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Remote sensing in plant diseases
using infrared colour aerial photography:
applications trials in the Ivory Coast to root diseases
of Hevea brasiliensis[1]

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Abstract

In spite of numerous aeroplane flights and different interpretations of the infrared colour photographs
obtained, the remote sensing of root rotting fungi of rubber tree has failed in practice in the Ivory Coast.
The reasons for this failure and conclusions on the efficiency of this method are discussed.

1 Introduction

Damage caused by fungi parasitic on roots in forests or plantations in the humid intertropical
zone can in certain cases limit their economic operation (PICHEL 1956; MARTIN and DU
PLESSIX 1969; NANDRIS et al. 1981). In this context, two Basidiomycetes, *Phellinus noxius*
(Corner) G. H. Cunn. and to a greater extent *Rigidoporus lignosus* (Kl.) Imaz. are well
known in the Ivory Coast because of the extent of the losses they may cause to certain rubber
plantations (Fig. 1). In spite of clearing the forest and preparing the soil before planting,
there persist infected roots or ligneous debris, each constituting a primary focus of the
disease for the future plantation. The parasites then progress from tree to tree by mycelial
contamination of the roots, followed by colonization and necrosis of the tap root. The
diseased state of the attacked tree is shown by the appearance of foliar symptoms preceding
death by only a short time. Until recently, recommended procedures for fighting this disease
in rubber plantations were expensive, required excessive labour and were not very effective.
Recent works carried out at the I.R.C.A. has led to the development of a control method
resulting in considerable limitation of the spread of the disease by protecting the trees
bordering the foci (TRAN VAN CANH 1982).

   Thus detection in young plantations as early as possible in order to eliminate the disease as
soon as possible is of basic importance. Detection methods currently used in this context are
limited and imperfect. They involve mainly uncovering the collar of the tree above the root
level to examine the state of the roots and to check for the presence of mycelial filaments
characteristic of each pathogenic fungus. Furthermore, the operations enable only the upper
part of the root system to be examined. Finally, they presuppose a large and well trained
labour force capable of recognizing the disease, as a result of the size of industrial plan-
tations.

[1] Communication presented to the International Rubber Tree Research Congress, Colombo, Sri Lanka,
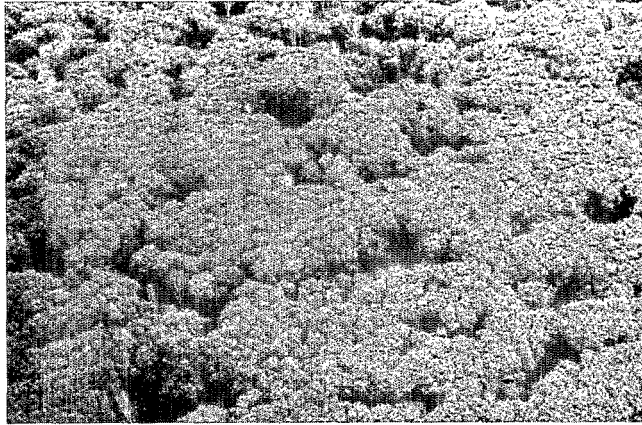September 20–22, 1984.

Fig. 1. Aerial photography of an heavily infested rubber plantation (15 years old) showing a great number of root disease centers (*Rigidoporus lignosus*). On the lower part of the photo, in the border of the openings due to the parasite, some diseased trees with foliar symptoms and some dead trees can be seen

Faced with this situation, different methodological trials have been used in an attempt to create a detection technique which would result in an early diagnosis and be able to be used on a large scale. In this context the method of detecting parasite attacks on vegetation by infrared aerial photography includes characteristics particularly interesting for use with rubber trees in the Ivory Coast. Indeed this method is used routinely by forest workers in temperate countries to precisely map different parasitic attacks by insects or fungi over vast forest areas (MEYER and FRENCH 1967; HELLER 1968, 1971; MURTHA and KIPPEN 1969; WILLIAMS and LEAPHART 1977; RIOM et al. 1979; *inter alia*). The technique involves detecting physiological disturbances, caused by a parasite to its host, by recording changes in foliar reflectance not perceivable by the eye on a photographic support sensitive to near infrared wavelengths.

As part of phytopathology research conducted by the I.R.C.A. and the O.R.S.T.O.M. on these parasites, teledetection trials on rubber trees were carried out in the Ivory Coast by applying techniques developed elsewhere. The first phase of this operation was to search for a pre-visual marker of the infection of the root system of the diseased rubber tree. The second phase was the definition of feasibility conditions and the resolving power of this methodology in order to be able to use it on the industrial scale.

