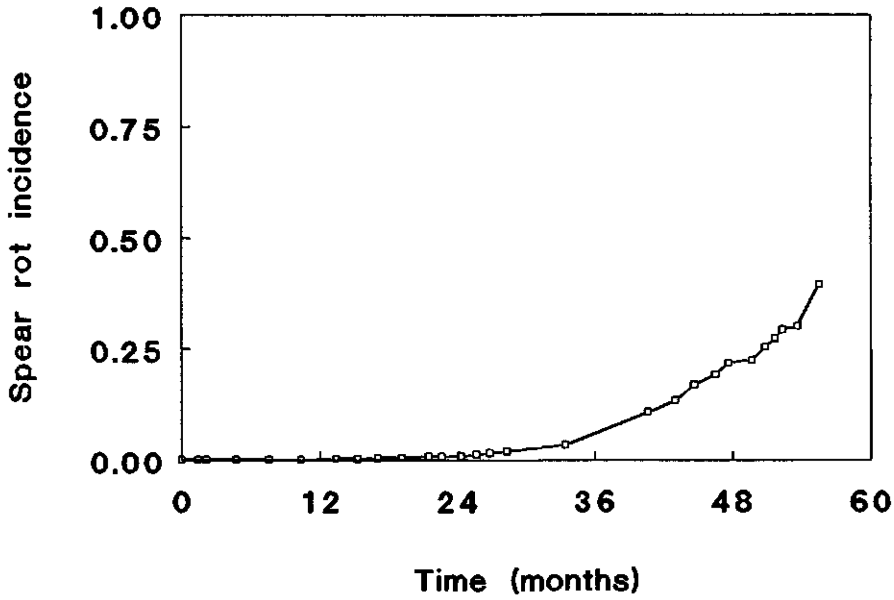
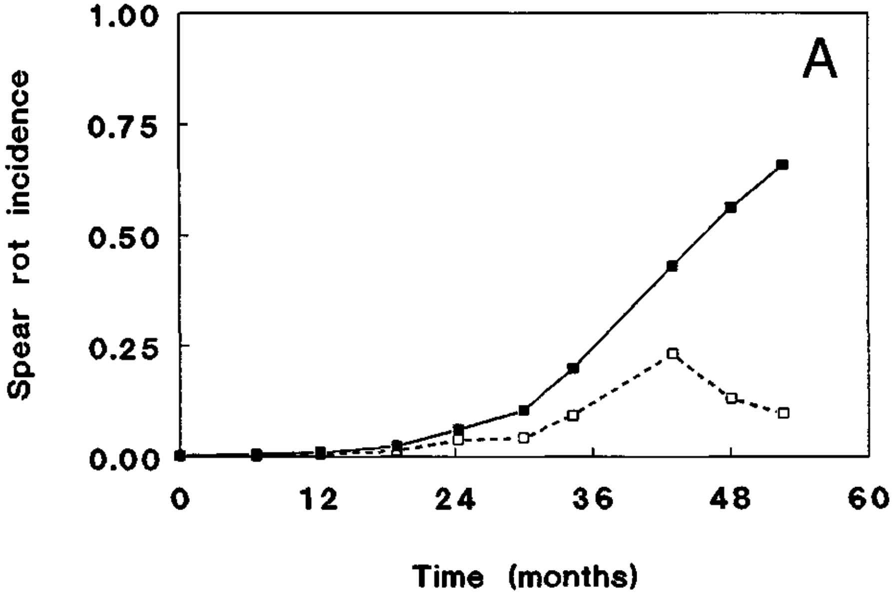
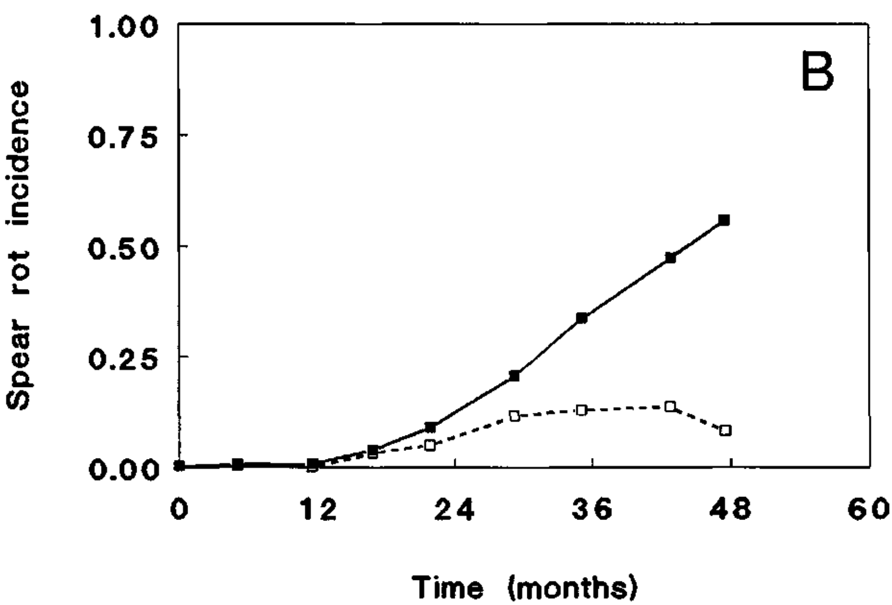


Figure 1. Disease progress curve of spear rot in oil palm of block 15 at Victoria, Suriname.

increase towards the highest y_f values (Figure 3B). On the basis of *Sy't* values, the monomolecuar model can be rejected as unsuitable.
The R^2 values can be compared between models and were generally over 0.90 in a majority of blocks when the exponential, logistic and Gompertz model were applied over the 0 to 0.40 range of incidence. The R^2 values of block 28 (Table 2A) were exceptionally low. This block had a low final disease incidence. Two thirds of the blocks had a coefficient of determination less than 0.80 when the monomolecular model was applied. Based on the R^2 values, the monomolecular model can be rejected.


1.00
0.75
0.50
0.25
0.00
Spear rot incidence
A
0
12
24
36
48
60
Time (months)


1.00
0.75
0.50
0.25
0.00
Spear rot incidence
B
0
12
24
36
48
60
Time (months)

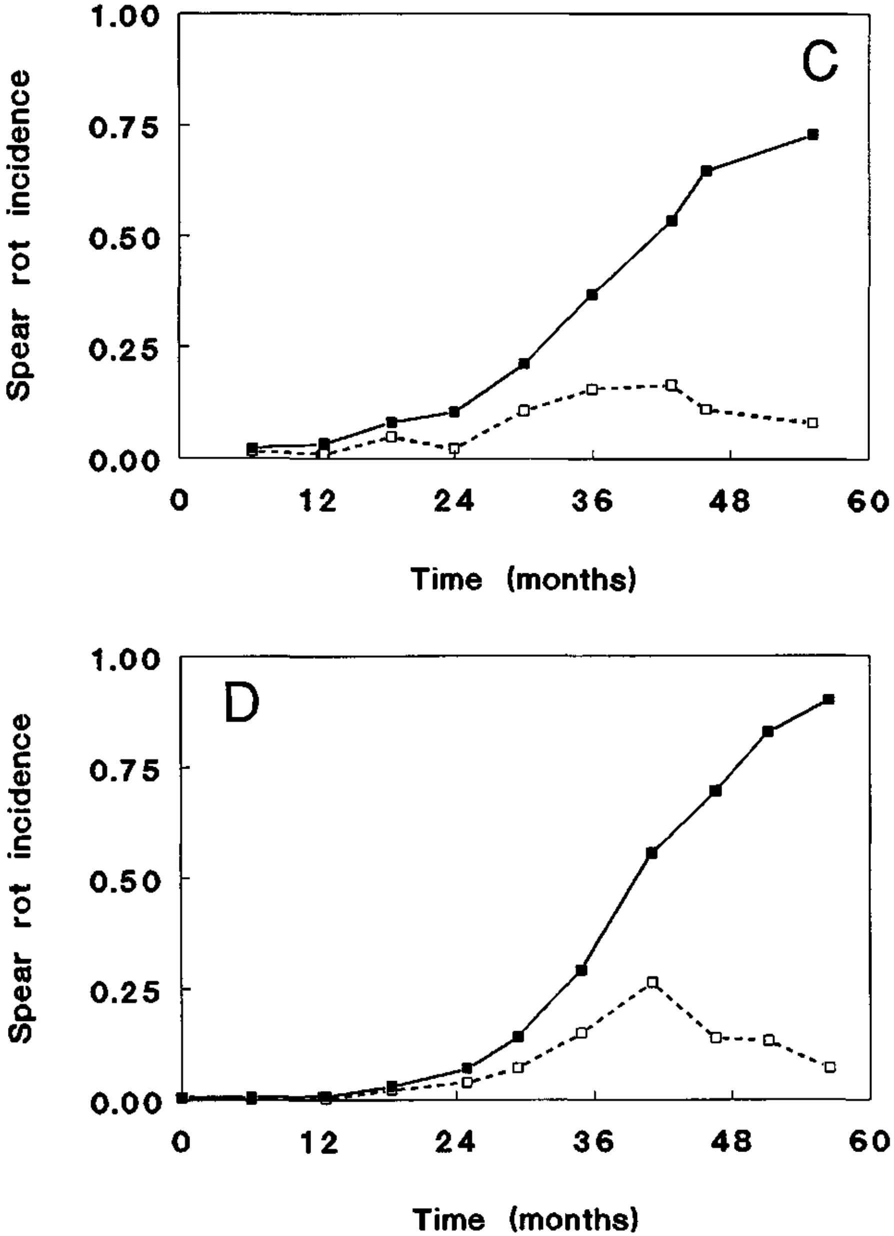


Figure 2. Disease progress curves of spear rot in oil palm, of the Victoria plantation in Suriname.

■ Disease incidence (cumulative proportion of diseased trees per block)

□ Growth rate of disease incidence (increments in the proportion of diseased trees per time).

Blocks 2 (A), 19 (B), 22 (C) and 34 (D).

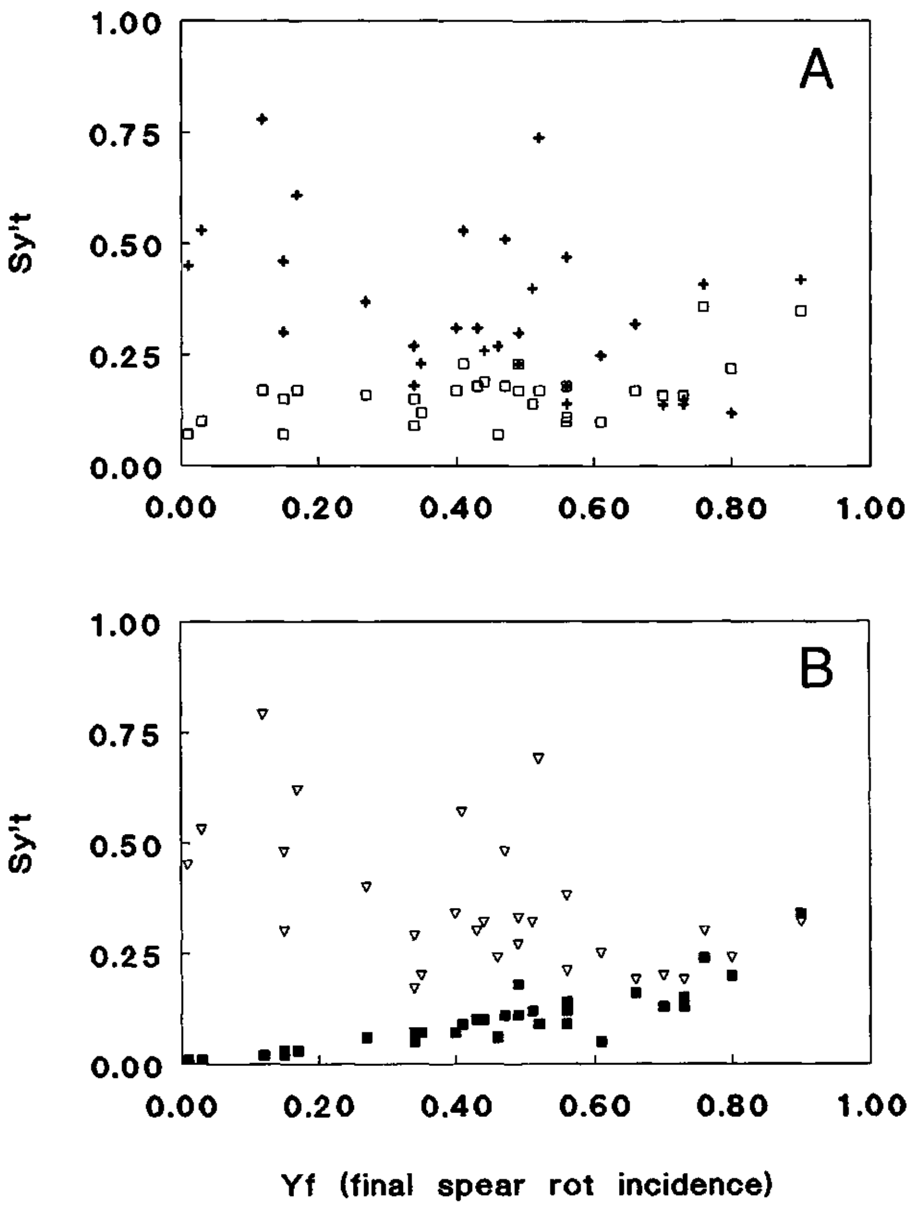


Figure 3. Analysis of spear rot epidemics in oil palm at Victoria, Suriname. Scatter diagram showing the relation between the standard error of *y* estimate (*Sy't*) and the last observed disease incidence (y_f) for various models. Figure 3A: □ = Gompertz model, + = exponential model; Figure 3B: ▽ = monomolecular model, ■ = logistic model.

Discussion

In the blocks 2, 19, 22 and 34 with a wide range of incidence over time, the observed inflection point of the disease progress curves plotting incidence was between 0.43 and 0.57. The span of time to reach this point was about 42 months. These blocks became affected nearly at the same time. They had an average logistic infection rate of 0.0047 (day^{-1}). Note that the infection rates are exceptionally high and may be compared with disease like Phytophthora cinnamomi in Cinchona ledgeriana which had an apparent infection rate of 0.0042 day^{-1} (Zadoks & Schein, 1979). A block with an average spear rot incidence of 0.50 comprises both dead trees and living trees in different disease stages (Van de Lande, submitted). The living palms still produce oil. This information will be of importance to later procedures with respect to optimization of sanitation measures.
The blocks shown in Figures 2A-D did not react according to the properties of unlimited growth in the exponential model.
The monomolecular model did not adequately describe the disease progress of blocks in Figure 2. These curves conformed to the logistic growth. The inflection points of the four blocks depicted, with wide disease ranges and high y_f values were at about y_{inf} = 0.50. The plot of the change in y (Δy) over time suggests a symmetrical bell-shaped curve. The Gompertz model with its asymmetrical distribution and its inflection point at 0.37 (Berger, 1981) does not fit these data adequately. In conclusion, the logistic transformation gave the best fit to the data.

Compared to the logistic model, the $Sy't$ values were low and R^2 values were relatively high with the Gompertz model in the lower disease ranges, which pleads for the Gompertz model. For all models, a low R^2 value was found in block 28. This is probably due to the declining counts, resulting from judgement errors by field workers in the numbers of diseased trees at short disease range (Van Dijk and Van de Lande, 1990). Adjustment of the R^2 (Cornell and Berger, 1987; Madden and Campbell, 1990) was not relevant here considering the comparable number of parameters in the four models.

Berger (1981) cautioned against the contribution of outliers to the correlation coefficient (Draper and Smith, 1966). He also stated that both the logistic and the Gompertz model effectively linearize values in the range of approximately 0.05 to approximately 0.60 disease proportion for both symmetrical and asymmetrical distributions. Luke and Berger (1982), Madden (1980) and Berger (1981) quoted Kranz's cautionary words (1974) 'not to apply a transformation model blindly to any disease, but to check the underlying distribution'. Pfender (1982) too, pointed to the erroneous approach in making conclusive remarks on the nature of the disease cycle, these remarks being inferred from the disease progress curve. In this study, the entire population of trees per block was considered. Evaluation of the point of inflection in the disease progress curves and of the *Sy't* and R^2 values, plead for the logistic as the most suitable among the growth models tested.

The intention was to select a model which satisfactorily describes the natural epidemic. The monomolecular, logistic and Gompertz models can be considered as derivations from the exponential model as the simplest of growth models, by addition of certain assumptions (Jowett *et al*, 1974). The application of the logistic model to these data, seems more appropriate than the Gompertz model at high disease incidences and over large disease ranges. Depending on the purpose of the model, the Gompertz model may be suitable under certain circumstances provided that only the disease range up to 0.40 is regarded.

The disease progress curves suggest that spear rot can be considered as a polycyclic (Zadoks and Schein, 1979) and compound interest (Van der Plank, 1963) disease.

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5. Development of epidemics of spear rot in oil palm at two plantations in Suriname

(Submitted, author Hanny L. Van de Lande)

Abstract: Disease progress curves of spear rot in oil palm at the Victoria and Phedra plantations in Suriname were studied by fitting the logistic model to the disease incidence data of about 50 blocks. Within plantation epidemic rates and periods of first detection were significantly related. It was hypothesized that a higher level of initial inoculum as a result of a difference in the vegetation surrounding the two plantations led to differences in infection rates of blocks at Victoria compared to blocks at Phedra.

Keywords: *Elaeis guineensis*, comparative analysis, epidemic.

Introduction

Spear rot is a fatal disease in oil palm (*Elaeis guineensis* Jacq.) in Suriname (Van de Lande, 1986). The causal agent is yet unknown (Van de Lande, 1986, 1990a).

At Victoria, a 1.710 hectare plantation, the disease was observed for the first time in 1976 and it developed slowly until 1982. Focal development then began in a few blocks (= fields) at Victoria and an alarming increase in the number of spear rot affected trees was observed in 1985 (Van de Lande, 1990a). Considering total costs and the economic life expectancy of the affected palms, the management of Victoria decided in 1985 (Van de Lande, 1990a) to maintain most of the diseased trees in the north which was the initially affected part of the plantation. At that time about 8 blocks, some with focal development of spear rot, had a disease incidence over 0.05 already. In the southern part diseased trees were removed only in two small fields, planted with a selection of mother trees. Meanwhile, the disease continued to spread. At Victoria, the epidemic developed at a logistic rate of approximately 1.2 year^{-1} (Van de Lande, 1990b).

At Phedra, a 875 hectare plantation, situated about 30 kilometres north of Victoria, first spear rot incidence was found in 1981 (Van de Lande, 1986) in a 3-year-old planting. As a rule, palms with spear rot were removed upon detection during phytosanitary rounds. For about a year and a half, starting October 1986, these sanitary procedures were frequently interrupted. During that period the plantation did not function well as a result of political problems in the interior of Suriname (Van de Lande, 1990a). After these interruptions the management at Phedra proceeded with the immediate elimination of all spear rot affected trees during regular phytosanitary rounds at approximately six weeks intervals.

Earlier studies (Van de Lande, submitted) indicated that logistic rates in the various blocks at Victoria varied between approximately 0.84 and 2.16 $year^{-1}$. The reason for this variability was not known. Disease incidence increased from about 0.01 to about 0.40. Epidemic rates of 27 blocks in the north of Victoria and 23 blocks in Phedra were compared, taking into consideration their different histories. The relation of epidemic rates to environmental parameters was evaluated for blocks in the north of Victoria and in Phedra.

This study aimed at clarifying the background for the differences in epidemic rates at the two plantations, to provide further information on the behaviour of this disease.

Materials and Methods.

Location and period. This study was carried out in Suriname at the Victoria and Phedra plantations from 1984 to 1989 and from 1986 to 1991, respectively. At Victoria, selected blocks were in the earliest planted area. They became affected in the initial stage of the spear rot epidemic. At Phedra, blocks were selected known to be affected in the early stage of the epidemic, before 1987. A block or subblock is a by plantation administration defined unit of field area, which is bordered by and separated from other (sub)blocks and/or forest area, by means of roads.

Layout and soil type. The layout of the plantations was determined by the topography of the area, resulting in blocks of various sizes and shapes. The plantations were intersected with areas covered by light secondary forest or swamp areas, and surrounded mostly by primary forest.

Soil types in the various blocks at Victoria were indexed 1 to 4 (river clays, low, mid and high terrace soils) respectively, according to De Boer and Bruin (1976). A suitable soil map of Phedra was not available.

Planting material and age of plantings. The planting material at Victoria-North (years of planting 1971 to 1974, and 1980), where the disease first appeared, was locally made *Deli-Dura* material pollinated with pollen partly originating from Papua New Guinea. The 1980 field in the north originated from seeds imported from New Guinea. At Phedra, the 1978 and part of the 1979 plantings originated from seeds imported from West Africa. Plantings of 1979 to 1981 originated from seeds imported from Papua New Guinea.

Disease history.

