Annual Research Report

2001

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Report by the Director of Research
to the
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Prolonged low palm oil prices have placed considerable financial strain on much of PNG's oil palm industry. Expenditure "belt-tightening" has been the order of the day for a number of years now. Despite this the oil palm industry, and the PNG Oil Palm Research Association (PNGOPRA) along side it, have managed to continue developing and improving. This says much about the commitment and professionalism that characterises this industry.

In 2001 the oil palm crop production was significantly below estimates and this directly affected PNGOPRA revenue. In addition, the last few years have seen very tight expenditure budgets set for the Association. Despite the pressures of limited resources, the last year has seen PNGOPRA continue to improve the service it provides to its Members. Agronomic constraints remain the industry's main barrier to optimum productivity and in the last year PNGOPRA has significantly strengthened its Agronomy Section and embarked upon a new and exciting work plan. The innovative work in pest IPM, pollination studies, *Ganoderma* research and smallholder socio-economic studies have continued. The research into Sexava biological control has been successfully completed and has resulted in the development of Stichotrema as a low-cost and effective mainstay to Sexava IPM. New foreign aid grants have been secured for research work on soil nitrogen losses and continued work on *Ganoderma* stem rots. We now look close to securing funding for a major study into the cation nutrition problems associated with the volcanic ash soils that support much of PNG's oil palm industry. External funding for an extension to the smallholder socio-economic was approved and work on this will continue throughout 2002.

Oil Palm Research in PNG

Oil palm research started in PNG with the establishment of seed gardens from genetic material brought into the country from Malaysia by Harrison's & Crosfield. The seed gardens led to the establishment of a very successful oil palm breeding programme, now managed by New Britain Palm Oil Ltd (NBPOL). With the expansion of the industry in the 70's, it was realised that research work was needed to address a number of significant agricultural constraints faced by the industry. Forming a single organisation responsible for this work was the most efficient approach. In 1979, PNG's oil palm companies and the Government formed PNGOPRA to function as the research arm of the oil palm industry. PNGOPRA now carries out research into oil palm agronomy, crop nutrition, entomology, plant pathology and smallholder socio-economics. PNGOPRA does not conduct plant-breeding work or seed production; this is carried out on a commercial basis by NBPOL at their Dami Research Station. NBPOL also conducts research work into oil palm tissue culture, mill waste management and composting. There is a high degree of collaboration and coordination between all areas of research.

The Association

PNGOPRA is an incorporated not-for-profit research association. Its current membership comprises New Britain Palm Oil Limited, Pacific Rim Plantations Ltd, Hargy Oil Palms Ltd and the Oil Palm Industry Corporation (OPIC). OPIC through its Membership represents the smallholder oil palm growers of PNG. The Members of the PNGOPRA have a close involvement in the direction and running of the organization thus ensuring the PNGOPRA is always responsive to the needs of the Members. The Members each have one representative on the PNGOPRA Board of Directors. Each representative holds voting rights within the meeting that reflect their Members input to the organization. This is calculated based on the previous year's FFB production, as the PNGOPRA Member's Levy is charged on an FFB basis. Voting rights in 2002 are presented below.

Members Voting Rights in 2002.

Member	FFB Production in 2001	Votes
New Britain Palm Oil Limited	498,716 tonnes	5
Pacific Rim Plantation Ltd	403,702 tonnes	5
Hargy Oil Palms Ltd	92,747 tonnes	1
Oil Palm Industry Corporation (smallholders)	525,298 tonnes	6
The Director of Research also holds one vote		

A sub-committee of the Board of Directors, the Scientific Advisory Committee, meets once a year and recommends the research programme for the coming year. Thus the Members can directly incorporate their research or technical service needs into the work programme of PNGOPRA. The Members voting rights within the Scientific Advisory Committee meeting are the same as for the Board of Directors meeting.

OPIC is responsible for the provision of agricultural extension for the smallholder growers. The link between PNGOPRA and smallholder extension is particularly strong with both organizations having seats on each other's planning and management meetings. Probably more important than this is a presence of a healthy and spontaneous informal communication between the officers in both organizations at both a national and local level.

PNGOPRA carries out research from three main centres, Dami in West New Britain Province, Higaturu in Oro Province, and Alotau in Milne Bay Province. PNGOPRA also runs sub-stations at Bialla & Kapiura in West New Britain, and Poliamba in New Ireland. PNGOPRA therefore has active research operations in all oil palm growing regions.

PNGOPRA as an organization is small in size, especially when compared to the scale and importance of the industry it serves. This size restriction is deliberate and allows a focusing on quality that in other organizations in PNG is too often compromised by the need to support quantity. In terms of personnel the Association is about the same size as when it was formed in 1980 and the cost of operations today for Members, in US$ terms, is no greater than it was ten years ago. Despite this, the output is much greater in terms of both quality and quantity.

Financing

PNGOPRA is funded by a research levy paid by all oil palm growers and by external funding from the PNG Government and foreign aid donors. The total expenditure budget in 2002 is estimated at K3,341,826. Today the Members levy represents about 64% of the organizations revenue and external funding 36%. The Member's levy, in general, finances core recurrent costs and the external funding covers research project specific costs. The Members levy in 2002 is set at a rate of K1.38 per tonne of FFB for Member companies and K0.90 per tonnes FFB for smallholders. Currently the external funding is supplied by the Government's Public Investment Project (PIP), the European Union through it's Stabex programme (3 projects), the Australian Centre for International Agricultural Research (ACIAR).

Administration

PNGOPRA is self administered and managed by a small team comprising the Director of Research, an Accounts Superintendent, an Administrative Officer, two Accounts Clerks, and a Secretary, all based at Dami Research Station. It is our aim to limit the size of the support operation and foster an emphasis on the research functions of the organization. Although this places a sizeable strain on the administration and accounting staff, the system does work well.

Entomology

During 2001 the Entomology Section at PNGOPRA worked on two EU-funded projects; the biological control of Sexava, which was completed in December 2001, and insect pollination of oil palm, which is due to finish at the end of June 2002.

The goal of the Sexava research project was to utilise the strepsipteran parasite *Stichotrema dallatorreanum,* found in Sexava in Oro Province (*Segestidea novaeguineae*), to control pest species of Sexava in the New Guinea Islands Provinces (*Segestidea defoliaria, Segestes decoratus,* and *Segestidea gracilis)*. During the project the parasite was introduced into areas of West New Britain and New Ireland and it has successfully established itself in field populations of the targeted pest species. Nymphs of the three Sexava species are infected with *S. dallatorreanum* in the laboratory and then released at regular intervals into a series of trial areas. Almost 10,000 infected host insects have now been released into more than 20 trial sites. Surveys have been undertaken in the release areas to determine the degree of infection by the parasite in subsequent generations of Sexava.

Information gathered from the release sites has shown that *S. dallatorreanum* can complete its life cycle in the field populations of *S. defoliaria* and *S. decoratus* in West New Britain. There is also evidence that the parasite is spreading from the original release sites to infect Sexava in surrounding areas. The releases that have been made into smallholder areas in West New Britain seem to have been particularly effective; especially at Siki, Kapore, Tamba, Sarakolok and Kavui. Pest damage levels in these areas were reaching the thresholds for chemical control when the introductions took place. The damage levels subsequently declined significantly during the months and years following the release of the parasite. No new outbreaks of Sexava have been reported in any of these areas since. Furthermore, field studies have demonstrated that fourth and fifth generation parasites are infecting Sexava in these areas.

The evidence from West New Britain therefore suggests that our research into the biological control of Sexava has been a success; with *S. dallatorreanum* demonstrated to be an effective bio-control tool for Sexava integrated pest management. However, although the presence of the parasite will suppress and even prevent Sexava outbreaks, it must be emphasized that it cannot be used against a large, and already established outbreak. Evidence from New Ireland suggests that the introductions of the parasite will not be as effective if the Sexava population is already large and increasing rapidly. In this case, the only effective control is the use of insecticide by trunk injection. The parasite should therefore be used as part of an overall integrated pest management system for Sexava. Both the parasite and Sexava host lack mobility and this limits the natural distribution of the parasite, thus there is a requirement for widespread and area-wide releases, which are logistically difficult. A project proposal was submitted to the EU at the end of 2001 to fund the area-wide releases of the parasite. Unfortunately no funding was forthcoming, and so the area-wide releases of the parasite remain problematic.

The oil palm pollination project started in July 2000 and was funded for a total of two years. Three objectives were to be addressed in the project; 1) Screening of the existing *Elaeidobius kamerunicus* populations within PNG for evidence of infection by parasites and pathogens, 2) determination of the degree of genetic separation between weevil populations in PNG and natural populations in West Africa using the amplified fragment length polymorphism (AFLP) genetic fingerprinting techniques, and 3) assessment of the potential to improve the genetic base of the existing population of *E. kamerunicus* within PNG, either by the introduction of fresh batches of the same weevil species or by the introduction of one or a number of new species of pollinating insect. Each of these objectives has been successfully addressed. With the project due to finish in two months, effort is now being focused on writing up as well as planning for a possible second phase (for which a project proposal has already been completed).

A haemocoel parasitising nematode has been found infecting *E. kamerunicus* in PNG, with infection levels approaching 50% in some populations. Infected weevil contain up to 15 adult females parasites plus numerous eggs and developing juveniles. However, although the nematode is present in most areas of PNG, with high levels recorded in some populations, the general level of infection seems to be relatively low (ranging from 0 to 30%). It must however be stressed that it is the future levels of

infection that should be of concern to the industry, particularly with regard to the effect that this would have on fruit-set and subsequent oil extract ratios. The type of parasitic nematode found in the pollinating weevil draws all its nutritional requirements from the host and therefore high parasitic burdens would have a marked effect on fecundity, perhaps even resulting in sterility due to depletion of the host's fat reserves. A reduction in energy reserves could also inhibit the ability of the weevils to fly and therefore directly impact their ability to pollinate.

Genetic fingerprinting, using the AFLP technique, has given a profound insight into the genetics of the weevil populations. This is particularly encouraging as it is the first time that the technique has been used for the study of weevil population genetics and it has successful produced robust phylogenic trees that can be used for genetic analysis. The phylogenic trees resulting from the AFLP analysis await further interpretation, but they already clearly indicate that the levels of genetic diversity in weevil populations from the various oil palm areas within PNG are significantly less than those from natural populations of weevils in Africa. All indications are that weevils in PNG are inbreed, lack genetic diversity and are susceptible to in-breeding suppression; the future consequences of this could be very significant to PNG's oil palm industry.

Large numbers of insects were collected on male and female oil palm inflorescences in Ghana. Of those insects present on male inflorescences it was found that *Elaeidobius* spp. and *Atheta spp*. were the most abundant. These included *E. kamerunicus*, *E. plagiatus*, and *E. subvittatus*. All these species also visited female inflorescences and were usually laden with pollen grains. The *Elaeidobius* species were found to carry the largest number of pollen grains. During the fieldwork it was found that the taxonomy of the *Elaeidobius* genus is more complicated and less well defined that previously thought. At least two previously undescribed species were identified within the genus. Two new species of *Elaeidobius* have been described during the project and the *Elaeidobius* genus taxonomy has also been revised. A taxonomic field guide, that is absolutely essential for any further field-work, is to be produced at the Natural History Museum in London. Unfortunately, this is on-hold due to lack of funding.

In Costa Rica, where *Mystrops costaricensis, E. subvittatus,* and *E. kamerunicus* are all present, *E. kamerunicus* was found to have out-competed the other two species. *E. kamerunicus* is generally the most dominant pollinator for most of the year and is particularly useful as it is numerous and active in both moderately dry and wet weather. *E. kamerunicus* was also found to carry more pollen grains than the other two species and responds better to the scent of the female inflorescence. *E. kamerunicus* also has the advantage of being host specific to oil palm, whereas *M. costaricensis* feeds from a number of other palms, including coconut. It was found that rain generally had a very suppressive effect on both *M. costaricensis* and *E. subvittatus*; indeed it was this that generated interest in introducing *E. kamerunicus* from Africa in the first place.

It has therefore not been possible to identify any candidate insects that might be able to complete with, or complement, *E. kamerunicus* to improve oil palm pollination in PNG. The introduction of fresh batches of *E. kamerunicus* into PNG from Africa is therefore recommended, as this action is expected to improve the genetic base of the existing populations. However this cannot be done until the uncertainty surrounding the taxonomy of the *Elaeidobius* genus is resolved; particularly regarding the status of the two previously undescribed species within the genus and what impact they might be having on pollination. Other problems include the widespread occurrence of nematode parasitism in the populations of pollinating weevils within PNG and the lack of basic biological information concerning these parasites and their effect on the host. As the origin of the nematodes is still uncertain, this has implications for the quarantining requirements of any new introductions. These are all matters to be addressed as part of a second phase of the project.

The Entomology Section has also continued with routine advisory and pest monitoring work. In the last year, this included 16 entomology training and field days for smallholder farmers and estate staff. A project proposal has been completed for the development of an IPM system for Finschhafen Disorder, which is now considered to be a significant threat to the oil palm industry in PNG. In addition to this several papers have been prepared/published in international scientific journals. A feature about the Sexava IPM project has been published in *Appropriate Technology*. There has also

been an article featured in *The Times Education Supplement* in the UK, and in the Oxford University Newsletter, BluePrint. Bill Page from the Natural Resources Institute in the UK visited PNGOPRA twice in the last year to study Sexava population dynamics and Finschhafen Disorder; the British Government funded Bill's work. Dr Kathirithamby at Oxford University continued as collaborator with the Sexava bio-control project. Drs Alex Reid and David Hunt at CABI Biosciences and Dr Ben Mensah at University of Cape Coast Ghana worked as collaborators on the pollination project. PNGOPRA's Entomologist, Takis Solulu, resigned during 2001 to take up postgraduate studies at the University of Queensland in Australia.

Plant Pathology

PNGOPRA's Plant Pathology Section was established in mid-1995 with substantial funding from the European Union through its Stabex programme. The primary focus of the Plant Pathology Section is to conduct research into Basal Stem Rot, a very serious oil palm disease caused by a fungus known as *Ganoderma*. Despite decades of work in other countries, no significant progress had been made in the understanding or control of Ganoderma. Unless significant progress is made, *Ganoderma* constitutes a significant threat to the future viability of the oil palm industry in PNG. The PNGOPRA Plant Pathology section, since its inception, has taken a world-lead in the study of this disease and has challenged the old models of disease epidemiology and the infection process. With our lead, a long-term effective control for *Ganoderma* is now visible on the horizon.

Our approach is to develop short-term control strategies that stall disease development while work continues to develop a long-term cure in the form of effective field resistance. A short-term control strategy developed as part of the programme is now in operation in most oil palm growing areas. Unfortunately this control strategy is expensive (although much cheaper than most overseas control strategies) and needs a high degree of management input. This makes it difficult to apply in the smallholder production system. Surveys have been initiated to determine more accurately the extent and economic impact of *Ganoderma* infection within smallholder blocks. Work is also underway to develop methods of controlling the disease that are more appropriate to the smallholder production environment; this will also provide commercial estates with a much more cost effective solution to short-term control. A main focus of this work is to develop biological control methodologies. The first approach is to develop an accelerated trunk rot that eliminates infected trunk material as a source of inoculum for further disease spread, and secondly the development of antagonistic organisms that can be used to suppress *Ganoderma* infection in the critical young-palm stage. A candidate organism has been isolated that can produce very rapid breakdown of felled oil palm trunk material; field trials with this organism are underway.

Efforts to control basal stem rot in SE Asia have been hampered by a lack of understanding of the causal pathogen, *Ganoderma boninense*. Our effectiveness in developing disease control methods is dependent upon generating a thorough understanding of the fungus. Great strides have been taken towards this goal and work continues, using molecular and mycological techniques, to investigate the modes of primary and secondary disease spread.

The establishment of a long-term control (eradication?) will depend up development of field-resistance within the planted oil palm stands. In order to do this, we need to develop tools to identify relative disease resistance and susceptibility amongst different palms. We are currently conducting field trials, and working on the development nursery and laboratory bioassays to do this. This work would eventually lead to the development of molecular techniques to identify resistance and susceptibility.

Training and dissemination of research findings is an important aspect of the control of any crop disease. Estate staff and OPIC extension officers are updated on new methods of control and taught to recognise new trends in the disease development.

Agronomy

The most serious factor limiting oil palm production in PNG is the ubiquitous presence of crop nutrient deficiencies. Understanding these problems and developing appropriate management strategies is the main task of PNGOPRA's Agronomy Section. If acceptable crop yields are to be

produced, the single highest cost involved in growing oil palm is going to be fertiliser input. A large part of the Agronomy Section's research focuses on the study of the soil chemistry and plant nutrition of oil palm growing on the wide range of PNG soil types; particularly the pedologically young volcanic soils. The major goal of the agronomy research is to develop the most economically optimal fertiliser practices dependent upon soil type, physical environment and economic conditions.

A large programme of formal fertiliser trials exists throughout the country. These trials are used to develop an understanding of the nutrient requirements of the oil palm and the responses to nutrient inputs. They also provide data that allows the extrapolation of findings to other areas, the tracking of fertility characteristics with time, and ultimately economic response models. Field trials work on a large plant like oil palm is difficult and much effort has gone into improving the experimental methodologies used. In the last year a series of new trial designs have been established that should greatly improve the value of the data derived from the trials. Since August 2001, ten new trials that had been planned in consultation with members have been established, with several more to commence in the coming two years.

During the last year considerable attention has been focussed on commencing specific research projects directed towards more fundamental soil and crop nutritional studies. These projects are designed to address the current knowledge gaps that hinder our development of improved nutrient management recommendations and technologies.

The first of these projects concerns the efficacy of nitrogen fertiliser inputs. Fertiliser constitutes the major cost input in oil palm cropping systems in PNG for both smallholder and plantation alike. The vast bulk of this fertiliser is nitrogenous fertiliser and the viability of the industry depends upon it. The biggest agronomic problem facing smallholder growers is nitrogen deficiency. Most of the oil palm in PNG is grown on coarse textured soils that are freely draining, have high hydraulic conductivity and are located in areas of high rainfall. Consequently nitrogen losses are likely to be very high due to one or a combination of leaching, surface run-off and denitrification. Losses could amount to as much as 50% of applied nitrogenous fertiliser, a loss that is intolerable to smallholder growers. PNGOPRA in collaboration with Massey University, New Zealand and with financial support from the European Union is initiating a study to identify the major mechanisms of nitrogen loss and to develop management practices that reduce losses as much as possible. Success in the project could have an enormous impact on the economics of oil palm production in PNG.

The second project relates to the cation nutrition problems experienced on the lowland volcanic soils that support most of PNG's oil palm crop. Widespread and serious magnesium deficiency symptoms have been identified in oil palm growing on the young, coarse-textured, volcanic ash soils in the West New Britain Province. The problem occurs on nearly all types of holdings (large plantations, village oil palm and land settlement schemes) placing a profitable industry at long-term risk.

Research work carried out in 2000-2001, funded by the PNGOPRA Members, has found a large and general imbalance between exchangeable calcium on the one hand, and exchangeable magnesium and potassium on the other. Calcium dominates the system to at least one metre depth, frequently exceeding the soil cation exchange capacity, preventing magnesium and potassium from occupying exchange sites. This explains why topical applications of soluble amendments such as kieserite (magnesium sulphate) have been largely ineffective. The most likely solution will be to introduce protected 'hot spots' of magnesium- and potassium-containing compounds into the soil to allow a percentage of roots to access and take up these elements.

PNGOPRA in collaboration with CSIRO in Townsville and the Australian Centre for International Agricultural Research (ACIAR) has developed a project proposal to address this cation problem. The project will focus on the type of amendments to apply and methods of placement. Field studies in PNG will be supported by laboratory-based work in Australia aimed at; 1) assessing the magnitude of the problem in volcanic ash soils across the Bismarck Archipelago, and 2) identifying the processes that have caused it.

The third project relates to the anomalous and poor responses to fertilizers in trials in West New Britain. Over the years considerable effort has gone into ensuring that experimental designs were

suitable for measuring responses. However, it still appears as though fertilisers are moving from plot to plot. This apparent movement has implications not just for experimental design, but also for management of nutrition in plantations. We are establishing experiments aimed at determining whether nutrients are moving in shallow groundwater.

A fourth project aims at rationalizing and making full use of the soil resource information that is available but not being properly utilized in the industry. By combining the resource maps available and reviewing classification of soils types, we will be able to extend management recommendations from detailed experimental sites to all areas of the industry.

PNGOPRA Agronomists give close technical support to the efforts of the extension service through smallholder block demonstrations, farmer field days, advisory services and training for extension officers. Agronomy research also addresses other issues such as nursery fertiliser practices, palm poisoning, and assisting in the development of mapping and GIS for the industry.

During 2001 the Agronomy Section underwent significant strengthening with the recruitment of a new Senior Agronomist and Agronomist. Following the lead of the Entomology Section and the Plant Pathology Section, I am confident that the improved staff strength and the newly formulated agronomy research programme will soon make its mark on the international stage as practitioners of leading oil palm research.

Smallholder Socio-Economic Studies

One of the most significant problems for the oil palm industry and its function in rural development is low productivity in the smallholder sector. In order to develop effective mechanisms to raise smallholder productivity it is necessary to understand smallholder livelihood strategies and the range of socio-economic factors constraining productivity. Between mid 2000 and January 2001 with ACIAR support and the collaboration of Curtin University and the ANU, PNGOPRA undertook smallholder surveys in two of the largest and most established oil palm project areas at Hoskins and Popondetta. In both locations the companies offered cooperation with the project.

A major finding of the research is that incomplete harvesting is a primary determinant of the lower yields from smallholdings. In the Hoskins scheme the annual losses from under-harvesting by smallholders are estimated to be in excess of 50,000 tonnes. The factors contributing to under-harvesting are complex and arise not only from direct labour shortages on individual blocks (e.g., elderly leaseholders without sons), but from complex social and economic forces that prevent labour from being deployed and adequately remunerated. For example, social conflict between co-resident families on a block can lead to labour shortages as only one family may be involved in each harvest round.

While there is much underemployed labour on the LSS and VOP schemes, uncertainty of payment for this labour is constraining its deployment in oil palm production. Often the excessive demands on leaseholders monthly oil palm cheques mean that the "labour contract" is not fulfilled so that contract harvesters (and family members) are not paid or underpaid. This is a major disincentive to the supply of contract labour.

A better understanding of these interactions was gained by examining the success of the Lus Frut Mama Scheme, introduced in 1997, which established a guaranteed payment system to remunerate women directly for the collection of loose fruit. Research into reasons for the success of the Lus Frut Mama Scheme led to several recommendations for modifications to smallholder payment schemes. One such, the Mobile Card is currently being piloted by OPIC and NBPOL in Hoskins. The Mobile Card is designed to promote labour flexibility and mobility while guaranteeing payment for contract labour. It aims to redistribute labour from labour surplus block to labour short blocks.

The results of the first phase of the research have now been published as a report which is available from PNGOPRA. In addition to the issues raised above the report contains information on other smallholder issues such as household production systems, replanting, debt recovery, land tenure, subsistence production and livelihood strategies. These are all factors affecting smallholder productivity.

In 2002, ACIAR extended funding for the smallholder study to evaluate the effectiveness of the Mobile Card, to examine various models for mini-estate development and to extend the smallholder study to the Bialla scheme.

Technical Services

The personnel within PNGOPRA represent an invaluable knowledge resource for oil palm industry. The services provided by PNGOPRA go beyond research alone. PNGOPRA staff from all sections are committed to providing technical support via special investigations, recommendations and direct technical input. For example; Plant Pathology are closely involved in the implementation of *Ganoderma* control measures, Entomology is an integral part of the pest management systems through their role in making recommendation and the production and release of biological control agents, PNGOPRA's Agronomists conduct the large scale annual leaf sampling operations and formulate the annual fertiliser recommendations. PNGOPRA staff also spend a significant amount of their time in providing technical training to plantation staff and extension officers.

For smallholder growers, research work is of limited value unless it works hand-in-hand with an effective extension service. Although these two functions are carried out by different organisations in the oil palm industry, the close and effective working relationship between PNGOPRA and OPIC is something that we feel proud of. It is not so much the formalised interface that produces this excellent working relationship but an informal interface borne of willingness by individuals in both organisations to work with a single-team spirit.

Since its formation, PNGOPRA has had an enormous impact upon the productivity and profitability of PNG's oil palm industry, and there is still much scope for further advancement. PNGOPRA's research programme aims at the production of optimum sustainable economic yields with the minimum pesticide and fertiliser inputs, this approach incorporates the principle that high & sustainable productivity is only possible by managing to prevent environmental degradation. This approach is equally applicable to both smallholder growers and estate companies.

PNGOPRA's small, highly-focussed and efficient mode of operation has certainly assisted in its ability to remain productive during financially tough-times; maybe some other institutions in PNG could learn from this. The PNG oil palm industry has a scientific service it can be proud of and one that fully reflects the commitment and professionalism of the industry it serves.

Ian Orrell
Director of Research
May 2002

1. AGRONOMY RESEARCH

(Dr. P. Nelson)

INTRODUCTION

STAFF

Senior Agronomist

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Mr. Thomas Betitis (Islands Region Agronomist, commenced May 2001)
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TRIAL RESULTS

In New Ireland, MOP continued to have a large effect on yield, maintaining or increasing yield over time in both trials. In trial 252, effects of SOA and TSP are starting to become significant. The spread of Ganoderma in these trials has provided a unique opportunity to study the effects of nutrition on Ganoderma incidence. Application of MOP in particular has substantially reduced Ganoderma incidence. A new trial with boron and MOP (Trial 254) is about to start in 2002.

At NBPOL there is currently one large factorial fertiliser trial, Trial 126 at Malilimi. In it, SOA is starting to increase yield. Factorial trial 402, which was closed in 2000, showed no response to fertilisers throughout its life. In the progeny x N x B trial (135), there was an N response at Garu but not at Kumbango. Interactions between progeny and fertiliser did not affect yield. A new P x K x Mg x B trial (132) has been started at Haella. In the fertiliser placement trial (129), placement has not yet affected yield, but tissue Mg and K contents were affected. In the N source trial (125), AMC appeared to give the highest yields. In the tissue monitoring trial (136) tissue nutrient contents were again fairly constant from month to month. In fertiliser trials at NBPOL over the last decade, yield has not been responding to fertilisers as expected; the yields in plots with no N addition have been unusually high. Assuming that plot-to-plot movement of fertiliser is responsible, trials with 'systematic' designs have been put in place. In these trials, adjacent plots have similar fertiliser rates. Of the systematic trials planned for NBPOL, one commenced in 2000 (403), one in 2001 (138a), and two commence in 2002 (137, 138b).

In Hargy trials, Sexava damage in Trial 204 caused the most remarkable result. Yield crashed to <12 t/ha, irrespective of fertiliser treatment. This trial was due for closure, but will be continued to monitor recovery from Sexava damage, and to determine the effects of fertilisers on recovery. In Trial 209, the effects of SOA, MOP and TSP are increasing with time. In trial 205, TSP and EFB both slightly increase yield, but the effect of TSP differs between progeny. Two systematic N trials (211 and 212) and an N x P trial on the high ground at Hargy (213) have recently commenced.

In Oro, the two trials with N plus K, S and Cl in different combinations (309 and 310) at Ambogo are showing different responses. In 309, N and S are affecting yield, but not K and Cl. In 310 (in which all treatments receive N), there was a response to Cl in the first 7 years of the trial, but in the subsequent 4 years until 2001, the Cl + S treatment showed the best response. In the two N x K x EFB trials (311 and 312), SOA has showed a large and increasing effect on yield, and EFB has shown an increasing effect with time. In 311 (Higaturu soils), MOP has had a small positive effect, but in 312 (Ambogo soils) it hasn't. One N source trial (324, Higaturu soils) has just started but no effects are evident. Another (325, Ambogo soils) has been marked out. One N x EFB trial (326, Higaturu soils) has been marked out and another (327, Ambogo soils) is yet to start. A factorial trial with N, P, K and Mg (329) has commenced at Mamba. Cation deficiencies are known to be important in the area, but factorial trials 317 and 318 did not give clear indications of what fertiliser rates should be used. The grassland N x S trial (330) will start in 2002. The spacing/thinning trial (331) was planted in 2001 and a range of cover crops was sown in 2002.

In Milne Bay the three factorial fertiliser trials continued. In Waigani, the trial on the good Plantation soils (502b) is showing substantial benefits from SOA and MOP in good years, and a positive effect of EFB in some years. On the poorer Hagita (buckshot) soils (511), there have been large positive effects of SOA, TSP and EFB, especially in good years. In the absence of SOA and TSP, the effect of EFB was as great as that of those fertilisers. MOP has had no effect. In Sagarai (504), MOP has had a positive effect over the last four years, and SOA over the last two years. The results of the POME monitoring (512) are given for the first time. POME has improved chemical fertility of the soils, but yield has generally been less in the POME block than the control block. The block designated for the spacing/thinning trial (513, same as 331 in Oro), in Padi padi has been cleared in 2002.

Most of the tissue analyses in this report are for Frond 17 leaflets (all nutrients) and Frond 17 rachis (K only), as has become the norm. The Frond 17 rachis still appears to be the best tissue for predicting K response. There generally does not appear to be a response at values >1.0 % DM. For some trials in Oro and Milne Bay in this report, results are also given for 'alternative sampling', in which samples are taken fresh, kept in plastic bags, and then analysed for water content. This allows nutrient contents to be expressed on the basis of fresh weight or, for those nutrients that exist mostly in the sap, as a concentration in the sap. From these results, there does not yet appear to be any particular advantage to calculating K, Cl or sulphate concentrations in the sap, but the picture may change as more data accumulates. Nutrient contents in Frond 3 leaflets appear to provide a better indicator of response than Frond 17 leaflets (see 309 report).

Finally, some comments about the calculation of yield are relevant to this report. At least since the Microsoft Access-based Agronomy database has been in use by OPRA (since 1998), FFB yields and bunch numbers, expressed on a per hectare basis, have been calculated for live palms only. For example, say a 16-palm plot of 0.125 ha (128 palms/ha), had 8 palms missing, and produced 1875 kg FFB in one year. The database calculated the yield for that plot as 30 t/ha, as though no palms were missing, not 15 t/ha as is the actual case for the plot. The difference between the two ways of calculating yield is inconsequential in most trials, because of the small numbers of missing palms. Calculation on a live palm basis continues in this report. However, in trials such as 251 and 252, in which the number of missing palms is becoming quite large due to Ganoderma, the choice of calculation method becomes significant. In this years reports for Trials 251 and 252 we have presented results for 2001 using both methods, so as to show the treatment effects on actual yields, and yields of the remaining palms.

RESEARCH DIRECTION

In previous reports, trials have been described as Phase 1 or Phase 2. The purpose of Phase 1 trials is to determine which nutrients are limiting. They typically involve a range of fertilisers, usually in factorial or some other combination. These trials must continue as new areas are brought into cultivation and as deficiencies evolve with time. Phase 2 trials are designed to determine responses to

limiting nutrients, allowing fertiliser recommendations to be made. The majority of nutrition research to date has fallen into these two categories.

While the large program of fertiliser trials over the last two decades has provided a great deal of important information, a number of major questions regarding optimum nutrition remain. It has become increasingly apparent that conventional fertiliser experiments are not answering these questions, and are therefore not providing solutions to some outstanding problems. Therefore we are now moving into Phase 3 research. Phase 3 research is designed to answer the questions that have not been answered by conventional fertiliser experiments:

- There appear to be large losses of N and cations from the system. What is the efficiency of uptake of N, Mg and K supplied in fertilisers, and can it be improved?
- Why are yields not responding to fertilisers in trials in West New Britain and what are the implications for research and management?
- How is management affecting the soil resource base, and what are the implications for future productivity?

The developing program for tackling these issues will be presented in the Research Proposals for 2003.

ABBREVIATIONS

AMC	Ammonium chloride (NH_4Cl)
AMN	Ammonium nitrate (NH_4NO_3)
BA	Bunch ash (burned EFB)
BNO	Number of bunches
$cmol_c/kg$	centimoles of charge per kg, numerically equal to meq % or meq/100g
CV	Coefficient of variation
DM	Dry matter
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
GM	Grand mean (average over all treatments)
KIE	Kieserite (mostly magnesium sulphate, $MgSO_4$)
l.s.d.	Least significant difference (p=0.05)
mM	Millimolar (millimoles per litre)
MOP	Potassium chloride (KCl)
n.s.	See Sig.
p	Significance (probability that treatment effect is due to chance)
SBW	Single bunch weight
s.d.	Standard deviation
s.e.	Standard error
s.e.d.	Standard error of the difference of the means
Sig.	Level of significance (n.s. not significant, * $p<0.05$, ** $p<0.01$, *** $p<0.001$)
SOA	Ammonium sulphate ($(NH_4)_2SO_4$)
SOP	Potassium sulphate (K_2SO_4)
TSP	Triple superphosphate (mostly calcium phosphate, $CaPO_4$)

SOIL ANALYTICAL METHODS USED (Hill Laboratories, NZ)

Parameter	Method
Preparation	Air dried at 35ºC overnight, crushed through 2 mm sieve
pH	pH electrode in 1:2 (v/v) soil:water slurry
'Available' P	Olsen extraction, det. by molybdenum blue colorimetry
Anion storage capacity /P ret.	Equilibration with 0.02M K_2PO_4 followed by ICP-OES
Total P	Nitric/perchloric acid digestion, det. by ICP-OES
Exch. Ca, Mg, K & Na	1M NH_4 acetate extraction (pH 7), meas. by ICP-OES
Exch. Al	1M KCl extraction, det. by ICP-OES
CEC	Sum of exchangeable cations plus exch. acidity
Volume weight	Weight/volume of dried, ground soil
Base saturation	Calculated from exchangeable cations and CEC
'Reserve' K	1M nitric acid extraction, det. by AA
'Reserve' Mg	1M HCl extraction, det. by AA, exch. Mg subtracted
Total N	Dumas combustion
'Available' N	7 day anaerobic incubation, 2M KCl extraction of NH_4^+
Organic S	0.02 M K_2PO_4 extraction followed by ICP-OES for total S, then subtraction of sulphate-S
Sulphate-S	0.02 M K_2PO_4 extraction followed by ion chromatography
Hot water soluble B	0.01M $CaCl_2$ extraction, det. by ICP-OES
Organic matter	Dumas combustion. Calculated at 1.72 x total carbon

FERTILISER COMPOSITION

Fertiliser and abbreviation	Approximate elemental content (% mass) N	P	K	S	Mg	Cl	B
Ammonium sulphate (SOA)	21			24			
Ammonium chloride (AMC)	25					66	
Ammonium nitrate (AMN)	35						
Urea	46						
Diammonium phosphate (DAP)	18	20					
Potassium sulphate (SOP)			14	17			
Triple superphosphate (TSP)		20		2			
Kieserite (KIE)				23	16		
Potassium chloride (MOP)			50			47	
Sodium chloride						61	
Borax							11
Ulexite							10

CLIMATE – Summary of selected locations across the industry

Monthly and annual rainfall for 2001

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Total**
						New Ireland Province							
Poliamba	127	499	247	444	464	257	314	209	95	247	231	679	**3814**
						West New Britain Province							
Navo	240	1143	457	273	291	232	246	265	98	131	228	768	**4371**
Hargy	242	113	194	209	203	147	155	212	248	260	219	613	**3466**
Dami	234	701	347	254	305	390	236	111	200	86	182	575	**3621**
Garu	213	901	362	384	337	328	118	182	257	54	276	774	**4186**
						Oro Province							
Mamba	344	325	508	441	474	353	288	100	262	183	302	219	**3797**
OPRA	300	261	308	201	108	137	87	62	157	275	155	461	**2513**
Embi	555	483	456	386	145	121	46	49	131	107	206	211	**2895**
Milne Bay Province													
Waigani	97	182	214	229	92	221	99	97	186	110	127	93	**1779**

Monthly and annual sunshine hours in 2001

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Total**
						New Ireland							
Poliamba	226	109	132	171	159	153	196	229	212	183	188	96	**2053**
West New Britain													
Navo	213	97	175	107	140	120	160	158	189	222	148	71	**1800**
Hargy	242	113	194	209	203	147	155	212	248	260	235	123	**2341**
Dami	158	74	150	145	174	114	147	196	185	198	164	75	**1778**
						Oro Province							
Mamba	173	93	169	148	156	132	160	195	165	217	136	134	**1877**
OPRA	213	112	196	172	173	162	173	207	190	244	177	172	**2193**
						Milne Bay Province							
Sagarai	140	99	163	94	113	12	69	114	100	168	111	100	**1283**

AGRONOMY TRIALS IN NEW IRELAND PROVINCE

(P. Nelson, T. Betitis)

Trial 251 and 252 Factorial Fertiliser Trials at Maramakas and Luburua Plantations

PURPOSE

To provide fertiliser response information that will be useful in developing strategies for fertiliser use.

SITE and PALMS

Trial 251 site: Fields 2B, 2C, 2D and 3A, Maramakas Plantation.
Trial 252 site: Block 4, Luburua Plantation.
Soils: Reddish brown clay soil overlying raised coral and showing great variability in depth. The soils are shallow on terrace margins and low ridges and moderately deep in depressions. The soil is freely draining.
Topography: Low rises and depressions
Palms: Dami commercial DxP crosses Planted in March 1989 (251) and September 1989 (252) at 128 palms/ha.

DESIGN

Treatments started in April 1991 at both sites, and both sites have the same experimental design. There are 36 treatments, comprising all factorial combinations of ammonium sulphate (SOA) and potassium chloride (MOP) each at three levels, and triple superphosphate (TSP) and kieserite (KIE) each at two levels (Table 1). Fertiliser application is split into three applications per year. Each of the 36 plots consist of 36 palms (6x6), of which the central 16 (4x4) are recorded.

Table 1. Rates of fertiliser used in trials 251 and 252.

	Amounts (kg/palm/yr)		
	Level 0	Level 1	Level 2
Ammonium sulphate (SOA)	0	2.5	5.0
Potassium chloride (MOP)	0	2.5	5.0
Triple superphosphate (TSP)	0	2.0	-
Kieserite (KIE)	0	2.0	-

These two trials were originally planned as single 3x3x2x2 factorial trial with two replicates, but because of restricted availability of land, the two replicates were located on two separate sites and regarded as two trials. However, as the two trials are performing quite differently, the data for the two sites has been analysed separately since 1997. The 4-factor interaction provides the error term in the statistical analysis. Soil depth was measured near each palm, and the mean depth per plot is used as a covariate in the analysis of variance. Minimum, maximum, mean and standard deviation of plot soil depths are 30.7, 66.2, 46.6 and 8.7 cm, respectively for Trial 251, and 16.5, 69.7, 41.2 and 14.8 cm, respectively, for Trial 252.

In the past, FFB yields and bunch numbers, expressed on a per hectare basis, have been calculated on the basis of living palms only, not on the actual plot area including dead or missing palms. The difference between the two ways of calculating yield is inconsequential in most trials, because of the small numbers of missing palms. However, in trials 251 and 252, in which the number of missing palms is becoming quite large due to Ganoderma, the choice of calculation method becomes

significant. In this report we have presented results for 2001 using both calculation methods, so as to show the treatment effects on actual yields, and yields of the remaining palms. The effects of the treatments on the number of Ganoderma-affected palms has been tested separately.

RESULTS

Yield and tissue nutrient concentrations in Trial 251

Results in 2001 were similar to previous years. Results were the same whether expressed on the basis of living palm numbers or plot area. The only treatment that significantly influenced yield and its components was MOP. The effect of MOP was not influenced by other treatments (Table 2). Yield was doubled by the application of 2.5 kg of MOP/palm, with 5 kg providing no extra benefit (Table 3). Soil depth did not significantly influence yield or its components (Table 2), nor did it improve the model for most parameters (Efficiency factor <1, Table 2). The effect of the interaction between SOA and MOP on yield is shown in Table 4.

Tissue concentrations of all nutrients were influenced by MOP application (Tables 5 and 6). In the leaflets, concentrations of N, P, K increased and ash, Mg, Ca, B and Cl decreased. In the rachis, ash and K concentrations increased. SOA application increased leaf N and P contents. The effect of the interaction between SOA and MOP on leaflet N and rachis K contents is shown in Tables 7 and 8. Leaflet N content was highest at SOA2 and MOP1 or MOP2. Rachis K content was highest at MOP2 and SOA1. When depth was not included as a covariate, leaflet P content was significantly ($p<0.05$) influenced by SOA, MOP, TSP and the three-way interaction between them. When the depth covariate was included in the analysis, its efficiency was very high and all treatments and interactions were highly significant (Table 5). Therefore, there was a strong interaction between soil depth and the effect of fertilisers on P uptake.

Yield and tissue nutrient concentrations in Trial 252

Firstly, effects of the treatments on yield were the same whether yield was calculated on a 'per living palm' basis or 'per total plot area' basis (Tables 9 and 10). SOA, MOP and TSP all had significant effects on FFB yield over the periods examined (Table 9). Considering the main effects, yield was highest at the intermediate level of SOA and the highest levels of MOP and TSP (Table 10). The interaction between SOA and MOP is shown in Table 11 and Fig. 1. When no MOP was added, yield was highest at the intermediate level of SOA and where no SOA was added, yield was highest at the intermediate level of MOP. Increasing MOP application from 2.5 to 5 kg/palm only increased yield when SOA was also applied (Figure 1). The highest yields were attained at the highest rates of both MOP and SOA. FFB yield was also significantly affected by the MOP x TSP interaction in 2001 and 1999-2001 (Table 9, Figure 1). Where no MOP was applied, TSP significantly increased yield. These interactions were not significant in Trial 251. The MOP effect was the greatest treatment effect in both the 1999-2001 and 2001 time periods, and could be attributed to increases in bunch numbers and bunch weights. The effects of SOA and TSP on yield in 2001 were due primarily to increased bunch numbers, in contrast to results in 2000, when the effects were due mainly to bunch weights.

Inclusion of soil depth as a covariate significantly improved the fit of the model for bunch numbers (Covariate efficiency factor >1, Table 9). However, soil depth itself did not significantly influence yield or its components (Table 9).

Tissue concentrations of all nutrients were influenced by MOP application (Table 12). Concentrations were affected in the same way as in trial 251. In the leaflets, concentrations of N, P, K increased and ash, Mg, Ca, B and Cl decreased. In the rachis, ash and K concentrations increased (Table 13). SOA application decreased rachis K contents. The effect of the interaction between SOA and MOP on leaflet N and rachis K contents is shown in Tables 14 and 15.

Main effects of treatments over the course of the trials (251 & 252)

The main effects of the treatments on FFB yield and tissue concentrations over the course of the trials are shown in Figure 2. The effect of MOP on yield has been increasing with time. The marked effect on rachis K contents was established early and has been fairly constant over the last five years. Leaf N levels appear to be declining slowly, even at the high rate of SOA. There has been little or no effect of SOA, TSP or kieserite on yield over the course of the trials. Kieserite has significantly increased leaf Mg contents over the last 8 years, but they are well within the adequate range in all treatments.

Relationship between fertiliser treatments and incidence of Ganoderma (251 & 252)

Since 1996 the incidence of Ganoderma has been increasing in the Poliamba plantations, including the sites of Trials 251 and 252. The spread of Ganoderma in the trials gave a unique opportunity to study the effect of fertilisers on Ganoderma incidence. Palm censes were carried out in 1996, November 1997, December 1998, March 2000 and July 2001. In the 1996 and 2001 censes, the number of missing or sick palms in each plot was recorded, specifying if they were recorded palms (the central 16) or guard row palms. For sick palms, the presence or absence of Ganoderma symptoms was noted. In the 1997, 1998 and 2000 censes, only recorded palms were assessed, not guard row palms. The status of each recorded palm was noted; healthy, missing, sick, Ganoderma or suspected Ganoderma. For the purpose of analysis, all palms designated missing or sick due to Ganoderma were combined and assumed to be, or have been before removal, Ganoderma-affected.

The effect of fertiliser treatments on Ganoderma incidence was analysed using analysis of variance for each year, on recorded palms (all years) or recorded plus guard row palms (1996 and 2001). Soil depth was used as a covariate in all cases because of its known effect on palm growth. The parameter analysed for Ganoderma incidence was the number of affected palms per plot, but results are shown as percentage of palms affected, for easier comparison. In Trial 252, an east-west trend in Ganoderma incidence was apparent from the 2001 census map, so the analysis of variance was repeated using east-west position of the plots as a covariate. The relationship between Ganoderma incidence and the east-west factor was also examined by linear regression.

In Trial 251, the main effects of TSP, MOP and kieserite application were significant ($p<0.1$) in several years (Table 16). Significance of the main effects increased initially and then decreased in 2001 (Figure 3). Application of TSP tended to Ganoderma incidence, although not in all years (Table 17). The intermediate rate of MOP tended to increase or not affect incidence, whereas MOP at the high rate decreased it. Inclusion of soil depth as a covariate slightly improved the fit of the model, shown by values of covariate efficiency greater than one (Table 16). Ganoderma incidence was positively related to soil depth.

In Trial 252, the effects of fertilisers and soil depth were generally clearer than in 251. Significance of the treatments increased with time (Figure 3). In 2001, all fertiliser treatments significantly influenced Ganoderma incidence ($p<0.05$, Tables 18 and 19). MOP, TSP and kieserite all reduced incidence, the effect of MOP being the greatest. The combined effects of MOP, TSP and kieserite on Ganoderma incidence in Trial 252 are shown in Figure 4. Where neither MOP, TSP nor kieserite were applied, 13% of palms were affected by Ganoderma, whereas at the high rate of MOP, combined with TSP, kieserite or both, incidence was less than 2%. SOA slightly increased incidence (Table 19).

The inclusion of soil depth as a covariate for Trial 252 considerably improved the model. Ganoderma incidence was negatively correlated with soil depth. In 2001 Ganoderma incidence decreased by 6.3% for every 10 cm increase in soil depth (recorded plus guard row palms). Including east-west position as a covariate only improved the model for the recorded palm data in 2001 (covariate efficiency of 1.83 in 2001, <1 in all previous years), and the recorded plus guard row palm data (efficiency of 1.27 in 1996 and 1.09 in 2001). Including east-west position as a covariate did not change the fertiliser effects substantially, so it is not included in the presented results. When analysed separately by linear regression, the effect of position was significant ($p<0.05$) in 2000 and 2001, accounting for 9-14% of

the variation in Ganoderma incidence (Figure 5). Over the period studied, the incidence of Ganoderma-affected palms increased more in the east than in the west of the trial.

In both trials, the largest fertiliser effect was the main effect of MOP, which is illustrated in Figure 6. The positive effects of fertiliser application on slowing spread of Ganoderma were fairly clear in Trial 252. We could speculate that poor nutrition, especially with respect to P, K and Mg, makes the palms susceptible to development of the disease. The negative correlation between soil depth and Ganoderma incidence ties in, as shallow soils would increase stress on the palm due to reduced water supply in dry periods, and may thereby make them more susceptible. However, in Trial 251 results were not so clear. The positive correlation between soil depth and Ganoderma incidence is difficult to explain. Perhaps the positive effect of soil depth was due to increased N uptake, similar to the positive effect of SOA in Trial 252. The decrease in significance of fertiliser treatments in 2001 is also difficult to explain. There are several possibilities. Perhaps disease pressure was so high (47 out of the 576 recorded palms, and 107 out of the 1296 recorded plus guard row palms) that even well fertilised palms were being affected. Alternatively, it may be that some of the well-fertilised palms that were suspect were culled between the 2000 and 2001 censes, but they may not have gone on to develop the disease. The shape of the disease curve in Figure 3 (Trial 251) is atypical, and also suggests that excessive culling may occurred between the 2000 and 2001 censes.

CONCLUSION

The effects of fertilisers on yield and tissue nutrient contents in these trials were similar in 2001 to previous years. MOP had a major effect on yield in both trials. In 252, SOA and TSP also had significant, but smaller, effects on yield. The spread of Ganoderma in these two trials indicated that fertiliser application, especially MOP, can play a positive role in reducing the incidence of Ganoderma on these K-deficient soils.

Table 2. Effects (p values) of treatments on FFB yield and its components, on the basis of living palms in 1999-2001 and 2001, and on the basis of actual plot area in 2001 (Trial 251). Also shown are the depth covariate coefficient (cm) and covariate efficiency. p values <0.05 are indicated in bold.

	1999-'01 (per live palm)			2001 (per live palm)			2001 (per plot)		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	0.646	0.686	0.868	0.837	0.582	0.623	0.948	0.736	0.459
MOP	**0.003**	**0.014**	**0.002**	**0.008**	**0.042**	**0.003**	**0.004**	**0.016**	**0.002**
TSP	0.769	0.677	0.503	0.917	0.855	0.477	0.750	0.760	0.615
KIE	0.908	0.543	0.283	0.951	0.696	0.272	0.706	0.435	0.191
SOA.MOP	0.536	0.784	0.236	0.764	0.876	0.279	0.590	0.960	0.132
SOA.TSP	0.762	0.769	0.473	0.833	0.862	0.507	0.581	0.590	0.527
MOP.TSP	0.507	0.502	0.419	0.515	0.362	0.929	0.255	0.168	0.671
SOA.KIE	0.908	0.897	0.406	0.808	0.798	0.355	0.577	0.602	0.354
MOP.KIE	0.793	0.771	0.708	0.970	0.756	0.480	0.941	0.640	0.345
TSP.KIE	0.329	0.230	0.913	0.629	0.472	0.653	0.124	0.087	0.489
SOA.MOP.TSP	0.575	0.311	0.910	0.642	0.350	0.801	0.423	0.219	0.637
SOA.MOP.KIE	0.553	0.668	0.779	0.621	0.718	0.806	0.314	0.430	0.634
SOA.TSP.KIE	0.307	0.267	0.767	0.527	0.530	0.279	0.166	0.151	0.125
MOP.TSP.KIE	0.894	0.908	0.337	0.524	0.662	0.326	0.309	0.523	0.329
Soil depth	0.482	0.309	0.921	0.670	0.989	0.416	0.862	0.482	0.123
Depth coeff.	-0.19	-14	0.01	0.13	0	0.13	-0.04	-7.7	0.20
s.e.	*0.242*	*11.7*	*0.102*	*0.275*	*12.3*	*0.134*	*0.206*	*9.65*	*0.092*
Effic.	*0.91*	*1.12*	*0.75*	*0.81*	*0.75*	*0.97*	*0.76*	*0.91*	*1.88*
CV %	14.7	13.4	7.2	18.3	15.8	9.0	14.7	13.5	6.3

Table 3. Main effects of treatments on FFB yield (t/ha) and its components, adjusted for depth covariate (Trial 251). Significant effects ($p<0.05$) are shown in bold.

	1999-'01 (per live palm)			2001 (per live palm)			2001 (per plot)		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA0	20.5	1102	18.6	19.3	984	19.6	18.0	914	19.4
SOA1	21.3	1109	18.6	19.3	982	19.2	18.0	908	19.2
SOA2	22.4	1176	18.4	20.2	1053	18.8	18.5	959	18.6
s.e.d.	*1.30*	*62.6*	*0.55*	*1.48*	*65.9*	*0.72*	*1.11*	*51.9*	*0.50*
MOP0	**12.0**	**834**	**13.9**	**12.5**	**823**	**14.3**	**10.7**	**703**	**15.2**
MOP1	**26.0**	**1256**	**21.0**	**23.9**	**1116**	**22.0**	**21.9**	**1027**	**21.5**
MOP2	**26.2**	**1298**	**20.7**	**22.4**	**1079**	**21.3**	**21.8**	**1051**	**20.6**
s.e.d.	*1.47*	*71.0*	*0.62*	*1.68*	*74.7*	*0.81*	*1.25*	*58.8*	*0.56*
TSP0	21.4	1129	18.7	19.5	1003	19.4	18.1	928	19.1
TSP1	21.4	1129	18.3	19.7	1009	19.0	18.2	926	19.0
s.e.d.	*1.09*	*52.4*	*0.46*	*1.24*	*55.2*	*0.60*	*0.93*	*43.4*	*0.41*
KIE0	22.0	1147	18.9	19.6	1002	19.5	18.3	932	19.2
KIE1	20.8	1112	18.1	19.6	1010	19.0	18.0	922	19.0
s.e.d.	*1.37*	*66.0*	*0.58*	*1.56*	*69.5*	*0.76*	*1.17*	*54.7*	*0.52*

Table 4. Effect of the interaction between SOA and MOP on FFB yield (t/ha) in 1999-2001 and 2001 on the basis of living palms (Trial 251).

1999-2001, lsd 8.77				2001, lsd 10.00			
	MOP0	MOP1	MOP2		MOP0	MOP1	MOP2
SOA0	14.0	22.4	25.1	SOA0	13.1	23.5	21.1
SOA1	9.2	28.5	26.4	SOA1	12.7	22.8	22.5
SOA2	12.7	27.2	27.3	SOA2	11.7	25.3	23.5

Table 5. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 251). Also shown are the depth covariate coefficient (cm) and covariate efficiency. p values <0.05 are indicated in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	0.281	**0.004**	**<.001**	0.794	0.931	0.490	0.149	**0.006**	0.354	0.206
MOP	**0.027**	**<.001**	**<.001**	**<.001**	**0.004**	**0.010**	**0.009**	**0.002**	**0.041**	**0.011**
TSP	0.840	**0.041**	**<.001**	0.391	0.735	0.402	0.507	**0.007**	0.455	0.613
KIE	0.639	**0.027**	**<.001**	0.255	0.119	0.294	0.260	0.945	0.786	0.479
SOA.MOP	0.675	0.057	**<.001**	0.669	0.966	0.676	0.275	0.073	0.398	0.607
SOA.TSP	0.637	0.441	**<.001**	0.879	0.983	0.628	0.719	0.105	0.467	0.304
MOP.TSP	0.992	**0.025**	**0.017**	0.609	0.781	0.787	0.958	0.013	0.319	0.330
SOA.KIE	0.812	0.087	**<.001**	0.826	0.754	0.526	0.253	0.054	0.575	0.626
MOP.KIE	0.618	0.112	**0.010**	0.481	0.853	0.858	0.882	0.493	0.934	0.891
TSP.KIE	0.716	0.432	**0.002**	0.228	0.338	0.397	0.896	0.179	0.461	0.296
SOA.MOP.TSP	0.527	**0.033**	**<.001**	0.515	0.921	0.574	0.834	**0.023**	0.928	0.817
SOA.MOP.KIE	0.765	**0.023**	**<.001**	0.753	0.770	0.442	0.188	0.093	0.800	0.657
SOA.TSP.KIE	0.871	0.172	**<.001**	0.994	0.799	0.773	0.965	**0.049**	0.973	0.736
MOP.TSP.KIE	0.923	0.596	**<.001**	0.488	0.821	0.398	0.837	**0.009**	0.985	0.891
Soil depth	0.884	0.326	**<.001**	0.755	0.727	0.740	0.459	0.104	0.970	0.766
Depth coeff.	0.009	0.003	0.000	0.002	-0.002	-0.003	-0.11	0.002	-0.002	0.009
s.e.	*0.057*	*0.003*	*0.000*	*0.005*	*0.005*	*0.008*	*0.13*	*0.001*	*0.042*	*0.027*
Effic.	*0.76*	*1.09*	*63.39*	*0.78*	*0.79*	*0.78*	*0.93*	*2.08*	*0.75*	*0.78*
CV %	9.9	1.4	0.2	9.9	20.4	8.7	10.5	1.9	15.2	39.5

Table 6. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (ppm). Values are adjusted for depth covariate (Trial 251). Significant effects ($p<0.05$) are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA0	7.1	**2.35**	**0.166**	0.64	0.34	1.19	15.1	0.65	3.7	0.97
SOA1	7.6	**2.43**	**0.162**	0.63	0.34	1.14	16.8	0.67	3.7	1.01
SOA2	7.7	**2.50**	**0.167**	0.65	0.35	1.16	16.7	0.70	3.4	0.69
s.e.d.	*0.31*	*0.014*	*0.0001*	*0.021*	*0.029*	*0.042*	*0.70*	*0.005*	*0.23*	*0.145*
MOP0	**8.4**	**1.20**	**0.155**	**0.35**	**0.53**	**1.35**	**19.4**	**0.72**	**3.1**	**0.29**
MOP1	**7.2**	**1.55**	**0.169**	**0.76**	**0.26**	**1.05**	**14.6**	**0.64**	**3.6**	**1.09**
MOP2	**6.8**	**2.53**	**0.171**	**0.81**	**0.25**	**1.09**	**14.5**	**0.65**	**4.1**	**1.29**
s.e.d.	*0.35*	*0.016*	*0.0002*	*0.030*	*0.033*	*0.047*	*0.79*	*0.006*	*0.26*	*0.165*
TSP0	7.5	**2.44**	**0.163**	0.65	0.34	1.15	16.4	**0.66**	3.7	0.91
TSP1	7.5	**2.41**	**0.167**	0.63	0.35	1.18	15.9	**0.69**	3.5	0.87
s.e.d.	*0.26*	*0.0117*	*0.0001*	*0.022*	*0.024*	*0.035*	*0.59*	*0.005*	*0.19*	*0.122*
KIE0	7.4	**2.44**	**0.165**	0.65	0.32	1.18	16.7	0.67	3.6	0.81
KIE1	7.5	**2.41**	**0.165**	0.63	0.37	1.14	15.7	0.68	3.6	0.97
s.e.d.	*0.32*	*0.015*	*0.0002*	*0.028*	*0.031*	*0.044*	*0.74*	*0.006*	*0.24*	*0.153*

Table 7. Effect of interaction between SOA and MOP on leaflet N content (% DM) in 2001 (Trial 251). P = 0.057, s.e.d. = 0.0297 and l.s.d.(0.05) = 0.0946. The ANOVA was adjusted for depth covariate and CV = 1.4%

	MOP0	MOP1	MOP2
SOA0	2.17	2.46	2.42
SOA1	2.19	2.57	2.53
SOA2	2.23	2.63	2.63

Table 8. Effect of interaction between SOA and MOP on rachis K content (% DM) in 2001 (Trial 251). P = 0.607, s.e.d. = 0.308 and l.s.d.(0.05) = 0.981. The ANOVA was adjusted for depth covariate and CV = 39.5%

	MOP0	MOP1	MOP2
SOA0	0.17	1.33	1.39
SOA1	0.52	1.02	1.50
SOA2	0.18	0.92	0.97

Table 9. Effects (p values) of treatments on FFB yield and its components, on the basis of living palms in 1999-2001 and 2001, and on the basis of actual plot area in 2001 (Trial 252). Also shown are the depth covariate coefficient (cm) and covariate efficiency. p values <0.05 are indicated in bold.

	1999-'01 (per live palm)			2001 (per live palm)			2001 (per plot)		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.032**	0.142	**0.037**	**0.019**	0.067	0.357	**0.024**	0.060	0.343
MOP	**<.001**	**0.010**	**<.001**	**<.001**	**0.003**	**0.015**	**<.001**	**0.003**	**0.021**
TSP	**0.049**	0.137	**0.048**	**0.032**	**0.048**	0.510	**0.021**	**0.032**	0.508
KIE	0.748	0.430	0.115	0.834	0.148	0.318	0.601	0.336	0.268
SOA.MOP	0.059	0.252	**0.049**	**0.029**	0.051	0.642	**0.043**	0.082	0.784
SOA.TSP	**0.031**	0.086	0.061	0.061	0.081	0.625	0.137	0.183	0.760
MOP.TSP	**0.042**	0.155	**0.046**	0.053	**0.034**	0.513	0.063	**0.037**	0.588
SOA.KIE	0.451	0.630	0.727	0.242	0.247	0.773	0.214	0.206	0.925
MOP.KIE	0.940	0.341	0.071	0.506	0.056	0.385	0.417	0.102	0.498
TSP.KIE	0.955	0.926	0.399	0.304	0.388	0.850	0.229	0.282	0.781
SOA.MOP.TSP	0.174	0.402	0.061	0.458	0.336	0.804	0.223	0.159	0.865
SOA.MOP.KIE	0.154	0.676	0.065	0.226	0.146	0.611	0.114	0.170	0.640
SOA.TSP.KIE	0.329	0.700	0.250	0.844	0.714	0.745	0.231	0.608	0.894
MOP.TSP.KIE	0.393	0.297	0.420	0.476	0.200	0.998	0.414	0.213	0.916
Soil depth	0.465	0.230	0.609	0.531	0.192	0.715	0.395	0.168	0.628
Depth coeff.	-0.059	-7.8	0.017	-0.042	-5.3	0.032	-0.065	-6.8	0.043
s.e.	*0.071*	*5.2*	*0.030*	*0.060*	*3.2*	*0.079*	*0.065*	*3.7*	*0.080*
Effic.	*0.92*	*1.32*	*0.83*	*0.87*	*1.45*	*0.79*	*0.99*	*1.57*	*0.82*
CV %	8.0	11.0	4.5	6.6	6.6	11.6	7.7	8.3	12.0

Table 10. Main effects of treatments on FFB yield (t/ha) and its components, adjusted for depth covariate (Trial 252). Significant effects (p<0.05) are shown in bold.

	1999-'01 (per live palm)			2001 (per live palm)			2001 (per plot)		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA0	**22.3**	1241	**17.3**	**22.8**	1273	17.8	**21.6**	1194	17.6
SOA1	**26.3**	1395	**18.9**	**27.0**	1408	19.4	**25.8**	1338	19.2
SOA2	**24.3**	1273	**18.3**	**25.7**	1334	18.9	**23.1**	1184	18.8
s.e.d.	*0.82*	*60.1*	*0.35*	*0.70*	*37.0*	*0.92*	*0.76*	*43.5*	*0.93*
MOP0	**16.5**	**1062**	**14.6**	**17.2**	**1106**	**15.2**	**14.8**	**948**	**15.3**
MOP1	**27.9**	**1427**	**19.9**	**28.7**	**1459**	**20.4**	**26.8**	**1366**	**19.8**
MOP2	**28.4**	**1420**	**20.0**	**29.7**	**1449**	**20.7**	**28.8**	**1403**	**20.5**
s.e.d.	*0.89*	*65.4*	*0.38*	*0.76*	*40.2*	*1.00*	*0.83*	*47.3*	*1.01*
TSP0	**23.2**	1252	**17.7**	**24.1**	**1289**	18.5	**22.1**	**1172**	18.3
TSP1	**25.3**	1354	**18.6**	**26.2**	**1387**	19.0	**24.8**	**1305**	18.8
s.e.d.	*0.65*	*47.9*	*0.28*	*0.57*	*29.5*	*0.73*	*0.61*	*34.7*	*0.74*
KIE0	24.5	1329	17.9	25.2	1370	18.3	23.3	1261	18.0
KIE1	24.1	1277	18.5	25.2	1307	19.2	23.6	1217	19.0
s.e.d.	*0.66*	*48.1*	*0.28*	*0.56*	*29.6*	*0.73*	*0.61*	*34.8*	*0.74*

Table 11. Effect of the interaction between SOA and MOP on FFB yield (t/ha) in 1999-2001 and 2001 on the basis of living palms (Trial 252).

1999-2001, $lsd_{0.05}$ 4.92				2001, $lsd_{0.05}$ 4.19			
	MOP0	MOP1	MOP2		MOP0	MOP1	MOP2
SOA0	14.0	27.5	25.3	SOA0	14.8	28.7	25.1
SOA1	22.4	27.5	29.0	SOA1	22.2	27.8	31.0
SOA2	13.2	28.6	31.0	SOA2	14.6	29.5	32.9

Table 12. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 252). Also shown are the depth covariate coefficient (cm) and covariate efficiency. p values <0.05 are indicated in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	0.622	0.474	0.430	0.448	0.485	0.816	0.679	0.165	0.051	**0.039**
MOP	**0.020**	0.158	**0.050**	**<.001**	**0.002**	**0.088**	**0.034**	0.196	**0.004**	**<.001**
TSP	0.542	0.467	0.102	0.213	0.199	0.706	0.548	0.479	0.883	0.976
KIE	0.196	0.882	0.371	0.173	0.051	0.138	0.549	0.573	0.193	0.254
SOA.MOP	0.863	0.751	0.456	0.411	0.509	0.758	0.968	0.708	0.459	0.306
SOA.TSP	0.978	0.739	0.607	0.471	0.960	0.629	0.676	0.745	0.207	0.425
MOP.TSP	0.866	0.900	0.805	0.284	0.132	0.315	0.545	0.092	0.493	0.526
SOA.KIE	0.188	0.968	0.275	0.827	0.935	0.864	0.580	0.889	0.480	0.360
MOP.KIE	0.612	0.507	0.684	0.462	0.704	0.845	0.831	0.101	0.311	0.199
TSP.KIE	0.845	0.948	0.810	0.416	0.806	0.863	0.607	0.054	0.594	0.209
SOA.MOP.TSP	0.775	0.897	0.663	0.445	0.914	0.878	0.965	0.137	0.960	0.755
SOA.MOP.KIE	0.804	0.895	0.798	0.631	0.949	0.785	0.661	0.228	0.210	0.195
SOA.TSP.KIE	0.829	0.800	0.594	0.656	0.703	0.955	0.984	0.120	0.367	0.259
MOP.TSP.KIE	0.994	0.622	0.827	0.422	0.755	0.695	0.957	0.297	0.192	0.319
Soil depth	0.984	0.606	0.994	0.667	0.861	0.056	0.622	0.750	0.059	0.058
Depth coeff.	-0.001	0.004	0.000	0.001	0.000	-0.012	-0.041	0.000	-0.041	-0.017
s.e.	*0.024*	*0.006*	*0.000*	*0.002*	*0.002*	*0.004*	*0.074*	*0.001*	*0.014*	*0.006*
Effic.	*0.75*	*0.83*	*0.75*	*0.81*	*0.76*	*3.04*	*0.82*	*0.78*	*2.96*	*2.99*
CV %	9.7	7.4	3.4	6.8	16.2	9.4	14.7	4.7	10.6	15.7

Table 13. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (ppm). Values are adjusted for depth covariate (Trial 252). Significant effects (p<0.05) are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA0	6.6	2.33	0.160	0.66	0.33	1.19	13.7	0.60	3.9	**1.12**
SOA1	6.7	2.41	0.163	0.65	0.30	1.16	13.7	0.62	3.7	**1.05**
SOA2	6.9	2.42	0.164	0.64	0.30	1.13	14.3	0.63	3.2	**0.82**
s.e.d.	*0.28*	*0.074*	*0.002*	*0.019*	*0.021*	*0.046*	*0.86*	*0.012*	*0.16*	*0.066*
MOP0	**7.7**	2.67	**0.156**	**0.40**	**0.47**	**1.27**	**16.4**	0.60	**2.8**	**0.25**
MOP1	**6.2**	2.44	**0.164**	**0.75**	**0.24**	**1.13**	**13.0**	0.62	**3.7**	**1.22**
MOP2	**6.3**	2.45	**0.166**	**0.81**	**0.23**	**1.08**	**12.4**	0.62	**4.3**	**1.50**
s.e.d.	*0.30*	*0.081*	*0.003*	*0.020*	*0.023*	*0.050*	*0.94*	*0.013*	*0.18*	*0.071*
TSP0	6.7	2.36	0.160	0.64	0.32	1.15	14.1	0.61	3.6	0.99
TSP1	6.8	2.41	0.164	0.66	0.30	1.17	13.7	0.62	3.6	1.00
s.e.d.	*0.22*	*0.059*	*0.002*	*0.015*	*0.017*	*0.037*	*0.69*	*0.010*	*0.13*	*0.052*
KIE0	6.9	2.39	0.163	0.66	0.28	1.20	14.1	0.61	3.7	1.04
KIE1	6.6	2.38	0.161	0.64	0.34	1.12	13.7	0.62	3.5	0.95
s.e.d.	*0.22*	*0.059*	*0.002*	*0.015*	*0.017*	*0.037*	*0.69*	*0.010*	*0.13*	*0.053*

Table 14. Effect of interaction between SOA and MOP on leaflet N content (% DM) in 2001 (Trial 252). P = 0.751, s.e.d. = 0.1395 and l.s.d.(0.05) = 0.444. The ANOVA was adjusted for depth covariate and CV = 7.4%

	MOP0	MOP1	MOP2
SOA0	2.22	2.37	2.39
SOA1	2.33	2.42	2.49
SOA2	2.26	2.54	2.48

Table 15. Effect of interaction between SOA and MOP on rachis K content (% DM) in 2001 (Trial 252). P = 0.306, s.e.d. = 0.124 and l.s.d.(0.05) =0.393. The ANOVA was adjusted for depth covariate and CV = 15.7%

	MOP0	MOP1	MOP2
SOA0	0.21	1.52	1.63
SOA1	0.46	1.12	1.55
SOA2	0.09	1.04	1.32

Table 16. Numbers of Ganoderma-affected palms, significance (F probability values) of treatment effects on Ganoderma incidence, and covariance efficiency (for soil depth) in Trial 251. p values <0.1 are shown in bold.