The present article describes the different aerial missions carried out and the method for interpreting the photographs obtained, in order to attempt to discriminate between a healthy and a diseased rubber tree.

2 Materials and methods

2.1 Choice and characteristics of the stations (Table 1)

This choice was determined on the following criteria.
·   a. *The geographical site.* In order to determine the potential effect of soil texture on the physiology of the tree and the expression of possible foliar symptoms, parallel studies were carried out in the southeastern part of the country on tiertary sandy soils and in the south-western part where soil tends to have a higher clay content.

b. *The age of the rubber trees.* It is generally held that root rot agents can be effectively detected starting at the fourth year. At this age, the root system of the young rubber trees is

well developed and the majority of primary foci are detectable in the field. In parallel, 8-year-old trees (tapped for almost two years) were also examined in order to evaluate the spectral characteristics resulting from the metabolic modifications caused by the exploitation of the tree.

c. *The infestation rate.* It was necessary for the study to have a sufficient population of infested trees at different stages of the disease at each site photographed. Phytosanitary surveys were done manually, tree by tree, in order to determine the sectors to be photographed subsequently.

Table 1

Characteristics of the areas studied

Site no.	Situation	Clone planted	Mode of planting	Superficy	Number of trees	Infestation rate*
1	Southeast Ivory Coast	AF 51	· in 1977 · budded stumps, in line	6,5 ha	3200	5 %
2	Southwest Ivory Coast	GT 1	· in 1973 · seed, in contour	1,5 ha	710	12 %
* percentage of trees infested by *Rigidoporus lignosus* and by *Phellinus noxius*.						

2.2 Schedule of the aerial photography missions

In plant disease teledetection, it is recommended to photograph at the moment of maximal exteriorization of the stress being studied (RIOM 1978). In this context, the flights were spread over a period of more than one year in order to take climatic changes (dry and humid seasons) into account, as well as their effects on the tree physiology. As a result of the yearly natural defoliation of rubber trees during the dry season, it was impossible to photograph for almost one month (February). Photographs were taken with sun at the zenith and with no clouds vertically over the site photographed.

2.3 Flight characteristics

A Cessna 172 airplane was used. The photographic material included two Hasselblad 500 EL/M (6 × 6 cm) cameras fixed in the place of the right front seat (Fig. 2). They were connected to each other by a tripping mechanism controlled by an intervalometer in order to obtain two closely spaced almost simultaneous pictures. The first camera was fitted with a 100 mm Planar lens and a Wratten filter No. 12, which cuts all wavelengths lower than 500 nm, thus eliminating a part of the blues. It was loaded with Kodak Aerochrome false colour infrared film, No. 2443. The film magazine contained 70 shots. The second camera was equipped with a 50 mm Distagon lens and loaded with Kodak Professional Ektachrome 200 film, No. 5036.
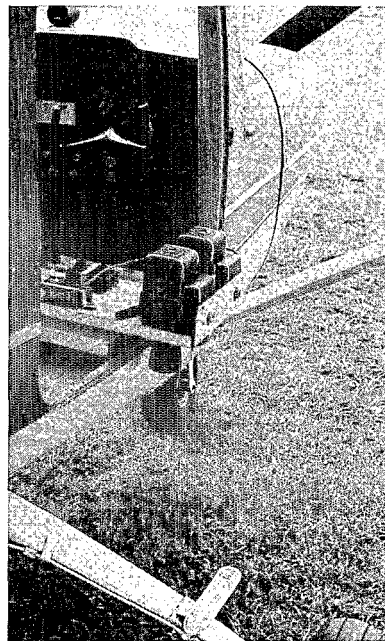

Fig. 2. Equipment used for aerial photography

Exposure characteristics for the Ektachrome camera were calculated with a photoelectric cell. For the infrared film, considering the data of the Kodak Aerial Exposure Computer and the slight annual variations of the inclination of the sun, photographs were generally taken at 1/500 " and f/8. Three scales were used for each site: 1/4500, 1/3000 and 1/1500.