Victoria. In the north of Victoria, where the epidemic began (Van de Lande, 1990a), incidence (= the number of diseased trees divided by the number of trees planted) in most blocks was 0.15 or higher (Van de Lande, submitted a) before 1989. Nearly half of the blocks had reached a disease incidence of 0.40 or more in that year. At Victoria diseased trees were not cut down and counting errors, which were made during phytosanitary detection rounds (Van de Lande, submitted b), were relatively large (Van Dijk & Van de Lande, 1990) because of difficulties in recognizing disease at early stages and during remission (Van de Lande, submitted a).

Phedra. In the second half of 1991, the disease incidence at Phedra was less than 0.05 in the majority of blocks (over 100 out of 126). Five blocks with a spear rot history beginning in 1982 had a higher disease incidence (over 0.10) in 1991. Unfortunately, detailed disease incidence data of individual blocks over the period 1982 to 1986 were destroyed in the raids aimed at the Phedra plantation during the years 1986 to 1987 (Van de Lande, 1990a).

Analysis of the disease progress curves. Transformations were applied to the disease incidence data according to the logistic (Van der Plank, 1963) model.

The relations between soil type, age of planting at first detection, period of first occurrence and the epidemic rate were studied for 30 blocks at Victoria-North, the part of the plantation with the most detailed data base. First observations per block were classified per 6 months period from June, 1982, to December, 1984.

Logistic rates of 27 blocks in Victoria were compared with rates of 22 blocks in Phedra. Also, logistic rates of 2 blocks in Victoria were compared with 8 blocks at Phedra randomly chosen from a group of blocks with similar age (1980 planting year) and genetic origin (Papua New Guinea).

Statistical analysis. Goodness of fit of the logistic model was evaluated by means of the coefficient of determination (R^2: Draper and Smith, 1966) and the standard error of the y estimate *Sy't*, calculated as $\{(\text{residual sum of squares}/\text{n-2})^{1/2}\}$. The smaller *Sy't* is, the more precise the predicted values will be (Harnett, 1982). Differences among soil types, periods of first observation and age of plantings of blocks in Victoria-North were tested for each parameter with the Kruskall-Wallis test (Sokal and Rohlf, 1981; Rohlf and Sokal, 1981). Differences in epidemic rates between plantations and in blocks of comparable planting years and genetic backgrounds were tested with the Mann-Whithney-U-test (Sokal and Rohlf, 1981; Rohlf and Sokal, 1981).

Results

Victoria. In Table 1 statistical parameters of spear rot epidemics in 27 blocks at Victoria-N were presented. Logistic infection rates varied between 0.64 and 2.53 $year^{-1}$ (median rate value: 1.56 $year^{-1}$). Coefficients of determination were high (generally over 0.80) and *Sy't*'s were between 0.01 and 0.65. The differences in epidemic rates of 25 out of 27 blocks at Victoria-North (Table 1) can hardly be ascribed to the origin of planting material, considering the similarity in genetic background. Only blocks 33 and 34 descend from Papua New Guinea material.

In Table 2 logistic rates, soil types, ages at first detection and period of first occurrence are presented for 30 blocks in Victoria-N. The relation between logistic rate and soil type or age of planting at first detection was not significant (Kruskal-Wallis statistic $H_{soil} = 0.613 < X^2_{0.01\,(3)}$, $P < 0.01$; $H_{age} = 6.577 < X^2_{0.01\,(5)}$, $P < 0.01$). The median values of logistic rates for soil types 1 to 4 were 1.38, 1.36 (one block), 1.46 and 1.54 respectively. Logistic rates for ages 4 (one block), 10 (one block), 10.5, 11, 11.5, and 12 (one block) years after first detection had a median value of, respectively, 1.78, 1.63, 1.37, 1.42, 1.40 and 1.42 $year^{-1}$. The median values and the results of statistical tests for logistic rates in the different groups indicate that the differences between logistic rates of blocks at Victoria cannot be ascribed to either soil type or to age of planting at first detection of the disease. Significant differences were found among periods of first detection (Kruskal-Wallis statistic $H_{1st\,det.} = 760 > X^2_{0.01\,(5)}$, $P < 0.01$) and epidemic rates of the various blocks in Victoria-North. In the six periods from the first half of 1982 to the second half of 1984 the medians per half year of the logistic rates were, respectively, 1.33, 1.01, 1.04, 1.39, 1.69 and 1.81 $year^{-1}$. Blocks with an early period of first detection showed lower rates than blocks where disease was detected later.

Table 1. Spear rot disease in oil palm at the Victoria plantation, Suriname. Statistical parameters of spear rot epidemics in the low incidence range (up to 0.05 disease incidence) according to the logistic model in 27 selected blocks.

Block	y_0	y_f	T_i	T_f	n	r	R^2	*Sy't*
1	0.001	0.043	21	1986	11	2.45	0.96	0.29
2	0.003	0.052	23	1986	11	1.70	0.97	0.20
5	0.006	0.046	19	1985	9	1.06	0.95	0.15
6	0.001	0.035	26	1986	15	2.21	0.96	0.37
7	0.022	0.049	16	1985	8	0.66	0.96	0.07
8	0.001	0.050	36	1987	15	1.52	0.93	0.35
9	0.001	0.031	31	1987	14	1.79	0.90	0.44
11	0.003	0.035	30	1986	16	0.88	0.98	0.20
12	0.001	0.026	42	1988	18	1.57	0.89	0.65
13	0.001	0.055	30	1987	15	1.39	0.83	0.48
14	0.001	0.057	44	1987	19	1.26	0.85	0.56
15	0.002	0.034	33	1987	17	1.14	0.91	0.33
16	0.004	0.050	26	1986	14	1.03	0.94	0.21
17	0.002	0.037	24	1986	12	1.74	0.83	0.56
18	0.002	0.051	15	1985	8	2.53	0.93	0.37
19	0.002	0.040	15	1985	8	1.98	0.91	0.35
20	0.003	0.023	10	1987	6	2.21	0.84	0.31
21	0.001	0.035	23	1986	13	1.66	0.94	0.27
22	0.006	0.043	15	1985	7	1.56	0.92	0.23
23	0.028	0.038	7	1984	4	0.64	0.49	0.21
26	0.040	0.060	7	1984	4	0.78	0.99	0.01
27	0.008	0.056	10	1985	5	1.76	0.73	0.42
29	0.001	0.033	29	1986	16	1.36	0.96	0.23
30	0.001	0.042	34	1987	18	1.84	0.95	0.38
32	0.003	0.044	22	1986	11	1.25	0.84	0.38
33	0.003	0.035	30	1983	4	1.00	0.99	0.02
34	0.005	0.051	14	1986	7	2.14	0.91	0.29

y_0 First reading in the observation series after 1980.
y_f Final disease incidence.
T_i Observation period in months.
T_f Year in which y_f was reached.
n Number of observations over period T_i.
r Logistic infection rate per month.
R^2 Coefficient of determination.
Sy't Standard error of the *y* estimate.

Phedra. In Table 3 statistical parameters of spear rot epidemics in 22 blocks at Phedra were presented. Logistic infection rates varied between approximately 0.16 and 0.97 $year^{-1}$ (median value of logistic rates was 0.40 $year^{-1}$). Coefficients of determination were generally high (over 0.80) and Sy'*t* 's were between 0.01 and 0.23.

Between-plantations comparison. Standard errors for blocks at Victoria were higher than for Phedra blocks, probably as a result of larger errors in data assessment at Victoria.

Logistic rates of the two plantations (Tables 1 and 3) are significantly different (Mann-Whitney-U statistic $t_s = 5.65 > t_{0.01\,(49)}$, $P < 0.01$).

The frequency of phytosanitary detection rounds was on average 1.3 months in the blocks studied at Phedra, but was about 2 months in the blocks at Victoria. The origin of planting material at Victoria (locally made) differs from that of Phedra (foreign material). This difference could have been crucial in the determination of the disease susceptibility of the material to spear rot. However, statistical evaluation (Mann-Whitney-U statistic $U_s = 16 > U_{0.05\,(8,2)}$, $P < 0.05$) of 10 blocks, two at Victoria and eight at Phedra, which were of the same age and genetic background and of more or less comparable size (Table 4), indicated that even in the beginning of the epidemic the rates at Victoria (2 blocks, median logistic rate value 1.57 $year^{-1}$) were higher than at Phedra (8 blocks, median logistic rate value 0.36 $year^{-1}$).

Block	r	Soil type	Age at first detection	Year of first detection
3	0.84	3	11.0	3
7	0.91	4	11.5	2
28	0.92	3	10.5	5
16	1.08	4	11.5	4
25	1.10	4	11.5	2
24	1.13	4	11.5	1
11	1.25	3	11.0	4
13	1.28	1	11.0	6
23	1.32	3	11.5	4
22	1.36	2	11.5	3
9	1.36	1	11.0	5
29	1.37	1	10.5	5
27	1.39	1	11.5	4
21	1.40	3	11.5	4
15	1.42	4	11.0	5
8	1.42	3	12.0	5
5	1.46	3	11.0	4
14	1.48	3	11.0	5
26	1.54	3	11.5	1
2	1.61	3	10.5	4
32	1.63	1	10.0	5
19	1.66	4	11.5	5
34	1.78	3	4.0	5
30	1.81	3	11.0	5
12	1.81	1	11.0	6
20	1.82	3	11.5	6
17	1.88	4	11.5	5
18	2.02	4	11.5	5
6	2.08	4	11.5	5
1	2.09	4	11.5	5

Table 2. Spear rot of oil palm in 30 blocks at Victoria-North, Suriname. Comparison of logistic growth rates, r ($year^{-1}$), in ascending order, with soil type, year of first incidence and planting age (in periods) at first detection of the disease.

Table 3. Spear rot disease of oil palm at the Phedra plantation, Suriname. Statistical parameters of spear rot epidemics in the low incidence range (up to 0.05 disease incidence) according to the logistic model in 22 selected blocks.

Block	y0	y_f	T_i	T_f	n	r	R^2	Sy't
2A	0.012	0.039	51	1991	36	0.32	0.94	0.101
3	0.006	0.045	50	1991	37	0.46	0.98	0.081
5A	0.009	0.046	40	1991	29	0.40	0.93	0.101
5B	0.006	0.044	40	1991	29	0.43	0.90	0.136
6	0.014	0.048	30	1990	22	0.37	0.91	0.084
7	0.021	0.047	25	1989	19	0.44	0.91	0.085
10B	0.008	0.046	46	1991	33	0.43	0.93	0.124
11	0.002	0.017	46	1991	33	0.36	0.91	0.118
14	0.009	0.030	45	1991	33	0.25	0.83	0.124
16A	0.004	0.051	31	1990	23	0.94	0.95	0.153
16B	0.005	0.048	32	1990	32	0.55	0.78	0.218
28A	0.005	0.051	33	1991	25	0.88	0.96	0.161
34	0.016	0.047	42	1991	31	0.29	0.91	0.088
40	0.029	0.050	15	1989	15	0.41	0.94	0.044
44	0.006	0.031	42	1991	32	0.44	0.81	0.225
46C	0.017	0.037	44	1991	33	0.18	0.90	0.060
46D	0.012	0.039	51	1989	36	0.32	0.94	0.101
47B	0.019	0.046	44	1991	33	0.25	0.96	0.049
47C	0.043	0.050	14	1989	10	0.16	0.93	0.015
49B	0.019	0.050	30	1990	21	0.37	0.96	0.051
52A	0.001	0.025	35	1991	23	0.97	0.95	0.225
52B	0.005	0.032	40	1991	30	0.46	0.81	0.231

Legend As in Table 1.

Table 4. Spear rot disease of oil palm at Victoria and Phedra plantations, Suriname. Comparison of statistical parameters of epidemics in 10 blocks (planting year 1980, Papua New Guinea material) in the low incidence range.

Block	Area (ha)	y_0	y_f	T_i	T_f	n	r	R^2	Sy't
Victoria									
33	2.4	0.003	0.035	30	1983	4	1.00	0.99	0.020
34	10.4	0.005	0.051	14	1986	7	2.14	0.91	0.294
Phedra									
40	10.9	0.029	0.050	15	1989	15	0.41	0.94	0.044
41A	1.3	0.010	0.045	41	1991	32	0.54	0.73	0.337
41B	1.5	0.025	0.053	21	1991	34	0.24	0.90	0.066
41D	6.5	0.045	0.052	5	1991	4	0.30	0.92	0.023
41E	2.2	0.003	0.041	28	1988	22	0.91	0.86	0.269
44	10.3	0.006	0.031	42	1991	32	0.44	0.81	0.225
46C	8.9	0.017	0.037	44	1991	33	0.18	0.90	0.060
49D	1.5	0.018	0.022	43	1991	33	0.04	0.41	0.053

Legend As in Table 1.

In conclusion, neither differences in soil type nor in age at first detection seemed to influence logistic rates in blocks at Victoria. Comparison of 2 blocks at Victoria and 8 at Phedra gave no indications about influence of genetic background, or about the difference between the two plantations in the duration of phytosanitary rounds. Climatological differences cannot be decisive since both plantations are situated along the river and in the interior of Suriname.

It is hypothesized that differences in surrounding vegetation might have been decisive for the provision of inoculum leading to increased disease pressure which may have led to higher rates at Victoria than at Phedra.

Discussion

Van Dijk and Van de Lande (1990) mentioned that observers at Victoria sometimes made errors in counting affected trees. Such errors, which led to unexpected fluctuations will result in high values of $Sy't$. Small errors at low incidences, producing large differences in the logits can be attributed to the characteristics of the logistic model (Rouse *et al.*, 1981).

The time dependency leading to higher logistic rates at Victoria in later years may be the result of a higher disease pressure due to the presence of affected trees maintained and to excessive weed growth in this plantation (Van de Lande, 1990). The combination of these two factors, affected trees plus excessive weed growth, probably led to an increase of inoculum (or of transmission efficiency). The level of inoculum and its bearing on apparent infection rates is of importance in the initial stage of the disease (Kingsolver *et al.*, 1959; Van der Plank, 1963; Rouse *et al.*, 1981).

Comparison of apparent infection rates of epidemics at different locations or in different years (Zadoks, 1961) as was carried out here for Victoria and Phedra, is common (Thresh, 1974). Age and genetic origin of plant material appeared not significant comparing the two locations. Soil type differences were not decisive to rate differences either. A difference of about two weeks within a period of approximately 1½ month (Phedra) to 2 months (Victoria) duration of phytosanitary detection rounds can hardly be considered influential. Differences in logistic rates of blocks in Victoria and Phedra can hardly be ascribed to climatological conditions since both plantations are situated in the interior and along the same river. There may however be differences in the natural vegetation which surrounds the blocks at Victoria, compared to Phedra.

Surrounding vegetation may be harbouring sources of infection and/or agents of transmission (Thresh, 1974) which, under favourable conditions may lead to increase of inoculum and high rates. High inoculum levels in the early stage of disease may lead to difficulties when practising sanitation procedures (Van der Plank, 1963). Since sanitation may be more difficult the higher the initial level of disease becomes (Van der Plank, 1963), it is concluded that elimination of affected palms must take place early in the epidemic as soon as initial symptoms appear.

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6. Spatial patterns of spear rot in oil palm at Victoria and Phedra, Suriname

(Submitted, author Hanny L. Van de Lande)

Abstract: Geostatistics and gradient analysis were used to examine the spatial variation of spear rot disease in 13 blocks at two oil palm plantations. The relation between pairs of sample points of spear rot incidence over various distances in different directions and over the years was determined by means of semivariograms. In two blocks, with initially low spear rot incidence, semivariogram analysis revealed a random pattern indicating that positions of affected trees were not spatially related implying that infection came from different sources. Later, in one of these two blocks and in seven others, semivariograms at different dates showed a linear increase with distance of the semi-variance between pairs of sample points. In four blocks, semivariograms revealed a nonlinear increase in variance. Over the years, semivariograms revealed anisotropy with preference for a westerly direction. Classical analysis of disease gradients over time confirmed the existence of a preferential direction. The data are compatible with the hypotheses that (1) spear rot is an infectious disease with (2) a first phase of randomly scattered appearance throughout blocks with (3) inoculum sources outside the plantation, (4) a second phase of focal spread starting from initially infected scattered trees, and (5) the causal agent or its vector being wind-borne. The trigger of the change from phase 1 to phase 2 remains unknown. The existence of two different vector populations seems plausible.

Keywords: Disease gradient, disease pattern, *Elaeis guineensis*, fatal yellowing, geostatistics, semivariogram, spatio-temporal dynamics.

Introduction

Spear rot of oil palm (*Elaeis guineensis* Jacq.) is a fatal disease of unknown etiology (Van de Lande, 1986). The disease was recognized at the Victoria oil palm plantation (Van de Lande, submitted: Figure 1) in Suriname, around 1976. At Phedra (Figure 1), a plantation situated 30 kilometres north of Victoria, the first tree affected by spear rot was noticed in 1981. Palms with spear rot exhibit chlorosis in the youngest leaves and rotting of one or more spears. The continuous breaking of spears and leaves results in gradual deterioration and finally, in the death of the tree. Effective means of control of spear rot are not yet available (Van de Lande, 1990a). In 1982 a dramatic change occurred in spatial arrangement from a pattern of isolated affected trees to a pattern of focal development of spear rot.

The increase in the number of trees affected or dead due to spear rot with time can be described by the logistic model (Van de Lande, submitted). Temporal studies of disease progress help to characterize the development of the disease and may lead to statements regarding future disease levels. When yield reduction is taken into consideration, spatial pattern of affected plants is often neglected (Hughes, 1990). The reduction in the proportion of productive trees per unit area is dramatic when affected or removed trees are arranged in groups, where inter-plant compensation for light, water and nutrients becomes impossible (Walker, 1987; Hughes, 1988; Hughes *et al.*; 1989, Zadoks and Schein, 1979). Furthermore, disease gradients can provide clues on the mode of spread of the disease. A preferential direction, as along rows, could indicate mechanical transmission through harvesting knives. Alternatively, a directional spread with the prevalent wind might suggest airborne dispersal.

In spatial analysis of diseased plants, doublet analysis (Van der Plank, 1946; Laville et Lossois, 1963) and runs analysis (Converse *et al*, 1979) are methods which do not consider the location of plants or the distances between them. In spatial point pattern analysis, the actual positions of sample units (quadrats) are not used in the analysis (Reynolds and Madden, 1988), whereas size of the quadrats can influence the results (Madden *et al*, 1987). None of these methods considers the distribution of diseased plants in space (Chellemi *et al.*, 1988) and the anisotropy of the variables of the sampled area (Lecoustre *et al.*, 1989). Most of the above mentioned methods therefore are inappropriate in solving data analysis problems related to the occurrence of vacancies (gaps) in the planted area or to the irregular shapes of blocks (Van de Lande, submitted). Freeman (1953) considered the occurrence of vacancies in a regular fields only.

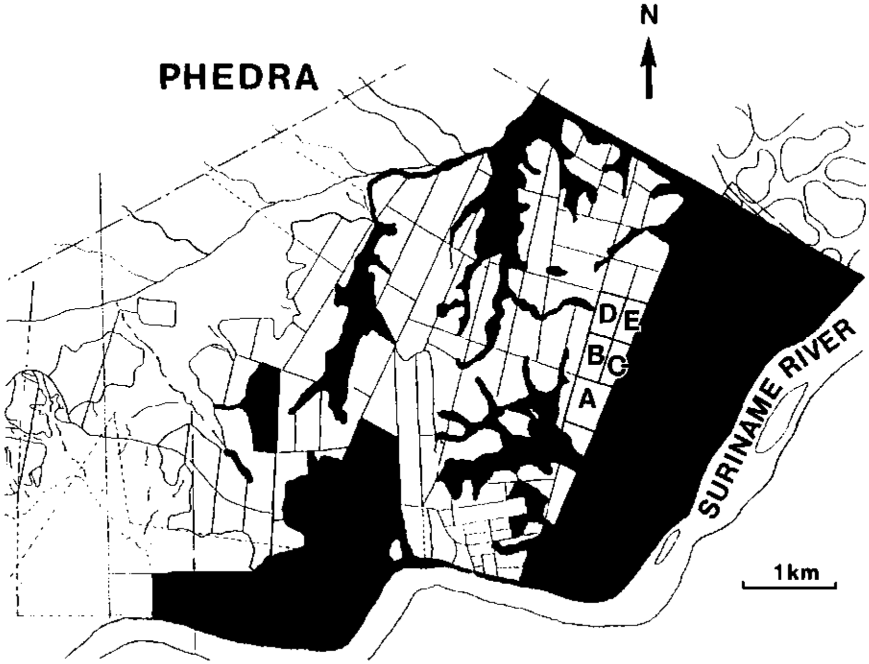

Figure 1. Location of blocks at the Phedra plantation in Suriname. In black: forest, swamp area and gullies.

A = Block 42A, B = Block 46A, C = Block 46b,
D = Block 46C and E = Block 46D.

Geostatistical analysis provides a solution to both problems, vacancies in espacement and irregular shapes of blocks (David, 1977). Geostatistics is based on the theory of regionalized variables (Matheron, 1963). A variable is called regionalized when its value depends upon its position in space (Matheron, 1963). Geostatistical analysis assesses the spatial dependence between specific observation points by measuring the 'semivariance'. The semivariance is plotted against distance in a 'semivariogram'.