	Recorded palms					Recorded + guard	
Factor	1996	1997	1998	2000	2001	1996	2001
Total affected palms	*4*	*14*	*13*	*25*	*46*	*16*	*109*
SOA	0.401	0.377	0.157	0.192	0.318	0.813	0.293
MOP	0.512	**0.096**	**0.099**	**0.067**	0.547	0.486	0.417
TSP	0.465	0.121	**0.034**	0.120	0.708	1.000	0.433
KIE	0.504	0.124	**0.078**	**0.028**	0.248	0.147	**0.094**
SOA.MOP	0.611	0.735	0.178	0.174	0.233	0.613	0.411
SOA.TSP	0.861	0.367	0.280	0.283	0.258	0.545	0.181
MOP.TSP	0.535	0.277	0.101	0.557	0.357	0.445	0.384
SOA.KIE	0.245	0.371	0.280	0.910	0.670	0.353	0.135
MOP.KIE	0.435	0.276	0.280	0.849	0.470	0.168	0.115
TSP.KIE	1.000	0.631	0.208	**0.038**	**0.057**	0.437	**0.060**
SOA.MOP.TSP	0.347	0.284	**0.060**	0.549	0.515	0.348	0.225
SOA.MOP.KIE	0.344	0.225	**0.040**	**0.090**	0.228	0.554	0.549
SOA.TSP.KIE	0.604	0.382	0.275	**0.097**	0.277	0.536	0.380
MOP.TSP.KIE	0.490	0.775	0.155	0.636	0.945	0.980	0.405
Soil depth	0.314	**0.068**	**0.015**	**0.032**	0.113	0.411	0.349
Depth. Coeff.	2.25	8.31	7.69	9.38	9.38	1.50	7.50
s.e.	*1.86*	***2.96***	***1.50***	***2.48***	*4.22*	*1.57*	*6.63*
Covar. Effic.	*1.11*	*2.71*	*7.28*	*4.34*	*1.99*	*0.98*	*1.06*

Table 17. Main effects of treatments on Ganoderma incidence (% of palms affected) in Trial 251. Some means are negative due to the effect of the soil depth covariate in the analysis. Effects with p < 0.1 are highlighted in bold.

	Recorded palms					Recorded + guard	
Factor	1996	1997	1998	2000	2001	1996	2001
SOA 0	0.14	1.56	1.51	3.69	6.31	1.03	7.14
SOA 1	0.53	3.69	3.14	3.66	8.38	1.39	8.58
SOA 2	1.43	2.06	2.13	5.66	9.31	1.31	9.53
s.e.d.	*1.00*	*1.59*	*0.81*	*1.33*	*2.27*	*0.84*	*1.58*
TSP 0	0.91	3.31	**3.01**	4.98	7.06	1.22	7.53
TSP 1	0.49	1.56	**1.51**	3.70	8.94	1.22	9.31
s.e.d.	*0.84*	*1.33*	***0.68***	*1.12*	*1.90*	*0.71*	*1.32*
MOP 0	1.51	**3.81**	**3.69**	**4.57**	9.75	1.47	9.25
MOP 1	1.05	**5.25**	**3.68**	**7.34**	9.44	1.86	9.75
MOP 2	-0.48	**-1.75**	**-0.60**	**1.11**	4.75	0.36	6.25
s.e.d.	*1.13*	***1.81***	***0.91***	***1.51***	*2.57*	*0.96*	*1.79*
KIE 0	0.63	2.31	**1.73**	**4.88**	7.69	1.58	**8.97**
KIE 1	0.76	2.56	**2.79**	**3.80**	8.31	0.89	**7.83**
s.e.d.	*1.05*	*1.68*	***0.85***	***1.41***	*2.39*	*0.89*	***1.66***

Table 18. Numbers of Ganoderma-affected palms, significance (F probability values) of treatment effects on Ganoderma incidence, and covariance efficiency (for soil depth) in Trial 252. p values <0.1 are shown in bold.

	Recorded palms					Recorded + guard	
Factor	1996	1997	1998	2000	2001	1996	2001
Total affected palms	*0*	*18*	*29*	*33*	*35*	*4*	*66*
SOA	-	0.336	**0.075**	0.202	**0.050**	0.582	**0.042**
TSP	-	0.654	0.139	0.164	**0.006**	1.000	**0.048**
MOP	-	0.664	0.149	0.417	**0.007**	0.175	**0.010**
KIE	-	1.000	**0.023**	0.187	**0.013**	1.000	**0.008**
SOA.TSP	-	0.492	**0.067**	0.310	**0.011**	1.000	**0.028**
SOA.MOP	-	0.818	0.140	0.723	0.113	0.504	**0.074**
TSP.MOP	-	0.341	0.585	0.617	**0.097**	1.000	0.375
SOA.KIE	-	0.443	**0.085**	0.395	**0.033**	1.000	**0.019**
TSP.KIE	-	0.412	**0.076**	0.368	**0.050**	1.000	1.000
MOP.KIE	-	0.583	0.143	0.503	0.256	1.000	**0.029**
SOA.TSP.MOP	-	0.243	**0.030**	0.195	**0.015**	1.000	**0.016**
SOA.TSP.KIE	-	0.850	0.460	0.929	**0.054**	0.138	**0.009**
SOA.MOP.KIE	-	0.279	**0.027**	0.185	**0.013**	1.000	**0.008**
TSP.MOP.KIE	-	0.314	**0.040**	0.417	0.124	1.000	**0.011**
Soil depth	-	0.104	**0.009**	0.251	**0.041**	**0.085**	**0.009**
Depth. Coeff.	0.00	-3.75	-5.75	-2.75	-2.13	-0.97	-6.25
s.e.	*0.00*	*1.63*	***0.96***	*1.92*	***0.62***	***0.38***	***1.02***
Covar. Effic.	-	*2.08*	*9.66*	*1.25*	*3.72*	*2.35*	*10.09*

Table 19. Main effects of treatments on Ganoderma incidence (% of palms affected) in Trial 252. Some means are negative due to the effect of the soil depth covariate in the analysis. Significant ($p<0.05$) effects are highlighted in bold.

	Recorded palms					Recorded + guard	
Factor	1996	1997	1998	2000	2001	1996	2001
SOA 0	0.00	2.25	**4.70**	4.13	**5.08**	0.18	**5.14**
SOA 1	0.00	3.19	**4.29**	5.25	**6.30**	0.48	**4.46**
SOA 2	0.00	3.94	**6.11**	7.75	**6.85**	0.26	**5.68**
s.e.d.	*0.00*	*1.88*	***1.11***	*2.23*	***0.72***	*0.44*	***0.53***
TSP 0	0.00	3.25	5.60	7.13	**7.88**	0.31	**5.56**
TSP 1	0.00	3.00	4.47	4.31	**4.28**	0.31	**4.62**
s.e.d.	*0.00*	*1.51*	*0.89*	*1.78*	***0.57***	*0.35*	***0.42***
MOP 0	0.00	5.56	8.91	8.81	**10.69**	0.36	**8.67**
MOP 1	0.00	3.31	5.00	5.88	**5.33**	0.98	**4.78**
MOP 2	0.00	0.50	1.19	2.50	**2.21**	-0.41	**1.83**
s.e.d.	*0.00*	*2.05*	*1.21*	*2.43*	***0.78***	*0.48*	***0.57***
KIE 0	0.00	3.13	**7.30**	7.44	**7.77**	0.31	**6.65**
KIE 1	0.00	3.13	**2.77**	4.00	**4.38**	0.31	**3.53**
s.e.d.	*0.00*	*1.51*	***0.89***	*1.79*	***0.57***	*0.35*	***0.42***

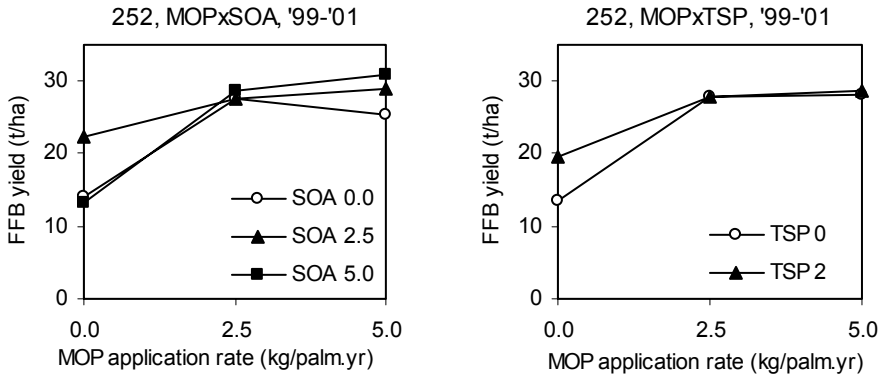


Figure 1. Effects of the MOP x SOA interaction and MOP x TSP interaction on FFB yield (t/ha) over the 1999-2001 period (Trial 252).

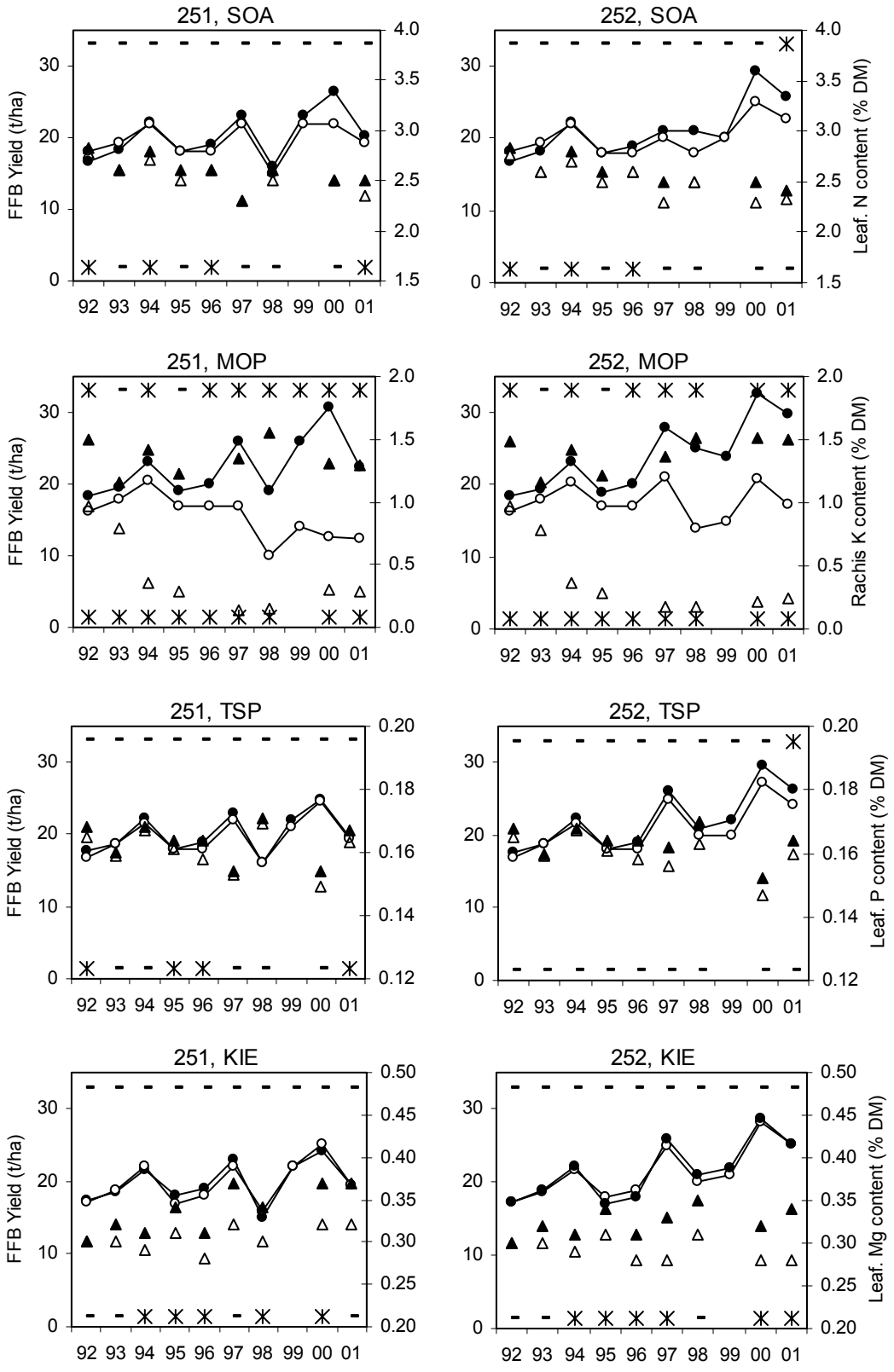


Figure 2. Main effects of SOA, MOP, TSP and kieserite over the course of Trial 252. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

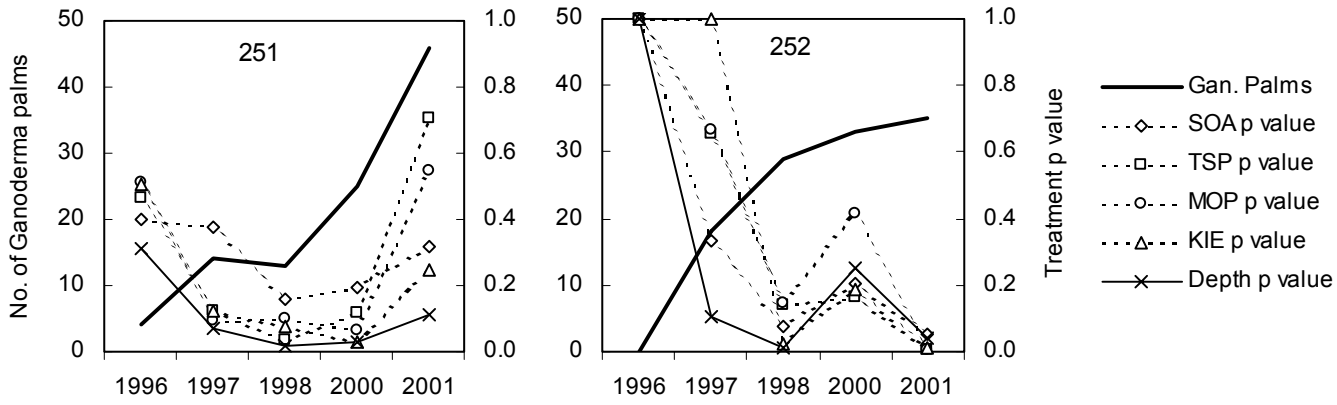


Figure 3. Number of Ganoderma-affected palms (out of 576 recorded palms) and significance of treatment main effects and soil depth covariate over the 1996-2001 period in Trials 251 and 252.

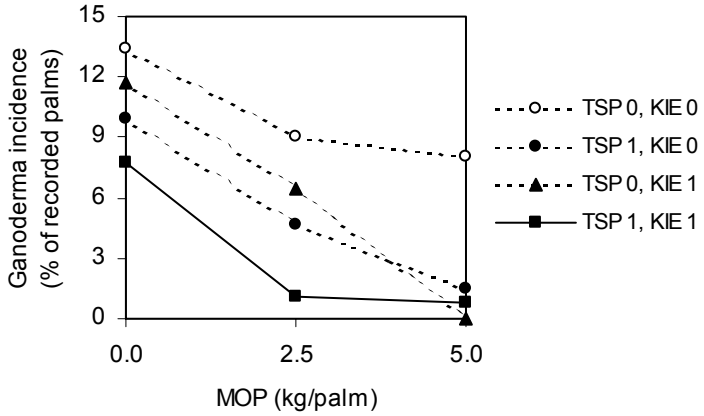


Figure 4. Combined effects of MOP, TSP (0 and 2 kg/palm.yr) and kieserite (0 and 2 kg/palm.yr) on Ganoderma incidence in Trial 252 in 2001.

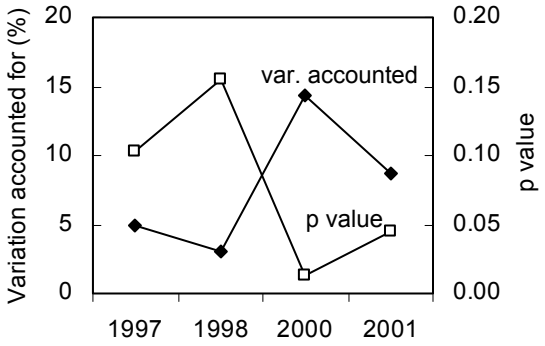


Figure 5. Parameters of linear regression between Ganoderma incidence (recorded palms) and east-west position over the 1997-2001 period.

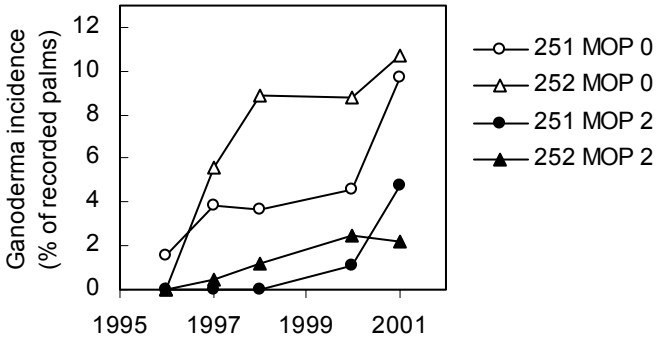


Figure 6. Main effect of MOP application (0 or 5 kg/palm.yr) on Ganoderma incidence in both trials over the 1996-2001 period.

Trial 254 Boron Trial at Poliamba

PURPOSE

To provide information that will help make recommendations for B fertiliser use at Poliamba. Specifically, to test response to Ca borate or Na borate at several rates, and secondarily, to test the interaction of B source and rate with adequate and high applications of the major deficient nutrient, K.

SITE and PALMS

Site: Maramakas Plantation, Nalik Estates, Division 2, Blocks 1, 2 and 3
Soils: Reddish brown clay soil overlying raised coral and showing great variability in depth. The soils are shallow on terrace margins and low ridges and moderately deep in depressions. The soil is generally freely draining except in depressions where soils can remain wet below 50 cm depth.
Topography: Gently undulating, depressions or sink holes. Back swamp at the edge of block 3.
Land use prior to this crop: Coconut plantation, and virgin forest on inland blocks
Palms: Dami commercial DxP crosses, planted in 1989 at 128 palms/ha

BACKGROUND

Boron has been a matter of concern at Poliamba right from the beginning, largely based on foliar symptoms. The need for a trial was discussed at Scientific Advisory Committee meetings from 1998-2001. In addition to foliar deficiency symptoms, there has also been a suppression in leaf B levels upon K addition. Levels at around 12 ppm in frond 17 are generally considered to be marginal, and as frond 17 is not particularly sensitive would speculate that the depression in younger fronds may be even greater. There is also concern about oil extraction rate, which has dropped in recent years.

DESIGN

A factorial design, with Ca borate or Na borate applied at 3 levels (0, 1 and 2 kg B/ha.year), and potassium chloride (MOP) applied at two levels (2.5, 5 kg MOP/palm.year). ie. 2 B sources x 3 B rates x 2 MOP rates, with 4 replicates = 48 plots. Completely randomised design, with pre-treatment measurements or other measurements used as covariates if necessary. The trial will receive a blanket application of 2 kg SOA/palm.year or equivalent.

PROGRESS

Plot marking has been completed and soil samples taken for analysis. Soil depths are being measured. Treatments and recording will commence in 2002.

AGRONOMY TRIALS IN WEST NEW BRITAIN PROVINCE

(P. Nelson, T. Betitis)

Trial 125 Sources of Nitrogen Fertiliser Trial, Kumbango Plantation

PURPOSE

To investigate the relative effects of different types of nitrogen fertiliser available in PNG, on oil palm. Of particular interest is the effect of the various nitrogen fertilisers on potassium and magnesium nutrition. The results of the trial will be used in formulating fertiliser recommendations.

SITE and PALMS

Site: Kumbango Plantation, Division II, Fields c4, c5 or c6
Soil: Young coarse textured freely draining soils formed on alluvially redeposited andesitic pumiceous sands and gravel with intermixed volcanic ash.
Palms: Dami commercial DxP crosses. Planted in April & May 1993 at 135 palms/ha.

DESIGN

There are 15 fertiliser treatments comprising of 5 fertilisers at 3 rates (Table 1). The 15 treatments are replicated four times in a randomised complete block design. Four control plots (zero fertiliser application) are located on the edge of the trial. Yield is recorded in these plots, but the data is not used in the analysis of variance. The mean yield from the control plots will be reported in the table of means as a comparison with the fertiliser treatments. 36 palm plots (6x6 palms) are used, the central 16 palms are recorded and the outer 20 palms are guard row palms.

Table 1. Treatments used in Trial 125

	Amounts (kg/palm.year)		
	Level 1	**Level 2**	**Level 3**
g N/palm.year	*520*	*1040*	*2080*
Ammonium chloride (AMN)	2.0	4.0	8.0
Ammonium sulphate (SOA)	2.6	5.2	10.3
Urea	1.2	2.4	4.7
Ammonium nitrate (AMN)	1.5	2.9	5.8
Di-ammonium phosphate (DAP)	3.0	6.0	12.0

Each rate of fertiliser at the same level contains the same amount of nitrogen. Treatments were first applied in June 1997 after pre-treatment yield data had been collected. Plot isolation trenches were completed prior to the first application of treatments. Until this time the palms had received a standard immature palm fertiliser input. Treatments are applied in 2 doses per year. Frond 17 leaflet, and rachis cross-section sampling were carried out prior to treatments being applied. This trial is the same design as Trials 324 and 325 in Oro Province.

RESULTS

The main effect of fertiliser rate on yield was significant ($p<0.05$) in 2001. Yield was highest at rate 2, due mainly to the effect on bunch numbers (Tables 2 and 3). However, neither the effect of fertiliser type nor the interaction between type and rate was significant (Tables 2 and 3). Nevertheless, the interaction is shown in Table 4 to illustrate that there was a slight difference between the treatments. The increase in yield between rates 1 and 2 was greatest for AMC and DAP (4-5 t/ha), and AMC appeared to show a continuing increase in yield between rate 2 and 3. The last time significant effects

were recorded for this trial was in 1998, when AMC and AMN both increased yields by about 3 t/ha between rate 1 and 3. Yields at rate 1 did not appear to be different from yields in the control plots (Table 3).

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 125). p values <0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Rate	**0.056**	0.140	0.907	**0.034**	**0.060**	0.982
Type	0.541	0.746	0.935	0.674	0.744	0.818
Rate.Type	0.952	0.968	0.636	0.204	0.551	0.331
CV %	*8.1*	*11.0*	*6.6*	*14.9*	*14.8*	*8.8*

Table 3. Main effects of treatments on FFB yield (t/ha) and its components (Trial 125). Effects with p<0.05 are shown in bold. The control values were not used in the ANOVA.

	1999-2001			2001		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Control	29.5	1887	15.8	28.9	1700	17.3
sd	*1.5*	*110*	*0.6*	*3.5*	*256*	*1.1*
Rate 1	28.7	1745	16.8	**28.3**	1606	18.1
Rate 2	30.3	1859	16.7	**31.6**	1776	18.2
Rate 3	28.6	1754	16.8	**28.4**	1615	18.2
s.e.d.	*0.7*	*62*	*0.3*	*1.4*	*78*	*0.5*
AMC	30.2	1836	16.9	31.2	1748	18.4
SOA	29.1	1788	16.7	28.9	1631	18.1
Urea	29.2	1812	16.5	29.0	1677	17.7
AMN	28.7	1745	16.8	29.1	1640	18.4
DAP	28.8	1749	16.8	29.2	1632	18.2
s.e.d.	*1.0*	*81*	*0.5*	*1.8*	*101*	*0.7*

Table 4. Effect of interaction between fertiliser type and rate on FFB yield (t/ha) in 2001 (Trial 125). The interaction was not significant. $Lsd_{0.05}$ = 6.2.

	AMC	SOA	Urea	AMN	DAP
Rate 1	27.9	30.8	26.7	29.5	26.7
Rate 2	32.4	31.1	30.1	32.5	31.9
Rate 3	33.2	24.7	30.1	25.3	28.9

CONCLUSION

In 2001, yield was highest at an N rate of 1 kg N/palm.year. Of the five N fertilisers examined, AMC appears to have the greatest effect on yield.

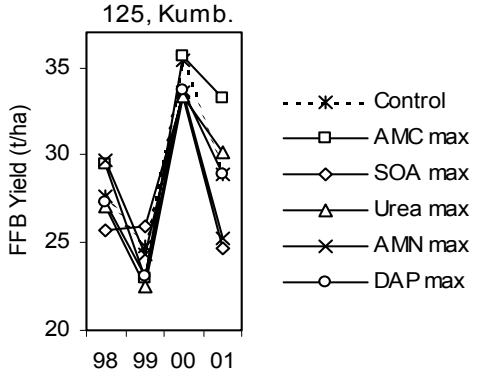


Figure 1. Effect of different N fertilisers (at rates equivalent to 2.08 kg N/palm.year) on yield in Trial 125

Trial 126 Factorial Fertiliser Trial, Malilimi

PURPOSE

To provide fertiliser response information that will be useful in developing strategies for fertiliser usage. This trial was also designed to investigate further the yield responses seen in Trial 119, i.e. was the response due to potassium or chlorine?

SITE and PALMS

Site Malilimi Plantation
Soil: Young coarse textured freely draining soils formed on alluvially redeposited andesitic pumiceous sand and volcanic ash. Palaeosols are common.
Palms: Dami commercial DxP crosses. Planted in 1985 at 135 palms/ha.

DESIGN

There are 72 treatments comprising all factorial combinations of ammonium sulphate (SOA), potassium sulphate (SOP), each at three levels, and triple superphosphate (TSP), kieserite (KIE) and sodium chloride (NaCl), each at two levels (Table 1). The 72 treatments are replicated only once and are divided among two blocks. The 3 factor interaction '2x2x2' is confounded with blocks. Third and higher order interactions provide the error term in the statistical analysis. Each of the 72 plots consists of 36 palms (6x6) of which the central 16 palms are recorded and the outer 20 palms are regarded as guard row palms.

Table 1. Fertiliser rates in Trial 126.

Fertiliser	Amounts (kg/palm.year)		
	Level 0	Level 1	Level 2
Ammonium sulphate (SOA)	0	3	6
Potassium sulphate (SOP)	0	3	6
Triple superphosphate (TSP)	0	4	-
Kieserite (KIE)	0	4	-
Sodium chloride (NaCl)	0	4	-

Note: Treatments are factorial combinations of levels of these fertilisers.

The ammonium sulphate and potassium sulphate are split into two applications per year, while the other fertilisers are applied once per year.

This trial was approved in the PNGOPRA Scientific Advisory Board meeting in November 1993. Site selection, a detailed site survey and site mapping was carried out in May and June 1994. Plot selection was carried out in June 1994. Pre-treatment yield recording commenced in 1995. Experimental fertiliser treatments started in July 1996. Plot isolation trenches were dug prior to commencement of treatments. Fertilisers are applied in 2 doses per year.

RESULTS

SOA and TSP consistently and significantly ($p<0.05$) increased yield in this trial (by 2.6 and 1.6 t/ha respectively), irrespective of the other treatments. Maximum yield was reached at an application of 3 kg/palm.year of SOA, with no further benefit at the higher rate. NaCl significantly increased bunch size, and the corresponding effect on yield was almost significant in 2001 (Tables 2 and 3). The effect of SOA on yield was related to increased leaf N and P contents, and leaf Mg and Ca contents. TSP increased leaf P content, and NaCl increased leaf Ca and Cl and rachis K contents (Tables 4 and 5). All of these nutrients were in the range generally accepted to be deficient, except for Ca and Cl. Therefore, the effects of the fertilisers on yield were most likely related to their effects on tissue N, P, K and Mg contents. The interaction between TSP and KIE had a significant effect on bunch numbers and yield in the 1999-2001 period (Table 2), and this was related to contents of several nutrients in the tissues. Application of either TSP or KIE increased yield and leaf P and rachis K contents in a similar way (Table 6). SOP had no significant effects on yield, despite a large effect on rachis K levels. The only other fertiliser to significantly influence rachis K content was NaCl.

The main effects of the treatments on yield and tissue nutrient contents over time are shown in Fig. 1. The effect of SOA on yield and leaf N content is increasing with time, as leaf N content with no SOA declines. The effects of the other fertilisers have been fairly consistent with time. Tissue contents of P and Cl also appear to be declining.

CONCLUSION

The main treatment effect in this trial is the positive and increasing effect of SOA on yield.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 126). p values less than 0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.044**	0.827	**0.007**	**0.033**	0.390	**0.021**
SOP	0.400	0.203	0.420	0.314	0.140	0.298
TSP	**0.033**	0.679	**0.016**	**0.068**	0.526	**0.031**
KIE	0.073	0.365	0.210	0.950	0.926	0.799
NaCl	0.220	0.769	**0.021**	0.116	0.977	**0.008**
SOA.SOP	0.794	0.963	0.718	0.554	0.847	0.455
SOA.TSP	0.586	0.765	0.797	0.415	0.372	0.879
SOP.TSP	0.520	0.500	0.551	0.456	0.507	0.759
SOA.KIE	0.923	0.797	0.460	0.678	0.844	0.249
SOP.KIE	0.738	0.710	0.174	0.363	0.829	0.515
TSP.KIE	**0.019**	0.548	**0.014**	0.391	0.532	**0.003**
SOA.NaCl	0.860	0.840	0.363	0.552	0.269	0.701
SOP.NaCl	0.578	0.865	0.921	0.581	0.390	0.897
TSP.NaCl	0.234	0.312	0.720	0.918	0.845	0.615
KIE.NaCl	0.809	0.853	0.709	0.752	0.721	0.639
SOA.SOP.TSP	0.598	0.705	0.399	0.444	0.536	0.320
SOA.SOP.KIE	0.636	0.733	0.867	0.469	0.418	0.596
SOA.TSP.KIE	0.345	0.229	0.432	0.207	0.108	0.739
SOP.TSP.KIE	0.585	0.528	0.460	0.362	0.640	0.295
SOA.SOP.NaCl	0.230	0.868	0.201	**0.082**	0.481	0.123
SOA.TSP.NaCl	0.565	0.603	0.343	0.483	0.587	0.608
SOP.TSP.NaCl	0.377	0.476	**0.056**	0.114	0.113	0.102
SOA.KIE.NaCl	0.168	0.329	0.982	**0.054**	**0.024**	0.948
SOP.KIE.NaCl	0.479	0.618	0.661	0.486	0.861	0.461
TSP.KIE.NaCl	0.810	0.431	0.408	0.659	0.742	0.841
CV %	*9.3*	*10.9*	*6.6*	*13.0*	*12.3*	*7.8*

Table 3. Main effects of treatments on FFB yield and its components (Trial 126). Effects with p<0.1 are shown in bold.

	1999-2001			2001		
	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
SOA0	**26.9**	1105	**24.7**	**25.2**	1090	**23.4**
SOA1	**28.5**	1126	**25.7**	**27.8**	1143	**24.6**
SOA2	**28.7**	1110	**26.5**	**27.5**	1131	**25.0**
sed	*0.8*	*35*	*0.5*	*1.0*	*40*	*0.5*
SOP0	28.1	1137	25.3	26.4	1128	23.9
SOP1	28.5	1127	25.8	27.7	1159	24.3
SOP2	27.5	1077	25.9	26.4	1077	24.8
sed	*0.8*	*35*	*0.5*	*1.0*	*40*	*0.5*
TSP0	**27.3**	1108	**25.1**	**26.0**	1111	**23.8**
TSP1	**28.7**	1120	**26.2**	**27.6**	1132	**24.8**
sed	*0.6*	*29*	*0.4*	*0.8*	*33*	*0.4*
KIE0	27.4	1100	25.4	26.8	1120	24.3
KIE1	28.7	1127	25.9	26.8	1123	24.4
sed	*0.6*	*29*	*0.4*	*0.8*	*33*	*0.4*
NaCl0	27.6	1118	**25.2**	26.1	1121	**23.7**
NaCl1	28.4	1109	**26.2**	27.5	1122	**25.0**
sed	*0.6*	*29*	*0.4*	*0.8*	*33*	*0.4*

Table 4. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 126). p values less than 0.1 are indicated in bold.

	Leaflet								Rachis	
Source	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	0.336	**0.001**	**0.027**	0.127	**0.003**	**<.001**	0.201	**0.093**	0.128	0.402
SOP	0.624	0.304	0.569	0.385	0.724	0.278	0.564	0.582	**<.001**	**<.001**
TSP	0.155	0.158	**0.080**	0.142	0.140	0.515	0.432	0.144	0.499	0.794
KIE	**0.073**	0.430	**0.058**	0.821	**0.001**	**0.021**	0.840	0.605	0.709	0.652
NaCl	**0.007**	0.430	0.777	**0.061**	0.140	**0.047**	0.183	**<.001**	**0.026**	**0.046**
SOA.SOP	**0.072**	0.211	0.172	0.803	0.632	0.768	0.393	0.038	0.260	0.657
SOA.TSP	0.518	0.779	0.654	0.468	**0.069**	0.348	0.632	0.150	0.162	0.384
SOP.TSP	0.834	0.582	0.787	0.488	0.822	0.394	0.893	0.775	**0.004**	0.218
SOA.KIE	0.524	0.432	0.892	0.623	**0.098**	**0.057**	0.828	0.922	**0.052**	0.400
SOP.KIE	0.553	0.695	0.532	0.265	0.456	0.101	0.393	0.407	0.232	0.408
TSP.KIE	0.611	0.720	0.701	**0.003**	0.633	**0.004**	0.893	**<.001**	**<.001**	**0.081**
SOA.NaCl	0.312	0.723	0.648	0.570	0.368	0.174	0.782	0.578	0.717	0.851
SOP.NaCl	0.923	0.660	0.256	0.832	0.179	0.171	0.580	0.287	0.129	0.375
TSP.NaCl	**0.094**	0.938	0.960	0.763	**0.005**	**0.075**	0.650	0.300	0.568	0.687
KIE.NaCl	0.312	0.263	**0.010**	0.707	0.750	0.862	0.027	0.392	**0.055**	0.321
SOA.SOP.TSP	0.569	0.987	0.642	0.403	0.683	0.212	0.955	**0.049**	**0.019**	0.371
SOA.SOP.KIE	0.682	0.936	0.589	0.265	0.457	0.924	0.446	0.121	**0.022**	0.172
SOA.TSP.KIE	0.172	0.772	0.597	0.568	0.191	0.485	0.698	0.628	**0.051**	0.146
SOP.TSP.KIE	0.824	0.196	0.169	0.628	0.789	0.317	0.856	0.760	0.565	0.747
SOA.SOP.NaCl	0.963	0.798	0.914	0.424	0.793	0.315	0.563	0.682	0.304	0.428
SOA.TSP.NaCl	0.610	0.673	0.518	0.939	0.885	0.757	0.453	0.400	**0.074**	0.168
SOP.TSP.NaCl	0.741	0.725	0.651	**0.015**	0.531	0.190	0.786	0.534	0.285	0.267
SOA.KIE.NaCl	0.938	0.794	0.438	0.422	0.283	0.225	0.725	**0.065**	**0.012**	**0.060**
SOP.KIE.NaCl	0.568	0.758	0.544	0.547	0.262	0.329	0.738	0.618	**0.050**	0.365
TSP.KIE.NaCl	0.933	0.467	0.726	0.125	**0.012**	0.264	**0.054**	0.119	0.358	0.211
CV %	*4.2*	*6.9*	*5.0*	*8.7*	*20.0*	*10.2*	*10.2*	*24.3*	*6.8*	*12.3*

Table 5. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (mg/kg) (Trial 126). Effects with p<0.1 are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA0	15.2	**2.05**	**0.135**	0.69	**0.165**	**0.92**	13.8	**0.39**	4.2	1.20
SOA1	15.3	**2.21**	**0.139**	0.71	**0.136**	**0.86**	13.8	**0.34**	4.0	1.16
SOA2	15.0	**2.21**	**0.141**	0.73	**0.136**	**0.80**	13.2	**0.35**	4.1	1.22
sed	*0.2*	*0.04*	*0.002*	*0.02*	*0.008*	*0.03*	*0.4*	*0.03*	*0.1*	*0.04*
SOP0	15.0	2.18	0.138	0.70	0.149	0.85	13.7	0.38	**4.0**	**1.09**
SOP1	15.2	2.17	0.139	0.71	0.142	0.84	13.4	0.36	**4.0**	**1.20**
SOP2	15.2	2.12	0.137	0.72	0.147	0.88	13.8	0.35	**4.3**	**1.29**
sed	*0.2*	*0.04*	*0.002*	*0.02*	*0.008*	*0.03*	*0.4*	*0.03*	*0.1*	*0.04*
TSP0	15.3	2.13	**0.137**	0.72	0.151	0.85	13.7	0.35	4.1	1.19
TSP1	15.0	2.18	**0.140**	0.70	0.141	0.87	13.5	0.38	4.1	1.20
sed	*0.2*	*0.04*	*0.002*	*0.01*	*0.007*	*0.02*	*0.3*	*0.02*	*0.1*	*0.03*
KIE0	**15.3**	2.14	**0.137**	0.71	**0.133**	**0.85**	13.6	0.37	4.1	1.19
KIE1	**15.0**	2.17	**0.140**	0.71	**0.159**	**0.87**	13.6	0.36	4.1	1.20
sed	*0.2*	*0.04*	*0.002*	*0.01*	*0.007*	*0.02*	*0.3*	*0.02*	*0.1*	*0.03*
NaCl0	**15.4**	2.17	0.139	**0.72**	0.141	**0.84**	13.8	**0.32**	**4.0**	**1.16**
NaCl1	**14.9**	2.14	0.138	**0.70**	0.151	**0.88**	13.4	**0.40**	**4.2**	**1.23**
sed	*0.2*	*0.04*	*0.002*	*0.01*	*0.007*	*0.02*	*0.3*	*0.02*	*0.1*	*0.03*

Table 6. Effect of the interaction between TSP and KIE on yield and some tissue nutrient contents in 2001 (Trial 126).

Yield (t/ha) * lsd=1.8			Leaf P (%) ** lsd=0.005			Leaf Mg (%) ns lsd=0.020		
	KIE0	KIE1		KIE0	KIE1		KIE0	KIE1
TSP0	26.0	28.7	TSP0	0.135	0.139	TSP0	0.140	0.162
TSP1	28.9	28.5	TSP1	0.138	0.141	TSP1	0.126	0.155
Leaf Ca (%) ** lsd=0.06			Leaf Cl (%) *** lsd=0.06			Rachis K (%) ns lsd=0.10		
	KIE0	KIE1		KIE0	KIE1		KIE0	KIE1
TSP0	0.84	0.86	TSP0	0.30	0.39	TSP0	1.15	1.23
TSP1	0.92	0.81	TSP1	0.43	0.32	TSP1	1.22	1.17

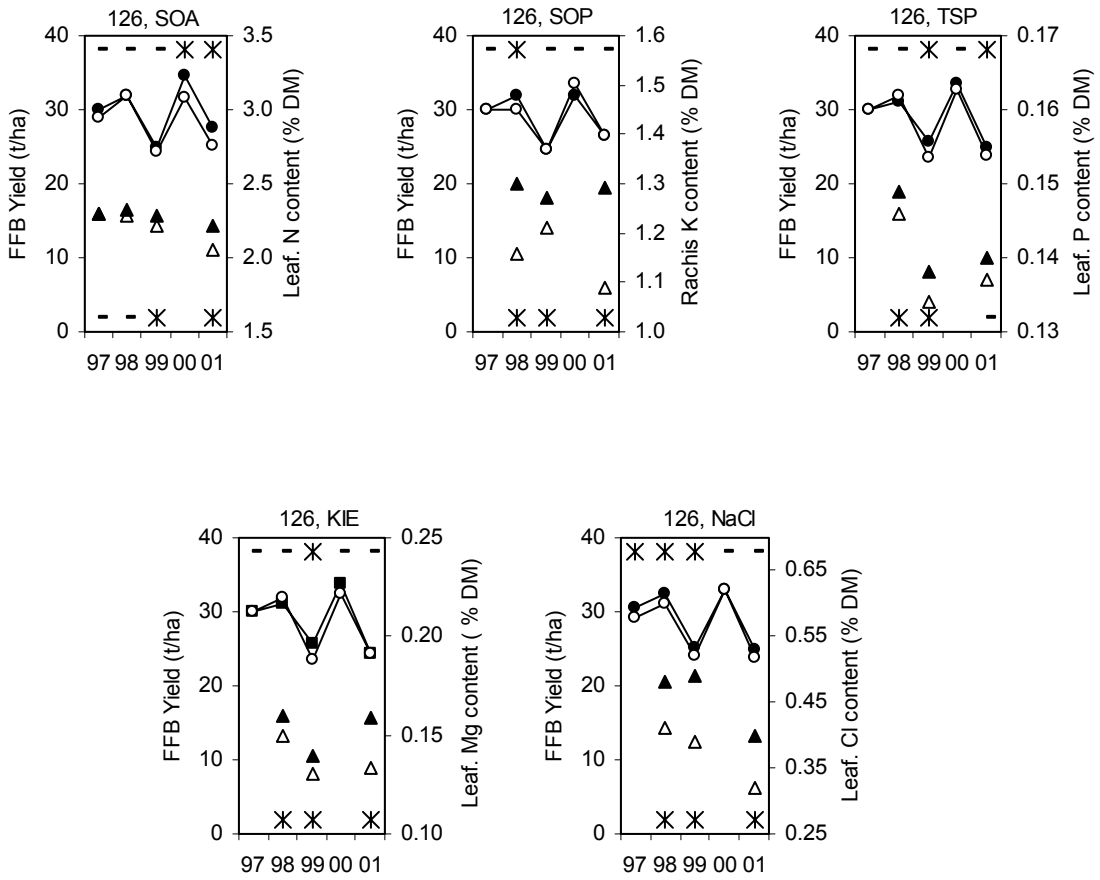


Figure 1. Main effects of SOA, SOP, TSP, KIE and NaCl over the course of Trial 126. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Trial 129 Crop Residue and Fertiliser Placement Trial, Kumbango

PURPOSE

To determine the effect of placing fertiliser on the weeded circle, frond pile or EFB.

SITE and PALMS

Site: Kumbango Plantation, Division 1
Soil: Young coarse textured freely draining soils formed on alluvially redeposited andesitic pumiceous sands and gravel with intermixed volcanic ash.
Palms: Dami commercial DxP crosses.
Planted in October 1994 at 135 palms/ha.

DESIGN

The trial was designed by biometricians from IACR - Rothamsted and the Pacific Regional Agricultural Program as a replacement for Trial 122 in 1998 replantings. There are in fact two separate trials side by side but the results will be reported together.

In Trial 129a there are two EFB treatments (nil & 50 t/ha.yr). The EFB is applied on either side of the harvest path as per normal plantation practice. A standard fertiliser treatment of ammonium chloride (AMC) and kieserite (KIE) is applied to all plots receiving fertiliser. The fertiliser is applied on either the weeded circle or on the frond pile. The six treatments (Table 1) are arranged in a randomised complete block design with 4 replicates.

Table 1. Treatments in Trial 129a

Treatment Number	Crop Residue	Fertiliser Applied (kg/palm.yr)	Fertiliser Placement
1	EFB	3 kg AMC & 3 kg KIE	Weeded Circle
2	EFB	3 kg AMC & 3 kg KIE	Frond Pile
3	EFB	Nil	-
4	Nil	3 kg AMC & 3 kg KIE	Weeded Circle
5	Nil	3 kg AMC & 3 kg KIE	Frond Pile
6	Nil	Nil	-

In Trial 129b all plots receive EFB at a rate of 50 t/ha.yr. A standard fertiliser treatment of ammonium chloride and kieserite is applied to all plots receiving fertiliser. The fertiliser is applied on the weeded circle, the frond pile or the EFB (Table 2). The four treatments are arranged in a randomised complete block design with 8 replications.

Table 2. Treatments in Trial 129b.

Treatment Number	Crop Residue	Fertiliser Applied (kg/palm/yr)	Fertiliser Placement
1	EFB	3 kg AMC & 3 kg KIE	Weeded Circle
2	EFB	3 kg AMC & 3 kg KIE	Frond Pile
3	EFB	3 kg AMC & 3 kg KIE	EFB
4	EFB	Nil	-

RESULTS

The year 2001 was the third year of yield recording for trial 129. Results of trial a and b were analysed together for the 2001 and 1999-2001 periods (Table 3). Similar to last years results, there is not yet any significant effect of fertiliser application or placement on yield (Table 4). However, fertiliser placement had a significant effect on tissue cation contents. Leaf Mg content was highest where fertiliser was applied to the frond pile or EFB (Table 5). As far as tissue Mg content is concerned, application of fertiliser to the weeded circle was the same as no application at all. Rachis K was also influenced by the treatments, but in a different way. Application of either fertiliser or EFB increased rachis K content, but where fertiliser was added, application to the weeded circle was most effective in raising rachis K content. These results suggest that Mg was being retained and released more effectively when applied to zones high in organic matter content. That result is consistent with the cation exchange chemistry of the Kumbango soils (Gillman, 2001). Their cation exchange sites are swamped with Ca, with exchangeable Ca contents greater than the CEC throughout the profile, and Ca/Mg ratios of 13 (0-30 cm depth) to 9 (30-130 cm depth). The additional organic CEC under frond piles and EFB may improve the retention and release of Mg.

CONCLUSION

There is not yet any effect of fertiliser application and placement on yield in this trial, but effects on tissue Mg and K contents are starting to become apparent.

Table 3. Analysis structure for results in this report (Trial 129)

Treatment no.	EFB	AMC & KIE	Placement	No. of reps	Code
1	0	0	0	4	0 0
2	0	1	Weeded circle	4	0 Weed
3	0	1	Frond pile	4	0 Frond
4	1	0	0	12	1 0
5	1	1	Weeded circle	12	1 Weed
6	1	1	Frond pile	12	1 Frond
7	1	1	EFB	12	1 EFB

Table 4. Effects of treatments on FFB yield and its components (Trial 129). Effects with p<0.1 are shown in bold.

	1999-2001			2001		
Treat. Code	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
0 0	30.0	2121	14.4	29.8	1835	16.8
0 Weed	31.0	2181	14.7	28.9	1856	16.2
0 Frond	30.4	2239	13.9	28.5	1827	15.9
1 0	30.7	2335	13.5	30.7	2099	15.2
1 Weed	30.0	2232	13.9	28.9	1919	15.7
1 Frond	30.5	2219	14.1	29.6	1927	16.0
1 EFB	30.4	2282	13.7	29.3	1992	15.2
p	0.679	0.306	0.370	0.526	**0.081**	0.116
sed	0.68	94	0.53	1.34	**111**	0.62
lsd	1.37	189	1.07	2.68	**223**	0.62
CV %	3.9	7.2	6.6	7.8	9.8	6.8

Table 5. Effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (mg/kg) (Trial 129). p values <0.1 are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
0 0	13.5	2.54	0.154	0.76	0.145	0.81	16.2	0.60	4.8	1.73
0 Weed	14.7	2.52	0.149	0.75	0.140	0.82	14.3	0.62	5.5	1.96
0 Frond	14.4	2.53	0.156	0.74	0.163	0.90	14.5	0.64	5.5	1.89
1 0	14.3	2.57	0.155	0.78	0.143	0.86	14.8	0.58	5.5	1.90
1 Weed	14.5	2.61	0.157	0.76	0.149	0.85	14.6	0.61	5.6	1.92
1 Frond	14.6	2.56	0.157	0.75	0.163	0.90	16.1	0.62	5.6	1.88
1 EFB	14.7	2.57	0.159	0.78	0.166	0.92	15.6	0.63	5.4	1.79
p	**0.099**	0.343	0.223	0.614	**0.012**	**0.041**	0.245	0.130	**0.019**	**0.028**
sed	**0.38**	0.04	0.003	0.03	**0.010**	**0.04**	1.0	0.02	**0.2**	**0.07**
lsd	**0.76**	0.09	0.007	0.06	**0.019**	**0.08**	2.1	0.05	**0.42**	**0.14**
CV %	4.5	2.9	3.8	6.7	10.8	7.5	11.7	6.5	6.6	6.3

Trial 132 Factorial Fertiliser Trial at Haella Plantation

PURPOSE

To determine, in the presence of adequate N, the responses to other nutrients, to guide fertiliser recommendations in this area.

BACKGROUND

This trial was approved at the 1997 SAC meeting. Several changes in design followed. In 1999 the design was changed to a 2^4 factorial with two rates of N, P, K, Mg and B. 48 plots had been marked out. Following the 2001 SAC meeting the design was changed to a 2^3 factorial, described below.

SITE and PALMS

Haella Plantation, Division 2, Field I-3, Avenue 10, Road 6-7
Soil: Freely draining alluvial deposits of fine textured volcanic ash over coarse pumiceous volcanic ash.
Topography: Flat with occasional depressions
Land use prior to this crop: Forest
Palms: Dami commercial DxP crosses
Planted in 1995 at 128 palms/ha

DESIGN

A factorial trial with two rates of triple superphosphate (TSP), potassium chloride (MOP), kieserite and borax (Table 1), and 2 replicates, resulting in 32 plots. The plots were chosen out of the 48 previously marked out by rejecting those that had extremely low or high WxT measurements. A blanket application of ammonium chloride (AMC) of 5 kg/palm.year will be applied across the trial. All fertiliser applications are made in 2 doses per year.

Table 1. Fertiliser rates (kg/palm.year) in trial 132.

	Level 0	Level 1
TSP	0	4
MOP	0	4
Kieserite	0	4
Borax	0	0.1

PROGRESS

Treatments commenced in October 2001. Tissues and soils have also been sampled.

Trial 135 Effect of Fertiliser on Incidence and Severity of Crown Disease, Garu and Kumbango Plantations

PURPOSE

Initial purpose was to determine if the interactions between N fertiliser, B fertiliser and progeny influence the incidence and severity of crown disease. The effects of interactions on palm growth and yield is now being assessed.

SITE and PALMS

Site: Two sites, one (Trial 271) at Garu Plantation, Road 13-14, Avenue 4-5. The other (Trial 272) at Kumbango Plantation, Field C12-C13.

Soil: Young free draining, formed on alluvially redeposited pumiceous sands, gravel and volcanic ash.

Landuse prior to this crop: At Garu the site has recently been cleared from primary rainforest and sago swamp whilst on Kumbango the site has been under oil palm for 20 years.

Palms: Four selected Dami DxP progenies known to be susceptible to crown disease were chosen and are described in the 1999 report. Both sites were planted in December 1998 at 120 palms/ha.

BACKGROUND

This is a joint agro-genetic trial between Dami OPRS and PNGOPRA. There is evidence that crown disease is a genetic disorder but there are reports that boron and possibly high nitrogen levels during the immature phase may also be linked with expression of the disease.

DESIGN

A factorial design, originally designed to have 3 rates of N, 2 rates of B, 3 progeny and 3 replicates, resulting in 54 plots. The plot layout and fertiliser treatments are as planned, but 4 progeny were planted instead of 3, making the design unbalanced. The progeny are 9701129, 9701608, 9701815 and 9703205. Hereafter the 970- prefix is ommitted. Fertiliser application commenced in January 1999. The first application of Borax was 3 months after planting. The fertiliser rates during the immature phase are described in the 1999 report. The current fertiliser rates are shown in Table 1. The plots consist of 12 palms (3 rows x 4 palms) with no guard rows. Data were collected by Dami OPRS until the end of 2001. It was decided to continue the trial as a fertiliser x progeny trial from 2002 onwards, with recording carried out by OPRA.

Table 1. Current fertiliser rates in Trial 135.

	Level (kg/palm.year)			
	0	1	2	3
Ammonium chloride (AMC), 2001		1.25	2.5	5.0
Ammonium chloride (AMC), 2002		2.0	4.0	8.0
Borax (B), 2001	0	0.1		
Borax (B), 2002	0	0.1		

In both years, application was split into two (April and October)

Tissue samples were taken for each treatment combination in 2000 and 2001. There were not sufficient degrees of freedom to statistically analyse the results separately for the two sites, so they were analysed together for each year.

RESULTS

Yield was significantly different ($p<0.05$) for the different progeny at Garu, but not at Kumbango (Table 2). At Garu, 3205 had the highest yield and 1608 the lowest yield. However, at Kumbango, 1608 had the highest yield (Table 3). There were no significant interactions between progeny and fertiliser as far as yield was concerned. Garu was the higher yielding site and the palms there had higher leaf Mg contents and lower ash and Ca contents than Kumbango in 2001 (Tables 6 and 7). B and Cl contents were also higher at Garu, but both were within the optimum range at both sites. In 2000 the Garu palms also had higher leaf N contents (Tables 4 and 5). At Garu, yield responded to AMC, whereas at Kumbango it did not. Borax had no effect on yield despite a substantial increase in leaf B contents (Tables 4-7). The progeny differed in their leaf nutrient contents, but the differences were not consistent in the two years (Tables 5 and 7). The only consistent effect in the two years was 1129 having the highest B content.

Mean CD scores for the various treatment combinations are shown in Table 8. Site and progeny effects appeared to be significant, with 1129 and 3205 having the highest scores, especially at Garu. Fertiliser effects only appeared to be significant for progeny 1815, with AMC increasing CD score at Garu and decreasing it at Kumbango (at B0). CD scores were not related to yield in 2001.

Table 2. Effects (p values) of treatments on FFB yield and its components at the Garu and Kumbango sites in 2001 (Trial 135). p values < 0.1 are indicated in bold.

	Garu			Kumbango		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Progeny	**0.018**	**0.010**	**0.097**	0.173	0.217	0.449
AMC	0.376	0.862	**0.090**	0.172	0.143	0.479
B	0.450	0.547	0.642	0.267	0.407	0.315
Progeny.AMC	0.241	0.139	0.535	0.924	0.991	0.736
Progeny.B	0.952	0.962	0.207	0.662	0.453	0.769
AMC.B	0.894	0.906	0.395	0.655	0.645	0.379
Progeny.AMC.B	0.748	0.593	0.840	0.838	0.865	0.306
CV %	13.9	12.5	5.5	28.9	24.8	10.2

Table 3. Main effects of treatments on FFB yield and its components at the Garu and Kumbango sites in 2001 (Trial 135). Effects with $p<0.1$ are shown in bold.

	Garu			Kumbango		
	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
1129	**16.8**	**3523**	**4.77**	10.8	3019	3.59
1608	**14.9**	**3065**	**4.88**	13.2	3603	3.63
1815	**15.5**	**3323**	**4.65**	10.7	3134	3.43
3205	**18.2**	**3745**	**4.88**	10.4	2968	3.48
sed	*1.06*	*199*	*0.12*	*1.5*	*372*	*0.17*
AMC1	15.6	3343	**4.67**	12.5	3468	3.57
AMC2	16.0	3375	**4.76**	10.8	3138	3.45
AMC3	16.7	3419	**4.87**	10.6	2939	3.58
sed	*0.75*	*141*	*0.09*	*1.1*	*263*	*0.12*
B0	16.3	3414	4.78	10.8	3091	3.48
B1	15.9	3344	4.75	11.8	3272	3.58
sed	*0.61*	*115*	*0.07*	*0.9*	*215*	*0.10*

Table 4. Effects (p values) of treatments on frond 17 leaflet nutrient concentrations in 2000 (Trial 135). p values less than 0.1 are indicated in bold.

Source	Ash	N	P	K	Mg	Ca	B	Cl
Site	**<.001**	**<.001**	**0.022**	**<.001**	**<.001**	**<.001**	**0.281**	**0.015**
Prog	0.104	**0.011**	**0.033**	0.351	**0.011**	0.115	**0.095**	**0.003**
AMC	0.307	0.122	0.430	0.307	0.462	0.383	0.396	**0.002**
B	0.809	0.668	0.571	0.485	0.226	0.973	**<.001**	0.415
Site.Prog	0.124	0.338	0.406	0.503	0.447	0.187	0.302	0.587
Site.AMC	0.199	0.139	0.603	0.739	0.221	0.423	0.149	0.507
Prog.AMC	0.193	0.367	0.566	0.868	0.576	0.197	0.149	0.189
Site.B	**0.026**	0.819	**0.034**	0.625	**0.051**	**0.005**	0.351	0.284
Prog.B	0.186	0.302	0.731	0.522	0.632	0.178	0.796	0.497
AMC.B	0.295	**0.086**	0.910	0.171	0.300	0.560	0.454	0.359
Site.Prog.AMC	0.223	0.490	0.381	0.732	0.279	0.463	0.354	0.275
Site.Prog.B	0.205	0.482	0.967	0.188	0.101	0.497	0.358	0.251
Site.AMC.B	0.123	0.905	0.230	0.457	0.146	**0.080**	0.118	0.494
Prog.AMC.B	0.310	0.998	0.910	0.420	0.875	0.538	0.197	0.311
CV %	3.3	2.0	2.1	6.0	6.3	4.0	19.3	7.6

Table 5. Main effects of treatments on frond 17 leaflet nutrient concentrations in 2000, in units of % dry matter, except for B (mg/kg) (Trial 135). Effects with p<0.1 are shown in bold.

	Ash	N	P	K	Mg	Ca	B	Cl
Garu	**12.9**	**2.73**	**0.157**	**0.78**	**0.303**	**0.96**	**21.7**	**0.61**
Kumbango	**14.5**	**2.63**	**0.160**	**0.90**	**0.204**	**1.08**	**23.2**	**0.65**
sed	*0.13*	*0.016*	*0.001*	*0.015*	*0.004*	*0.012*	*1.25*	*0.014*
1129	14.0	**2.73**	**0.161**	0.84	**0.265**	1.03	**25.9**	**0.63**
1608	13.6	**2.68**	**0.160**	0.83	**0.240**	0.99	**21.1**	**0.61**
1815	13.4	**2.69**	**0.158**	0.86	**0.267**	1.03	**21.5**	**0.71**
3205	13.7	**2.62**	**0.156**	0.82	**0.243**	1.02	**21.2**	**0.58**
sed	*0.18*	*0.022*	*0.001*	*0.021*	*0.007*	*0.016*	*1.77*	*0.020*
AMC1	13.6	2.68	0.159	0.86	0.250	1.01	23.4	**0.57**
AMC2	13.6	2.66	0.160	0.83	0.258	1.03	21.2	**0.65**
AMC3	13.8	2.70	0.158	0.83	0.253	1.01	22.6	**0.68**
sed	*0.16*	*0.019*	*0.001*	*0.018*	*0.006*	*0.014*	*1.53*	*0.017*
B0	13.7	2.68	0.159	0.83	0.250	1.01	**15.7**	0.62
B1	13.7	2.68	0.159	0.84	0.257	1.01	**29.2**	0.64
sed	*0.13*	*0.016*	*0.001*	*0.015*	*0.005*	*0.012*	*1.25*	*0.014*

Table 6. Effects (p values) of treatments on frond 17 leaflet nutrient concentrations in 2001 (Trial 135). p values less than 0.1 are indicated in bold.

Source	Ash	N	P	K	Mg	Ca	B	Cl
Site	**<.001**	0.219	**0.011**	0.832	**<.001**	**<.001**	**<.001**	**0.024**
Prog	0.221	0.421	0.298	0.569	**0.067**	**0.095**	**0.027**	**<.001**
AMC	0.693	0.637	0.679	0.548	0.773	0.485	0.131	**0.002**
B	0.493	0.774	0.744	0.409	0.600	0.804	**<.001**	0.918
Site.Prog	0.501	0.580	**0.005**	0.626	0.922	0.119	0.185	**0.059**
Site.AMC	0.227	0.166	0.217	0.283	**0.087**	0.147	0.285	0.582
Prog.AMC	0.570	0.288	0.211	0.821	0.783	0.190	0.673	0.551
Site.B	0.124	0.164	0.589	0.751	0.939	**0.008**	0.223	**0.043**
Prog.B	0.406	0.945	0.212	0.884	0.212	0.159	**0.026**	0.458
AMC.B	0.253	0.959	**0.097**	0.834	0.232	**0.012**	0.566	0.716
Site.Prog.AMC	0.785	0.238	0.267	0.916	0.945	0.946	0.165	0.270
Site.Prog.B	0.443	0.415	**0.064**	0.930	0.484	0.375	0.189	0.525
Site.AMC.B	0.797	0.718	**0.029**	0.657	0.145	0.514	0.459	0.660
Prog.AMC.B	0.855	0.595	0.612	0.963	0.872	0.417	0.800	0.898
CV %	6.5	2.5	1.6	6.4	7.4	3.4	8.7	4.3

Table 7. Main effects of treatments on frond 17 leaflet nutrient concentrations in 2001, in units of % dry matter, except for B (mg/kg) (Trial 135). Effects with p<0.1 are shown in bold.

	Ash	N	P	K	Mg	Ca	B	Cl
Garu	**11.7**	2.68	**0.156**	0.81	**0.300**	**0.90**	**21.9**	**0.64**
Kumbango	**13.4**	2.65	**0.158**	0.82	**0.196**	**1.07**	**18.3**	**0.61**
sed	*0.23*	*0.02*	*0.001*	*0.015*	*0.005*	*0.01*	*0.50*	*0.008*
1129	12.8	2.69	0.156	0.83	**0.248**	**0.99**	**21.8**	**0.62**
1608	12.1	2.66	0.157	0.82	**0.263**	**1.01**	**20.2**	**0.70**
1815	12.5	2.65	0.158	0.80	**0.239**	**0.97**	**19.5**	**0.58**
3205	12.7	2.65	0.157	0.82	**0.241**	**0.98**	**18.9**	**0.60**
sed	*0.33*	*0.03*	*0.001*	*0.021*	*0.007*	*0.01*	*0.71*	*0.011*
AMC1	12.5	2.67	0.157	0.82	0.249	0.98	20.8	**0.59**
AMC2	12.5	2.65	0.157	0.82	0.245	0.99	20.2	**0.63**
AMC3	12.7	2.66	0.156	0.80	0.249	0.99	19.3	**0.65**
sed	*0.29*	*0.02*	*0.001*	*0.018*	*0.006*	*0.01*	*0.62*	*0.010*
B0	12.6	2.66	0.157	0.81	0.249	0.99	**16.2**	0.63
B1	12.4	2.66	0.157	0.82	0.246	0.99	**24.0**	0.63
sed	*0.23*	*0.02*	*0.001*	*0.015*	*0.005*	*0.01*	*0.50*	*0.008*

Table 8. Summary of Crown Disease scores by progeny and fertiliser combination (Trial 135).

	Garu				*Kumbango*			
	1129	**1608**	**1815**	**3205**	**1129**	**1608**	**1815**	**3205**
AMC1 B0	3.3	0.0	1.8	3.0	1.8	1.0	2.8	2.5
AMC2 B0	3.3	0.0	2.9	4.0	2.3	0.0	2.7	2.8
AMC3 B0	3.2	0.0	3.1	3.0	2.6	1.0	1.3	2.0
AMC1 B1	3.2	0.0	3.1	3.6	3.1	0.0	2.8	2.3
AMC2 B1	2.8	0.0	2.8	3.0	2.5	0.0	2.7	2.2
AMC3 B1	2.3	0.0	2.6	3.0	2.1	0.0	2.7	2.3

Trial 136. Monthly Frond Sampling Trial

PURPOSE

To determine variations in tissue nutrient levels over the year to help interpret routine tissue sampling results.

BACKGROUND

The PNGOPRA Scientific Advisory Committee meeting in 1997 requested that monthly leaf sampling be conducted on NBPOL plantations. Similar trials have been carried out in Oro in 1985-1987 (Trial 708, 1988 Annual Report), Milne Bay in 1990 (Trial 508, 1990 Annual Report) and Bebere in 1984 (Trial 101b, 1984 Annual Report).

DESIGN

Plantation sites selected for sampling are listed in the table below. The trial commenced in early 1998 and will continue for a period of at least five years.

Table 1. Plantation and Sampling sites for Trial 136.

Plantation	Year of planting	Location
Haella	1995	Between road 5 and 6 and Avenue 12 and 13
Kumbango	1993 (replant)	Behind Kumbango office, D/C 13-14
Malilimi	1985	Field 85B – Road 1 and 2 and Avenue 5 and 6.
Bilomi	1987	Field 86K- Road 2 and 3, and Avenue 9 and 10
Kautu	1986	Road 7 and 8, Avenue 14 – 15

Leaf and rachis tissue are taken from frond 17 from approximately 40 palms from each field at the same time each month. Sampling intensity is every 10^{th} palm in every 10^{th} row with different palms sampled on each date. Samples are taken to the station where they are dried according to standard procedure. Analyses are carried out for the major nutrients – N, P, K and the secondary nutrients – Ca, Mg and Cl. Boron is the only minor nutrient included in these analyses. Rachis samples are analysed for K only.

Fertiliser applications at each sampling site are carried out under the management of each plantation. This varies with each site and each year.

RESULTS

The mean annual tissue nutrient concentrations for the five sites are shown in Table 1.30. K and Mg contents generally appeared to be low and Ca contents high. Haella, the most recently planted site, consistently has the highest N, P, K, Mg and Cl contents of the five sites. Kumbango has the highest Ca content and lowest Mg and B contents. Malilimi has the lowest N, P and Cl contents. Over the four year period, there has been a consistent downward trend for P at most sites. Other nutrients have not shown consistent trends over the period.

At all sites, leaflet contents of all nutrients except B stayed fairly constant throughout the year, showing no obvious response to rainfall or applications of N, K, and Mg fertilisers (Tables 3-7 and Figure 1). B fluctuated through the year, but it should be kept in mind that B contents are 4 orders of magnitude lower than the other nutrients.

The lack of fluctuations during the year was consistent with previous year's results, and indicates a high degree of buffering within the soil/plant system. We do not yet know to what extent the nutrients are being retained in the soil or other plant tissues.

Table 2. Mean annual tissue nutrient concentrations for the five sites in 1998 – 2001

Site	Nutrient	1998	1999	2000	2001
Haella	Nitrogen	2.62	2.42	2.61	2.56
Kumbang	(%)	2.38	2.38	2.42	2.37
Malilimi		2.26	2.38	2.33	2.24
Bilomi		2.37	2.34	2.34	2.36
Kautu		2.46	2.38	2.42	2.42
Haella	Phosphorus	0.160	0.158	0.158	0.153
Kumbang	(%)	0.146	0.143	0.146	0.142
Malilimi		0.141	0.138	0.137	0.136
Bilomi		0.148	0.138	0.140	0.139
Kautu		0.157	0.153	0.150	0.150
Haella	Potassium	0.81	0.81	0.80	0.75
Kumbang	(%)	0.69	0.76	0.68	0.69
Malilimi		0.67	0.73	0.69	0.73
Bilomi		0.66	0.79	0.69	0.70
Kautu		0.72	0.74	0.72	0.73
Haella	Calcium	0.92	0.88	0.85	0.87
Kumbang	(%)	0.97	0.89	0.92	0.98
Malilimi		0.91	0.85	0.83	0.88
Bilomi		0.93	0.82	0.86	0.98
Kautu		0.79	0.70	0.68	0.75
Haella	Magnesium	0.26	0.23	0.21	0.21
Kumbang	(%)	0.17	0.14	0.14	0.14
Malilimi		0.16	0.15	0.15	0.16
Bilomi		0.18	0.17	0.15	0.16
Kautu		0.24	0.23	0.19	0.23
Haella	Chlorine	0.69	0.71	0.63	0.59
Kumbang	(%)	0.59	0.62	0.59	0.56
Malilimi		0.46	0.48	0.44	0.45
Bilomi		0.57	0.61	0.50	0.54
Kautu		0.49	0.50	0.44	0.44
Haella	Boron		13.4	14.0	14.9
Kumbang	(mg/kg)		11.4	11.9	13.2
Malilimi			12.4	15.0	17.4
Bilomi			11.9	14.6	17.8
Kautu			12.9	15.5	16.9

Table 3. Rainfall, fertiliser applications and tissue nutrient concentrations at Kautu in 2001.

Month	Rainfall (mm)	Fertiliser (kg/palm)	Nutrient content (% DM, except B, in mg/kg)								
			Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	192		14.2	2.37	0.152	0.71	0.25	0.74	18.8	0.40	0.83
Feb	668		14.3	2.46	0.150	0.75	0.25	0.69	19.2	0.47	0.95
Mar	342		13.1	2.35	0.149	0.65	0.26	0.77	14.8	0.45	1.07
Apr	375	AMN (1.5)	13.3	2.54	0.156	0.77	0.21	0.94	14.2	0.70	1.01
May	222		13.7	2.35	0.141	0.69	0.21	0.67	13.8	0.41	1.03
Jun	380		13.6	2.33	0.154	0.73	0.24	0.79	14.9	0.41	1.22
Jul	327		13.5	2.39	0.147	0.71	0.25	0.79	16.2	0.40	1.22
Aug	251		13.4	2.38	0.149	0.69	0.21	0.71	20.1	0.42	1.01
Sept	209		12.4	2.34	0.149	0.79	0.24	0.65	18.7	0.43	0.91
Oct	66	AMN (1.0)	14.2	2.46	0.151	0.75	0.21	0.76	17.8	0.42	1.16
Nov	228		14.0	2.63	0.153	0.75	0.20	0.71	18.1	0.42	1.16
Dec	396		15.0	2.43	0.148	0.79	0.23	0.79	16.1	0.38	1.03
Total:	**3656**	**Mean:**	**13.7**	**2.42**	**0.150**	**0.73**	**0.23**	**0.75**	**16.9**	**0.44**	**1.05**

Table 4. Rainfall, fertiliser applications and tissue nutrient concentrations at Bilomi in 2001.

Month	Rainfall	Fertiliser	Nutrient content (% DM, except B, in mg/kg)								
	(mm)	(kg/palm)	Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	100		16.0	2.81	0.142	0.69	0.15	1.01	19.3	0.58	1.62
Feb	636		15.8	2.36	0.143	0.69	0.16	1.06	18.2	0.51	1.70
Mar	326		15.2	2.27	0.137	0.73	0.16	0.91	18.4	0.53	1.58
Apr	440		16.0	2.26	0.135	0.65	0.15	1.03	16.2	0.52	1.54
May	177	AMN (2.0)	17.0	2.35	0.139	0.67	0.15	1.10	16.3	0.52	1.58
Jun	407		16.0	2.19	0.133	0.69	0.16	0.95	17.7	0.52	1.50
Jul	287		14.5	2.22	0.132	0.69	0.17	0.91	12.1	0.54	1.30
Aug	221		14.4	2.34	0.144	0.69	0.15	0.87	19.6	0.54	1.34
Sept	164		15.6	2.24	0.140	0.61	0.21	1.02	21.1	0.58	1.34
Oct	151		16.1	2.34	0.140	0.85	0.19	1.04	20.6	0.62	1.54
Nov	254		15.4	2.49	0.144	0.73	0.15	0.95	18.4	0.51	1.54
Dec	425		16.4	2.40	0.138	0.69	0.12	0.92	16.2	0.46	1.50
Total:	**3588**	**Mean:**	**15.7**	**2.36**	**0.139**	**0.70**	**0.16**	**0.98**	**17.8**	**0.54**	**1.51**

Table 5. Rainfall, fertiliser applications and tissue nutrient concentrations at Malilimi in 2001.