2.4 Procedures for interpreting photographs

a. *Visual interpretation of the photographs*. The integration of data simultaneously contained in the infrared false colour and Ektachrome films and from the tree by tree disease survey (performed on the ground), enabled us to seek differences which could exist in the spectral properties of the leaves of healthy and diseased trees.

b. *Digital processing*. The digital processing of a photograph involves transforming it into a series of coded data representing the optical density of each basic point (or pixel) composing the photograph. Digitalization was performed successively with a digital camera in the O.R.S.T.O.M. Teledetection Laboratory and in the Teledetection Laboratory of the I.N.R.A. with an Optronics P 1000 microdensitometer.

c. *Trichromatic selection*. The principle of trichromatic selection (RIOM et al. 1979) involves restoring the information contained separately on each of the three layers composing the infrared film by successively scanning the film through filters corresponding to the sensitivity range of each layer: blue = 500 to 600 nm, green = 600 to 700 nm, red = 700 to 900 nm. This operation is carried out automatically with the microdensitometer using W 47 B, W 58 and W 15 filters. The digital data thus obtained are stored on diskette (ANDRIEU 1982) and the film is interpreted either by layer analysis or by combining pairs of layers (BOISSARD et al. 1980).

2.5 Radiometric analyses

a. *Multichannel terrain radiometer* (Exotech 100 A). This instrument is used to obtain either the incident energy of solar radiation or the energy reflected by an object in four channels simultaneously: 500 to 600 nm, 600 to 700 nm, 700 to 800 nm and 800 to 900 nm. This operation with rubber trees was carried out at noon from a scaffolding erected on a plantation at the border of a clearing caused by the parasite (section 1). The views are slightly oblique as a result of the height of the trees.

b. *Spectroradiometer* (Lincoln 470 SR). This instrument is used to measure the electromagnetic radiation reflected or refracted by an object at visible and infrared wavelengths, 380 to 750 and 750 to 1550 nm, respectively. This spectrum includes the sensitivity domain of infrared film (500 to 900 nm). The spectral signature of diseased rubber trees was performed with leaves freshly removed from 6-month-old plants grown in greenhouse and artificially infested using a technique described previously (NANDRIS et al. 1983). Controls in the experiment were non-infested rubber trees.

3 Results

3.1 Analysis of photographs

After the technical aspects were optimized, the first aerial mission was carried out with young, 4-year-old rubber trees (section 1) in the southeastern region of the Ivory Coast. Regardless of the scale of the infrared photographs no pathological change in reflectance could be detected in the crowns of trees which were found to be diseased during the preliminary ground survey. Colour heterogeneities in the canopy of trees in this site were however detected, especially at low altitudes. These heterogeneities are primarily attributable to the successive but not simultaneous formation of flushes of young leaves, whose light green colour is clearly different from that of older leaves (Fig. 3). As a result of this, the vertical photograph shows an individual tree as a combination of unit spots, either dark or

light green, whose relative proportions vary throughout the year as a function of the rhythm of plant growth. These colour changes on the infrared film, from pink to dark red, totally distort the global reflectance of the tree and thus interfere to a considerable extent with the search for pathological symptoms in the leaves.

The amplitude of natural colour variations in the crowns of young rubber trees is even greater in Figure 4, which represents a young section of a rubber plantation in the Southwest. The colour differences observed here, which clearly characterize a certain number of trees in the infrared, are in fact attributable uniquely to the formation of young leaves. In the corresponding colour picture, the same trees are the only ones which can be distinguished by the light green colour of a part of their foliage.

These two groups of photographs were taken respectively in January and March of the same year, i. e. in the middle of the dry season, just before and after defoliation. This is a period which can legitimately be described as optimal for both photography and for the exteriorization of water stress caused by the degradation of the roots of the rubber tree. The analysis of photographs taken of these two sites at other periods of the year do not contribute additional information on the possible existence of foliar symptoms on diseased trees which are visible uniquely in the infrared.

In older stands, the search for infrared manifestations directly related to the disease was equally unsuccessful. Some trees, in an advanced stage of the disease and presenting foliar symptoms of degeneration (light green foliage on Figure 5), can easily be located in infrared (Figure 6) by the pale pink colour of their entire foliage. These foliar symptoms, which are an omen of the imminent death of these trees, can be detected by an observer on the ground and so their aerial detection on infrared film or on Ektachrome is not agronomically interesting. Except for these trees which present pronounced foliar symptoms in the visible, no other correlation between change in the whole crown and pathological state of the tree could be characterized in the population of diseased rubber trees in this section.