In this study, the spatial pattern of spear rot disease was examined over the years by means of geostatistics and by gradient analysis (Zadoks and Schein, 1979) in order to gain insight in the behaviour of this disease of unknown etiology.

Materials and Methods

This study focuses on blocks of the plantations Victoria and Phedra in Suriname. A block or field is defined as an agronomic and administrative unit, in which all trees have the same genetic background and age. This field unit is bordered by roads and surrounded by other blocks, primary or secondary forest. Over 90% of blocks bordered forest or swamp area at least at one side. Size and form of a block were determined by the layout of the plantation and modified by the topography of the area. The blocks were selected for their disease history, known over several years.

Sample locations. Spear rot data of blocks 3, 5, 6, 7, 9, 15, 16, and 34 of Victoria and blocks 42B, 46 A, B, C and D of Phedra were analyzed. Most blocks in Victoria are bordering primary or secondary forest, road or river verges, or swampy areas at one or more sides (Van de Lande, submitted: Figure 2). The blocks of interest at Phedra are located in the east of the plantation (Figure 1). Three out of 4 blocks border an over 1 kilometre wide strip of primary forest, at their eastern side. The blocks studied at Victoria and Phedra are of different ages with planting years varying from 1972 to 1981. Block areas vary between 2.5 and 45 hectares.

The origin of the planting material in blocks 3, 5, 6, 7, 9, 15 and 16 is *Deli-Dura* from crossings made in Suriname. The remaining blocks were planted with Harrison Crossfield material originating from Papua New Guinea. The palms were planted in a triangular design of either 9x9 (Victoria) or 8.5x8.5 metres (Phedra). The rows are generally oriented perpendicular to the main road along the block side were the first palm in the first row is located. In the Victoria blocks 3, 5, 9, 15, 16, and 34 the rows are oriented in a north-south direction; in blocks 6 and 7 the rows are oriented at approximately minus 20 degrees North. In the five Phedra blocks rows were oriented at approximately minus 70 degrees North. Affected palms were detected through phytosanitary rounds which were performed about once in every two months. As a rule, harvesting and pruning procedures were performed every 2 weeks and 6 months, respectively, starting with the first palm in row number one and proceeding up and down along the consecutive rows. The direction in which the harvesters were heading could be East-West or West-East depending on the location of their starting position (Table 1).

Table 1. The geographic position of palm number one in the first row of the various blocks studied at Victoria and Phedra.

Geographic position(*) of 1st palm, 1st row			
SW	SE	NE	NW
3	5	6	42B
7	9	15	46B
46A	16		46D
46C	34		

(*) Indicates starting point of harvest and pruning procedures: NW (North-West), NE (North-East), SE (South-East), SW (South-West).

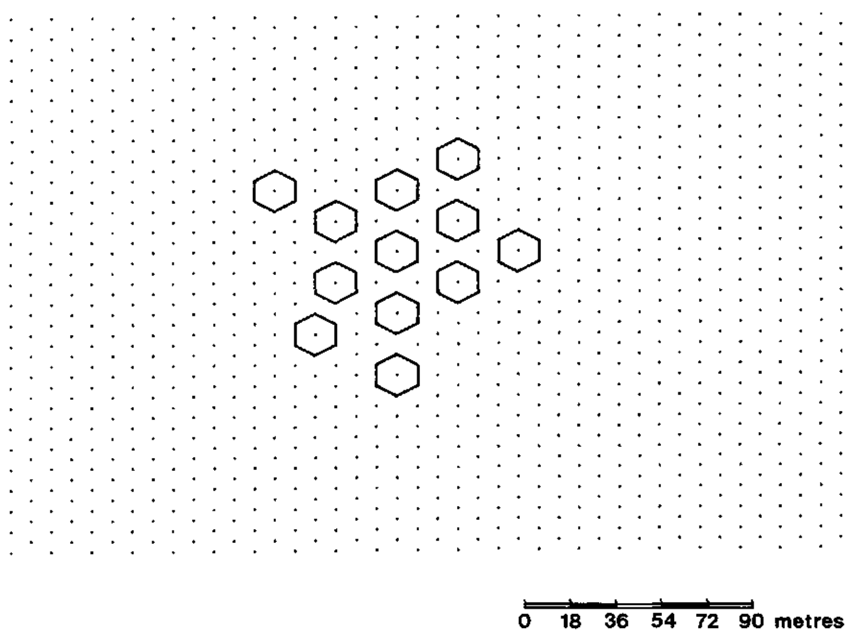

Figure 2. Grid of trees with hexagonal 'sample points' consisting of seven trees used in geostatistical studies at Victoria and Phedra, Suriname. Each point of the grid represents one palm tree. The distance between trees is 8.5 (Phedra) or 9 (Victoria) metres.

Construction of semivariograms and sampling technique. To construct the experimental, omnidirectional semivariograms, calculations were based on all distances (h) shorter than or equal to one half of the length of the longest side of the area to be evaluated (Spatanal program by A. Stein (1986) Wageningen Agricultural University; Basic programs written by R. Rossi, Washington State University, Pullman). A value of h equal to the distance between rows of samples was taken. Presampling was carried out to determine the best scale (Van de Lande, unpublished). Geostatistical analysis may be affected by the support of the sample, which expresses the size, shape, orientation, scale and spatial arrangement of samples (Schotzko and O'Keefe, 1989). Choosing the hexagonal shape conformed to the field situation of espacement. Samples were generally chosen in a regular grid except for those situations where palms were lacking (gullies, unplanted area or missing palms). The grid consisted of hexagons (Figure 2) with their centres spaced 27 metres apart according to a triangular design. Sample areas comprised seven palms in a hexagon, resulting in an evaluation of over 75% of all trees. Incidence was assessed as the proportion of palms with spear rot relative to the total number of trees planted in a block. A value of zero indicated that the palms in the sample bore no signs of spear rot symptoms.

The conditions of the intrinsic hypothesis in geostatistics had to be fulfilled (1. The expected value of the difference $x(z)$ $-x(z+h)$ is independent of the point z for any distance h and, 2. The semivariogram is independent of the point z for all possible distances h, Rendue, 1981; Journel and Huijbregts, 1978). Therefore, only that part of the block area comprising a clear focus was evaluated in blocks 3, 5, 6, 7 and 9. In block 6 and 7 the remaining area with scattered diseased palms was evaluated separately.

Semivariogram analysis. The semivariance, (γ(h)), is estimated by calculating the mean of the squared differences between values of pairs of samples which are separated by the same distance (h). To obtain a reliable estimate of the variance the number of sample pairs was at least 100 for each distance (David, 1977). For sampling distance (h) formula (1) is applied assuming validity of the intrinsic hypothesis (Journel and Huijbregts, 1978).

$$\gamma(h) = \Sigma(Fx_{i+h} - Fx_i)^2 / (2.N_h) \qquad (1)$$

x_i = the position of a sample point.
x_{i+h} = the position of another sample point at distance h from x_i.
Fx = the value measured at location x.
N_h = the number of sample pairs for distance h.

As the distance h between individuals in a sample pair increases these individuals will be less related to each other. The semivariance, $\gamma(h)$, sometimes reaches a maximum value. The distance at which this maximum is reached, is called the 'range' (David, 1977) or 'distance of influence' (Rendu, 1981). The semivariogram detects spatial dependance and quantifies spatial relationship between data from a point in space and similar data at a distance h.

Modelling the semivariogram. The line or curve appearing in the semivariogram can be described by a mathematical equation (Journel and Huijbregts, 1978). Two groups of models are distinguished, models with and without a maximum value called a 'sill' (Maximum value for the semivariance). The spherical model is arranged under models with a sill. There is a range and outside this distance of influence the variance between pairs of samples does not increase with increasing distance. The theoretical model (2, 3, 4) given by Matheron (1963) is

$$\gamma(h) = 0 \qquad h = 0 \qquad (2)$$

$$\gamma(h) = C_0 + C_1\{1½*(h/a) - ½*(h/a)^3\} \qquad 0 < h \leq a \qquad (3)$$

$$\gamma(h) = C_0 + C_1 \qquad h > a \qquad (4)$$

where, C_0 = the nugget variance.
$C_0 + C_1$ = the sill or maximum value.
h = the sampling distance.
a = the range or distance of influence.

The tangent at the origin C_0 intersects the sill at a distance equal to ⅔a (David, 1977). When there is no correlation between sample points, the semivariogram has a maximum value represented by a flat semivariogram. This means that we are dealing with a random phenomenon (pure nugget effect $\gamma(h) = C_0$; David, 1977). The major characteristic of the semivariogram of the random or uniform distribution is the linearity with little or no slope which results in a low R^2. The occurrence of this 'nugget' variance (C_0) implies the presence of a discontinuity at the origin or can be ascribed to sampling errors or to microstructures which cannot be detected (Rendu, 1981); $\gamma(h)$ does not approach zero at zero value of h. In models without a sill the semivariance increases over increasing sampling distance. When the semivariances show a linear trend the model $\gamma(h) = C + b.h$ (where b = the slope) can be fitted.

Interpretation of the shape of the semivariogram. A spherical shape implies a gradual reduction in dependence of $\gamma(h)$ with increasing distance until the maximum or sill is attained. At this point the semivariance no longer increases or becomes random. An epidemiological interpretation is the occurrence of transmission from a certain source over a specific range. Beyond this maximum distance there is no relationship between the sample points and the position of incidence values in space is random, determined by chance. The shape of the flat semivariogram can be interpreted as evidence of spatial independence of the incidence data at the scale of sampling, suggesting that there is no relationship between sampling pairs irrespective of the distance. Then, the position of diseased palms in space is unrelated and subject to chance, implying infection of palms from different sources within or outside the sampled area. The linear spatial structure shows a continuous reduction in dependence of the semivariance with increased distance. Epidemiologically this linear spatial structure can be interpreted as a spreading mechanism which operates over long distances, but within sampled area.

Sampling distance. Values of semivariograms were calculated for the sampling distances, h, between sample pairs. The larger h, the smaller the number of sample points which participate in the calculation, and the more inaccurate the result. Therefore, the semivariogram is most accurate in the area close to the origin (David, 1977).

Directional effects. To visualize the change of disease incidence with time, maps with the locations of diseased trees were generated (Figures 3 and 4). Disease gradients were analyzed in several directions, comparing two methods.

a. *Semivariogram analysis.* To detect anisotropy (David, 1977), the semivariograms were calculated in 4 different directions, 0, 45, 90 and 135 degrees. In the analysis, 0 degrees corresponded to the original direction of the palm rows of the respective blocks. The preferential direction was assessed by selecting the longest range (spherical model) or the steepest slope (linear model).

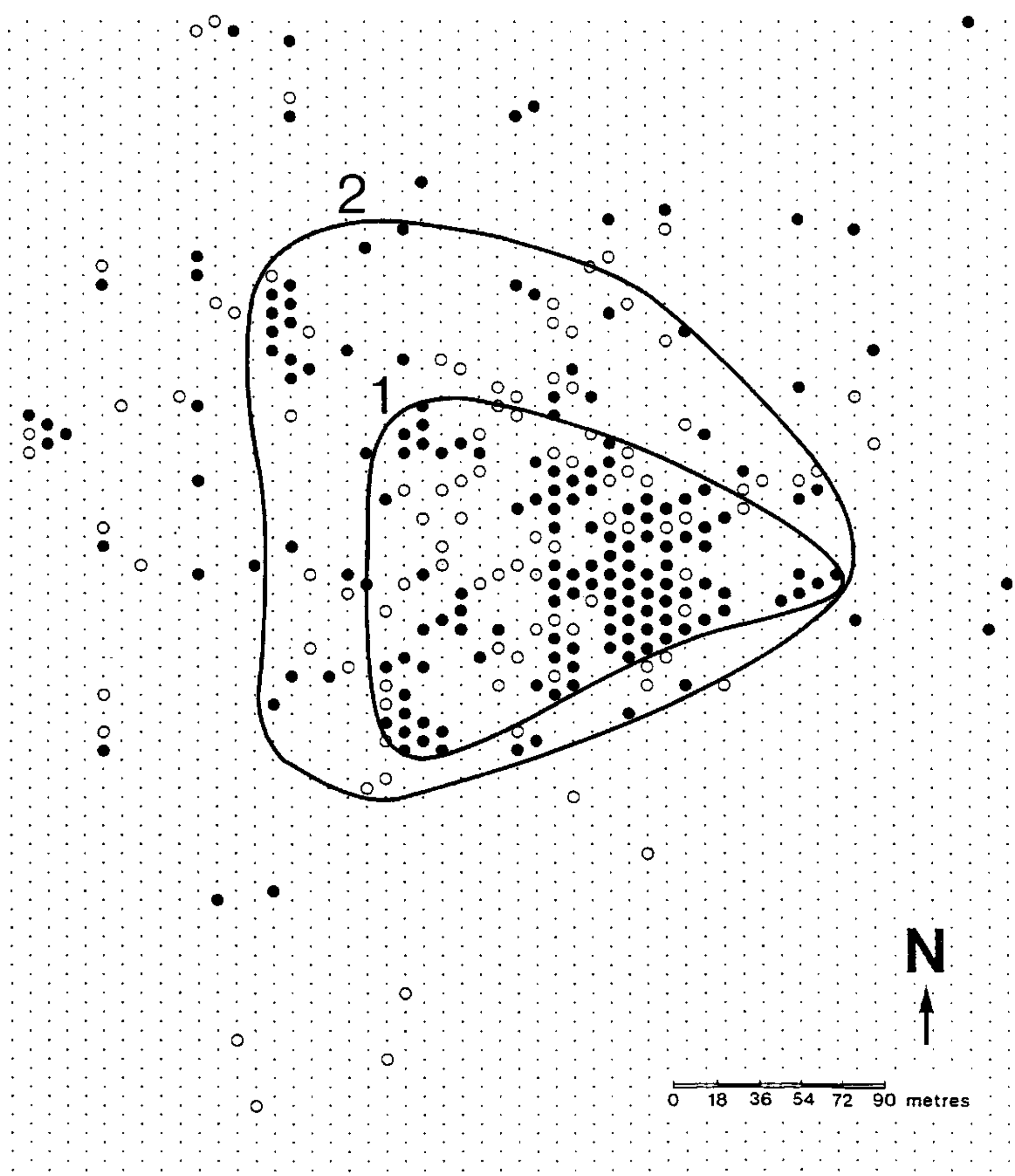

Figure 3. Spear rot of oil palm in Victoria, Suriname. Grid points (9 m apart) represent individual trees. Pattern (borders:1 and 2) of diseased trees in block 6 at two dates.
● = January 1986, ○ = January 1987.

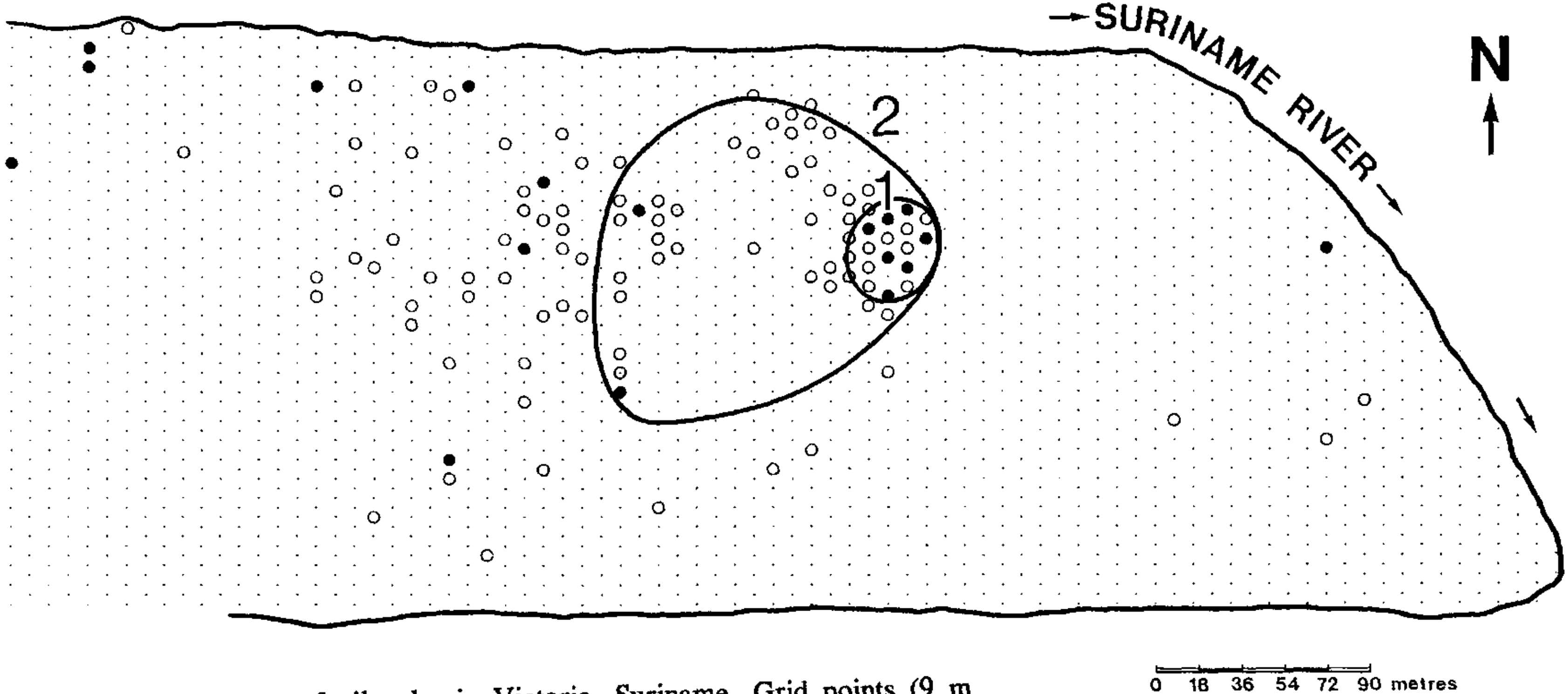

Figure 4. Spear rot of oil palm in Victoria, Suriname. Grid points (9 m apart) represent individual trees. Pattern (borders 1 and 2) of diseased trees in block 9 at two dates.
● = December 1985, ○ = December 1987

b. *Gradient analysis.* By means of gradient analysis (Zadoks and Schein, 1979) the decrease of the disease incidence at increasing distances from a known source, here a clump of affected trees, was evaluated on a double log scale (Gregory, 1968) at different time intervals. The first affected tree of a focus could not always be identified with certainty. Disease gradients with (probably) first affected trees as origins were determined in various directions using blocks with clear primary foci only. The shape of the gradient provides information on the type of spread and the source of inoculum. The slope is flattest in the downwind direction (Gregory, 1968).

Meteorological data. Information on wind directions was obtained from the Meteorological Service in Paramaribo, Suriname. Data came from the Zanderij Airport, located at about 30 and 60 kilometres from Phedra and Victoria, respectively. Wind direction was measured at 1.5 metres above soil level. Wind direction generally depends on the so-called trade winds, coming from the east.

Topographical information. Topographical data of the plantations were obtained from the Central Institute for Aerial Mapping in Paramaribo. Maps showed contour lines at 5 metres distance in altitude. Generally, altitude increased from the block side bordering a swamp or marshy forest area towards the centre of the block. Altitudes of blocks bordering the river were generally lower than blocks in the middle of the plantation.

Statistical analysis. Model fitting of the theoretical to the experimental semivariograms was made using gamfit (written by R. Rossi). Selection of models was based on the highest coefficient of determination (R^2) and further evaluated with the F-test ($P < 0.05$; Harnett, 1982). A t-test (Harnett, 1982) was used to test slopes ($P < 0.05$) and y-intercepts in the linear semivariograms ($P < 0.05$). Slopes of gradient lines were tested with a t-test ($P < 0.05$; Harnett, 1982).

Results

Location and size of foci

The locations of the focal centres varied from one block to the other. At an early stage of infection some blocks of Victoria and Phedra had a few scattered trees affected, sometimes only in one part of a block. Clusters of affected trees, here called foci, were formed predominantly at a border near other infested blocks (5, 34, 46A and C), close to a forest or a swamp area (3, 7, 16, 42B, 46B and D), but seldom in the middle of a block (6 and 9, Figures 3 and 4). In block 15, spear rot trees were scattered over the entire area.

Semivariogram analysis

Linear model. According to the R^2 criterium all 9 blocks (Table 2) showed a significant linear regression of $\gamma(h)$ on h at least once. Usually both intercept C and slope b differed significantly from zero at the $P < 0.05$ level. Blocks generally had a mean spear rot incidence of 0.01 or higher. The linear model fitted to the data of blocks 5 (1983) and 7 (Eastern part in 1982, Table 2) was not significant. Mean incidence of spear rot in these two blocks was 0.02 and 0.002, respectively. The semivariogram values indicated a linear relationship in the data of block 7-west and confirmed early focal development here (mean incidence 0.018).
The linear model was fitted to the data of 5 (1983), January, 1987, in block 6 east, which lacked focus development, but no significant data resulted (Table 2). The same was true for blocks 5 (1983), 9 East (1985 and 1986), 46B (1990) and 46C (1990).
Slope. The slope of the regression line increased over the years (Blocks 3 (Fig. 5), 15 (January to September 1986) and 46D). The slope of the regression line in block 5 (1983) and 7 East (1982) was close to zero.
Directional preference. In the directional semivariogram of blocks 3 and 7 the coefficient b at approximately 135 degrees North was significantly larger than at 35 degrees. In blocks 5 (Figure 6) and 34 (Table 2), b in the directional semivariograms of 45 degrees was significantly larger than at 135 degrees.