Month	Rainfall	Fertiliser	Nutrient content (% DM, except B, in mg/kg)								
	(mm)	(kg/palm)	Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	198		14.7	2.14	0.134	0.75	0.15	0.86	17.9	0.55	1.12
Feb	588	AMN (3.8)	14.6	2.22	0.136	0.73	0.17	0.91	15.0	0.49	1.30
Mar	435		14.6	2.25	0.141	0.75	0.16	0.86	15.5	0.50	1.42
Apr	280	MOP (1.5)	15.4	2.25	0.137	0.67	0.17	0.97	16.8	0.47	1.38
May	238	KIE (2.0)	15.1	2.20	0.135	0.71	0.17	0.93	15.6	0.47	1.22
Jun	454		14.3	2.28	0.132	0.67	0.17	0.91	14.4	0.43	1.26
Jul	205		14.4	2.32	0.133	0.67	0.15	0.81	16.7	0.43	1.30
Aug	103		14.9	2.27	0.144	0.79	0.16	0.87	23.2	0.39	1.12
Sep	36		14.5	2.27	0.140	0.77	0.15	0.81	21.8	0.41	1.22
Oct	146		15.9	2.28	0.132	0.83	0.16	0.89	17.7	0.44	1.16
Nov	294		15.9	2.19	0.133	0.65	0.14	0.83	18.3	0.38	1.12
Dec	442		16.2	2.26	0.133	0.71	0.17	0.94	15.4	0.44	1.22
Total:	**3419**	**Mean:**	**15.0**	**2.24**	**0.136**	**0.73**	**0.16**	**0.88**	**17.4**	**0.45**	**1.24**

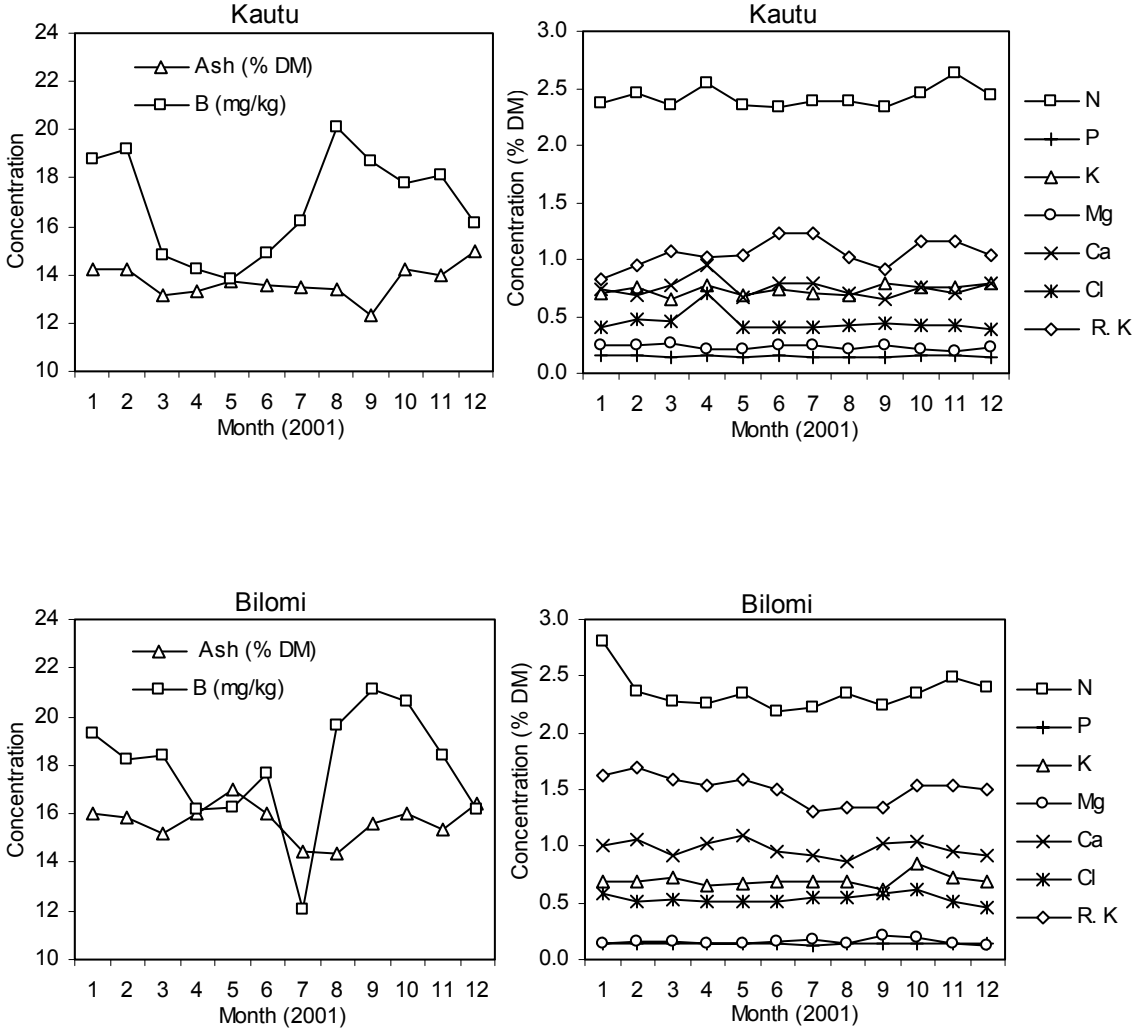
Table 6. Rainfall, fertiliser applications and tissue nutrient concentrations at Kumbango in 2001.

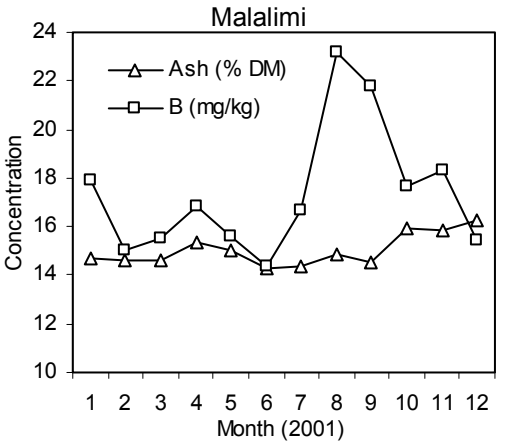
Month	Rainfall	Fertiliser	Nutrient content (% DM, except B, in mg/kg)								
	(mm)	(kg/palm)	Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	236		16.3	2.32	0.144	0.71	0.14	0.96	13.0	0.57	1.58
Feb	724		15.8	2.38	0.144	0.67	0.16	1.03	10.3	0.50	1.58
Mar	304		16.1	2.37	0.149	0.67	0.15	1.07	13.3	0.62	1.58
Apr	155	KIE (1.0)	15.9	2.39	0.146	0.63	0.16	1.05	13.6	0.54	1.66
May	135	AMN (1.9)	16.0	2.38	0.143	0.65	0.16	1.04	12.8	0.56	1.70
Jun	360		14.0	2.38	0.141	0.67	0.13	0.88	11.0	0.61	1.66
Jul	172		15.3	2.37	0.139	0.65	0.12	0.90	13.0	0.60	1.58
Aug	108		15.5	2.31	0.146	0.81	0.16	0.98	16.0	0.60	1.46
Sep	110		16.7	2.40	0.146	0.75	0.13	0.99	15.4	0.52	1.62
Oct	155		16.8	2.33	0.136	0.69	0.12	0.87	15.1	0.57	1.58
Nov	240		17.7	2.41	0.139	0.73	0.14	1.05	12.6	0.51	1.54
Dec	287		16.6	2.37	0.136	0.61	0.11	0.90	12.1	0.50	1.50
Total:	**2984**	**Mean:**	**16.1**	**2.37**	**0.142**	**0.69**	**0.14**	**0.98**	**13.2**	**0.56**	**1.59**

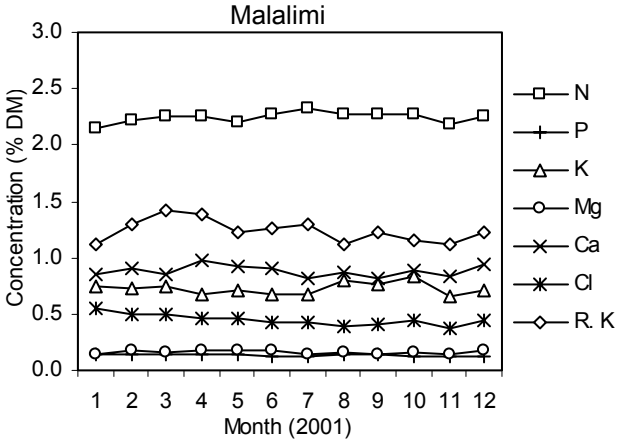
Table 7. Rainfall, fertiliser applications and tissue nutrient concentrations at Haella in 2001. Rainfall figures are from Garu.

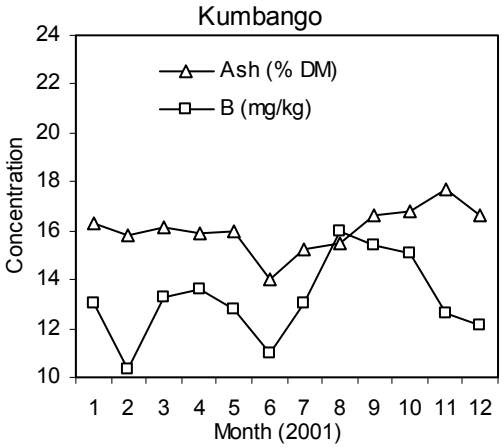
Month	Rainfall (mm)	Fertiliser (kg/palm)	Nutrient content (% DM, except B, in mg/kg)								
			Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	213		14.8	2.60	0.157	0.75	0.22	0.87	12.6	0.62	1.42
Feb	901		13.5	2.58	0.161	0.75	0.22	0.93	10.1	0.57	1.70
Mar	362		14.0	2.64	0.158	0.79	0.22	0.99	14.5	0.66	1.66
Apr	384		13.5	2.44	0.148	0.73	0.22	0.95	14.1	0.67	1.66
May	337	KIE (2.0)	13.6	2.40	0.152	0.71	0.23	0.76	17.4	0.40	1.62
Jun	328		14.0	2.67	0.156	0.67	0.19	0.87	13.9	0.65	1.46
Jul	118	AMC (1.5)	13.2	2.54	0.148	0.79	0.21	0.85	14.4	0.68	1.34
Aug	182		13.9	2.60	0.153	0.85	0.22	0.83	19.7	0.62	1.42
Sep	257		14.9	2.52	0.155	0.77	0.23	0.97	18.0	0.59	1.12
Oct	54		16.4	2.65	0.151	0.79	0.19	0.89	17.1	0.57	1.38
Nov	276		15.5	2.58	0.149	0.75	0.17	0.76	13.5	0.50	1.07
Dec	774		15.5	2.47	0.146	0.69	0.18	0.82	13.9	0.50	1.22
Total:	**4186**	**Mean:**	**14.4**	**2.56**	**0.153**	**0.75**	**0.21**	**0.87**	**14.9**	**0.59**	**1.42**

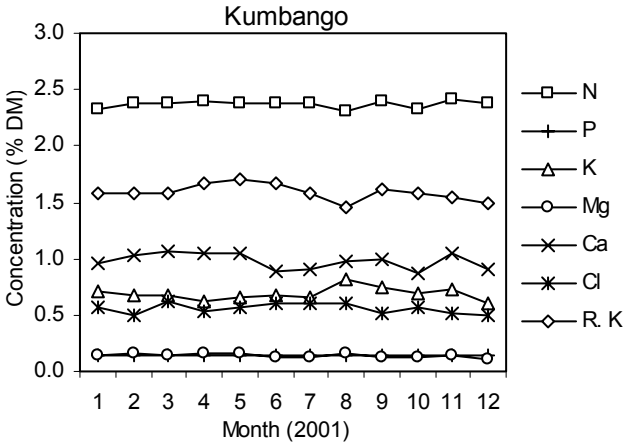
Figure 1. Graphs of leaflet nutrient contents and rachis K content during 2001 (Trial 136).

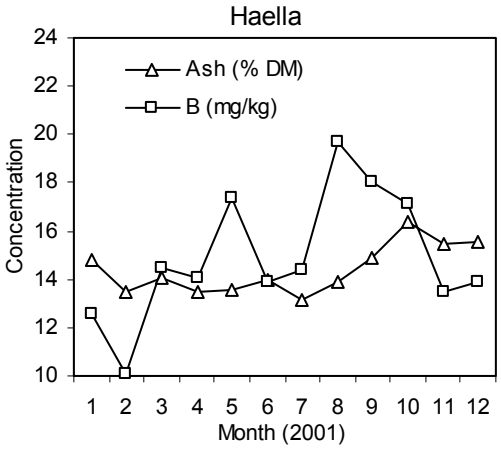


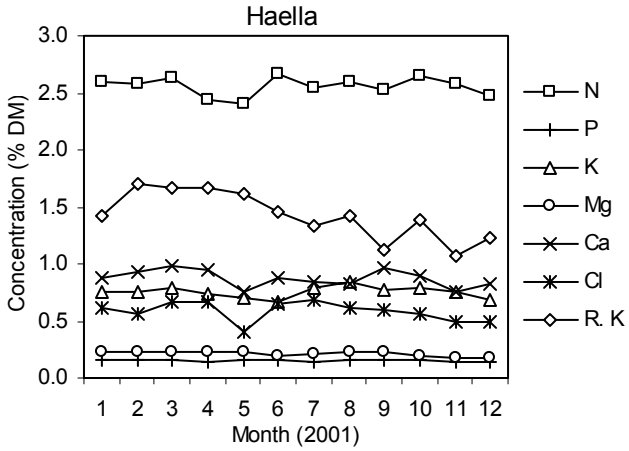

Malalimi
Ash (% DM)
B (mg/kg)
Concentration
Month (2001)


Malalimi
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2001)


Kumbango
Ash (% DM)
B (mg/kg)
Concentration
Month (2001)


Kumbango
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2001)


Haella
Ash (% DM)
B (mg/kg)
Concentration
Month (2001)


Haella
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2001)

Trial 137 Systematic N Fertiliser Trial, Kumbango

PURPOSE

To provide a response curve to N fertiliser that will be used to determine optimum N input in the area.

BACKGROUND

Factorial fertiliser trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in NBPOL trials. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting.

SITE and PALMS

Kumbango Division 1

Soil: Freely draining pumiceous sand and gravel intermixed with finer volcanic ash

Topography: Flat

Land use prior to this crop: Oil palm

Palms: Dami commercial DxP crosses

Planted in October 1999 at 128 palms/ha

DESIGN

The trial will have 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg AMC/palm.yr), and 8 replicates. Each plot is 4 rows of 16 palms. N rates (N 0 – N 8) vary systematically along the trial. The direction of increasing application rates is different in the different replicates, to counter the effect of any unknown fertility gradient. Plots were marked out in 2000.

The main factor for which estimation of a response is required is nitrogen. The design allows possible K treatments to be added later if necessary. Phosphorus and magnesium are unlikely to demonstrate yield increases but may need to be applied to maintain nutrient levels. Four replicates will receive their AMC in 2 doses per year while the other 4 replicates will receive 10 doses per year.

PROGRESS

Palms are currently under immature fertiliser regime. Treatments will commence in 2003.

Trial 138a Systematic N Fertiliser Trial, Haella

PURPOSE

To provide a response curve to N fertiliser that will be used to determine optimum N input in the area.

BACKGROUND

Factorial fertiliser trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in NBPOL trials. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting.

SITE and PALMS

Haella Plantation, Division 2, Field 95J, Avenue 11

Soil: Freely draining fine textured alluvial soils over coarse pumiceous sand and ash soils

Topography: Flat with very minor depressions

Land use prior to this crop: Forest

Palms: Dami commercial DxP crosses

Planted in 1995 at 128 palms/ha

DESIGN

The trial has 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg AMC/palm.yr), and 8 replicates. Each plot is 2 rows of 32 palms. N rates (N0 – N8) vary systematically along the trial. Fertiliser is applied in 4 doses per year.

PROGRESS

Plots were marked out in 2001 and treatments and yield recording commenced in December 2001.

Trial 138b Systematic N Fertiliser Trial, Haella

PURPOSE

To provide a response curve to N fertiliser that will be used to determine optimum N input in the area.

BACKGROUND

Factorial fertilsier trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in NBPOL trials. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting.

SITE and PALMS

Haella Plantation, Division 2, Field I-95, Avenue 11, Road 7-8

Soil: Freely draining fine textured alluvial soils over coarse pumiceous sand and ash beds

Topography: Flat with very minor depressions

Land use prior to this crop: Forest

Palms: Dami commercial DxP crosses

Planted in 1995 at 128 palms/ha

DESIGN

The trial has 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg AMC/palm.yr), and 8 replicates. Each plot is 4 rows of 32 palms. N rates (N0 – N8) vary systematically along the trial. Fertiliser is applied in 2 doses per year.

PROGRESS

Plots were marked out in February 2001 and treatments and yield recording commenced in July 2002.

Trial 139 Palm Spacing Trial at Kumbango Plantation

PURPOSE

Investigate the possibilities of field planting arrangements and how to make use of increased inter-row spacing to facilitate mechanised in-field collection. The investigation will include looking at the effects of planting patterns on oil palm growth, leaf nutrient level and crop production as well as the effect of mechanical in-field collection on soil properties.

BACKGROUND

Mechanical removal of FFB from the field after harvest is now a common practice in plantations. This is intended to reduce harvesting labour cost. Little is known however about the impacts that machine traffic will have on the physical properties and long-term sustainability of these soils.

SITE and PALMS

Kumbango Plantation, Division 1, Field B

Topography: Flat

Land use prior to this crop: Oil palm

Palms: Dami commercial DxP crosses planted in 1999 at 128 palms/ha (spacing treatments given below)

DESIGN

The field layout comprises three replicates for each of the three spacing arrangements, giving a total of nine plots, each 10.6 ha in area. The planting density remains constant at 128 palms per hectare. The tree spacing regimes are: a) standard 9.5 m triangular spacing, b) and avenue width of 9.5 m between the rows and 9 m between palms, and c) an avenue width of 10.6 m between rows and 8.6 m between palms.
Bunch numbers will be counted for all palms. Bunch weights and vegetative measurements will be made on every 5th palm.

PROGRESS

Plots were laid out in 2001.

Trial 204 Factorial Fertiliser Trial at Navo Plantation

PURPOSE

To provide fertiliser response information that will be useful in developing strategies for fertiliser use.

SITE

Site:Navo Plantation, Field 9, Block GH, Avenue 23, 24 and 25
Soil: Very young coarse textured freely draining soils formed on air-fall volcanic scoria
Topography: Flat
Palms: Dami commercial DxP crosses
Planted in 1986 at 125 palms/ha

DESIGN

Treatments commenced in May 1989. There are 36 treatments, comprising all factorial combinations of ammonium chloride (AMC) and triple superphosphate (TSP), each at three levels, and potassium chloride (MOP) and kieserite (KIE), each at two levels (Table 1). The AMC application is made in two doses per year, while the other fertilisers are applied once per year.

Table 1. Fertiliser rates in Trial 204.

	Amounts (kg/palm.yr)		
	Level 0	Level 1	Level 2
AMC	0	3	6
TSP	0	2	4
MOP	0	3	-
KIE	0	3	-

The 36 treatments are replicated twice and grouped into 2 blocks (not corresponding with replicates). The trial was originally designed as a 3x3x2x2x2 factorial, one factor being left 'vacant' and used as a replication for the time being. The 3 factor interaction 2x2x2 is confounded with blocks. High order interactions provide the error term in the statistical analysis.

RESULTS

Sexava damage was first reported in this area in June 1999, and the outbreak intensified until the end of 2000, with almost complete defoliation. In 2001 the trial was assessed by Dr. Rob Caudwell and Peter Tarramurry, and damage was rated as moderate to severe (50-100% defoliation) across the site.

In previous years, AMC has had a major effect on yield in this trial (Figure 1). That effect disappeared in 2001 (Figure 1, Table 2) due to the over-riding effect of the Sexava damage. Overall, FFB yields dropped to less than 10 t/ha in 2001 (Table 3, Figure 1). The drop in yield was primarily due to a decrease in bunch numbers, although bunch weights also declined (Table 3). The only significant treatment effects in 2001 were a small effect of AMC on bunch weight (Table 2 and 3), and an effect of the AMC x TSP x KIE interaction on bunch numbers and yield (Table 4). Yields were low (<7 t/ha) in the absence of AMC and presence of TSP and KIE, and were high (11.5 t/ha) at the high rate of AMC with no added TSP or KIE (Table 4). We will continue to monitor this trial to assess the effects of fertiliser treatments on recovery from Sexava damage. In addition to showing the effect of Sexava damage, Figure 1 shows that leaflet N content has declined throughout this trial, even where high rates of AMC have been applied. In 2001 the extent of defoliation was too great for tissue samples to be taken.

CONCLUSION

In the past, AMC has consistently increased yields in this trial, while the other fertilisers have had little or no significant effects on yield. In 2001, yield crashed to <12 t/ha due to Sexava damage, irrespective of fertiliser treatment.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 204). p values <0.05 are indicated in bold.

	1999-2001			2001		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
AMC	**<.001**	**<.001**	**<.001**	0.345	0.542	**0.008**
TSP	0.260	0.391	0.506	0.524	0.820	0.127
MOP	0.659	0.645	0.842	0.419	0.589	0.418
KIE	0.398	0.317	0.898	0.132	0.109	0.161
AMC.TSP	0.343	0.208	0.289	0.180	0.173	0.887
AMC.MOP	0.527	0.451	0.962	0.622	0.495	0.983
TSP.MOP	0.493	0.615	0.723	0.410	0.292	0.900
AMC.KIE	0.218	0.543	0.540	0.448	0.358	0.690
TSP.KIE	0.961	0.459	0.217	0.554	0.255	0.802
MOP.KIE	0.679	0.562	0.854	0.691	0.562	0.954
AMC.TSP.MOP	0.764	0.868	0.687	0.961	0.823	0.744
AMC.TSP.KIE	0.315	0.087	0.222	**0.013**	**0.008**	0.269
AMC.MOP.KIE	0.552	0.370	0.725	0.615	0.524	0.779
TSP.MOP.KIE	**0.033**	0.142	0.137	0.325	0.248	0.896
CV %	13.1	10.6	5.9	26.1	21.6	9.8

Table 3. Main effects of treatments on FFB yield (t/ha) and its components (Trial 204). Significant effects (p<0.05) are shown in bold. CV% is for the interaction of block x plot.

	1999-2001			2001		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
AMC0	**14.4**	**661**	**21.8**	8.2	422	**19.6**
AMC1	**19.2**	**731**	**26.5**	8.6	408	**21.4**
AMC2	**20.5**	**771**	**26.7**	9.2	437	**21.0**
s.e.d.	*0.68*	*26.0*	*0.43*	*0.65*	*26.4*	*0.58*
TSP0	18.4	729	25.3	9.0	427	21.3
TSP1	17.4	700	24.8	8.2	413	20.1
TSP2	18.3	734	25.0	8.7	428	20.6
s.e.d.	*0.68*	*26.0*	*0.43*	*0.65*	*26.4*	*0.58*
MOP0	17.9	716	25.1	8.4	416	20.5
MOP1	18.1	726	25.0	8.9	428	20.9
s.e.d.	*0.56*	*21.2*	*0.35*	*0.53*	*21.5*	*0.48*
KIE0	18.3	732	25.1	9.0	440	21.0
KIE1	17.8	710	25.0	8.2	405	20.3
s.e.d.	*0.56*	*21.2*	*0.35*	*0.53*	*21.5*	*0.48*

Table 4. Effect of interaction between AMC, TSP and KIE on FFB yield ($lsd_{0.05}$ = 3.2) and bunch number ($lsd_{0.05}$ = 131) in 2001 (Trial 204).

Yield (t/ha)						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
AMC0	7.8	8.9	9.4	6.7	10.1	6.4
AMC1	7.7	8.8	11.0	7.3	7.4	9.0
AMC2	11.5	9.1	6.5	8.5	10.0	9.4
Bunches/ha						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
AMC0	382	459	491	353	512	334
AMC1	366	396	516	362	359	449
AMC2	520	438	351	403	464	448

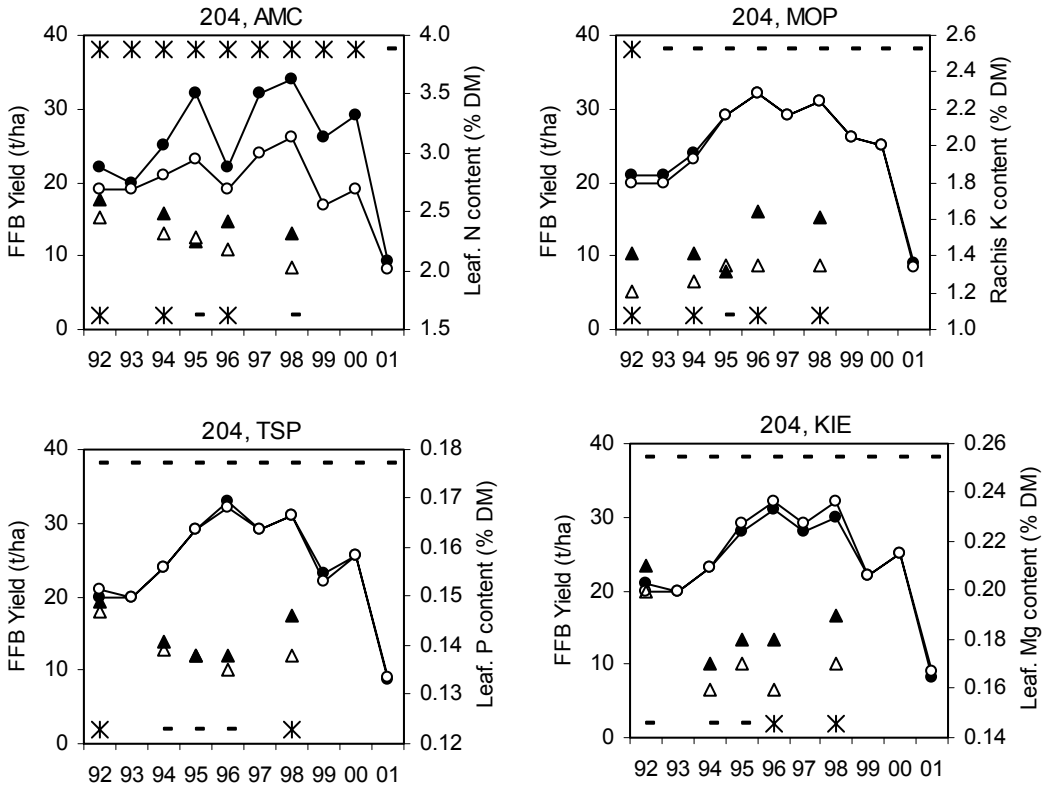


Figure 1. Main effects of SOA, MOP, TSP and kieserite over the course of Trial 204. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Trial 205 EFB x Fertiliser Trial at Hargy Plantation

PURPOSE

To investigate the response of oil palm to application of empty fruit bunches (EFB), and to investigate whether the uptake of phosphorus and magnesium from triple superphosphate and kieserite can be improved by applying the fertiliser in conjuction with EFB.

SITE and PALMS

Site: Blocks 7 and 8, Area 9, Hargy Plantation, Bialla, WNBP.
Soil: Freely draining Andosol formed on intermediate to basic volcanic ash.
Topography: Gentle mid-slope, sloping towards NE
Landuse prior to this crop: Replant. Previous crop was clear felled and windrowed
Palms: 16 Dami identified DxP crosses.
Planted in July and August 1993 at 135 palms/ha

DESIGN

There are eight treatments comprising all factorial combinations of EFB, triple superphosphate (TSP) and kieserite (KIE) each at two levels (Table 1). The treatments are replicated six times, with each replicate comprising one block. A blanket application of 3 kg/palm.year of ammonium chloride is applied across the trial. 36-palm plots (6 x 6 palms) are used, the central 16 palms are recorded and the outer 20 palms are regarded as guard row palms. The recorded palms comprise 16 different identified Dami DxP progenies that have been arranged in a random spatial configuration in each plot. The 16 progenies are shown in Table 2. The trial is analysed as a split-plot design.

Table 1. Fertiliser and EFB treatments used in Trial 205.

Treatment	EFB (kg/palm.yr)	TSP (kg/palm.yr)	KIE (kg/palm.yr)
1	0	0	0
2	0	0	3
3	0	3	0
4	0	3	3
5	230	0	0
6	230	0	3
7	230	3	3
8	230	3	3

Table 2. Progeny numbers and codes in Trial 205

Code	Progeny Number	Code	Progeny Number
A	9004093E	I	9009127E
B	9009030E	J	9103073E
C	9009149E	K	9103136E
D	9102109E	L	9010217E
E	9010040E	M	9010190E
F	4091	N	9009110E
G	9008022E	O	9101100E
H	5148	P	9007130E

RESULTS

The main effects of the treatments on yield and tissue nutrient contents over the course of the trial are shown in Figure 1. All the treatments have had small effects on yield in different years. Tissue P and Mg contents appear to be declining with time. In 2001, yields were high, but not as high as in 2000. Over the 1999-2001 period TSP and EFB both increased yields (Tables 3 and 4). The interaction between TSP and EFB had a significant effect on yield (Tables 3 and 5). TSP and EFB increased yield by the same amount whether applied individually or together. However, while TSP increased leaf P content, EFB alone did not (Table 5). TSP also decreased leaf K content (Tables 7 and 8). Kieserite and EFB both increased rachis K contents, but these were already adequate without kieserite or EFB (Tables 7 and 8).

Progenies yielded quite differently. Over the 1999-2001 period, Progenies H and I yielded best and Progenies F, G and K yielded worst (Table 4). There was a significant interaction between Progeny and TSP (Table 3). Over the 1999-2001 period TSP application increased the yield of Progenies B, N, O and P and decreased the yield of Progenies G and K (two of the progeny that yielded lowest overall) (Table 6).

CONCLUSION

TSP and EFB both increased yield over the 1999-2001 period, but neither had a significant effect in 2001. TSP increased the yield of some progeny and decreased the yield of others.

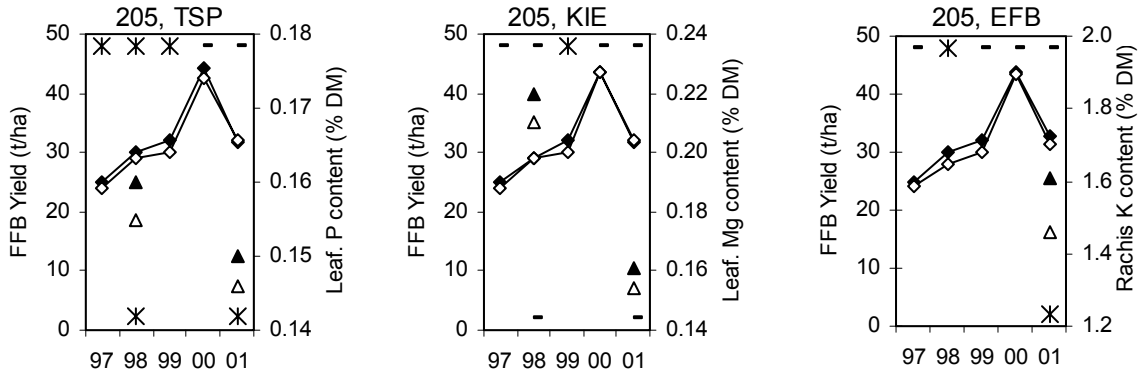


Figure 1. Main effects of TSP, kieserite and EFB over the course of Trial 205. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 3. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 205). p values <0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Rep.Plot stratum						
TSP	**0.042**	0.476	**0.056**	0.892	0.721	0.710
KIE	0.441	0.628	0.495	0.502	0.549	0.808
EFB	**0.037**	0.838	**0.005**	0.123	0.563	0.139
TSP.KIE	0.558	0.393	**0.072**	0.551	0.819	0.385
TSP.EFB	**0.057**	0.159	0.272	**0.097**	0.147	0.402
KIE.EFB	0.624	0.265	0.381	0.779	0.378	0.743
TSP.KIE.EFB	0.424	**0.057**	**0.083**	0.720	0.123	**0.052**
CV%	*4.7*	*4.6*	*3.2*	*9.1*	*7.7*	*3.7*
Rep.Plot.Palm (Progeny) stratum						
Prog	**<.001**	**<.001**	**<.001**	**0.059**	**0.039**	**<.001**
TSP.Prog	**0.027**	**0.040**	0.121	**0.068**	0.111	0.192
KIE.Prog	0.502	0.502	0.441	0.402	0.331	0.236
EFB.Prog	0.571	0.509	0.253	0.722	0.675	0.567
TSP.KIE.Prog	0.252	0.170	0.294	0.138	0.101	0.843
TSP.EFB.Prog	0.987	0.860	0.821	0.893	0.695	0.673
KIE.EFB.Prog	0.830	0.968	**0.056**	0.653	0.456	0.380
TSP.KIE.EFB.Prog	0.855	0.980	0.198	0.236	0.390	**0.064**
CV%	*19.5*	*19.2*	*12.5*	*32.9*	*31.6*	*15.4*

Table 4. Main effects of treatments on FFB yield (t/ha) and its components (Trial 205). Effects with p<0.1 are shown in bold.

	1999-2001			2001		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
TSP0	**35.0**	2313	**15.2**	32.0	1971	1.64
TSP1	**36.0**	2335	**15.5**	31.9	1955	16.3
KIE0	35.3	2317	15.3	32.2	1976	16.4
KIE1	35.7	2332	15.4	31.7	1950	16.4
EFB0	**35.0**	2321	**15.2**	31.3	1950	16.2
EFB1	**36.1**	2328	**15.6**	32.6	1976	16.5
Fert. s.e.d.	*0.49*	*30.6*	*0.14*	*0.84*	*43.8*	*0.17*
A	**37.0**	**2340**	**15.8**	**31.4**	**1831**	**17.1**
B	**35.7**	**2211**	**16.3**	**32.1**	**1887**	**17.2**
C	**35.4**	**2339**	**15.3**	**31.1**	**1958**	**16.2**
D	**34.5**	**2264**	**15.4**	**30.7**	**1921**	**16.2**
E	**33.5**	**2335**	**14.5**	**30.5**	**1938**	**15.7**
F	**32.7**	**2216**	**14.9**	**28.5**	**1792**	**16.0**
G	**32.6**	**2169**	**15.1**	**30.0**	**1915**	**15.4**
H	**37.7**	**2434**	**15.6**	**35.8**	**2216**	**16.3**
I	**38.0**	**2455**	**15.6**	**33.6**	**2050**	**16.5**
J	**36.9**	**2231**	**16.6**	**33.6**	**1949**	**17.4**
K	**32.5**	**2123**	**15.3**	**29.6**	**1862**	**15.7**
L	**35.9**	**2350**	**15.4**	**33.5**	**2011**	**16.9**
M	**36.5**	**2391**	**15.3**	**31.4**	**1896**	**16.6**
N	**35.9**	**2402**	**15.1**	**31.5**	**1912**	**16.7**
O	**36.4**	**2399**	**15.3**	**33.0**	**2121**	**15.7**
P	**37.2**	**2530**	**14.7**	**34.5**	**2154**	**16.2**
Prog. s.e.d.	*1.41*	*90.9*	*0.39*	*2.14*	*126.7*	*0.51*

Table 5. Effect of interaction between TSP and EFB on FFB yield (t/ha) in 1999-2001 and leaf P content (in brackets, in % DM) in 2001 (Trial 205). For yield, p=0.057 and $lsd_{0.05}$ =1.39. For P content, p=0.094 and $lsd_{0.05}$=0.0026.

	EFB0	EFB1
TSP0	34.0 (0.147)	36.0 (0.146)
TSP1	36.0 (0.149)	36.1 (0.151)

Table 6. Effect of interaction between TSP and Progeny on FFB yield in 1999-2001 (Trial 205) p=0.027 and $lsd_{0.05}$=3.92

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
TSP0	37.4	**33.5**	36.1	33.2	33.3	32.9	**35.0**	37.0	36.6	36.0	**34.2**	34.9	36.2	**34.0**	**33.9**	**35.7**
TSP1	36.5	**38.0**	34.7	35.8	33.8	32.4	**30.2**	38.3	39.3	37.8	**30.9**	36.9	36.8	**37.8**	**38.8**	**38.7**

Table 7. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 205). p values less than 0.1 are indicated in bold.

				Leaflet					Rachis	
Source	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
TSP	0.466	0.857	**<.001**	**0.009**	0.868	0.271	0.283	0.969	0.554	0.147
KIE	0.745	0.418	0.372	0.514	0.141	0.126	0.719	0.510	0.267	**0.079**
EFB	**0.061**	0.393	0.928	0.161	0.740	0.920	0.584	0.179	**0.075**	**0.051**
TSP.KIE	0.875	0.393	0.474	0.586	0.323	0.762	0.175	0.614	**0.072**	0.542
TSP.EFB	0.738	0.528	**0.094**	0.663	0.619	0.702	0.572	0.786	**0.038**	0.132
KIE.EFB	0.605	0.153	0.372	0.329	0.868	0.920	0.331	**0.086**	0.709	0.769
TSP.KIE.EFB	0.581	0.195	0.372	0.663	0.740	0.732	0.452	0.846	0.978	0.897
CV%	*4.0*	*2.6*	*2.2*	*7.5*	***11.0***	*6.8*	*9.6*	*7.3*	*11.6*	*15.9*

Table 8. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (mg/kg) (Trial 205). Effects with p<0.1 are shown in bold.

				Leaflet					Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
TSP0	14.1	2.45	**0.146**	**0.73**	0.158	1.03	17.2	0.51	4.6	1.59
TSP1	14.0	2.46	**0.150**	**0.68**	0.157	1.05	17.7	0.51	4.5	1.48
KIE0	14.0	2.45	0.149	0.70	0.154	1.06	17.3	0.50	4.4	**1.47**
KIE1	14.1	2.46	0.148	0.71	0.161	1.02	17.5	0.51	4.6	**1.60**
EFB0	**14.2**	2.46	0.148	0.69	0.157	1.04	17.6	0.50	**4.4**	**1.46**
EFB1	**13.9**	2.45	0.148	0.72	0.158	1.04	17.3	0.51	**4.6**	**1.61**
sed	*0.16*	*0.018*	*0.001*	*0.015*	*0.005*	*0.021*	*0.48*	*0.011*	*0.15*	*0.070*

Trial 209 Factorial Fertiliser Trial at Hargy Plantation

PURPOSE

To provide fertiliser response information that will be useful in developing strategies for fertiliser recommendations.

BACKGROUND

Proposed to replace the discontinued trial 201.

SITE and PALMS

Hargy Plantation, Area 1, Blocks 4, 6 and 8
Soil: Freely draining Andosol formed on intermediate to basic volcanic ash
Topography: Gently sloping
Land use prior to this crop: Replant
Palms: Identified Dami commercial DxP crosses (the same 16 progeny in each plot)
Planted in October and November 1994 at 135 palms/ha

DESIGN

There are 81 treatments comprising all factorial combinations of ammonium sulphate (SOA), triple superphosphate (TSP), potassium chloride (MOP) and kieserite (KIE), each at three levels (Table 1). There are a total of 81 plots, comprising one replicate, and they are arranged in 9 blocks of 9 plots. The site was surveyed, and palm labeling was carried out in November 1996. For the first 36 months, the palms received a standard immature palm fertiliser input. Pre-treatment yield recording commenced in January 1997 and the treatments were first applied in June 1998.

Table 1. Rates of fertiliser and EFB used in Trial 209.

	Amounts (kg/palm.yr)			
	Level 0	Level 1	Level 2	Level 3
SOA	-	2	4	8
TSP	0	4	8	
MOP	0	2	4	
KIE	0	4	8	

RESULTS

The data was analysed by analysis of variance with and without blocks. However, because the effect of blocks is confounded with a number of treatments, the results presented here are the results of the analysis without blocks.

Yields in 2001 were less than in 2000. Over the 1999-2001 period, SOA, TSP and MOP all significantly ($p<0.02$) increased yield (Tables 2 and 3). In 2001 the results were less marked; SOA and MOP increased yield at $p<0.08$, the effects being due to significant ($p<0.02$) increases in bunch weight (Tables 2 and 3). There was a significant interaction between MOP and KIE (Tables 2 and 4). Yield was lowest at the highest rate of kieserite with no MOP, and highest at the moderate level of MOP with KIE2, or highest level of MOP with KIE0 or KIE 1 (Table 4). There was also a significant interaction between SOA, TSP and MOP (Tables 2 and 5). Yield was lowest where none of the three fertilisers were added, and highest where all three were added at the highest rates. Although the

effects of treatments were small in 2001, effects of SOA, MOP and TSP appear to be slowly increasing with time (Figure 1).

The small but significant effect of SOA on yield was not reflected in leaflet N contents (Tables 6 and 7). TSP increased leaflet N and P contents and kieserite increased leaflet Mg contents. MOP Increased leaflet N, Ca and Cl and rachis K contents and decreased leaflet K and B contents.

Analysis of cation exchange properties of a soil very close to this trial (Bialla Area 9, LSU 1), showed low levels of exchangeable K (<0.02 $cmol_c$/kg), moderate levels of exchangeable Mg (~1 $cmol_c$/kg) and high levels of exchangeable Ca (10-16 $cmol_c$/kg) throughout the profile.

CONCLUSION

Effects of fertilisers were small, but yield was highest at the highest rates of SOA, MOP and TSP, irrespective of kieserite application.

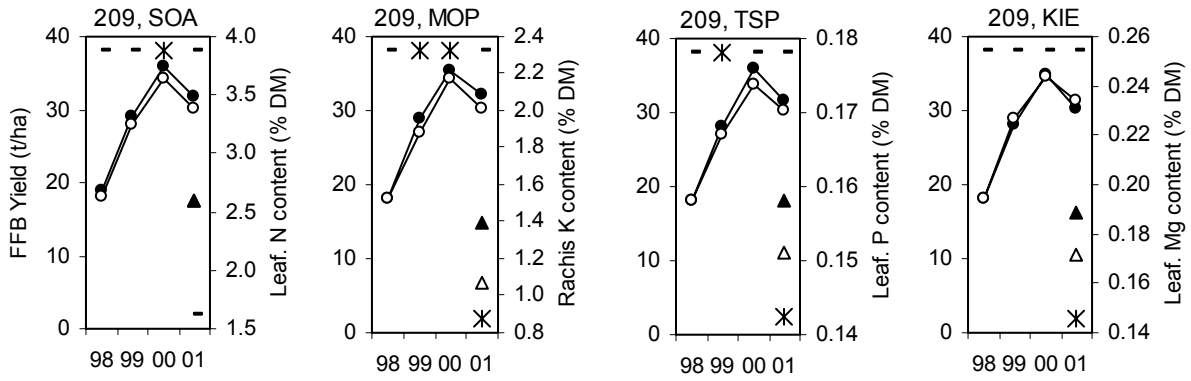


Figure 1. Main effects of SOA, MOP, TSP and KIE over the course of Trial 209. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols the lowest level. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 209). p values <0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.021**	0.246	**0.007**	**0.076**	0.156	**0.014**
TSP	**0.005**	0.202	0.297	0.107	0.332	0.302
MOP	**0.006**	0.927	**0.010**	**0.070**	0.954	**<.001**
KIE	0.423	0.422	0.416	0.109	0.163	0.974
SOA.TSP	0.422	0.634	0.868	0.780	0.743	0.500
SOA.MOP	0.955	0.550	0.444	0.228	0.255	0.240
TSP.MOP	0.437	0.674	0.429	0.800	0.812	0.949
SOA.KIE	0.144	0.439	0.144	0.204	0.111	0.115
TSP.KIE	0.967	0.934	0.681	0.997	0.982	0.631
MOP.KIE	**0.003**	**0.074**	0.909	**0.009**	0.112	0.404
SOA.TSP.MOP	**0.005**	0.141	0.639	**0.019**	**0.024**	0.145
SOA.TSP.KIE	0.662	0.931	0.986	0.469	0.643	0.344
SOA.MOP.KIE	**0.038**	0.208	0.315	0.133	0.175	0.137
TSP.MOP.KIE	0.404	0.196	0.291	0.390	0.291	0.351
CV %	5.4	7.9	5.4	8.3	9.8	4.0

Table 3. Main effects of treatments on FFB yield and its components (Trial 209). Effects with p<0.1 are shown in bold.

	1999-2001			2001		
	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
SOA1	**30.8**	2366	**13.1**	**30.2**	2211	**13.7**
SOA2	**31.3**	2457	**12.8**	**31.7**	2335	**13.6**
SOA3	**32.2**	2408	**13.5**	**31.7**	2261	**14.1**
TSP0	**30.4**	2354	13.0	30.3	2217	13.7
TSP1	**31.8**	2404	13.2	31.7	2285	13.9
TSP2	**32.1**	2422	13.3	31.7	2306	13.7
MOP0	**30.5**	2405	**12.8**	**30.3**	2276	**13.3**
MOP1	**31.5**	2404	**13.2**	**31.2**	2258	**13.9**
MOP2	**32.2**	2422	**13.5**	**32.1**	2273	**14.2**
KIE0	31.7	2426	13.2	31.4	2283	13.8
KIE1	31.4	2435	13.0	31.9	2323	13.8
KIE2	31.1	2370	13.3	30.3	2202	13.8
s.e.d.	*0.46*	*52.0*	*0.19*	*0.71*	*60.8*	*0.15*

Table 4. Effect of MOP.KIE interaction on FFB yield (t/ha) in 1999-2001 (Trial 209). $Lsd_{0.05}$ = 1.7. Yields <29 t/ha and >32 t/ha are highlighted.

	KIE0	KIE1	KIE2
MOP0	30.9	31.8	**28.8**
MOP1	31.5	30.1	**32.8**
MOP2	**32.7**	**32.4**	31.7

Table 5. Effect of SOA.TSP.MOP interaction on FFB yield (t/ha) in 1999-2001 (Trial 209). $Lsd_{0.05}$ = 2.9. Yields <29 t/ha and >34 t/ha are highlighted.

		MOP0	MOP1	MOP2
SOA1	TSP0	**28.7**	**28.4**	30.6
	TSP1	30.1	31.3	32.1
	TSP2	31.1	32.6	31.9
SOA2	TSP0	**28.5**	29.0	32.7
	TSP1	31.3	34.0	30.4
	TSP2	30.9	31.9	32.8
SOA3	TSP0	31.6	33.2	30.9
	TSP1	32.9	29.7	**34.2**
	TSP2	29.5	33.3	**34.6**

Table 6. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 209). p values <0.1 are indicated in bold.

	Leaflet								Rachis	
Source	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	**0.012**	0.926	0.556	0.225	**0.089**	0.942	0.773	0.925	0.706	0.590
TSP	0.378	**0.066**	**<.001**	**0.020**	0.806	0.649	0.895	0.676	0.618	0.233
MOP	**<.001**	**0.085**	0.289	**0.006**	0.592	**0.006**	**0.015**	**<.001**	**<.001**	**<.001**
KIE	0.515	0.949	0.841	0.525	**0.055**	0.212	0.834	0.962	0.816	0.595
SOA.TSP	0.453	0.981	0.052	0.609	0.371	0.749	0.571	0.281	0.147	0.280
SOA.MOP	0.162	0.160	0.433	0.752	0.183	0.917	0.704	0.986	0.707	0.678
TSP.MOP	0.153	0.287	**0.031**	0.406	0.613	0.732	**0.035**	0.514	0.763	0.811
SOA.KIE	0.334	0.757	0.456	0.744	0.208	0.566	**0.042**	0.123	0.629	0.248
TSP.KIE	0.417	0.149	0.438	**0.053**	0.327	0.647	0.827	0.439	0.980	0.981
MOP.KIE	0.900	0.293	0.125	0.809	0.361	0.410	0.584	0.957	0.295	0.120
SOA.TSP.MOP	0.210	0.152	**0.031**	0.715	0.642	0.971	0.573	0.711	0.963	0.972
SOA.TSP.KIE	0.330	0.778	0.124	0.549	**0.092**	0.764	0.533	0.760	0.956	0.770
SOA.MOP.KIE	0.899	0.967	0.262	0.301	0.635	0.682	**0.027**	0.783	0.565	0.716
TSP.MOP.KIE	0.681	0.435	0.526	0.331	0.212	0.820	**0.063**	0.775	0.384	0.194
CV %	4.7	3.1	2.1	6.6	13.4	10.3	9.6	27.1	14.4	17.5

Table 7. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter, except for B (ppm) (Trial 209). Effects with p<0.1 are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA1	**13.6**	2.59	0.155	0.81	**0.184**	0.92	16.6	0.38	3.8	1.20
SOA2	**13.8**	2.59	0.155	0.83	**0.184**	0.92	16.4	0.39	3.9	1.25
SOA3	**14.2**	2.59	0.156	0.80	**0.171**	0.93	16.7	0.38	3.8	1.25
TSP0	13.9	**2.56**	**0.151**	**0.83**	0.182	0.91	16.4	0.37	3.9	1.29
TSP1	14.0	**2.60**	**0.157**	**0.79**	0.179	0.93	16.6	0.39	3.9	1.23
TSP2	13.8	**2.61**	**0.158**	**0.82**	0.178	0.93	16.6	0.39	3.7	1.18
MOP0	**14.4**	**2.57**	0.154	**0.84**	0.178	**0.87**	**17.3**	**0.25**	**3.4**	**1.07**
MOP1	**13.6**	**2.62**	0.156	**0.81**	0.184	**0.94**	**16.4**	**0.44**	**3.9**	**1.25**
MOP2	**13.7**	**2.59**	0.155	**0.79**	0.178	**0.96**	**15.9**	**0.46**	**4.2**	**1.39**
KIE0	14.0	2.59	0.155	0.82	**0.172**	0.95	16.7	0.38	3.8	1.20
KIE1	13.9	2.59	0.156	0.80	**0.178**	0.93	16.5	0.39	3.8	1.24
KIE2	13.8	2.59	0.155	0.82	**0.189**	0.90	16.5	0.38	3.9	1.26
s.e.d.	*0.18*	*0.022*	*0.001*	*0.015*	*0.007*	*0.026*	*0.43*	*0.028*	*0.15*	*0.059*

Trial 211 Systematic N Trial at Navo

PURPOSE

To provide N response information that will be useful for determining optimum N input in the area.

BACKGROUND

Factorial fertiliser trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in West New Britain. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting as a replacement for Trial 204.

SITE and PALMS

Navo Plantation, Field 11, Road 6 and 7, Avenue 11, 12 and 13

Soil: Aerated peat soils over redeposited scoria ash fall over coarse sandy subsoils with loose structures

Topography: Flat and swampy

Land use prior to this crop: Mostly sago and forest

Other site factors: Area extensively drained

Palms: Dami commercial DxP crosses

Planted in March 1988 at 115 palms/ha

DESIGN

The trial has 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg/palm.yr), and 8 replicates. Each plot is 4 rows of 15 palms. N rates vary systematically along the trial. Standard immature fertiliser regime was used initially. Plots were marked in 2001, fertiliser treatments commenced in November 2001, and yield recording commenced in February 2002. Fertiliser is applied in 2 doses per year.

RESULTS

In September 2001, tissue samples were taken for analysis of pre-treatment nutrient contents. Samples were combined from palms along a zigzag transect (2 palms in each of the 4 rows) in each plot. Results showed that the site is fertile, with adequate contents of all nutrients, and is also acceptably uniform (Table 1). There is a good ground cover of legume, mostly *Pueraria* and *Calopogonium*.

Table 1. Pre-treatment tissue nutrient contents of frond 17 leaflets and rachis (mean and sd of 8 replicates) in 2001 (Trial 211). Units are % DM, except for B, which is in mg/kg.

	Treatment								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ash	11.9	12.4	12.4	12.5	12.2	12.0	11.9	12.2	12.0
sd	*1.2*	*1.4*	*1.5*	*1.5*	*1.4*	*1.2*	*1.4*	*1.0*	*1.1*
N	2.72	2.71	2.73	2.76	2.70	2.77	2.72	2.70	2.69
sd	*0.10*	*0.13*	*0.11*	*0.13*	*0.09*	*0.12*	*0.14*	*0.08*	*0.13*
P	0.158	0.159	0.161	0.162	0.162	0.161	0.161	0.162	0.162
sd	*0.005*	*0.006*	*0.005*	*0.007*	*0.007*	*0.008*	*0.008*	*0.010*	*0.004*
K	0.90	0.89	0.87	0.87	0.88	0.87	0.87	0.87	0.86
sd	*0.09*	*0.07*	*0.14*	*0.09*	*0.09*	*0.09*	*0.06*	*0.09*	*0.07*
Mg	0.27	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.29
sd	*0.02*	*0.04*	*0.03*	*0.02*	*0.02*	*0.02*	*0.02*	*0.04*	*0.03*
Ca	1.04	1.11	1.11	1.10	1.09	1.06	1.06	1.06	1.09
sd	*0.06*	*0.10*	*0.09*	*0.13*	*0.09*	*0.07*	*0.07*	*0.05*	*0.07*
B	15.1	15.7	15.4	14.8	14.5	14.9	16.0	15.7	15.6
sd	*1.8*	*2.5*	*2.5*	*2.8*	*1.7*	*2.2*	*1.3*	*3.0*	*1.9*
Cl	0.56	0.56	0.55	0.54	0.58	0.55	0.54	0.55	0.57
sd	*0.04*	*0.02*	*0.03*	*0.03*	*0.04*	*0.02*	*0.04*	*0.04*	*0.05*
Rachis ash	4.9	5.1	4.9	5.2	4.8	5.2	5.3	5.0	4.9
sd	*0.4*	*0.8*	*0.4*	*0.5*	*0.5*	*0.5*	*0.4*	*0.6*	*0.8*
Rachis K	1.75	1.82	1.77	1.87	1.70	1.90	1.90	1.80	1.75
sd	*0.22*	*0.31*	*0.20*	*0.27*	*0.22*	*0.22*	*0.19*	*0.36*	*0.37*

Trial 212 Systematic N trial at Hargy

PURPOSE

To provide N response information that will be useful for determining optimum N input in the area.

BACKGROUND

Factorial fertiliser trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in West New Britain. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting as a replacement for Trial 209.

SITE and PALMS

Hargy Estate, Area 8, Blocks 10 and 11

Soil: Freely draining Andosol formed on volcanic ash

Topography: Gentle to moderate slope

Land use prior to this crop: Oil palm

Palms: Dami commercial DxP crosses

Planted in February 1996 at 140 palms/ha

DESIGN

The trial has 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg/palm.yr), and 8 replicates. Each plot is 4 rows of 15 palms. N rates vary systematically along the trial. From 2003, fertiliser application frequency will be 2 doses/year in 4 replicates and 10 doses/year in the other 4 replicates.

PROGRESS

The site was chosen in 2001 and treatments will commence in 2002.

Trial 213 N and P Fertiliser Trial for the High Ground at Hargy Plantation

PURPOSE

To provide fertiliser response information necessary for determining fertiliser recommendations for the palms on the high ground of Hargy Plantation.

BACKGROUND

This trial was proposed at the 2000 SAC meeting. It had been observed that oil palm on the high ground at the back of Hargy plantation had been exhibiting poor growth. It was suspected from visual observation that the poor growth may be due to deficiencies of nitrogen and phosphorus.

SITE and PALMS

Hargy Estate, Area 11, Blocks 9 and 10

Soil: Freely draining Andosol formed on volcanic ash

Topography: Moderately sloping

Land use prior to this crop: Forest

Palms: Dami commercial DxP crosses

Planted in February/March 1997 at 129 palms/ha

DESIGN

Factorial design with 3 levels of ammonium chloride (AMC, 0, 3 and 6 kg/palm.year), 3 levels of triple superphosphate (TSP, 0, 3 and 6 kg/palm.year) and 4 replicates, resulting in a total of 36 plots. Plots consist of 36 palms (6x6), of which the central 19 (4x4) are recorded. Boron may be applied, depending on visual symptoms.

PROGRESS

Plot marking was completed and pre-treatment yield recording commenced in 2002.

Trial 215 Smallholder Under-Planting Trial at Bialla

PURPOSE

To examine practical means for lessening the drop in production during replanting of smallholder blocks.

BACKGROUND

Many small holder blocks in the LSS areas are due for replanting. However, growers are reluctant to replant as they fear a substantial loss of income, particularly at this time of relatively high prices. This trial has been initiated at the request of OPIC and has been endorsed by the Bialla LPC.

DESIGN

The trial will be carried out using three smallholder blocks. Half of each block will be poisoned and replanted using standard practice. The other half of each block will have one of the following treatments:

1. Poison every second palm, replant (under-plant), and poison the remaining mature palms 9 months later.
2. Replant (under-plant), and poison mature palms 9 months later.
3. Replant (under-plant), and poison mature palms 18 months later.

PROGRESS

Blocks were chosen and treatments were to commence in 2002. However, it was decided at the 2002 SAC meeting not to go ahead with the trial. Results of similar trials were reported recently by Tittinutchanon and Corley in the 2002 IOPRI Conference Proceedings. They found the best technique was to under-plant, fell 50% of the old stand 6 months later, and the remaining palms 24 months later.

Trial 402 Factorial Fertiliser Trial at Bilomi Plantation

PURPOSE

To provide fertiliser response information that will be useful in developing strategies for fertiliser usage.

SITE and PALMS

Kapiura Estates, Bilomi Plantation, Division 2, Field 11C.

Soil: Young coarse textured freely draining soils formed on alluvially redeposited andesitic pumiceous sands and volcanic ash.

Palms: Dami commercial DxP crosses.

Planted in early 1987 at 120 palms/ha.

DESIGN

There are 36 treatments, comprising all factorial combinations of N and P at three levels and K and Mg each at two levels (Table 1).

Table 1. Fertiliser rates used in Trial 402 and their main element contents.

	Amounts (kg /palm.year)		
	Level 0	Level 1	Level 2
Ammonium chloride	0	3	6
Triple superphosphate	0	2	4
Muriate of potash	0	3	---
Kieserite	0	3	---
		(t/ha/yr)	
EFB	0	50	---

Note: Treatments are factorial combinations of levels of these fertilisers.

The ammonium chloride is split into two applications per year, while the other fertilisers are applied only once. EFB applications started in mid 1993. EFB is applied with a Giltrap EFB applicator.

There are 72 plots, each plot consisting of 36 palms (6x6) of which the central 16 are recorded. The 72 treatments are replicated once and are grouped into two blocks. The 3 factor interaction '2x2x2' is confounded with blocks. High order interactions provide the error term in the statistical analysis.

The trial commenced in May 1990 and was closed at the end of 2000.

RESULTS

The trial was closed at the end of 2000, but some summary graphs are presented here to show the treatment main effects over the course of the trial (Figure 1). There were virtually no treatment effects on yield over the life of the trial. Results of the EFB main effect are not shown, but they were not significant either. Tissue N and P contents declined over time, irrespective of fertiliser addition. A final report is being written for this trial, and the large yield increase in 2000 will be examined.

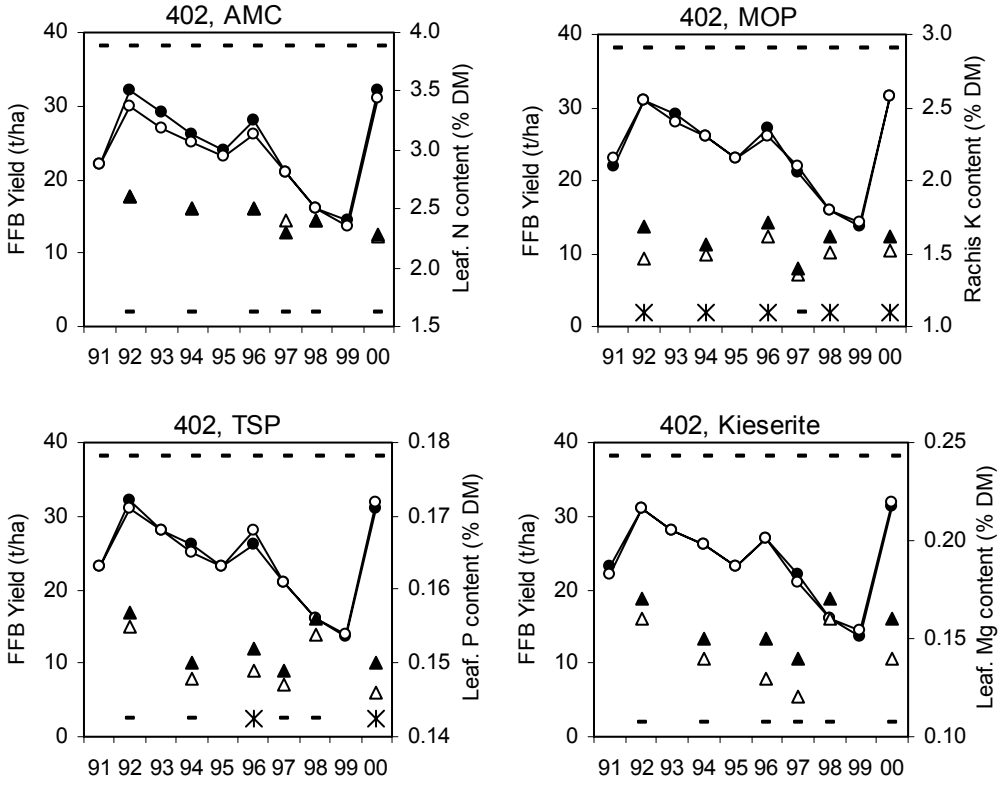


Figure 1. Main effects of AMC, MOP, TSP and kieserite over the course of Trial 402. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Trial 403 Systematic N Trial, Karausu

PURPOSE

To provide a response curve to N fertiliser that will be used to determine optimum N input in the area.

BACKGROUND

Factorial fertiliser trials with randomised spatial allocation of treatments are generally showing poor responses to fertilisers in West New Britain. Yields and tissue nutrient concentrations in control plots are generally higher than would be expected. It is suspected that fertiliser may be moving from plot to plot. Systematic designs are seen as a way of avoiding this problem, by ensuring that high and low rates of application are not adjacent. This trial was approved in the 1999 SAC meeting.

SITE and PALMS

Karausu Plantation, Division 1, Block I-3 and I-4, Field Mn
Soil: Freely draining soils formed on redeposited andesitic pumiceous volcanic ash and sand
Topography: Flat
Land use prior to this crop: Forest
Palms: Dami commercial DxP crosses
Planted in 1987 at 120 palms/ha

DESIGN

The trial has 9 treatments, which are 9 rates of ammonium chloride (0, 1, 2, 3, 4, 5, 6, 7 and 8 kg AMC/palm.yr), and 8 replicates. Each plot is 4 rows of 15 palms. N rates (N 0 – N 8) vary systematically along the trial. The trial was laid out in 2000 and treatments commenced in September 2000. From 2000 to 2002, fertiliser was applied in two doses per year. From 2003, fertiliser will be applied in 2 doses per year in 4 replicates and 10 doses per year in the other 4 replicates.

The trial will be analysed as a regression with 9 points (N levels). The 4 rows are essentially replication, but when analysing the data, it will be useful to examine the data on a row-by-row basis, to see if the effects of higher N levels encroach onto plots with lower N levels. Therefore, all recording is being done on the basis of rows (or individual palms for many parameters), rather than plots.

N0	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N8**	**N7**	**N6**	**N5**	**N4**	**N3**	**N2**	**N1**	**NO**
N8	**N7**	**N6**	**N5**	**N4**	**N3**	**N2**	**N1**	**NO**	**NO**	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**

RESULTS

There was no response to N fertiliser in this the first year of the trial (Figure 1). Yields tended to be higher in the first row of each plot, because in some early harvests, bunch numbers and weights from all four rows were attributed to the first row. Yields are also shown for the two blocks separately (Figure 2). Those results show that variation with 4 replicates is not much greater than variation with 8 replicates (Figure 1), as the two blocks are very similar.

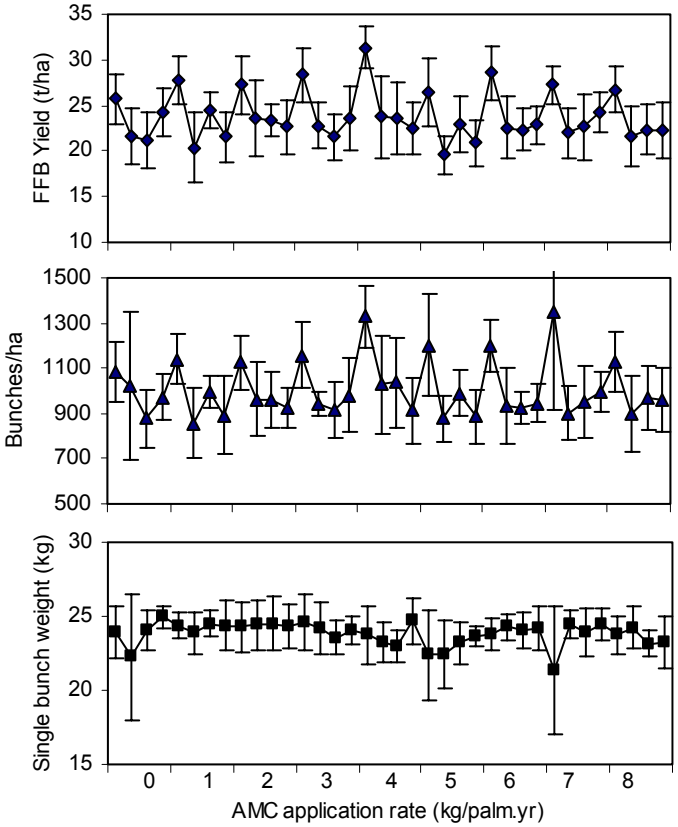


Figure 1. Mean FFB yield (a), bunch numbers (b) and single bunch weights (c) on a row-by-row basis in 2001 (Trial 403). Error bars show ± standard deviations.

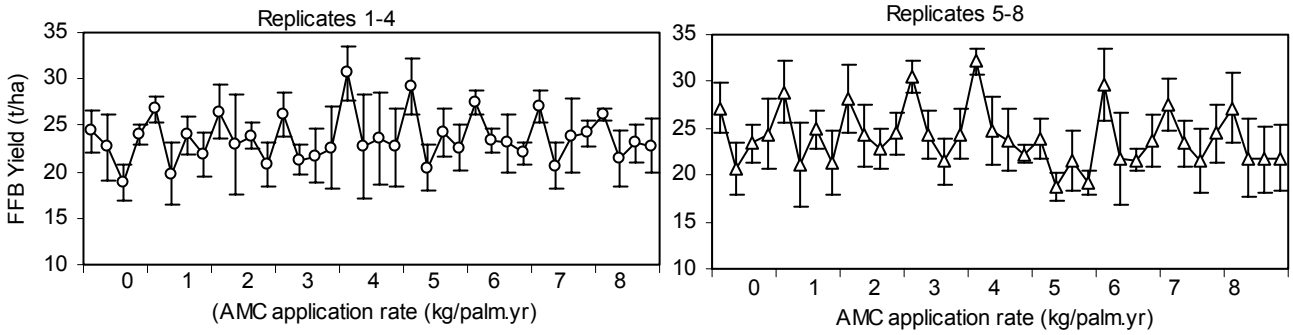


Figure 2. Mean 2001 FFB yield for the two blocks shown separately (Trial 403). Error bars show ± standard deviations.

AGRONOMY TRIALS IN ORO PROVINCE

(P. Nelson, M. Banabas)

Trial 309 Potassium, Chlorine and Sulfur Trial, Ambogo Estate

PURPOSE

To test the response to potassium, chlorine and sulphur.

DESCRIPTION

Site: Ambogo Estate Block 80H
Soil: Penderetta family. Thin dark sandy loam topsoil over sandy loam subsoil derived from alluvially deposited volcanic ash. Mottling due to seasonally high water tables.
Palms: Dami commercial DxP crosses planted in 1980 at 143 palms per hectare

DESIGN

The trial is a Latin Square with five treatments and five replicates, giving a total of 25 plots. The trial is laid down on the site of an earlier trial that was started in 1984 to test effects of EFB. Rows correspond to the old treatments and columns correspond to replicates. Each plot contains 16 core palms. The core palms are surrounded by at least one guard row, and a trench. The trial started in June 1990.

The treatments are combinations of ammonium sulphate (SOA), ammonium chloride (AMC), potassium chloride (MOP) and bunch ash (BA) (Table 1). The effect of an element is found by comparing the yields from two treatments; for example the effect of chlorine is found by comparing the yields from treatments 4 and 5.

The treatments that were used from January 1988 to June 1990 were similar to treatments used from 1991 to the present, but there are some important differences. Treatment 3 now receives N and S, but used to receive only K. Treatment 2 now receives N and Cl, but used to receive K and Cl. Thus when comparing a treatment with either 2 or 3 in order to test the effect of K the effect will be underestimated if there is a residual effect of the K that was given in the early part of the trial.

Table 1. Types and amounts of amendment given in each treatment, and the corresponding amounts of nutrient element in Trial 309

Treatment No	Amount of fertiliser (kg/palm.yr)				Amount of element (kg/palm.yr)			
	MOP	BA	SOA	AMC	N	K	Cl	S
1	-	-	-	-	-	-	-	-
2	-	-		3.2	0.80	-	2.1	-
3	-	-	4.0	-	0.84	-	-	0.96
4	4.4	-	4.0	-	0.84	2.3	2.1	0.96
5	-	8.8	4.0	-	0.84	2.2	-	0.96

RESULTS

Similarly to previous years, yield showed large responses to N and S and little or no response to K or Cl (Table 2 and 4). After a period of low yields in 1994-2000, yields are now back up to the values

they were early in the trial for most treatments. Yields in the nil and NCl treatments have improved slightly in the last few years, but not to their original levels (Table 3 and Fig. 1).