3.2 Digital processing of the photographs

The digitalization of the infrared films taken at the different sites of the study confirmed the absence of any significant differences between healthy and diseased rubber trees (in the absence of visible foliar symptoms). More precisely, the distribution of each photograph into classes of optical density isovalues and then the colour composition on a screen by density class, did not enable us to distinguish a diseased tree or group of trees from healthy subjects. At most, it was possible to quantitatively determine the reflectance difference between a healthy tree and one presenting foliar symptoms. The increased foliar reflectance of a moribund individual in comparison to a healthy tree thus varied from 8 to 15 %, depending on the tree.

In a second phase, "noise removal" trials by chromatic selection of each layer forming the emulsion of the infrared film were carried out on the photographs which had been digitalized. Addition or subtraction of the layers in relation to each other was made possible by computerized processing of the microdensitometer data. Although this method leads to an excellent resolution in the basic analysis of the slide, the images obtained on the Pericolor screen after performing these various combinations do not supply information which is any different from that on the initial infrared photo.

3.3 Establishment of spectral signatures of healthy and diseased rubber trees

Because of the failure in the pre-visual characterization of the pathological state of rubber trees with infrared film, we recorded the radiation spectra of leaves with radiometers in order to confirm or invalidate the absence of differences between the reflectances of a healthy and a diseased tree.
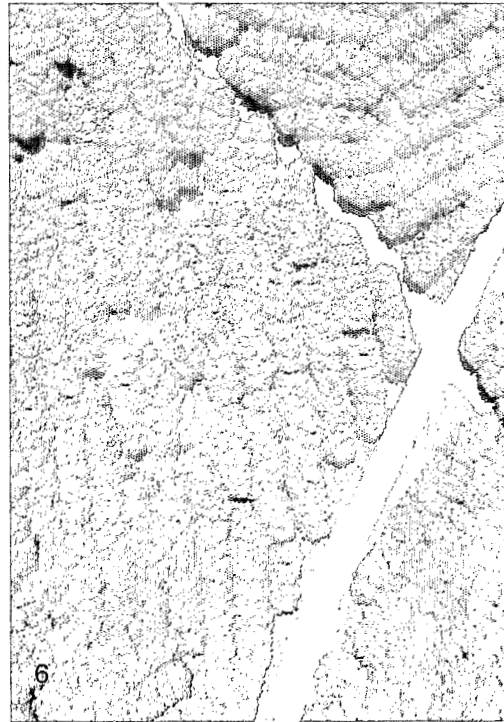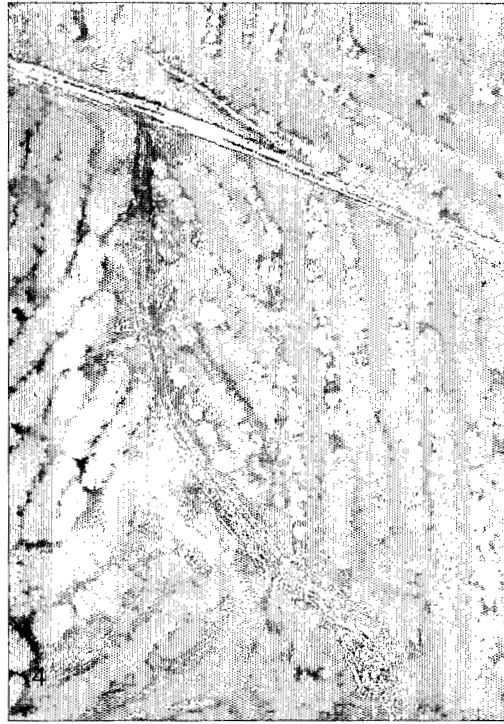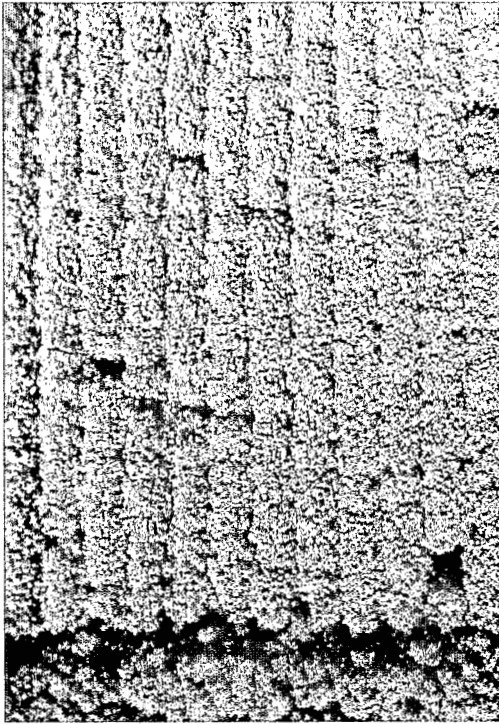
a. *Measurements with a portable multichannel radiometer.* Numerical data on the reflectances of rubber trees recorded with the Exotech radiometer are shown in Table 2. Even though a slight decoloration of the foliage is already perceivable, the reflectance of the diseased tree studied increases only slightly, especially in channel 2 which corresponds to the chlorophyll function of these leaves. This would tend to prove that, with the exception of extreme foliar symptoms (severe decoloration of leaves), the slight pigment changes, even though they are perceivable by the naked eye in the field, are not sufficient to significantly change the measured reflectance values.