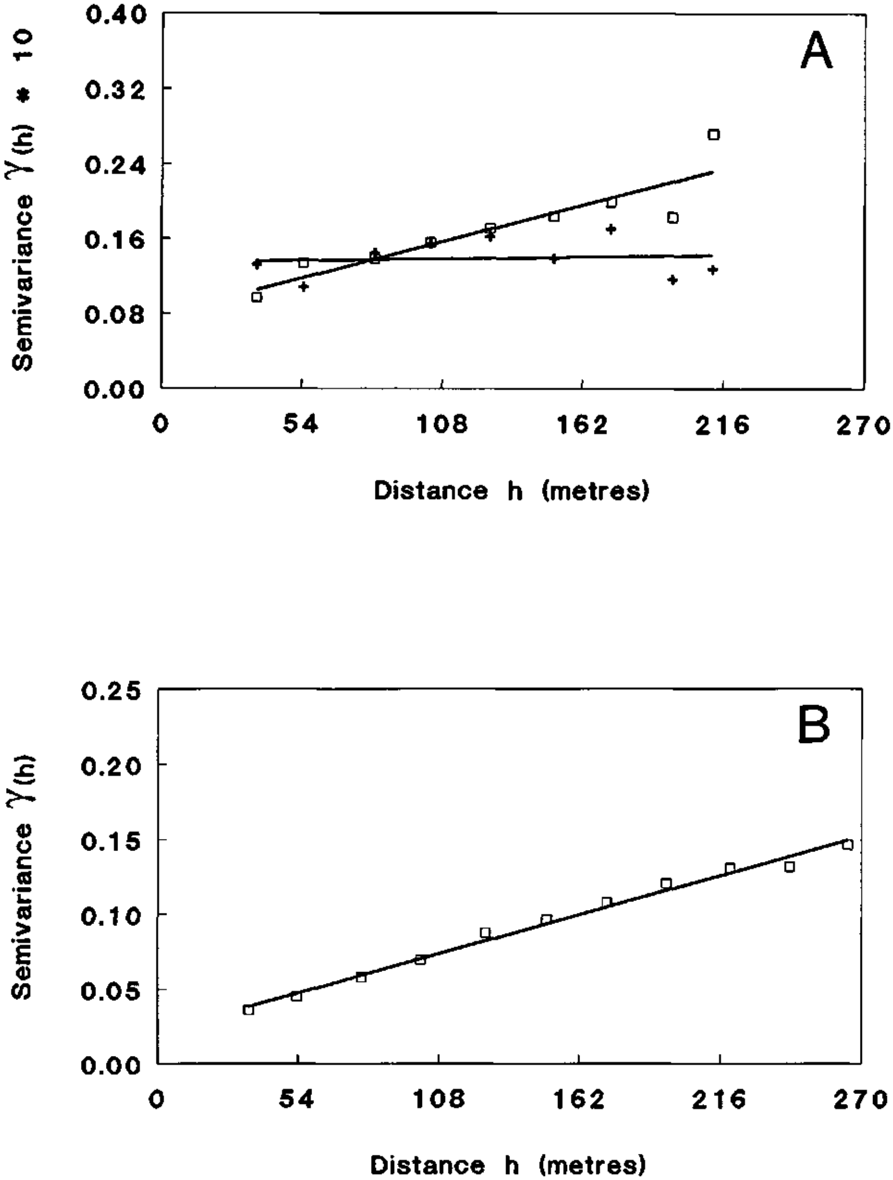

Figure 5. Experimental semivariograms of spear rot distribution in block 3, in the years 1983 (A) and 1986 (B). Fig. 5A + = 135°, □ = 45°; Fig. 5B □ = omnidirectional.

Table 2. Spear rot of oil palm in Suriname. Geostatistical analysis of blocks in the plantations Victoria and Phedra. The linear model ($G(h) = C + b^*h$) was fitted to the experimental semivariograms of spear rot incidence.

Block	Year	Direction[#]	C	*b*	R^2	Incidence
Victoria						
3	1983	omni	.0117 *	.000024 *	.74 *	.061
		45	--	--	.01 NS	.061
		135	.0079 NS	.000072 *	.83 *	.061
	1984	omni	.0148 *	.000141 *	.94 *	.127
	1986	omni	.0216 *	.000480 *	.99 *	.415
		45	.0295 *	.000253 *	.84 *	.415
		135	.0216 *	.000484 *	.99 *	.415
5	1983	omni	--	--	.15 NS	.021
	1986	omni	.0276 NS	.000175 *	.97 *	.326
		45	.0263 NS	.000260 *	.95 *	.326
		135	.0354 NS	.000050 *	.65 *	.326
6	J. 1987 E	omni	--	--	.12 NS	.151
7	1982 E	omni	--	--	.00 NS	.002
	1982 W	omni	.0022 *	.000004 *	.94 *	.018
	1986 E	omni	--	--	.02 NS	.047
	1986 W	25	--	--	.16 NS	.152
		115	.0133 *	.000303 *	.98 *	.152
9	1985 E	omni	--	--	.02 NS	.007
	1986 E	omni	--	--	.03 NS	.007
15	J. 1986	omni	.0025 *	.000002 *	.68 *	.016
	S. 1986	omni	.0037 *	.000004 *	.60 *	.020
	J. 1987	omni	.0071 NS	.000004 *	.59 *	.036
		0	.0052 *	.000023 *	.85 *	.036
		90	--	--	.06 NS	.036
16	1984	0	--	--	.49 NS	.009
		45	.0012 *	.000001 *	.58 *	.009

		135	.0012 *	.000001 *	.59 *	.009
34	1986	45	.0180 *	.000076 *	.83 *	.155
		135	--	--	.62 NS	.155
Phedra						
42B	1990	omni	.0040 *	.000278 *	.97 *	.758
		0	.0520 *	.000201 *	.95 *	.758
		90	.0066 *	.000413 *	.95 *	.758
46A	1990	omni	.0189 *	.000024 *	.54 *	.118
		0	.0146 *	.000094 *	.98 *	.118
		90	.0151 *	.000045 *	.86 *	.118
46B	1990	omni	--	--	.23 NS	.190
46C	1990	omni	--	--	.13 NS	.081
46D	1985	omni	.0037 *	.000024 *	.90 *	.022
	1988	omni	.0105 *	.000030 *	.99 *	.109
		0	.0063 *	.000050 *	.99 *	.109
		90	.0205 *	.000057 *	.88 *	.109

E = Eastern part of the block, W = Western part including focal area, NS - Not Significant, * = Significant ($P \leq 0.05$), # = direction corrected to compass North.

Random model and early disease development in block parts. The data of blocks 5 (1983; Table 2), 6 West (1987; Figure 7) and 7-East (Table 2 and 3) showed a random character. Semivariogram values in block 7 West were about 10 times higher than in 7 East as were mean incidences.

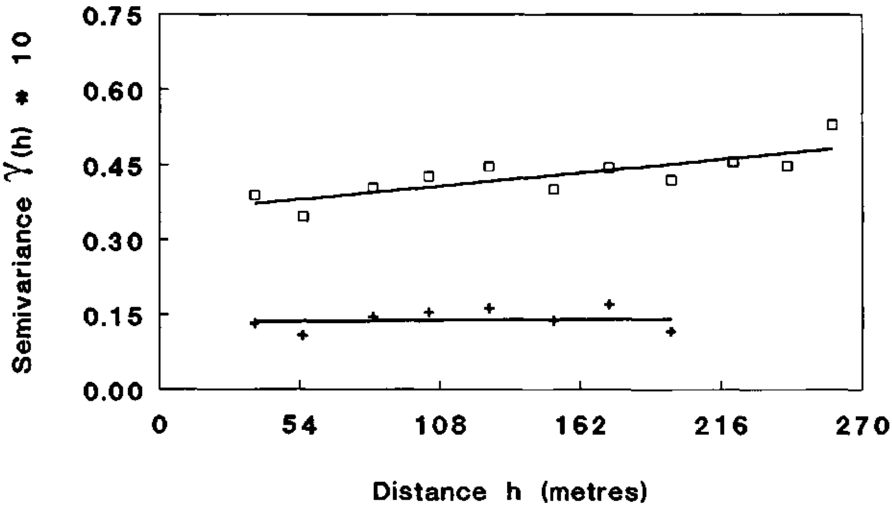

Figure 6. Unidirectional semivariograms of spear rot distribution in block 5 (December 1986).
+ = 45^0 North, □ = 135^0 North

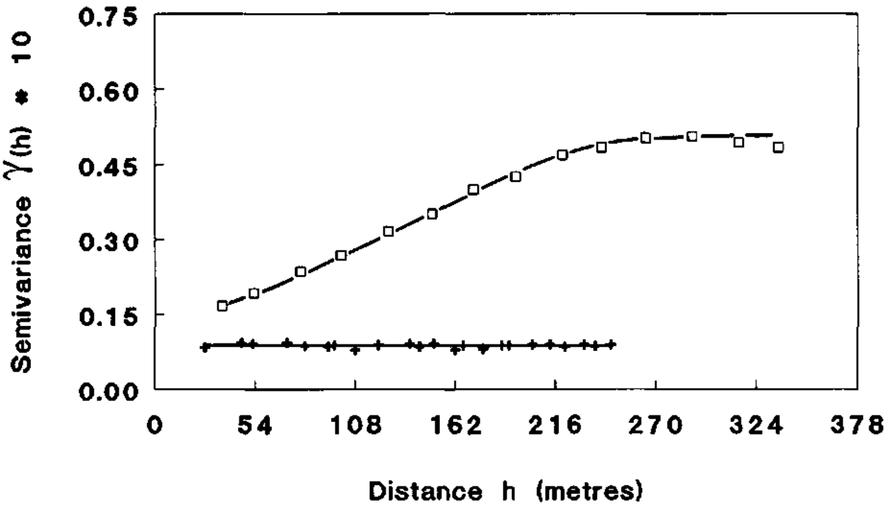

Figure 7. Omnidirectional semivariograms of spear rot distribution in the Eastern and Western part of block 6 in 1987.
+ = West, □ = East

Table 3. Spear rot of oil palm at Victoria, Suriname. Average experimental semivariogram values of spear rot incidence in the eastern and western (focal) part of block 7 in the year 1982.

	7 - West		7 - East	
h[1]	G_h	N_h	G_h	N_h
36	.0024	1782	.00029	1810
53	.0025	1148	.00034	971
78	.0024	3295	.00031	3197
100	.0027	2684	.00031	2452
126	.0028	4449	.00030	4133
149	.0029	3585	.00029	3425
172	.0029	4318	.00031	4055
195	.0029	4309	.00029	4013
220	.0031	5177	.00029	4785
241	.0031	3527	.00030	3281
259	.0033	2680	.00033	2465

[1] = Average distance h in metres.
G_h = Value of the semivariogram at distance h.
N_h = Number of sample pairs at distance h.

Spherical model. For blocks 6 (January 1986 and January 1987; Figure 7) and 9 (1987 and 1988) at Victoria and block 46C (1990) at Phedra the spherical model could be significantly fitted ($R^2 \geq 0.79$) to the semivariograms (Table 4). The fit of the spherical model for the 1986 data of block 9 was better than of the linear model, but was not significant in either model.

Table 4. Spear rot of oil palm in Suriname. Geostatistical analysis of blocks in the plantations Victoria and Phedra. The spherical model was fitted to the experimental semivariograms of blocks of spear rot incidence.

Block	Year	Dir.	C_0	C_1	Sill	Range metres	R^2	M. Inc.	tg α
Victoria									
6 #	J. 86	omni	.0072	.0143	.0215	225	.98 *	.047	≤.0001
	J. 87	omni	.0098	.0596	.0694	275	.99 *	.151	.0003
9	1986	omni	--	--	--	--	.38 NS	.007	--
	1987	0	.0009	.0174	.0183	94	.99 *	.051	.0003
	1987	90	.0085	.0132	.0217	250	.87 *	.051	≤.0001
		omni	.0051	.0134	.0185	116	.94 *	.051	≤.0002
	1988	omni	.0136	.0728	.0864	226	.99 *	.231	.0005
Phedra									
46 B	1990	omni	--	--	--	--	.52 NS	.190	--
46 C	1990	omni	.0044	.0138	.0183	51	.79 *	.081	.0004
		-70	--	--	--	--	.52 NS	.081	--
		-160	--	--	--	--	.14 NS	.081	--

Dir = Direction, M. Inc. = Mean incidence, # Centre of block, comprising focus, NS = Not Significant, * = Significant ($P \leq 0.05$).

Range. In the omnidirectional semivariograms of blocks 6 and 9 the range increased with the years (Table 4; Figures 3 and 4). The largest range was measured at 90 degrees North for block 9. The range, estimated through semivariogram analysis corresponded with the size of the foci, illustrated in the maps of blocks 6 and 9 (Figures 3 and 4).
Sill. Over the years the sill increased with increasing incidence in blocks 6 and 9.

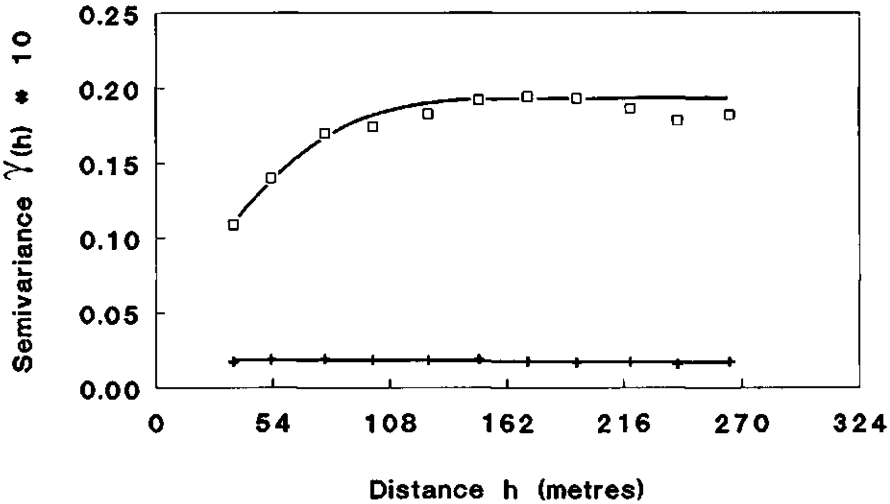

Figure 8. Omnidirectional semivariograms of spear rot distribution in block 9.
+ = 1985, □ = 1987.

Slope. The value of tg α, used to estimate the slope of the regression line in the steep part of the semivariogram, increased over the years in blocks 6 and 9 (Figure 8). In block 9 the slope was flatter in the direction of preference in 1987 (Table 4).
Directional preference. Blocks at Phedra had a directional preference between -70 and +20 degrees North. In some cases, the direction of preference was about the same as the direction of rows (Blocks 15, 16 at Victoria and 42B, 46A and D at Phedra), and in other cases it was about perpendicular to the rows (blocks 6, 9 at Victoria and 46B and C at Phedra).

In conclusion. Semivariogram analysis of 9 blocks resulted in linear and 4 blocks in spherical semivariograms. The slopes in the linear model, and the ranges and sills in the spherical model increased significantly over the years and in the direction of preference. With increasing ranges and sills the slopes of the steep parts in the spherical model decreased. The changes in spatial patterns of a few blocks at low spear rot incidence (0.002), from a pure nugget situation to linear semivariograms, suggests that in these blocks the random situation is disturbed at an early stage of disease development. In most blocks, however, semivariogram analysis resulted in either a linear, or a spherical relationship at low spear rot incidence already (0.009 or higher).

In eight blocks at Victoria and five blocks at Phedra a preferential direction was determined, approximately between 45 and 135 degrees North. This preferential direction was not related to the direction of tree rows or harvest and maintenance procedures.

Gradient analysis

Gradient analysis was applied to blocks 7-West and 9. In block 7 the first affected tree occurred in the North-West corner. Here, long gradients could be analyzed in south-easterly directions, in sectors of about 35 degrees spreading to the south-east-east (SEE) and south-south-east (SSE). In block 9, the approximate location of the first affected tree was in the central east of the block. Disease spread was mainly directed towards the western part of the block resulting in a funnel-shaped pattern of spread (Figure 4). Disease gradients were analyzed in south-south-westerly (SSW), westerly (W) and north-north-westerly (NNW) directions.

Generally, b coefficients tended to decrease over the years, indicating a change with time towards flatter gradients (Tables 5 and 6). Over the years, the b coefficient was lower in the SEE sector than in the SSE sector of block 7, suggesting a preferential spreading of disease in a direction of approximately 160 degrees North. Generally, in block 9, the slope was flattest in W or SSW directions (Table 6), suggesting a preferential spread at minus 90 to 135 degrees north (Figure 9). In block 9 the steep W and NNW gradients over the years 1985 to 1987 flatten at a distance of approximately 95 metres (Figure 9A). This flattening was also observed in the NNW direction in 1987 (Figure 9B). The b coefficients were significant in all years and directions in both blocks ($P < 0.05$).

Topography

Observations in blocks 3, 7 and 9 indicated that the location of initial foci corresponded with depressions in the field. Topographical maps were not detailed enough, so that it was impossible to relate focal site to altitude.

Table 5. Spear rot of oil palm in Victoria, Suriname. Statistical parameters of disease gradients in SSE and SEE directions in block 7 over 4 years.

Year	SSE			SEE		
	R^2	$b^\#$	S.E.	R^2	$b^\#$	S.E.
1983	0.88	-0.45	0.04	0.78	-0.35	0.05
1984	0.78	-0.42	0.06	0.73	-0.33	0.06
1985	0.65	-0.25	0.05	0.75	-0.24	0.04
1986	0.63	-0.23	0.05	0.75	-0.18	0.03

R^2 Coefficient of determination.
b Coefficient of linear regression.
S.E. Standard error of the coefficient *b*.
\# *b* Coefficients differed significantly from zero ($P \leq 0.05$) in each year and every direction.

Table 6. Spear rot of oil palm in Victoria, Suriname. Statistical parameters of disease gradients in SSW, W and NNW directions in block 9 over 4 years.

Year	SSW			W			NNW		
	R^2	$b^\#$	S.E.	R^2	$b^\#$	S.E.	R^2	$b^\#$	S.E.
1985	0.94	-1.22	0.13	0.95	-1.41	0.13	0.99	-1.81	0.02
1986	0.94	-1.21	0.13	0.97	-1.12	0.09	0.99	-1.69	0.08
1987	0.82	-0.87	0.17	0.87	-0.91	0.15	0.93	-0.83	0.13
1988	0.74	-0.38	0.09	0.88	-0.33	0.05	0.97	-0.49	0.05

R^2 Coefficient of determination.
b Coefficient of linear regression.
S.E. Standard error of coefficient *b*.
\# *b* Coefficients differed significantly from zero ($P \leq 0.05$) in each year and in every direction.

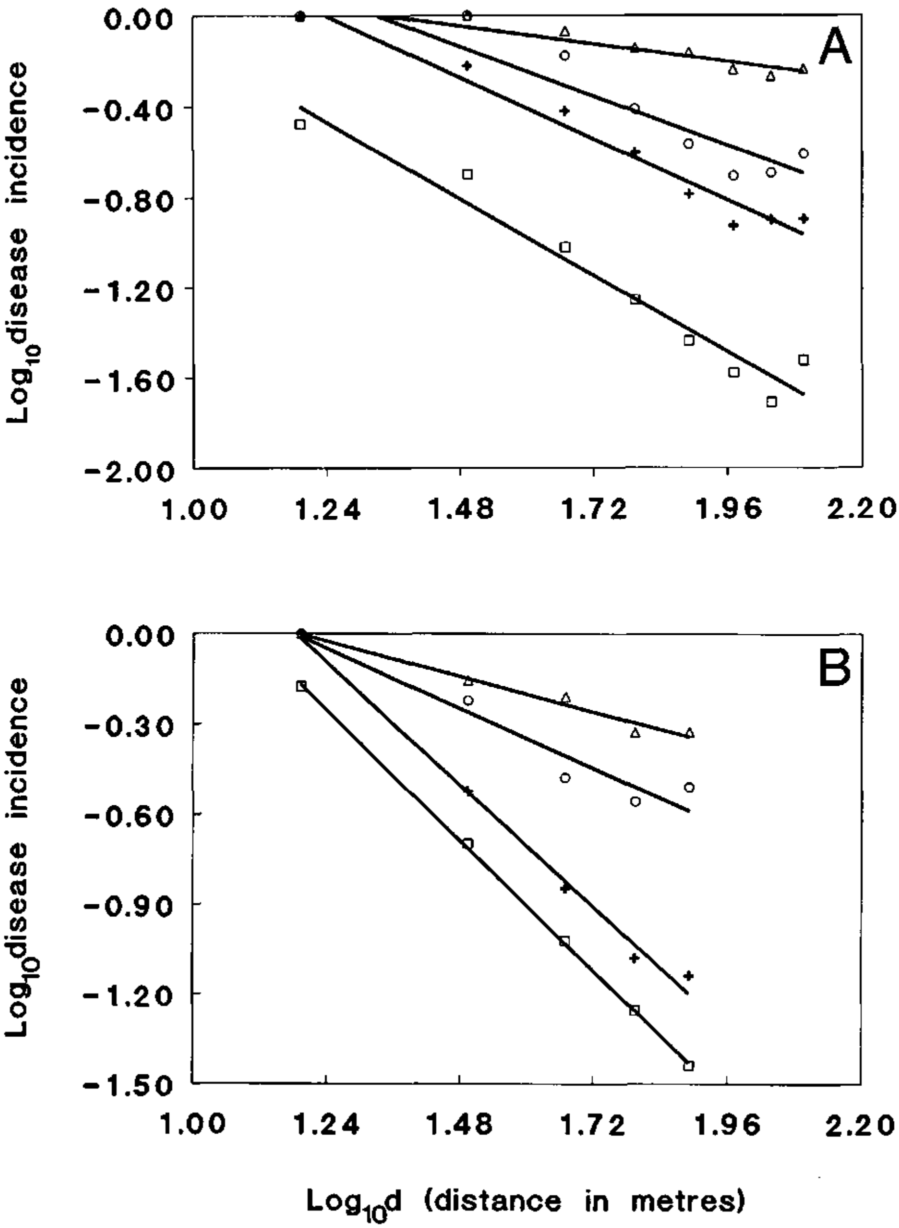

Figure 9. Spear rot of oil palm in the Victoria plantation, Suriname. Disease gradients of block 9 in W (A) and NNW (B) directions at 4 dates, calculated as regression lines of $\log_{10}$ incidence on $\log_{10}$ distance.
(□ = 1985, + = 1986, ◇ = 1987 and ▲ = 1988).