Frond 3 and 17 leaflet and rachis tissues from one plot of each treatment were sampled and analysed. Samples were taken into pre-weighed bags, weighed, oven dried at 70°C and weighed again. This form of sampling has been called 'alternative sampling'. Results are expressed in the normal way, as % DM, for all nutrients. For nutrients that exist mostly in the sap (K, Cl and SO_4), solution concentrations were calculated, assuming that all of the nutrient existed in the sap.

The tissue nutrient contents (Table 5) showed some interesting phenomena. It should be kept in mind however that these nutrient contents were for single plots, so we have no idea of the significance of the effects discussed. Firstly, in the nil treatment, the low yield and lack of fertiliser input was reflected much more accurately for all nutrients in Frond 3 leaflets than Frond 17 leaflets (except for Cl and SO_4 in the sap). In Frond 17, the nil treatment had higher N, P, K, Mg and S (as % DM) contents than the fertilised treatments. The difference between the nutrient contents in the two fronds was partially, but not wholly, due to the difference in the way their ash contents responded to fertiliser.

Of all the nutrient contents, Cl (as % DM or mM in sap) was the only one that reflected fertiliser input in a straight-forward manner in all tissues. The other nutrient contents were influenced differently by different fertiliser combinations in different tissues. N content reflected fertiliser input in the frond 3 leaflets and rachis, but not in the Frond 17 tissues. In the rachis of both fronds, N content was highest in the NCl treatment even though this treatment had the lowest yield of the +N treatments. P content was raised by addition of all fertilisers in the Frond 3 leaflets, but the reverse was true for all other tissues. For K, fertiliser inputs were best reflected in the Frond 17 rachis. Concentrations of most nutrients were higher in Frond 3 leaflets than Frond 17 leaflets. Ash and Ca contents tended to be higher in Frond 17 leaflets.

CONCLUSION

Yield continues to be greatly increased by N and S addition in this trial, with K and Cl having little or no effect. Fertiliser additions and yield appeared to be better related to nutrient contents of Frond 3 leaflets than Frond 17 leaflets.

Table 2. Effects of N, S, K, and Cl in different combinations on FFB yield and its components in 1999-2001 and 2001 (Trial 309). CV value is for the interaction between old treatment and replicate.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
4 N S K Cl	26.7	1025	26.7	31.2	1103	28.9
5 N S K	25.3	970	26.5	32.6	1174	28.5
3 N S	25.7	1012	26.0	30.9	1192	26.9
2 N Cl	17.8	848	21.2	19.8	945	21.3
1 Nil	9.6	667	14.6	11.2	767	15.2
GM	21.0	904	23.0	25.2	1036	24.2
p	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.004**	**<0.001**
sed	1.59	62.5	0.87	2.29	95.2	1.15
$lsd_{0.05}$	3.5	136	1.9	5.0	207	2.5
CV%	12.0	10.9	5.9	14.4	14.5	7.5

Table 3. Effects of N, S, K, and Cl, in different combinations on fresh fruit bunch yields in 1991-2001 (Trial 309).

	FFB yield (t/ha)										
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Palm age:	11	12	13	14	15	16	17	18	19	20	21
4 N S K Cl	31.3	32.5	28.4	27.7	18.6	18.7	21.1	15.4	25.4	23.6	31.2
5 N S K	28.6	30.9	28.7	26.4	19.7	14.7	19.4	12.2	21.3	21.9	32.6
3 N S	28.5	27.8	25.2	24.2	28.6	15.1	18.7	17.3	24.4	22.0	30.9
2 N Cl	24.5	21.7	19.4	18.7	14.4	13.8	14.5	14.3	18.9	15.4	19.8
1 Nil	16.4	13.6	9.8	7.1	6.4	7.6	8.3	6.3	9.1	9.1	11.2
GM	25.9	25.3	22.3	20.8	17.5	14.0	16.4	13.1	19.8	18.4	25.2
Sig	**	***	***	***	***	Ns	***	**	***	***	***
sed									2.38	2.95	2.29
CV%	17.1	20.1	19.1	9.4	26.3	30.4	11.1	27.4	12.0	16.1	14.4

Table 4. Comparison of effects of N, S, K, and Cl, in different combinations on fresh fruit bunch yields in 1991-2001 (Trial 309). In the last three years, significant values ($p<0.05$) are highlighted in bold. Numbers in brackets are palm age.

Element(s)	Treatment	FFB yield (t/ha)										
		1991 (11)	1992 (12	1993 (13)	1994 (14)	1995 (15)	1996 (16)	1997 (17)	1998 (18)	1999 (19)	2000 (20)	2001 (21)
Cl	5 minus 4	2.7	1.6	-0.7	0.3	-0.9	4.0	1.7	3.2	**4.1**	1.7	-1.4
NKS	5 minus 1	12.2	17.3	18.9	19.3	13.3	7.1	11.1	5.9	**12.2**	**12.8**	**21.4**
NKClS	4 minus 1	14.9	18.9	18.6	20.6	12.2	11.1	12.8	9.1	**16.3**	**14.5**	**20.0**
K	5 minus 3	0.1	3.1	3.5	2.2	-8.9	-0.4	0.1	-5.1	-3.1	-0.1	1.7
N Source	3 minus 2	4.0	6.1	5.8	5.5	14.2	1.3	4.2	3.0	5.5	**6.6**	**11.0**

Table 5. Concentration of nutrients in tissues from selected plots in 2001 (Trial 309).

Plot	Treat.	Water	Tissue concentration (% DM)									Conc. (mM in sap)		
		(%)*	Ash	N	P	K	Mg	Ca	Cl	S	SO_4	K	Cl	SO_4
Frond 3 Leaflets														
23	NSKCl	180.8	7.2	2.60	0.171	1.20	0.24	0.55	0.50	0.14	0.42	170	78.0	24.2
9	NSK	192.3	6.6	2.73	0.185	1.34	0.27	0.50	0.33	0.15	0.45	178	48.4	24.4
19	NS	180.2	7.0	2.69	0.177	1.18	0.26	0.47	0.37	0.14	0.42	167	57.9	24.3
12	NCl	177.5	6.1	2.54	0.177	1.24	0.28	0.45	0.58	0.13	0.39	179	92.2	22.9
3	Nil	131.8	13.4	1.97	0.137	0.73	0.27	0.60	0.21	0.12	0.36	142	45.0	28.4
Frond 3 Rachis														
23	NSKCl	263.9	4.3	0.30	0.073	1.52	0.05	0.24	0.91	0.07	0.21	147	97.3	8.3
9	NSK	245.5	3.7	0.30	0.072	1.42	0.05	0.17	0.39	0.07	0.21	148	44.8	8.9
19	NS	206.6	3.7	0.32	0.064	1.34	0.06	0.20	0.50	0.08	0.24	166	68.3	12.1
12	NCl	233.1	4.1	0.40	0.078	1.52	0.07	0.19	1.01	0.06	0.18	167	122.2	8.0
3	Nil	229.0	4.1	0.24	0.107	1.37	0.08	0.10	0.46	0.06	0.18	153	56.7	8.2
Frond 17 Leaflets														
23	NSKCl	92.6	13.6	2.08	0.134	0.69	0.19	0.80	0.47	0.13	0.39	191	143.2	43.8
9	NSK	149.6	13.7	2.13	0.140	0.71	0.20	0.71	0.26	0.13	0.39	121	49.0	27.1
19	NS	131.8	14.6	2.09	0.132	0.63	0.20	0.63	0.29	0.12	0.39	122	62.1	30.8
12	NCl	140.7	12.1	2.14	0.135	0.61	0.22	0.69	0.49	0.12	0.36	111	98.3	26.6
3	Nil	191.4	7.2	2.36	0.173	1.20	0.39	0.38	0.28	0.14	0.42	160	41.3	22.8
Frond 17 Rachis														
23	NSKCl	241.6	4.5	0.24	0.131	1.42	0.04	0.33	0.87	0.07	0.21	150	101.6	9.0
9	NSK	239.4	4.4	0.27	0.141	1.37	0.04	0.26	0.15	0.08	0.24	146	17.7	10.4
19	NS	266.0	3.7	0.27	0.090	1.14	0.04	0.31	0.26	0.08	0.24	110	27.6	9.4
12	NCl	233.6	4.8	0.41	0.171	1.26	0.09	0.37	0.96	0.05	0.15	138	115.9	6.7
3	Nil	215.9	3.9	0.25	0.223	1.22	0.08	0.18	0.18	0.09	0.27	145	23.5	13.0

* g water /100 g DM

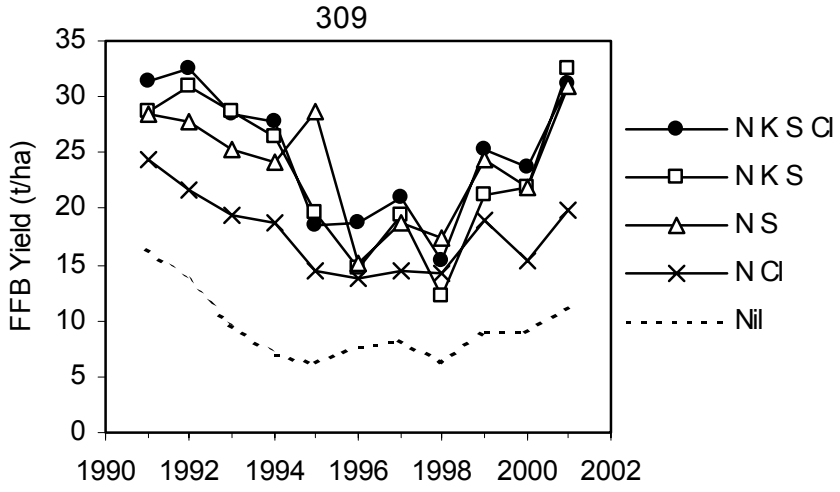


Figure 1. Mean FFB yield over the course of trial 309.

Trial 310 Potassium, Chlorine and Sulfur Trial, Ambogo Estate

PURPOSE

To test the response to potassium, chlorine and sulphur in the presence of nitrogen

DESCRIPTION

Site: Ambogo Estate block 80D5
Soil: Ambogo and Penderetta families. Silt loam over sandy loam, with mottling due to seasonally high water tables, derived from alluvially deposited volcanic ash.
Palms: Dami commercial DxP crosses planted in 1980 at 143 palms per hectare.

DESIGN

The trial consists of five replicate blocks each containing seven treatments, randomised within the block. The seven treatments provide various combinations of K, Cl and S, all at a given rate of N, using various combinations of urea, ammonium sulphate (SOA), ammonium chloride (AMC), bunch ash (BA) and potassium chloride (MOP) (Table 1). The effect of an element is found by comparing the yields from two treatments; for example the effect of chlorine in the absence of K and S is found by comparing treatments 3 and 1. There are a total of 35 plots, each containing 16 core palms. In each plot the core palms are surrounded by at least one guard row, and a trench. The trial started January 1986, but present treatments started in November 1990.

In 2001, samples from fronds 3 and 17 leaflets and rachis in treatments 1 and 3 (Table 1) were analysed for nutrient content. The data were analysed by analysis of variance to test for the effect of Cl.

Table 1. Amount of each type of fertiliser, and each element, used for each treatment in Trial 310.

	Amount of Fertiliser (kg/palm.yr)					Amount of Element (kg/palm.yr)			
Treatment	Urea	SOA	AMC	BA	MOP	N	K	Cl	S
1	1.8	-	-	-	-	0.81	-	-	-
2	-	4.0	-	-	-	0.84	-	-	0.96
3	-	-	3.2	-	-	0.80	-	2.1	-
4	-	4.0	-	4.4	-	0.84	1.10	-	0.96
5	-	-	3.2	4.4	-	0.80	1.10	2.1	-
6	-	4.0	-	-	2.2	0.84	1.04	1.1	0.96
7	-	2.0	1.6	-	-	0.82	-	1.1	0.48

RESULT

Yields have shown a general decline over the 11 years of the trial, with a distinct 2-3 year cycle (Fig. 1). Yields have generally, but not always, been lowest in the N only treatment. Yields were generally highest in the +Cl treatment in the first 7 years, but in the last four years yields have been highest in the +S +Cl treatment (Tables 2- 4). K has had little effect on yield over the course of the trial.

Frond 3 and 17 leaflet and rachis tissues from all the plots receiving urea or AMC alone were sampled and analysed. Samples were taken into pre-weighed bags, weighed, oven dried at

70°C and weighed again. This form of sampling has been called 'alternative sampling'. Tissue nutrient contents are shown in Tables 5 and 6. Results are expressed in the normal way, as % DM, for all nutrients. For nutrients that exist mostly in the sap (K, Cl and SO_4), solution concentrations were calculated, assuming that all of the nutrient existed in the sap.

Contents of N, P, K and Mg were higher in Frond 3 leaflets than Frond 17 leaflets, but ash and Ca contents were higher in Frond 17 leaflets. The effect of N source on nutrient content was similar in the two fronds. In the rachises, contents of N, P, K, Mg, Ca and Cl were higher with AMC than urea. In the leaflets, K and S contents were higher with urea, and Cl contents were higher with AMC. N content was higher with AMC in Frond 3 leaflets, but not affected by N source in Frond 17 leaflets.

CONCLUSION

In the first 7 years of this trial the +Cl treatment had the highest yields, whereas in the last 4 years the +Cl +S treatment has had the highest yields. K has had small and inconsistent effects on yield over the course of the trial.

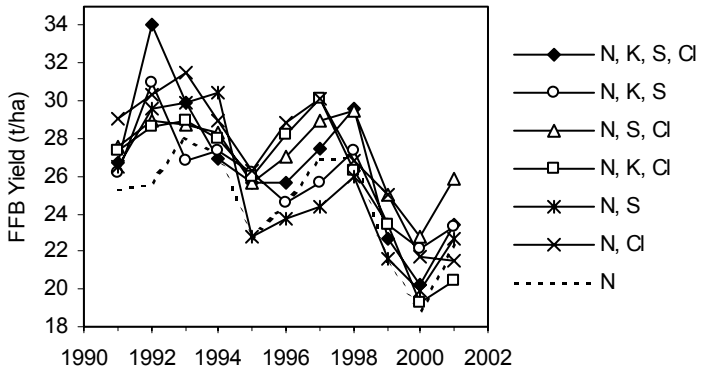


Figure 1. Mean FFB yield over the course of Trial 310.

Table 2. Effects of K, S and Cl on FFB yield and its components in 1999-2001and 2001 (Trial 310). All plots received the same rate of N. CV value is for the interaction between blocks and plots.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
6 K S Cl	20.9	748	28.3	23.4	825	29.0
4 K S	22.4	860	26.7	23.3	865	27.5
7 S Cl	24.0	915	26.7	25.9	963	27.5
5 K Cl	19.9	749	27.5	20.4	755	27.9
2 S	20.6	841	25.6	22.7	884	26.6
3 Cl	21.7	824	27.2	21.5	823	27.3
1 Nil	20.3	919	23.0	22.2	972	23.9
GM	21.4	837	26.4	22.8	869	27.1
p	0.132	**0.049**	**<0.001**	0.220	0.060	**0.028**
sed	1.49	62.1	0.94	2.00	71.8	1.32
$lsd_{0.05}$	3.1	128	1.9	4.1	148	2.7
CV%	11.0	11.7	5.6	13.9	13.1	7.7

Table 3. Effects of K, S and Cl on FFB yields in 1991-2001 (Trial 310). Numbers in brackets are palm age. The highest yield in each year is shown in bold.

	FFB yield (t/ha)										
	1991 (11)	1992 (12)	1993 (13)	1994 (14)	1995 (15)	1996 (16)	1997 (17)	1998 (18)	1999 (19)	2000 (20)	2001 (21)
6 K S Cl	26.7	**34.0**	29.9	26.9	25.7	25.6	27.5	**29.6**	22.7	20.2	23.4
4 K S	26.2	31.0	26.8	27.4	**26.2**	24.6	25.7	27.4	23.4	22.1	23.3
7 S Cl	27.6	28.9	28.7	28.3	25.7	27.0	28.9	**29.5**	**25.0**	**22.8**	**25.9**
5 K Cl	27.4	28.6	28.9	28.0	26.0	28.2	**30.1**	26.3	23.4	19.3	20.4
2 S	26.5	29.6	29.9	**30.4**	22.8	23.7	24.4	26.0	21.6	19.9	22.7
3 Cl	**29.1**	30.3	**31.5**	28.9	**26.3**	**28.8**	**30.1**	26.8	**25.0**	21.7	21.5
1 Nil	25.3	25.6	28.1	27.1	22.7	24.5	26.9	27.0	21.3	18.8	22.2
GM	27.0	29.7	29.1	28.1	25.1	26.1	27.7	27.5	23.2	20.7	22.8
Sig	ns	**	ns	ns	ns	ns	*	ns	ns	ns	ns
sed					1.8	3.5	3.1	2.2	2.8	2.7	1.5
CV%		8.8	12.0	10.5	11.5	13.6	11.1	12.6	12.1	13.1	11.0

Table 4. The effects of S, Cl, K and K in the presence of Cl (K(Cl)) on FFB yield from 1991 to 2001 (Trial 310). Numbers in brackets are palm age. The largest difference in each year is shown in bold.

		Yield difference (t/ha)										
Effect of Element	Treat.	1991 (11)	1992 (12)	1993 (13)	1994 (14)	1995 (15)	1996 (16)	1997 (17)	1998 (18)	1999 (19)	2000 (20)	2001 (21)
S	2 minus 1	1.2	4.0	1.8	**3.3**	0.1	-0.8	-2.5	-1.0	0.3	1.1	0.5
Cl	3 minus 1	**3.6**	**4.7**	**3.4**	1.8	**3.6**	**4.3**	**3.2**	-0.2	**3.7**	2.9	-0.7
S + Cl	7 minus 1	2.3	3.3	0.6	1.2	3	2.5	2	**2.5**	**3.7**	**4**	**3.7**
K (+S)	4 minus 2	-0.3	1.4	3.1	-3.0	3.4	0.9	1.3	1.4	1.8	0.4	0.6
K (+Cl)	5 minus 3	-1.7	-1.7	-2.6	-0.9	-0.3	-0.6	0.0	-0.5	-1.6	-2.4	-1.1
Cl vs S	2 minus 3	2.6	0.7	1.6	-1.5	3.5	5.3	5.7	0.8	3.4	1.8	1.2

Table 5. Significance (p value) of effects of frond number (3 vs 17, FR), leaflet vs rachis (LR) and urea vs ammonium chloride application (Cl) on concentration of nutrients in tissues from treatments 1 and 3 in 2001 (Trial 310).

Source	Tissue concentration (% DM)									Conc. (mM in sap)		
	Ash	N	P	K	Mg	Ca	Cl	S	SO_4	K	Cl	SO_4
FR	**<.001**	**<.001**	**0.047**	**<.001**	**<.001**	**<.001**	**0.001**	0.417	0.435	**<.001**	0.995	**<.001**
LR	**<.001**	**<.001**	**<.001**	**0.022**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	0.117	**<.001**
Cl	0.196	**0.001**	0.081	0.669	0.133	**0.020**	**<.001**	0.149	0.277	**0.041**	**<.001**	**0.002**
FR.LR	**<.001**	**<.001**	**<.001**	**0.018**	**<.001**	**<.001**	**0.016**	0.625	0.638	**0.022**	0.620	**<.001**
FR.Cl	0.433	0.525	0.196	0.951	0.795	0.101	**<.001**	0.870	0.875	0.903	**<.001**	0.367
LR.Cl	**0.002**	0.147	0.133	**0.019**	0.697	0.474	**<.001**	0.417	0.638	**0.010**	**<.001**	0.079
FR.LR.Cl	0.145	0.200	0.336	0.654	0.349	0.976	**<.001**	0.258	0.277	0.738	0.206	0.159
CV%	*12.2*	*5.1*	*15.6*	*15.0*	*43.7*	*23.6*	*7.8*	*10.4*	*10.7*	*13.5*	*10.0*	*12.5*

Table 6. Table of means for the interaction between frond, leaf vs rachis, and urea vs AMC (Trial 310). s.e.d. and lsd are for the three-way interaction.

Treatment	Tissue concentration (% DM)									Conc. (mM in sap)		
	Ash	N	P	K	Mg	Ca	Cl	S	SO_4	K	Cl	SO_4
Frond 3 Leaflets												
Urea	7.7	2.66	0.188	1.32	0.42	0.36	0.17	0.138	0.41	200	28.7	25.5
AMC	7.1	2.75	0.187	1.20	0.47	0.36	0.56	0.134	0.41	170	87.7	23.6
Frond 3 Rachis												
Urea	3.5	0.33	0.089	1.17	0.12	0.19	0.14	0.050	0.15	135	17.9	7.1
AMC	3.9	0.43	0.097	1.34	0.14	0.24	0.91	0.044	0.13	141	106.6	5.7
Frond 17 Leaflets												
Urea	16.6	2.11	0.145	0.71	0.16	0.77	0.11	0.142	0.43	137	22.9	33.6
AMC	14.6	2.11	0.150	0.63	0.17	0.88	0.50	0.132	0.40	110	95.5	28.5
Frond 17 Rachis												
Urea	3.3	0.32	0.143	0.85	0.10	0.29	0.04	0.050	0.15	104	5.2	7.5
AMC	4.1	0.45	0.184	0.97	0.19	0.45	1.00	0.052	0.16	105	117.4	6.8
sed	*0.59*	*0.045*	*0.015*	*0.097*	*0.061*	*0.066*	*0.021*	*0.006*	*0.019*	*11.8*	*3.82*	*1.36*
$Lsd_{0.05}$	*1.2*	*0.09*	*0.030*	*0.20*	*0.12*	*0.13*	*0.04*	*0.124*	*0.04*	*17*	*7.8*	*2.8*

Trial 311 Nitrogen, Potassium, and EFB Trial, Isavene Estate

PURPOSE

To test the response to N and K fertilisers, with and without EFB, with a view to using EFB to replace or supplement inorganic fertiliser.

DESCRIPTION

Site: Isavene Estate Block 78A
Soil: Higaturu family, deep sandy clay loam with good drainage, derived from volcanic ash.
Palms: Dami commercial DxP crosses. Planted in 1978 at 128 palms/ha.

DESIGN

The 32 plots are a single replicate containing 32 treatments, made up of all combinations of four levels each of ammonium sulphate (SOA) and potassium chloride (MOP), and two levels of EFB (Table 1). Fertiliser application was split into 2 doses per year from 1988 to 1994 and 3 doses per year since 1995. The EFB is applied by hand as a mulch between the palm circles. The weights of EFB given in Table 1 are fresh weights ex-mill. When EFB was given for the first time in November 1988, the amount was 333 kg/palm. In September 1990 it was increased to 500 kg/palm and it is intended to apply this amount every two years. Each plot contains 16 core palms. In each plot the core palms are surrounded by at least one guard row and a trench. Trenches were established in 1995.

Table 1. Amounts of fertiliser and EFB used in Trial 311.

	Amount (kg/palm.year)			
Fertiliser	Level 0	Level 1	Level 2	Level 3
SOA	0	2	4	6
MOP	0	2	4	6
	kg/palm/2 years			
EFB	0	500		

RESULTS

Trial 311 was closed at the end of 2000, and a final report is being written. Yields and tissue contents over the course of the trial are shown in Figure 1. Yields and leaf N contents were maintained with SOA application, but without SOA yields declined with time. EFB also had an increasing positive effect on yield with time. MOP had a small positive effect on yield, the effect being greatest at 2 kg/palm.year of SOA. The effect of EFB was greatest at 0 and 2 kg/palm.year of SOA (Figure 2). The effects of the interactions between SOA, MOP and EFB on yield, leaflet N and rachis K contents in 2000 are shown in Tables 2-4.

Table 2. Effect of interaction between SOA, MOP and EFB on FFB yield (t/ha) in 2000 (Trial 311). There are insufficient degrees of freedom to analyse the three-way interaction statistically; these are simply results from individual plots.

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	14.1	18.5	29.6	27.1	MOP0	29.2	32.6	28.3	36.1
MOP1	15.0	15.9	30.4	35.3	MOP1	26.4	33.9	29.9	39.5
MOP2	23.3	31.7	26.9	32.0	MOP2	23.3	37.9	30.3	32.0
MOP3	23.6	30.5	35.6	31.3	MOP3	23.9	38.0	27.9	38.1

Table 3. Effect of interaction between SOA, MOP and EFB on leaflet N content (% DM) in 2000 (Trial 311). There are insufficient degrees of freedom to analyse the three-way interaction statistically; these are simply results from individual plots.

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	1.92	2.06	2.22	2.45	MOP0	2.02	2.27	2.29	2.34
MOP1	1.90	2.00	2.18	2.38	MOP1	2.06	2.22	2.37	2.23
MOP2	1.89	2.09	2.20	2.47	MOP2	2.00	2.24	2.22	2.18
MOP3	1.91	2.13	2.18	2.19	MOP3	2.18	2.25	2.28	2.39

Table 4. Effect of interaction between SOA, MOP and EFB on rachis K content (% DM) in 2000 (Trial 311). There are insufficient degrees of freedom to analyse the three-way interaction statistically; these are simply results from individual plots.

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	0.83	0.97	0.61	0.95	MOP0	1.66	1.46	1.26	1.07
MOP1	1.34	1.22	1.42	1.26	MOP1	1.46	1.46	1.26	1.46
MOP2	1.42	1.58	1.46	1.46	MOP2	1.50	1.74	1.46	1.54
MOP3	1.42	1.38	1.62	1.50	MOP3	1.26	1.62	1.58	1.58

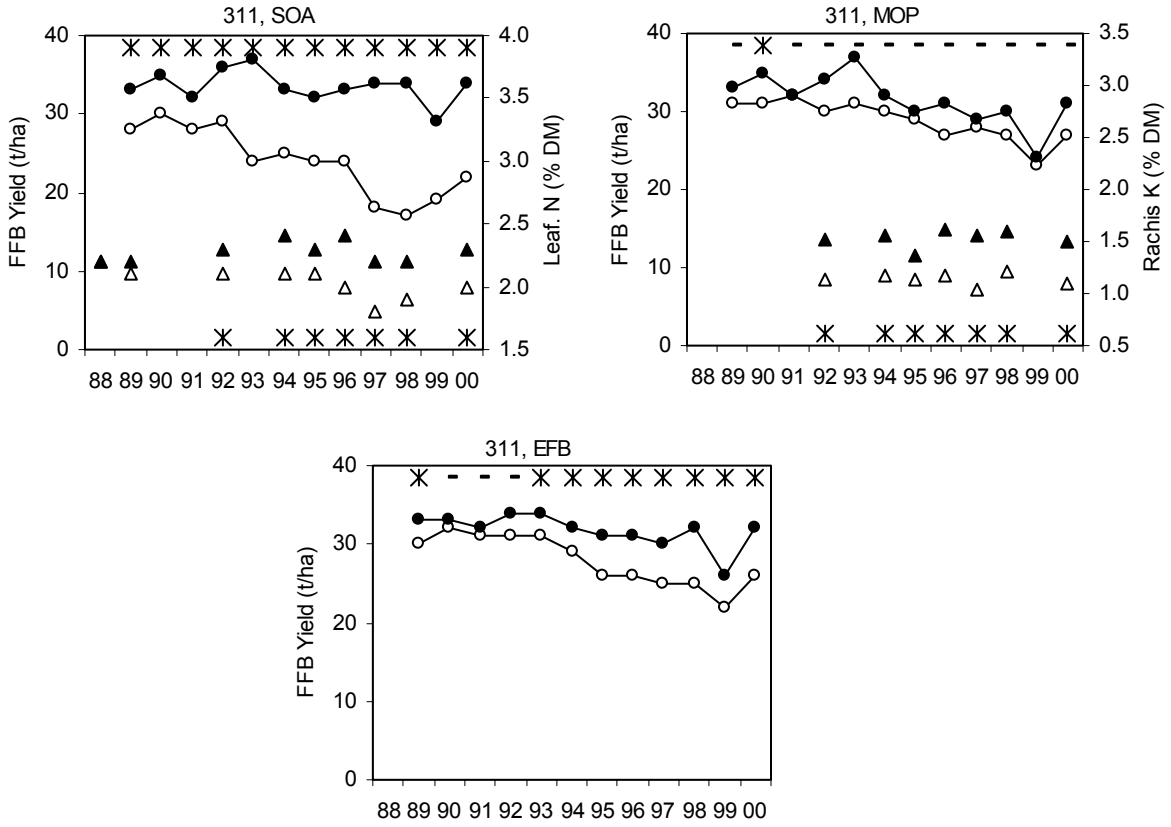


Figure 1. Main effects of SOA, MOP and EFB over the course of Trial 311. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

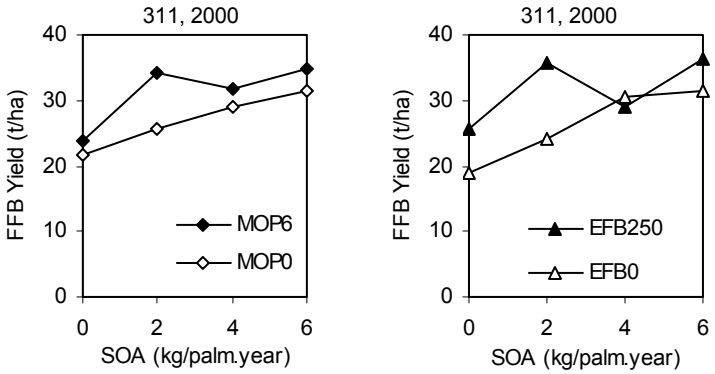


Figure 2. The effects of the interactions between SOA and MOP and between SOA and EFB on FFB yield in 2000 (Trial 311).

Trial 312 Nitrogen, Potassium and EFB Trial, Ambogo Estate

PURPOSE

To test the response to N and K fertilisers, with and without EFB, with a view to using EFB to replace or supplement chemical fertiliser.

DESCRIPTION

Site: Ambogo Estate block 80E2
Soil: Ambogo family, which is of recent alluvially reworked volcanic origin, with silty loam topsoil and sandy loam subsoil, with seasonally high water tables.
Palms: Dami commercial DxP crosses. Planted 1980 at 143 palms/ha.

DESIGN

The 32 plots are a single replicate containing 32 treatments, made up from all combinations of four levels each of ammonium sulphate (SOA) and potassium chloride (MOP), and two levels of EFB (Table 1). The three-way interaction provides the error term in the analysis of variance. Fertiliser application was split into two doses per year from 1988 to 1994 and three doses per year since 1995. EFB is applied by hand as mulch between palm circles. The weights of EFB given in Table 1 are the fresh weights ex-mill. When EFB was given for the first time in November 1988 the amount was 333 kg/palm every two years. In September 1990 it was increased to 500 kg/palm, and it is intended to give this amount every two years. Each plot has 16 core palms. Core palms are surrounded by at least one guard row and a trench.

In 2001, samples from fronds 3 and 17 leaflets and rachis in selected plots were analysed for nutrient content. The plots sampled were the SOA0 MOP0 EFB0 plot, and all the SOA2 plots. The results for the SOA2 plots were analysed by analysis of variance.

Table 1. Amounts of fertiliser and EFB used in Trial 312.

	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0	2	4	6
MOP	0	2	4	6
	kg/palm.2 years			
EFB	0	500		

RESULTS

Yield has tended to decline through the life of this trial. Throughout its course, SOA has had a large effect on yield and MOP has had no effect. The effect of EFB has been increasing with time (Figure 1). The most recent years were no exception (Tables 2 and 3). Bunch numbers increase with SOA rate and bunch weights are greatest at the intermediate SOA rates. EFB increases bunch numbers and weights. MOP has no significant effects, and there are no significant interactions between the treatments. Nevertheless, the effect of the two-way interactions on yield are shown in Table 4 and Figure 2. The effect of EFB was greatest at low levels of SOA. The effect of the three-way interaction on yield is shown in Table 5.

Nutrient contents in the selected plots are shown in Table 7, with the ANOVA results for the SOA2 plots in Table 6. SOA increased N content of all tissues but had no consistent effects on other tissue contents. It increased rachis K in Frond 17 (% DM). EFB application increased tissue N and K contents in most cases.

CONCLUSION

SOA has a large positive effect on yield in this trial and the positive effect of EFB is increasing with time. Both treatments tend to increase tissue N and K contents. MOP has no effect on yield.

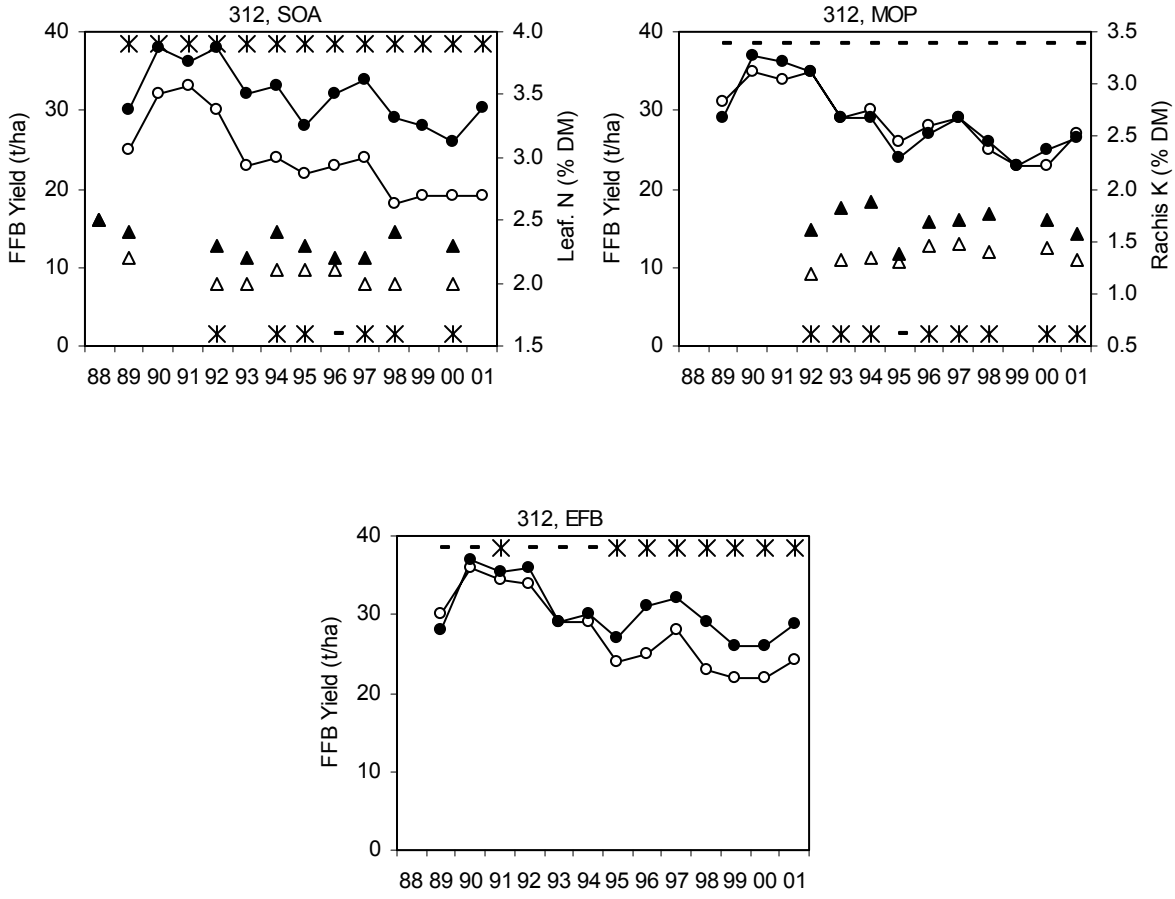


Figure 1. Main effects of SOA, MOP and EFB over the course of Trial 312. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 312). No blocking was used in the analysis. p values <0.05 are indicated in bold.

	1999-2001			2001		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**0.002**	**0.040**	**<.001**	**<.001**	**<.001**	**0.002**
MOP	0.912	0.668	0.448	0.703	0.123	0.195
EFB	**0.006**	**0.035**	**0.011**	**0.006**	**0.008**	**0.020**
SOA.MOP	0.930	0.900	0.653	0.943	0.935	0.377
SOA.EFB	0.351	0.988	**0.008**	0.198	0.539	**0.057**
MOP.EFB	0.417	0.802	0.341	0.244	0.104	0.562
CV %	13.9	12.3	7.1	13.9	9.2	7.9

Table 3. Main effects of treatments on FFB yield and its components (Trial 312). Significant effects (p<0.05) are shown in bold.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**18.6**	**929**	**20.1**	**19.2**	**923**	**20.9**
SOA1	**25.0**	**995**	**25.7**	**29.1**	**1143**	**26.2**
SOA2	**26.4**	**1072**	**25.2**	**27.3**	**1111**	**25.3**
SOA3	**27.6**	**1143**	**24.7**	**30.2**	**1245**	**24.7**
sed	*1.70*	*63.9*	*0.85*	*1.84*	*50.6*	*0.95*
MOP0	24.1	1012	24.3	27.0	1123	24.6
MOP1	23.9	1028	23.2	25.2	1064	23.5
MOP2	25.0	1084	23.6	27.2	1178	23.5
MOP3	24.7	1016	24.5	26.5	1057	25.5
sed	*1.70*	*63.9*	*0.85*	*1.84*	*50.6*	*0.95*
EFB0	**22.3**	**979**	**23.0**	**24.1**	**1044**	**23.3**
EFB1	**26.5**	**1091**	**24.9**	**28.8**	**1167**	**25.2**
sed	*1.20*	*45.2*	*0.60*	*1.30*	*35.8*	*0.67*

Table 4. Effect of two-way interactions on FFB yield (t/ha) in 1999-2001 and 2001 (Trial 312). P values were >0.1 in all cases. Yields <20 and >28 t/ha are highlighted in bold.

1999-2001					2001				
SOA.MOP, lsd=7.68					*SOA.MOP, lsd=8.31*				
	MOP0	MOP1	MOP2	MOP3		MOP0	MOP1	MOP2	MOP3
SOA0	**17.7**	**16.9**	20.9	**18.8**	SOA0	20.8	**18.0**	20.5	**17.4**
SOA1	24.8	26.0	25.8	23.2	SOA1	29.0	27.9	31.9	27.8
SOA2	26.6	25.8	25.0	**28.2**	SOA2	27.7	26.1	27.1	**28.4**
SOA3	27.2	26.9	**28.1**	**28.4**	SOA3	**30.7**	**28.8**	**29.2**	**32.3**
SOA.EFB, lsd=5.43					*SOA.EFB, lsd=5.88*				
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
EFB0	**14.9**	22.5	24.5	27.2	EFB0	**14.5**	26.2	26.1	**29.6**
EFB1	22.2	27.4	**28.4**	**28.1**	EFB1	23.8	**32.0**	**28.6**	**30.8**
MOP.EFB, lsd=5.43					*MOP.EFB, lsd=5.88*				
	MOP0	MOP1	MOP2	MOP3		MOP0	MOP1	MOP2	MOP3
EFB0	21.7	21.9	24.4	21.1	EFB0	23.2	23.1	27.1	23.2
EFB1	26.4	25.9	25.5	**28.2**	EFB1	**30.9**	27.3	27.2	**29.8**

Table 5. Effect of three-way interaction between SOA, MOP and EFB on FFB yield (t/ha) in 2001 (Trial 312). There are insufficient degrees of freedom to analyse the three-way interaction statistically; these are simply results from individual plots.

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	16.6	25.9	23.2	26.9	MOP0	24.9	32.0	32.2	34.4
MOP1	12.3	26.0	27.5	26.4	MOP1	23.6	29.7	24.8	31.1
MOP2	15.8	32.8	28.7	31.2	MOP2	25.1	30.9	25.6	27.3
MOP3	13.4	20.2	25.1	34.0	MOP3	21.3	35.5	31.7	30.5

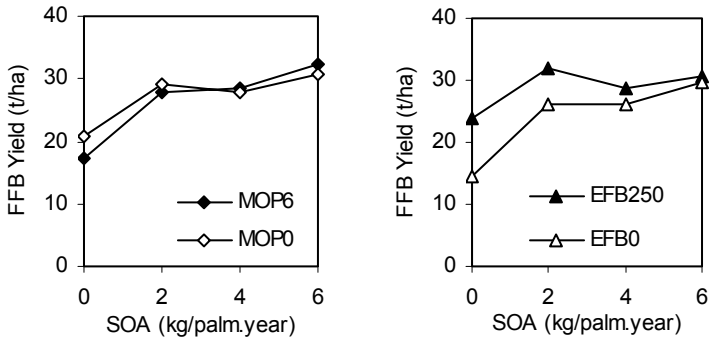


Figure 2. The effects of the interactions between SOA and MOP and between SOA and EFB on FFB yield in 2001 (Trial 312).

Table 6. Effects (p values) of frond (3 vs 17, FR), leaflet vs rachis (LR), MOP and EFB on nutrient concentrations at SOA2 in 2001 (Trial 312). p values < 0.05 are indicated in bold.

	Tissue concentration (% DM)									Conc. (mM in sap)		
	Ash	N	P	K	Mg	Ca	Cl	S	SO_4	K	Cl	SO_4
FR	**<.001**	**<.001**	**0.050**	**<.001**	**<.001**	**<.001**	0.268	0.444	0.731	**<.001**	0.102	**0.012**
LR	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**0.024**	**0.031**	**<.001**
MOP	0.624	0.832	0.442	**0.041**	0.075	**0.027**	**0.003**	0.065	0.199	**0.032**	**0.003**	0.150
EFB	0.085	**0.038**	0.897	**0.007**	0.638	**0.015**	0.305	0.444	0.731	0.200	0.814	0.640
FR.LR	**<.001**	**0.002**	**<.001**	**<.001**	**<.001**	**0.012**	0.268	**0.016**	**0.032**	**<.001**	0.070	**0.006**
FR.MOP	0.961	0.927	0.175	0.058	**0.007**	0.173	0.309	0.339	0.865	0.424	0.421	0.634
LR.MOP	0.458	0.721	0.284	**0.012**	0.146	0.246	**0.015**	0.107	0.202	0.080	**0.029**	0.353
FR.EFB	0.407	0.592	0.748	0.223	**0.007**	0.555	0.172	0.789	1.000	0.306	0.123	0.991
LR.EFB	0.090	0.124	0.039	0.223	0.080	0.738	0.581	0.444	0.505	0.096	0.851	0.801
MOP.EFB	0.298	0.722	0.180	**0.027**	**0.028**	0.051	**0.040**	0.227	0.327	**0.039**	**0.022**	0.674
FR.LR.MOP	0.526	0.636	0.696	0.240	**0.039**	0.315	0.335	0.107	0.229	0.533	0.416	0.626
FR.LR.EFB	0.285	0.336	0.427	**0.015**	**0.018**	0.257	0.286	0.789	0.731	0.081	0.332	0.883
FR.MOP.EFB	0.348	0.373	0.676	**0.031**	0.120	0.555	0.673	0.248	0.292	0.092	0.693	0.384
LR.MOP.EFB	0.366	0.648	0.479	0.418	0.184	0.216	0.139	0.192	0.319	0.493	0.182	0.672

Table 7. Nutrient concentrations in tissues from selected plots in 2001 (Trial 312).

	Tissue concentration (% DM)									Conc. (mM in sap)		
	Ash	N	P	K	Mg	Ca	Cl	S	SO_4	K	Cl	SO_4
Frond 3 Leaflets												
N0 K0 EFB0	8.4	2.40	0.178	1.28	0.29	0.54	0.34	0.14	0.42	196	57.5	26.2
N2 K0 EFB0	7.9	2.61	0.184	1.22	0.26	0.49	0.37	0.15	0.45	181	60.5	27.1
N2 K0 EFB1	7.2	2.91	0.188	1.46	0.24	0.49	0.47	0.16	0.51	214	75.9	30.4
N2 K1 EFB0	7.4	2.62	0.178	1.24	0.23	0.51	0.54	0.14	0.42	191	91.6	26.3
N2 K1 EFB1	7.1	2.76	0.187	1.32	0.23	0.47	0.50	0.13	0.39	174	72.7	20.9
N2 K2 EFB0	7.9	2.73	0.176	1.22	0.24	0.56	0.62	0.15	0.48	174	97.5	27.9
N2 K2 EFB1	7.3	2.72	0.189	1.24	0.23	0.49	0.57	0.16	0.48	174	88.3	27.4
N2 K3 EFB0	8.1	2.70	0.181	1.20	0.24	0.60	0.57	0.15	0.45	167	87.4	25.5
N2 K3 EFB1	7.0	2.63	0.177	1.30	0.23	0.48	0.57	0.15	0.45	189	91.2	26.6
Frond 3 Rachis												
N0 K0 EFB0	3.8	0.26	0.100	1.37	0.07	0.19	0.43	0.06	0.18	173	59.8	9.2
N2 K0 EFB0	4.1	0.29	0.078	1.37	0.06	0.22	0.41	0.08	0.24	158	52.0	11.2
N2 K0 EFB1	4.4	0.35	0.070	1.57	0.05	0.20	0.66	0.07	0.21	170	78.9	9.3
N2 K1 EFB0	4.0	0.36	0.070	1.42	0.05	0.26	0.87	0.09	0.27	158	106.9	12.2
N2 K1 EFB1	4.0	0.38	0.070	1.42	0.05	0.21	0.88	0.09	0.27	144	98.4	11.1
N2 K2 EFB0	4.5	0.32	0.068	1.62	0.05	0.24	1.09	0.06	0.18	167	124.1	7.6
N2 K2 EFB1	4.2	0.39	0.074	1.42	0.05	0.23	0.95	0.08	0.24	142	104.8	9.8
N2 K3 EFB0	4.6	0.35	0.079	1.57	0.06	0.29	1.08	0.07	0.21	166	125.9	9.0
N2 K3 EFB1	4.1	0.38	0.066	1.52	0.05	0.21	0.86	0.06	0.18	160	100.0	7.7
Frond 17 Leaflets												
N0 K0 EFB0	17.4	1.96	0.134	0.59	0.15	0.74	0.26	0.15	0.45	122	59.5	38.0
N2 K0 EFB0	19.5	2.11	0.132	0.63	0.14	0.65	0.30	0.16	0.51	128	67.5	42.3
N2 K0 EFB1	16.0	2.24	0.141	0.65	0.13	0.74	0.44	0.17	0.51	128	95.5	40.8
N2 K1 EFB0	16.5	2.16	0.136	0.57	0.15	0.78	0.50	0.15	0.45	106	102.6	34.1
N2 K1 EFB1	15.6	2.30	0.142	0.61	0.17	0.73	0.49	0.17	0.54	104	92.5	37.6
N2 K2 EFB0	16.3	2.07	0.131	0.61	0.13	0.75	0.55	0.16	0.48	108	107.5	34.6
N2 K2 EFB1	17.4	2.29	0.137	0.61	0.16	0.70	0.48	0.16	0.51	110	95.9	37.6
N2 K3 EFB0	18.4	2.06	0.135	0.57	0.15	0.87	0.49	0.15	0.51	104	98.7	37.9
N2 K3 EFB1	14.5	2.25	0.144	0.69	0.18	0.79	0.52	0.14	0.45	123	102.2	32.6
Frond 17 Rachis												
N0 K0 EFB0	4.6	0.23	0.211	1.20	0.06	0.35	0.13	0.07	0.21	156	18.7	11.1
N2 K0 EFB0	4.5	0.28	0.102	1.28	0.04	0.32	0.20	0.08	0.27	151	26.1	13.0
N2 K0 EFB1	4.4	0.27	0.095	1.37	0.03	0.30	0.60	0.06	0.18	155	74.8	8.3
N2 K1 EFB0	5.0	0.27	0.100	1.37	0.05	0.43	0.95	0.06	0.18	149	113.6	7.9
N2 K1 EFB1	5.1	0.29	0.105	1.47	0.05	0.37	0.92	0.07	0.21	147	101.7	8.6
N2 K2 EFB0	5.0	0.26	0.107	1.47	0.05	0.39	0.91	0.06	0.18	154	105.3	7.7
N2 K2 EFB1	5.3	0.31	0.102	1.52	0.06	0.42	1.07	0.07	0.21	152	117.9	8.5
N2 K3 EFB0	5.2	0.26	0.131	1.47	0.05	0.48	1.14	0.05	0.15	150	128.4	6.2
N2 K3 EFB1	5.1	0.28	0.105	1.67	0.05	0.32	1.01	0.05	0.15	172	114.8	6.3

Trial 324 Nitrogen Source Trial on Higaturu Soils, Sangara Estate

PURPOSE

To test relative effectiveness of different nitrogen fertilisers on Higaturu Soils (Volcanic plains).

DESCRIPTION

Site: Sangara Estate Blocks 2 and 3
Soil: Higaturu family, Deep sandy clay loam with good drainage, derived from volcanic ash.
Palms: Dami commercial DxP crosses replanted in 1996 at 135 palms per hectare.

DESIGN

Five N sources are tested at 3 different rates. The N sources are ammonium sulphate (SOA), ammonium chloride (AMC), ammonium nitrate (AMN), urea and diammonium phosphate (DAP). The rates provide equivalent amounts of N for the different N sources (Table 1). Fertiliser is applied in 3 doses/year. Each treatment is replicated 4 times. There are also 4 zero fertiliser plots at the edge of the trial, giving a total of 64 plots. Data collected from the zero fertiliser plots is not used in the analysis of variance. A basal application of MOP at 2 kg/palm.year (2 doses/year) is applied to all plots. Each of the plots consists of 36 palms, the central 16 being recorded. The trial started in January 2001. This trial is the same design as Trial 325 in Ambogo and Trial 125 in Kumbango. See 2001 Proposals for background.

Table 1. Nitrogen source treatments and levels

	Amount (kg/palm.year)		
Nitrogen Source	Level 1	Level 2	Level 3
Ammonium sulphate	2.0	4.0	8.0
Ammonium chloride	1.6	3.2	6.4
Urea	0.9	1.8	3.6
Ammonium nitrate	1.2	2.4	4.8
Diammonium phosphate	2.3	4.6	9.2
	(g N/palm.year)		
All sources	420	840	1680

RESULT

2001 was the first year of treatments and yield recording in 324. The soil analyses (Table 2) show a chemically fertile soil. pH is neutral-slightly acidic throughout the profile, CEC is moderate, with adequate amounts of exchangeable K and Mg. Organic matter contents and total N contents are also reasonable.

Yields were high and not affected by fertiliser type or rate (Tables 3 and 4). Tissue nutrient contents were not affected by fertiliser rate, but they were affected by fertiliser type, and the interaction between type and rate (Table 6). Leaflet N content was greatest with DAP and urea, and least with AMC (Table 7). The interaction between type and rate showed that increasing SOA rate increased leaf N content, but increasing urea rate decreased it. Increasing urea rate also decreased rachis K content (Table 8).

Table 2. Soil analysis results from samples taken in 2000 (Trial 324). See introductory section for methods.

	Depth	pH	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC	Al	Res. K	Res. Mg	Base Sat.	Organic Matter	Total N	Avail. N	Olsen P	Total P	Sulfate S	Extr. org. S	Boron	P ret.
	(cm)		(cmolc/kg)								(%)	(%)	(%)	(kg/ha)	(mg/kg)					(%)
Rep1	0-10	6.6	0.43	10.7	1.45	<0.05	14.5	<0.1	0.26	20.5	87	4.3	0.26	173	20	458	3	4	0.4	42
	10-20	6.4	0.24	6.5	0.77	<0.05	10.1	<0.1	0.26	20.5	74	1.8	0.11	54	5	584	3	<2	0.2	49
	20-30	6.6	0.29	8.1	1.13	0.06	12.3	<0.1	0.20	26.4	78	1.2	0.07	28	7	710	4	<2	<0.1	71
	30-60	6.7	0.40	9.3	1.92	0.11	15.6	<0.1	0.18	29.9	75	1.0	0.05	<10	15	26	9	2	<0.1	83
Rep 2	0-10	6.1	0.35	7.9	1.44	<0.05	13.1	<0.1	0.20	17.4	74	3.7	0.24	160	16	706	3	4	0.4	33
	10-20	6.4	0.30	8.1	0.94	<0.05	12.6	<0.1	0.20	23.2	74	1.9	0.11	44	8	606	4	2	0.2	58
	20-30	6.6	0.23	8.0	1.05	0.08	11.7	<0.1	0.20	28.8	80	1.0	0.07	20	5	436	4	<2	<0.1	65
	30-60	6.8	0.29	9.8	1.69	0.15	14.8	<0.1	0.28	34.8	81	0.8	0.05	<10	11	710	6	<2	<0.1	84
Rep 3	0-10	6.4	0.38	10.6	1.57	<0.05	16.2	<0.1	0.23	17.6	77	4.9	0.30	180	23	822	3	3	0.7	31
	10-20	6.6	0.33	7.3	0.81	<0.05	10.7	<0.1	0.20	20.3	79	1.8	0.12	57	7	492	4	<2	0.3	46
	20-30	6.8	0.33	9.4	1.17	0.05	13.5	<0.1	0.20	30.7	81	1.1	0.07	17	9	474	6	<2	0.1	64
	30-60	6.8	0.36	11.1	1.84	0.12	17.4	0.1	0.23	35.6	77	0.9	0.05	<10	18	812	11	<2	<0.1	89
Rep 4	0-10	6.2	0.41	8.8	1.55	<0.05	14.2	<0.1	0.18	19.6	76	4.8	0.30	202	19	766	6	3	0.4	32
	10-20	6.3	0.34	6.2	0.78	<0.05	9.8	<0.1	0.20	25.1	76	1.5	0.11	56	4	392	6	<2	0.2	46
	20-30	6.7	0.28	8.8	1.18	0.09	12.9	<0.1	0.20	33.1	81	0.9	0.06	<10	4	422	8	<2	<0.1	69
	30-60	6.7	0.29	9.7	2.08	0.17	15.1	<0.1	0.20	38.0	81	0.8	0.05	<10	9	580	15	2	<0.1	82
Zero	0-10	6.1	0.42	7.4	1.57	<0.05	13.1	<0.1	0.20	21.2	72	4.1	0.25	144	20	782	3	3	0.4	31
	10-20	6.1	0.41	6.6	0.72	<0.05	12.1	<0.1	0.18	22.5	64	2.0	0.17	56	8	538	5	3	0.30	41
	20-30	6.4	0.37	7.4	0.87	0.07	11.7	<0.1	0.23	27.3	75	1.1	0.10	20	8	550	10	<2	0.10	62
	30-60	6.7	0.31	9.3	1.82	0.15	14.4	<0.1	0.23	36.3	80	0.9	0.08	<10	18	992	12	2	<0.1	83

Table 3. Effects (p values) of treatments on FFB yield and its components in 2001 (Trial 324).

Source	Yield	BNO	SBW
Type	0.256	0.279	0.300
Rate	0.402	0.331	0.372
Type.Rate	0.451	0.279	0.852
CV %	8.3	9.9	8.7

Table 4. Main effects of treatments on FFB yield and its components in 2001 (Trial 324). No effects were significant (See Table 3). Values for plots receiving zero N (in brackets) were not included in the analysis of variance.

	Yield (t/ha)	BNO (/ha)	SBW (kg)
Zero N	(32.3)	(2947)	(11.0)
AMC	34.4	3075	11.5
AMN	37.2	3274	11.7
DAP	35.6	3070	12.0
SOA	35.6	3157	11.5
Urea	35.9	3012	12.3
sed	*1.22*	*125.5*	*0.42*
Level 1	36.5	3182	11.7
Level 2	35.3	3133	11.6
Level 3	35.5	3038	12.0
sed	*0.94*	*97.2*	*0.32*

Table 5. Effect of interaction between fertiliser type and rate on FFB yield (t/ha) in 2001 (Trial 324). The interaction was not significant. $Lsd_{0.05} = 4.24$.

	AMC	SOA	Urea	AMN	DAP
Rate 1	33.7	34.2	37.8	39.0	37.7
Rate 2	34.1	35.9	35.3	36.5	34.5
Rate 3	35.4	36.6	34.4	36.2	34.7

Table 6. Effects (p values) of treatments on frond 17 nutrient concentrations in 2001 (Trial 324). p values less than 0.05 are indicated in bold.

	Leaflet								Rachis	
Source	Ash	N	P	K	Mg	Ca	Cl	S	Ash	K
Type	0.192	**0.043**	0.382	0.254	0.725	0.576	0.836	**0.042**	0.851	0.969
Rate	0.347	0.928	0.437	0.338	0.228	0.378	0.899	0.250	**0.010**	0.381
Type.Rate	0.962	**0.041**	0.936	0.759	**0.003**	0.318	0.386	0.726	**0.009**	**0.001**
CV %	5.8	3.0	2.3	6.7	7.8	5.8	11.2	8.2	8.4	8.7

Table 7. Main effects of treatments on frond 17 nutrient concentrations in 2001, in units of % dry matter (Trial 324). Significant effects ($p<0.05$) are shown in bold. Values for plots receiving zero N (in brackets) were not included in the analysis of variance.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	Cl	S	Ash	K
Zero N	(13.9)	(2.46)	(0.151)	(0.8)	(0.22)	(0.84)	(0.40)	(0.145)	(4.5)	(1.47)
AMC	13.6	**2.45**	0.153	0.77	0.24	0.86	0.40	**0.153**	4.1	1.38
AMN	13.2	**2.51**	0.156	0.82	0.23	0.85	0.40	**0.162**	4.0	1.37
DAP	13.8	**2.54**	0.156	0.80	0.23	0.88	0.41	**0.152**	4.1	1.40
SOA	13.9	**2.51**	0.156	0.79	0.24	0.88	0.39	**0.151**	4.0	1.38
Urea	13.4	**2.54**	0.154	0.80	0.23	0.86	0.40	**0.145**	4.2	1.40
sed	*0.32*	*0.031*	*0.001*	*0.022*	*0.007*	*0.021*	*0.018*	*0.005*	*0.14*	*0.050*
Level 1	13.5	2.51	0.155	0.81	0.23	0.85	0.40	0.154	**4.3**	1.41
Level 2	13.8	2.51	0.156	0.80	0.24	0.88	0.40	0.155	**4.0**	1.36
Level 3	13.5	2.50	0.154	0.78	0.24	0.87	0.40	0.149	**4.0**	1.39
sed	*0.25*	*0.024*	*0.001*	*0.016*	*0.006*	*0.016*	*0.014*	*0.004*	*0.11*	*0.038*

Table 8. Effects of interaction between N source and rate on leaflet N and rachis K content (Trial 324).

Leaflet N (% DM), $lsd_{0.05} = 0.11$

	AMC	AMN	DAP	SOA	Urea
Rate 1	2.44	2.48	2.52	2.46	2.64
Rate 2	2.45	2.52	2.55	2.51	2.54
Rate 3	2.45	2.53	2.54	2.57	2.43

Rachis K (% DM), $lsd_{0.05} = 0.18$

	AMC	AMN	DAP	SOA	Urea
Rate 1	1.37	1.38	1.44	1.37	1.50
Rate 2	1.38	1.24	1.22	1.50	1.45
Rate 3	1.40	1.50	1.54	1.26	1.25

Trial 325 Nitrogen Source Trial on Ambogo/Penderretta soils, Ambogo Estate

PURPOSE

To test relative effectiveness of different nitrogen fertilisers on Ambogo / Penderretta soils (Outwash plains).

DESCRIPTION

Site: Ambogo Estate

Soil: Ambogo family, which is of recent alluvially reworked volcanic origin, with silty loam topsoil and sandy loam subsoil, with seasonally high water tables. Penderetta family. Thin dark sandy loam topsoil over sandy loam subsoil derived from alluvially deposited volcanic ash. Mottling due to seasonally high water tables.

Palms: Dami commercial DxP crosses to be replanted in 2001/2002 at 135 palms per hectare.

DESIGN

Five N sources are tested at 3 different rates. The N sources are ammonium sulphate (SOA), ammonium chloride (AMC), ammonium nitrate (AMN), urea and diammonium phosphate (DAP). The rates provide equivalent amounts of N for the different N sources (Table 1). Each treatment is replicated 4 times. There are also 4 zero fertiliser plots at the edge of the trial, giving a total of 64 plots. Data collected from the zero fertiliser plots is not used in the analysis of variance. Each of the plots consists of 36 palms; the central 16 being recorded. The trial started in January 2001. This trial is the same design as Trial 324 in Sangara and Trial 125 in Kumbango. See 2001 Proposals for background.

Table 1. Nitrogen source treatments and levels in Trial 325

	Amount (kg/palm.year)		
Nitrogen Source	Level 1	Level 2	Level 3
Ammonium sulphate	2.0	4.0	8.0
Ammonium chloride	1.6	3.2	6.4
Urea	0.9	1.8	3.6
Ammonium nitrate	1.2	2.4	4.8
Diammonium phosphate	2.3	4.6	9.2
	(g N/palm.year)		
All sources	420	840	1680

PROGRESS

The site was mapped out in 2001. About 100 plots have been planted with the same 16 identified progeny, randomly placed within the plot. At the 2002 SAC meeting it was decided to put this trial on hold, as Trial 324 should provide the necessary information. If this trial does eventually go ahead, the design will be changed to a full factorial with 4 rates (0, 1, 2, 3), rather than just having 4 control plots. That will allow a more powerful analysis of variance. A full factorial design will require 80 plots (5 fertilisers x 4 rates x 4 replicates) rather than the currently planned 64. The difference is due to more plots with no fertliser. The extra control plots will also allow a better assessment of possible plot-to-plot movement of fertilisers.

Trial 326 Nitrogen x EFB Trial on Higaturu Soils, Sangara Estate

PURPOSE

To provide information on the minimum EFB requirements of palms to help formulate fertiliser recommendations on volcanic plain soils

DESCRIPTION

Site: Sangara Estate
Soil: Higaturu family, deep sandy clay loam with good drainage, derived from volcanic ash.
Palms: Dami commercial DxP crosses replanted in 1998/1999 at 135 palms per hectare.

DESIGN

A randomised complete block design with 4 levels of N (SOA) and 3 levels of EFB in all factorial combinations (Table 1) in 5 replicate blocks, resulting in 60 plots. Each plot will have 36 palms; the inner 16 being recorded and the outer 20 acting as guard rows. The plots will also be surrounded by a trench to prevent plot-to-plot poaching. SOA will be applied in 3 doses per year. EFB treatments will be applied once per year. MOP will be applied as a blanket across the trial at the commercial rate of 2 kg/palm in order to maintain adequate K levels in the rachis. The trial has the same design as Trial 327 in Ambogo. See 2001 Proposals for background.

Table 1. Fertiliser treatments and levels in Trial 326.

	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0	2.5	5.0	7.5
EFB	0	130	390	-

PROGRESS

The trial was mapped out in 2001 and will start in 2002.

Trial 327 Nitrogen x EFB Trial on Ambogo/Penderretta Soils, Ambogo Estate

PURPOSE

To provide information on the minimum EFB requirements of palms to help formulate fertiliser recommendations for soils of the outwash plains.

DESCRIPTION

Site: Ambogo Estate

Soil: Ambogo family, which is of recent alluvially reworked volcanic origin, with silty loam topsoil and sandy loam subsoil, with seasonally high water tables. Penderetta family. Thin dark sandy loam topsoil over sandy loam subsoil derived from alluvially deposited volcanic ash. Mottling due to seasonally high water tables.

Palms: Dami commercial DxP crosses to be replanted in 2001/2002 at 135 palms per hectare.

DESIGN

A randomised complete block design with 4 levels of N (SOA) and 3 levels of EFB in all factorial combinations (Table 1) in 5 replicate blocks, resulting in 60 plots. Each plot will have 36 palms; the inner 16 being recorded and the outer 20 acting as guard rows. The plots will also be surrounded by a trench to prevent plot-to-plot poaching. SOA will be applied in 3 doses per year. EFB treatments will be applied once a year. The trial has the same design as Trial 326 in Sangara.

See 2001 Proposals for background. The trial will start 36 – 48 months after replant.

Table 1. Fertiliser treatments and levels in Trial 327.

	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0	2.5	5.0	7.5
EFB	0	130	390	-

PROGRESS

Following the 2002 SAC meeting it was decided to keep this trial on hold.

Trial 328 Nitrogen, Phosphorus and Magnesium Trial on Ohita Soils, Sumbiripa Estate

PURPOSE

To provide information/data for fertiliser recommendations to both estate and smallholders on Ohita Soil Family.

DESCRIPTION

Site: Sumbiripa Estate
Soil: Ohita family, Soils are formed from several shallow recently deposited volcanic ash falls overlying older alluvial surface and are found on the lower terraces. Many of the lower terraces are also mixed with alluvial materials from the Higaturu Soils Family. The topsoil is moderately to strongly developed structure and have rapid permeabilities and excellent physical properties.
Palms: Dami commercial DxP crosses to be replanted at 135 palms per hectare.

DESIGN

It is proposed to have a 3 x 3 x 3 non-confounded factorial in randomised complete block design. Fertilisers will be ammonium sulphate (SOA), triple superphosphate (TSP) and kieserite (KIES). Potassium chloride (MOP) will be applied to all plots. There will be a single replicate of 3 blocks of 27 plots, totalling 81 plots. Each plot will have 36 palms; 20 of the palms will provide the guard row while recordings will be done from the 16 core palms. The plots will also be surrounded by a trench to prevent plot-to-plot poaching. See 2001 Proposals for background. Trial to start in 36 – 48 months after replant.

Table 1.92 Fertiliser treatments and levels in Trial 328.

	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	-	2	4	6
TSP	0	2	4	-
KIE	0	2	4	-

PROGRESS

Waiting replant and maturity. There is only patchy occurrence of the Ohita soil type in the plantation, so it might be difficult to find a large enough site. Following the 2002 SAC meeting it was decided to keep this trial on hold. It is only relevant to smallholders in the Aeka Division, and surveys of tissue nutrient contents in that area will be a more efficient means of determining nutrient limitations there.

Trial 329 Nitrogen, P, K and Mg Trial on Mamba Soils, Mamba Estate

PURPOSE

To provide information/data for fertiliser recommendations to both estate and smallholders in the Kokoda Valley and Ilimo/Papaki Areas on soils that are cation depleted and have high P retention

DESCRIPTION

Site: Mamba Estate Blocks 97 G1
Soil: Dark sandy loam airfall ash overlying coarse to medium textured alluvial materials from the Mount Owen Stanley Ranges.
Palms: Dami commercial DxP crosses were planted from old cocoa plantations at 135 palms per hectare in 1997.

DESIGN

This trial is a 2x3x3x3 confounded factorial of single replicate of 3 blocks of 18 plots, totalling 54 plots. Fertilisers used are ammonium sulphate (SOA), triple superphosphate (TSP), potassium chloride (MOP) and kieserite (KIES) (Table 1). Each plot has 36 palms; 20 of the palms will provide the guard row while recording is done from the 16 core palms. The plots will also be surrounded by a trench to prevent plot-to-plot poaching. The trial area will receive a basal application of borate at 50 g/palm.year. Treatments and yield recording started in September 2001. See 2001 Proposals for background.

Table 1. Fertiliser treatments and levels in Trial 329.

	Amount (kg/palm.year)		
Fertiliser	Level 0	Level 1	Level 2
SOA	-	2	4
TSP	0	2	4
MOP	0	2	4
KIES	0	2	4

PROGRESS

Treatments and yield recording started in September 2001. Pre-treatment soil analyses are shown in Table 2. Exchangeable Mg levels are fairly high, possibly because the site had had kieserite for about 3 years.

Table 2. Soil chemical characteristics for bulked samples taken from each of the three experimental blocks in 2001 (Trial 329)

Depth	pH	Olsen P	Total P	P Ret.	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC	Base Sat.	K/Mg	Res. K	Res. Mg	Exch. Al	Org. Matter	Total N	Avail. N	Org. S	Sulfate S	B
		(mg/kg)		(%)	(cmolc/kg)					(%)		(cmolc/kg)			(%)	(%)	(kg/ha)	(mg/kg)		
Block 1																				
0-10	5.6	22	1670	98	0.37	7.5	1.62	<0.05	25.5	37	0.2	0.23	25.8	0.2	15.6	0.84	137	9	16	0.4
10-20	5.3	8	1980	100	0.16	0.6	0.22	<0.05	16.2	6	0.7	0.33	28.0	0.4	9.4	0.51	51	<2	98	0.2
20-30	5.3	5	1280	100	0.13	<0.5	0.11	<0.05	11.6	<5	1.1	0.38	32.2	0.2	6.3	0.36	23	<2	184	0.1
30-60	5.4	7	926	92	0.14	<0.5	0.11	<0.05	8.1	6	1.3	0.46	40.0	0.1	3.0	0.19	<10	<2	176	0.1
Block 2																				
0-10	5.6	17	1610	99	0.43	6.3	1.41	<0.05	24.2	34	0.3	0.23	25.5	0.2	14.4	0.81	130	8	23	0.4
10-20	5.3	6	1710	100	0.16	0.9	0.24	<0.05	14.9	9	0.7	0.31	30.0	0.3	8.9	0.52	55	<2	133	0.2
20-30	5.4	5	1440	100	0.17	0.6	0.19	<0.05	12.9	7	0.9	0.31	31.0	0.2	7.5	0.38	38	<2	202	0.1
30-60	5.5	7	1010	95	0.18	<0.5	0.11	<0.05	8.4	7	1.7	0.36	38.5	0.1	3.5	0.20	<10	<2	201	<0.1
Block 3																				
0-10	5.8	14	1820	96	0.37	9.3	1.94	<0.05	25.1	46	0.2	0.26	25.1	0.9	13.9	0.81	128	9	16	0.3
10-20	5.6	5	1740	100	0.22	1.3	0.33	<0.05	14.5	13	0.7	0.33	29.4	0.3	9.1	0.52	58	3	75	0.2
20-30	5.6	5	1570	100	0.18	0.7	0.19	<0.05	11.0	10	0.9	0.38	35.4	0.1	6.8	0.40	23	<2	155	0.1
30-60	5.6	7	1000	97	0.17	<0.5	0.14	<0.05	8.5	9	1.2	0.44	40.9	<0.1	4.0	0.23	<10	<2	182	0.1

Trial 330 Grassland Sulphur Trial on Outwash Plains, Parahe Mini Estate

PURPOSE

To provide information/data for fertiliser recommendations to the estate, mini estates and smallholder growers in the grassland areas of Popondetta.