Table 2

Reflectance measurement using Exotech
(after C. M. and M. C. GIRARD)

Channels	1 (500–600 nm)	2 (600–700 nm)	3 (700–800 nm)	4 (800–1100 nm)
Diseased rubber tree (light discoloration of the canopy)	5.7	4.9	3.7	50
Healthy rubber tree	5.3	4.8	34.1	50

b. *Spectroradiometer measurements.* The comparison of the spectra of healthy and diseased seedlings (without foliar symptoms) between 500 and 1300 nm does not create a true discrimination (Figure 7). In the case of a subject in an advanced phase of infestation, however, there is a slight increase in reflectance between 600 and 700 nm. This spectral change, comparable to that classically recorded in the same wavelength range for a diseased plant (ANDRIEU et al. 1980) is nonetheless not quantitatively sufficient to be recorded on an infrared photographic support.

4 Discussion

The examination of the different types of photographs and spectra obtained in this study, as well as their comparison with the "on site situation" does not lead to a correlation between the pathological state of a diseased tree and the spectral characteristics of its foliage. Regardless of the degree of sophistication of the methods used to interpret the data contained in the infrared film, there was no reflectance difference in the whole crown between healthy and diseased trees. Radiometric data showed that parasitic attack of the root system of rubber trees does not result in spectral reflectance
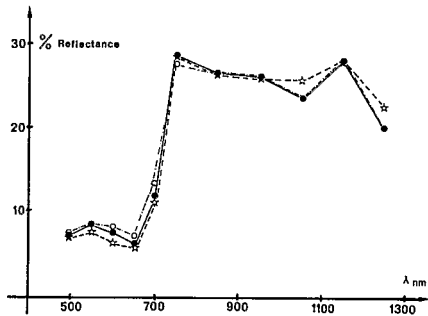
Fig. 7. Foliar reflectance spectra of healthy and diseased rubber seedlings:
● healthy plant (control)
✶ diseased plant without foliar symptoms
○ diseased plant with foliar symptoms

Fig. 3. Site 1, January 1982, scale 1:3000, Ektachrome 200. The heterogeneous colour of canopies are due to the flushes of young leaves (light green). Each opening on the planting line correspond to a root diseased center with 1 or 2 dead trees. – *Fig. 4.* March 1982, scale 1:4500, infrared film. Colour variations of canopies are easily observable for some young trees (on the right of the photo) as for older trees (left side). They could not be attributed to a pathological state of the root system.– *Fig. 5.* Site 2, April 1982, scale 1:9000, Ektachrome 200. The diseased trees detected in Figure 6 (infrared) can also be located on this colour film by their foliage discolouration that are a sign of inpending death. – *Fig. 6.* Site 2, April 1982, scale 1:4500, infrared film. Certain trees show a pink colouration of their foliage

changes which can be recorded between 500 and 900 nm on any of the 3 layers composing the infrared emulsion. This result does not depend on the site (edaphic, or soil-related parameters) or on the period of the year (climatic influence). In this context, it is nevertheless surprising that the photographs taken in the middle of the dry season did not reveal physiological disturbances in water metabolism, especially since the trees should have been affected at the level of the decayed root system.

