Annual Research Report

2002

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Report by the Director of Research

to the

PNGOPRA Annual General Meeting - June 2003

We are all too used to Papua New Guinea being way down on any international list of achievements and at the top of the list when it comes to problems. For a welcome change we can proudly say that Papua New Guinea is at the top of the international list when it comes to the performance of its oil palm industry. With higher cost structures than other countries, and less Government assistance, the oil palm industry in PNG must be more productive and more efficient than elsewhere in order to survive, let alone grow. Research and development plays a vital role in ensuring this sustainability and competitiveness. Technical developments by our milling companies and the research and development functions carried out by the PNG Oil Palm Research Association (PNGOPRA) and Dami Oil Palm Research Station (NBPOL) are now leading the World in many areas of technical innovation.

Formation

The country's oil palm companies and the Papua New Guinea Government formed PNGOPRA in 1979 to function as the research arm of the oil palm industry. PNGOPRA carries out research into oil palm agronomy, soils & crop nutrition, entomology, plant pathology and smallholder socio-economic studies. PNGOPRA does not conduct plant-breeding work, this is carried out very effectively on a commercial basis by New Britain Palm Oil Ltd at their Dami Research Station.

Locations

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 operates 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.

Membership

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, Ramu Sugar and the Oil Palm Industry Corporation (OPIC).

OPIC, by way of its Membership, represents the smallholder oil palm growers of PNG. Ramu Sugar, started its own oil palm operation in 2003, formally became the newest PNGOPRA Member in early 2003.

The Members of the PNGOPRA have a close involvement in the direction and running of the organization thus ensuring that 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 Board that reflect their Members financial 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 2003 are presented above.

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.

Members Voting Rights in 2003:

Member	FFB Production in 2000	Votes
New Britain Palm Oil Limited	555,681 tonnes	6
Pacific Rim Plantation Ltd	448,766 tonnes	5
Hargy Oil Palms Ltd	82,375 tonnes	1
Oil Palm Industry Corporation (smallholders)	531,264 tonnes	6
Ramu Sugar	nil	1
The Director of Research (Executive Director) also holds one vote		

Financing

PNGOPRA as an organization is small in size, especially when compared to the scale 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 fifteen years ago; despite this the output is now much greater in terms of both quality and quantity.

PNGOPRA is funded by a research levy paid by all oil palm growers and by external grant funding. Today the Members levy represents about 65% of the organizations revenue and external grants 35%. The Members levy in 2003 is set at a rate of K1.77 per tonne of FFB for all growers. Currently external grant funding is provided to support two ACIAR projects and three European Union projects. Government financial support was withdrawn in 2003 for the first time; this now seems to be accepted as being an ill-conceived move and it is hoped that funding will be reinstated during 2003.

Administration

PNGOPRA is self-administered and managed by a small team based at Dami Research Station. It is a deliberate strategy to limit the size of the support operation and foster an emphasis on the research functions of the organization.

Research

On the face of it the last year should have been a difficult one for our research programmes, with our entomology and plant pathology operations falling within a wide gap in external grant support and the Government withdrawing funding for the core agronomy research programme. Fortunately with industry support, the start of two new agronomy research programmes (*supported by the European*

Union and ACIAR) and the dedicated commitment of the PNGOPRA staff, we have actually made some very significant advances.

Entomology

Sexava IPM

The EU-funded Sexava project, which focused on attempts to transfer the strepsipteran parasite, *Stichotrema dallatorreanum,* from Oro to West New Britain and New Ireland Province finished at the end of 2001 and the project final report was written and submitted in early 2002. Further releases of Stichotrema were made during 2002 and the total of all releases, into more than 20 trial sites, reached 10,878 by September 2002. Regular sampling at 14 of the sites produced two returns of the parasite during 2002 and there has not yet been any indication of *Stichotrema* successfully infecting *Segestidea gracilis* in the New Ireland. The method used for recording infection, the presence of the dark patches on the underside of the Sexava host produced by the extrusion of the parasite's cephalothorax through the skin of the host, was supplemented after October by the dissection of all specimens collected from release areas to look for the immature stylops inside the hosts. Between October 2002 and the beginning of February 2003, 547 Sexava from *Stichotrema* release areas were dissected and no stylops were found. It is possible that if the Sexava eggs laid in the field during the year held up development (diapause) during the dry season until the start of the rains at the beginning of October, no or very few Sexava nymphs or adults would have been available for *Stichotrema* to infect and the population cycle of the parasite could have been broken. This would only be expected to happen in a particularly dry season although confirmation of this will not be forthcoming until the egg diapause is fully understood. Work during 2003 will concentrate on further understanding the sexual/asexual reproduction of *Stichotrema* and the breeding of the parasite through successive generations of *Segestes decoratus* (and later *Segestidea defoliaria*) in the insectary, so that stocks of the parasite can be released from the correct hosts.

Parasites of Sexava eggs, *Leefmansia bicolor*, were reared throughout the year in the laboratory and then released into oil palm growing areas where low-level Sexava populations were present. There were an estimated 180,000 of these egg parasitoids released during 2002.