DESCRIPTION

Site: Parahe Mini Estate
Soil: Soils at the grassland area are formed from alluvial volcanic materials. The black top soils are loamy sand to sandy loam and over lay more sandier materials at the subsurface.
Palms: Dami commercial DxP crosses were planted at 135 palms per hectare in 2000.

DESIGN

The trial was planned as a randomised block design with 3 replicates, each containing all factorial combinations of 3 levels of elemental sulphur (powder) and 4 levels of ammonium nitrate (Table 1). Each of the 36 plots will have 64 palms; 48 of the palms will provide double guard rows while recordings will be done from the 16 core palms. There will be no need for trenches to prevent plot-to-plot poaching.

There is no nil N treatment because it was felt landowners might not want very low crop yields in the mini estates. Also it is already known that in Popondetta soils, crop yield can be extremely low (<10 t/ha.yr) in plots not receiving nitrogen fertilisers. The trial will receive an annual blanket application of MOP at the rate recommended for HOP estates on grasslands: 0.5 kg/palm in year 1, 1 kg/palm in year 2 and 2 kg/palm in year 3 and thereafter. (2 doses of 1 kg/palm). SOA was applied in 2000, 2001 and 2002 in order to get the palms and cover crops established. Treatments and yield recording will commence in 2003.

Table 1. Fertiliser treatments and levels in Trial 330.

	Amount (kg/palm.year)			
Fertiliser	Level 1	Level 2	Level 3	Level 4
Elemental Sulphur	0	0.15	0.30	
Ammonium nitrate	0.7	2.0	3.3	4.6

PROGRESS

Plots have been mapped.

Trial 331 Spacing and Thinning For Mechanical In-field Collection Trial, Ambogo Estate

PURPOSE

To investigate the possibilities of field planting requirements, and how best to make use of increased inter-row spacing to facilitate mechanical infield collection.

DESCRIPTION

Site: Ambogo Estate
Soil: Ambogo family, which is of recent alluvially reworked volcanic origin, with silty loam topsoil and sandy loam subsoil, with seasonally high water tables. Penderetta family. Thin dark sandy loam topsoil over sandy loam subsoil derived from alluvially deposited volcanic ash. Mottling due to seasonally high water tables.
Palms: Dami commercial DxP crosses replanted at various densities in April/May 2001.

DESIGN

There are 6 treatments initially of different planting densities but of equilateral triangular spacing (Table 1.). Every third row (33%) in treatments 4, 5 and 6 will be thinned at year 5 after planting while treatments 1, 2 and 3 will remain. The final densities of treatments 4, 5 and 6 will be similar to treatments 1, 2 and 3 but will have increased avenue widths. This will result in a wide avenue interline before the next pair of rows for treatments 4, 5 and 6. Treatment 2 will be used as a control because this is the density at which the plantation is planting. Treatments 1 and 3 are provided for comparisons with treatments 4 and 6 respectively to see the effects from thinning and increased avenue widths. Trial is to start in 36 – 48 months after replant.

Table 1. Treatment allocations in Trial 331.

Treatment No	Initial Density (palms/ha)	Triangular spacing (m)	Density after thinning (palms/ha)	Avenue width (m)	Number of Rows*
1	128	9.5	No thin.	8.23	7
2	135	9.25	No thin.	8.01	7
3	143	9.0	No thin.	7.79	7
4	192	7.75	128	13.43(6.71)	8
5	203	7.55	135	13.08(6.54)	9
6	215	7.33	143	12.70(6.35)	9

( ) Avenue width before thinning
* includes 2 guard rows on either sides of the plots

There are 6 treatments and 3 replicates, totalling 18 plots. Each plot is approximately 1.25 ha therefore a total of 25 ha is used. In each replicate, the treatments are allocated randomly. Plots are separated from each other by 2 rows of palms, however, the avenue widths on either side of the rows will be that of the plot they are surrounding. The avenue width of guard rows of adjacent plots is the average width of the 2 adjacent plots. Within each plot there are 6 subplots of different cover crops randomly allocated and planted across the plot field. Fertiliser application is on a per palm basis during the immature phase. It is proposed that when the palms mature, all density/spacing treatments will receive the same amount of fertiliser on a per ha basis.

PROGRESS

Cover crop seeds were obtained in 2001 and sown in 2002.

AGRONOMY TRIALS IN MILNE BAY PROVINCE

(P. Nelson, M. Banabas)

Trial 502B Nitrogen, Phosphorus, Potassium and EFB Trial, Waigani Estate

PURPOSE

To test the response to N, P and K in factorial combination, with and without EFB, with a view to using EFB to replace or supplement chemical fertiliser.

DESCRIPTION

Site: Waigani Estate, Field 6503 and 6504.
Soil: Plantation family, which of recent alluvial origin.
Palms: Dami commercial DxP crosses. Planted 1986 at 127 palms/ha

DESIGN

Trial 502B relocation is a factorial fertiliser trial with 4 levels of ammonium sulphate (SOA), 4 levels of potassium chloride (MOP), 2 levels of triple superphosphate (TSP) and 2 levels of EFB (Table 1). It has a single replicate (64 plots), and is split into four blocks. Each plot contains 16 core palms, which are surrounded by one guard row and a trench. Trenching was completed in 1995, and the first dose of fertiliser was applied in the fourth quarter of 1994. Applications of EFB started in August 1995. EFB is applied by hand as mulch between palm circles once per year. Fertiliser is applied in 3 doses per year.

Table 1. Amount of fertiliser and EFB used in 2000 (Trial 502b)

	Amounts (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0.0	2.0	4.0	6.0
MOP	0.0	2.5	5.0	7.5
TSP	0.0	2.0	-	-
EFB	0.0	300	-	-

RESULTS

The main effects of the treatments on yield and tissue contents over the course of this trial are shown in Figure 1. SOA and MOP have significantly increased yield in high yielding years such as 1999 and 2000, but the effects were not significant in lower yielding years such as 2001 (Table 2). TSP has tended to decrease yield (Table 3). The effects of two-way interactions on yield in 1999-2001, some significant and some not (Table 2), are shown in Table 4. The effect of SOA was greatest at 4 kg/palm, and was enhanced by a high rate of MOP, the presence of EFB, and the absence of TSP. The effects of MOP and EFB were synergistic, and the effects of both were greatest in the absence of TSP. The effect of the interaction between SOA, MOP and EFB on yield is shown in Table 5.

Tissues from selected plots were sampled and analysed. One lot of sampling was carried out in the conventional manner. Another lot of samples was taken into pre-weighed bags, weighed, oven dried at 70°C and weighed again. This form of sampling has been called ‘alternative sampling’. The alternative samples were taken from frond 3 and frond 17. Tissue nutrient contents are shown in Tables 6-9. The results of conventional and alternative samples for frond 17 were treated as 2 replicates and analysed by analysis of variance to determine the effect of MOP and EFB (Table 4).

There were not sufficient degrees of freedom to analyse the results from alternative leaf sampling alone in this manner.

The combined effects of MOP and EFB on yield corresponded with the highest leaf N, leaf P and rachis K contents being found in plots with MOP2 and EFB1 (SOA2, Frond 17, Table 5). Rachis K content was very low without MOP or EFB (0.54 %, Table 5). Addition of EFB alone had a similar effect on rachis K to 5 kg/palm of MOP.

CONCLUSION

SOA, MOP and EFB all have positive effects on yield in this trial. The effects of SOA and MOP are synergistic, and in the absence of SOA or MOP, EFB is an effective substitute. The effects of SOA and MOP are greatest in high yielding years.

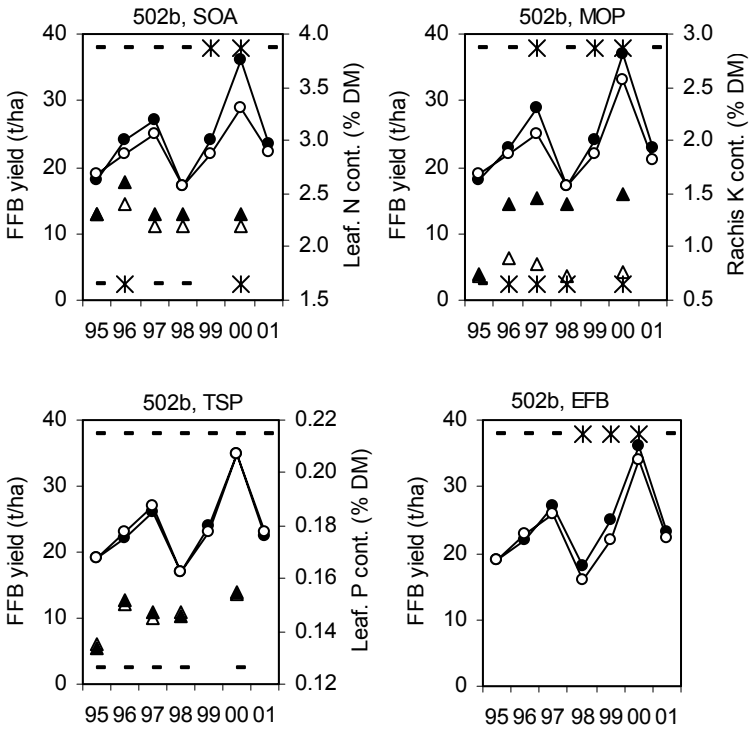


Figure 1. Main effects of SOA, MOP and TSP over the course of Trial 502b. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 502b). p values less than 0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<.001**	**<.001**	**0.039**	0.680	0.783	0.151
TSP	**0.053**	0.718	**0.029**	**0.046**	0.246	0.158
MOP	**0.004**	**0.012**	**0.100**	0.283	0.676	0.243
EFB	**<.001**	**0.019**	**0.002**	**0.064**	0.992	**0.006**
SOA.TSP	0.606	0.789	0.554	0.532	0.585	0.493
SOA.MOP	**0.044**	**0.031**	0.505	0.609	0.813	0.276
TSP.MOP	**0.011**	**0.003**	0.357	0.640	0.471	0.429
SOA.EFB	**0.062**	**0.013**	0.406	0.628	0.638	0.816
TSP.EFB	0.292	0.138	0.571	0.740	0.709	0.876
MOP.EFB	**0.009**	0.438	**0.020**	0.248	0.660	0.055
SOA.TSP.MOP	0.152	**0.028**	0.467	0.642	0.460	0.405
SOA.TSP.EFB	0.205	0.467	0.335	0.873	0.884	0.282
SOA.MOP.EFB	0.225	**0.026**	0.616	0.773	0.789	0.704
TSP.MOP.EFB	0.269	**0.058**	0.601	0.487	0.430	0.950
CV %	3.9	2.8	3.7	11.4	12.2	5.7

Table 3. Main effects of treatments on FFB yield and its components (Trial 502b). Significant effects ($p<0.1$) are shown in bold. CV value is for the Block.Plot interaction.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**24.5**	**1054**	**23.4**	22.8	1049	21.9
SOA1	**26.9**	**1100**	**24.6**	23.3	1024	23.1
SOA2	**27.9**	**1159**	**24.3**	24.0	1070	22.8
SOA3	**27.4**	**1161**	**24.0**	23.1	1039	22.8
sed	*0.37*	*11.2*	*0.32*	*0.94*	*44.9*	*0.45*
MOP0	**25.4**	**1086**	**23.5**	22.1	1017	22.0
MOP1	**26.6**	**1120**	**24.2**	23.9	1069	22.6
MOP2	**27.0**	**1123**	**24.2**	23.8	1059	22.9
MOP3	**27.7**	**1143**	**24.4**	23.5	1037	22.9
sed	***0.37***	*11.2*	*0.32*	*0.94*	*44.9*	*0.45*
TSP0	**27.0**	1120	**24.4**	**24.1**	1066	22.9
TSP1	**26.3**	1131	**23.7**	**22.5**	1025	22.4
sed	*0.26*	*7.9*	*0.23*	*0.66*	*31.8*	*0.32*
EFB0	**25.7**	**1106**	**23.5**	**22.6**	1045	**22.0**
EFB1	**27.6**	**1131**	**24.7**	**24.1**	1046	**23.3**
sed	*0.26*	*7.9*	*0.23*	*0.66*	*31.8*	*0.32*

Table 4. Effect of two-way interactions on FFB yield (t/ha) in 1999-2001 (Trial 502b).

	SOA.MOP, p=0.04 , lsd=1.82			
	SOA0	SOA1	SOA2	SOA3
MOP0	23.6	25.3	26.9	25.6
MOP1	23.3	28.7	26.7	27.7
MOP2	25.0	25.6	28.9	28.4
MOP3	26.0	27.8	29.0	27.9

	MOP.TSP, p=0.01 , lsd=1.29	
	TSP0	TSP1
MOP0	26.2	24.5
MOP1	25.8	27.5
MOP2	27.9	26.1
MOP3	28.1	27.3

	SOA.TSP, p=0.61, lsd=1.29			
	SOA0	SOA1	SOA2	SOA3
TSP0	24.7	27.5	28.0	27.7
TSP1	24.2	26.3	27.8	27.1

	EFB.TSP, p=0.29 , lsd=0.91	
	TSP0	TSP1
EFB0	26.2	25.2
EFB1	27.8	27.5

	SOA.EFB, p=0.06 , lsd=1.29			
	SOA0	SOA1	SOA2	SOA3
EFB0	22.7	26.0	27.2	26.8
EFB1	26.3	27.8	28.6	28.0

	MOP.EFB, p=0.01 , lsd=1.29	
	EFB0	EFB1
MOP0	23.3	27.4
MOP1	25.4	27.9
MOP2	26.7	27.3
MOP3	27.3	28.1

Table 5. Effect of interaction between SOA, MOP and EFB on FFB yield (t/ha) in 1999-2001 (Trial 502b). P=0.225, s.e.d. = 1.051 and l.s.d.(0.05) =2.572. CV (block.units)= 3.9%

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	20.6	22.5	24.9	25.1	MOP0	26.6	28.1	28.8	26.0
MOP1	21.4	28.1	25.8	26.2	MOP1	25.2	29.3	27.6	29.3
MOP2	24.1	26.2	28.7	27.9	MOP2	25.9	25.0	29.2	28.9
MOP3	24.7	27.0	29.5	28.1	MOP3	27.3	28.6	28.6	27.8

Table 6. Significance (p values) for effects of MOP and EFB (at SOA2 and TSP0) on Frond 17 leaflet and rachis nutrient concentrations, expressed as a proportion of dry matter (Trial 502b). Significant values (p<0.05) are highlighted in bold.

	Ash	N	K	P	Mg	Ca	B	Cl
				Frond 17 leaflets				
MOP	**<0.001**	0.056	0.460	0.061	0.756	0.707	0.118	**0.047**
EFB	**0.001**	**0.014**	**0.006**	0.085	0.206	0.395	**0.018**	0.068
MOP.EFB	**<0.001**	**<0.001**	0.055	**0.002**	0.610	0.512	**<0.001**	0.398
CV %	1.6	2.1	5.1	1.5	7.8	5.3	4.8	4.7
				Frond 17 rachis				
MOP	**0.009**	0.830	**<0.001**	0.058	**0.002**	0.151	0.949	**<0.001**
EFB	**0.048**	0.557	**<0.001**	**0.039**	**<0.001**	**0.007**	0.142	**0.003**
MOP.EFB	0.143	**0.036**	**<0.001**	**0.009**	**0.017**	0.487	**0.014**	**0.015**
CV %	8.2	9.0	4.6	7.0	8.7	11.1	11.4	5.8

Table 7. Frond 17 leaflet and rachis nutrient contents from selected plots (all TSP0) in 2001, expressed as a proportion of dry matter (Trial 502b). Figures in bold indicate a significant ($p<0.05$) MOP.EFB interaction. Values in brackets are the $lsd_{0.05}$ values for the MOP.EFB interaction. See table 4 for p values. Values for the SOA0 plot were not included in the analysis of variance.

Frond 17 leaflet contents (% DM, except B, in mg/kg DM)

		Ash	(0.48)	N	(0.11)	P	(0.005)	K	(0.09)	Mg	(0.05)	Ca	(0.08)	B	(1.1)	Cl	(0.06)
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*12.1*		*2.13*		*0.149*		*0.61*		*0.43*		*0.83*		*12.1*		*0.50*	
2	**0**	**15.4**	**11.7**	**2.34**	**2.35**	**0.147**	**0.151**	0.63	0.79	0.34	0.30	0.71	0.67	**12.7**	**8.4**	0.49	0.49
2	**1**	**11.4**	**13.3**	**2.29**	**2.48**	**0.151**	**0.149**	0.73	0.69	0.32	0.25	0.70	0.63	**9.8**	**11.3**	0.50	0.52
2	**2**	**12.4**	**12.5**	**2.26**	**2.57**	**0.144**	**0.154**	0.73	0.73	0.31	0.30	0.68	0.66	**10.1**	**10.4**	0.55	0.52
2	**3**	**13.1**	**12.4**	**2.29**	**2.27**	**0.152**	**0.141**	0.73	0.73	0.33	0.27	0.74	0.68	**9.7**	**9.6**	0.51	0.55

Frond 17 rachis contents (% DM, except B, in mg/kg DM)

		Ash	(0.73)	N	(0.06)	P	(0.012)	K	(0.13)	Mg	(0.02)	Ca	(0.08)	B	(1.5)	Cl	(0.10)
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*2.5*		*0.22*		*0.089*		*0.39*		*0.22*		*0.37*		*5.3*		*0.57*	
2	**0**	2.5	3.9	**0.28**	**0.25**	**0.062**	**0.073**	**0.54**	**1.28**	**0.15**	**0.10**	0.34	0.28	**6.1**	**5.1**	**0.44**	**0.62**
2	**1**	3.0	4.0	**0.22**	**0.28**	**0.065**	**0.078**	**0.83**	**1.34**	**0.11**	**0.09**	0.32	0.29	**4.5**	**6.3**	**0.56**	**0.78**
2	**2**	3.9	4.2	**0.25**	**0.25**	**0.069**	**0.097**	**1.26**	**1.42**	**0.10**	**0.10**	0.29	0.28	**5.1**	**5.5**	**0.79**	**0.87**
2	**3**	4.3	4.4	**0.28**	**0.26**	**0.087**	**0.069**	**1.42**	**1.42**	**0.10**	**0.08**	0.29	0.27	**6.0**	**4.8**	**0.88**	**0.81**

Table 8. Frond 3 and 17 Leaflet and Rachis nutrient contents in sap (mM), Trial 502b.

Frond 3 Leaflets

		K		Cl		SO_4	
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*125*		*77*		*63*	
2	**0**	148	173	85	77	73	71
2	**1**	178	176	92	89	81	83
2	**2**	172	169	92	82	70	68
2	**3**	157	207	80	100	60	74

Frond 17 Leaflets

		K		Cl		SO_4	
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*99*		*91*		*75*	
2	**0**	111	134	82	86	93	84
2	**1**	123	125	101	86	88	76
2	**2**	130	134	95	95	80	75
2	**3**	119	143	83	110	78	78

Frond 3 Rachis

		K		Cl		SO_4	
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*71*		*61*		*20*	
2	**0**	75	149	47	73	17	23
2	**1**	121	148	82	88	19	20
2	**2**	144	148	91	93	19	17
2	**3**	144	142	87	90	19	25

Frond 17 Rachis

		K		Cl		SO_4	
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*35*		*76*		*17*	
2	**0**	104	144	78	69	29	21
2	**1**	106	174	76	110	21	23
2	**2**	170	158	106	100	22	19
2	**3**	173	154	101	95	21	21

Table 9. Alternative sampling, frond 3 and 17 nutrient contents (% DM, except B, in mg/kg) from selected plots (all TSP0) in 2001 (Trial 502b).

		Ash		N		P		K		Mg		Ca		B		Cl		S		SO_4	
										Frond 3 leaflets											
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*7.3*		*2.47*		*0.176*		*0.95*		*0.45*		*0.63*		*10.9*		*0.58*		*0.16*		*0.48*	
2	**0**	8.7	7.5	2.88	2.78	0.184	0.181	1.10	1.24	0.36	0.34	0.59	0.50	11.2	8.8	0.63	0.55	0.18	0.17	0.54	0.51
2	**1**	7.8	8.2	2.78	2.88	0.181	0.187	1.12	1.20	0.36	0.31	0.59	0.54	10.5	9.9	0.58	0.61	0.17	0.18	0.51	0.57
2	**2**	7.7	7.4	2.64	2.78	0.168	0.182	1.18	1.34	0.33	0.32	0.54	0.50	10.4	10.6	0.63	0.65	0.16	0.18	0.48	0.54
2	**3**	7.9	7.4	2.75	2.60	0.178	0.174	1.26	1.34	0.34	0.31	0.52	0.48	10.3	9.9	0.64	0.65	0.16	0.16	0.48	0.48
										Frond 17 leaflets											
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*11.5*		*2.14*		*0.147*		*0.55*		*0.39*		*0.78*		*11.8*		*0.51*		*0.14*		*0.42*	
2	**0**	15.4	12.1	2.40	2.34	0.144	0.152	0.61	0.81	0.28	0.32	0.63	0.71	11.5	8.0	0.45	0.52	0.17	0.17	0.51	0.51
2	**1**	11.8	13.6	2.35	2.42	0.152	0.151	0.67	0.79	0.30	0.30	0.73	0.69	9.4	10.6	0.55	0.54	0.16	0.16	0.48	0.48
2	**2**	12.0	12.4	2.20	2.54	0.139	0.152	0.73	0.81	0.30	0.31	0.64	0.66	9.7	9.7	0.53	0.57	0.15	0.15	0.45	0.45
2	**3**	12.7	12.2	2.41	2.18	0.146	0.143	0.73	0.77	0.30	0.30	0.66	0.66	9.5	8.8	0.51	0.59	0.16	0.14	0.48	0.42
										Frond 3 rachis											
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*2.40*		*0.25*		*0.063*		*0.63*		*0.16*		*0.25*		*6*		*0.54*		*0.06*		*0.18*	
2	**0**	2.94	3.88	0.37	0.34	0.06	0.055	0.91	1.34	0.12	0.08	0.25	0.18	6.3	5	0.57	0.66	0.07	0.07	0.21	0.21
2	**1**	3.45	4.48	0.31	0.44	0.058	0.069	1.16	1.52	0.10	0.09	0.24	0.25	4.9	6.4	0.79	0.9	0.06	0.07	0.18	0.21
2	**2**	3.85	4.35	0.32	0.41	0.049	0.064	1.34	1.57	0.09	0.09	0.19	0.22	5.2	5.9	0.85	0.98	0.06	0.06	0.18	0.18
2	**3**	3.66	3.86	0.32	0.33	0.052	0.054	1.37	1.34	0.08	0.07	0.19	0.16	5.5	4.8	0.83	0.85	0.06	0.08	0.18	0.24
										Frond 17 rachis											
SOA	**MOP**	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1	EFB0	EFB1
0	***0***	*2.75*		*0.25*		*0.102*		*0.30*		*0.27*		*0.45*		*6.9*		*0.65*		*0.05*		*0.15*	
2	**0**	3.22	3.61	0.35	0.24	0.071	0.073	0.65	1.22	0.17	0.1	0.41	0.27	7.9	4.1	0.49	0.59	0.06	0.06	0.18	0.18
2	**1**	3.75	4.12	0.26	0.31	0.075	0.085	0.93	1.37	0.14	0.09	0.42	0.30	5.6	6.0	0.67	0.86	0.06	0.06	0.18	0.18
2	**2**	4.31	4.24	0.27	0.29	0.074	0.089	1.37	1.47	0.11	0.10	0.34	0.29	5.4	6.3	0.85	0.93	0.06	0.06	0.18	0.18
2	**3**	4.38	3.91	0.29	0.26	0.076	0.067	1.47	1.34	0.10	0.08	0.30	0.24	6.6	4.9	0.86	0.82	0.06	0.06	0.18	0.18

Trial 504 Nitrogen and Potassium Trial, Sagarai Estate

PURPOSE

To test the response to N and K and an allowance made for one additional treatment in Sagarai Estate.

DESCRIPTION

Site: Sagarai Estate, Fields 0610, 0611 and 0612.
Soil: Tomanau family, which is of recent alluvial origin, with deep clay loam soils and reasonable drainage status. This is a predominant soil family on the Sagarai Estate.
Palms: Special Dami DxP crosses of 16 progenies that were randomised within each plot. The palms were planted in January 1991 at 127 palms/ha.

DESIGN

There are 64 plots, each with a core of 16 palms. The numbers and weights of bunches from each individual core palm are recorded at intervals of 14 days. In each plot the core palms are surrounded by a guard row and a trench.

The 64 plots are divided into two replicates of 32 plots each. In each replicate there are 32 treatments, made up from all combinations of four levels each of N and K, and two levels of an additional treatment, which is currently vacant (Table 1). The trial commenced in 1994. Fertilisers are applied in 3 doses per year.

Table 1. Types of treatment fertiliser and rates used in Trial 504.

	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0	2.0	4.0	6.0
MOP	0	2.5	5.0	7.5
Vacant Treatment	-	-	-	-

RESULT

The main effects of the treatments on yield and nutrient contents are shown in Figure 1. Yield went through a pronounced trough in 1998-1999 as a result of the 1997 drought, and then peaked in 2000. The MOP effect has been significant for four years and the SOA effect for two years. In 2001 SOA and MOP had similar effects on yield (Tables 2 and 3). There was a significant interaction between them, and yield was greatest at 5 kg/palm MOP and 2 kg/palm SOA over the last three years (Table 4).

Application of SOA and MOP increased N, K, S and Cl contents of all tissues (Tables 5 and 6). The K effects were most pronounced in the Frond 17 rachis.

CONCLUSION

Over the last 2-4 years, the effects of SOA and MOP on yield have become significant. The maximum yield is reached at 5 kg/palm of MOP and 2 kg/palm of SOA.

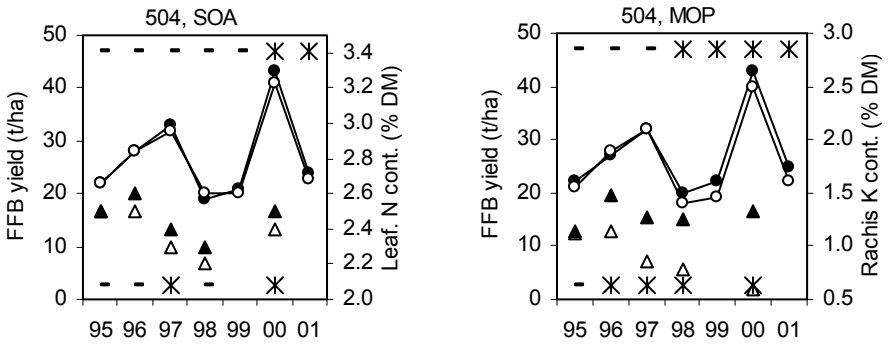


Figure 1. Main effects of SOA and MOP over the course of Trial 504. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 504). p values less than 0.05 are indicated in bold.

	1999-2001			2001		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<.001**	**0.015**	0.536	**0.018**	**0.031**	0.454
MOP	**<.001**	**0.019**	**0.037**	**0.012**	0.236	0.269
SOA.MOP	**0.006**	**0.009**	0.547	0.148	0.131	0.522
CV %	5.0	5.3	4.2	9.9	9.4	6.5

Table 3. Main effects of treatments on FFB yield and its components (Trial 504). Significant effects ($p<0.05$) are shown in bold. CV% is for the block.plot interaction.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**27.6**	**1375**	20.4	**22.7**	**1202**	19.2
SOA1	**29.8**	**1462**	20.7	**24.5**	**1263**	19.8
SOA2	**29.4**	**1438**	20.7	**25.5**	**1332**	19.4
SOA3	**29.3**	**1437**	20.7	**24.0**	**1266**	19.2
MOP0	**27.3**	**1384**	**20.1**	**22.7**	1230	18.9
MOP1	**29.0**	**1424**	**20.6**	**23.7**	1242	19.3
MOP2	**30.4**	**1472**	**20.9**	**25.2**	1304	19.7
MOP3	**29.5**	**1432**	**20.9**	**25.1**	1289	19.6
sed	*0.51*	*24.8*	*0.31*	*0.84*	*42.0*	*0.44*

Table 4. Effect on SOA.MOP interaction on FFB yield (t/ha) in 1999-2001 (Trial 504). Yields >30 t/ha are highlighted in bold.

	SOA.MOP, p=0.006, lsd=2.07			
	MOP0	MOP1	MOP2	MOP3
SOA0	25.9	26.7	**30.1**	27.9
SOA1	25.9	**30.3**	**32.3**	**31.8**
SOA2	28.4	29.6	**30.4**	29.1
SOA3	29.1	29.3	29.7	29.1

Table 5. Nutrient concentrations (conventional analysis) in selected plots: mean of replicates 1 and 2 in block 2 (Trial 504).

		Tissue concentration (% DM, except B, in mg/kg DM)							
MOP	*SOA*	Ash	N	P	K	Mg	Ca	B	Cl
					Frond 17 leaflets				
0	*0*	12.3	2.37	0.151	0.57	0.36	0.77	9.6	0.41
1	*2*	13.0	2.51	0.162	0.56	0.38	0.89	10.7	0.51
2	*2*	11.9	2.54	0.152	0.57	0.37	0.82	9.2	0.51
3	*2*	12.0	2.53	0.155	0.58	0.36	0.87	8.7	0.52
					Frond 17 rachis				
0	*0*	2.8	0.27	0.108	0.56	0.16	0.37	5.9	0.29
1	*2*	3.4	0.31	0.081	0.98	0.15	0.41	5.6	0.74
2	*2*	4.1	0.28	0.104	1.34	0.14	0.40	5.6	0.86
3	*2*	4.4	0.28	0.110	1.57	0.11	0.38	5.6	0.93

Table 6. Nutrients concentrations (alternative analysis) in selected plots: mean of replicates 1 and 2 in block 2.

MOP	SOA	Tissue concentration (% DM, except B, in mg/kg DM)										Conc. (mM in sap)		
		Ash	N	P	K	Mg	Ca	B	Cl	S	SO_4	K	Cl	SO_4
							Frond 3 Leaflets							
0	0	6.3	2.79	0.196	1.12	0.39	0.51	9.9	0.46	0.18	0.50	144	64.4	25.9
1	2	6.3	2.81	0.198	1.20	0.38	0.57	12.1	0.57	0.18	0.53	156	81.0	27.8
2	2	6.4	2.92	0.195	1.30	0.34	0.50	9.6	0.58	0.19	0.56	155	75.7	27.0
3	2	6.7	2.93	0.194	1.33	0.32	0.51	10.7	0.65	0.19	0.56	154	83.1	26.2
							Frond 3 Rachis							
0	0	2.7	0.30	0.093	0.88	0.11	0.20	6.2	0.31	0.06	0.18	90	34.4	7.5
1	2	3.2	0.36	0.078	1.21	0.10	0.23	5.9	0.57	0.08	0.24	133	68.8	10.8
2	2	3.6	0.36	0.082	1.35	0.09	0.21	6.1	0.64	0.08	0.24	118	61.8	8.5
3	2	3.9	0.35	0.084	1.57	0.08	0.20	5.7	0.75	0.07	0.21	141	73.6	7.7
							Frond 17 Leaflets							
0	0	12.9	2.32	0.155	0.61	0.41	0.82	9.9	0.44	0.15	0.45	102	79.8	30.7
1	2	12.0	2.45	0.154	0.59	0.36	0.83	10.3	0.55	0.17	0.50	96	98.1	32.7
2	2	11.8	2.53	0.157	0.60	0.39	0.83	8.7	0.56	0.17	0.51	92	94.7	31.9
3	2	11.7	2.52	0.157	0.64	0.35	0.82	10.3	0.56	0.18	0.54	97	94.0	33.5
							Frond 17 Rachis							
0	0	2.4	0.26	0.105	0.49	0.15	0.35	4.9	0.24	0.06	0.17	52	27.4	7.1
1	2	3.5	0.28	0.084	1.04	0.16	0.44	5.9	0.74	0.07	0.20	94	72.3	7.0
2	2	4.1	0.28	0.105	1.38	0.13	0.39	5.8	0.89	0.08	0.23	133	94.7	8.8
3	2	4.6	0.31	0.114	1.62	0.12	0.40	5.2	0.94	0.06	0.17	151	96.7	6.3
0	0	2.4	0.26	0.105	0.49	0.15	0.35	4.9	0.24	0.06	0.17	52	27.4	7.1

Trial 511 Fertiliser Trial on Interfluve Terrace Soils, Waigani Estate.

PURPOSE

To investigate the response of oil palm to applications of ammonium sulphate, triple super-phosphate, muriate of potash and empty fruit bunch on interfluve terrace soils ("buckshot soils").

DESCRIPTIONS

Site: Waigani estate, Field 8501 and 8502
Soil: Hagita family, texture contrast soils with very slowly permeable clay to heavy clay subsoil and very gravelly loam top soil. Gravel maybe cemented into massive blocks of laterite. Soil dominantly poorly drained. Although these soils are dominantly poorly drained, somewhat imperfectly drained variants with olive grey subsoil have been included into this family. Mostly on gently sloping terraces, but also found on spur crest of hilly terrain.
Palms: Dami commercial DxP crosses. Planted in 1988 at 127 palms/ha.

DESIGN

There are 64 plots each containing 16-core palms. The numbers and weights of bunches for each individual core palm are recorded at intervals of 14 days. In each plot the core palms are surrounded by a guard row and a trench.

There is a single replicate of 64 plots, arranged in 4 blocks, comprising factorial applications of 4x2x4x2 of N, P, K and EFB treatments. The treatments are made up from all combinations of four levels each of N and K and two levels each of P and EFB (Table 1.102). EFB is applied by hand as mulch between palm circles once per year. Fertilisers are applied in 3 doses per year. Trial started in 1994.

Table 1.113 Amounts of fertiliser and EFB used in Trial 511.

Type of Fertiliser or EFB	Levels and amounts (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0.0	2.0	4.0	6.0
MOP	0.0	2.5	5.0	7.5
TSP	0.0	2.0		
EFB	0.0	300		

RESULTS

The main effects of the treatments over the course of the trial are shown in Figure 1. SOA has the largest effect on yield and TSP and EFB also have significant effects. The effects of all treatments have been greatest in the highest yielding year, 2000. The pattern of response was the same in 2001, but the responses were not as large (Tables 2 and 3). There are consistent significant interactions between SOA and EFB and TSP and EFB (Table 4 and Figure 2). In the absence of SOA or TSP, EFB appears to be an adequate substitute, and even at high levels of SOA or TSP, yield is still higher when EFB is also present. MOP has had no significant effect on yield throughout the trial. The effect of the interaction between SOA and EFB at MOP0 and TSP1on yield is shown in Table 5 and the effect of the interaction between SOA, EFB and TSP on yield is shown in Table 6.

The tissue nutrient contents corresponded with the effects on yield (Tables 5 and 6). N and P contents were very low without fertilisers. For frond 17, EFB alone raised leaflet P content more than TSP

alone, and raised leaflet N by about the same amount as SOA3. EFB alone also raised rachis K substantially. The effects were similar for Frond 3.

CONCLUSION

On this soil with very low ability to supply N and P, SOA and TSP have substantial effects on yield. EFB substantially increases yield in the absence of SOA or TSP, and enhances yield when they are present.

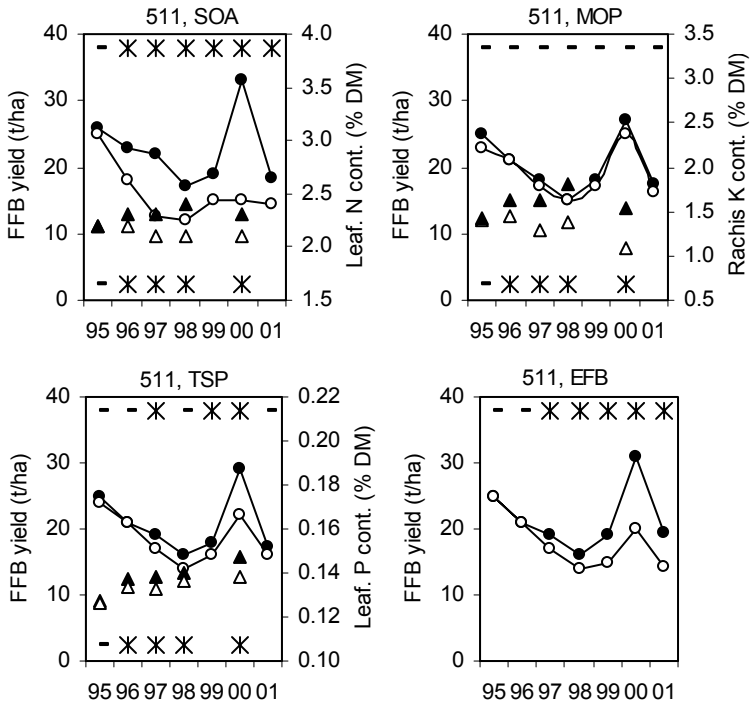


Figure 1. Main effects of SOA, MOP and TSP over the course of Trial 511. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on yield, and along the bottom indicate significance of the main effect on tissue concentration. Stars indicate significance ($p<0.05$) and dashes non-significance.

Table 2. Effects (p values) of treatments on FFB yield and its components in 1999-2001 and 2001 (Trial 511). p values less than 0.1 are indicated in bold.

	1999-2001			2001		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<.001**	**0.007**	**0.003**	**0.018**	0.291	**0.002**
MOP	0.364	0.698	0.673	0.477	0.458	0.280
TSP	**<.001**	**0.014**	**0.046**	0.153	0.453	**0.025**
EFB	**<.001**	**<.001**	**0.001**	**<.001**	**0.017**	**<.001**
SOA.MOP	0.659	0.806	0.771	0.926	0.832	0.449
SOA.TSP	0.117	0.458	0.170	0.774	0.189	0.069
MOP.TSP	0.520	0.501	0.595	0.203	0.480	0.317
SOA.EFB	**0.032**	0.318	**0.084**	**0.012**	**0.036**	**0.010**
MOP.EFB	0.850	0.999	0.818	0.514	0.589	0.682
TSP.EFB	**0.018**	0.108	0.164	**0.035**	0.089	0.152
SOA.MOP.TSP	0.981	0.998	0.945	0.584	0.772	0.598
SOA.MOP.EFB	0.193	0.627	0.625	0.444	0.705	0.161
SOA.TSP.EFB	0.206	0.830	0.606	0.785	0.502	0.189
MOP.TSP.EFB	0.840	0.923	0.893	0.271	0.554	0.635
CV %	10.5	13.4	9.7	16.7	17.2	7.5

Table 3. Main effects of treatments on FFB yield and its components (Trial 511). Significant effects ($p<0.05$) are shown in bold. CV value is for the Block.Plot interaction.

	1999-2001			2001		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**14.7**	**798**	**18.3**	**14.7**	822	17.4
SOA1	**19.1**	**901**	**21.1**	**17.1**	882	19.6
SOA2	**21.2**	**935**	**22.7**	**18.5**	903	20.8
SOA3	**23.5**	**1047**	**22.6**	**19.2**	936	20.8
sed	*0.73*	*43.7*	*0.73*	*1.02*	*53.8*	*0.52*
MOP0	19.1	889	21.4	16.6	841	19.6
MOP1	19.3	924	20.7	16.9	881	19.2
MOP2	19.7	931	21.1	17.9	934	19.4
MOP3	20.4	938	21.6	18.0	888	20.3
sed	*0.73*	*43.7*	*0.73*	*1.02*	*53.8*	*0.52*
TSP0	**18.0**	**867**	**20.6**	16.8	871	**19.1**
TSP1	**21.2**	**974**	**21.8**	18.0	901	**20.2**
sed	*0.51*	*30.9*	*0.51*	*0.72*	*38.1*	*0.37*
EFB0	**16.4**	**818**	**19.7**	**14.9**	**823**	**17.9**
EFB1	**22.9**	**1023**	**22.7**	**19.8**	**948**	**21.3**
sed	*0.51*	*30.9*	*0.51*	*0.72*	*38.1*	*0.37*

Table 4. Effect of two-way interactions on FFB yield (t/ha) in 1999-2001 (Trial 511). Significant ($p<0.05$) interactions are shown in bold.

	SOA.MOP, p=0.66, lsd=3.56			
	SOA0	SOA1	SOA2	SOA3
MOP0	14.4	18.5	20.7	22.7
MOP1	15.1	17.2	21.4	23.6
MOP2	14.3	19.9	21.7	22.9
MOP3	14.9	20.7	21.1	24.9

	SOA.TSP, p=0.12, lsd=2.52			
	SOA0	SOA1	SOA2	SOA3
TSP0	14.2	17.6	19.0	21.1
TSP1	15.1	20.5	23.4	25.9

	*SOA.EFB**, p=0.03**, lsd=2.52*			
	SOA0	SOA1	SOA2	SOA3
EFB0	**10.2**	**15.2**	**18.2**	**21.9**
EFB1	**19.2**	**23.0**	**24.2**	**25.1**

	MOP.TSP, p=0.52, lsd=2.52	
	TSP0	TSP1
MOP0	18.1	20.0
MOP1	17.4	21.3
MOP2	17.9	21.5
MOP3	18.6	22.2

	*EFB.TSP, **p=0.02**, lsd=1.78*	
	TSP0	TSP1
EFB0	**13.9**	**18.8**
EFB1	**22.1**	**23.7**

	MOP.EFB, p=0.85, lsd=2.52	
	EFB0	EFB1
MOP0	15.4	22.7
MOP1	16.2	22.4
MOP2	16.5	22.9
MOP3	17.3	23.5

Table 5. Effect of SOA x EFB interaction on FFB yield (t/ha) at MOP0 and TSP1 in 1999-2001 (Trial 511). There are insufficient degrees of freedom to analyse the four-way interaction statistically; these are simply results from individual plots.

	SOA0	SOA1	SOA2	SOA3
EFB0	9.8	16.5	19.6	22.9
EFB1	18.2	22.2	24.3	26.5

Table 6. Effect of the SOA x EFB x P interaction on FFB yield (t/ha) in 1999-2001 (Trial 511). P=0.206, s.e.d. = 1.455 and l.s.d.(0.05) =3.560. CV (block.units)= 10.5%

	TSP0	
	EFB0	EFB1
SOA0	9.2	19.2
SOA1	13.7	21.6
SOA2	14.2	23.8
SOA3	18.4	23.8

	TSP1	
	EFB0	EFB1
SOA0	11.1	19.2
SOA1	16.6	24.3
SOA2	22.2	24.7
SOA3	25.3	26.5

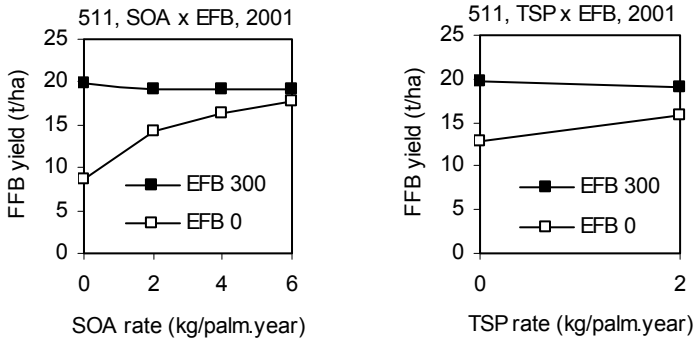


Figure 2. Effects of the interaction between SOA and EFB, and between TSP and EFB on FFB yield in 2001 (Trial 511).

Table 5. Nutrient content of tissues sampled conventionally from selected plots in 2001 (Trial 511).

					Nutrient content (% DM, except B, in mg/kg DM)							
Plot	SOA	MOP	TSP	EFB	Ash	N	P	K	Mg	Ca	B	Cl
					Frond 17 leaflets							
32	0	0	0	0	12.0	1.59	0.117	0.49	0.52	0.81	9.5	0.47
61	0	0	1	0	11.0	1.93	0.124	0.55	0.43	0.64	11.5	0.48
15	0	0	0	1	10.0	2.28	0.137	0.63	0.38	0.71	9.4	0.53
46	0	0	1	1	10.5	2.22	0.145	0.75	0.32	0.71	8.7	0.48
13	1	0	0	0	13.8	1.94	0.123	0.45	0.43	0.82	10.2	0.45
39	1	1	1	1	12.1	2.26	0.148	0.61	0.30	0.72	8.6	0.52
53	2	0	0	0	11.8	2.12	0.131	0.55	0.38	0.70	11.0	0.39
22	2	0	1	0	12.4	2.35	0.140	0.55	0.37	0.76	9.0	0.46
45	2	0	0	1	11.3	2.27	0.142	0.81	0.31	0.73	9.8	0.49
48	3	0	0	0	13.0	2.27	0.130	0.67	0.33	0.70	10.0	0.39
49	3	3	1	1	9.9	2.53	0.146	0.75	0.30	0.62	10.3	0.54
Frond 17 rachis												
32	0	0	0	0	3.7	0.23	0.041	1.22	0.19	0.26	5.0	0.95
61	0	0	1	0	4.4	0.22	0.211	1.47	0.19	0.25	4.8	0.88
15	0	0	0	1	4.4	0.25	0.049	1.77	0.09	0.25	4.5	1.01
46	0	0	1	1	5.8	0.24	0.203	0.83	0.12	0.35	5.1	0.89
13	1	0	0	0	3.2	0.26	0.035	0.71	0.18	0.35	5.2	0.62
39	1	1	1	1	5.2	0.21	0.147	1.77	0.11	0.36	4.9	1.13
53	2	0	0	0	2.7	0.23	0.027	0.71	0.14	0.31	4.5	0.57
22	2	0	1	0	3.6	0.27	0.071	0.81	0.18	0.40	6.0	0.67
45	2	0	0	1	5.0	0.25	0.047	1.88	0.10	0.35	5.3	1.04
48	3	0	0	0	3.5	0.28	0.038	1.05	0.13	0.32	5.6	0.72
49	3	3	1	1	4.8	0.28	0.071	1.67	0.10	0.35	5.9	1.25

Table 6. Nutrient contents in tissues from selected plots (alternative sampling), Trial 511.

					Conc. In % DM, except B & SO_4, in mg/kg										Conc. in sap (mM)		
Plot	SOA	MOP	TSP	EFB	Ash	N	P	K	Mg	Ca	B	Cl	S	SO_4	K	Cl	SO_4
Frond 3 Leaflets																	
32	0	0	0	0	7.1	1.92	0.139	0.95	0.52	0.64	10.80	0.55	0.16	0.48	108	69.1	22.3
61	0	0	1	0	6.4	2.05	0.159	1.24	0.46	0.52	11.30	0.64	0.15	0.45	181	102.9	26.7
15	0	0	0	1	6.6	2.86	0.174	1.24	0.35	0.52	9.10	0.60	0.17	0.51	175	93.5	29.3
46	0	0	1	1	6.6	2.56	0.174	1.34	0.30	0.45	10.30	0.51	0.16	0.48	176	73.7	25.6
13	1	0	0	0	7.1	2.33	0.152	0.91	0.45	0.59	10.00	0.51	0.17	0.51	127	78.3	28.9
39	1	1	1	1	6.9	2.57	0.180	1.30	0.29	0.50	8.80	0.59	0.21	0.63	170	85.2	33.6
53	2	0	0	0	7.1	2.55	0.153	0.99	0.40	0.59	9.60	0.52	0.16	0.48	130	75.2	25.6
22	2	0	1	0	6.9	2.74	0.178	1.10	0.38	0.52	8.50	0.47	0.19	0.57	173	81.6	36.5
45	2	0	0	1	7.3	2.88	0.175	1.30	0.29	0.52	10.30	0.53	0.18	0.54	178	80.1	30.1
48	3	0	0	0	7.5	2.69	0.160	1.03	0.37	0.56	11.20	0.49	0.17	0.51	150	78.9	30.3
49	3	3	1	1	7.3	2.89	0.182	1.22	0.30	0.53	11.10	0.67	0.17	0.51	172	104.1	29.3
Frond 3 Rachis																	
32	0	0	0	0	4.0	0.19	0.037	1.47	0.14	0.23	5.20	0.97	0.07	0.21	170	124.0	9.9
61	0	0	1	0	4.1	0.21	0.096	1.57	0.11	0.17	4.40	1.01	0.06	0.18	191	135.2	8.9
15	0	0	0	1	4.5	0.26	0.050	1.83	0.09	0.25	5.00	1.07	0.07	0.21	125	80.8	5.9
46	0	0	1	1	4.1	0.28	0.083	0.63	0.08	0.20	5.60	0.75	0.07	0.21	59	77.6	8.0
13	1	0	0	0	3.0	0.22	0.030	0.67	0.18	0.34	6.10	0.64	0.06	0.18	43	44.9	4.7
39	1	1	1	1	4.4	0.28	0.074	1.67	0.09	0.23	5.30	1.09	0.05	0.15	162	116.5	5.9
53	2	0	0	0	2.8	0.23	0.026	0.81	0.13	0.26	4.70	0.56	0.05	0.15	88	67.2	6.6
22	2	0	1	0	3.2	0.33	0.061	0.97	0.12	0.23	5.90	0.50	0.09	0.27	100	56.7	11.3
45	2	0	0	1	4.0	0.29	0.042	0.63	0.09	0.24	5.30	0.90	0.08	0.24	61	96.1	9.5
48	3	0	0	0	2.9	0.27	0.029	0.87	0.13	0.26	5.20	0.59	0.06	0.18	93	69.6	7.8
49	3	3	1	1	4.5	0.34	0.057	1.72	0.08	0.24	5.40	1.03	0.06	0.18	148	97.8	6.3
Frond 17 Leaflets																	
32	0	0	0	0	11.9	1.70	0.120	0.41	0.48	0.76	10.30	0.45	0.20	0.60	88	106.3	52.3
61	0	0	1	0	11.7	1.83	0.135	0.61	0.49	0.75	13.30	0.45	0.15	0.45	122	99.2	36.6
15	0	0	0	1	9.9	2.29	0.136	0.69	0.37	0.69	11.40	0.49	0.18	0.54	116	91.2	37.1
46	0	0	1	1	11.1	2.22	0.146	0.77	0.35	0.74	9.00	0.49	0.16	0.48	132	92.6	33.5
13	1	0	0	0	14.3	1.95	0.123	0.43	0.47	0.82	10.50	0.44	0.20	0.60	86	97.6	49.1
39	1	1	1	1	12.2	2.23	0.150	0.69	0.33	0.81	8.60	0.57	0.19	0.54	117	106.4	37.2
53	2	0	0	0	12.1	2.24	0.123	0.51	0.39	0.71	11.70	0.39	0.15	0.45	106	89.6	38.2
22	2	0	1	0	13.4	2.33	0.149	0.55	0.39	0.82	8.90	0.43	0.19	0.57	104	90.0	44.0
45	2	0	0	1	10.9	2.39	0.141	0.81	0.29	0.65	10.00	0.50	0.17	0.51	140	95.2	35.9
48	3	0	0	0	12.0	2.19	0.121	0.61	0.30	0.63	10.80	0.38	0.16	0.48	119	81.7	38.1
49	3	3	1	1	10.1	2.59	0.156	0.81	0.31	0.69	10.80	0.55	0.16	0.48	144	107.9	34.7
Frond 17 rachis																	
32	0	0	0	0	3.7	0.20	0.035	1.24	0.18	0.23	4.60	0.92	0.08	0.24	154	126.4	12.2
61	0	0	1	0	4.3	0.22	0.228	1.47	0.20	0.24	4.70	0.89	0.06	0.18	182	121.2	9.0
15	0	0	0	1	4.3	0.32	0.046	1.77	0.09	0.22	5.60	1.02	0.07	0.21	152	96.4	7.3
46	0	0	1	1	5.7	0.25	0.217	2.08	0.12	0.36	6.50	0.91	0.07	0.21	230	110.8	9.4
13	1	0	0	0	2.8	0.23	0.029	0.87	0.13	0.24	5.00	0.58	0.06	0.18	115	84.2	9.6
39	1	1	1	1	5.0	0.23	0.145	1.88	0.11	0.37	4.60	1.22	0.06	0.18	196	140.2	7.6
53	2	0	0	0	3.0	0.24	0.025	0.75	0.16	0.32	4.90	0.64	0.04	0.12	91	85.4	5.9
22	2	0	1	0	3.4	0.26	0.075	0.79	0.18	0.41	5.40	0.65	0.09	0.27	71	64.3	9.9
45	2	0	0	1	5.2	0.25	0.046	0.77	0.11	0.37	5.40	1.05	0.06	0.18	79	118.9	7.5
48	3	0	0	0	3.5	0.22	0.026	1.03	0.13	0.33	5.00	0.69	0.05	0.15	119	87.6	7.0
49	3	3	1	1	5.0	0.30	0.079	1.88	0.10	0.35	5.00	1.34	0.05	0.15	198	155.4	6.4

Trial 512 Monitoring of POME Blocks

PURPOSE

To determine the effect of palm oil mill effluent (POME) on oil palm growth and soil properties. For background, see Trail 109a in 1986 Annual Report.

DESIGN

Three areas, similar in soil type and topography, but with different histories of POME application (Table 1) have been monitored since 1995. Soils were analysed on a 6 monthly basis between 1995 and 2002.

Table 1. Location and treatment of the monitored areas (Trial 512).

Estate	Block	Code	Treatment	Area (ha)
Waigani	6602 & 6603 (86A2)	OP	Receiving POME	58
Hagita	6304 & 6305 (86A3)	NOP	Received POME since 1998?, but not before	50
Hagita	6306 (86A4)	NP	No POME application	4

RESULTS

POME is known to have high biological oxygen demand (BOD), low pH and high K content. Samples taken in 1994 also show moderate contents of N, Ca and Mg (Table 2).

Table 2. Concentration (mg/L) of nutrients in samples taken from POME ponds in 1994.

Pond	N	P	K	Ca	Mg	Mn	B	Cu	Zn
1	921	195	2028	502	438	4.8	1.8	1.42	2.08
2	308	127	1521	353	311	4.7	0.87	0.36	0.98
3	171	70	1014	231	211	6.0	1.2	0.09	1.16
4	232	79	831	861	490	13.1	1.5	4.33	3.42

Although it should be kept in mind that the blocks are not quantitatively comparable, the following differences are apparent. Yield has tended to be slightly less in the POME block than in the control block (Figure 1). Tissue contents of N and P are at least as high in the POME block as in the control block, and rachis K contents are substantially higher (Figure 1). POME application has increased soil pH and cation exchange capacity throughout the profile, and increased the amount of total N, extractable P and exchangeable K (Figure 2). The change in soil K has been the largest of the changes. Despite a general increase in soil fertility, yields have not increased. This may be due to negative effects of POME that have not been measured. The most likely explanation would be a decrease in aeration due to the high BOD of the POME. Cover crops are also destroyed by POME and it may be that removal of their beneficial effects, such as surface soil structure perhaps, has limited yield. Finally, the incidence of Ganoderma in POME blocks is higher than in comparable non-POME blocks.

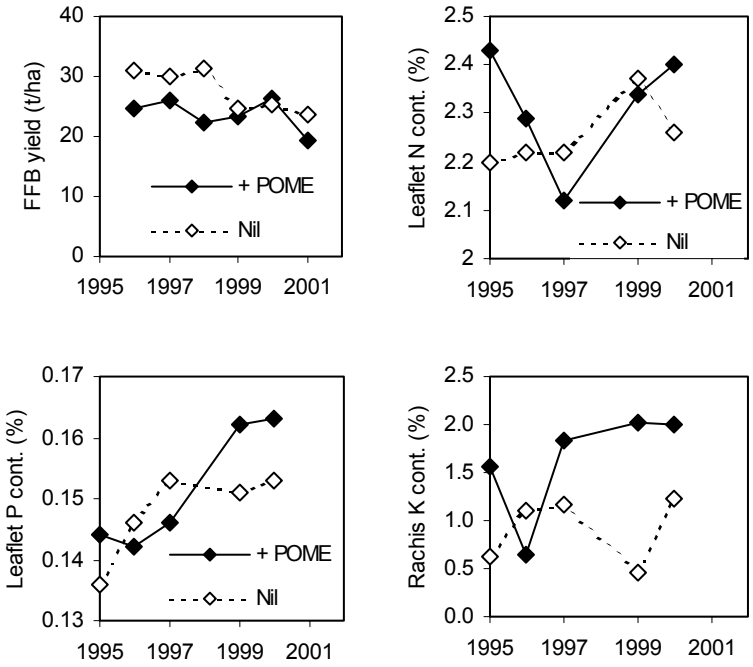


Figure 1. Effect of POME application (Blocks 6306 and 6602) on FFB yield and Frond 17 N, P and K contents (Trial 512).

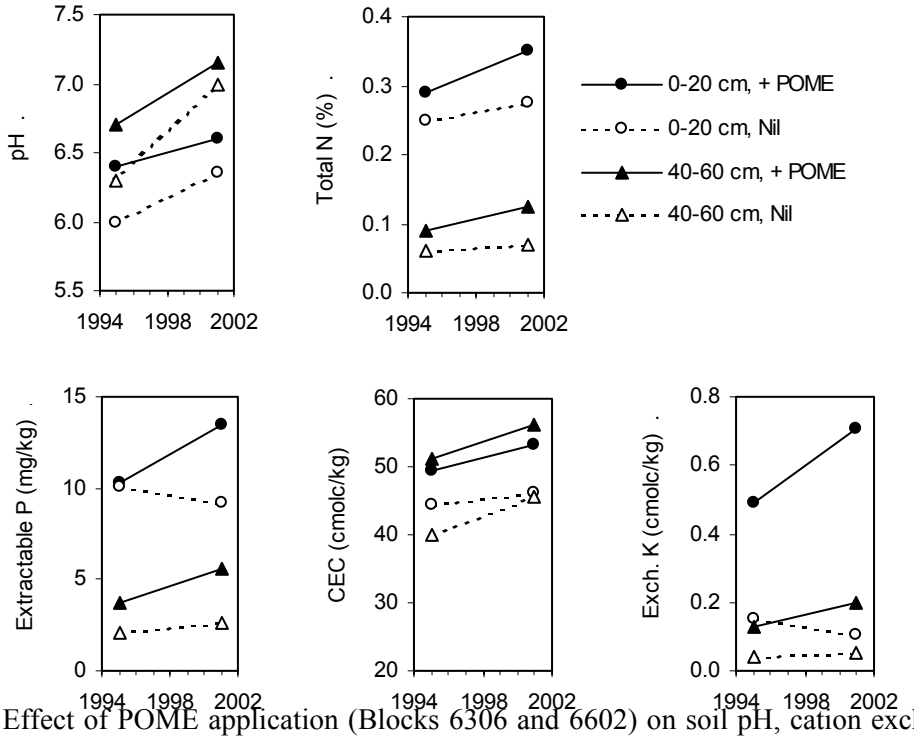


Figure 2. Effect of POME application (Blocks 6306 and 6602) on soil pH, cation exchange capacity (CEC) and N, P and K contents (Trial 512).

Trial 513 Spacing and Thinning For Mechanical In-field Collection Trial, Padi padi

PURPOSE

To investigate the possibilities of field planting requirements, and how best to make use of increased inter-row spacing to facilitate mechanical infield collection.

DESCRIPTION

Site: Padi padi Estate, Block 1051
Soil: Tomanou soil family. Deep black and very dark brown clay and silty clay topsoils grading into dark yeloowish brown clay B horizons overlying dark yellowish brown and very dark brown silt clay subsoils
Topography: Flat
Landuse prior to this crop: Mostly savanna
Palms: To be planted

DESIGN

The design is the same as Trial 331. There are 6 treatments initially of different planting densities but of equilateral triangular spacing (Table 1.). Every third row (33%) in treatments 4, 5 and 6 will be thinned at year 5 after planting while treatments 1, 2 and 3 will remain. The final densities of treatments 4, 5 and 6 will be similar to treatments 1, 2 and 3 but will have increased avenue widths. This will result in a wide avenue interline before the next pair of rows for treatments 4, 5 and 6. All treatments are replicated 3 times. Within one of the replicates, plots with different cover crops will be established. The trial will start when the area is cleared and planted in 2002. Fertiliser application will be on a per palm basis during the immature phase. It is proposed that when the palms mature, all density/spacing treatments will receive the same amount of fertiliser on a per ha basis.

Table 1. Treatment allocations in Trial 513.

Treatment No	Initial Density (palms/ha)	Triangular spacing (m)	Density after thinning (palms/ha)	Avenue width (m)	Number of Rows*
1	128	9.50	No thin.	8.23	7
2	135	9.25	No thin.	8.01	7
3	143	9.00	No thin.	7.79	7
4	192	7.75	128	13.43(6.71)	8
5	203	7.55	135	13.08(6.54)	9
6	215	7.33	143	12.70(6.35)	9

( ) Avenue width before thinning
* includes 2 guard rows on either sides of the plots

PROGRESS

Block was cleared in 2002.

2. SMALLHOLDER STUDIES

(Dr. G. Curry[1], G. Koczberski[1] and Prof. K. Gibson[2])

The ACIAR-funded smallholder study examining socio-economic factors affecting productivity among LSS and VOP smallholders ended in December 2001. The twelve-month study was a collaborative project between PNGOPRA, the ANU and Curtin University with the primary aim of the research being to recommend ways to improve smallholder oil palm productivity. The project received strong support from the oil palm companies, OPIC and the smallholders. The results of the study have been disseminated at several seminars both in PNG and in Australia and a report from the study was completed in January 2002. Three hundred copies of the report have been distributed to industry stakeholders, other tree crop research organisations, National Agricultural Research Institute, government departments, the World Bank university libraries and overseas funding agencies.

At the beginning of 2002 ACIAR extended funding for the smallholder project for a further 12 months to help implement some of the recommendations of the study. The project "Monitoring interventions deriving from the study on improving productivity in the smallholder oil palm sector of Papua New Guinea" include the following objectives:

- Monitor and evaluate the introduction of a new payment card for smallholders.
- Strengthen the Mama Lus Frut Scheme at Popondetta, through working with OPIC and the company and using OPRA staff to support the project.
- Make a preliminary exploration of the land tenure issues associated with mini-estates and assess the potential risks of this intervention.
- Communicate the success of recent smallholder interventions in the oil palm industry to other tree-crop export industries in PNG.

The main focus of the extension project is for the research team to work in collaboration with OPIC and NBPOL to design, monitor and support the introduction of a new payment card for smallholders. The new card is called the mobile card. The project extension will allow the research team to examine the impact of the mobile card upon production, household income and distribution, and family and community cohesion.

Alternative Payment Systems for Smallholders – the mobile card

A major finding of the research to date is that incomplete harvesting is a primary determinant of low yields from smallholdings. The research traced underharvesting, among other factors, to both labour shortages and under-utilisation of labour. Labour shortages can be ongoing as in the case of young families, elderly settlers without sons living on the block, or blockowners with multiple blocks or off-block employment. Labour shortages can also be temporary, the result of illness, or, as in the case of coastal VOPs, a seasonal abundance of fish or better returns on other cash crops. However, underharvesting also results from complex social forces and structural barriers that prevent labour from being deployed and adequately remunerated. For example because of incomplete, deferred or non-payment of family labour (e.g., to brothers, wives, children), or of hired labour (e.g., youth groups), the supply of labour for oil palm harvesting and block maintenance is constrained as people withdraw their labour. This results in a great deal of under-utilised labour, particularly among the under-employed youth on the more heavily populated blocks on the LSS schemes. Thus, one solution to underharvesting is to find a way to tap this under-utilised labour on the smallholder blocks.

Research into the reasons for the success of the Mama Lus Frut Scheme provided ideas about how an alternative smallholder payment system should be designed to encourage full harvesting. The study

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[2] Australian National University, Canberra

identified the following three key principles underpinning the success of the mama card. These include:

1. Direct payment for labour by the company. Low rates of loose fruit collection by women prior to the mama card were the result of limited remuneration for their labour and lack of payment certainty for their labour expended in loose fruit collection. Women relied on their husbands to give them some of the oil palm income on paydays, but the social pressures on men to redistribute this income and engage in beer drinking meant that wives, who received less priority in this redistribution than other claimants, often missed out or received an amount less than the value of their labour contribution.

   The under-utilisation of women's labour was correctly identified by OPIC as resulting from an ineffective payment mechanism for their labour. OPIC saw that this problem could be overcome by a payment system that guaranteed direct payment to women. By paying women directly for loose fruit collection, NBPOL removed much of the uncertainty surrounding payment to women when they relied on their husbands to remunerate them from the papa cheque. Because loose fruit collection is a separate process from harvesting fresh fruit bunches (FFB) and loose fruit can be easily distinguished from FFB, it was relatively easy for the loose fruit to be stacked and weighed separately from the FFB, thereby making it possible to guarantee payments to women. Thus, a "labour contract" between the company and women can be fulfilled.

   The separate payment card for women also means that it is easier for men to remunerate women's labour for other forms of work such as block maintenance (and also to contribute to the upkeep of the household). Payment for work in fruit by placing FFB on the mama net means that men are able to circumvent the often-considerable social pressures on them to redistribute income when this income is in the form of cash. In this way, payment in fruit rather than cash is more likely to lead to the "labour contract" being fulfilled between husband and wife.

2. Cashless transactions are attractive forms of payment for blockholders. For the reasons outlined above, many blockowners are reluctant or unable to pay cash for labour. Yet, most men are willing to place FFB bunches on the mama card which they see as their financial contribution to the upkeep of the household. Prior to the introduction of the mama card many men were reluctant or unable to hand over a share of the oil palm income to their wives and this was the cause of many domestic disputes. It is much easier for men to give FFB to their wives rather than cash because competing claims on fruit are virtually absent. So, the cashless transaction of placing FFB on the mama card circumvents the excessive demands on cash, and women are effectively guaranteed a contribution to the household from their husbands.

3. Allows for flexible labour practices and new payment arrangements to emerge. Because of the absence of loan deductions on the mama card when it was initially introduced, it has enabled more flexible labour practices and payment systems to emerge both within and between blocks. Some examples of the labour flexibility afforded by the mama card are lending the card to children to pay school fees, to visitors for the purchase of travel tickets home, or to help relatives out of financial difficulties or to fulfil customary obligations. It has also become an important avenue for women to organise their own cash and labour transactions. This not only raises women's social status, but increases oil palm productivity as inter-block co-operation in oil palm production rises. The enhanced labour flexibility provided by the scheme has increased smallholders' motivation to produce oil palm as they are now more able to meet their socio-economic needs and obligations.

   Also, the existence of two payment cards on the one block has opened up multiple ways of allocating oil palm labour and income within and between households. This has enabled smallholders to tailor their labour and income strategies to their own particular situations on the blocks. This is especially useful to smallholders given the complexity and diversity of family situations and needs now characterising Hoskins LSS. In essence, the mama card has

broadened the range of options and choices open to families and has given them greater flexibility in how work and income are allocated, usually in ways that have tended to raise smallholder productivity.

In reviewing the reasons for the success of the Mama Card we identified how a new payment system that guarantees payment for labour and allows for greater labour and payment flexibility might work. The idea here was to trial an initiative to facilitate across-block labour flexibility to encourage more complete harvesting and thus raise productivity. The trial entails a payment card that differs from the existing mama and papa cards in that it is not tied to a particular block. The new card is mobile in the sense that it can be used to pay labour for harvesting and block maintenance on any LSS or VOP block which requests labour. The mobile card has the potential to facilitate labour mobility across blocks and sections, and even subdivisions.

Payment for the labour of the mobile card worker/team is in FFB with a specified proportion of the harvested fruit being used to remunerate the mobile cardholder (ideally the percentage split between the blockowner and mobile cardholder would be made by NBPOL's payment system). In this way the reluctance or inability of blockholders to pay cash for labour is circumvented, and the work team is guaranteed timely payment. Also, because the transaction is cashless, this labour arrangement will probably be much more attractive to blockholders because they are not required to outlay any cash in advance, and nor is it necessary for them to retain a portion of their monthly oil palm cheque for the payment of hired labour. Thus the probability of the blockholder not complying with the labour contract is greatly reduced.

For blockholders experiencing labour shortages and VOP smallholders with a range of cash crops and subsistence options, the mobile card offers a way to significantly increase income without additional inputs of their own labour. Also, for smallholders experiencing temporary disruptions to oil palm production through illness or cultural proscriptions against working during mourning periods, for example, the mobile card offers a means to maintain productivity and income.

For labourers or work teams, the benefits are likely to be significant, especially if they are able to negotiate contracts with VOP blockholders where productivity is lower and many blocks are not in production. Apart from significant productivity gains in the smallholder sector, other anticipated benefits of the mobile card include:

- Abandoned blocks brought into production.
- An increase in the amount of smallholder income subject to debt recovery.
- Promotion of replanting by providing an alternative income source.
- Improved block maintenance, fertiliser application rates, etc.
- Utilisation of surplus labour on LSS and VOP blocks.
- More regular harvesting leading to better quality fruit at the mill.

In terms of a target group for this intervention, it is important that potential participants in the scheme have the labour capacity to commit fully to the scheme. The MLFS was successful because a previously unremunerated group of people (women) were brought into oil palm production. Another group currently being identified to participate in the trial is the large number of under-employed young men, many of whom are the sons of settlers living on highly populated blocks.