On the other hand, different biological, ecological and climatic factors naturally cause foliar colour changes. These modifications are not correlated with a particular pathological state of the plant, but cause considerable interference with the phenomenon studied. They are thus limiting factors for the utilization of teledetection by infrared photography of rubber trees in a tropical environment. In the current state of knowledge it remains difficult to distinguish among the absence of early foliar manifestations which can be detected in the infrared, a masking of this exteriorization or, finally, the inadequacy of the method used. From this viewpoint, we should note the following:

– The death of a tree infected with a root rot agent generally results from the progressive destruction of its root system and thus from the quasi-total blocking of the supply of water and inorganic salts to the aerial parts. It then becomes of interest to ponder the mechanism which masks the intense changes in general metabolism caused by the disease for most of the pathological cycle. The special morphogenesis of the root system of rubber trees (OTOUL 1960) and its capacity to regenerate afflicted organs (PICHEL 1956; NICOLE et al. 1983) constitute elements for responding to this point. The root system of rubber trees, composed of a tap root and lateral roots, has a considerable water draining capacity. Thus, as long as the root plate (below the collar) is spared by the parasite, the assimilation functions of the tree remain. In addition, the capacity of the tree to react to attack by the *de novo* formation of secondary orthotropic axes and/or the hypertrophy of lateral roots which have remained healthy, also contribute to the physical and physiological compensation for the loss of the tap root.

– The establishment of the energy balance and radiation exchanges of a rubber tree canopy (MONTENY et al. 1983) also show that the tree utilizes two mechanisms to adapt to the dry season, or to the harmattan : a significant increase in the capacity of the roots to absorb water from the soil, combined with a mobilizing of residual water contained in the tissues of the trunk. In view of these considerations, it is consistent to suppose that these compensatory mechanisms also contribute to minimize water loss and its repercussions to the foliar system.

– The composition of the lower atmospheric layer on the Gulf of Guinea coastal is very rich in CO_2 and water vapor (MONTENY 1982). It has been shown that the absolute value of the water vapor concentration is maximal during the dry season, especially around noon. As a result of the fact that these two gases absorb in the infrared, it is possible that they are a source of interference in the utilization of infrared colour film in a tropical zone.

Regardless of the true causal mechanism, we are forced to admit that teledetection by aerial infrared photography cannot currently be recommended for the early detection of root diseases of rubber trees. This negative result is to be compared with the conclusions drawn by different workers, e. g. BENSON and SINS (1967) and CIELSA et al. (1967). For these authors, indeed, this methodology is not satisfying since the spectral changes recorded on the infrared film are often also perceptible visually or on conventional photographic supports.

Based on this analysis, KNIPLING (1969) was able to demonstrate that infrared reflectance is in fact related uniquely to the internal structure of the leaf. Thus, spectral changes observed in the corresponding band (750 to 1300 nm) indicate a severe degradation of the leaf tissue which constitutes a later marker of the attack. In this context, ANDRIEU (1983) noted that in most cases where the infrared photo was useful, it was a question of considerable variations in the reflectance of the plant cover, resulting from foliar necroses, defoliations or, finally, from variations in the attachment of leaves, i. e. late symptoms of an infection.

In addition, the work of HOFFER and JOHANNSEN (1969), KNIPLING (1969), RIOM (1978) and MOREAU (1981) showed that reflectance changes in the visible (400 to 700 nm) are often much better indicators of an attack because they are the result of early pigment changes (chlorosis), in turn resulting from metabolic disturbances. In practice, these latter results are not applicable to rubber trees since the foliar symptoms of attack on the roots are perceptible in the visible only a very short time before the death of the tree.

From a more general viewpoint, and following the preceding conclusions, one must probably question the use of infrared emulsions for pre-visual plant disease detection; this is in contradiction with the current craze among a large number of users of this technique.

5 Conclusion

In the experimental conditions used in this study, the usefulness of infrared film for a pre-visual plant disease diagnosis in a tropical forest environment could not be demonstrated. In this context, we could observe only the rarity of publications devoted to the use of this method in tropical countries. As suggested by HOWARD and LANLY (1979), questions deserve to be asked.

A number of researchers are currently using thermography with portable scanners. It appears that a lack of water can cause an increase in the radiometric temperature of the canopy which is perceptible in the interval of 8–14 μm, well before there are any changes in the near infrared spectrum (ANDRIEU 1983; BOISSARD, personal communication). In light of this, the small number of models of existing equipment and the high cost of its utilization imply logistics which are out of proportion with the means available for this study.

On the other hand and at present, black and white or colour aerial photography, as used for example for *Armillaria* on sea pines (GUYON 1982), could be useful in rubber plantations. It in fact leads to an excellent initial localization of planted sites, as well as the cartography (kinetic if need be) of parasitic clearings existing in the plantation. As a result of this, their counting and the planimetry of surfaces attacked on large scale photographs (WILLIAMS and LEAPHART 1977; OFONG 1981) lead to a rapid approximate estimation of losses caused by *Rigidoporus lignosus* and *Phellinus noxius* to rubber plantations.