Discussion

The causal organism of spear rot is still unknown but an infectious character of the disease is suspected (Van de Lande, 1990a). This brings to mind an incidence in medical history (Gale, 1959). At one time, the infectious nature of cholera was suspected but its causal agent was unknown. Careful spatial analysis of a cholera epidemic in London led to an association of disease incidences with a water source. The cholera problem could be solved by changing the water sources.

Returning to spear rot, spatial analysis, now supported by modern statistics may help to understand the nature of the disease (Cliff and Ord, 1981). By using two complementary methods, semivariogram and gradient analysis, the underlying processes which probably led to the transmission of the disease and which shaped spatial patterns of diseased trees, were elucidated.

Semivariogram analysis

Absence of spatial relationships. The random model fitted to semivariograms at low disease incidences in blocks 5, 6 East and 7 East indicated the absence of spatial relationships between pairs of sample points. Apparently, the position of the affected trees in these blocks had a random pattern in the beginning. Though these early observations do not inescapably point to the infectiousness of spear rot disease, the result is compatible with the hypothesis of sources of inoculum far away (multiples of 27 m) from the diseased tree, in other parts of the plantation or outside. By the same token, the result suggests a mechanism of disease dispersal which can overcome at least 27 metres.

Presence of spatial relationships. In the majority of blocks a linear or spherical model could be fitted to the spatial pattern of spear rot tree, even at low disease incidence. Initial discontinuities in the semivariograms, demonstrated by the nugget, primarily related to the discontinuity (or sampling error) in the observations (Rendu, 1981; Lannou and Savary, 1991), since the smallest distance between two samples points was about 27 metres. The 'nugget effect' could explain the poor fit of the spherical and linear models in block 9 (1985, 1986), where the map (Figure 4) suggests a focal pattern of disease in 1985.

The situation which was found in those blocks in which semivariogram analysis resulted in linear and spherical relationships between pairs of sample points differed from the random situation. The linear relationship extended over long distances over the entire block area analyzed. In spherical relationships there was one preferential compass direction with a range of influence longer than the other directions, or, in other words, the spatial dependence of sampling points extended over a longer distance. Over the years, as disease incidences and herewith the sills increased, the ranges tended to enlarge independent of compass direction. We observed

(1) a close relationship between diseased trees at a certain average distance through time,
(2) an increase of the range with time, and
(3) beyond this range, a spatial relation between the positions of diseased trees following a random pattern through time.

Similar phenomena are seen with focus development of infectious disease (Zadoks and Kampmeijer, 1977; Zawolek and Zadoks, 1989). The hypothesis of spear rot being an infectious disease becomes almost inescapable, even though there is no clue about the nature of the infectious agent.

The statements 1, 2 and 3 suggest the presence of two different mechanisms of dispersal in the spherical model. The first one works over short distances causing a distinct focus, which increases in intensity and enlarges in diameter (Lannou and Savary, 1991), indicating transmission from tree to tree (Lecoustre and de Reffye, 1986), typically within block dispersal. The second mechanism causes the occurrence of diseased trees which are scattered over larger distances and which appear to be spatially unrelated, indicating dispersal from different (outside) sources. The relatively large range in one compass direction, actually downwind, is compatible with the hypothesis that the causal agent of spear rot is vector-borne, the displacement of the vector being sensitive to wind.

The data, and the results of semivariogram analysis are compatible with the hypothesis that spear rot is an infectious disease, appearing in two distinct phases.

Phase 1 has scattered diseased trees at very low incidence, apparently after infection from inoculum sources beyond the borders of the investigated area. Phase 2 is characterised by focal spread of disease starting from scattered trees infected in phase 1. Foci intensify and expand, either with or without clearly defined borders, indicating, respectively, the spherical and the linear shapes of semivariograms.

In the random situation of spatial patterns semivariograms confirmed the presence of scattered peripheral diseased trees, which are of great importance since they are potential sources for secondary spread (Pedgley, 1982).

Gradient analysis

Gradient analysis confirms the picture of phase 2 in a more classical way than geostatistics. Flat, declining or shallow disease gradients (Gregory, 1968; Zadoks and Kampmeijer, 1977) such as in block 7 and 9 indicate that diseased plants are scattered over a wide area. Motile vectors may be involved. In block 9 west (1986 and 1987) flattening of gradients can be explained by background infection (Gregory, 1968), whereas steep gradients as found in the NNW direction indicated clumping of diseased plants near the initial focus (Van der Plank, 1963), and suggest that vectors could be involved (Pedgley, 1982).

Topography and Soil

Topographical maps did not give enough detail. Evaluation of the altitude levels within the boundaries of the various blocks did not indicate that spear rot spread took place from high to low areas. Movement through the soil by means of surface or groundwater is therefore unlikely. Forest and swamp areas may have acted as sources of infection considering the fact that the majority of blocks were bordering such areas at least at one side.

It was shown earlier, that the disease occurs in fields with different soil types (Van de Lande, 1990a). The effect of soil type on disease occurrence can therefore be neglected.

Mechanical transmission

Harvesting and pruning procedures were carried out from the first row towards the last row of a block. Should mechanical transmission have taken place, the development of a disease gradient should have been in the direction of movement. In 6 out of 13 blocks (5, 6, 9, 15, 16 and 34) the preferential direction of spread was to the west, perpendicular to the direction of field procedures. Consequently, the hypothesis of disease spread by mechanical transmission can be rejected.

Wind influence

The mean wind direction in the interior of the country echoes that of the trade winds coming from the east. Considering the age of the palms (generally over 5 years) at the time of study the canopy was closed and crown height of the trees was 2 to 5 metres. Preferential compass directions of disease spread coincide more or less with the main wind direction. This result leads to the hypothesis that the causal agent of the disease or its eventual vector can be wind-borne, certainly in phase 2. Generally once an organism is air-borne it tends to drift down-wind. The variation between the various blocks in preferential direction in comparable years of observation , could be the result of differences in wind direction and spread (Pedgley, 1982).

Infectious nature of spear rot

The data are compatible with the hypothesis that (1) spear rot is an infectious disease with (2) a first phase of randomly scattered appearance throughout blocks with (3) inoculum sources outside the plantation, (4) a second phase of focal spread starting from initially infected randomly scattered trees, and (5) a causal agent or its vector being wind-borne in view of the preferential down-wind spread of the disease. The trigger of the change from phase 1 to phase 2 remains unknown. The existence of two different vector populations seems plausible.

Disease spread in the direction of the prevailing winds was also observed in an oil palm plantation affected by amarelecimento fatal in Brazil (Van Slobbe, 1990b). At plantations with pudrición del cogollo in Ecuador, the association between location of affected trees and the presence of the nearby forest was made with semivariogram analysis (Anonymous, 1989).

Control of spear rot

The control of spear rot, especially phase 1 infections, will be difficult. Infection sources from outside the fields are generally hard to control. The lay-out of the plantation with palm-free strips as a 'cordon sanitaire' (Thresh *et al*, 1988) in blocks bordering forest or swamp areas could be a temporary solution to keep infestation at a low level. Drastic clearing of any area containing a focus of diseased trees should be performed as soon as possible.

Spatial pattern analyses and directional studies using geostatistics and gradient analysis were useful to recognize the physical and biological mechanisms, which underlie the evolution of spatial patterns over time. They can be of importance in studies with respect to yield loss assessment and in decision making on selection of planting locations and in extension with new oil palm areas. This study may provide clues in the analysis of spatial patterns of important fatal diseases of unknown etiology in oil palm: amarelecimento fatal in Brazil (Van de Lande, 1986; Celestino e Lucchini, 1990; Martins e Silva and Oliveira Freire, 1990; Van Slobbe, 1990a, b) and pudrición del cogollo (Turner, 1981; Perthuis, 1990) in South and Central America.

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7. Management of spear rot affected oil palm plantations: A Suriname case study on decision rules for abandonment

(Submitted, author Hanny L. Van de Lande)

Abstract: The development of yields, losses and costs was analyzed in 7 blocks at the Victoria oil palm plantation in Suriname, between 1980 and 1989 before and after spear rot or fatal yellowing appeared, to decide when blocks or areas should be abandoned. The application of two methods: a) comparison of actual with reference yields and b) linear regression of relative yields on the logistically transformed values of disease incidences, led to the conclusion that the critical point where harvesting became questionable was at a relative yield of 50%, at about 0.40 disease incidence. When net earnings were related to logistic values of disease incidence the critical point where profits turned into losses appeared to be about 0.45 disease incidence. The conclusion that harvesting ceases to be profitable at about 0.40 disease incidence and that blocks should be abandoned was supported by economic evaluation. The results could be useful to other plantations with a disease history comparable to Victoria. Given local variations in costs analysis results may differ from Suriname conditions.

Keywords: critical point assessment, *Elaeis guineensis*, fatal yellowing, yield loss.

Introduction

Spear rot or fatal yellowing (Turner, 1981) is an infectious disease of unknown etiology in African oil palm at the plantations in Suriname (Van de Lande, 1986, 1990). Affected trees die.

Initially, when spear rot had a low incidence, the diseased trees were randomly dispersed (Van de Lande, c). In the early stage of the epidemic foci developed around isolated trees. As the epidemic developed, more trees became affected and died. In the early stages of disease the bunches of a diseased palm bore no symptoms of spear rot but in the advanced stages bunches tended to become smaller. Diseased trees were not cut and contributed to the bunch production for several months after the first observation of symptoms (Van de Lande, 1990; a). Diseased trees in the advanced stages had crowns with the typical flat-top-appearance or open spreading character, due to the rotting and breaking of central and middle leaves. More sunlight passed through the affected crown and weed growth under the palm increased. The plantation management decided to abandon blocks which combined a high level of disease incidence, a heavy weed infestation and a reduced production of bunches, but later such blocks produced promising bunches and harvesting was resumed. As the epidemic proceeded and more affected trees reached the advanced disease stages, the harvesters experienced difficulties to find trees with harvestable fruit bunches within the affected area.

This study tries to provide information for the management in order to decide when a block should be abandoned. The yield of fresh fruit bunches was recorded over several years before and after the disease appeared. The yield data of blocks with a known pathological, agronomical and economical history over several years were evaluated to estimate the critical point in time at which harvesting of bunches was not profitable any more. Such information will be of use to other plantations with a disease development comparable to Victoria, where the affected palms were maintained.

Materials and methods

Location selection. The study focused on field units, here called blocks in the plantation Victoria-North. Records of disease and exploitation costs were available over a range of years. Seven blocks were selected according to the criterion that data on yield of fresh fruit bunches (FFB) and on spear rot incidence had to be available over a period of 5 years or more before and at least some months after the disease became a yield limiting factor.

Type and age of planting material. The planting material in the blocks was locally made from *Deli-Dura* material pollinated with *pisifera* pollen from West-Africa. Blocks comprised planting years 1971 (block 6), 1972 (blocks 14, 15, 20 and 21) and 1973 (blocks 29 and 30).

Disease incidence. Palms affected by spear rot were identified by trained observers of the phytosanitary department of Victoria during inspection rounds in which every palm was checked for the presence or absence of diseases and pests. These inspection rounds were made at least 4 to 6 times per year. Disease incidence was expressed as the number of palms with spear rot divided by the total number of palms planted per block.

Yield records. To minimize yield fluctuations due to age, yield records of fresh fruit bunches (FFB) of palms in the adult stage (over 7 years old) were used. In oil palm average bunch yield hectare^{-1} fluctuates during the year according to external effects of the weather and internal plant factors (Breure and Menendez, 1990). As the disease spread over the entire plantation within few years after focal development started (Van de Lande, c), there was no area available which could serve as a disease-free check. Records of the seven selected blocks were used over at least five consecutive years to determine a reference yield (Zadoks and Schein, 1979) or economic yield, defined as the yield which provides a profitable return for a given investment (Chiarappa, 1981) under 'normal', i.e. pre-epidemic, conditions. This reference is expressed as a set of 12 monthly yields averaged over seven years.

Normally, blocks were harvested once every two weeks. Political disturbances made the area inaccessible at times, beginning October 1986 (Van de Lande, 1990). Between October, 1986, and December, 1987, yield records were lacking over a period of several months (Van de Lande, 1990). To alleviate the effect of variable harvest intervals the yield data were aggregated to tonnes/hectare/month (fresh fruit bunches plus loose fruits). Yield depression was expressed as the amount of reference yield, Y_r, minus the actual yield, Y_a, for the respective month (Zadoks, 1981).

Meteorological data. Data on monthly rainfall and total monthly sunshine hours were furnished by the phytosanitary department at Victoria. Precipitation data were means of records from two locations in the plantation.

Economic evaluation. Data on earnings from FFB yield processed to edible oil and exploitation costs were furnished by the management of Victoria. Exploitation costs were defined as the costs which were directly related to procedures in obtaining the processed oil. Such costs comprised the within-field costs (weeding, pruning, fertilizing, phytosanitary control, harvesting, agrochemicals, tools, transportation and salaries of field workers) and the costs made at mill and refinery (fuel, maintenance, salaries).

When to abandon a block? Economic principles were largely adapted from a study by Renkema and Stelwagen (1979), discussing the replacement decision in diary herds. In this study, in stead of replacement, abandonment of blocks affected by spear rot was the managerial decision under discussion. Assuming a constant number of palms in a given block a decision had to be made in a certain year whether the blocks should be kept in production or be abandoned. A block should be kept in production as long as its expected marginal profit is higher than zero. Profit (=net earnings) is defined as gross earnings minus all costs which can be directly attributed to the bunch yield obtained. Here, the marginal profit is the profit in any one extra month of production. Profits and costs are expressed in Suriname guilders per hectare.

Statistical analysis. The disease incidence of a block at any month was calculated by means of the relevant logistic equation (Van de Lande, b) describing the progress of disease incidence with time for that block. To estimate the critical point in disease progress where the situation of predominantly profits changed to one with predominantly losses, the actual yields were compared to the reference yields. For each month a lower tolerance level was constructed at $P \leq 0.10$ as $\{Y_r(t) - 1.645\ \sigma(t)\}$. To assess the relation between relative yields (Y_a/Y_r*100) and the disease incidence (values transformed logistically) a regression line was constructed.

Results

Relation yield-weather. Figure 1A,B shows the fluctuations in monthly yields of blocks 14, 20 and 30. At Victoria, a peak tends to occur in the period November through January followed by a drop in yield in the period of June and July. Peaks generally occur at the beginning of the small rainy season (Figure 2).

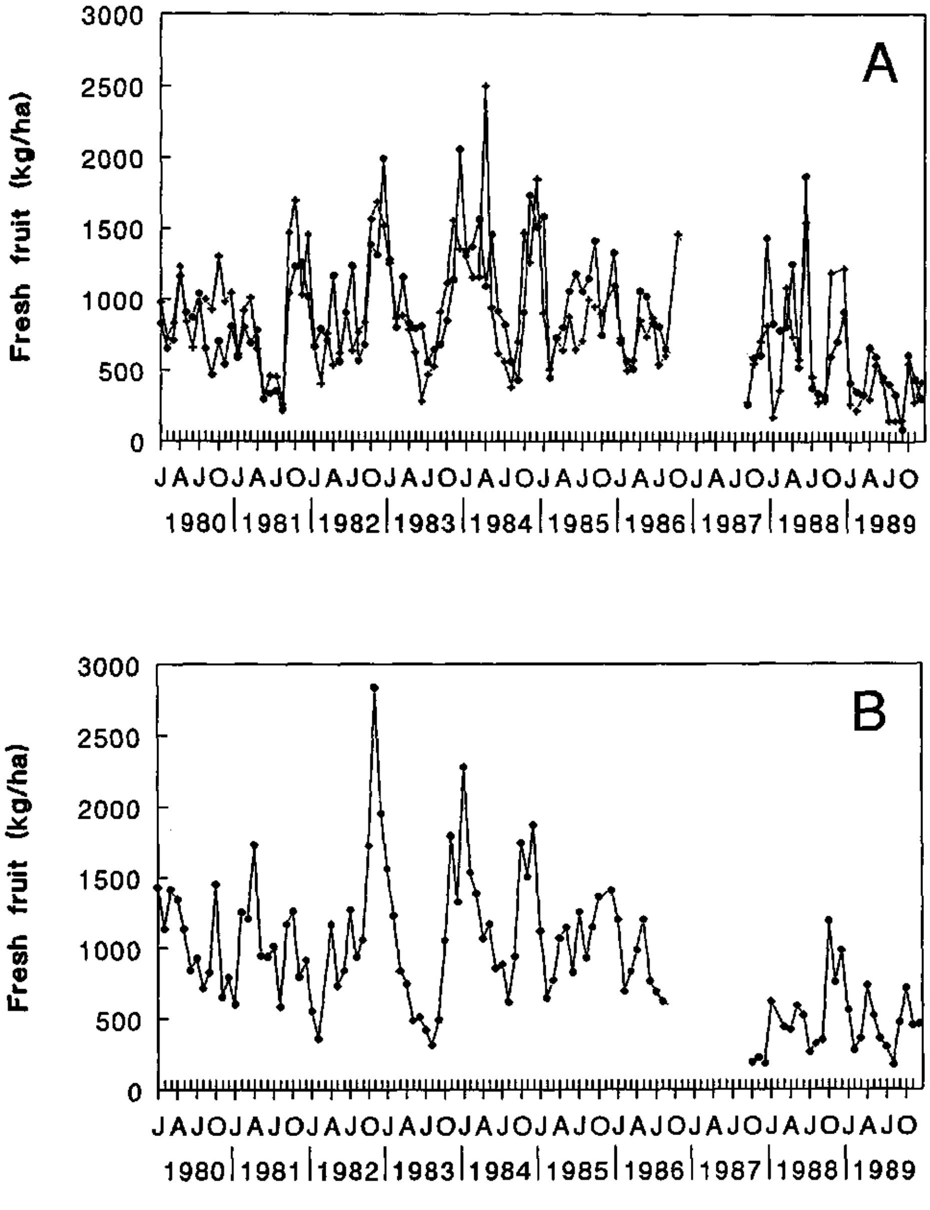


Figure 1. Monthly yields in 3 blocks at the Victoria oil palm plantation, Suriname, between 1980 and 1989. Data of 1987 were lacking due to interruptions in plantation activities.

A + = Block 14 ● = Block 20 B ● = Block 30

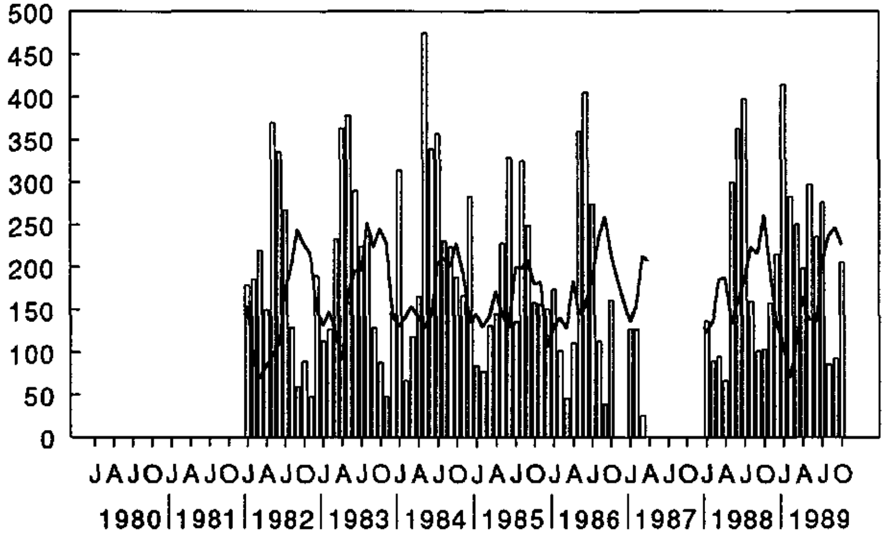


Figure 2. Monthly precipitation in mm (open bars) and sunshine duration in hours (drawn line) at the Victoria oil palm plantation, Suriname, between 1982 and 1989. Values of 1980 and 1981 were not available. Data of 1987 were lacking due to interruptions in plantation activities.