Introduction and Monitoring of the Mobile Card

Since April 2002 the smallholder team at OPRA has been working closely with OPIC (Hoskins) in the design and establishment of the mobile card trial. The trial is expected to commence in the beginning of July with up to 30 mobile cards issued across the LSS and VOP subdivisions. Those selected for the trial must meet two or more of the following criteria:

- The applicant (male/female, individual/group) has a good production track record and/or is known to be a reliable and hard worker.

- The applicant has limited access to oil palm income (e.g., from a recently poisoned block, high population block and/or conflicts over income on block, etc).
- The applicant comes with a recommendation from the OPIC Divisional Manager.
- The applicant has access to tools and harvesting nets (either their own or an OPIC kit hire).

ACIAR project funds have been used to employ an OPIC officer to assist with the introduction of the mobile card and the identification of potential mobile cardholders and blockholders interested in employing mobile card labourers. The officer is assisting with the negotiation of contracts between blockowners and mobile cardholders, and is responsible for monitoring the use of the card and dealing with problems that arise.

As OPIC and NBPOL prepare the groundwork for the introduction of the mobile card trial in July, the research team together with OPIC have been involved in:

- Formulating the final rules and regulations on how the mobile card will be used and by whom.
- Promoting the mobile card among smallholders. Various mediums have been used including radio programmes, community meetings with smallholders and individual block visits.
- Carrying out smallholder post-harvest surveys on LSS and VOP blocks to estimate the amount of fruit lost each harvest round and recording harvesting rates for the various planting phases on the blocks.
- Identifying blocks and individuals that would benefit most from the mobile card.
- Interviewing mobile cardholders selected for the trial to collect information on the economic and social environment on their blocks.

Following the introduction of the mobile card by OPIC, OPRA will begin monitoring and evaluating the impacts of the card. Data will be collected over a six-month period and will focus on the impacts (both positive and negative) of the mobile card on mobile cardholders' block and on blocks where the mobile card is used. Surveys will focus on production, farming practices, inter and intra household income distribution and labour arrangements, debt repayments and family welfare.

Mini Estates

As noted above, a further objective of the project extension is to make a preliminary exploration of land tenure issues associated with mini-estates and the potential risks of this intervention. In all oil palm schemes, except Bialla, the oil palm companies are establishing mini-estates to expand oil palm production. Mini-estates are arranged under lease, lease-back regulations in which customary landowning groups register as Incorporated Land Groups (ILGs). The ILG then leases the designated land to the State which then leases it back to the ILG (the lease is registered under the Land Registration Act). The ILG then sub-leases the registered land parcel to the company on a 20 or 40 year lease. The company manages the estate, and the land owning group receives annual land rental fees and royalty payments. At Hoskins, ILGs are also issued with company shares. The shift to mini-estate production is driven largely by the restrictions on private companies obtaining alienated state land for plantation development and in part by the interest of local landowners to enter agricultural sub-lease agreements with the oil palm companies.

Mini-estates are a recent phenomenon and undergoing rapid expansion, yet the long-term socio-economic impacts are little understood and difficult to predict. There are also potential investment risks for the companies given the long lease periods and the experiences of other industries of lease, lease-back models of resource development (e.g., mining and forestry). Of particular concern for landowners is how to ensure that the benefits from mini-estate development flow to all members of the community, especially women and groups holding secondary rights in the resource. The research team will examine the various mini-estate models at each project site, and interviews with companies

and landowners will explore land tenure issues, second-generation issues, economic benefits for communities, and the social impacts of mini-estates. Some work has been completed at Hoskins and Popondetta and visits to Milne Bay and New Ireland are scheduled for October/November 2002.

Bialla Oil Palm Scheme

In May 2002 OPRA began work on a smallholder study in the Bialla scheme. The Bialla scheme was omitted from the earlier study in 2000-1 because company support for the study was not guaranteed. With a change of management in mid 2001, Hargy Oil Palm Company requested OPRA to include Bialla in the smallholder study.

Data were collected over a four week period in May/June, 2002. The study began with a workshop with OPIC officers to identify the main constraints on smallholder productivity and the primary factors explaining variations in productivity between growers. Several research questions emerged from the OPIC workshop that helped shape research design and data collection. The research among smallholders employed semi-structured interviews, case studies, questionnaire surveys and community meetings. Over 200 blocks were visited in all three divisions. The main areas of data collection were:

- Block planting and replanting details
- Block population and demographics
- Labour supply and agronomic practices
- Household labour and income decision-making
- Factors influencing household and family members' participation in oil palm production
- Constraints on production
- Impacts and perceptions of agricultural extension.

Data entry and analysis will begin in August with a draft report released in October 2002.

While in Bialla the research team also looked at the Community Oil Palm Estate Developments (COPED). COPED is an alternative model to mini-estates. In the COPED model the community develops and manages their own oil palm estate (ranging in size from 20 ha to over 600 ha) with technical and credit support provided by the company. The community estates provide an interesting contrast to the lease, lease-back system and a comparison will be made in terms of the financial returns and risks for landowners and companies.

3. ENTOMOLOGY

(Dr. R. Caudwell)

1. Integrated management of Sexava pests of oil palm

Introduction

The principal pests of oil palm in PNG are a group of species from the Tettigoniidae family (Orthoptera), collectively known as Sexava. Four species of Sexava are pests of oil palm in PNG, *Segestes decoratus* Redtenbacher and *Segestidea defoliaria defoliaria* Uvarov in West New Britain Province, *Segestidea novaeguineae* Brancsik in Oro Province, and *Segestidea gracilis* in New Ireland Province. These insects cause damage by feeding on the oil palm fronds and defoliation levels can be very severe where high population densities occur. During the last six years an integrated pest management (IPM) system has been developed for sexava. This IPM system has the following components:- (1) knowledge of the biology and ecology of the pest, (2) economic thresholds, (3) monitoring system for the pest, (4) precise targeting of chemical control agents, (5) biological control and (6) cultural control. This is summarized in Figure 1.

Knowledge of the biology and ecology of the pest (*by Bill Page*)

During 2001 Bill Page of the Natural Resources Institute in the UK visited PNG to advise on Sexava population dynamics. During the visit two main techniques were used to gather information on Sexava population dynamics:

(1) The collection of adult female Sexava from the field and examination of the potential number of eggs that they are capable of laying, and how this is achieved in the field (looking for multiple layings and egg resorption).

(2) The surveying and collection of eggs from the ground (which are normally laid singly but can be found in groups of up to four) and examination to determine whether there could be techniques for showing the potential for mass hatchings. The latter could be due to large numbers of developing eggs having come out of a period of senescence (diapause), all at the same time.

Neither of these two approaches has been used before for Sexava by previous researchers.

Results of these studies showed that:

(a) Female Sexava have a potential to lay up to 100 eggs or more during their life (previous work in the laboratory on coconut suggested an average of only 40 eggs). The eggs may be laid in batches of up to 14 per egg-laying session. This suggests that females, which are poor fliers, have to come down to the ground regularly from the protective canopy of the oil palm trees (up to 12-15m above the ground) to lay and may therefore be much more vulnerable to predation and possibly control. Evidence from the field females dissected so far suggests that most eggs develop fully in the ovaries and few are resorbed. Long-term monthly collection and dissection of females to look at egg development in the ovaries would show any seasonal/ weather-correlated changes in egg laying potential which might contribute to upsurges.

(b) Eggs can be monitored in known low-level damage outbreaks by digging transects from the tree trunks (3m x 0.5m used in the study) and counting the number of hatched eggs, dead eggs and viable eggs. By dissection of the viable eggs and examining the embryos the proportions of young close to hatching can be found and any mass hatching predicted. Long-term monitoring of eggs by monthly survey would show any seasonal/ weather-correlated changes in numbers of eggs per unit area (which can be linked to the female collection results) and also numbers of eggs hatching at any one time. The latter would help to show whether eggs are in fact coming out of diapause en masse causing possible upsurges in population and subsequent damage.

Monitoring system for the pest

Since 1995 a regular programme of training in entomology has been conducted for plantation workers, smallholder growers, and extension officers. This has involved both formal and informal training, as well as features on rural radio stations. The result is that most people that are directly associated with oil palm growing in West New Britain Province are now able to recognize the very early signs of insect damage. The training programme that was undertaken in 2001 is given in Table 2.1.

Precise targeting of chemical control agents

The control of a large and rapidly increasing Sexava population is dependent on the use of precisely targeted chemical control agents. This involves the use of trunk-injected methamidiphos, and involves the application of 10mls of neat formulation into a single 1.5cm diameter hole, 15cm deep and drilled at a 45^{o} angle into the trunk, 1m above the ground. The active ingredient persists for approximately 60 days in the leaf tissue of the palm. A follow up treatment is required after approximately 12 weeks to coincide with the emergence of nymphs from eggs laid by the original pest population.

The oil palm growing areas in West New Britain and New Ireland that required chemical treatment for economically significant levels of Sexava damage during 2001 are shown in Table 2.2. From the table it can be seen that during the year there were 13 outbreaks that were recommended for chemical treatment, with a total area of approximately 1398 ha. The oil palm growing areas in West New Britain that required chemical treatment for economically significant levels of Sexava damage during 1996, 97,98, 99, 2000 and 2001 are shown in Table 2.3.

Biological Control

Egg parasitoids

Leefmansia bicolor and *Doirania leefmansi* have been reared in the laboratory for several years. They are reared on Sexava eggs and then released into oil palm growing areas where low-level Sexava populations are present. Several million of these egg parasitoids are usually released into the field each year. Table 2.4 gives details of the releases of egg parasitoids during 2001.

Figure 1. A summary of the IPM system that has been developed for Sexava pests of oil palm in PNG.

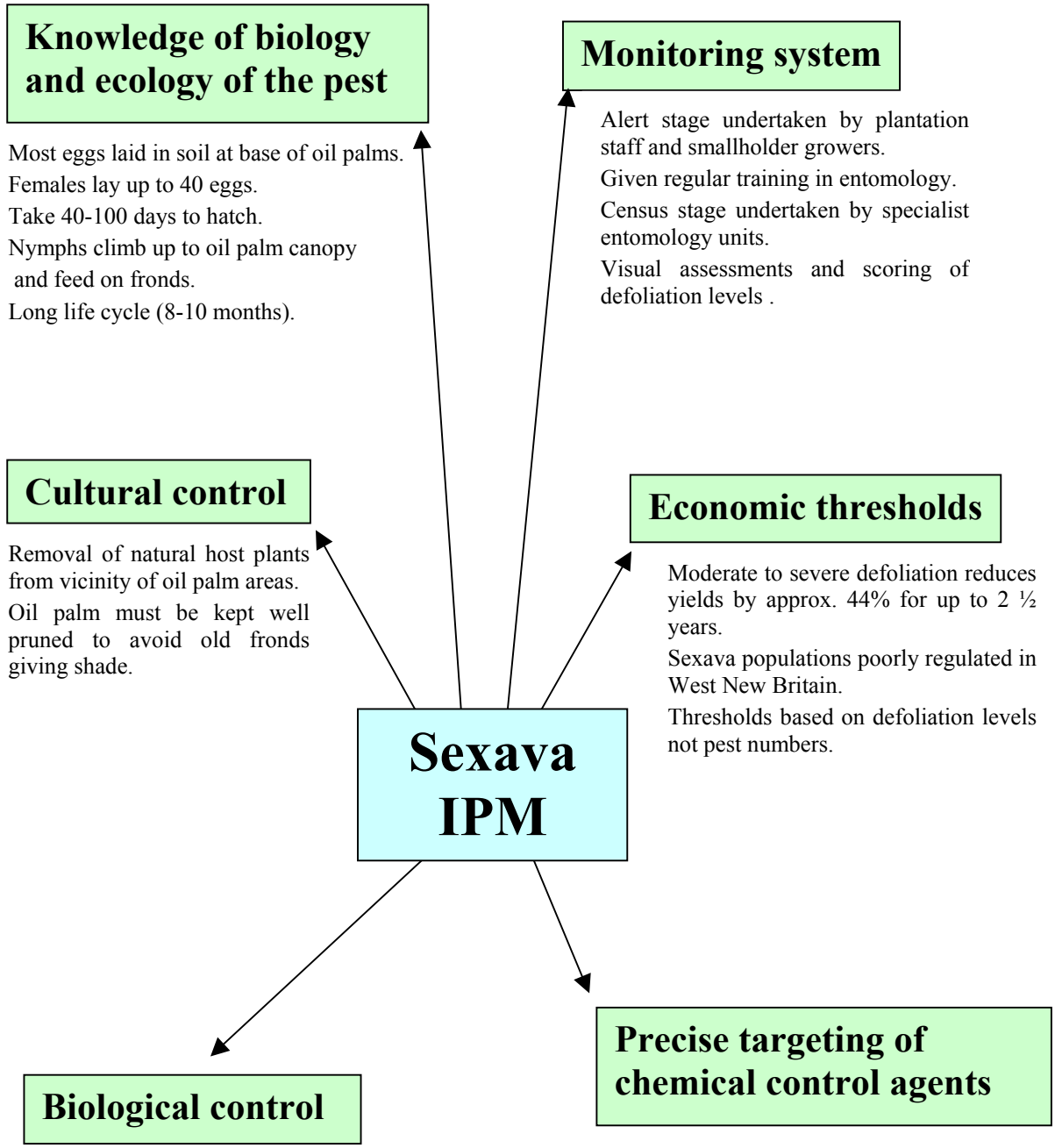


Table 1. A summary of the entomology training programme for 2001.

Month	Plantation / smallholder group	Activity
June	Higaturu Oil Palms	Entomology training course
	Higaturu Oil Palms	Entomology training course
	Higaturu Oil Palms	Entomology training course
	OPIC, Popondetta project	Entomology training course
July	OPIC, Bialla project	Farmer field day at Kabaiya
August	Milne Bay Estates	Entomology training course
	Milne Bay Estates	Entomology training course
	Milne Bay Estates	Entomology training course
	OPIC, Milne Bay project	Entomology training course
September	Hargy Oil Palms	Entomology training course
	Hargy Oil Palms	Entomology training course
	Hargy Oil Palms	Entomology training course
	OPIC, Bialla project	Entomology training course
October	Poliamba Oil Palms	Entomology training course
	Poliamba Oil Palms	Entomology training course
	OPIC, New Ireland	Entomology training course

Table 2. The oil palm growing areas in West New Britain that required chemical treatment for economically significant levels of Sexava damage in 2001.

Date	Plantation / Smallholders	Site	Approximate Area (ha)	Volume of formulation (l)
26 Feb	NBPOL, Mosa Group	Togulo	32	80
19 Mar	NBPOL, Kapiura Group	Malilimi	60	150
21 Jun	Hoskins Smallholders	Ganeboku VOP	2	4
26 Jun	Hoskins Smallholders	Kavui	19	48
06 Jul	Bialla Smallholders	Kabaiya	200	500
12 Jul	Bialla Smallholders	Wilelo	240	600
15 Aug	NBPOL, Mosa Group	Togulo	80	200
16 Aug	NBPOL, Kapiura Group	Bilomi	150	375
30 Aug	Bialla Smallholders	Tiauru	112	280
03 Oct	Bialla Smallholders	Balima	96	240
01 Nov	Poliamba, New Ireland	Kafkaf	161	403
02 Nov	NBPOL, Mosa Group	Togulo	70	175
05 Dec	Bialla Smallholders	Wilelo	176	440
		Total	1,398	3,494

Table 3. The oil palm growing areas in West New Britain that required chemical treatment for economically significant levels of Sexava damage in 1996, 97,98, 99, 2000, and 2001.

Year	Approx. area (ha)	Volume of formulation (l)
1996	910	2,275
1997	215	538
1998	36	90
1999	548	1370
2000	2,592	6,481
2001	1,398	3,494

Table 4. The oil palm growing areas in West New Britain in which Sexava egg parasitoids were released during 2001.

Location	Estimated number of *L. bicolor* expected to emerge
NBPOL	
Bebere Division 2	4,600
Bilomi Division 1	6, 660
Dami OPRS	3,400
Togulo	6,660
Numundo	4,440
Smallholders - Hoskins	
Kavui	3,200
Sarakolok	3,750
Siki	2,750
Hargy	
Navo plantation	53,000
Smallholders - Bialla	
Bayia	3,250
Barema	8,000
Soi	3,500
Tiauru	5,250
Wilelo	5,300
VOP – Central Nakania	
Milikina	3,000
Sege	5,250
PNGCCRI – Kerevat ENBP	16,850
Total	138,860

Strepsipteran Parasites

The EU-funded Sexava project focused on attempts to transfer the strepsipteran parasite, *Stichotrema dallatorreanum,* from Oro to West New Britain and New Ireland Province. During the project the parasite has been introduced into the oil palm growing areas of West New Britain and New Ireland in an attempt to get it established in field populations of *S. defoliaria, S. decoratus,* and *S. gracilis.* The nymphs of these three species have been infected with *S. dallatorreanum* in the laboratory, then been released at regular intervals into a series of trial areas. Almost 10,000 infected insects have now been released into more than 20 trial sites. Surveys have been undertaken in the release areas to determine the degree of infection by the parasite in subsequent generations of Sexava populations.

Information gathered from the release sites has shown that *S. dallatorreanum* can complete its life cycle in the field populations of *S. defoliaria* and *S. decoratus* in West New Britain. There is also evidence to suggest that the parasite is spreading from the original release sites to infect Sexava in surrounding areas. The releases that have been made into smallholder areas in West New Britain seem to have been particularly effective; especially at Siki, Kapore, Tamba, Sarakolok and Kavui. As damage levels in these areas were reaching the thresholds for chemical control when the introductions took place. Subsequently the damage levels then improved significantly during the months and years following the release of the parasite, and no new outbreaks of Sexava have since been reported in any of these areas. Furthermore, field studies have demonstrated that fourth and fifth generation parasites are infecting Sexava in these areas.

The evidence from West New Britain therefore suggests that our research into the biological control of Sexava has been a success; with *S. dallatorreanum* demonstrated to be an effective biocontrol tool for Sexava integrated pest management. However, although the presence of the parasite will suppress and even prevent Sexava outbreaks, it must be emphasized that it cannot be used against a large, and already established outbreak. Evidence from New Ireland suggests that the introductions of the parasite will not be effective if the Sexava population is already large and increasing rapidly. In this case, the only effective control is the use of insecticide by trunk injection. The parasite should therefore be used as part of an overall integrated pest management system for Sexava. Both the parasite and Sexava host lack mobility, and this limits the distribution of the parasite, thus the requirement for widespread and area-wide releases, which are logistically difficult. A project proposal was submitted to the EU at the end of 2001 to fund the area-wide releases of the parasite. Unfortunately no funding was forthcoming, and so the problems associated with the area-wide releases of the parasite remain unresolved.

Details of the field releases up to the end of 2001 are given in Table 5

Table 5. Details of field releases of S. dallatorreanum during 2000 and 2001

Site	Site location	Date	Sexava species	No.
1	Siki smallholders	Feb-Jun 00	*defoliaria*	593
2	Dami plantation	Feb-Jun 00	*decoratus* and *defoliaria*	668
3	Kapore smallholders	Jun-Sep 00	*defoliaria*	606
4	Kavui smallholders 1	Sep-Dec 00	*defoliaria*	499
5	Tamba smallholders	Feb-Mar 01	*decoratus* and *defoliaria*	793
6	Sarakolok smallholders 1	Mar-Apr 01	*decoratus* and *defoliaria*	562
7	Kapso, Poliamba	Apr-Nov 01	*gracilis*	209
8	Luburua, Poliamba	Apr-Sep 01	*gracilis*	469
9	Sarakolok smallholders 2	Apr-May 01	*decoratus* and *defoliaria*	922
10	Sarakolok smallholders 3	May-Jul 01	*decoratus* and *defoliaria*	322
11	Baia, Poliamba	May-Aug01	*gracilis*	267
12	Kafkaf, Poliamba	May-Oct 01	*gracilis*	349
13	Piere, Poliamba	May-Nov01	*gracilis*	289
14	Kavui smallholders 2	Aug-Oct 01	*decoratus* and *defoliaria*	513
15	Numundo Plantation	Oct–Dec 01	*decoratus*	396
16	Medina, Poliamba	Nov-Dec 01	*gracilis*	324
17	Lak, Poliamba	Sep-Dec 01	*gracilis*	165
18	Mar, Poliamba	Oct-Dec 01	*gracilis*	50
19	Soi, Bialla	Nov-Dec 01	*defoliaria*	35
20	Balaha, Bialla	Nov-Dec 01	*defoliaria*	274
			Grand total	**8,305**

2. Insect pollination of oil palm

Introduction

Elaeidobius kamerunicus was introduced into Papua New Guinea in 1982. This resulted in significant improvements to oil palm pollination, similar to those in Malaysia as described by Basri (1984). The introductions thereby improved fruitset levels and oil extraction ratios, and hence increased yields. The introductions of the pollinating weevil made a significant contribution to the economic viability of the oil palm industry in PNG, and was particularly helpful to the smallholder sector because yields were significantly increased with no direct cost to the farmers, and this continued in the medium to long term.

Recently Ming (1999) highlighted concerns regarding the periodic occurrence of poor pollination and yield (drop by as much as 30%) in certain locations in Malaysia. Ming (1999) reported that low weevil populations have been observed to be associated with the problem and suggested that this may be caused by the direct or indirect effects of weather, or due to parasitism by the nematodes *Aphelenchoides bicaudatus* and *Cylindrocorpus* sp. enhanced by weather change. Ming (1999) also suggested that a second pollinator, e.g. *E. subvittatus* may be able to ovecome this situation, and hence complement *E. kamerunicus.* Ming (1999) concluded that a thorough study on this subject is of the utmost urgency.

Rao and Law (1998) reported on the problem of poor fruitset in parts of East Malaysia. These authors highlighted that large sums of money are being lost each year because of seasonal reductions in FFB, OER and KER because of poor fruitset. The poor fruitset is reported to be due to poor pollination five months earlier when weevil numbers are drastically low. The authors suggest that poor pollination could be due to (1) insufficient viable pollen, (2) reduced pollinating activity by the pollinating weevil, and (3) combinations of (1) and (2). Research undertaken at Pamol since 1992 has ruled out low pollen viability as a likely cause of poor fruitset. It was found that the seasonal low fruitset is due to poor pollination because of insufficient weevils (Rao and Law, 1988). Weevil numbers fell dramatically when their breeding sites, the male inflorescences, became less abundant, and this was coincident with extensive infection by parasitic nematodes and unfavourable weather. Rao and Law (1998) regarded the nematode infection of weevils as an intractable problem. They suggested that the present weevil populations, derived from only a few pairs, may be suffering inbreeding depression, and hence more rapidly succumb to nematode parasitism. Furthermore, it is suggested that these weevils lacked the features necessary for adaptation to wet conditions. Syed has suggested the immediate action of importing *E. kamerunicus* from Peninsular Malaysia and, subsequently, other *Elaeidobius* species from Africa. Rao and Law (1998) considered that a complex of pollinating insects, some of whose niche is not the oil palm inflorescence may eventually be necessary.

Rao and Law (1998) highlighted that suggestions of importing fresh batches of *E. kamerunicus* or indeed other species of pollinating insects from Cameroon requires some priority research into some key issues. For instance, in their native Cameroon, weevil populations were also observed to decline in the rainy season but the reduction was less pronounced. It would therefore be useful to determine the cause of the decline in native Cameroon. A high proportion of the dead pupae and weevils of the original importation into Malaysia were nematode infected (Kang *et al.*, 1982) and hence destroyed. So the nematodes that are now causing the problems were probably brought in with the original populations.

Rao and Law (1998) considered that the suggestion of inbreeding depression, or extreme homozygosity, raises the question of why the effects were not manifested sooner after the introduction given the weevil's short generation time. Furthermore, populations at other localities, some experiencing seasonal wet weather, also grew from a limited number of mating pairs. They suggest that it would therefore be interesting to find out how potentially serious the nematode parasitism is in these areas. Rao and Law (1998) concluded that containing nematode parasitism requires an understanding of the manner of parasitism and the predisposing factors favouring the rise in nematode parasitism in the weevil population. They also highlighted that the introduction of new weevils into a

given area requires the predetermination of levels of resistance, or at least heterozygosity, in sub groups if they exist and in different species on the weevil in the genera.

Although excellent levels of fruitset are being achieved in most project areas within PNG it is considered that urgent action is necessary to address the sustainability of the current levels of insect pollination, as well as to possibly make improvements for the future. The current population of pollinating weevils within Papua New Guinea is derived from a relatively small number of weevil individuals introduced from West Africa in 1982. It is therefore apparent that the oil palm industry in PNG faces the same problems as in other areas of South East Asia, that the narrow genetic base of the weevil population poses a very significant risk to viable and sustainable production.

An initial, two-year research project, funded by the European Union, was undertaken between 2000 and 2002. This involved collaboration between the Oil Palm Research Association in Papua New Guinea, CABI Biosciences in the UK, and the University of Cape Coast in Ghana.

The objectives of the project were:

(1) To screen the existing *E. kamerunicus* populations within PNG for evidence of infection by the nematodes *Aphelenchoides bicaudatus* and *Cylindrocorpus* sp., or any other species of nematode, or other parasites and pathogens.

(2) To determine the degree of genetic separation between weevil populations in Papua New Guinea and natural populations in West Africa, using the amplified fragment length polymorphism (AFLP) technique.

(3) To assess the potential to improve the genetic base of the existing population of *E. kamerunicus* within Papua New Guinea as well as on a regional level. This could be done by the introduction of fresh batches of the same weevil species, or possibly by the introduction of one or a number of new species of pollinating insects from West Africa or South America.

Depending on the outcome of (1), (2), and (3) further work was planned after this initial project, as this work is considered to be of high priority to the oil palm industry in all areas of South East Asia that are dependent on introduced weevils for effective pollination.

The results of the first phase of the project are described here.

2.1. Parasitism of *E. kamerunicus* populations (*David Hunt*).

Collections of weevils were made by Dr Rob Caudwell (PNGOPRA) and brought to CABI Bioscience, Egham as fixed and/or live insects. Weevils were collected from oil palm plantations in Papua New Guinea, Ghana and Costa Rica. An additional population was also received from Sumatra. The sampling site data are as follows.

Weevils were collected from sixteen sites in Papua New Guinea and New Britain:

New Ireland	Lamerika *
	Kabil
Milne Bay	Waigini *
	Baraga
Oro Province	Sangara *
	Embi
West New Britain	Dami *
	Kumbango *
	Kavugara *
	Kautu *
	Hargy *
	Bebere
	Haella
	Numundo
	Karausu
	Maliilimi

Collections of weevils were either preserved in formaldehyde (*) or alcohol, or kept alive and returned to the UK where live beetles were selected and frozen at –80°C until required for DNA analysis. The abdomen of weevils preserved in alcohol became very flattened and tough and were extremely difficult to dissect. As a result, most of these accessions were not dissected.

A single population from was collected from Bah Lias Research Station, nr. Medan, Sumatra in May 2001. Weevils were also collected from Costa Rica in June, 2001. The Costa Rican collection sites were as follows:

Coto 1
Coto 2
Celates
Mirador
Quepos 1
Quepos 2

Collections of weevils were preserved in dilute formaldehyde. One population (Quepos) was kept alive and returned to the UK where live beetles were selected and frozen at –80°C until required for DNA analysis.

Nine samples of weevils were collected in December 2000 from oil palms at various sites in Ghana according to the list below.

Site 1	Kade, Eastern Region
Site 2	Ajukato, Eastern region
Site 3	Benso Oil Palms, Western Region
Site 4	Sekondi School, Western Region
Site 5	Twifo Oil Palms, Central Region
Site 6	Ankaako, Central Region (between Twifo and Cape Coast)
Site 7	Assin Dadieso, Central Region
Site 8	Egyirkrom, Central Region
Site 9	Ewusi, Western Region

Collections of weevils were either preserved in dilute formaldehyde or kept alive and returned to the UK where live beetles were selected and frozen at –80°C until required for DNA analysis.

As these Ghanaian collections comprised a mixture of weevil species, outside assistance was required in order to accurately discriminate *Elaeidobius kamerunicus* from the swarm. Weevils were individually identified to species and sexed by Dr Richard Thomson, Natural History Museum, London, UK. In addition to *Elaeidobius kamerunicus*, the collections also contained other pollinator species in the same genus, viz. *E. bilineatus*, *E. plagiatus* and *E. subvittatus*. Occasional examples of other curculionids also occurred.

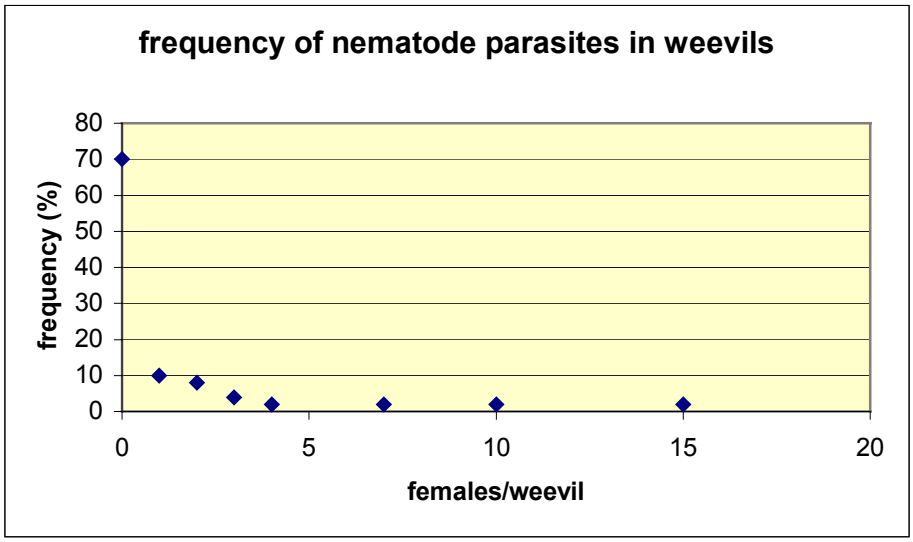
Materials and methods

Dissections were carried out under the stereomicroscope at a magnification of ×25 and ×50. Individual beetles were placed in a small drop of fixative in a Petri-dish and, using fine watchmaker's forceps, mounted micro-pins and a fine syringe needle, the elytra were removed and examined for nematode dauerlarvae and ectophoretic mites. The abdomen was then carefully dissected and examined for internal nematode parasites (mature females, eggs and/or juveniles). Instruments were rinsed between dissections to avoid cross-contamination. The original intention was to dissect 50 beetles of each sex, but this was not always possible due to limited material of *E. kamerunicus* in some samples from Ghana. Early results indicated that there were no differences in nematode infection rate between males and females and so in most accessions only females were dissected.

Results

A preliminary examination of a population of weevils, forwarded by Rob Caudwell from Papua New Guinea before the project began, showed 30% parasitism by an entomopathogenic nematode with a mean of 3.7 (range: 1-15) obese females, plus numerous eggs and juveniles, per infected weevil (Fig. 2). This frequency distribution, corresponding more or less to a Poisson distribution, indicated that in this population about 70% of the infected weevils were parasitized by only a single female nematode and that 90% of the infected weevils contained three or fewer mature female nematodes, although occasional beetles carried a very much higher burden. It should, however, be borne in mind that a single female entomoparasitic nematode has a substantial fecundity and may produce literally hundreds of offspring.

Figure 2.



Subsequently, when the project proper began, many more samples were received and the results of these dissections are summarised in Tables 6, 7, 8, 9 and 10. Overall data are presented in Table 11. The previous study referred to above (*i.e.* the one carried out before the funded project commenced) had revealed that there were no sexual differences in parasitism by the nematode. As a result, only female weevils were dissected for the majority of sites. The number of parasitic females per weevil varied considerably, the lowest number being one and the highest 15. Most weevils infected by the mature female nematodes also carried a considerable burden of eggs and various juvenile stages of the nematode parasite. In heavily infected weevils, almost all the haemocoelic cavity appeared to be occupied by the various stages of the parasite.

The accessions from Papua New Guinea revealed that some weevil populations were apparently free of the nematode whereas in others the parasite was present in 50% of the beetles examined. Low infection rates seemed to be prevalent in accessions from West New Britain where nematode parasites were found in three (Kumbango, Kavugara and Kautu) of the five accessions examined. Over the five sites from West New Britain the infection rate varied from 0% to 10% with a mean value of 4.8%. The mean number of mature parasitic females per infected weevil ranged from 1.4 to 2.0 with a mean of 1.8. The accession from Baraga, Milne Bay showed a 50% infection rate with a mean of 1.6 female nematodes per beetle while Waigini, the other site from Milne Bay, had a much lower percentage infection (4%). The accession from Sangara, Oro Province, although only 8% parasitized, had a mean of 2.5 female nematodes per infected beetle whilst Embi, also from Oro Province, was 20% infected with a mean of 1.8 female parasites per infected weevil. Other accessions from Lamerika (New Ireland), Dami and Hargy (both from West New Britain) revealed no parasitic nematodes, although they might still have been present, but at a much lower incidence. It is planned to re-visit these samples at a later date to check whether this is indeed the case. Ectophoretic mite burdens were absent in the Papua New Guinea weevil accessions.

The accessions from Ghana, on the other hand, proved to be free of nematode parasitism apart from a single female weevil from Kade, Eastern Region. This infection was represented by a solitary female nematode, a number of juveniles and eggs and several immature males. Ghana weevils often carried large burdens of ectophoretic mites, indeed the sub-elytral space was often crammed with such passengers. Percentage infestation with ectophoretic mites ranged from a low of 2% at Benso Oil Palms (Western Region) to a high of 48% at Assin Dadieso (Central Region), the mean infestation rate being 20%. Although data are limited, the mites appeared to be most prevalent in the accessions from the Central Region (26.8%) and least prevalent in the Western Region (11%) and Eastern Region (12%).

Table 6. Occurrence of parasitic nematodes, dauerlarvae and ectophoretic mites on female *Elaeidobius kamerunicus* from Papua New Guinea – 2000 (* = accessions fixed in formaldehyde, remainder in alcohol).

Area	Site	Sampling date	% infected with parasitic nematodes	Mean no. mature female nematodes /parasitised insect	% with nematode dauerlarvae	% with ectophoretic mites
New Ireland	Lamerika *	8/2000	0	0	0	0
	Kabil	8/2000				
Milne Bay	Waigini *	8/2000	4	3.0	0	0
	Baraga	8/2000	50	1.6	0	0
Oro Province	Sangara *	8/2000	8	2.5	2	0
	Embi	8/2000	20	1.8	0	0
West New Britain	Dami *	7/2000	0	0	0	0
	Kumbango *	8/2000	8	2.0	0	0
	Kavugara *	8/2000	6	2.0	0	0
	Kautu *	8/2000	10	1.4	0	0
	Hargy *	8/2000	0	0	0	0

Table 7. Occurrence of parasitic nematodes, dauerlarvae and ectophoretic mites on female *Elaeidobius kamerunicus* from selected oil palm plantations in Papua New Guinea - 2001.

Province	Site	Sampling date	% infected with parasitic nematodes	Mean no. mature female nematodes /parasitised insect	% with dauerlarvae	% with ectophoretic mites
West New Britain	Kumbango, Kimbe	6/10/01	14	2.5	2	0
	Kautu	19/10/01	18	4.2	0	0
	Kavugara Plantation	16/10/01	2	3.0	0	0
	Dami OPRS	16/10/01	2	1.0	0	0
New Ireland	Kabil	22/08/01	0	0	0	0
	Lamerika	22/08/01	0	0	0	0
Milne Bay	Hagita Estate	August 2001	10	2.8	2	0
	Waigani	August 2001	6	1.3	0	0
Oro	Sangara Estate	August 2001	4	1.5	2	0

Table 8. Occurrence of parasitic nematodes, dauerlarvae and ectophoretic mites on female *Elaeidobius kamerunicus* from Costa Rica.

Site	Sampling date	% infected with parasitic nematodes	Mean no. mature female nematodes/ parasitised insect	% with dauerlarvae	% with ectophoretic mites
Coto 1	6/2001	0	0	16	0
Coto 2	6/2001	0	0	0	0
Celates	6/2001	0	0	18	0
Mirador	6/2001	0	0	22	0
Quepos 1	6/2001	0	0	10	0
Quepos 2	6/2001	0	0	12	0

Table 9. Occurrence of parasitic nematodes, dauerlarvae and ectophoretic mites on male *Elaeidobius kamerunicus* from Costa Rica.

Site	Sampling date	% infected with parasitic nematodes	Mean no. mature female nematodes/ parasitised insect	% with dauerlarvae	% with ectophoretic mites
Coto 1	6/2001	0	0	12	0
Coto 2	6/2001	0	0	2	0
Celates	6/2001	0	0	20	0
Mirador	6/2001	0	0	18	0
Quepos 1	6/2001	0	0	6	0
Quepos 2	6/2001	0	0	16	0

Table 10. Occurrence of parasitic nematodes, dauerlarvae and ectophoretic mites on female *Elaeidobius kamerunicus* from Ghana.

Area	Site	Sampling date	% infected with parasitic nematodes	Mean no. mature female nematodes /parasitised insect	% with dauerlarvae	% with ectophoretic mites
Eastern Region	Kade	12/2000	2	1	16	18
	Ajukato	12/2000	0	0	34	6
Western Region	Benso Oil Palms	12/2000	0	0	16	2
	Sekondi School	12/2000	0	0	2	20
Central Region	Twifo Oil Palms	12/2000	0	0	46	34
	Ankaako	12/2000	0	0	18	16
	Assin Dadieso	12/2000	0	0	4	48
	Egyirkrom	12/2000	0	0	12	32
	Ewusi	12/2000	0	0	4	4

Table 11. Combined data from all sites (on a per country basis) for incidence of female parasitic nematode, ectophoretic nematode dauerlarvae and ectophoretic mites.

Country of origin	Total number of beetles dissected	Number of beetles with parasitic nematodes	% infected with parasitic nematode	Total female parasitic nematodes	Mean parasitic females/ infected beetle	Mean parasitic females/beetle	Number of beetles with dauerlarvae	% with dauer-larvae	Number of beetles with ectophoretic mites	% with ectophoretic mites
Papua New Guinea 2000	500	53	10.6	190	3.58	0.38	1	0.20	0.0	0.0
Papua New Guinea 2001	450	28	6.2	161	5.75	0.36	3	0.67	0.0	0.0
Papua New Guinea (combined)	**950**	**81**	**8.5**	**350**	**4.32**	**0.37**	**4**	**0.42**	**0.0**	**0.0**
Sumatra	**100**	**6**	**6.0**	**11**	**1.83**	**0.11**	**15**	**15.0**	**0.0**	**0.0**
Ghana	**450**	**1**	**0.2**	**1**	**1.0**	**0.002**	**76**	**16.9**	**90**	**20.0**
Costa Rica	**600**	**0**	**0.0**	**0**	**0.0**	**0.0**	**76**	**12.7**	**0.0**	**0.0**

Discussion

Over the two-year span of this project, a number of weevil populations from Papua New Guinea, West Africa, Costa Rica and Sumatra have been examined for parasitic nematodes. A total of 34 accessions have been examined and over 2000 weevils dissected.

A haemocoel parasitizing tylenchid nematode (initially suspected of being a *Metaparasitylenchus* sp., but now known to be a new species and new genus) is now known to infect *Elaeidobius kamerunicus* in Malaysia, Sumatra and Papua New Guinea. It is likely to be widespread in the Indo-Malayan region wherever oil palm plantations have been established. Nematode infestation levels approaching 50% occurred in some populations from Papua New Guinea with up to 15 adult parasitic females, plus numerous eggs and developing juveniles, in each infected weevil. Male and female weevils were equally infected.

Although the parasitic nematode was widespread amongst the accessions from Papua New Guinea, the infestation rates were mostly on the low side. Infection seemed to be absent in New Ireland and low to high in West New Britain, Oro Province and Milne Bay.

The type of parasitic nematode found in the weevils draws all its nutritional requirements from the host and therefore high parasitic burdens would be expected to have an effect on fecundity, perhaps even resulting in sterility due to depletion of the host's fat body. A reduction in energy reserves could also inhibit the ability of the weevils to fly and therefore impact on their ability to pollinate the oil palm flowers within a plantation.

It is not yet clear whether the tylenchid nematode parasite discovered was carried to Malaysia with the original weevil introductions from West Africa (this would have to have been at a very low infestation level as the weevils were screened before release). It may have been acquired subsequently from a local infection source. What is clear from the results obtained so far is that the nematode is widespread in weevils collected from the Indo-Malayan region, although, from the samples examined, not all populations are currently infected. This in turn may be a result of physical environmental factors (such as rainfall). The chance introduction of clean weevils to isolated plantations or other, unknown factors, including the presence or absence of other organisms such as predatory mites.

Of the nine weevil populations examined from Ghana, West Africa, only one was recorded with a nematode parasite in the haemocoel and this record was restricted to a solitary female nematode and associated juvenile stages in a single beetle. This nematode was not particularly well preserved, but appeared to belong to a different genus to the Malaysian/Indonesian nematode, although this supposition needs to be confirmed. What is clear is that, from the samples examined, nematode parasitism of *Elaeidobius kamerunicus* in Ghana appears to be almost non-existent.

Furthermore, none of the six accessions from Costa Rica, another country where the weevil was introduced to enhance oil palm pollination, were infected with the entomoparasitic nematode. It is always possible, of course, that the parasite is present but in numbers too low to be detected by the current investigation. This contrasts with the situation in Malaysia/Indonesia, although even here parasite-free populations of *Elaeidobius kamerunicus* apparently exist.

Description of the nematode

The entomoparasitic nematode found in this study belongs to the Order Tylenchida, suborder Hexatylina. The taxonomy of insect parasitic nematodes from the Tylenchida is complex, the numerous genera being currently defined by the type of life cycle (*i.e.*, the number of generations in the life cycle and the number that occur within the host) and the morphology of the various stages, particularly that of the free-living/infective stage. This is not a particularly satisfactory situation and the systematic arrangement is probably not robust (see Siddiqi, 2000). The entomoparasitic nematode found in *E. kamerunicus* represents both a new species and a new genus (and possibly a new family as a result of its unusual biology) and is currently being described from Malaysian material by independent authors. The proposed genus and species name are therefore unavailable for general use (such as in this report) until after the publication date of the article. This is to respect confidentiality

of information derived from the peer review process and to conform to the Rules of Zoological Nomenclature.

Although biological studies of the species are still incomplete, the life cycle appears to be as follows. The mature parasitic female is found in the haemocoel of the adult weevil (it is also likely to be found in late instar larvae). The sausage shaped female grows to a length of several millimetres, but smaller in multiple infections. Almost the entire body is taken up by the genital system, the female producing hundreds of eggs. Reproduction is apparently parthenogenetic, no males having been found. The eggs hatch within the host and the juveniles develop, probably to the immature vermiform female stage. Vermiform females (? and maybe fourth stage juveniles) are oviposited by the female along with her own eggs. The nematodes then exist in the environment for a while as a free-living stage, possibly feeding on fungal hyphae, before penetrating a weevil larva and migrating to the haemocoel. Here they absorb nourishment from the haemolymph (presumably depleting the fat reserves of the host as a result) and grow enormously as they mature. All this is at the expense of the host and so one might expect an impact on the fat body and hence fecundity. Migratory ability might also be impaired, although to some extent this might be compensated by the high-energy food source of the adult weevil. Nematodes parasitising male weevils presumably represent a loss to the population, although it is possible that parasitic stages might be able to exit a dead male and thus make their way into the breeding environment.

The precise interaction of parasite and host remain to be elucidated. This is something that can only be done by controlled biological studies utilising laboratory-based cultures. Detailed ecological studies are also required to study the population dynamics of the entomoparasite under field conditions in Papua New Guinea. Only then can the impact of the parasite be adequately assessed and predictions made as to future population levels and dispersal to new areas.

Although the entomoparasitic nematode has been known for several years (I first received material of it from Sarawak in 1999), the assumption has always been that it was introduced with weevils that had been isolated from West Africa and then reared in captivity before being released into Malaysian oil palm plantations in the early 1980s. This certainly seems to be very reasonable supposition, but one which the data from the current project cast some doubt upon.

The entomoparasite is known from Malaya, Sarawak, Sumatra and Papua New Guinea (including New Britain). Intriguingly, it has not so far been recorded from New Ireland (Lamerika and Kabil). All nine accessions from Costa Rica (where the weevil was also introduced) proved to be free of the parasite (although it may be present at levels below the sensitivity of the assessment method employed). Even more interesting was its apparent absence from the nine Ghana accessions. It is true that a single female entomoparasitic nematode was found in one weevil from Kade, but this, although in a poor state of preservation, appeared to be a different species to the isolate from Papua New Guinea. Figure 3 summarises the weevil burden (entomoparasitic nematodes, ectophoretic dauerlarvae and ectophoretic mites) for these countries.

Of course, the fact that the Papua New Guinea nematode was not found in the Ghana samples does not unequivocally imply that the parasite did not originate in West Africa, but it is suggestive. If the nematode is of West African origin, then either it may be at a very low incidence (only one weevil, corresponding to 0.2% of the 450 insects examined, had any entomoparasite), or it may be of local or restricted occurrence. For instance, for logistical reasons no weevil material from Cameroon was examined, and it was from Cameroon that the founder colonies of the weevil were originally taken.

If the entomoparasite did not originate in West Africa (and the case is not yet proven), the implication is that it is indigenous, at least to Malaysia, and crossed over from a local host. This is a potentially more serious situation, as the adaptive host/parasite balance will have had virtually no time in which to settle down, thus opening up the possibility of parasite dominance impacting catastrophically on weevil population dynamics. This is, of course, speculation, yet the scenario does merit serious consideration.

The parasite burden in Sumatra (although only represented by one accession) is broadly similar to that in Papua New Guinea (19 accessions). In Sumatra, 6.0% of the beetles examined were parasitised by the entomoparasitic nematode, the mean number of female nematodes/infected beetle being 1.83. In

Papua New Guinea, 8.5% of the weevils were infected with an average of 4.32 females/infected beetle. However, infection rates vary widely as may be seen in the more extensive data from Papua New Guinea. The number of mature female parasites/host varied from 1 to 15, the usual level being between 1 and 5 with the distribution pattern approximating to a Poisson distribution. (Figure 2).

Within Papua New Guinea, the parasite burden is highly variable. No parasites at all were recorded from the New Ireland accessions, the highest infection levels being recorded from West New Britain (Kumbango and Kautu). Comparison of a number of sites sampled in 2000 and again in 2001 provided some interesting points for discussion. As already mentioned, the New Ireland accessions remained free of the parasite, but Kumbango and Kautu showed quite substantial increases in percentage infection (Kumbango: 8% in 2000; 14% in 2001. Kautu: 10% in 2000; 18% in 2001). Mean number of mature female nematodes/host also increased. Dami was free of parasites in 2000, but showed a low 2% incidence in 2001.

Although some sites showed an increase in parasitism between 2000 and 2001, when all sites were considered for each year there was an overall decrease in parasitism from 10.6% to 6.2% respectively, although the mean number of mature female entomoparasites/infected beetle increased from 3.58 to 5.75 respectively (Figure 4). However, the higher percentage parasitism for 2000 was influenced by one site (Baraga) where 50% of the insects were infected. Unfortunately, this site was not one of the ones re-sampled in 2001.

Figure 3. Country comparison of weevil burden (parasitic nematodes, dauerlarvae and ectophoretic mites)

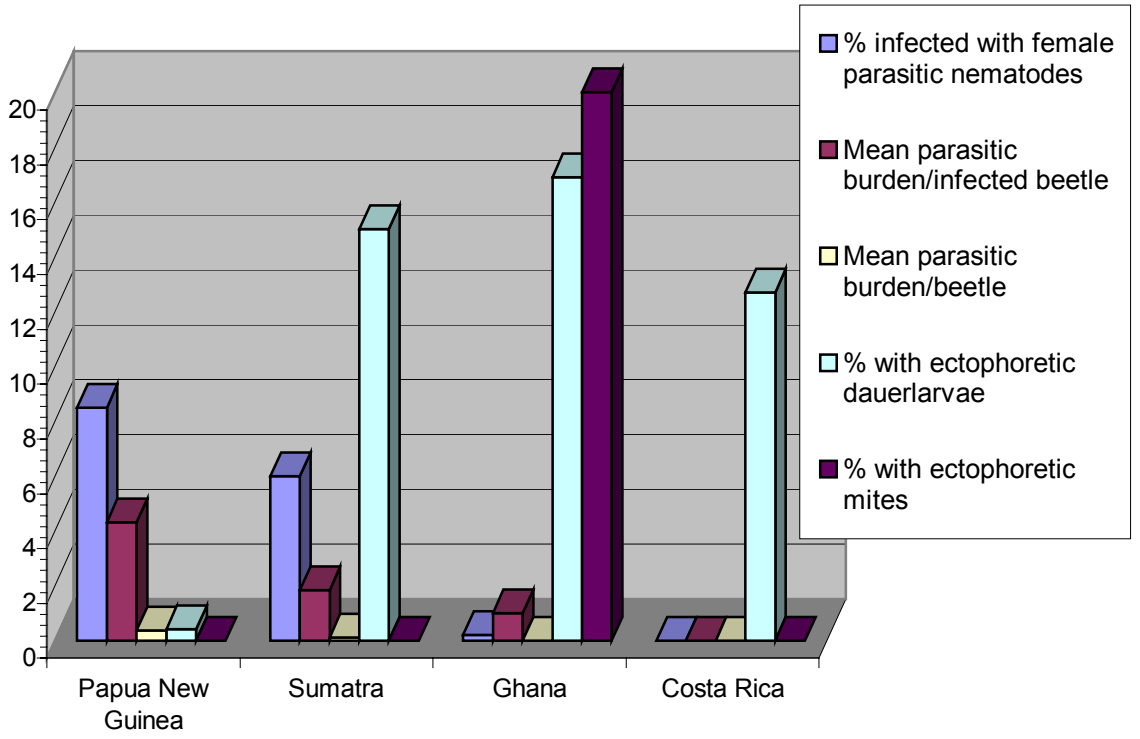


Figure 4. Comparison of parasitic nematode infection for Papua New Guinea sites, 2000 and 2001

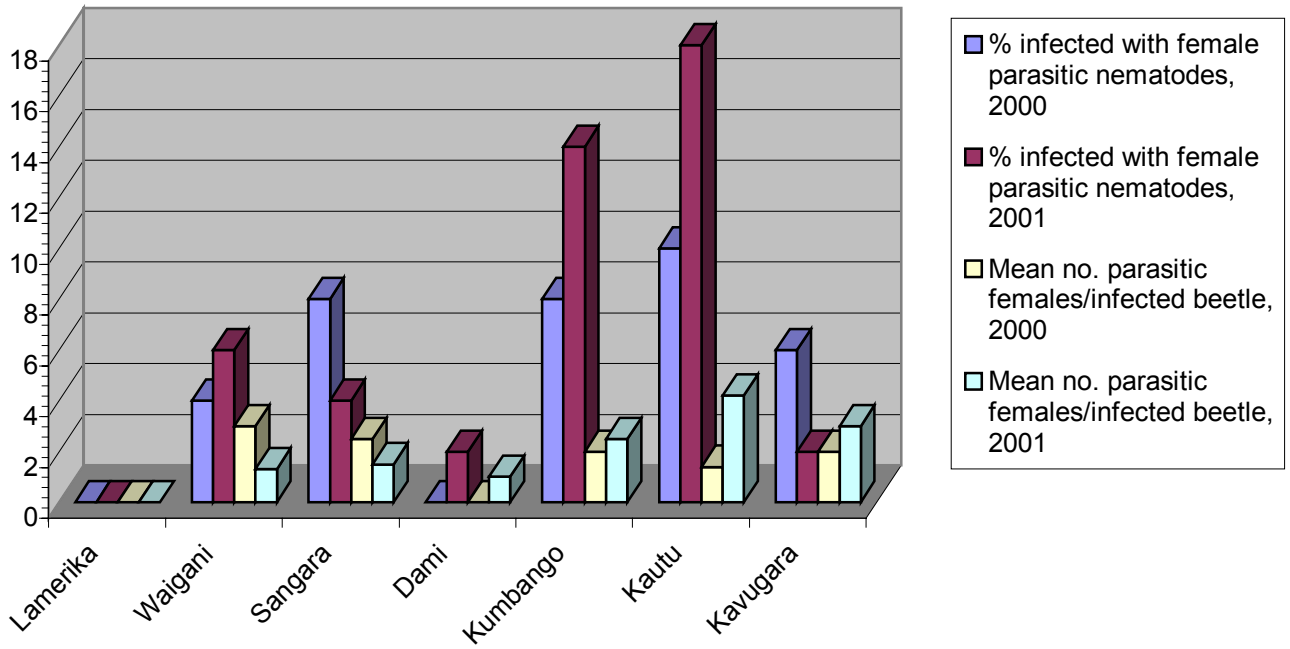
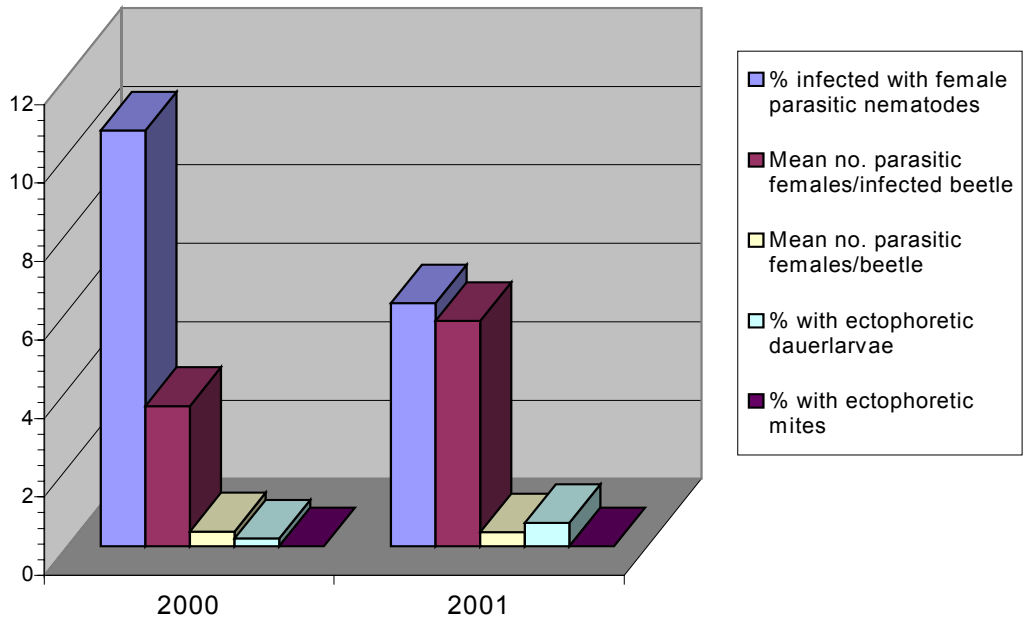


Figure 5. Comparison of mean weevil burden (parasitic nematodes, dauerlarvae and ectophoretic mites), Papua New Guinea, 2000 and 2001



None of these differences can be statistically assessed because of the way in which the samples were collected, but it is apparent that levels of parasitism may vary widely from year to year and from plantation to plantation. A frequent, more rigorously designed sampling protocol would doubtless throw further light on the population dynamics of host and parasite and perhaps indicate whether parasite load was demonstrably related to palm oil yield.

The ectophoretic nematode dauerlarvae

Many nematode species are known to have an ectophoretic association with insects. Such nematodes have a resistant, non-feeding stage in the life cycle called a dauerlarva. These dauerlarvae are covered with an oily film to prevent excessive water loss and are found under the elytra and between the tergites and sternites of the adult insect. The vast majority of such species feed on bacteria and fungi growing in the larval habitat of the associated insect. They therefore rely upon the insect to act as a transport and dissemination device in order that they may colonise new habitats. No harm is caused to the insects that unwittingly carry them.

The commonest nematode genus transported in such a fashion by *E. kamerunicus* is *Cylindrocorpus* (Diplogastrida: Cylindrocorporidae). *Cylindrocorpus* species are widespread throughout the world, usually being found in habitats with an abundance of decaying organic matter where they feed on bacteria and fungal spores. Although they are adapted to take advantage of the free transport provided by beetles, they are quite capable of surviving in the natural environment as long as adequate food is present.

Cylindrocorpus dauerlarvae have been known to be associated with *E. kamerunicus* in Malaysia for many years. They were probably introduced with the weevils, but they may have been already present in the environment. Such nematodes do not cause harm to the insects that vector them and, even if they were completely eliminated from weevils before release in a new area, they would almost certainly reappear from natural populations and fill the vacant niche.

In the present study, *Cylindrocorpus* was recorded from weevils from Papua New Guinea, Sumatra, Ghana and Costa Rica. The genus is almost certain to be ubiquitous wherever *E. kamerunicus* occurs.

Interestingly, the dauerlarvae were in greater incidence and abundance in weevil material from Ghana (16.9% of adult weevils infested). Costa Rica (12.7%) and Sumatra (15.0%). In weevil accessions from Papua New Guinea, the dauerlarvae were apparently of low occurrence, although occurring abundantly in the decaying matter of the male oil palm florets. Low occurrence on weevils and high abundance on male florets does not form a contradiction, however, as the nematodes reproduce at an extremely fast rate, their life cycle being completed in several days at high temperatures and in the presence of a copious food supply. The relative absence of dauerlarvae on adult weevils is difficult to explain. It is possible that they may have been dislodged/lost during the collection/preservation phase. It is also possible that the high humidity of Papua New Guinea militates against dauerlarva formation (although the single Sumatra accession studied had many dauerlarvae), or that it is the result of a seasonal phenomenon. What is certain, however, is that presence or absence of such nematodes is highly unlikely to have an impact on the weevil.

The *Cylindrocorpus* species from Papua New Guinea and Sumatra represents a new species to science. As in the case of the entomoparasitic species, it is being independently described for publication in an international journal. There appears to be two *Cylindrocorpus* species from Costa Rica, one similar to the Papua New Guinea species and one with a rather different male tail. This may also prove to be a new species.

The ectophoretic mites

Many beetles that breed in wood, decaying organic material or plant material carry ectophoretic mites under the elytra. The mites cause no harm to the insect (apart from a possible weight penalty restricting flight range) and rely on the insects as a dispersal device to reach new habitats. Such mites

largely feed on fungal material and other detritus in the breeding habitat of the beetles, but may also consume other organisms such as nematodes.

In the current research programme, ectophoretic mites were only found to have a high incidence and abundance in the weevil material from Ghana where the mites were present in all nine accessions with a mean occurrence of 20.0 (2-48)%. In the two accessions from the Eastern region, the mean incidence of infestation was 25 (16-34)%; in the two accessions from the Western Region the mean incidence of infestation was 8 (2-16)% and in the five accessions from the Central Region the mean incidence was 16.8 (4-46)%. Some weevils carried so many mites under the elytra that the concave under-surface of each wing cover was filled to capacity.

Ectophoretic mites were apparently absent in the accessions from Costa Rica, Sumatra and Papua New Guinea. Why this should be so is not clear, although it may be related to the fact that these weevils were originally introduced from laboratory-reared populations where any original ectophoretic mites were either lost or deliberately removed. It is also possible that the mites, although abundant in the Ghana populations of *E. kamerunicus*, are not so prevalent in weevils from other areas of West Africa, such as Cameroon from where at least some of the breeding stock was obtained. An alternative explanation could be that some other environmental factor(s) inhibit the mites in their areas of introduction.

Could it be that the ectophoretic mites predate upon the free-living stages of the entomoparasitic nematodes, thus limiting their impact in West Africa? This is possible, although probably unlikely, the weevils from Ghana supporting one of the highest infestation levels of ectophoretic nematode dauerlarvae (2-46% of all beetles carried such nematodes under the elytra), despite the presence of numerous, potentially predaceous, mites in the ecosystem.

The importance of the ectophoretic mites associated with the weevils is therefore unclear and remains one of the many environmental factors that need to be resolved if we are to understand the complex interactions that undoubtedly exist.

Description of the entomoparasitic tylenchid nematode

The haemocoel parasitising nematode belongs to the Tylenchida, suborder Hexatylina. It is unusual in this group in that males are apparently absent, the females being parthenogenetic. Nematodes in this group are primarily classified according to the type of life cycle that they follow. The fact that this nematode has an entirely different life cycle to the other representatives indicates that it justifies the erection of a new genus, possibly a new family.

During the course of this project, the senior author was asked to referee a paper for an international journal. In this paper, the authors described the same nematode currently under study, their material coming from *Elaeidobius kamerunicus* obtained from Malaysia. This proposal, by independent researchers to those involved in the current project, is currently in press, but until their paper is published, it is not permissible to use herein the name that they have proposed as this would both contravene the Code of Zoological Nomenclature and impinge upon the confidentiality explicit in peer review.

DESCRIPTION

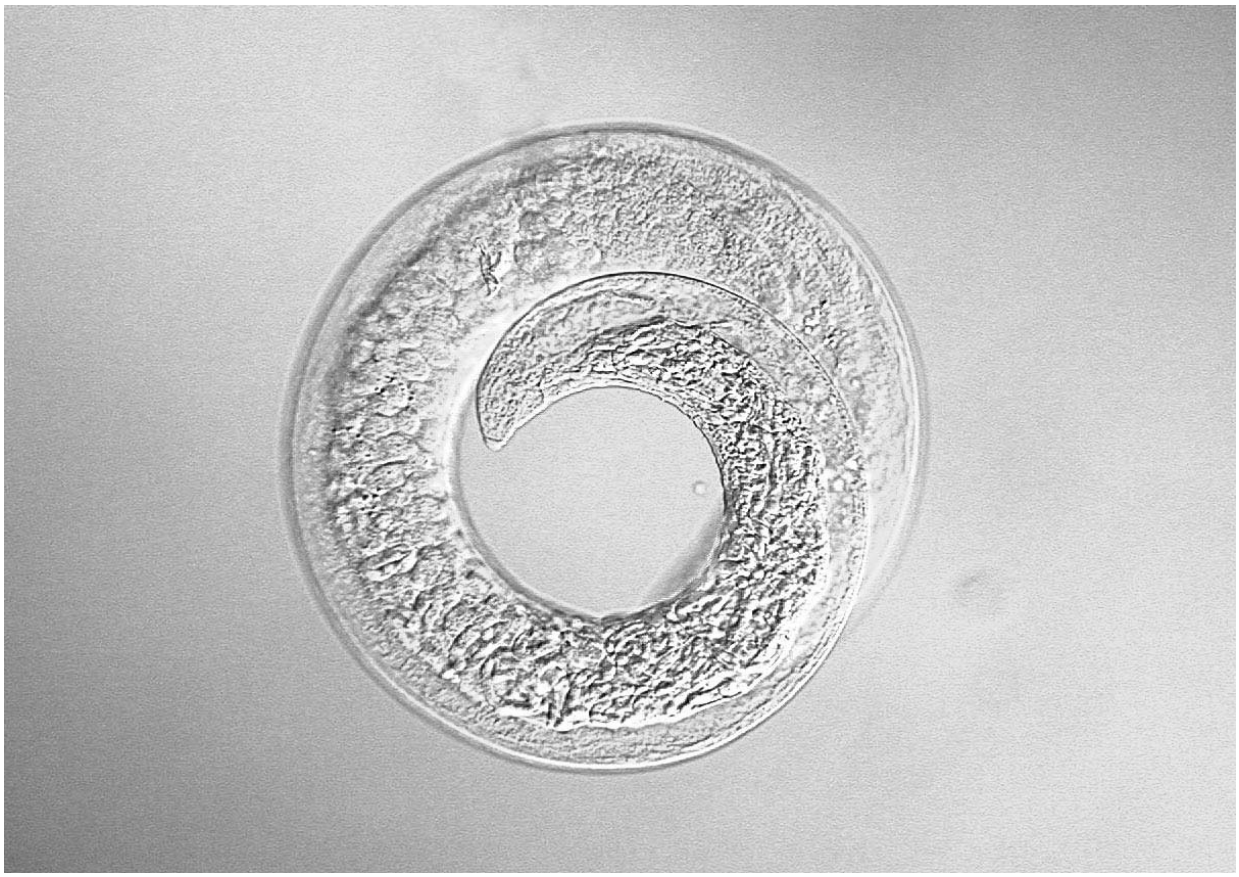
Tylenchida; Hexatylina; Allantonematidae (after Siddiqi, 2000).

Mature entomoparasitic female: Located in haemocoel of host. Heat relaxed specimens dying in a tight, overlapping spiral. Body obese, cylindroid, rather short and white in colour. Cephalic region barely demarcated from body. Stylet short, delicate, with small basal knobs; partially sunken into body. Oesophagus largely degenerate. Vulva in form of a transverse slit and located near the posterior extremity just anterior to anus. Genital tract monoprodelphic with many flexures. Uterus enormous and hypertrophied; containing many eggs and developing juveniles. Tail short; dorsally convex, conoid; terminus finely rounded. No male or complete generation occurring within the host, but numerous eggs and developing juveniles found within the haemocoel.

Free-living stages: The vermiform immature females are found in proximity to the beetle larvae on the male flower spikes. They are probably non-feeding, although more work is required to elucidate the life cycle in detail. Males are apparently absent, the females being parthenogenetic. The vermiform female infects a weevil larva before developing into the swollen entomoparasitic form.

HOST *Elaeidobius kamerunicus* collected from oil palm florets, Papua New Guinea.

Figure 6. Mature entomoparasitic female nematode from haemocoel of *Elaeidobius kamerunicus*. Note the spiral form and hypertrophied genital tract.



2.2. Molecular genetics of *E. kamerunicus* populations (*Alex Reid*)

Materials and methods

A number of live weevils from each site were picked from the total sample and frozen at -80ºC to await DNA extraction. Individual weevils were placed in a watch-glass in 100 µl 1xTE buffer (10 mM Tris pH 8.0, 1 mM EDTA). Each insect was dissected under a dissecting microscope and checked for contamination with nematodes and/or mites. Where possible only weevils without either of these contaminants were used for DNA extraction. Where this was not possible the weevil material was picked out leaving as many of the nematodes/mites as possible behind. The dissected material from each individual weevil was placed in a sterile 1.5 ml microcentrifuge tube and stored at -20ºC until all of the samples had been dissected. DNA extraction was carried out using a Phytopure DNA extraction kit (Nucleon Biosciences) as per the manufacturers instructions. After extraction the DNA pellets were resuspended in 50 µl sterile water. Five individual weevils were analysed from each site (Table 4.1) by AFLP.

AFLP reactions were performed using a protocol modified from the original of Vos *et al*. (1995). Restriction enzyme digestion of 20 µl of genomic DNA was performed using 5 units of *Eco*R I and 5 units of *Hpa* II in Multi-Core buffer (Promega) in volumes of 40 µl for 1 h at 37°C. Double stranded adapters were ligated onto the digested genomic DNA fragments in total volumes of 50 µl using 1 unit of T4 DNA Ligase in 10x Multi-Core Buffer and 0.1 µl of ATP (100 mM). The reactions were incubated overnight at 37°C. Adapter strands were as follows ECO-AD1 5' CTC GTA GAC TGC GTA CC 3' and ECO-AD2 5' AAT TGG TAC GCA GTC TAC 3', HPA-AD1 5' GAC GAT GAG TCC TGA G 3' and HPA-AD2 5' CGC TCA GGA CTC ATC GT 3'. All primers were synthesized by Amersham Pharmacia Biotech. The adapter strands were mixed together in equimolar amounts, heated at 95ºC for 5 min. and allowed to cool slowly to room temperature to form the double stranded adapters. The ECO-AD was used at a concentration of 5 pmols/µl and the HPA-AD at 50 pmols/µl. The adapter ligation mixes were diluted 1 in 10 with sterile water and stored at -20°C.

Preamplification reactions were performed using primers ECO-AD1 and HPA-AD1 by the following method. Reactions were carried out in volumes of 20 µl containing 2.0 µl of 10x Buffer, 2.0 µl $MgCl_2$ (25 mM), 0.5 µl of each dNTP (20 mM), 0.5 µl of each primer (100 pmol/µl), 0.2 µl *Taq* polymerase (5 U/µl) (Sigma) and 1 µl of the diluted sample. Amplification was carried out under the following conditions, 94°C for 5 min followed by 30 cycles of 94°C for 30 s, 56°C for 60 s, 72°C for 90 s and a final step of 72°C for 5 min. After amplification the reactions were diluted 1 in 10 with sterile water and stored at -20°C.

Selective PCR reactions were performed using three combinations of primers, ECO-AT and HPA-CAT, ECO-AT and HPA-CTC, ECO-GC and HPA-CTC. The core sequences of the primers were ECO-NN 5' GAC TGC GTA CCA AAT TC-NN 3' and HPA-NNN 5' GAT GAG TCC TGA GCG G-NNN 3'. The fluorescently labelled ECO primers were synthesized by MWG Biotech and the unlabelled HPA primers obtained from Amersham Pharmacia

Biotech. Selective amplifications were made up in the same manner as the preselective amplifications except that the ECO primer was used at a concentration of 2 pmols/µl and 5 µl of the preselective amplification was added to each reaction. Cycling conditions were as follows, 94°C for 2 min followed by 13 touchdown PCR cycles of 94°C for 30 s, 65°C for 30 s (reduced by 0.7°C each cycle), 72°C for 90 s, followed by 23 cycles of 94°C for 30 s, 56°C for 30 s, 72°C for 90 s and a final step of 72°C for 10 min. Prior to electrophoresis 10 µl of loading buffer (Cambio) was added to each reaction. The reactions were heated at 90°C for 3 min and immediately placed on ice prior to running on an 8.0% denaturing Long Ranger (Flowgen) acrylamide gel on a LiCor 4200 automated sequencer. A molecular weight marker ladder containing band sizes of 350, 325, 300, 255, 230, 204, 200, 175, 145, 120, 105, 100, 95 75 and 50 base pairs (MWG Biotech) was loaded between each ten sample lanes to allow for calibration of each gel in subsequent analysis.