In Sexava, the length of the hind femur can be measured to delineate the instars and examine the linear growth of a population. It is only when a population of insects is under severe conditions and individuals are smaller than they should be, or instars stages are missed out, that the technique falls down. This is unlikely in the case of Sexava feeding on oil palm. In addition the elytra (*wing*) length and stage of oocyte (*egg*) development can be recorded for each adult (*note that for S. decoratus found in New Britain there are only females present*). The oocyte development dissections can give information on how mature a female is, how many eggs have been laid, and how many times the female has laid eggs. The morphometric techniques were therefore introduced to look at: (i) whether Sexava populations are overlapping or succinct (ii) the number of instars that *S. decoratus* and *S. defoliaria* have in the field (iii) examine the rate of development in the field (iv) being able to predict when oviposition is beginning to take place and (v) being able to predict the time of eggs hatching in relation to rainfall. Although at an early stage, the initial results, using *S. decoratus* samples from outbreaks in the Dami area, have been encouraging with the prediction for egg hatch fitting in with the first rains of the season (end of September) after a particularly dry season. The rate of development inferred from the morphometric results fitted in with the life tables worked out by previous workers using caged insects.

A major constraint in carrying out experimental work on Sexava in the laboratory has been the difficulty of maintaining stocks of the different species, particularly *S. decoratus* and *S. defoliaria* at Dami. Stocks had been kept solely on reject oil palm seedlings of approximately 7 months old. Since Sexava had originally fed on indigenous plants prior to the introduction of oil palm it was decided to try giving the stocks a mixture of young oil palm, young coconut palm and wild *Heliconia* sp. Both *S. decoratus* and *S. defoliaria* showed a particular preference for coconut; with oil palm being the second choice and *Heliconia* last in terms of amount eaten. The stocks showed a considerable improvement in health (reduction in mortality) so it was decided to continue giving a mixture of the food plants. Coconut is now presented using 2-4 cut fronds and keeping them in wet soil. Handling of the Sexava, perceived to be a major cause of mortality, now no longer appears to be a problem.

Insect Pollination

The two-year research project on the pollinating weevil, *Elaeidobius kamerunicus*, funded by the European Union, was completed by the end of June 2002, other than the conversion of part of the insectary at Dami to a quarantine facility, which was delayed because an inspection report was required from National Agriculture Quarantine and Inspection Authority (NAQIA). The project report was written up by the end of June and was updated and submitted in early 2003. The main outcomes of the project (reported on in detail in the 2001 Annual Report) were: (i) there can be a high level of parasitic nematode infection in the pollinating weevil population (up to 50% infection with high parasite loading). This level of parasitism must have a considerable impact on weevil survival and reproductive capacity. (ii) The PNG population is genetically distinct from the West African and Central American, however the genetic diversity within PNG does not appear to be as restricted as originally feared. Inbreeding is not so much of a concern. (iii) It would be better to supplement the current pollinating weevil population with imports of new genetic material of the same species rather than importing new pollinator species.

The parasitic nematode has been identified as *Elaeolenchus parthenonema* by Poinar et al 2002, who give a brief outline of the stages of this parthenogenetic nematode.

Quarantine facilities to house the introduction of new genetic material of *Elaeidobius kamerunicus* proposed by the pollination project were designed in October to fit in the requirements set out by the NAQIA in their report of June 2002 "Pre-accreditation Report on Dami Oil Palm Insectary". The plan for the conversion was submitted to NAQIA to ensure that the conversion would meet their requirements and clearance was received at the beginning of December. The building of the facility with high, medium and low security rooms was initiated at that time.

Work was initiated in October to study further the infection levels in the pollinating weevils of the internal nematode *E. parthenonema* and to gain further understanding of the population dynamics, life cycle and effect of the nematodes on the weevil population. Initial collections of weevils from anthesing male inflorescences showed a marked difference between the levels of infection between different sites. Studies on the levels of nematode infection in male and female weevils emerging from their breeding sites (post-anthesing male spikelets) have shown that: (i) the majority of females emerge over the first four days whereas males emerge over a period of two weeks or more. The sex ratio reaches about 50:50 if the population is healthy (ii) in areas with high levels of the internal nematode, there can be a very high variation in infection levels in weevils emerging from different inflorescences sampled within 50m of each other (iii) there appears to be mortality caused by the internal nematodes if the numbers of nematodes per infected individual is high (iv) male emergence is affected more than females, the higher the level of infection the higher the male mortality (vi) the internal nematodes are immature in the first emerging weevils (females) but have reached maturity by the time the majority of the male weevils are emerging (vii) there appears to be a link between the wetness of the inflorescence and the level of infection where the nematodes are occurring, hence the reason why levels of nematode infection are perceived to be higher during the main rains and in areas with higher rainfall (viii) up to 100% nematode infection has been found in the emergence samples and up to 57 nematodes in one individual have been found.