Yield decrease related to spear rot disease incidence. Yield decreased after 1987 in all blocks (Figures 1 and 3). Yields below the $P \leq 0.10$ threshold were considered to be significantly lower than average and were marked accordingly in Figure 3 as filled circles. Monthly yields of block 15 were considered 'normal', that is not less than $\{Y_r(t) - 1.645\ \sigma(t)\}$, in the first half of 1988, with a large peak in December, then dropped significantly after January, 1989, when spear rot incidence was close to 0.40 (Table 1). Most 1989 monthly yields were significantly lower than the 1988 monthly yields. In block 21 monthly yields were 'normal', except for September and December, 1987 up to December 1988. Beginning with January, 1989, when spear rot incidence was over 0.40, monthly yields were significantly lower than the reference yields. In conclusion, in these 2 blocks the monthly FFB yields that were significantly lower than those of the reference years, occurred either in the low-yield season (April to September) and/or when disease incidence of spear rot was at least about 0.40.

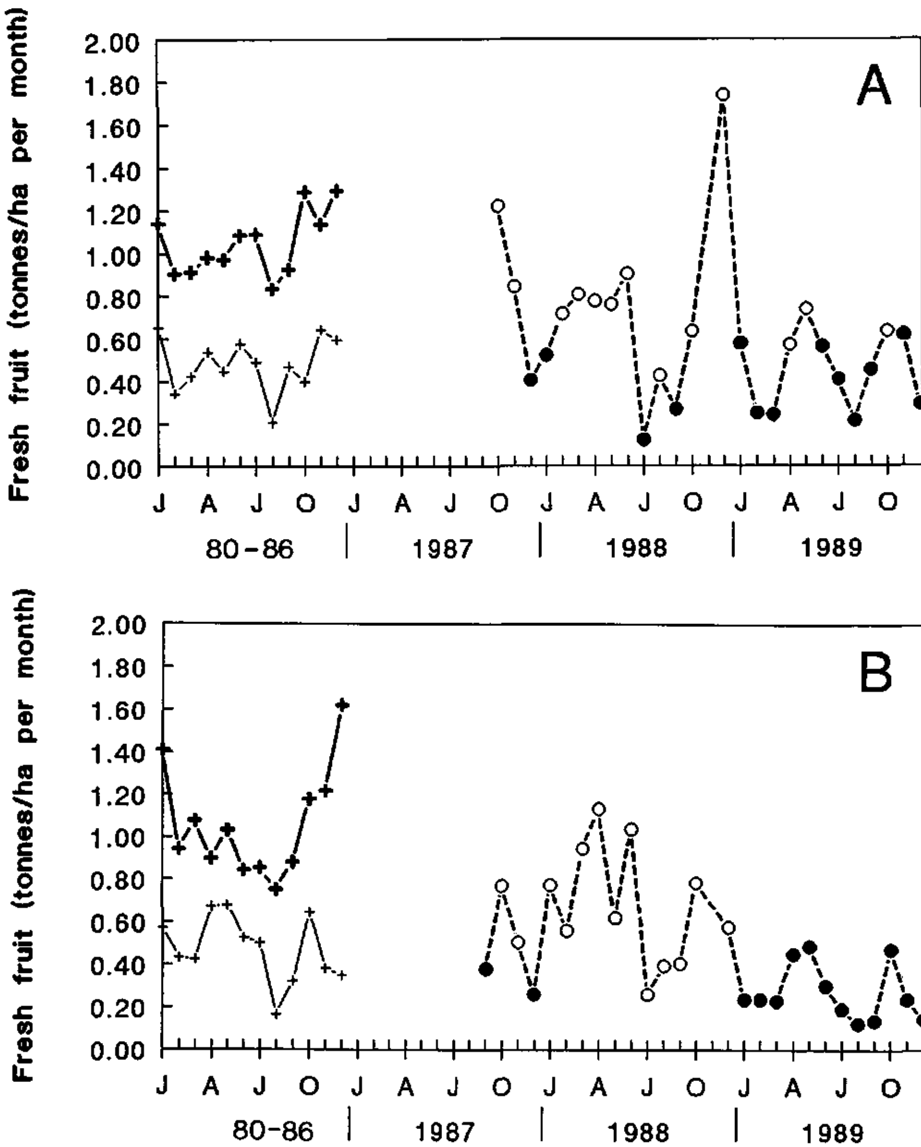


Figure 3. Monthly yields of fresh fruit in blocks 15 (A) and 21 (B) at the Victoria oil palm plantation in Suriname. Monthly reference yields are the means of monthly yields over 7 years. Thick continuous line — monthly yields (tonnes ha^{-1}) averaged over 1980-1986 ('reference yields'). Thin line — reference yields minus 1.65 standard deviations. Interrupted lines — dots indicate monthly yields (tonnes ha^{-1}), as far as available) in 1987, 1988 and 1989. Closed dots indicate values significantly ($P < 0.10$) lower than the reference yields.

Table 1. Spear rot at the Victoria oil palm plantation, Suriname. Estimated months of four disease incidence (y) levels in 7 blocks.

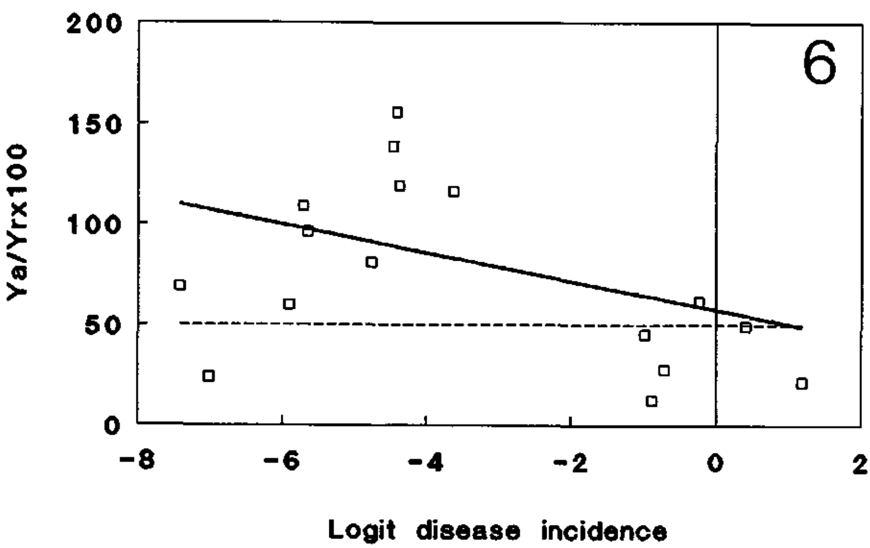
Block	Estimated months of four disease incidence levels			
	$y_{0.05}$	$y_{0.20}$	$y_{0.40}$	$y_{0.60}$
6	9/86	7/87	1/88	6/88
14	11/87	8/88	3/89	9/89
15	5/87	6/88	2/89	7/89
20	6/87	3/88	10/88	3/89
21	1/87	2/88	9/88	2/89
29	12/86	5/88	1/89	6/89
30	5/87	3/88	10/88	3/89

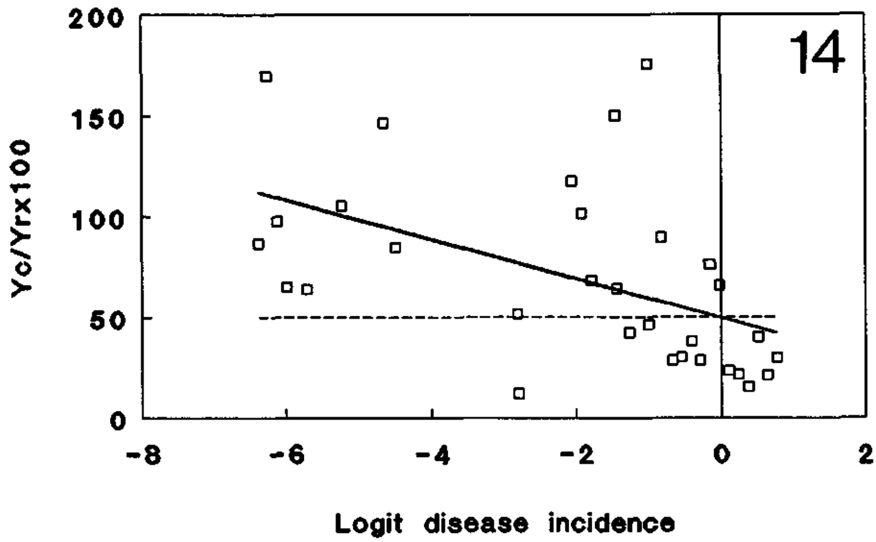
Figure 4 shows two clusters of data around the regression lines of relative yield on disease incidence y in logits. The gap between the two clusters is due to the lack of information during the period of disturbances. The centre of the first cluster of points, when disease incidences were still low (logit values of disease incidence y between -8 and -2) is at about 100% relative yield. The second cluster indicates relative yields at higher disease incidences (range -1 to +1, logit values) with its centre at roughly about 50% relative yield. For the seven blocks (6, 14, 15, 20, 21, 29 and 30) with suitable data, the 50% relative yield line intersects the regression line between logit y -1.7 and 1.0, on average at about logit y = - 0.3. High standard errors of the y estimate (Sy) and low R^2 values (Table 2) should be ascribed to the seasonal fluctuations in yield discussed earlier. The slopes (b coefficients) had large confidence intervals and they can be considered to belong to one group ($P < 0.10$). Summarizing we may conclude from the data of these seven blocks at Victoria that when disease incidence is about 0.42 a relative yield of about 50% is reached.

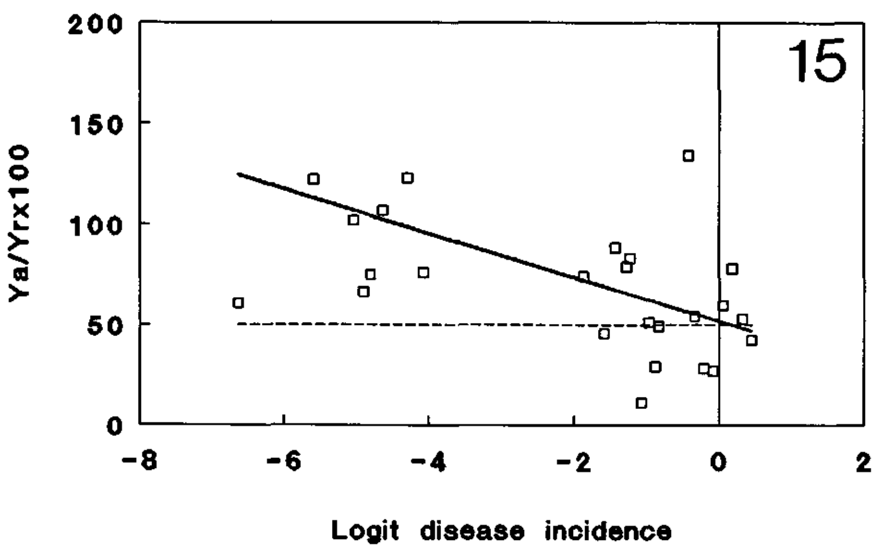
Table 2. Spear rot in oil palm in 7 blocks at Victoria, Suriname. Statistical parameters of the linear relation between the relative yield of fresh fruit and the logistic transformed values of disease incidence (y).

Block	Statistical parameters				
	R^2	Sy	*b*	S*b*	n
6	.13	51.4	- 7.06	4.77	17
14	.25	40.4	- 9.78	3.13	31
15	.27	41.6	-10.99	3.71	26
20	.05	47.4	- 4.98	5.88	17
21	.43	25.1	- 9.20	1.86	34
29	.52	24.1	-10.44	2.18	23
30	.51	22.3	- 8.98	1.76	27

R^2 Coefficient of determination.
Sy Standard error of the y estimate.
b Value of the *b* coefficient in linear regression.
S*b* Standard error of the *b* coefficient.
n Number of observations in linear regression analysis.




14
200
150
100
50
0
Yc/Yrx100
-8
-6
-4
-2
0
2
Logit disease incidence


15
200
150
100
50
0
Ya/Yrx100
-8
-6
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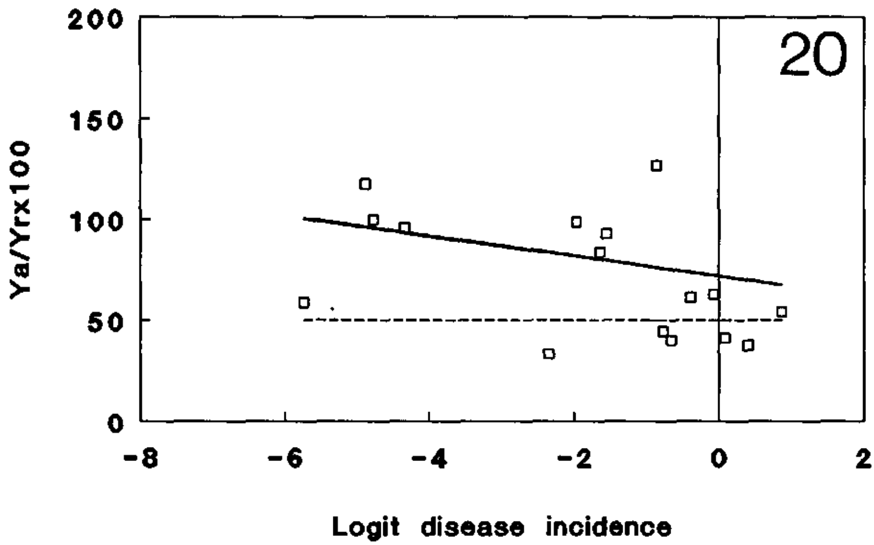
0
2
Logit disease incidence


20
Ya/Yrx100
200
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-8
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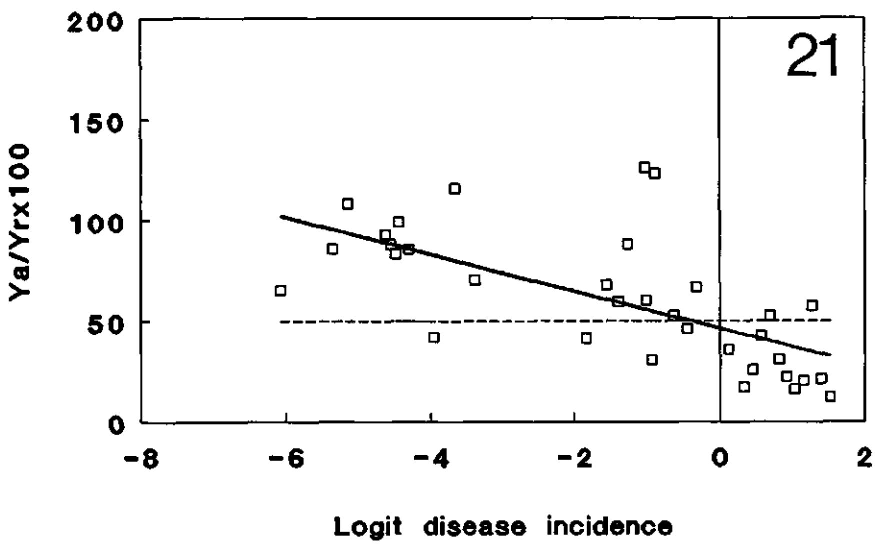
2
Logit disease incidence


21
Ya/Yrx100
200
150
100
50
0
-8
-6
-4
-2
0
2
Logit disease incidence

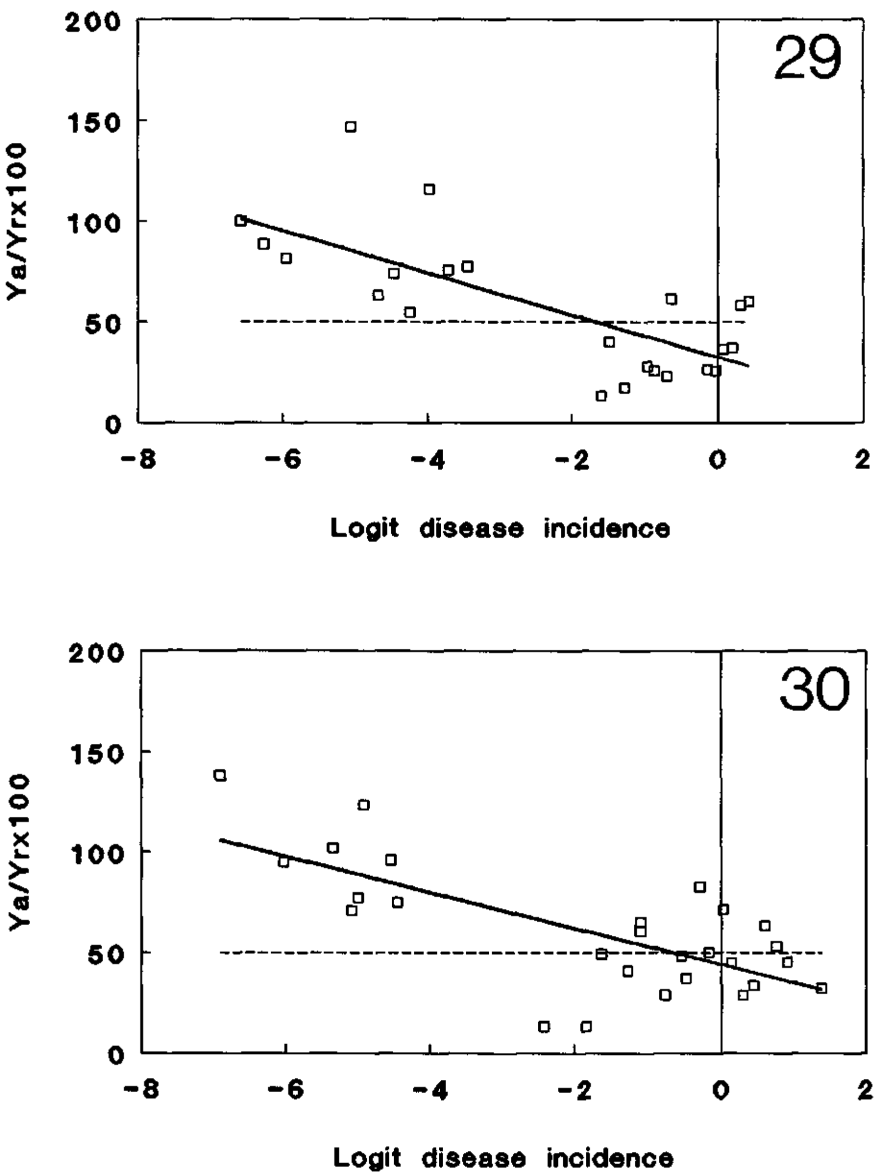


Figure 4. Spear rot in oil palm in seven blocks (6, 14, 15, 20, 21, 29 and 30) at Victoria, Suriname. Relation between relative yields (Y_a/ Y_rx100) and logit values of disease incidence (logit y). Thick continuous line –: regression line of relative yield on logit y. Thin vertical line | zero level of logit y. Thin interrupted line — the 50 % level of relative yield.

Table 3. Exploitation costs and net earnings[1] in six blocks, affected by spear rot at the Victoria oil palm plantation, Suriname, in the years 1988 and 1989.

Block	1988		1989	
	Expl. c.[2]	Net e.[3]	Expl. c.[2]	Net e.[3]
14	4.777	263	2.797	- 577
15	4.728	252	3.863	- 503
20	5.218	282	3.504	- 528
21	4.640	232	2.550	- 594
29	2.655	- 213	2.909	- 569
30	3.846	54	3.750	- 510

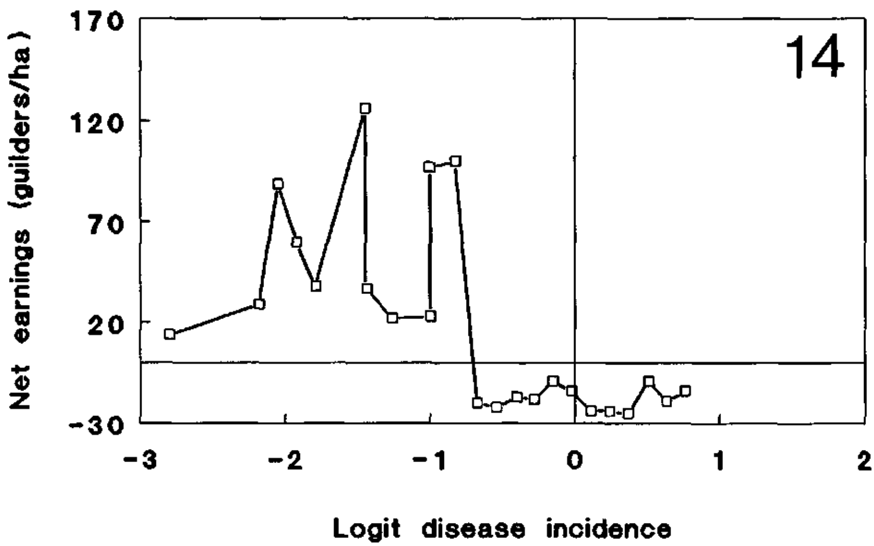
[1] During the entire study the value of the Suriname guilder was related to U.S. currency by a fixed official rate of 1.80 S. guilders to 1 U.S. dollar.