The computer package GelComparII (Applied Maths) was used to analyse these AFLP data. This package allows different gel runs to be imported and standardised to one another by use of the molecular weight ladders loaded on each gel. A binary table was constructed from these AFLP data showing the presence/absence for each of the 341 different bands yielded by the various primer combinations. This table was then analysed in PAUP v4b.10 using Neighbour Joining (with BioNJ option in effect), a 1000 round bootstrap calculation also based on Neighbour Joining as well as a further parsimony heuristic search also with 1000 rounds of bootstrapping.

Results

Examples of the AFLP profiles obtained were illustrated in the Interim Report by Hunt and Reid (2001). These initial results are repeated here for completeness. Examples of AFLP profiles are shown in Figure 7. Preliminary visual inspection of the AFLP profiles for the samples from West New Britain showed that these were much more uniform than those from Ghana where some samples displayed bands unique to one particular site (Hunt and Reid, 2001). Some of these are marked (►) for the Ajukato samples. Other primer combinations show similar result to those in Figure 7 (data not shown).

Phylogenetic trees using various construction methods were drawn from these initial data based on band sharing (the more bands two isolates have in common the more closely related they are). The three methods used for tree construction were UPGMA (Figure 8), Neighbour joining (Figure 9) and Ward (Figure 10). All three tree-construction methods separate the West New Britain isolates from the Ghana isolates on two distinct branches. The UPGMA and Ward trees show that the degree of genetic variability within the samples from Ghana is greater (these samples have deeper branch lengths) than those from West New Britain indicating more heterogeneity in the African weevils. Within the West New Britain sites the individual isolates from the three sites are mixed in together with no one particular site displaying a difference in genetic variability from that of the overall diversity. However, within the isolates from Ghana one site in particular tends to cluster on its own (site 2 Ajukato) with all of the isolates, bar one, from this site falling into a distinct branch.

Figure 7. **A** contains the profiles for samples from the Ajukato, Assin Dadieso and Sekondi School regions in Ghana and **B** Dami, Kavugara and Kumbango sites from West New Britain. All profiles were obtained by amplification with E-AT and H-CAT selective primers. Bands unique to the Ajukato isolates are marked ►. Size markers on the left of the gels are in base pairs.

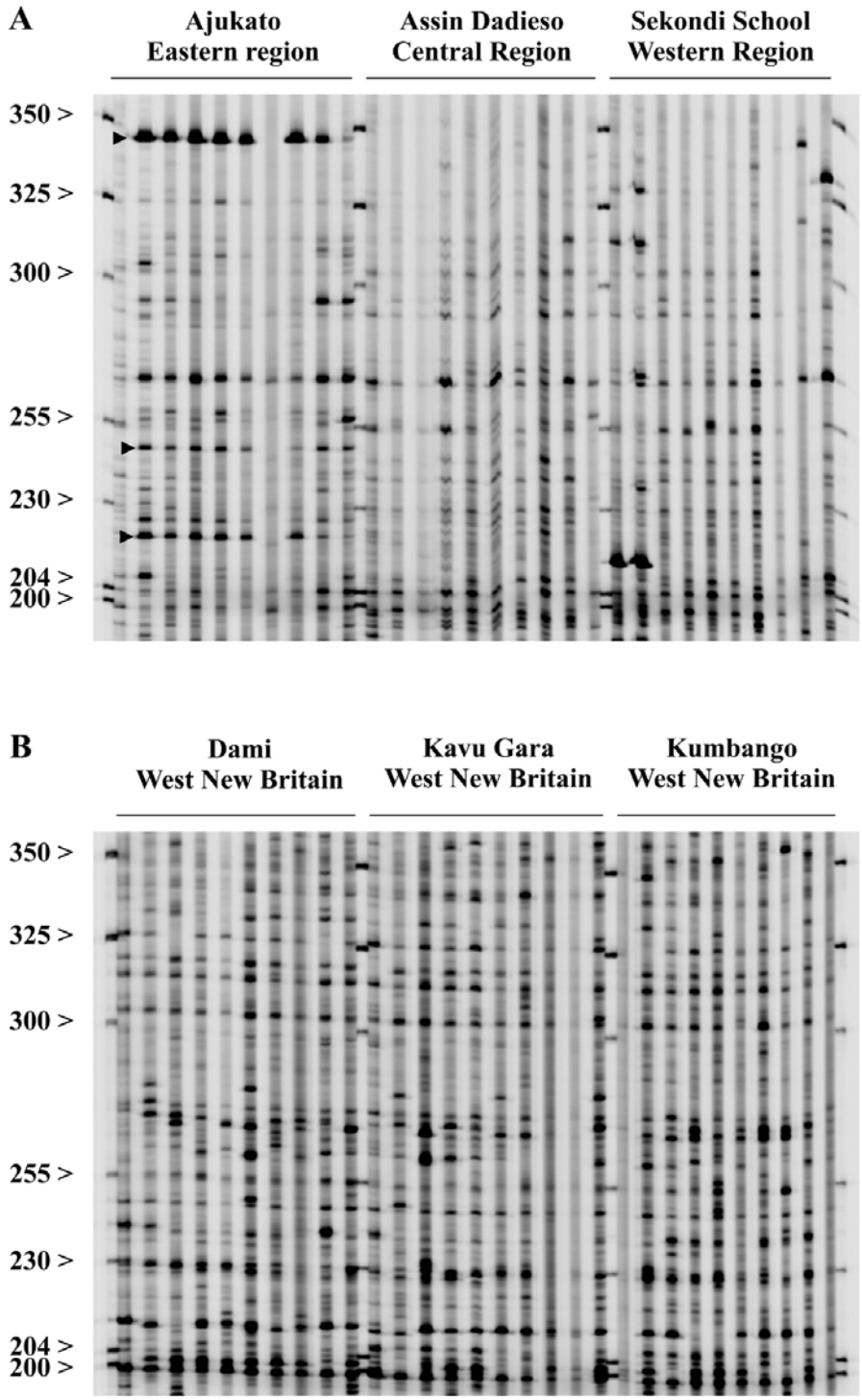


Figure 8. UPGMA tree drawn from AFLP data for samples from three sites in Ghana (■) and West New Britain (■).

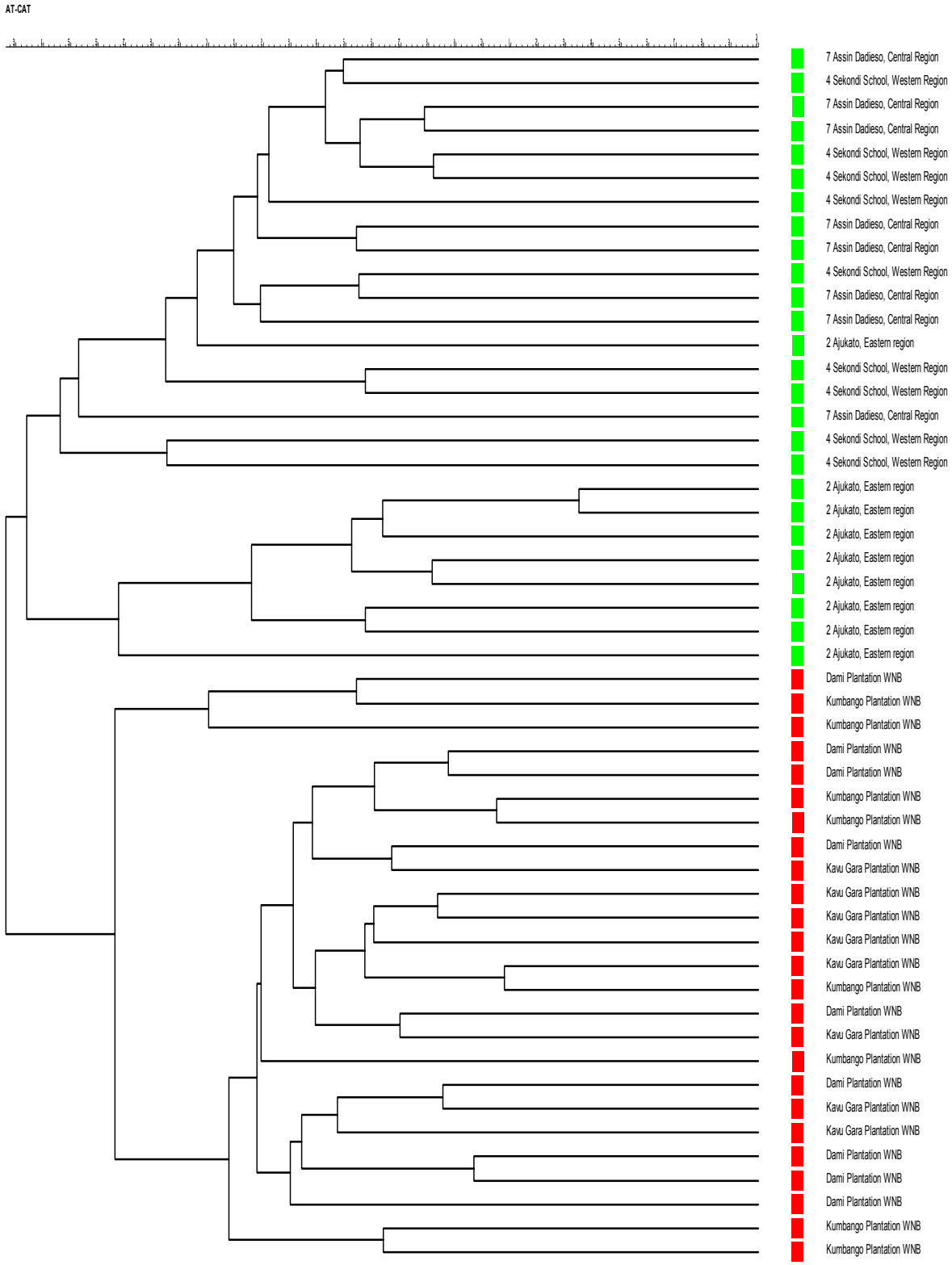


Figure 9. Neighbour joining tree for the same isolates as Figure 8.

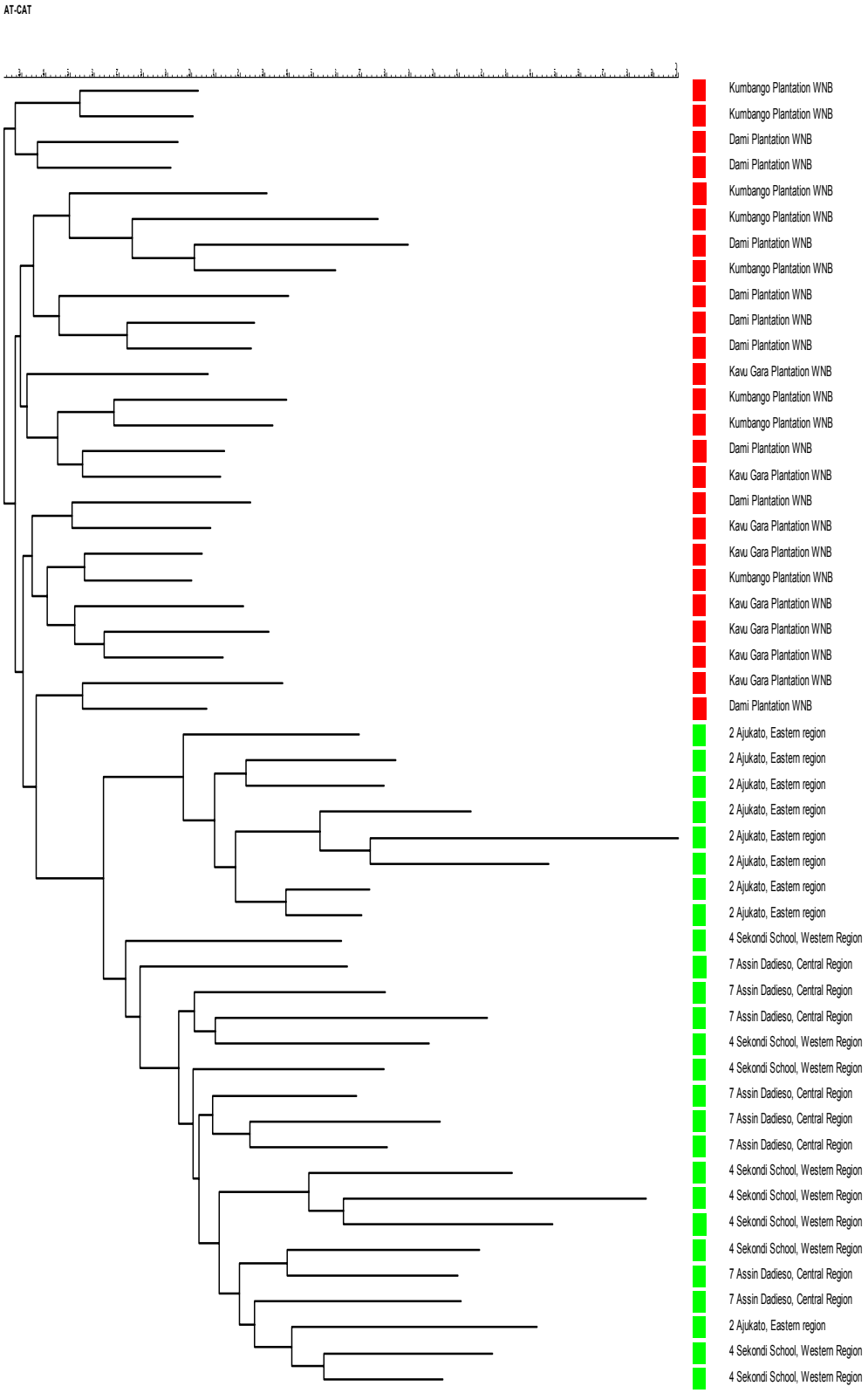
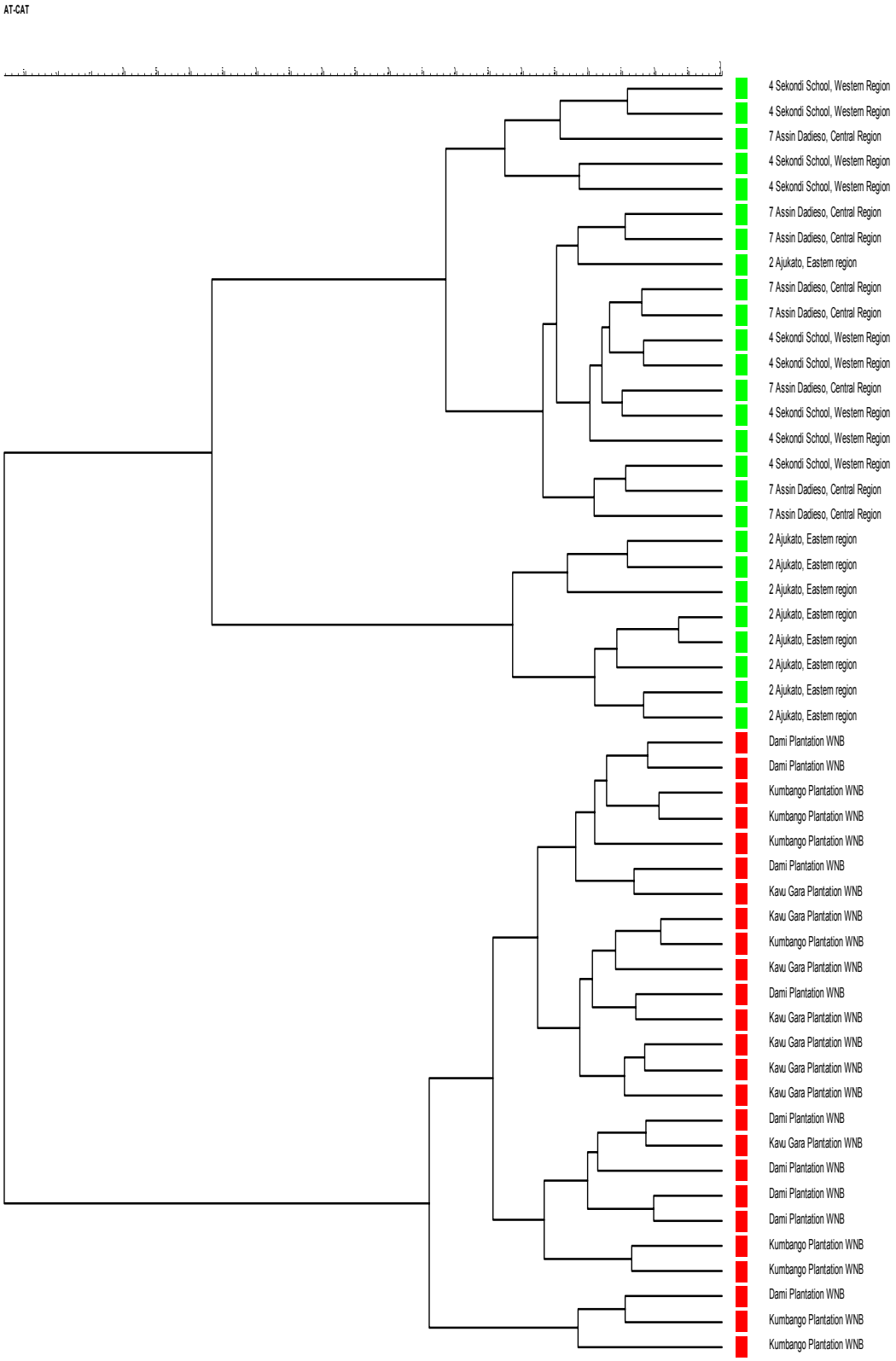


Figure 10. Ward tree for the same isolates as Figure 8.



Polymorphic bands can clearly be seen within isolates from this site (Figure 7) and these cannot be attributed to mite infection as this site had one of the lowest mite burden of all the sites from Ghana. In the second phase of the project, AFLP profiles were obtained from additional isolates of the weevil.

AFLP analysis using three different selective primer combinations yielded a total of 341 bands. These were scored as present/absent using GelCompar II for each of the 85 samples analysed and the binary table produced treated to three different forms of analysis using PAUP. All three tree-building techniques yielded similar topological trees. Figure 11 shows the Neighbour joining phylogram, showing two major clades, one containing the Papua New Guinea and Costa Rica isolates and the other containing the samples from Ghana. Each of these major clades can be further sub-divided. Within the Ghana samples there are two clades. The first contains all of the isolates from sites B, D and G and two samples from site H and 1 from site E. The second contains all of the isolates from site A, C and F as well as the remaining samples from sites E (4) and H (3). Within the Papua New Guinea clade there is one branch containing the Costa Rican samples as well as the samples from sites 4 and 8. The remainder of the Papua New Guinea samples cluster together on a separate branch within which it is possible to distinguish two further branches one containing samples from sites 1, 2 and 3 and the other sites 5, 6 and 7. When a bootstrap analysis is performed on these data using neighbour joining the cladogram (Figure 12) shows a similar topography to the NJ tree. The Ghana and Papua New Guinea samples remain separated and there are still two branches for the Ghana samples. These two branches mostly contain the same samples as for the NJ tree. The bootstrap tree still separates the Costa Rican and Papua New Guinea sites 4 and 8 sites from the remainder of the Papua New Guinea sites but in this tree these remaining samples are not so easily separated into two further branches. The heuristic parsimony analysis coupled with bootstrapping yields a cladogram (Figure 13) with exactly the same groupings as the NJ tree. In general the bootstrap values for the deeper-rooted nodes are not well supported for either trees but as the general topographies for all three trees are broadly similar this is not a major concern.

Discussion

All three methods for tree construction give a similar result, that is, the samples from Papua New Guinea are genetically distinct from those from Ghana. The sample from Costa Rica clusters with the Papua New Guinea isolates, which strongly suggests that this population is a subset of those originally introduced to Papua New Guinea and was not a fresh isolation from Africa. The strongly supported separate branches for the Papua New Guinea and Ghana samples indicates that the former population is evolving separately from those in Africa. However, the branch lengths in the Neighbour Joining tree do not indicate any less genetic diversity within the Papua New Guinea isolates than within those from Ghana. This could be a reflection of the limitations of the AFLP technique as AFLP markers are dominantly inherited so no measurement of allelic variation can be made. It is possible that there is a higher degree of homozygosity in the Papua New Guinea population of weevils than for those from Ghana and this could be shown by a more discriminatory technique.

However, the lack of genetic diversity could either indicate either be a reflection that the founder population was large enough to prevent a genetic bottleneck occurring or, more likely, that not enough time has yet elapsed for this effect to be seen. The drop in efficacy in the weevil population seen in Papua New Guinea could therefore be largely due to the parasitism by the nematodes, although this susceptibility could, in turn, have been due to low levels of genetic diversity within the founder population. A rapid method for the screening of weevil populations for nematode infection would be advantageous. This could be achieved by the cloning of a species-specific fragment of DNA from the nematode. PCR primers could be designed to amplify this specific piece of DNA thus allowing the rapid screening of weevil populations to assess parasite burden.

Unfortunately it is not possible to determine the level of gene flow using AFLP data. This is due to the way that AFLP markers are dominantly inherited thus rendering it impossible to score heterozygotes. To obtain a true reflection of the levels of gene flow between sites in Papua New

Guinea it would be necessary to screen the populations using a marker that allows the scoring of heterozygotes. Microsatellite markers are ideally suited to such a study. The advantages of the construction of a library of such markers are twofold; it would be possible to determine the level of integration of any subsequent introduction of new populations of the weevil from Africa, microsatellite markers would also enable the spread of newly introduced isolates from their source to be measured.

Table 12. Origins of oil palm weevil samples examined by AFLP and their identifying codes used on trees.

Country	**Sample site**	**Code**
PNG	Oro	1
PNG	Hargy WNB	2
PNG	New Ireland	3
PNG	Milne Bay	4
PNG	Dami Plantation WNB	5
PNG	Kavugara Plantation WNB	6
PNG	Kumbango Plantation WNB	7
PNG	Kautu Plantation WNB	8
Costa Rica		CR
Ghana	Kade, Eastern Region	A
Ghana	Ajukato, Eastern Region	B
Ghana	Benso Oil Palms, Western Region	C
Ghana	Sekondi school, Central Region	D
Ghana	Twifo Oil Palms, Central Region	E
Ghana	Between Twifo Oil Palms and Cape Coast, Central Region (Ankaako)	F
Ghana	Assin Dadieso, Central Region	G
Ghana	Ewusi, Western Region	H

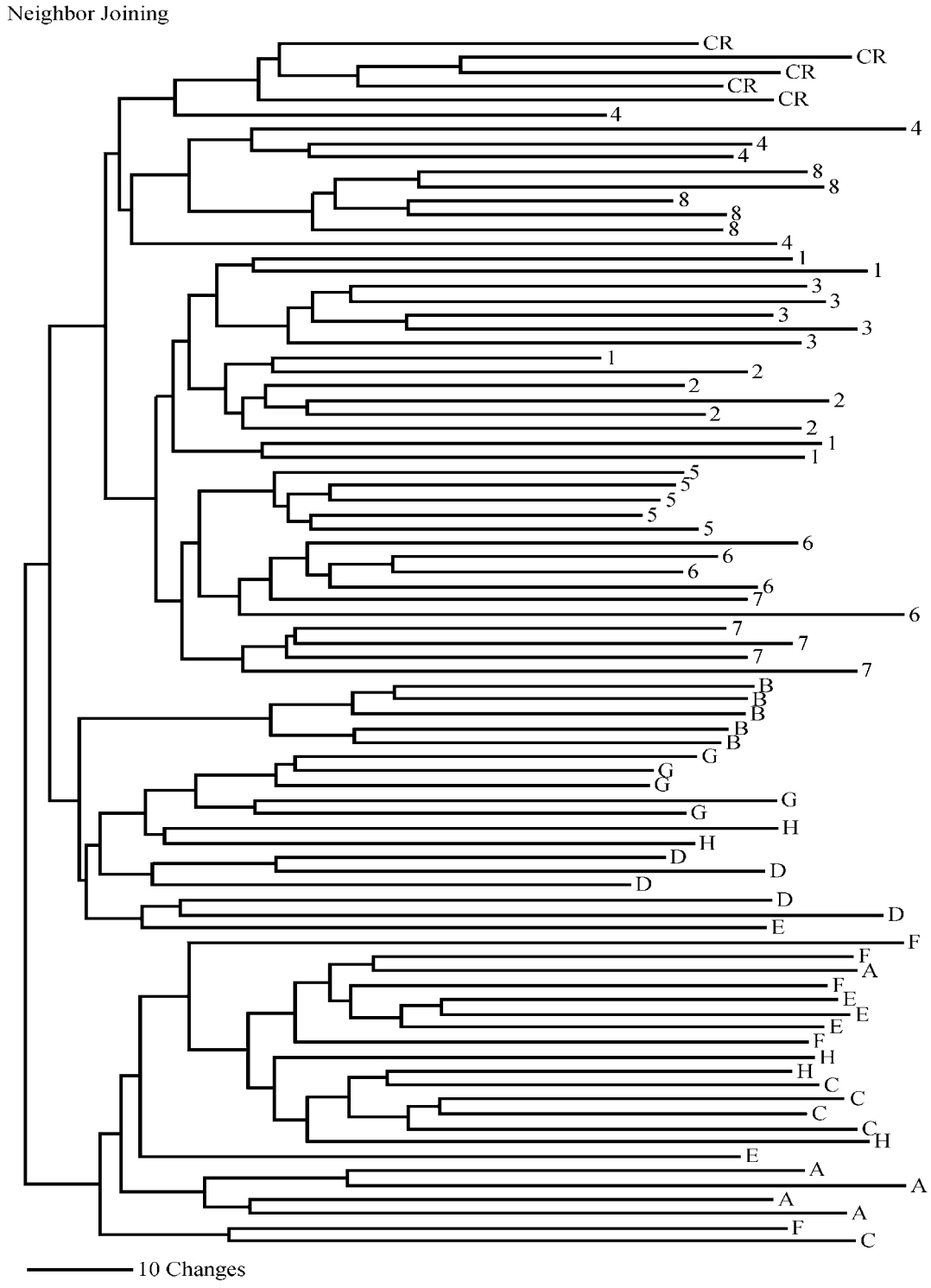


Figure 11. Neighbour joining phylogram.

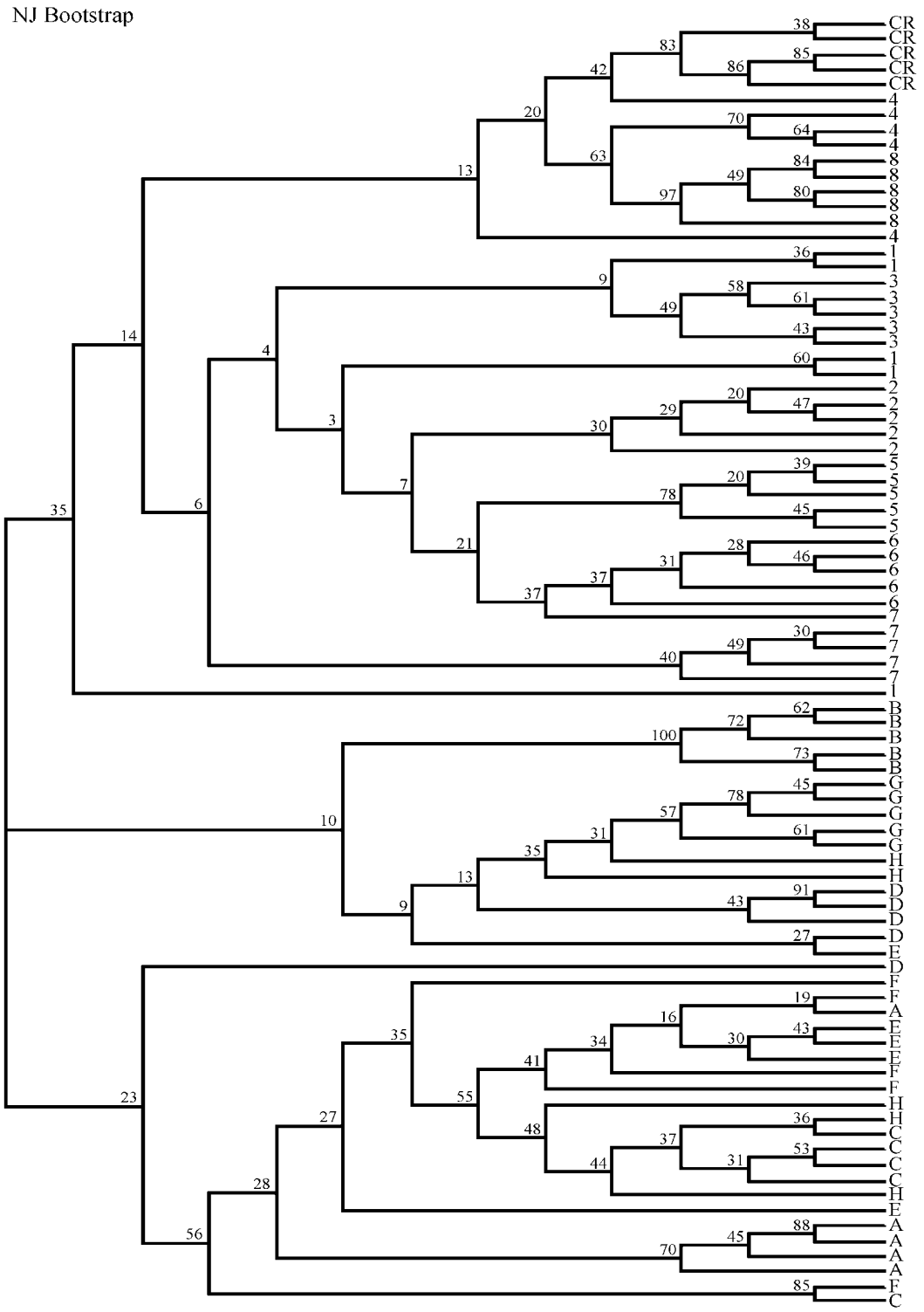


Figure 12. Neighbour Joining Bootstrap cladogram. The numbers at the nodes are bootstrap values.

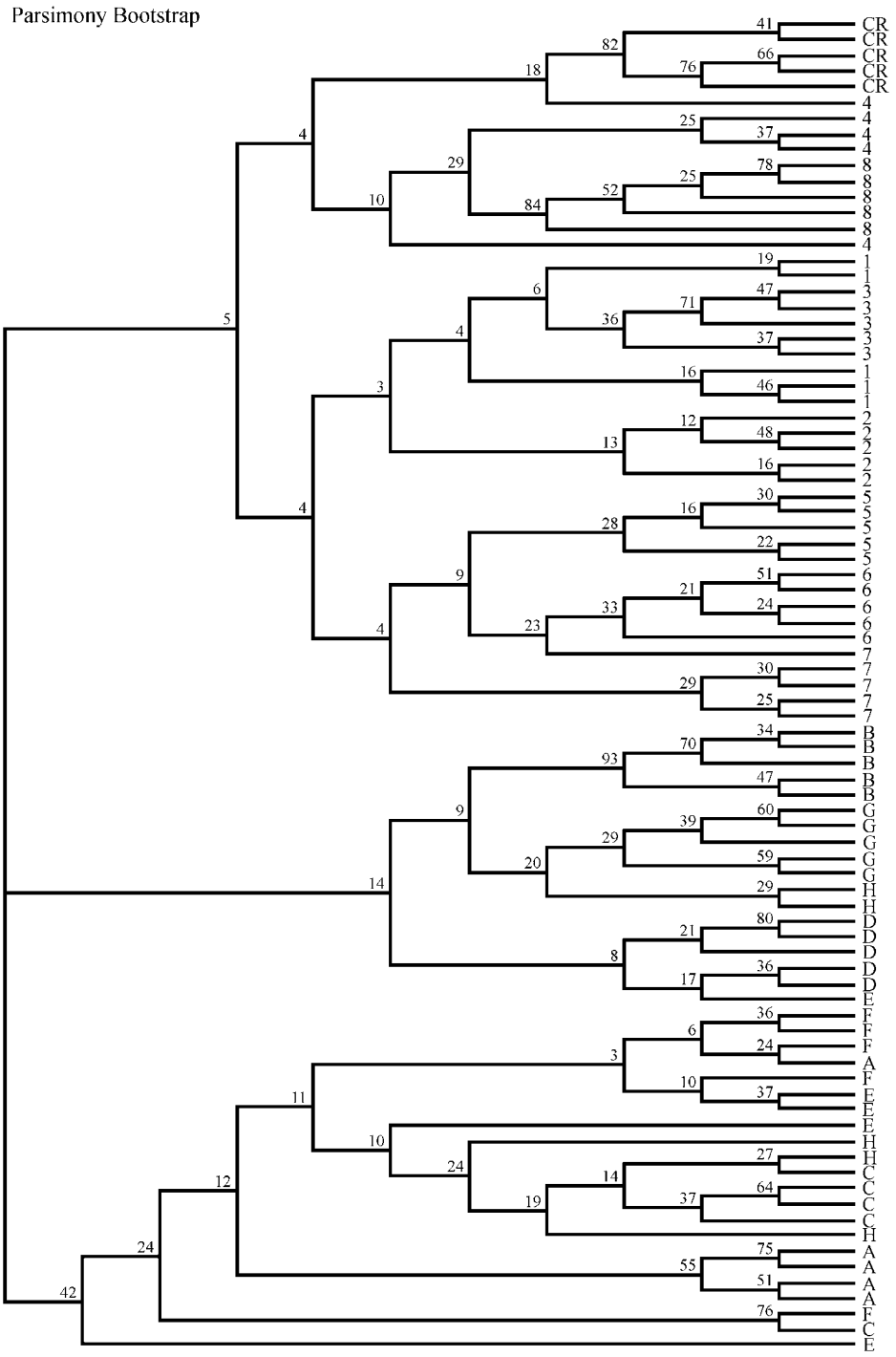


Figure 13. Parsimony analysis bootstrap cladogram. The numbers at the nodes are bootstrap values.

Conclusions

Since the project started in October 2000, *Elaeidobius kamerunicus* accessions have been received from Papua New Guinea (23), Sumatra (1), Ghana (9) and Costa Rica (6). Samples from all of these countries have been dissected (totalling in excess of 2000 weevils) and examined for entomoparasitic nematodes and AFLP profiles established for accessions from all countries except for Sumatra.

The main objectives of the project were achieved in that the distribution, incidence and abundance of a new genus and species of entomoparasitic nematode were established and the necessity for more detailed biological and ecological studies to quantify its impact on weevil fecundity, population dynamics and dispersal, justified. The genetic diversity of weevils from Papua New Guinea, Ghana and Costa Rica was successfully established using AFLP banding profiles.

The origin of the entomoparasitic nematode is still in doubt, although the balance of current evidence suggests that it is more likely that the parasite is of local origin and has transferred to the oil palm weevil since its introduction to South East Asia. However, more extensive sampling of weevil populations in West Africa (only material from Ghana was available in this study) may indicate otherwise. The nematode found on the external surfaces of the beetle was shown to be a new species of *Cylindrocorpus*, a harmless ectophoretic associate feeding on bacteria and fungi in the breeding galleries of the weevil larvae. Even cleaning beetle introductions of this nematode would probably not prevent it, or a similar species, being picked up again from the environment.

The genetic diversity of the Papua New Guinea weevils was wider than might have been anticipated from the founder effect, suggesting that the original introductions may have been made from a relatively broad spectrum of populations. Of interest was the clustering of the Costa Rican weevils with some populations from Papua New Guinea.

As there was little evidence of restricted genetic diversity within the weevils introduced to Papua New Guinea, it is more likely that a reduction in their efficacy as pollinators of the oil palm has more to do with parasite burden, although environmental factors such as heavy rainfall can not be discounted at this point.

The initial phase of the project has thus set the stage for a more detailed assessment of the nematode/weevil/environment interactions and has emphasised the importance of additional research in order to enhance the pollinator suite with the aim of reducing reliance on a single species on such an economically important crop.

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2.3. The potential to improve the genetic base of the existing population of *E. kamerunicus* within Papua New Guinea (*Rob Caudwell*).

Two short field visits were undertaken during the first phase of the project, to Ghana (5 weeks) and to Costa Rica (2 weeks). During this time samples were collected to address objectives (1) and (2), and some short field studies were also undertaken.

Large numbers of insects were found on male and female oil palm inflorescences in Ghana. These insects were present on the male inflorescence during anthesis and on the female flowers during the first few days of receptivity. Of those insects present on male inflorescences, *Elaeidobius* spp. and *Atheta* spp. were the most abundant. These included *E. kamerunicus*, *E. plagiatus*, and *E. subvittatus*. Of those insects present in large numbers on the male inflorescences, only *E. subvittatus* and *Atheta* sp. were found in the female inflorescences, and these were only present in very small numbers. However, as Syed (1979) reported, continuous observations of female inflorescences throughout the period of their receptivity revealed that a large number of insects visited them during the daytime, and that these insects tended to arrive in intermittent storms.

E. kamerunicus, *E. plagiatus*, and *E. subvittatus* were founds to visit female inflorescences and were usually laden with pollen grains. Species of *Elaeidobius* were found to carry the largest number of pollen grains. During the fieldwork it was found that the taxonomy of the *Elaeidobius* genus is somewhat complicated, and that at least two previously undescribed species are present within the genus. Two new species of *Elaeidobius* have been described during the project, and the *Elaeidobius* genus has also been revised. A taxonomic field guide, that is absolutely essential for any further field operations, is to be produced at the Natural History Museum in London. Unfortunately, this is on-hold due to lack of funding.

In Costa Rica, where *M. costaricensis, E. subvittatus,* and *E. kamerunicus* are all present, *E. kamerunicus* was found to have out competed the other two species. *E. kamerunicus* is the generally the most dominant pollinator for most of the year, and is particularly useful as it is numerous and active in both moderately dry and wet weather. It was also found to carry more pollen grains than the other two species, and also responds better to the scent of the female inflorescence. *E. kamerunicus* also has the advantage of being host specific to oil palm, whereas *M. costaricensis* feeds from a number of other palms, including coconut. It was found that rain generally had a very depressive effect on both *M. costaricensis* and *E. subvittatus*, indeed it was this that generated interest in introducing *E. kamerunicus* from Africa in the first place.

It has therefore been very difficult to identify any candidate insects that might be able to compete with *E. kamerunicus* to improve oil palm pollination in PNG. Hence the introduction of fresh batches of *E. kamerunicus* into PNG from Africa is recommended, as this action is expected to improve the genetic base of the existing populations. However this cannot be done until the uncertainty surrounding the taxonomy of the *Elaeidobius* genus is resolved, particularly regarding the status of the two previously undescribed species within the genus, and what impact they might be having on pollination. Other problems include the widespread occurrence of nematode parasitism in the populations of pollinating weevils within PNG, and the lack of basic biological information concerning these parasites, particularly with regard to the effect that they might be having on the host. As the origin of the nematodes is still uncertain, this has implications for the quarantining requirements of any new introductions. These are all matters to be addressed as part of a second phase of the project, the proposal for which is detailed in the 2003 research proposals document.

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3. Finschhafen Disorder (*By Bill Page*)

During 2001 Bill Page of the Natural Resources Institute in the UK visited PNG to provide technical advice on the IPM of Finschhafen disorder caused by a leafhopper (*Zophiuma lobulata* Ghauri) on oil palms.

3.1. Introduction

Finschhafen disorder was first observed on coconut palms near to Finschhafen in Morobe Province, Papua New Guinea in 1960. Early symptoms of the disorder include a yellow bronzing from the tip of coconut leaflets, with the bronzing later extending towards the petiole. As the condition advances the leaflet tips become necrotic, with advanced symptoms appearing as senescence of leaves, with accelerated and pronounced yellowing and necrosis. In coconuts this disorder results in reduction of yields, slowing of growth rates and occasionally, the death of young palms.

Feeding by a small brown leafhopper (*Zophiuma lobulata* Ghauri) causes Finschhafen Disorder on coconuts. It is most probable that the symptoms are caused by a localised toxic reaction to *Z. lobulata* feeding on the fronds (Smith, 1980). Control of the disorder is therefore dependent on the management of *Z. lobulata* populations.

In March 1994, Finschhafen Disorder was observed for the first time on coconuts in West New Britain Province. At this time the outbreak was localised and confined to a very small area. The leafhopper, *Z. lobulata* was confirmed as the causal agent of the disorder. Betelnut and oil palms were also affected by the disorder, but to a much lesser extent. Since 1994, Finschhafen Disorder of coconuts has spread throughout West New Britain Province. Damage levels are currently very high, and the disorder has resulted in a massive loss of coconut production in the West New Britain region. In addition to this, the disorder is now being observed with increasing frequency on oil palm in PNG both in West New Britain Province and on the mainland. The symptoms are similar to coconut except that the yellowing and necrosis tends to be confined towards the tips of the leaves that are affected. Recently there have been two serious outbreaks of Finschhafen Disorder on oil palm on the mainland of PNG at Embi Estate in Oro Province and at Milne Bay Estates in Milne Province, both in excess of 100 ha. The appearance and increased frequency of Finschhafen Disorder in oil palm is causing considerable concern within the PNG oil palm industry. As both copra and oil palm production are vital to the economy of Papua New Guinea it is imperative that attempts are made to control Finschhafen disorder.

There is very little known or published about Finschhafen Disorder or the leafhoppers causing the problem in coconut and nothing published at all on the disorder in oil palm. There is only one scientific paper on studies of the disorder and its causal agent *Zophiuma lobulata*, Ghauri (Smith 1980). Other papers cover the identification (Ghauri, 1966) and the incidence of the disorder (Anon, 1969; Anon, 1971; Bourke *et al* 1969)

The Director of the PNG Oil Palm Research Association requested technical assistance in developing work to examine IPM strategies for the control of *Z. lobulata*, the causal agent of Finschhafen Disorder.

3.2. Suggested activities on Finschhafen Disorder on oil palm

Although a small amount of work has been done on Finschhafen Disorder, this has been entirely on coconut palm. The nature of the symptoms on oil palm is different than on coconut and the leafhopper behaviour may be different on the different crops. It is therefore important that basic studies of the disorder, the nature of the damage and the leafhopper biology and behaviour are understood so that the correct monitoring and control techniques can be established for the oil palm industry. It would be hoped that such studies would have added value in helping to solve the problem on coconut and betelnut.

The disorder

The work on coconut has shown that when insects are removed from plants there is a remission of symptoms indicating that the disorder is caused by a localised toxic reaction to *Z. lobulata* feeding on the frond. Viruses were looked for using electron microscopy with negative results. It is therefore probably not worth checking whether pathogens are present using more up to date methods unless studies on oil palm suggest otherwise.

It is, however, important to understand the effects of the toxic reaction in relation to degree of damage on each frond, the timing for symptoms to appear under different population pressures and whether the effect is localised to a frond which has high numbers of *Z. lobulata* on or whether the toxic effect can spread to other fronds on the palm. All these can probably be studied using sleeving experiments or other field techniques (see below).

During the visit, some initial clip cage experiments on growing oil palm suggest that there is a strong local reaction to probing and feeding by *Z. lobulata* but individual probes may be difficult to recognise under field conditions. This requires further investigation. If such reactions can be repeated under different conditions it may suggest that the toxic reaction is very strong and the nature of the toxin should be investigated.

The timing of the appearance of the disorder in the field is important for monitoring and control decisions as the symptoms may not appear for a long period after peak numbers of leafhoppers have been feeding on the fronds. In the coconut work, for instance, the first signs of symptoms on the fronds appeared after six to seven months of continuous feeding by the leafhoppers although the numbers may have been comparatively low.

It is also important to understand how the disorder develops under an outbreak situation as this will help to define whether there has been a build up of the outbreak, whether a spread is occurring, whether there has been one large upsurge of the incidence of symptoms so that damage has occurred over a comparatively short period or whether damage is continuing (thus helping control decisions). A method and form has been devised and tested in the field during the visit that will show variations in the incidence of symptoms within an outbreak (see below).

The leafhoppers

Although work has already been done on the life history of *Z. lobulata* on coconut palm, it is important that this should be done for oil palm. An understanding of the timing of various stages of the leafhoppers will assist in the interpretation of field monitoring data and subsequent control decisions.

Discussions and observations during the visit suggests that, in general, outbreaks of Finschhafen disorder in West New Britain (WNB) have been widespread in coconut and where damage has occurred on oil palm this has usually been associated with the outbreaks on coconut and betelnut in small-holder areas. There have been isolated outbreaks (a few palms) where the disorder has appeared on oil palm in the absence of nearby coconut. On the mainland, however, large outbreaks on oil palm have occurred, the two most recent being in excess of 100 ha. The observation that the disorder is now being seen with increasing frequency on oil palm suggests that the leafhoppers may be surviving and breeding more readily on the palms and it is thought that this trend may continue to get worse. With the possible differences being observed between West New Britain and the mainland it is suggested that comparisons are made of the survival of leafhoppers on oil palm and coconut using insects from WNB (from coconut/oil palm) and from the outbreaks in oil palm on the mainland. This work could be undertaken at both Dami (WNB) and at Popondetta (mainland PNG) using clip cages for the experiments (see below).

In order to understand how the disorder develops, a study of the feeding behaviour, particularly feeding site preferences, should be carried out. It would be possible to examine the survival times of different stages of the leafhopper on different fronds using clip cages (see below) sited on the petiole, different parts of the mid-rib and on different leaflets. This could also be used to examine preferences for different aged plants in the field. It is known that 1st instar nymphs tend to remain in the vicinity

of the egg batch from which they have hatched (Smith, 1980; discussions and pers. obs.). In order to ensure maximum survival of the nymphs the females are likely to select the best feeding sites on which to oviposit. Feeding site preference could therefore also be identified in the field by recording the sites where egg batches are found. A form has been devised to record such observations.

Another factor in understanding how upsurges of the disorder can occur is the rate of reproduction. Work during the visit has shown that the potential numbers of eggs that can be laid by a female in one batch is 44 (by counting the total number of ovarioles in the paired ovaries). More work is needed on this using samples from different locations. Work by Smith (1980) showed that batches of eggs could contain up to 217 eggs, which suggests that some sort of aggregation of laying might be occurring. As a routine, egg batches from oil palm, coconut and betelnut should be collected for counting the numbers of eggs in each batch to confirm whether aggregation is occurring and, if so, this should be followed up in order to establish whether any chemical signalling is involved.

Egg batches, which are covered with white waxy threads, are the most conspicuous stage in the life cycle of *Z. lobulata*. Routine counting of egg batches on a random number of palms within an outbreak may help to indicate when population increases are likely to occur and may even be an indicator of current populations. The field monitoring form would help doing this routine monitoring.

If observations from an outbreak suggest that the whole of the outbreak started at the same time (e.g. even distribution of the position of fronds with symptoms throughout the outbreak) then the possibility of mass immigration and oviposition should be suspected and migration of the leafhoppers investigated using, possibly, light traps and flight duration experiments.

It is well known that many leafhoppers and planthoppers produce sound by vibrations on the plants that they are living on or, often in the case of the males during mate-seeking, visiting (e.g. Claridge MF, 1985; Claridge MF and de Vrijer PWF, 1994). It may be worth investigating whether *Z. lobulata* are using acoustic signalling for mate finding both in terms of possible novel control and identifying/confirming possible biotypes of the leafhopper.

Yield loss

A major factor in the study of Finschhafen disorder is to establish the levels of yield loss on oil palms with differing degrees of damage. Since damage in oil palms is long term it is important to start monitoring, as soon as possible, the levels of damage in the two current outbreaks on the mainland. The monitoring would need to be on a transect basis taking in undamaged palms as controls. The form for monitoring has already been devised which will record current damage (see below) and, with regular visits (monthly or bi-monthly), show any increase in damage or remission from the disorder on individual palms. Since the repeated transects will examine the same numbered trees on each visit they can be followed through to examine both the proportions of male to female flowers and yield over a period of two or more years (assuming a project is able to take place). This will provide a basis for identifying levels of damage and subsequent yields and establishing economically viable control strategies.

Implications for control

A major problem at present with deciding whether or not to control is the fact that the symptoms are likely to have taken some time to appear and any peaks in *Z. lobulata* population may have already occurred and the damage done. At the time of visiting an outbreak the symptoms may already be in remission. It may be possible to visit the outbreak after, say, a month to establish whether there has been any increase in the disorder, either on the fronds that already were showing the symptoms or on additional fronds. With further knowledge it might be possible to use egg batch counts as an indicator of the levels of *Z. lobulata* incidence.

In an outbreak situation on an oil palm estate, trunk injection may be a suitable short-term solution if it is shown that it is economically viable. In a village/small holder situation where the oil palm is in amongst coconut and betelnut, where the whole area requires treatment, trunk injection is more problematic as the fruits of the coconut and betlenut would contain insecticide residues. Because the

fruits are not processed as with oil palm nuts, the villagers could ingest these residues. The fruits would therefore have to be cut down under supervision to ensure that no accidental poisoning occurs. A single trunk injection would suffice as the eggs only take 7-10 days to hatch on coconut (Smith, 1980). Spraying using non persistent/systemic insecticides would require treatments two weeks apart to ensure that any hatching nymphs would be controlled.

Parasitoids such as encyrtid wasps are known to parasitize the eggs of *Z. lobulata*. Smith (1980) found that, over a ten month period, the level of parasitism in the leafhoppers ranged from 45 to 82%, averaging 65.5% and 69.9% of all eggs sampled in two localities. Up to 80% parasitism has been recorded in the outbreak at Embi Estates in Oro Province on the mainland.

Egg parasitoids are likely to build up in a *Z. lobulata* outbreak situation and may be one of the major controlling factors in suppressing the population after a few generations. It is therefore important to establish the fluctuations of the parasitoids within an outbreak, particularly if the outbreak is found at an early stage. The release of large numbers of parasitoids would probably only be effective if an outbreak was found at a very early stage, but until more is known about the population levels of *Z. lobulata* and the timing of subsequent damage/symptom expression, this method need not be studied.

Other natural controlling factors are entomophagus fungi that appear to infect both nymphs and adults in the field. Like most naturally occurring fungi they are likely to proliferate under specific conditions (e.g. under regular rainfall conditions) so may suppress *Z. lobulata* population build up under those conditions. The fungi occurring in the leafhoppers should be identified and the possibility of using them as controlling agents investigated.

Dissemination

In discussions, it became apparent that there has been confusion amongst farmers, extension workers and estate workers about the identification of the symptoms of Finschhafen disorder in comparison with trace element deficiencies, particularly magnesium deficiency. This has almost certainly led to the under-reporting of Finschhafen disorder, since magnesium deficiency is quite common. The production of a leaflet showing the differences between the various symptoms and a short explanation of how Finschhafen disorder is caused would be a useful tool in the fight against the disorder.

3.3. Field methods tested during visit

Methods have been developed for monitoring outbreaks to establish aspects of *Z. lobulata* behaviour, dynamics of the outbreak, preferred feeding sites/damaged leaves, degree of symptoms, oviposition sites and numbers of egg batches (as a possible means of population estimation). A form was developed to record the data and the methods were then tested in the field and adapted.

Sleeving could be used to help establish the nature of damage, population numbers to cause damage, timing of symptom expression, spread of toxic saliva through plant, translocation of toxic saliva to tip and rate, survival on different leaves and subsequent appearance of symptoms. In order to give an idea whether sleeving is practical, suitable netting material was found locally and a 4m x 1m sleeve was made in order to hold large numbers of *Z. lobulata* on an oil palm frond. About 800 *Z. lobulata* (mostly adults) were collected from coconut and betelnut at Milikina (WNB) and put into the sleeve on a suitable frond (17^{th}) of a 3-year-old palm at Dami Research Station. The results of this test are shown in Appendix 3. Many egg batches were laid in the sleeve and it is recommended that this be left to see if nymphs survive on the frond and whether symptoms appear and when. It would be useful, as additional preliminary tests, (a) to repeat this on another palm at Dami and regularly top up the numbers of leafhoppers so that the frond is under constant pressure (b) to carry out similar sleeving in Popondetta using *Z. lobulata* from the outbreaks on oil palm

Clip cages could be used to establish preferred site of feeding (petiole, different parts of mid-rib, different leaflets) on different leaves using survival rates. The cages can also be used to examine localised probing and damage in detail. Initial trials were carried out with clip cages on one leaf of a three-year-old oil palm. Cages were set up on the petiole (2 cages), four different sections of the mid-rib and two leaflets. The full results are shown in Appendix 4. In summary, only the insects in one

cage on the petiole died of causes other than interference by ants. However some leafhoppers did survive up to 4 days before being eaten by ants after being transferred to a new leaf. There was a surprisingly high degree of localised damage in the area of the clip cages on the mid-rib and smaller amounts on the petiole and, possibly, the leaves (see results in Appendix 4). This work requires repeating as such studies may lead to a better understanding on the nature of the damage/symptoms of Finschhafen disorder.

By examining female *Z. lobulata* ovaries from different sites, the potential for the numbers of eggs each can lay can be established. Specimens examined during the visit suggest that females can lay up to 44 eggs in a batch. See Appendix 5 for results.

Field collection of egg batches can establish how many eggs are being found in a batch. More than 44 eggs may indicate more than one female laying eggs to form the batch. Levels of parasitism can also be established. A collection of adults from an outbreak on coconut and betelnut at Milikina (WNB) showed that the mean number of eggs per batch was 35.6 and 10.9% of the eggs were parasitized (n=67 batches, for details see Appendix 6). The indication, from the degree of Finschhafen disorder, the high numbers of *Z. lobulata* and the low level of parasitism, is that the outbreak was comparatively new and therefore it is suggested that further samples are taken from this site to examine changes in parasitism levels as well as other records, particularly if the disorder appears on the nearby oil palm.

3.4. Conclusion

It is clear from the above comments that, because so little is known about Finschhafen disorder, much work has to be done on both the appearance of the disorder, the causal agents (*Z. lobulata*) and the consequent damage and yield loss. Such knowledge would be required before adequate recommendations can be made on the monitoring and control of the leafhoppers.

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4. Minor insect pests of oil palm during 2001

PNG Islands

1. Bagworms (Lepidoptera: Psychidae)

There were minor outbreaks of Bagworm damage at Kautu, Sarakolok, Kumbango, Bebere nursery, and Garu during 2001. Chemical treatment was not required for these outbreaks.

2. Leafhoppers (Hemiptera: Cicadelloidea)

There were small outbreaks of Finschhafen disorder of coconuts and oil palm due to feeding by *Zophiuma lobulata* at Kaurausu and Kautu Plantation, Kavui Smallholders, and Waisilau, Umu, Uasilau, Sege, and Banaule VOP. In each of these outbreaks a small number (10-20) oil palms were recommended for chemical treatment.

3. Rhinoceros beetles (Coleoptera: Scarabaeidae)

No outbreaks during 2001.

PNG Mainland (by Ross Safitoa)

1. Sexava

No new outbreaks of Sexava was reported this year 2001

2. Leafhoppers (Hemiptera: Cicadelloidea)

Zophiuma lobulata causes Finschhafen disorder on coconuts and oil palm in both Milne Bay and Oro Provinces. In Sagarai plantation, Milne Bay Estate, 390 hectares of oil palms was affected and in Embi estate, Higaturu Oil Palm, 101 hectares were affected. The prevalence of the disorder was such that in areas with old damages the palm density was higher then the other areas as the palms affected were sporadic and isolated (1-3 palms per ha). At Embi estate the disorder has spread to neighbouring areas.

3. Stick insect (Phasmatodea: Phasmidae)

Species of stick insect, *Eurycantha* species, have previously been recorded as important pest of oil palm in Oro Province, with the first economic damage reported in 1986. Further economic damage was reported in 1989 and 1990. There was an increased incidence of stick insect damage to oil palm in Oro province between 1996 and 1999. During 1997 there was a total 4 smallholder blocks at Koropata division that were recommended for chemical treatment for the control of stick insect. A further 7 smallholder blocks in the same division was recommended for treatment in 1998, and 34 blocks during 1999. The 1999 outbreaks were at Koropata (18 blocks) and New Warisota VOP (16 blocks). There were however no new out breaks of stick insects during 2000 and 2001.

4. Bagworms (Lepidoptera: Psychidae)

Damage by bagworms, *Mahasena corbetti* (rough bagworm), *Clania* species (smooth bagworm), and the 'ice-cream cone' bagworm remained low throughout 2001, in both Milne Bay and Oro Provinces. The occurrence of field populations was sporadic and isolated, with light damage of no economic significance.

5. Acria moths (Xyloryctidae) – Sagarai M/Bay

Acria moth is widespread throughout Milne Bay Estates from Giligili to Hagita, Waigani and Sagarai. During 2001 some damage to oil palm was observed in areas throughout these locations, especially the Sagarai area. Although this pest has been causing damage, no control measures have been recommended since 1994. There appears to be a wide range of naturally occurring biological agents that usually provided adequate population regulation

6. Cockchafer beetles (Coleoptera: Melonothinae)

Two species (*Dermolopida sp.* and *Litura sp.*) of Cockchafer beetles are widespread throughout the oil palm growing areas of Oro Province. Population levels are however usually very low, and damage levels light. Light levels of damage was observed at Embi Plantation (Higaturu Oil Palm) towards the end of 2001. At Mamba estate damages were light beginning of April and in August the population declined. No control measures were recommended but continued monthly monitoring at Embi Plantation. In both areas the damages caused had no economic significance.

7. Psyllid (Hemiptera: Psyllidae)

Psyllid was released into Mimosa (Leguminosae: Mimosaceae) patches at Sumbiripa and Embi mini estates, Higaturu Oil Palms. The number of mimosa patches declined and with the help of the cover crop (*Puraria sp* and *Calopoganium sp*) the weed was suppressed.

5. Pollination Trials

The number of male flowers at anthesis and the number of female flowers at the receptive stage in the three trial plots at Mamba Estate, HOPPL are shown in Figures 14 and 15.

The mean number of weevil progency emerging from each spikelet and the mean percentage fruitset in the three trial plots at Mamba Estate, HOPPL are shown in Figures 16 and 17.

The mean number of weevil progency emerging from each spikelet in the four trial plots at Kapiura Plantation, NBPOL is shown in Figure 18.

The number of male flowers at anthesis and the number of female flowers at the receptive stage in the four trial plots at Garu and Haella, NBPOL are shown in Figures 19 and 20.

The mean number of weevil progency emerging from each spikelet in the four trial plots at Garu and Haella, NBPOL are shown in Figure 21.

6. Publications, Conferences, Consultants, and Staff

The following papers have been written during the second phase of the Sexava project:

Caudwell, R.W. 2000. Integrated management of insect pests of oil palm in Papua New Guinea. *The Planter* **76,** 393-407

Caudwell, R.W. 2000. The development of a sustainable IPM system for oil palm in Papua New Guinea. *Brighton Crop Protection Conference - Pests and Diseases* **2000,** 215-220

Kathirithamby, J., Solulu, T.M., and Caudwell, R.W. 2000. Morphology and biogeography of female Myrmecolacidae parasitic in Orthoptera in Papua New Guinea. *Proceedings XX1 International Congress of Entomology* **2000**

Kathirithamby, J., Solulu, T.M., and Caudwell, R.W. 2001. Description of female Myrmecolacidae (Strepsiptera) parasitic in Orthoptera (Tettigoniidae) in Papua New Guinea. *Tijdschrift voor Entomologie* **144,** 187-196.

Kathirithamby, J. 2001. Stand tall and they still get you in your Achilles foot-pad. *Proceedings of the Royal Society, London, B*. In Press

Caudwell, R. W. 2002. Integrated management of insect pests of oil palm in Papua New Guinea - A review of successful IPM implementation. *Integrated Pest Management Reviews* In Press

Caudwell, R.W. 2002. Feld trials with biological control agents for oil palm IPM in Papua New Guinea. *Crop Protection* In Prep

In addition to these scientific papers, a feature about the IPM project has been published in *Appropriate Technology* (Volume 28, No 1). There has also been an article featured in *The Times Education Supplement* in the UK, and in the Oxford University Newsletter, BluePrint.

The following papers have been written during the first phase of the pollination project:

Insect pollination of oil palm - time to evaluate the long-term viability and sustainability of *Elaeidobius kamerunicus*? *The Planter* **77,** 181-190

Dr Kathirithamby continued to advise as part of the Sexava biocontrol project. This collaboration finished at the end of 2001.

Drs Alex Reid and David Hunt at CABI Biosciences, and Dr Ben Mensah at University of Cape Coast Ghana, are currently working as collaborators as part of the EU-funded pollination project.