Summary

Infrared aerial photography was used as a means of teledetection of root rot fungi in rubber tree plantations in the Ivory Coast in an attempt to improve on the usual methods. In spite of several trials and microdensitometric analyses of the infrared photographs, there was no evidence of any previsual differences between the reflectances of healthy and diseased trees. Certain physiological, ecological and climatic factors cause considerable colour heterogeneities of the crowns of the trees, which interfere with the pathological variations of the reflectance of the foliage. The inadequacy of infrared colour photography for early pre-visual detection of rubber tree root diseases is discussed.

Résumé

Télédétection phytosanitaire par photographie aérienne infrarouge couleur:
Essais d'application en côte d'Ivoire aux maladies racinaires d'Hevea brasiliensis

La télédétection par photographie aérienne infrarouge a été utilisée en Côte d'Ivoire sur des plantations d'hévéas pour essayer de caractériser précocement des cas d'attaque du système racinaire de l'arbre par des champignons parasites, agents de pourridiés. Malgré différents essais, aucune différence significative n'a pu être caractérisée en ce qui concerne la réflectance du feuillage d'hévéas sains et malades. L'utilisation de méthodes d'analyse numérique des clichés par microdensitométrie et sélection trichromatique ainsi que l'établissement des signatures spectrales d'hévéas sain et malade confirment l'absence de modifications spectrales de la réflectance du houppier à la suite de la nécrose du système racinaire de l'arbre. L'adéquation de cette méthode de télédétection par film infrarouge pour repérer précocement l'état pathologique d'un végétal est également remise en cause.

Zusammenfassung

Fernerkundung von Pflanzenkrankheiten durch Infrarot-Luftbilder:
Anwendungsversuche bei Wurzelkrankheiten von Hevea brasiliensis an der Elfenbeinküste

Bei dem Versuch, herkömmliche Methoden der Früherkennung von Krankheiten zu verbessern, wurden Infrarot-Luftaufnahmen verwendet, um Schäden durch Wurzelfäuleerreger in Gummibaumplantagen an der Elfenbeinküste frühzeitig zu entdecken. Trotz mehrerer Versuche und mikrodensitometrischer Auswertungen der Infrarotbilder waren keine dem bloßen Auge unsichtbaren Unterschiede zwischen gesunden und kranken Bäumen nachzuweisen. Bestimmte physiologische, ökologische und klimatische Faktoren bewirken erhebliche Farbunterschiede der Baumkronen, die die krankheitsbedingten Unterschiede in der Reflektion des Laubes überdecken. Die Eignung der Infrarot-Farbbilder für die Früherkennung von Wurzelschäden bei Gummibäumen (*Hevea brasiliensis*) wird diskutiert.

References

ANDRIEU, B., 1982: Evaluation des données fournies par la télédétection aérospatiale pour l'étude multithématique d'un massif forestier. Thèse de docteur ingénieur Univ. Paris VI, 193 p.
– 1983: Utilisation de la télédétection pour l'étude des maladies et de l'état hydrique des forêts et cultures. Journées d'étude de la Société française des Thermiciens; Progrès de la thermographie infrarouge, la télédétection dans l'environnement, Paris, mars 1983.
ANDRIEU, B.; BOISSARD, P.; PERRIN, R.; VALERY, P., 1980: Cartographie des atteintes à la végétation forestière causées par l'attaque d'insectes ou la pollution aérienne: apport de la télédétection par avion et par satellite. Association Française des Ingénieurs Ecologues, Grenoble, 13–14 novembre 1980, 1–22 p.
BENSON, M. L.; SINS, W. G., 1967: False color fails in practice. J. of Forestry **65**, 904.
BOISSARD, P.; PERRIN, R.; ANDRIEU, B.; VALERY, P., 1980: Exploitation numérique du film infrarouge couleur pour l'étude de la maladie de l'écorce du hêtre (*Fagus silvatica*). 14ème Congrès de la Société Internationale de Photogramétrie, Hambourg 1980, Commission VII, Groupe de travail no. 2, 463–472.
CIESLA, W. M.; BELL, J. C.; CURLIN, J. W., 1967: Color photos and the southern pine beatle. Photogr. Engr. **31**, 883–888.
GUYON, D., 1982: Compte rendu no. 3 ENITA, Bordeaux. «Action Armillaire», pp. 31–58.
HELLER, R. C., 1968: Previsual detection of Ponderosa Pine trees dying from bark beetle attack. 5ème Symp. Intern. on "Remote Sensing of environment". Ann. Arbor. 387–434.
HELLER, R. C., 1971: Detection characterization of stress symptoms in forest vegetations. Proc. Intern. Workshop on earth ressources survey system. Ann. Arbor., Vol. II, 109–150.
HOFFER, R. M.; JOHANNSEN, C. S., 1969: Ecological potential in spectral signatures analysis. In "Remote sensing in ecology", 1–16.
HOWARD, J. A.; LANLY, J. P., 1975: Télédétection et inventaires forestiers. Unasylva **27**, no. 108, 32–37.
KNIPLING, E. B., 1969: Leaf reflectance and image formation on color infrared film. In "Remote sensing in ecology", 155–171.
MARTIN, R.; DU PLESSIX, C. J., 1969: White root rot (*Leptoporus lignosus*) of Rubber on lower Ivory Coast. J. Rubb. Res. Inst. Malaya **21** (1), 363–372.
MEYER, M. P.; FRENCH, D. W., 1967: Detection of diseased trees. Photogr. Engr. **33**, 1035–1040.