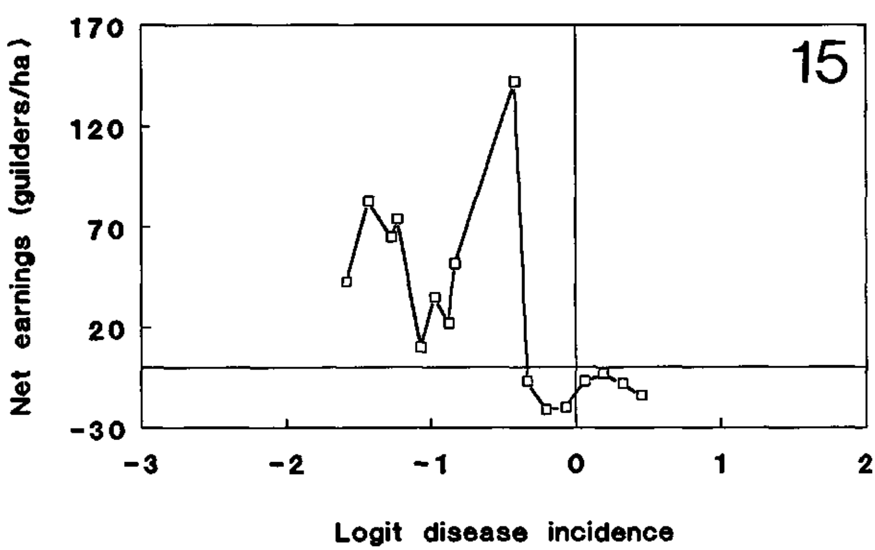
[2] Exploitation costs were expressed in Suriname guilders and comprised costs covering field and harvesting operations, transport of fresh fruit bunches within the field and towards the mill and costs of processing of the fresh fruit including energy, maintenance and salaries at the mill and the refinery.

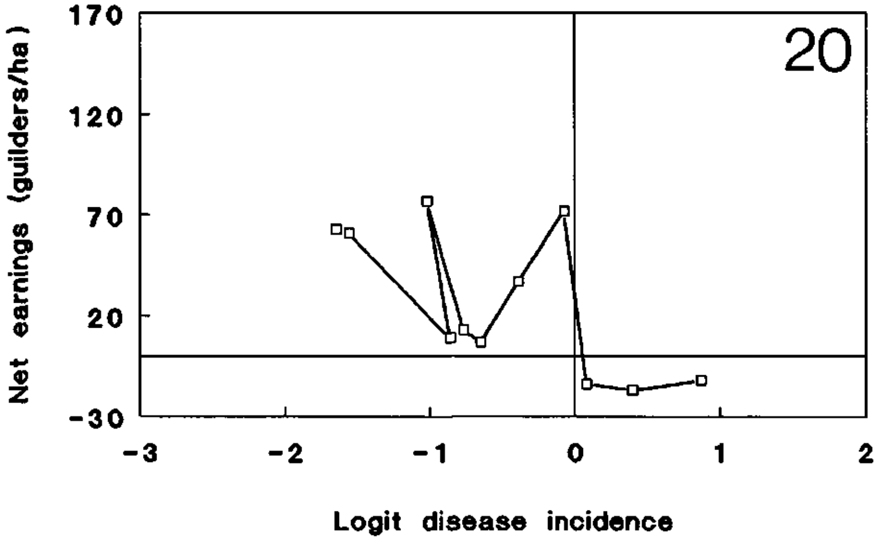
[3] Net earnings from fresh fruit bunches hectare^{-1} processed into consumable palm oil, expressed in Suriname guilders.

Cost-benefit analysis. Disease incidence in the last reference year, 1986, was less than 0.05. A comparison of costs and net earnings from FFB yield processed to oil in selected blocks (Table 3) showed that in 1 block out of 6 the net earnings were negative in 1988. In the year thereafter, 1989, net earnings were negative in all 6 blocks. In 1989 disease incidences of 0.40 or more were reached. These 6 blocks reached the 40% disease incidence level either in the 4th quarter of 1988 or in the 1st quarter of 1989 (Table 1). Figure 5 shows the relation between net earnings from FFB, processed to palm oil, and disease incidence in logits for six blocks (14, 15, 20, 21, 29 and 30) over the years 1988 and 1989. Data on exploitation costs before 1988 were not available. The descending logits, and consequently, backward leaning logit line intervals, around -1 logit value in Figure 5 (Blocks 20 and 21) are the result of counting errors by field observers during the phytosanitary survey. Net earnings turned to losses at an average logit value of -0.19 (= 0.45 disease incidence).

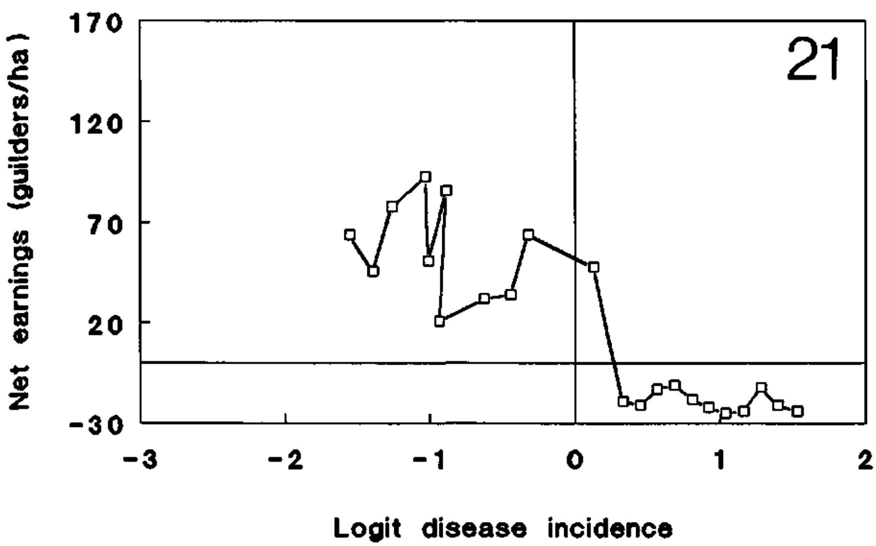
The general conclusion is that in the six blocks studied in more detail costs began to exceed benefits during 1989 when disease incidences were around 0.42. Apparently, it is not profitable to keep such blocks in production when this disease incidence level is reached. Highest losses tended to occur in the January to March and in the July to September periods, when yields had their usual seasonal lows. The critical point at which the marginal profit of another month of maintenance and harvesting becomes negative is at a disease incidence level of about 0.45. The economic analysis resulting in a critical point of about 0.45 disease incidence corroborates the critical point of about 0.42 for relative yield. When the epidemic has reached this value the block should be abandoned. The available data do not allow to give a more precise value, nor to calculate a confidence interval.


14
Net earnings (guilders/ha)
170
120
70
20
-30
-3
-2
-1
0
1
2
Logit disease incidence


15
Net earnings (guilders/ha)
170
120
70
20
-30
-3
-2
-1
0
1
2
Logit disease incidence



170
120
70
20
-30
Net earnings (guilders/ha)
20
-3
-2
-1
0
1
2
Logit disease incidence



170
120
70
20
-30
Net earnings (guilders/ha)
21
-3
-2
-1
0
1
2
Logit disease incidence

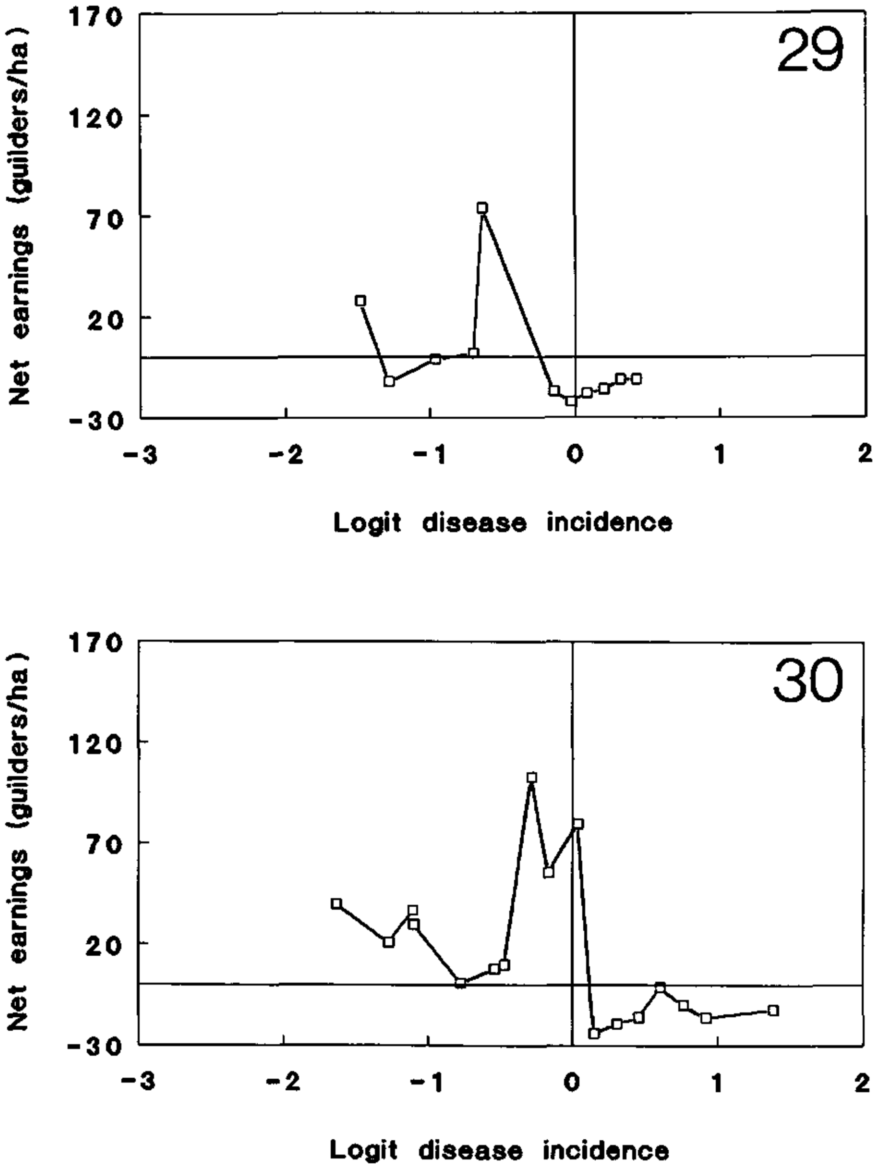


Figure 5. Spear rot in oil palm in six blocks (14, 15, 20, 21, 29 and 30) at Victoria, Suriname, between 1988 and 1989. Relation between net earnings (Suriname guilders ha^{-1}) and logit values of disease incidence (logit y). Horizontal line — zero level in earnings (no profits, no losses). Vertical line | zero level of logit y (disease incidence level in logits).

Discussion

Relationship yield and weather. The graphs show a gradual decrease of yield beginning around 1988 for most blocks. Bunch yield may vary in response to variations of factors which affect growth (Corley, 1976; Turner, 1977; Breure, 1987). Favourable conditions in the dry season may affect activities of pollinators, resulting in increased fruit set and consequently in a high bunch yield about 5 months later (Syed *et al.*, 1982). The pattern of rainfall is more or less uniform over the years. The amount of precipitation or hours of sunshine cannot influence the trend in yield decrease which seemed to have set in around the end of 1988 in the blocks studied.

Relation spear rot incidence and yield loss. When diseased plants are clustered yield loss per unit area is greater (Walker, 1987; Hughes, 1990) than when the same number of diseased plants are scattered over the field. In the latter case, some compensation by surrounding healthy plants is possible. Focal development and thus clustering of diseased trees started in the early disease stage in most blocks affected. A study in oil palm (Bachy, 1965) planted in the 9x9 m triangular pattern showed that when palms were removed the remaining palms tended to compensate for the yield loss of their missing neighbours. There was a inverse linear relationship between the weight and number of bunches per tree, and the number of neighbouring trees that were living.

At Victoria focal development and therewith clustering of diseased trees was seen in the early epidemic stage of most blocks. Assuming an average disease duration of about one year and a half for each affected tree, palms in the initial stage of spear rot will continue to produce for at least one year after the first observation of symptoms. On average, a healthy adult oil palm with a crown of 40 leaves produces 20 to 24 leaves per year (Hartley, 1988). As a rule, each leaf axil of an adult oil palm carries either a male or a female inflorescence. Assuming a sex ratio of about 50% (published agronomical data for Suriname conditions were not available) and counting from the first open inflorescence (mostly leaf number 17) about 10 bunches can still be produced by any affected palm. A palm which reaches an advanced disease stage within one and a half year may have lost most of its central leaves.

Consequently, yield decrease per tree will be most conspicuous about one and a half year after the first observation of symptoms. A block which has reached 0.05 disease incidence two or three years after the first affected palm was observed has a small part of affected trees in the advanced stage of spear rot with no or minimal fruit production. Development of open or non-producing areas within blocks would therefore occur at a late stage of the epidemic when there are many trees in the final stage of spear rot. In conclusion, compensation for yield is not important within 1 to 2 years after focal development has begun. some yield compensation from surrounding trees may occur in those cases where their neighbouring affected trees lack the majority of leaves.

Decision making and economic evaluation. The critical point were yield decrease started, indicated also the moment where marginal monthly profit became negative. Since seasonal fluctuations in yield are considerable an occasional rise in the monthly bunch yield may occur after that critical point. Monthly calculations of net earnings are therefore preferable over yearly calculations. Yield predictions based on weather factors alone are not adequate, since shifts in the fluctuating pattern may occur through other influences. For the time being, economic evaluation of yield should therefore be accompanied by evaluation of disease incidences and of fluctuating expected yields. Thus, financial loss at a disease incidence of about 0.40 and at the end of a yield peak, mostly in January, should lead to the decision to abandon a block or an area. The findings here apply to Suriname conditions. In individual countries cost items may cover different cost components (Moll, 1987). Exploitation costs may vary as a result of differences in economic situation.

According to Bachy (1965) production losses are about 5% when 20% of the originally planted trees at the age of 25 to 30 years are dead. When the trees have reached the advanced stage of spear rot and their growing point is killed they are not yet dead. Palms with a flat-top-appearance, still having most of their middle and lower leaves available, will still compete for light. Nevertheless, cutting the non-productive trees at such advanced stages is not recommended. Trunk tissues of diseased trees appeared to be relatively tough, thus complicating cutting procedures by chain saw. Uptake of herbicides after injection did not suffice to kill the tress.

The social effects of this disease on the plantation workers must not be overlooked. During the epidemic several control procedures were evaluated (Van de Lande, 1990). None resulted in bringing a halt to the disease. As time went by and more trees became affected workers tended to become more frustrated and careless. The harvesters were paid by the bunch. Having to cover about the same area but reaping less bunches than in a healthy plantation, they tended to 'overlook' ripe bunches in a heavily affected area. Thus, the biological phenomenon of yield depression was enhanced by a social phenomenon, aggravating the financial loss.

Models for predicting bunch yields based on physiological and climatological factors are being developed for Indonesian conditions (W. Gerritsma, personal communication). They will be welcomed in Suriname, particularly if they relate economic variables to damage due to pests and diseases.

Acknowledgements

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8. General discussion

Spear rot or fatal yellowing is the number one problem in oil palm in Suriname as the disease affects all ages of field trees, independent of their genetic background. Effective control measures on the short run are not available (Van de Lande, a, b). The causal agent of spear rot is not yet known. Much has become known of the symptomatology of the disease both in young and adult stages of the palm and throughout the seasons (Van de Lande, a).

At the plantation Victoria, the management decided to maintain the affected trees to benefit from their production, though this practice was not advisable from a phytosanitary point of view. The decision, not made overnight, was supported by several arguments (Van de Lande, 1990). It provided a unique opportunity to gain knowledge on several unknown aspects of the behaviour of the disease. Studies on the development in time indicated the polycyclic character of spear rot (Van de Lande, c). The infectious character of spear rot was illustrated by the fact that the epidemic seemed to develop faster (expressed by the higher logistic infection rates) in those blocks which became affected at a later stage in the epidemic than in blocks which became affected early in the epidemic at the Victoria (Van de Lande, d). At Phedra, however, blocks of an age and a genetic origin comparable to others at Victoria had lower logistic infection rates. It was hypothesized that differences in the environment of the two plantations may have led to higher epidemic rates at Victoria than at blocks at Phedra. Analysis of spatial patterns revealed that original infection sources were outside the plantation and that, as the epidemic proceeded, infection sources became established within plantation (Van de Lande, e). The infestation from outside sources, the importance of the surrounding vegetation, mostly forest or swamp area at Victoria and Phedra, and a directional effect in the disease pattern was confirmed at plantations affected by pudrición del cogollo in Ecuador (Anonymous, 1989; Perthuis, 1990) and amarelecimento fatal in Brazil (Anonymous, 1989).

The random occurrence of diseased palms at the initial stage of epidemic development calls for immediate eradication measures so that these trees cannot act as new infection sources. Omitting these procedures may lead to the infection of new trees in the neighbourhood of the scattered trees, thus creating focus formation. Once focal development has begun, scattered affected trees will be found which in turn may give rise to new focal development, thus making the problem more complex and more difficult to control. Though bunches from diseased trees were being harvested during about one year (Van de Lande, a) tree production decreases with time. Once the epidemic has reached an incidence of about 40% affected trees per block the marginal profitability of harvesting becomes questionable, as returns will probably turn into losses (Van de Lande, g). This general rule has to be modulated case by case taking into consideration the seasonality of yield.

Many questions regarding optimization of harvest and maintenance procedures remain unanswered especially in situations where palms are affected in the first years of production. The economics of this problem are still to be studied (Carlsson, 1979). The cooperation between research disciplines in the field of agronomy, pathology and economics needs intensification because optimization is a question which comes up already at the beginning of the epidemic. Considering the long term investments in oil palm each action needs to be carefully considered from phytosanitary and economical points of view (Norton, 1976).

The decisions to be made by the management at the plantation level differ from those to be taken at government level by policy makers (Norton and Mumford, 1983). The three parties, government, plantation management and research cannot decide on their own and need to cooperate. There are, however, moments that the plantation management must make decisions, eventually assisted by the researchers, especially on daily field procedures which affect both the short and the long term activities (Norton, 1976).

With respect to spear rot or fatal yellowing in Suriname, AF in Brazil and PC in the Spanish speaking countries, the following issues came up.

A. What measures do plantation managers take when confronted with the disease?
B. What questions do plantations managers ask?
C. What questions do policy-makers ask?

The situation at different locations in South America can be summarized as follows.

A. Plantation managers keep the affected palms either because they have not recognised the problem or because they want to benefit from the last bunches (Van de Lande, 1990a).
They poison or cut the affected trees either immediately after detection (Martin e Silva and Oliveira Freire, 1990) or in an advanced stage, their decision depending largely on the interpretation of the phytosanitary inspection rounds results or on local situations (Van de Lande, 1990a).

The questions asked by the plantation managers depend largely on their knowledge of the problem, and the actions that are usually taken depend on the local situation.

B.

	Questions	Actions taken
1	Must we get rid of the affected palms.	Yes, always.
2	How quick must we get rid of affected trees.	Immediately after detection.
3	What method should we use.	Cut or poison with herbicide.
4	When can we stop with the eradication of affected trees.	Depends on economic evaluation.
5	When should we stop with harvesting in a block with a high percentage diseased trees.	Depends on economic evaluation.
6	What must be done with an abandoned and affected area.	Depends on local situation. Clear with bulldozer and/or burn.
7	When can we start replanting.	Not recommended while diseased area exists.
8	How and where should we (re)plant.	Upwind, install a phytosanitary border.
9	What should we plant.	Preferably resistant hybrids.
10	What should be done to prevent disease occurrence.	Prevention possible with resistant hybrids.

C. The questions which policy-makers tend to ask mostly concern the financial risks they may run with respect to investment in the short and long run, and job security of the personnel at the plantation.

1. Should we continue to invest in oil palm or should we switch to another culture?
2. What guarantee do we have that the crop will not be affected from the first year from planting?
3. Is the cultivation of oil palm economically still feasible, considering the risk of spear rot or fatal yellowing, AF and PC?