Figure 14. The number of male flowers at anthesis (average/day/135 palms) in the three trial plots at Mamba Estate, HOPPL, Oro Province during 2001

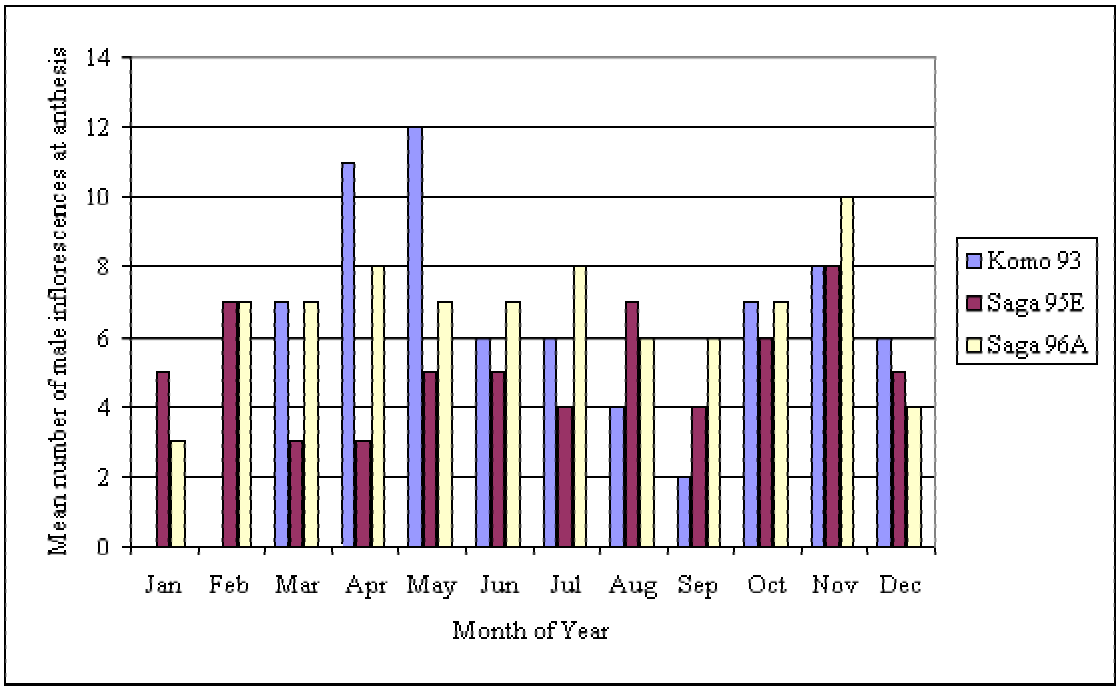


Figure 15. The number of female flowers at receptive stage (average/day/135 palms) in the three trial plots at Mamba Estate, HOPPL, Oro Province during 2001

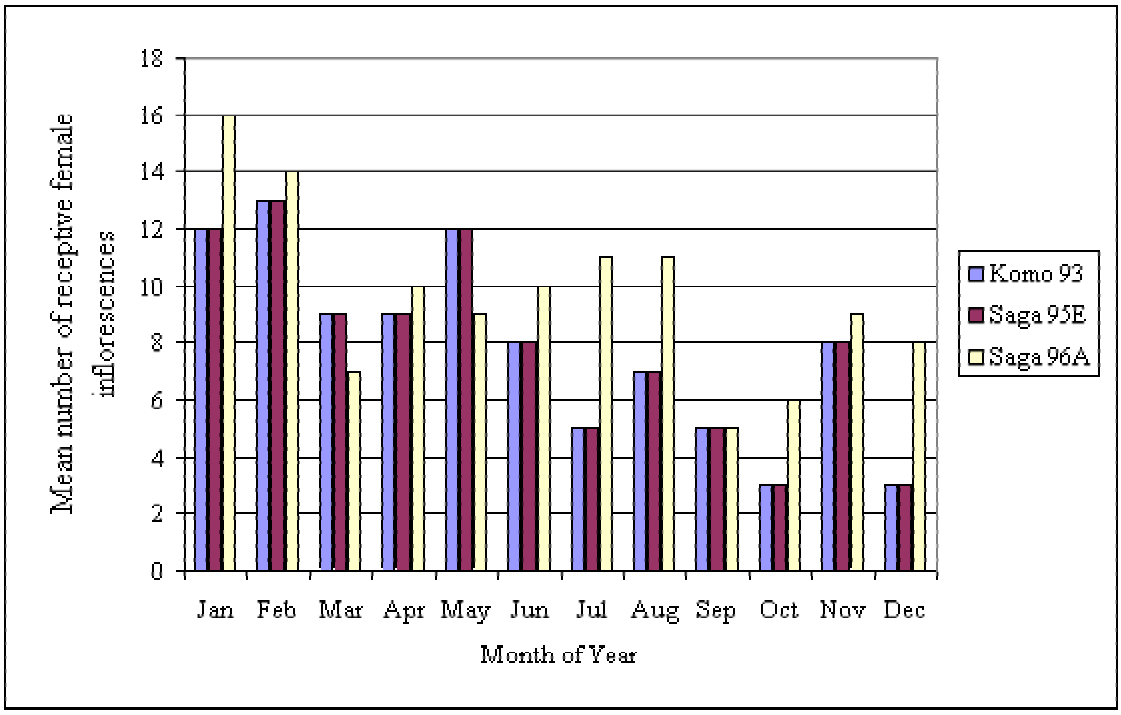


Figure 16. The mean number of weevil progency emerging from each spikelet from the trial plots at Mamba Estate, HOPPL, Oro Province during 2001

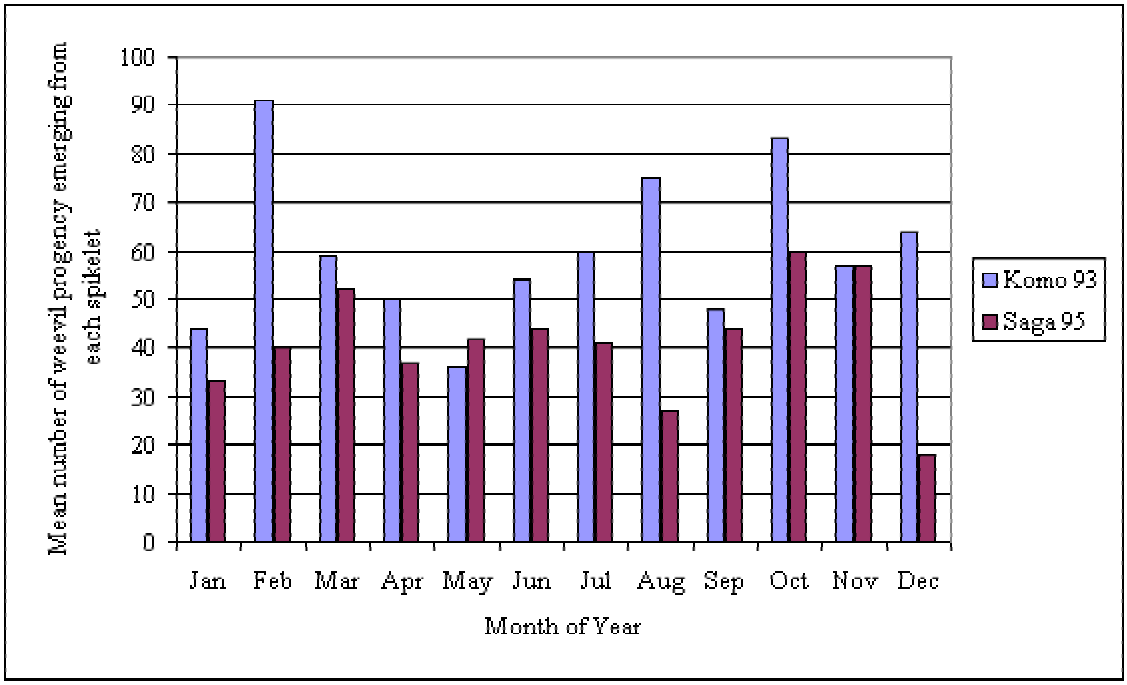


Figure 17. The mean percentage fruitset for the trial plots at Mamba Estate, HOPPL, Oro Province during 2001

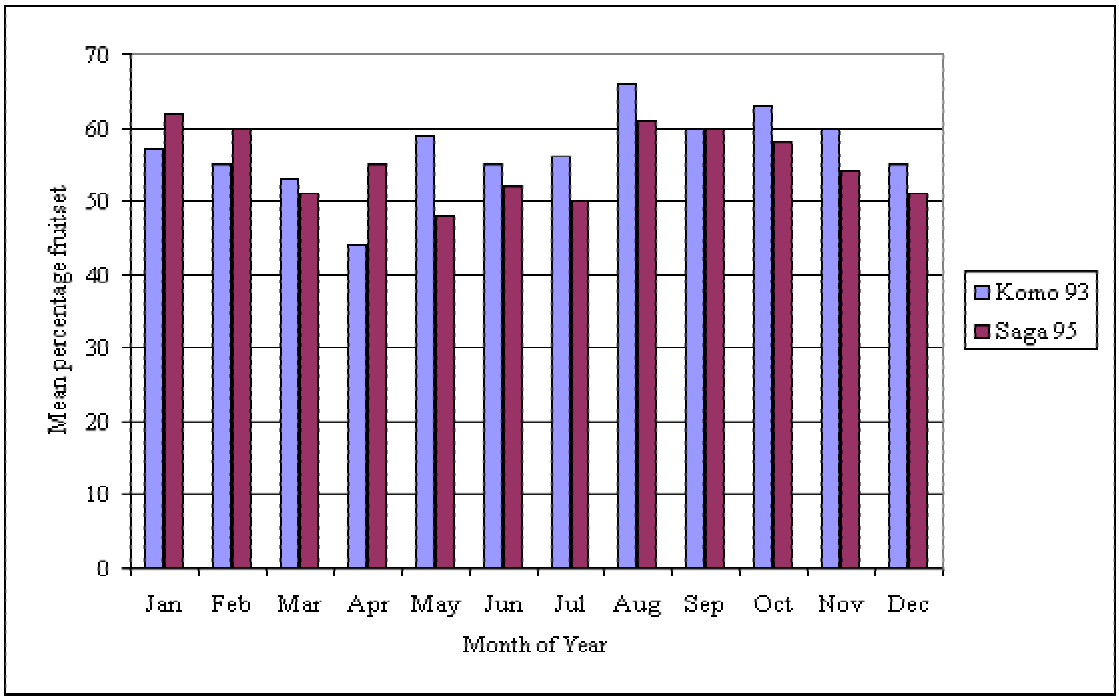


Figure 18. The mean number of weevil progency emerging from each spikelet from the trial plots at Kapiura Plantation, NBPOL, West New Britain Province during 2001

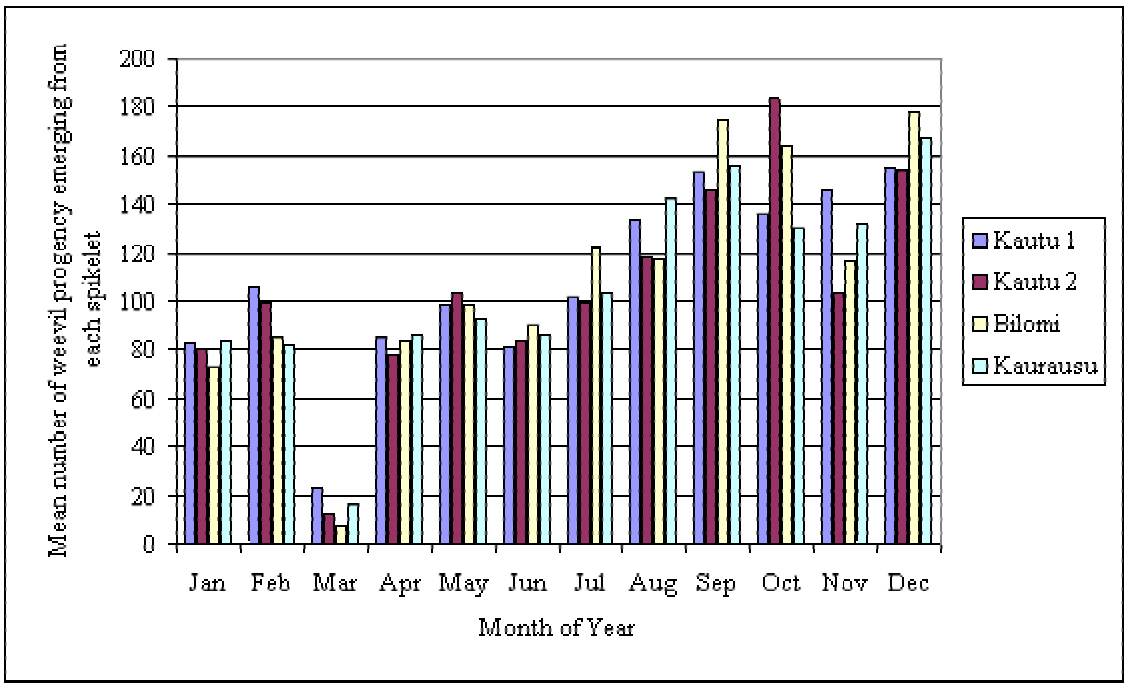


Figure 19. The number of male flowers at anthesis (average/day/135 palms) in the four trial plots at Garu and Haella, NBPOL, WNBP during 2001

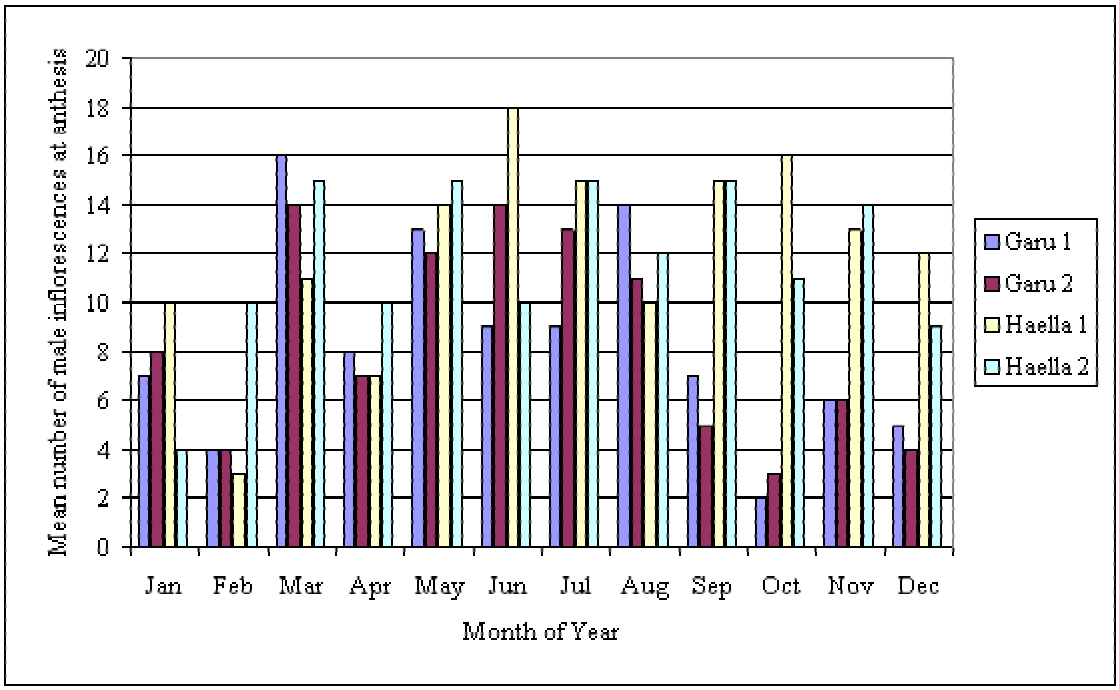


Figure 20. The number of female flowers at receptive stage (average/day/135 palms) in the four trial plots at Garu and Haella, NBPOL, WNBP during 2001

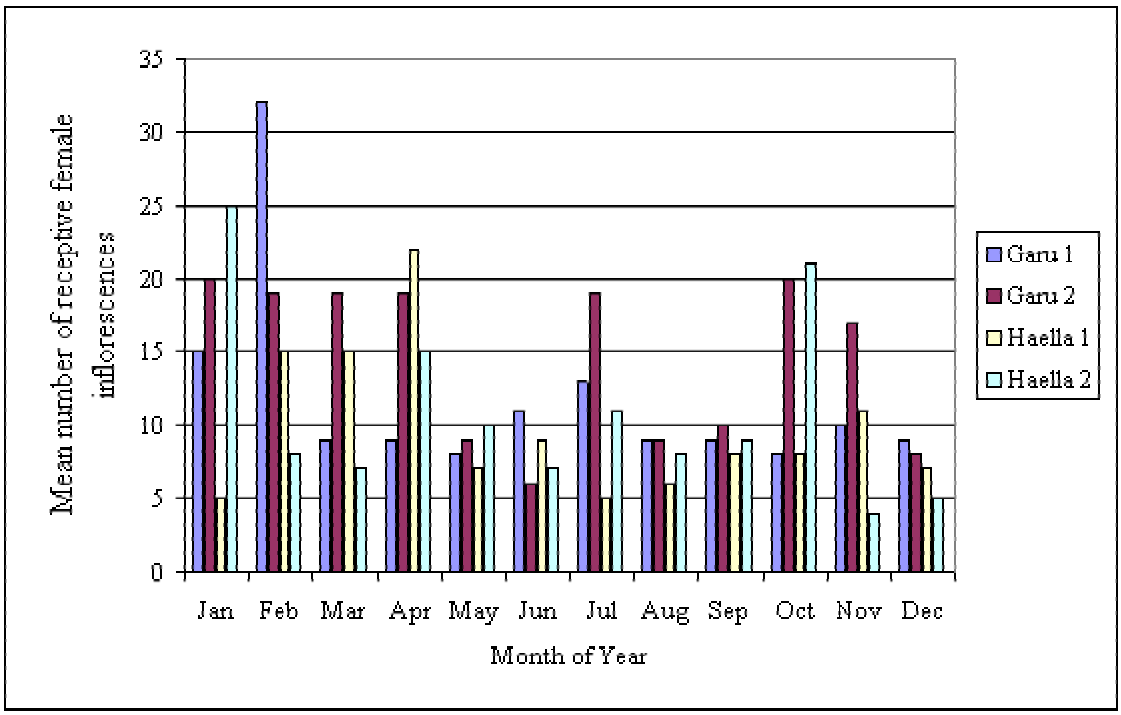
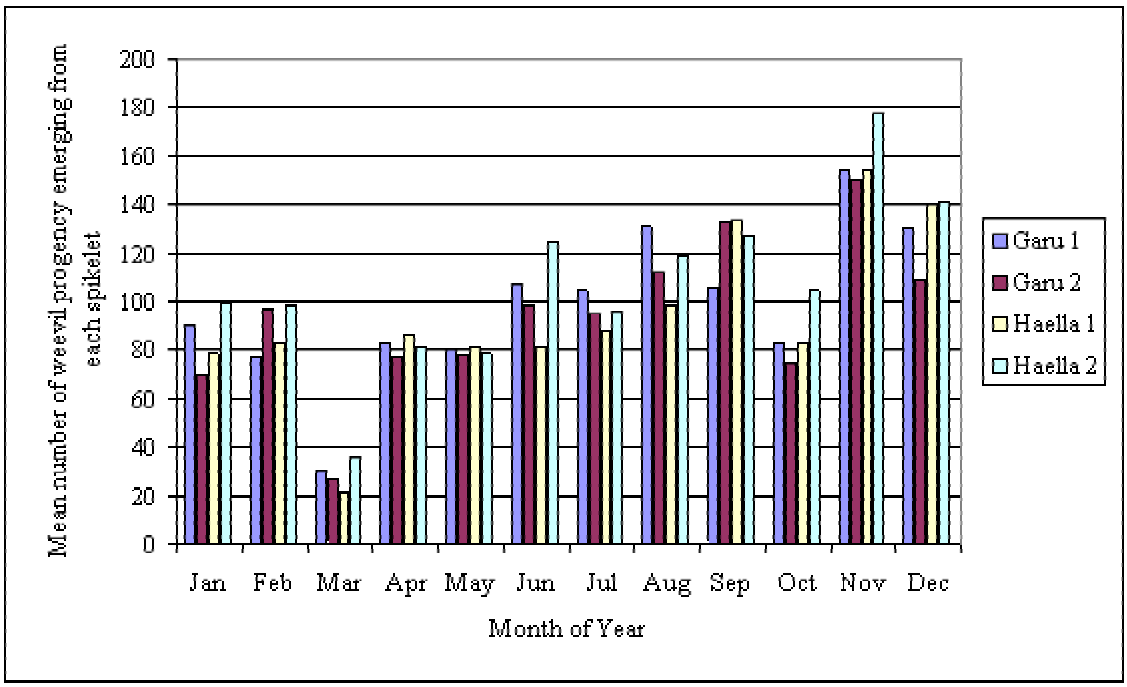


Figure 21. The mean number of weevil progency emerging from each spikelet from the trial plots at Garu and Haella, NBPOL, West New Britain Province during 2001



4. PLANT PATHOLOGY

(Dr. C. A. Pilotti)

SUMMARY

Research activities in 2001 involved *Ganoderma* surveys, epidemiology and nursery screening tests.

Survey results indicate that the annual disease incidence has decreased slightly at both Milne Bay and Poliamba. Cumulative totals in Milne Bay range from 0.5 to 6% in individual blocks while the highest average total was recorded in Waigani with 4.7% total disease incidence due to *Ganoderma.* Disease incidence at Poliamba for 2001 ranged from 0.03% at Fissoa to 1.06% in Medina. Smallholder surveys were also completed this year with a small number of palms found to have basal stem rot.

The study of the *Ganoderma* population continued this year with further out-crosses amongst isolates obtained in the surveys. Some evidence for secondary infection by basidiospores has been found.

Investigations into the epidemiology of *Ganoderma* on oil palm have revealed that the fungus is present in the frond bases of apparently healthy young palms. This may be a possible route to infection of the palms as they mature if the conditions are favourable.

Wood degradation studies continued this year with the positive identification of the candidate fungus as *Ceratocystis paradoxa*. The final laboratory trials were completed and the results emphasise the need for high humidity for effective degradation.

Trials for resistance screening of nursery palms were initiated this year. Inoculated palms did not succumb to infection when checked at 6 and 11 months after inoculation. This indicates either resistance of the palms or poor growth of the fungus due to other factors.

RESEARCH RESULTS

SURVEYS AND IMPLEMENTATION OF THE CONTROL STRATEGY

Milne Bay Estates

Two disease surveys were carried out this year, each six months apart. Both surveys and sanitation have been completed in all estates.

The survey team identified three categories of palms in 2001:

(1) Those which had brackets at the base of the palms classified as ‘bracket palms’

(2) Palms with brackets in the upper portion of the palm -‘upper stem rot’

(3) Palms with no brackets but visible symptoms of basal stem rot -‘suspect’ palms.

Total disease incidence, expressed as a percentage of the total number of palms for the three estates is shown in Figure 1. This is the total number of diseased palms in all three categories pooled together. Average disease incidence in each division ranged from 0.1% in Sagarai to 0.78% in Kwea. Interestingly, Kwea had the highest total incidence in 2001 compared to a larger percentage of older plantings in Waigani. Also of interest are the very similar levels of infection in Giligili (%) and Waigani (%) despite the younger age of the palms at Giliglili. This may be due to an overall decline in the disease incidence in Waigani Estate in 2001.

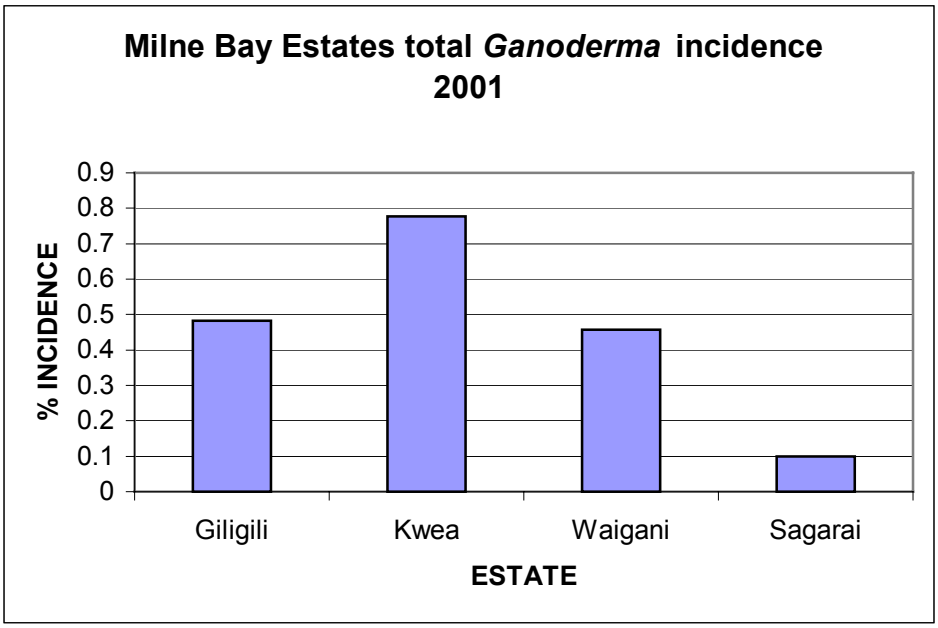


Figure 1. Total disease incidence due to Ganoderma *for Milne Bay Estates in 2001.*

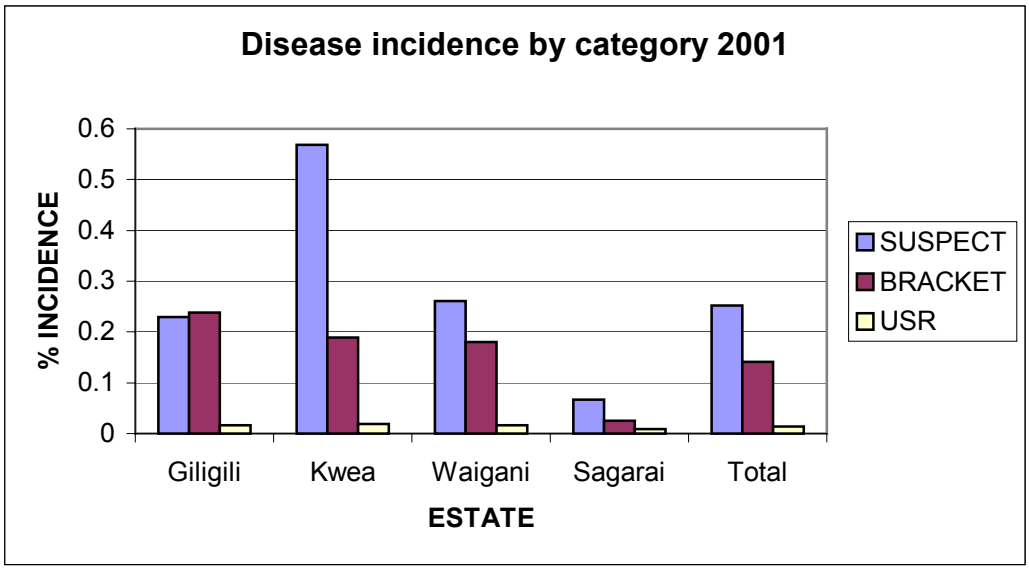


Figure 2. Disease incidence by category in the Milne Bay plantation for 2001.

Figure 2 shows the disease incidence by category. In all estates except Giligili, the number of suspect palms is higher than the number of palms that have brackets of *Ganoderma* present. This is a new trend and the reasons for this is are at present unknown. One possibility is that suspect palms are invaded by secondary pathogens that prevent further growth and fruiting of *Ganoderma.* Further investigations on 'suspect' palms will be necessary to determine if these palms actually have *Ganoderma* present in the wood.

The numbers of palms with upper stem rot in the 2001 survey ranges from 0.009 % in Sagarai to 0.02 % in Kwea. There appears to be a correlation with age with older plantings showing a higher percentage of palms with upper stem rot caused by *Ganoderma* (cf. Waigani and Kwea). Upper stem rot may be secondary infection from basal stem rot.

Figures 3, 4, 5 and 6 show the disease incidences in all blocks within each estate. In Giligili Estate, almost 50% of the blocks have a higher number of 'suspect' palms than palms with brackets at the base. The blocks with the highest number of 'bracket' palms (Fig. 3 -7210, 7211, 7212, 7213, 7214) were previously planted with coconut. In addition, upper stem rot has been detected in almost 50% of the blocks in Giligili Estate although the levels are very low (<0.01 %). In contrast, upper stem rot has only been detected in a about 30% of blocks in Sagarai Estate (Fig. 6). However, in the majority of these blocks the number of USR palms (although very low) outnumbers the palms that have basal stem rot. This situation can not be explained but may indicate vector involvement in dissemination of spores. However, these results represent only a single survey and when analysed with data from previous surveys this interpretation may be revised. In Kwea, suspect palms outnumber bracket palms in all except one block (Fig. 4). In some blocks, the percentage of suspect palms is more than double that of the palms with brackets.

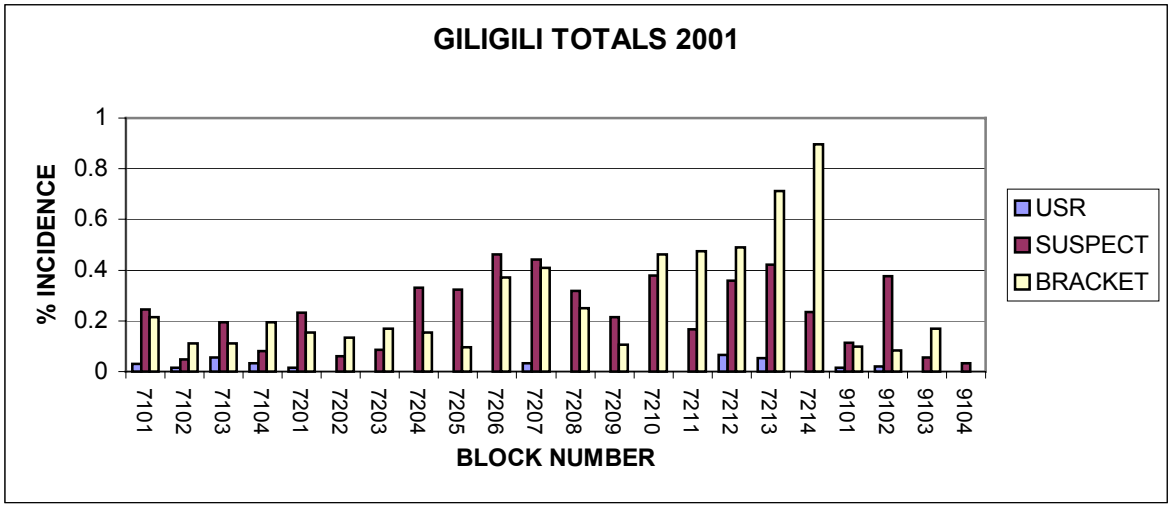


Figure 3. Disease incidence by category in all blocks surveyed in Giligili Estate in 2001.

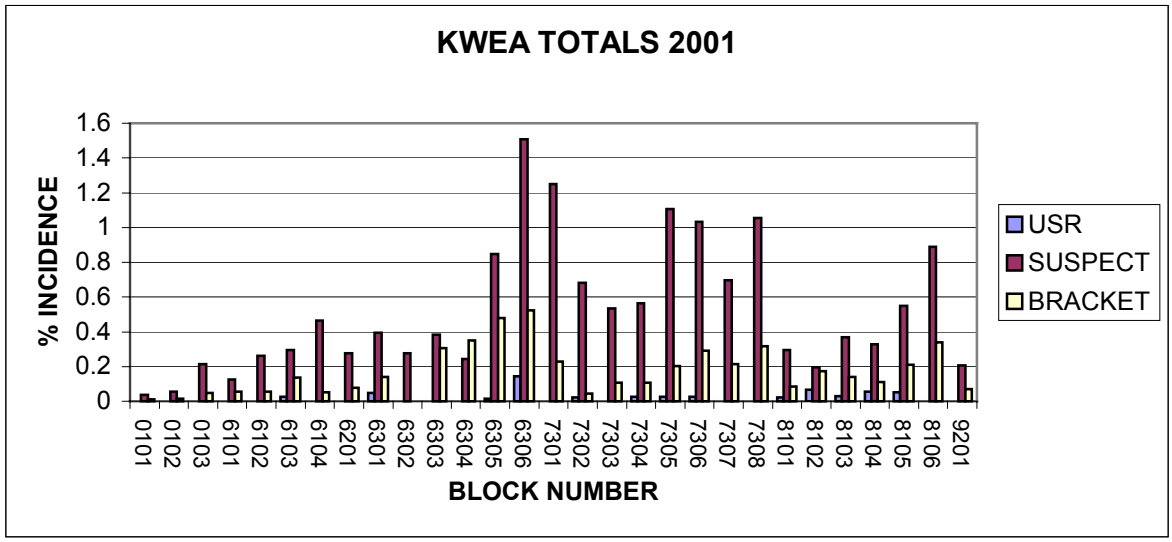


Figure 4. Disease incidence in all blocks surveyed in Kwea for 2001.

The same trend is seen in Waigani with only seven blocks (out of a total of 40 surveyed) having more 'bracket' palms than suspects (Fig. 5).

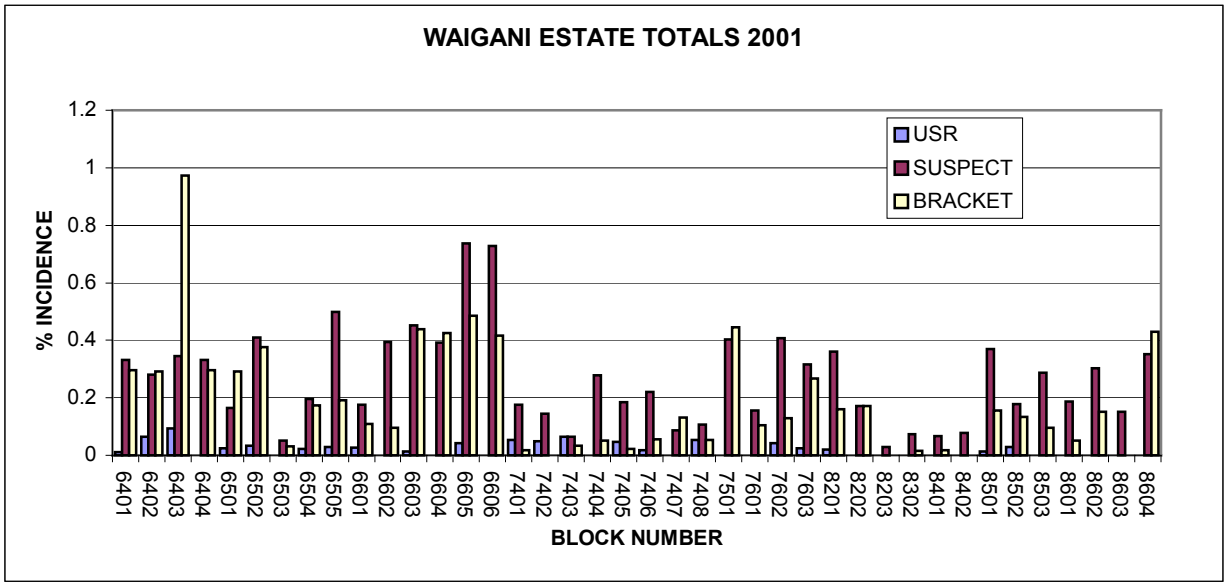


Figure 5. Disease incidence by category in all surveyed blocks in Waigani Estate in 2001.

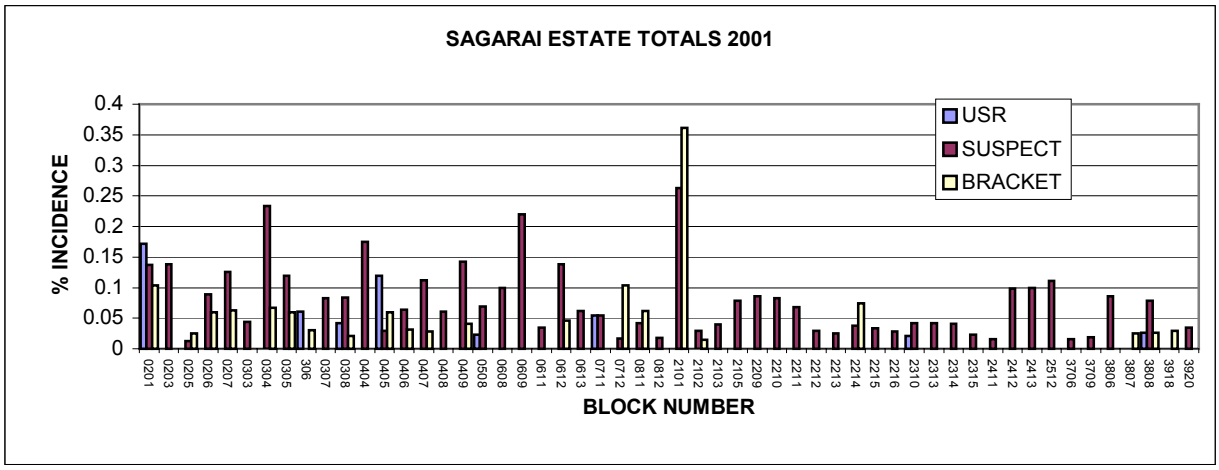


Figure 6. Disease incidence by category and by block in Sagarai Estate.

When disease incidence is viewed by year from the first survey in 1995, a decline in incidence can be seen for the period 2000-2001 for all estates except Kwea (Fig. 7). However, Kwea showed a decline in the 1999-2000 period, as did Waigani.

Cumulative average percentages (Fig. 8) show that disease levels are now approaching 5% in Waigani that has a high proportion of the older palms.

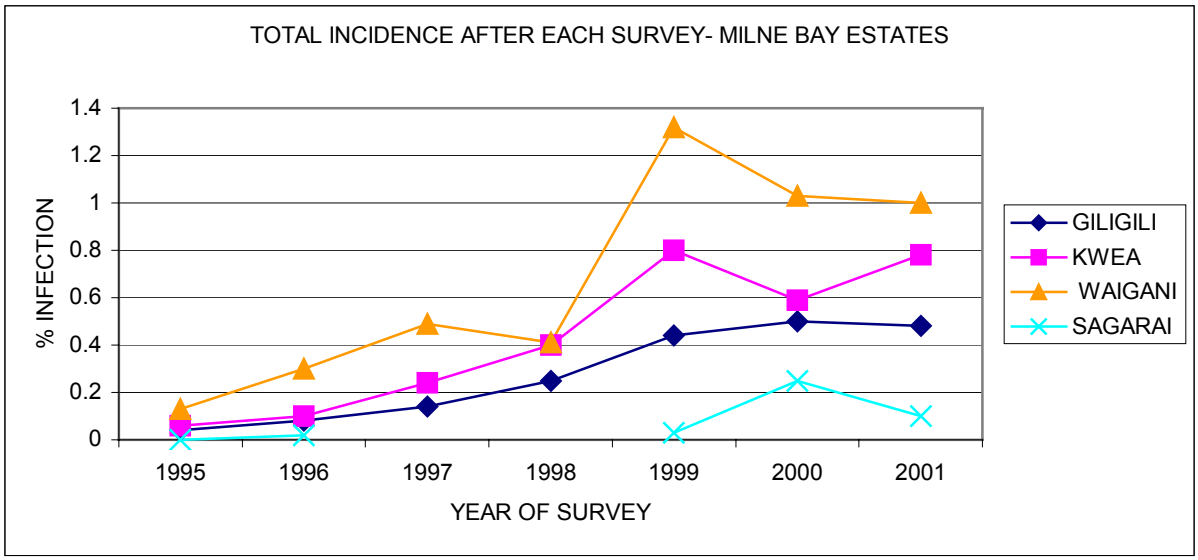


Figure 7. Total disease incidence in each division (estate) for each year of survey for the Milne Bay Estates plantation.

Figure 9 shows the disease incidence with age of the palms for the 2001 survey only. Again, disease levels are highest in the 1986/87 plantings and lowest in the younger plantings. In fact, disease levels are ten times higher in palms that are 15 to 16 years old compared to the 8 to 9- year-old palms.

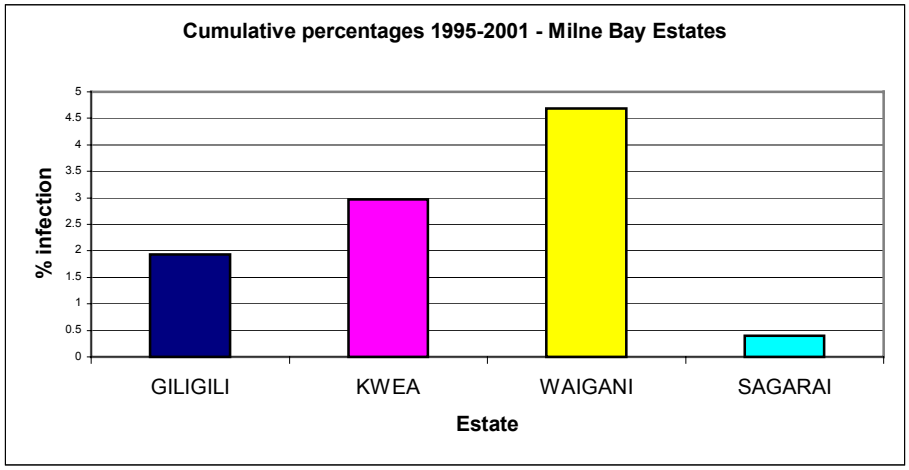


Figure 8. Cumulative incidence of infection for the period 1995-2001 for each estate within the Milne Bay plantation.

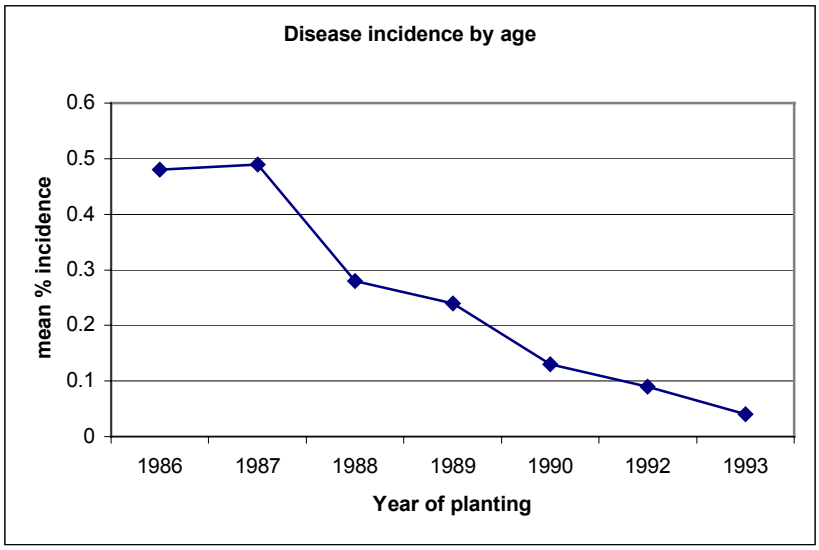


Figure 9. Disease incidence by age for the Milne Bay plantation.

Some blocks in Kwea and Waigani receive palm oil mill effluent (POME) at regular intervals throughout the year. A comparison of the mean disease incidence within blocks that receive POME and those that do not in each of the two estates shows that the total incidence observed in 2001 is slightly higher in the POME blocks (Fig. 9) in both Waigani and Kwea. The differences in disease incidence are not significant in the Waigani blocks but are significant (0.1% level) in the Kwea blocks.

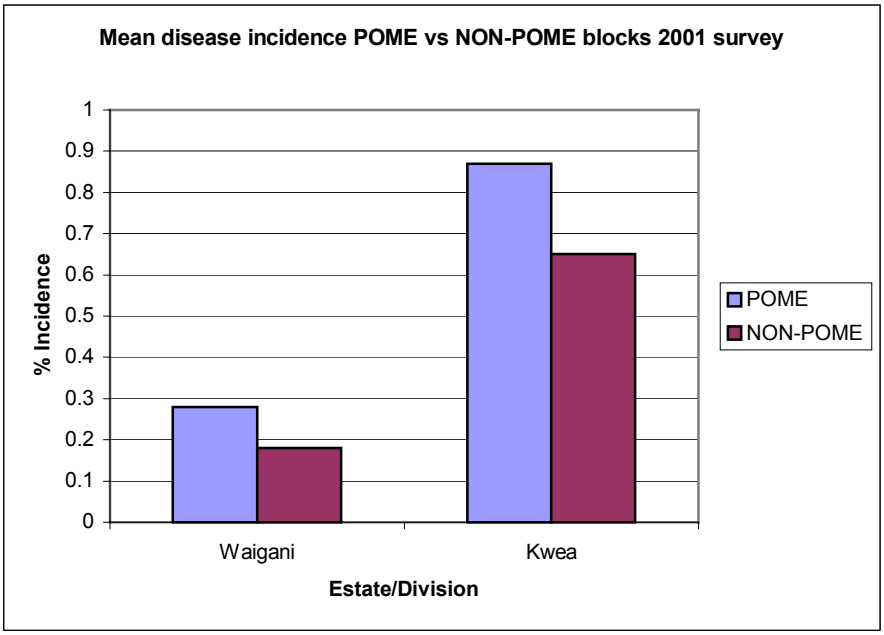


Figure 10. Disease incidence in blocks where POME has been applied compared to non-POME blocks in Kwea and Waigani.

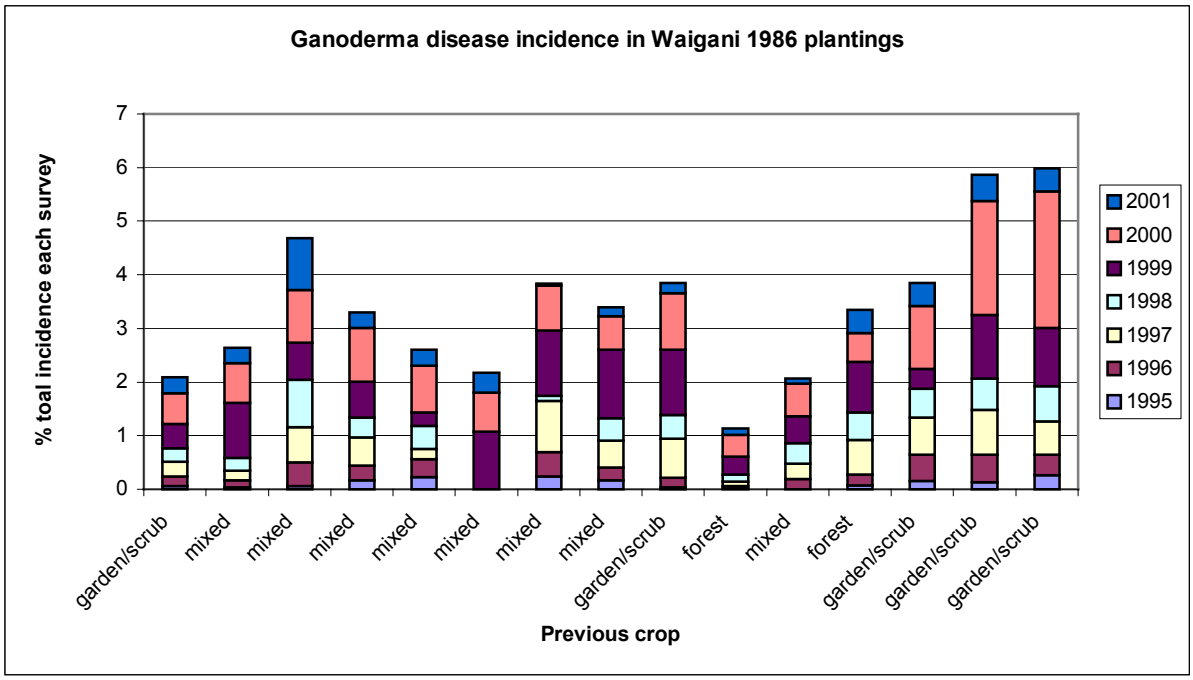


Figure 11. Incidence of bsr (1995-2001) in Waigani 1986 plantings. The vegetation prior to oil palm in each of the blocks is indicated.

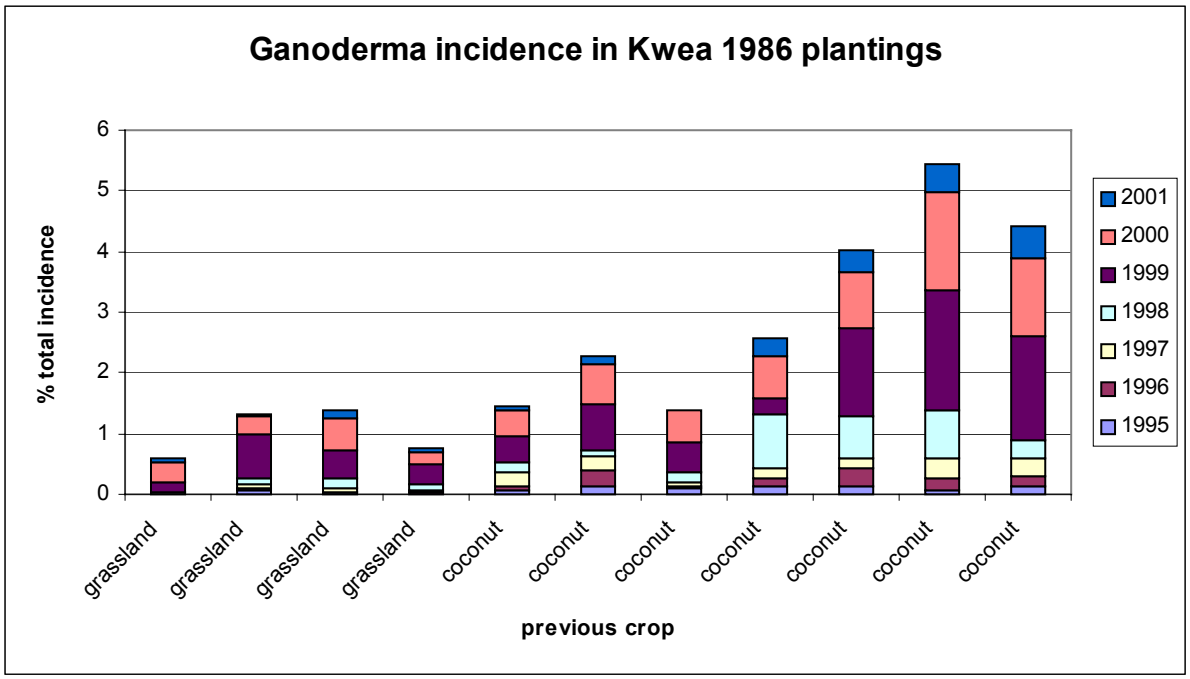


Figure 12. Cumulative incidence of bsr (1995-2001) in Kwea 1986 plantings by previous crop history.

Disease incidence and crop history

There is still no clear correlation between previous crop history and incidence of basal stem rot in Milne Bay (Figures 11-13). This is probably due to the fact that a large proportion of the blocks are 'mixed' or 'garden' areas that may have had a significant amount of coconut planted. In the Kwea 1986 plantings however, disease incidence in the ex-coconut blocks appears to be higher than the grassland blocks (Figure 12). The highest incidence is recorded in the blocks that also receive POME.

The results are similar for the 1987 plantings that indicate that other site factors influence disease incidence since the ex-coconut blocks have a relatively low disease incidence (Figure 13).

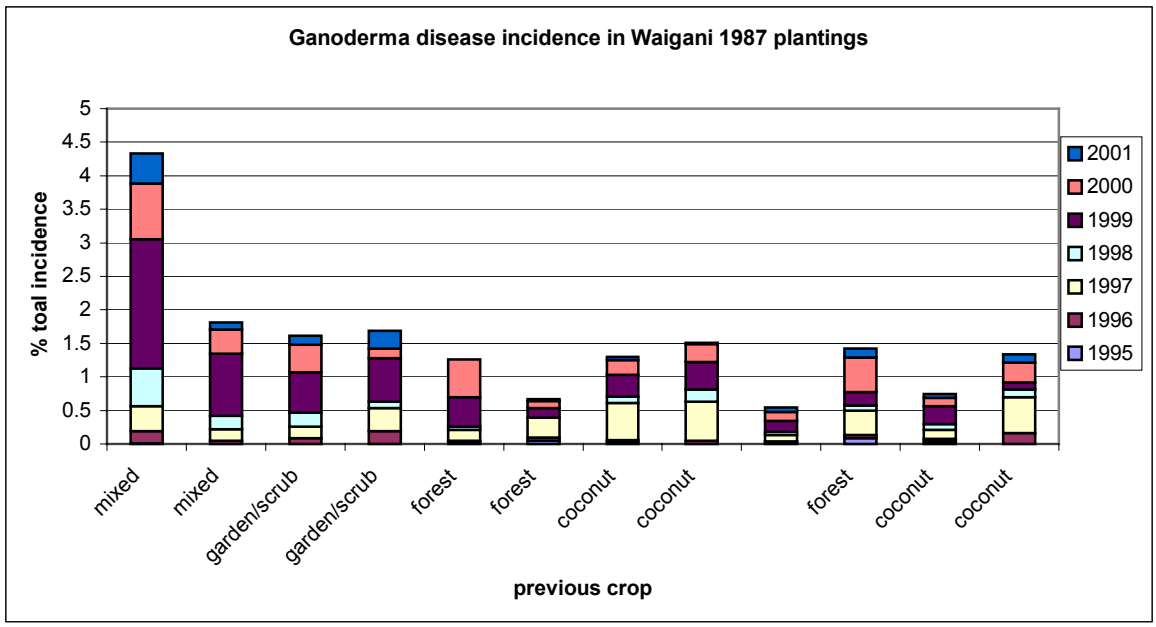


Figure 13. Cumulative incidence of bsr (1995-2000) in Waigani 1987 plantings by previous crop history.

Poliamba Plantation

Disease levels in New Ireland ranged from 0.03% to just over 1% in 2001 (Figure 14). In some plantations no new diseased palms were recorded (Penipol, Libba and Lossu) in 2001. Disease incidence has risen from 1999 figures (Figure 15). Data for the 2000 survey was not obtained and it is assumed that these were incorporated into the data for 2001.

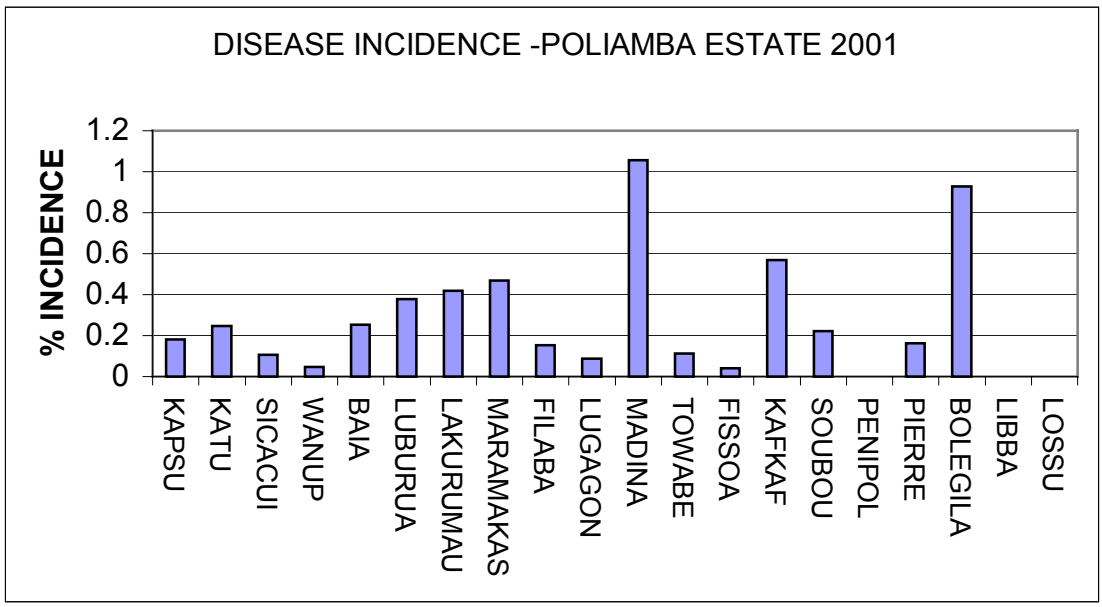


Figure 14. Disease incidence (% diseased palms) in each plantation in the New Ireland Province for 2001.

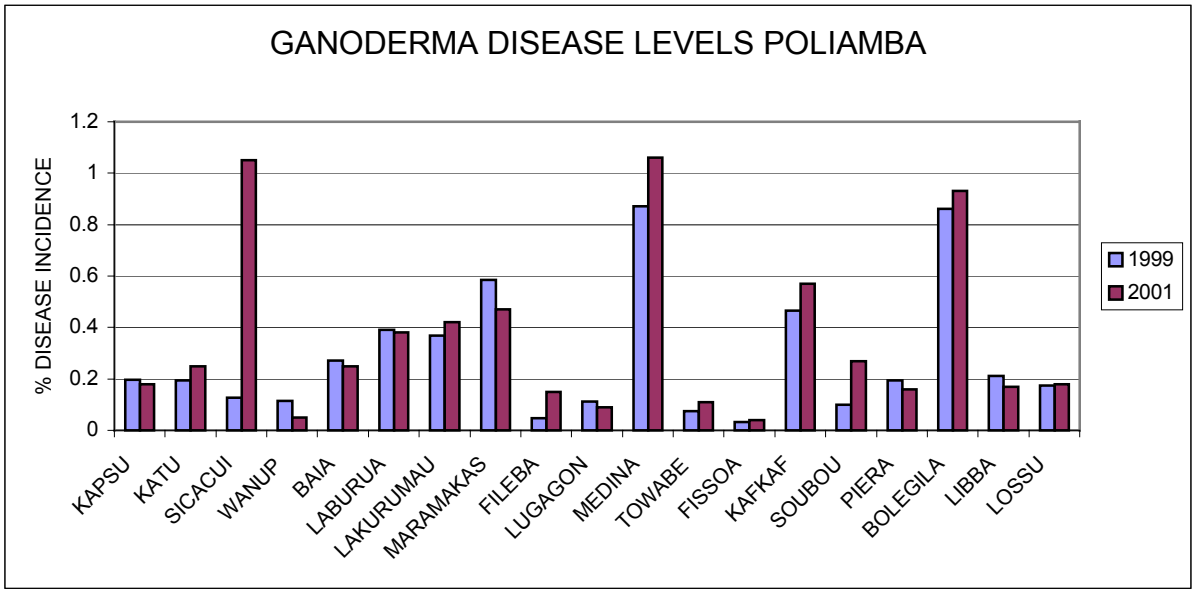


Figure 15. Disease incidence in each plantation for the years 1999-2001 in the New Ireland Province.

Smallholder surveys

Milne Bay Province

There are nearly 200 small block holders in Milne Bay. This year surveys that began in 2000 were completed. The surveys were carried out to determine what levels of infection are present in the smallholder blocks. Results (Table 1) indicate that the disease incidence in these blocks is very small and at present there is no threat to the main plantation. However, the number of suspect palms is high and these will need to be monitored closely over the next 12 months. Some blocks were not checked due to inaccessibility or because the palms were newly planted.

Table 1. Incidence of basal stem rot in smallholder blocks in the Milne Bay Province.

Total No. of blocks surveyed	Total area surveyed Ha.	No. of suspect palms	No. of confirmed *Ganoderma*
174	438	528	12

DISEASE DYNAMICS

Characterization of the Ganoderma population

Activity

The study of the population of *G. boninense* within the Milne Bay plantation continued this year with further sampling of isolates in all blocks selected for the population study –7213, 7214, 6404, 6503, 6504 and 7501. Sampling was carried out after each of the two surveys – in January/February and July/August.

Reciprocal crosses of all isolates in blocks 7213 and 7214 were completed. Crosses between isolates from other blocks have not been completed as yet.

Previously, over 80 A and B mating type alleles were detected in the population. Out-crossing between selected isolates in the laboratory revealed further unique mating alleles (Table 2). Common alleles were also found between an isolate causing upper stem rot and an isolate previously obtained causing basal stem rot (#761 and #432, Table 2).

Table 2. Crosses between some isolates from block 7213, Giligili.

S. No.	S. No.	432A	432B	432D	432F	763F	763G	763K	763M
	ALLELES	A18B19	A19B19	A18B18	A19B18	A85B85	A85B83	A86B83	A86B85
761B	A82 B18	+	+	-	-	+	+	+	+
761C	A82B82	+	+	+	+	+	+	+	+
761G	A81B82	+	+	+	+	+	+	+	+
761D	A82B18	+	+	-	-	+	+	+	+
764C	A83B83	+	+	+	+	+	-	-	+
764F	A84B83	+	+	+	+	+	-	-	+
764G	A83B83	+	+	+	+	+	+	+	+
764I	A84B84	+	+	+	+	+	+	+	+
767A	A87B87	+	+	+	+	+	+	+	+
767F	A87B88	+	+	+	+	+	+	+	+
767H	A88B88	+	+	+	+	+	+	+	+
767P	A88B87	+	+	+	+	+	+	+	+

This indicates secondary infection by spores from isolates causing basal stem rot but further sampling will be required to confirm this.

Interpretation

In two instances, different mating type ratios were revealed after crossing of samples in block 7213. In the first case, two diseased palms directly opposite to each other in adjacent rows were found to have common mating alleles. The mating type ratios revealed that both an A and a B allele were shared between the two isolates (Table 3).

This could be interpreted in two ways: (1) Spores from the fruiting body on one palm spread to the next palm, germinated and caused infection. (2) The fungus spread vegetatively through the roots from one palm to the other. Vegetative compatibility tests between isolates should verify or negate vegetative spread. Unfortunately, it will not disprove spread by basidiospores.

In the second case, isolates from two diseased palms situated two rows apart were found to share common mating alleles (Table 3). In this case, vegetative spread is unlikely and spores are implicated in this relationship. It should be noted that isolates 432 and 433 were collected two years prior to 666 and 716 (see Table 3).

Table 3. Results of mating between neighbouring palms (# 432 and #666) and palms situated two rows apart (#716 and #433) in Giligili estate.

Isolate No.		716A	716B	716D	716M	432A	432B	432D	432F
		A89	A89	A12	A12	A18	A19	A18	A19
	ALLELES	B11	B89	B86	B11	B19	B19	B18	B18
433B	A11B12	-	+	+	-	+	+	+	+
433D	A12B12	+	+	-	-	+	+	+	+
433E	A11B12	+	+	+	+	+	+	+	+
433G	A12B11	-	+	-	-	+	+	+	+
666A	A19B18	+	+	+	+	-	-	-	+
666C	A19B19	+	+	+	+	-	+	-	-
666D	A18B19	+	+	+	+	+	-	-	-
666H	A18B18	+	+	+	+	-	-	+	-

Field trapping of Ganoderma spores

Activity

Small-scale field trials were set up at Giligili to test the availability of *Ganoderma* spores in the air close to fructifications. Three stumps with *Ganoderma* fruiting bodies were selected and stakes were placed 1, 2 and 3m apart in two directions (North and East) away from the stump. Plates containing monokaryotic cultures of *G. boninense* were placed on the stakes at three different heights and exposed for 1hour. Control plates without cultures of *Ganoderma* were included.

Results from two sets of experiments are presented in Table 4. From a total of 30 plates exposed, 5 were dikaryotized by airborne spores liberated most probably from the brackets on the stumps. Although there was a high level of contamination, the dikaryotization of some of the isolates is encouraging and confirms the ability of basidiospores to mate with compatible monokaryons in the natural environment within a short period of time. This implies that dikaryon formation is continuous in the natural environment and therefore, the likelihood of finding monokaryons on oil palm is small.

Table 4. Exposure of Ganoderma cultures to spore rain from fruiting bodies growing on stumps in the field.

Stump no.	Location and direction	Isolate No.	Result
1	1m North A	717B	Contaminated
	1m North B	597O	Not dikaryotized
	1m East A	730C	Contaminated
	1m East B	433E	Contaminated
	2m North A	719L	Dikaryotized
	2m North B	729B	Contaminated
	2m East A	597A	Contaminated
	2m East B	696A	Not dikaryotiaed
	3m North A	696D	Not dikaryotized
	3m North B	CONTROL	No dikaryon
	3m East A	728E	Contaminated
	3m East B	CONTROL	No dikaryon
2	1m North A	717B	Contaminated
	1m North B	728E	Dikaryotized
	1m East A	433E	Contaminated
	1m East B	730C	Contaminated
	2m North A	597O	Not dikaryotized
	2m North B	696A	Contaminated
	2m East A	719L	Contaminated
	2m East B	729B	Contaminated
	3m North A	597A	Contaminated
	3m North B	CONTROL	No dikaryon
	3m East A	696O	Contaminated
	3m East B	CONTROL	No dikaryon
3	1m North A	730C	Contaminated
	1m North B	696A	Contaminated
	1m East A	597O	Contaminated
	1m East B	728E	Contaminated
	2m North A	717B	Not dikaryotized
	2m North B	696D	Contaminated
	2m East A	719L	Dikaryotized
	2m East B	433E	Dikaryotized
	3m North A	597A	Contaminated
	3m North B	CONTROL	No dikaryon
	3m East A	729B	Dikaryotized
	3m East B	CONTROL	No dikaryon

A= 1m up from the ground; B= 2m up from the ground

Molecular epidemiology

Activity

The investigation of the epidemiology of *Ganoderma* in oil palm plantings has continued this year. Samples taken from young oil palms have been screened with the specific PCR primer and protocol previously developed. Activity was concerned with identifying potential above ground infection routes, and focused on the potential role of cut frond bases. Cut frond bases were identified as providing potential infection routes during the epidemiology investigations in 2000, and in the artificial inoculation trials in 2000-2001. Two sets of young oil palms at Numundo plantation, West New Britain were selected for the initial screening. One set of palms consisted of 6-year-old palms that had been planted in an area previously planted with coconut palms. Coconut palm debris had been windrowed, and had developed *Ganoderma* brackets. The windrowed material had subsequently been cleared and buried some 4-6 months before sampling. A second set of palms was 3-4 years old and these had been planted into windrowed coconut debris that was still present. Numerous *Ganoderma* brackets were present on this debris, largely below the legume cover crop.

Samples were taken from a series of frond bases, starting at soil level. For larger palms up to 5 frond bases were sampled, for younger palms with short stems 2-3 frond bases were sampled. Fresh palm material was removed from approximately 1cm below the surface of each frond base, and tissue was stored under ethanol or propanol.

The PCR based diagnostic detected *Ganoderma boninense* in a minority of samples. Among the samples from 3-year-old palms where the windrow had recently been buried, 11/95 samples (corresponding to 8/31 palms) were positive. In the samples from the 2-year-old palms where the windrow was still present, 6/31 samples (corresponding to 6/22 palms) were positive.

Interpretation

These results demonstrate that *Ganoderma* can be detected below the surface of cut frond bases in apparently healthy palms. This confirms the results obtained in 2000, and suggests that cut frond bases may provide a route for future infections. There is a small difference in the frequency of occurrence between the two sets of palms sampled, and both frequencies are considerably higher than the expected disease incidence. The frequency of positive samples is higher (19%) for the younger palms than for the older ones (12%). This may be because the windrowed material was still present with the younger palms, providing a possible continuing source of inoculum. The results obtained so far could suggest a number of scenarios to explain discrepancies in frequencies. The younger palms had short stems, and in most cases it was only possible to sample 2 frond bases, whereas the older palms had longer stems and usually 5 frond bases were sampled. Among these older palms, 8 of the 11 positive samples were obtained from frond bases that were numbered 3, 4 or 5 above soil level, and would correspond to those most recently pruned. These are clearly not frond bases that were available for infection in previous years, and so they are not indicative of established infections. These observations may therefore suggest that freshly cut frond bases continuously receive spores from outside inocula, and that these may persist as either spores or mycelium for some months. This does not however always lead to infection, and it would seem likely that the possible future infections will come only from the older frond bases where the *Ganoderma* has persisted. In the results obtained here for the 3 year old palms that could suggest a possible infection rate of 3/95 (3.5%). These results are however based on relatively limited sampling over a short time period, and more extensive sampling of these and other palms is required over a longer time period in order to determine if this scenario is accurate.

Molecular comparison of other species of Ganoderma

Comparison of ITS rRNA sequences from other species of *Ganoderma* has been compromised by recent additions to the publicly available sequence databases. These now contain more than 200 sequences described as from *Ganoderma* sp., which effectively prevent the comparison of new sequences with those from named specimens or cultures. To overcome this DNA is being extracted from authenticated *Ganoderma* specimens held at Royal Botanic Gardens, Kew.

Resistance Screening

Nursery screening

In 2001, one hundred 2-year-old palms were inoculated with a number of cultures of *Ganoderma* grown on wooden dowels. After 6-11 months, palms were cut up and examined to assess the extent of *Ganoderma* growth into the woody tissue. In only a small percentage of the palms the mycelium was still viable. The majority of palms showed very little growth of the *Ganoderma* mycelium or movement of the fungus into the live tissue. However, the growth of the fungus was fairly strong into the frond base. Some modifications to the inoculation technique was done and a further 120 palms were inoculated in October/November. Results are not yet available.

Rapid wood degradation

This project has been carried out in collaboration with CABI Biocience and Birkbeck College in the U. K. The objective of the project was to find a fungus that could rapidly break down oil palm trunks in the field. One candidate was isolated and has been under study since 1998.

Ceratocystis (anamorph *Thielaviopsis*) *paradoxa* is an ascomycete that occurs naturally and in abundance within the plantation. Twenty-nine isolates of this fungus (three from West New Britain) were cultured and stored. Some have been lost due to contamination.

Because *Thielaviopsis (Ceratocystis) paradoxa* has been implicated in bud rots and a dry stem rot in South America, it is important to confirm the identification of the PNG isolates and to carry out further studies of this fungus before it is used as a biocontrol. Although this fungus is implicated in a number of diseases of oil palm not much is known about its pathogenicity and variability of isolates in the field.

Taxonomy

Activity

Isolates from PNG were taken to Birkbeck College for identification of the fungus in April, 2001.

The identity of strains selected for the oil palm degradation studies was investigated by analysis of the sequences of the internal transcribed spacers (ITS) of the ribosomal RNA (rRNA) gene cluster. ITS sequences from strains from PNG were compared to previously published sequences from other fungi, and to sequences obtained from reference cultures of *Thielaviopsis paradoxa*. The sequences of all the PNG isolates closely matched those obtained from the reference cultures and those previously published as *Thielaviopsis* or *Ceratocystis paradoxa* (greater than 96% similarity). There were slight (2-5 base pair) differences between individual isolates, but these did not apparently correlate with any specific factors such as host or location.

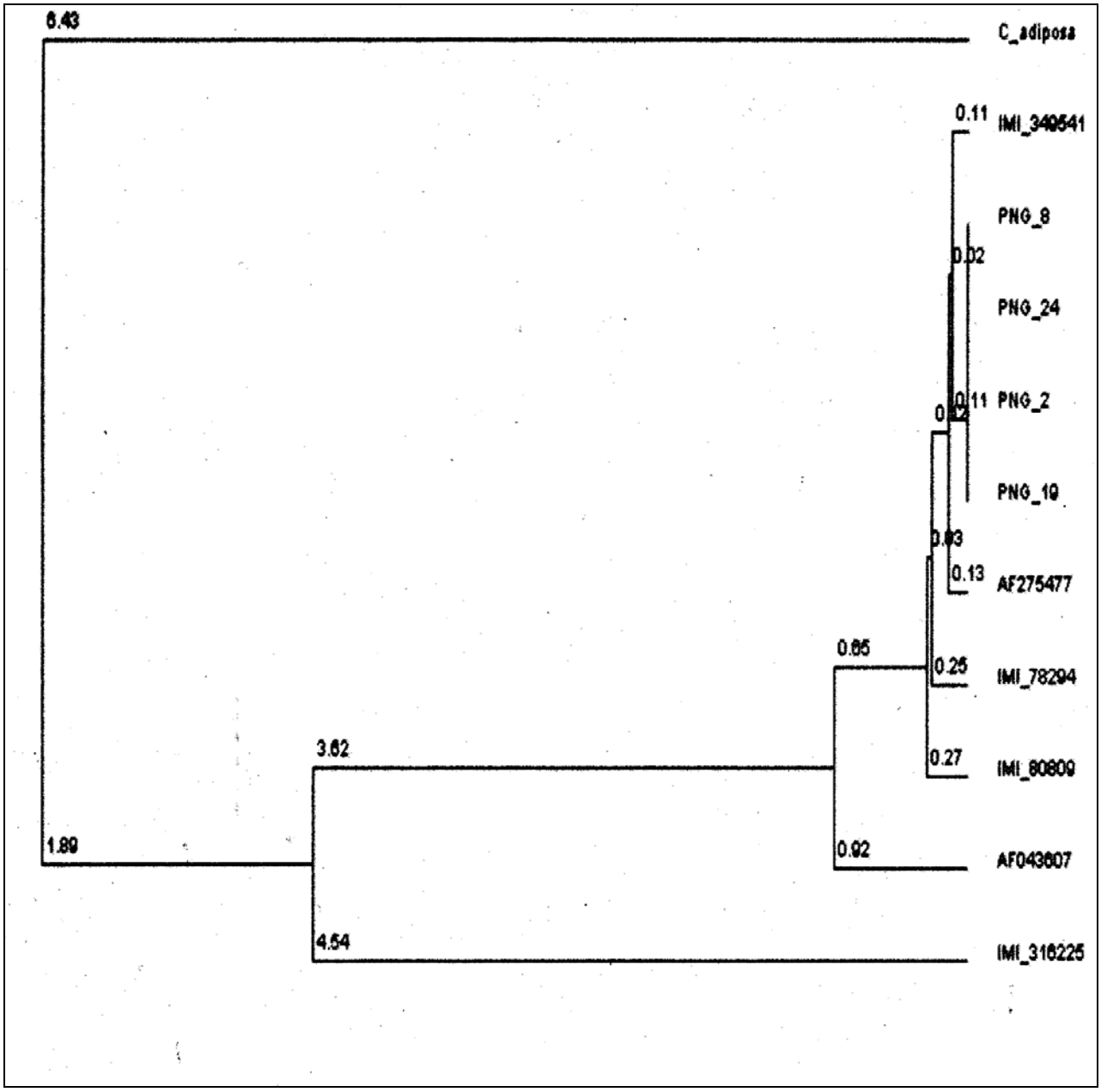


Figure 16. Dendrogram showing the similarity of PNG isolates of C. paradoxa *to other collections from around the world.*

Interpretation

The isolates selected for the palm stem degradation work are typical strains of the mitosporic species *Thielaviopsis paradoxa*. Mating studies in our Milne Bay laboratory have subsequently shown that these strains are capable of producing the meiotic state *Ceratocystis paradoxa.*

Laboratory based wood degradation trials

Activity

Barbara Ritchie spent three weeks in Milne Bay in May 2001.

Two trials were carried out this year. The objective of both trials was to determine the best candidate isolates of *Ceratocystis* for field trials. The trials were carried out under uncontrolled conditions in the nursery. Blocks of wood 5X3X15cm were sawn from sound wood of suspect or USR palms and

brought back to the laboratory. They were then dipped in Benlate and the volume was crudely determined by displacement. The ends of the blocks were cut off with a saw and both ends were inoculated with agar plugs of *C. paradoxa*. Good coverage of the wood blocks was obtained after 7 days. Unfortunately the weight loss and penetration results were inconsistent with earlier trials in 2000 and 2001 due to difficulty in control of the conditions under which the fungus was grown (Table 4 A and B).

Table 5. Penetration of Ceratocystis in experimental blocks after 7 days of activity under laboratory conditions.

A

Isolate	Average rot penetration (cm)
PNG 1	1.10
PNG 2	1.07
PNG 3	1.12
PNG 6	1.78
PNG 8	1.77
PNG 13	1.38
PNG 16	1.92
PNG 18	2.29
PNG 19	2.46
PNG 20	0.20
PNG 24	0.71
PNG 25	0.16
Control	1.34

B

Isolate	Rot penetration (cm)
PNG 1	0.25
PNG 2	0.25
PNG 3	0.25
PNG 6	0.26
PNG 7	0
PNG 8	0.37
PNG 16	0.30
PNG 19	0.53
PNG 20	0.59
PNG 4	0.25
PNG 5	0.42
PNG 9	0.44
PNG 11	0.37
PNG 12	0.27
PNG 21	0.36
PNG 22	0.27
PNG 26	0.25
PNG 27	0.43
PNG 28	0.36
PNG 29	0.42
Control	0

Figure 17. Oil palm wood blocks in plastic bags one day after being inoculated with Ceratocystis *cultures.*

Figure 19. Wood blocks being dried after seven days to check shrinkage due to degradation by *Ceratocystis*.

Figure 18. Field trial of *Ceratocystis* isolates on cut portions of an oil palm trunk after one week under wet conditions in Milne Bay.

Meetings & Conferences

Drs Sanderson and Pilotti and Prof. Bridge attended an informal meeting in Medan, Indonesia in April 2001 and made presentations on the status of Ganoderma research and the future strategies for control. Following this meeting, visits were made to PT Smart plantations in Sumatra and the Indonesian Oil Palm Research Institute where discussions were held with the Director and his staff on their research programme on *Ganoderma*.

Dr. F. Sanderson and Professor Bridge attended the annual Palm Industries Palm Oil Conference in Kuala Lumpur Malaysia in May 2001 and three poster papers were exhibited.

Dr. C. Pilotti attended the 13th Biennial Australasian Plant Pathology Conference in Cairns, Australia in September 2001 and presented a paper.

Publications

Pilotti, C.A**.** (2001) Genetic studies of *Ganoderma* spp. associated with oil palm in Papua New Guinea*.* Ph.D. Thesis University of Queensland, Australia.

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Pilotti, C.A., Sanderson, F.R. and Aitken, E.A.B. (2001). The population structure of *G. boninense* on oil palm. *13th Biennial Meeting*, The Australasian Plant Pathology Society, Cairns, Australia.

Griffith, W., Castle**,** J., Sanderson, F., Pilotti, C. and Bridge, P. (2001). Control of *Ganoderma* stem rot in the Pacific Rim Palm Oil Limited's estates in Papua New Guinea*. International Palm Oil Congress, Cutting Edge Technologies for Sustained Competitiveness*, *Proceedings of 2001 PIPOC Agriculture Conference,* Kuala Lumpur, Malaysia.

Bridge, P., Panchal, G., Sanderson, F. and Pilotti, C.A**.** (2001). Environmental sampling for *Ganoderma* in oil palm: a molecular tool for elucidating epidemiology. *International Palm Oil Congress, Cutting Edge Technologies for Sustained Competitiveness*, *Proceedings of 2001 PIPOC Agriculture Conference,* Kuala Lumpur, Malaysia.

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