MONTENY, B. A., 1982: Variations de la concentration du gaz carbonique de l'atmosphère en basse Côte d'Ivoire. ORSTOM, Abidjan, 14 p.

MONTENY, B. A.; BARBIER, J. M.; BERNOS, C. M., 1983: Determination of the energy exchanges of a forest-type culture: *Hevea brasiliensis*. Forest Environment Measurements International Conference. 23–28 octobre 1983, Oak Ridge, Tennessee. U. S. A.

MOREAU, J. P., 1981: Caractérisation des maladies de type jaunisse grâce aux mesures de réflectance. Signatures spectrales d'objets en télédétection, 15ème Congr. Soc. Intern. Photogrammétrie et Télédétection, Avignon, 443–453.

MURTHA, P. A.; KIPPEN, F. W., 1969: *Fomes annosus* infection centers are revealed on false-color aerial photographs. Can. Dept. Forestry Bimon. Res. Notes **25**, 15–26.

NANDRIS, D.; NICOLE, M.; GEIGER, J. P.; HUGUENIN, B.; GOUJON, M., 1981: Les pourridiés de l'Hévéa. I. Incidence des facteurs édaphiques sur le pouvoir pathogène de *Rigidoporus lignosus*. Proc. Congr. Intern. sur la Protection des Cultures Tropicales, sect 1 B, **43**, 8–10 juillet, Lyon.

NANDRIS, D.; NICOLE, M.; GEIGER, J. P., 1983: Infections artificielles de jeunes plants d'*Hevea brasiliensis* par *Rigidoporus lignosus* (Kl.) Imaz et *Phellinus noxius* (Corner) G. H. Cunn. Eur. J. For. Path. **13**, 65–76.

NICOLE, M.; NANDRIS, D.; GEIGER, J. P., 1983: Cinétique de l'infection de plants d'*Hevea brasiliensis* (Willd. ex. A. dr. de Juss) Mull. Arg. par *Rigidoporus lignosus* (Kl.) Imazeki. Can. J. For. Res. **13**, 359–364.

OFONG, A. U., 1981: The use of phytopathometric techniques in forest protection. Eur. J. For. Path. **11**, 15–24.

OTOUL, E., 1960: Le système radiculaire de l'hévéa dans les conditions écologiques de Yangambi. Publ. INEAC, Série Technique no. 62, 61 p.

PICHEL, R. J., 1956: Les pourridiés de l'hévéa dans la cuvette congolaise. Publ. INEAC, Série Technique no. 49, 480 p.

RIOM, J., 1978: Aperçu des méthodes de la télédétection phytosanitaire. Bulletin de la Société Française de Photogramétrie, no. 61, 21 p.

RIOM, J.; GOILLOT, C.; FABRE, J. P., 1979: Télédétection d'attaques de la Cochenille *Matsucoccus feytaudi* duc. (Coccoidea Margarodidae) dans les forêts de pins maritimes du Sud-Est de la France par microdensitométrie trichrome sur film I.R.C. Ann. Sci. Forest. **36**, (4), 299–320.

TRAN VAN CANH, 1982: Lutte contre le Fomes, nouvelle méthode d'étude, Caoutchoucs et Plastiques no. 617/618.

WILLIAMS, R. E.; LEAPHART, C. D., 1977: A system using aerial photography to estimate area of root disease centers in forests. Can. J. For. Res. **8**, 214–220.

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