Answers depend largely on local situations and the countries' needs of nationally produced palm oil and by-products. The involvement of agricultural economists in the evaluation is necessary. It is clear that with *E. guineensis* no guarantee can be given that the crop will remain free from infection from the beginning. In the long run the solution to the problem lies in breeding resistant varieties (Turner, 1981; Anonymous, 1989; Barcelos and Amblard, 1990).

In conclusion, the recommendations that resulted depended on the issues put forward by, based on the interests of, the plantation manager or the policy-maker.

Recommendations to plantation managers

1. Phytosanitary inspection rounds, which generally serve the purpose to detect diseases and pests in the field, should be performed at intervals of at least 14 days in order to be able to kill the affected trees at the initial stage of disease.
2. Upon detection each affected tree must be removed, so as to prevent such a tree from acting as a local infection source.
3. Replanting of formerly affected areas with African oil palm is not recommended as long as the old affected planting still exists, since infection of the new stand may occur (Van de Lande, 1990b) from inoculum sources still present within the old plantings.

4. Old stands which have been abandoned because they are no more profitable should be removed as they may act as inoculum sources.
5. New plantings of African oil palm in the interior of Suriname should be protected by an unplanted strip of at least 100 metres wide, which separates new fields from bordering forest, so as to provide a phytosanitary border area (Anonymous, 1989).
6. New areas should not be planted next to the old affected stands and should always be upwind of former areas affected by spear rot.
7. Economic evaluation of costs and returns should be started in the initial stage of the epidemic.

Recommendations to policy-makers

1. To prevent 'no-sense' research, i.e. research which is not directly beneficial to the plantations, research programs should preferably be developed in cooperation with the plantation managers and their phytosanitary department heads.
2. To prevent loss of valuable time in travelling it is essential to base research facilities mainly at or near the plantations, directing the research towards agronomical, pathological and economic aspects.
3. To evaluate the possibilities of oil palm cultivation in areas other than the interior the initiation of a 100 hectares pilot project with African oil palm planted in the North of Suriname should be considered.
4. Research on commercialization of hybrids between *Elaeis oleifera* and *E. guineensis* must be speeded up.

The government of Suriname, fearing the effects of the disease on oil palm, seems to consider the gradual abandonment of this culture and replacement by large scale planting of soybean thus creating more sources of fodder and meet local needs of vegetable oil.

Bearing in mind the Surinamese history of coffee and cocoa, abandoned mainly because of disease problems, a similar threat is experienced by the oil palm culture. It seems ironical that in coffee and cocoa basic research on characteristic diseases, phloem necrosis (Stahel, 1920; Bally, 1931) and witches broom (Stahel, 1915; Thorold, 1975), was initiated in Suriname. Today, the cultivation of these crops flourishes in most countries in South and Central America, as a result of research, directed either towards the development of stringent control measures or to resistant hybrids. This experience shows that the design and the execution of appropriate research, directed towards the reduction of limiting factors in the cultivation of any crop, are basic conditions to retain its successful cultivation.

We need to exploit the available oil palm knowhow which was built up at several levels in more than 20 years. Switching because of the spear rot problem towards another crop, for instance soybean, will by no means guarantee a new crop without risks of economically important diseases and pests. The planting of any crop, oil palm included, in new areas may result in a shift towards other phytosanitary problems and may need a totally different approach of the management.

We should concert our research efforts not in Suriname alone, but also internationally, considering the fact that spear rot or fatal yellowing is not just a Surinamese problem, and bearing in mind that amarelecimento fatal in Brazil and pudrición del cogollo in several Latin American countries urgently need elucidation too.

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9. Summary

Chapter 1. The epidemiology of spear rot a fatal yellowing disease of African oil palm was studied at the plantations Victoria, Phedra and Patamacca, together totalling 6.000 hectares of planted area in Suriname. Spear rot is an infectious disease of which the causal agent is yet unknown. Affected trees die. Since the detection of the first spear rot tree in 1976 the productive area at Victoria, the oldest plantation, was reduced to less than one tenth in 1992.

Chapter 2. The symptomatology of spear rot was studied in palms of different developmental stages of the disease. The most characteristic symptoms involve a chlorosis which gradually proceeds from the young towards the older leaves and the rotting and breaking of spear leaves. Remission of spear rot, which occurred in individual trees, could last over six months but was not permanent.

Chapter 3. Remission fluctuations over time appeared to be closely related to an excess or a deficit in total monthly precipitation over the month preceding the remission. Symptom expression and disease duration could differ in young and adult palms, and seasonal variation in symptomatology was observed. Histopathological studies of leaf rachides and upper trunk parts, using light microscopy, did not reveal the presence of microorganisms in association with the affected tissues.

Chapter 4. Four mathematical models were discussed in relation to the observed disease progress curves of spear rot at Victoria. The simple logistic model gave the best fit to the data. The results suggest that the disease is polycyclic.

Chapter 5. Fitting the logistic model to the disease incidence data of Victoria and Phedra led to the conclusion that within plantation epidemic rates and periods of first detection were significantly related. It was hypothesized that a higher level of initial inoculum as a result of a difference in the vegetation surrounding the two plantations led to differences in infection rates of blocks (= field units) between Victoria and Phedra.

Chapter 6. Spatial variations of spear rot disease data at Victoria and Phedra plantations were examined with geostatistics and gradient analysis. The relation between pairs of sample points of spear rot incidence over various distances in different directions and over the years was determined by means of semivariograms. Semivariogram analysis revealed initially, at low disease incidence, a random pattern, indicating that affected trees were not spatially related, suggesting that infections came from different sources. Later, semivariograms at different dates showed a linear increase with distance of the semi-variance between pairs of sample points, suggesting that a spreading mechanism operated over longer distances, but within the sampled area. In some blocks semivariograms revealed a nonlinear increase in variance, suggesting the occurrence of transmission from a certain source over a specific range. Generally, semivariograms revealed anisotropy, with preference for a westerly direction. This result was confirmed by more classical gradient analysis over time. The hypotheses that 1) spear rot is an infectious disease, with 2) a first phase of randomly scattered appearance throughout blocks, 3) inoculum sources outside the plantation, 4) a second phase of focal spread starting from initially infected scattered trees, and 5) the causal agent or its vector being wind-borne were supported by the data. The trigger of the change from a phase 1 to a phase 2 spreading pattern remains unknown. The existence of two different vector populations seems plausible.

Chapter 7. The development in monthly fresh fruit bunch yields was analyzed in 7 blocks at the Victoria plantation between 1980 and 1989 before and after spear rot or fatal yellowing appeared, to decide when blocks or areas should be abandoned. The application of two methods: a) comparison of actual with reference yields and b) linear regression of relative yields on the logistically transformed values of disease incidences, led to the conclusion that the critical point where further bunch harvesting turned to losses was at a relative yield of 50%, at about 40% disease incidence. When net earnings were related to logistic values of disease incidence the critical point where profits turned to losses appeared to be about 0.45 disease incidence. The conclusion that harvesting ceases to be profitable at about 0.40 disease incidence and that blocks should then be abandoned, was supported by the data of the economical evaluation. These results are useful to other plantations, provided they have a disease history comparable to Victoria. Variations in costs due to variations in space and time should be considered.

Chapter 8. The general issues brought forward by at the plantation manager and policy-maker when confronted with fatal yellowing at their plantation, were discussed. It was concluded that the questions asked and the actions taken, depended largely on, knowledge of the problem, local situations and needs of nationally produced oil. Plantation managers are recommended to 1) perform phytosanitary inspection rounds of at least 2 weeks on a continuous basis, 2) remove affected trees at the early stage of spear rot and in the initial stage of the epidemic, 3) eradicate abandoned stands of oil palm in affected areas, 4) not to replant within or close to an area affected by spear rot, 5) lay out a phytosanitary strip of at least 100 metres wide separating new fields from nearby forest or marsh area, 6) not to plant downwind of an affected area, and 7) to consider an economical evaluation of costs and returns beginning at the early stage of the epidemic. Policy makers are recommended to develop research programs preferably in cooperation with plantation managers and the available oil palm expertise. Research stations or its dependencies should be preferably based at or near the plantations. Agronomic, disease and economic aspects should be emphasized. Testing of resistant hybrids of oil palm in the interior and the initiation of a pilot project of oil palm in the North of Suriname need consideration. Research towards commercialization of resistant hybrids of South-American and West-African oil palm should be speeded up.

Samenvatting

Hoofdstuk 1. De epidemiologie van speerrot, een fatale vergelingsziekte van de afrikaanse oliepalm, werd in Suriname bestudeerd op de plantages Victoria, Phedra en Patamacca, met een totaal areaal van 6.000 hectares. Speerrot is een besmettelijke ziekte waarvan de oorzaak onbekend is. De aangetaste bomen gaan dood. Sinds de ontdekking van de eerste speerrot bomen in 1976 nam het productieve areaal van Victoria, de oudste aanplant, af tot minder dan een tiende in 1992.

Hoofdstuk 2. De symptomatologie van speerrot werd bestudeerd bij palmen in verschillende ontwikkelingsstadia van de ziekte. De meest karakteristieke symptomen omvatten een chlorose, die geleidelijk voortschrijdt vanaf de jonge naar de oudere bladeren en een rot met breuk van de speerbladeren. Herstel van speerrot, dat alleen in individuele bomen optreedt, kon langer dan zes maanden duren, maar was steeds tijdelijk.

Hoofdstuk 3. De fluctuaties in het optreden van de herstelfase bleken nauw gerelateerd te zijn aan een overmaat of een tekort in de totale maandelijkse neerslag welke voorafging aan de maand waarin het herstel optrad. De symptoom-expressie en de ziekteduur konden verschillen in jonge en volwassen palmen en in de symptomatologie werd een seizoensvariatie waargenomen. Lichtmicroscopisch onderzoek aan de histopathologie van de rachidae en de bovenste stamdelen, liet geen micro-organismen zien die geassocieerd zijn met de aangetaste weefsels.

Hoofdstuk 4. Vier wiskundige modellen werden besproken in relatie tot de ziektevoortschrijdingscurven van speerrot op Victoria. Het eenvoudige logistische model paste het best bij de gegevens. De resultaten doen veronderstellen dat de ziekte polycyclisch van aard is.

Hoofdstuk 5. Het passen van het logistische model aan de gegevens van ziekte-incidentie in Victoria en Phedra leidde tot de conclusie dat binnen de plantage de epidemische snelheden en de tijdstippen van eerste ontdekking duidelijk verband vertoonden. De hypothese werd gesteld dat een hoger niveau van begin-inoculum, tengevolge van een verschil in vegetatie rondom de twee plantages, tot de verschillen in infectiesnelheden per blok (= veld eenheid) tussen Victoria en Phedra leidde.

Hoofdstuk 6. De ruimtelijke variaties van de speerrot ziekte op Victoria en Phedra werden bestudeerd met behulp van geostatistiek en gradient analyse. De relatie tussen punten paren van speerrot incidentie over verschillende afstanden en in verschillende richtingen en op verschillende tijdstippen, werd bepaald door middel van semivariogrammen. Semivariogramanalyse liet aanvankelijk, bij een laag ziekteniveau, een toeval patroon zien, hetgeen aangaf dat de aangetaste bomen ruimtelijk niet gerelateerd waren. Vandaar de veronderstelling dat infecties van verschillende bronnen afkomstig was. Semivariogrammen vertoonden later, op verschillende tijdstippen en over verschillende afstanden, een rechtlijnige toename van de semivariantie tussen puntenparen, hetgeen deed veronderstellen dat er sprake was van een verspreidingsmechanisme dat binnen het bemonsteringsgebied over langere afstanden actief was. In sommige blokken vertoonden de semivariogrammen een niet-rechtlijnige toename van de semivariantie tussen puntenparen met de afstand, hetgeen deed veronderstellen dat er, binnen het bemonsteringsgebied er sprake was van ziekteoverdracht. In het algemeen toonden semivariogrammen een anisotropie met voorkeur voor een westelijke richting. Dit resultaat werd bevestigd met de meer klassieke gradient analyse op verschillende tijdstippen. De hypothesen dat 1) speerrot een besmettelijke ziekte is met, 2) een eerste fase van een toevallige verdeling over de blokken, 3) inoculumbronnen die zich buiten de plantage bevinden, 4) een tweede fase van verspreiding middels haarden, die vanuit in eerste instantie verspreid voorkomende bronnen beginnen en 5) de veroorzaker of zijn vector door de wind wordt verspreid, werden ondersteund door de data. De aanleiding tot de verandering van een fase 1 naar een fase 2 patroon van verspreiding blijft onbekend. Het bestaan van twee verschillende vector populaties lijkt aannemelijk.

Hoofdstuk 7. De ontwikkeling in maandelijkse vrucht opbrengsten werd geanalyseerd aan de hand van 7 blokken van de Victoria onderneming, tussen 1980 en 1989, voor en nadat speerrot of fatale vergelingsziekte verscheen, teneinde te kunnen beslissen wanneer blokken of gebieden verlaten zouden moeten worden. De toepassing van twee methoden: a) vergelijking van de werkelijke met de referentie opbrengsten en b) lineaire regressie van de werkelijke opbrengsten op de logistisch getransformeerde waarden van de ziekte-incidenties, leidde tot de conclusie dat het kritieke punt waar de oogst van de trossen verlieslatend werd, optrad bij een relatieve opbrengst van 50%, bij ongeveer 40% ziekte incidentie. Wanneer netto inkomsten werden gerelateerd aan de logistische waarden van de ziekte-incidentie bleek het kritieke punt, waar de opbrengsten overgingen tot verliezen, zich op een ziekte incidentie van ongeveer 0.45 te bevinden. De conclusie dat oogsten niet meer rendabel is bij een ziekte-incidentie van ongeveer 0.40 en dat dan blokken verlaten zouden moeten worden, werd ondersteund door de gegevens van de economische evaluatie. De geschiktheid van deze resultaten voor andere plantages werd benadrukt, vooropgesteld dat ze een ziekte-historie hebben welke vergelijkbaar is aan die van Victoria en met inachtname van variaties die in de kostenanalyse kunnen optreden als gevolg van locale verschillen.

Hoofdstuk 8. De voor- en nadelen van het instandhouden van aangetaste palmen om van hun productie te profiteren werd besproken. Plantage-managers wordt aangeraden om 1) voortdurend fytosanitaire rondgangen te doen uitvoeren met een tijdsinterval van ten hoogste twee weken, 2) aangetaste bomen te verwijderen in een vroeg stadium van speerrot en in het beginstadium van de epidemie, 3) verlaten oliepalm-aanplantingen op te ruimen, 4) niet opnieuw te planten binnen of dichtbij een door speerrot aangetast gebied, 5) een fytosanitaire strook aan te leggen van ten minste 100 meter breed, die nieuwe aanplant scheidt van dichtbij gelegen bos- of moerasgebied, 6) niet aan de leizijde van een aangetast gebied te planten en 7) een economische kosten en baten analyse uit te voeren die dient te starten in een vroeg stadium van de epidemie. Beleidmakers wordt aangeraden onderzoekprogrammas op te stellen in nauwe samenwerking met plantage-managers en oliepalm-deskundigen. Onderzoekinstellingen of afdelingen daarvan dienen bij voorkeur op de plantages gevestigd te worden. De teeltkundige, ziektekundige en economische aspecten moeten benadrukt worden. Het uittesten van verschillende kruisingen van oliepalm in het binnenland en het starten van een oliepalm-proefproject in het Noorden van Suriname moet worden overwogen. Het onderzoek aan en het uittesten van variëteiten van hybriden van de Zuid-Amerikaanse en de West-Afrikaanse oliepalm die geschikt zijn voor commerciële beplanting moet geintensifeerd worden.

Nawoord

Zo, het zit erop. Het werk rond "speerrot" is echter nog lang niet ten einde. Dit is echter een goede gelegenheid om hen die elk op hun wijze een steentje bijdroegen tot het tot stand komen van dit werk, persoonlijk te bedanken.

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Curriculum vitae

Hanny Lucia van de Lande werd geboren op 5 juni 1952 te Paramaribo, Suriname. Zij behaalde haar H.B.S. diploma aan het Christelijk Lyceum Dr. W.A. Visser 't Hooft te Leiden en begon in 1971 met de studie biologie aan de Rijksuniversiteit te Utrecht. De doctoraal-studie omvatte het hoofdvak tropische botanie en de bijvakken fytopathologie en vergelijkende dierfysiologie. Na het behalen van het doctoraalexamen in 1978 werkte zij tot en met medio 1987 als hoofd van de afdeling mycologie/bacteriologie op het Landbouwproefstation van het Ministerie van Landbouw, Veeteelt en Visserij te Paramaribo. In die periode verrichte zij onderzoek aan ziekten van economisch belang in diverse groentegewassen, pinda, rijst, suikerriet, citrus en oliepalm. Van 1980 tot en met 1988 was zij als part-time docente verbonden aan het Instituut voor de Opleiding van Leraren te Paramaribo en doceerde binnen de opleiding biologie (voor L.O. en M.O onderwijs) het vak tropische botanie. Sinds medio 1987 is zij als wetenschappelijk medewerkster in dienst van de Anton de Kom Universiteit te Paramaribo, doceert het vak gewasbescherming en coördineert ondermeer het onderzoek aan oliepalm in samenwerking met de oliepalm-bedrijven.

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Van de Lande, H.L., submitted c. Disease progress curves of spear rot in oil palm at Victoria, Suriname.

Van de Lande, H.L., submitted d. Development of epidemics of spear rot in oil palm at two plantations in Suriname.

Van de Lande, H.L. submitted e. Spatial patterns of spear rot in oil palm at Victoria and Phedra, Suriname.

Van de Lande, H.L., submitted f. Management of spear rot affected oil palm plantations: A Suriname case study on decision rules for abandonment.

Propositions

1. 'We shall find the real epidemic muddy and uncomfortable. And the explicit and logical analysis of our scattered observations is not only less comfortable than the statement of generalities, it also puts our cards on the table for all to see. Nevertheless, we must put or shut up, striving constantly to use to the utmost the knowledge accumulated with such pain'. (*Waggoner, Paul E.*, 1962. Weather, space, time and chance of infection. Phytopathology 52: 1100-1108).

2. Spear rot or fatal yellowing in oil palm is not a wilt disease.

   This thesis.

3. Though translation of the local name 'speerrot' suggests otherwise, spear rot of oil palm in Suriname is not identical to pudrición de la flecha in Latin America.

4. In contrast to early views (*Hartley, C.W.S.*, 1965. Some notes on the oil palm in Latin America. Oléagineux 20: 359-363) and supported by later views {*Turner, P.D.* 1981, Oil Palm Diseases and Disorders, p. 171; *Perthuis, B.*, 1990. La investigación acerca de la pudrición del cogollo de la palma africana en el Ecuador. pp. 66-68 in Memorias Primer Taller sobre Palma Aceitera (*Elaeis guineensis* Jacq.) Santo Domingo de los Colorados Ecuador. 147 pp.} spear rot or fatal yellowing in oil palm in Suriname is an infectious disease which is vector-transmitted, the displacement of the vector being sensitive to wind.

   This thesis.

5. The differences in disease patterns of spear rot, confirmed by geostatistics, prove that two different forms of one species of a vector population or two different species of vector populations are involved in the disease transmission.

   This thesis.

6. The use of geostatistics in agronomy and crop protection must be intensified.

7. Given the destructive character of spear rot or fatal yellowing at several oil palm plantations in South America, the development of resistant varieties of the hybrid *Elaeis oleifera* x *E. guineensis* for commercial planting becomes urgent.

   This thesis.

8. The economic life of oil palm, determined mainly by its height, can be increased when height increment characteristics of the Surinamese variety of *E. oleifera* can be crossed with *E. guineensis*.

This thesis.

9. I agree with the conclusion by *Imro E. Fong Poen* (former director of the Oil Palm Companies in Suriname, 1989) that 'spear rot must not be used as an excuse to abandon oil palm cultivation in Suriname, and that the design and execution of appropriate research strategies are basic conditions to save and to keep this crop for Suriname'.

10. The switch-over from oil palm to soybean is no guarantee for a culture without risks of diseases and pests.

11. I agree with the conclusion by *Norton, G. A. and Mumford, J.D.* (1983. Decision-making in pest control. Advances Applied Biology 8: 87-119) that 'the decision-making with respect to pest control in plantations is not only influenced by the pest-crop interaction but also by the interests and actions of other parties such as government and agrochemical industry', but I complement their statement by pointing to the importance of cooperation between plantation-manager, research-unit and, eventually, policy-maker.

12. I support the conclusion by *E.C. Pielou* (1977, p. 117 in Mathematical Ecology. John Wiley and Sons, New York.): 'to avoid ambiguity in statistical ecology it is most desirable to use the word "distribution" in its statistical sense only'. Then, 'a variate has a distribution, whereas a collection of organisms has a pattern' applies to other research fields as well.

13. The frustration of the field observers in the phytosanitary detection team at Victoria is proportional to the increase of spear rot over the years.

14. The local name *'kankergras'* (cancer grass) for *Cyperus rotundus* L. (purple nutsedge) expresses the danger of this weed to agriculture in Suriname.

PhD-Thesis: *Hanny L. van de Lande*, 1993. 'Studies on the epidemiology of spear rot in oil palm (*Elaeis guineensis* Jacq.) in Suriname'. Wageningen, The Netherlands.