Work will continue on the affect of the internal nematodes and other factors on the health of the pollinating weevils and the subsequent affect on pollination and fruitset in oil palm.

The Entomology Section has continued with routine advisory and pest monitoring work. A total of 30 requests for advice on pest damage were responded to of which 24 where due to Sexava.

Agronomy

In 2002 the Agronomy research program consolidated a major change in direction that aimed at understanding the processes that determine the returns on fertiliser investments. We expect that improved management recommendations based on the new work will start emerging within the coming year.

The highest returns on investment in the oil palm industry are those made on the purchase and application of fertiliser. While returns are high, the potential for losses or increased gains are also enormous.

As with all investments, the key to maximising return is to understand the nature of the investment, in this case the processes that underlie response of oil palm to fertilisers. Considering the sums involved, our understanding of these processes is not yet what it should be. In addition to the bottom line of profitability, the industry is increasingly committing itself to protecting the environment. One of the major potential areas for minimising impact on the environment is nutrient loss from fertiliser inputs. Understanding nutrition and developing appropriate management strategies is the main task of PNGOPRA's Agronomy Section.

Improving nutrient use efficiency

The first priority of the Agronomy research program was to understand the nutrient requirements of palms in different areas and to determine the response to nutrient inputs. Although that phase of research has been carried out to a large extent, it must still continue as production moves into new areas and as soils change. What has now become clear is that there may be large potential gains in efficiency of fertiliser use. Also, the fertiliser trials have thrown up a number of related questions. For example, what is the best way to apply nitrogen fertiliser to maximise uptake and response in the varied climates and soils of the industry? And why doesn't kieserite (magnesium sulphate) eliminate the symptoms of magnesium deficiency widespread in West New Britain? Underpinning all the questions about improving nutrient use efficiency is the issue of the long-term sustainability of agricultural management - how can we best maintain or improve soil fertility and avoid degradation?

Maintaining soil fertility

Our research therefore now focuses on understanding the ways in which nutrients are retained and lost from the system, and how retention and losses are influenced by management. The ability of soils to retain and supply nutrients varies enormously within plantations and between different soil types, and is also influenced by management. From recent results it is becoming clear that soil organic matter and soil pH are the key to nutrient retention in most of our soils. For example, one of the negative impacts of using ammonium-based fertilisers is a decrease in soil pH, which is significantly reducing the capacity of our soils to retain and supply cations such as potassium and magnesium. Soil pH and soil organic matter are both amenable to management- what we need to know is the critical processes and the economics of influencing them.

In this last year two major projects commenced. They concentrate on the retention and losses of nitrogen and magnesium on volcanic ash soils.

Minimising nitrogen losses

The 'N losses' project is being carried out in collaboration with Massey University, New Zealand and with financial support from the European Union. It is concerned with the efficacy of nitrogen fertiliser inputs. The aim is to identify the major mechanisms of nitrogen loss and to develop management practices that reduce losses as much as possible. 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. Success in the project could have an enormous impact on the economics of oil palm production in PNG.

We have started gathering the data needed to determine losses of N. We have measured the distribution of rainfall under the canopy and the infiltration capacity of the soil in the different zones such as the frond pile and weeded circle. These factors determine whether rainfall infiltrates or runs off. Surface infiltration rates are generally very high. Deeper down in the soil profile the infiltration capacity declines, acting as a bottle-neck and causing the over-lying soil to become saturated, eventually to the surface. At this stage runoff increases markedly. We have measured runoff in several large plots on the Higaturu soil type. It varies from about 1% of rainfall in small events to 36% in large events. Knowledge of the surface infiltration characteristics of soils will allow us to predict runoff at other sites with similar slope. We are now commencing to measure the generation of mineral N in the soil profile (*mineralisation*) and the concentration of N in runoff and leachate water. Putting these results together will allow the first estimate of N losses by leaching and runoff.

Improving cation nutrition

The 'Magnesium nutrition' project is being carried out in collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia and with financial support from the Australian Centre for International Agricultural Research (ACIAR). It relates to the cation nutrition problems experienced on the volcanic ash 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. 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, 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 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. 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) determining the properties of soils that will allow us to predict where various management practices should be used, and 2) identifying the processes that have caused the problem so as to determine whether it will increase or decrease in these rapidly weathering soils.

Understanding responses to fertiliser trials in WNB

A third major project that commenced this year concerns 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 fertilised areas into control plots. This apparent movement has implications not just for experimental design, but also for management of nutrition in plantations. We have established experiments aimed at determining whether nutrients are moving in shallow groundwater, and are looking into ways of determining from where nutrients in a particular area have come.

More effective use of existing information

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 soil types, we will be able to extend management recommendations from detailed experimental sites to all areas of the industry. We are in the process of incorporating all available soil maps into a GIS.

Providing technical support

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.

Plant Pathology

Ganoderma Control

Basal stem rot, the only disease of importance on oil palm in Papua New Guinea, is a threat to the future sustainability of the oil palm industry. The disease is found in all oil palm growing areas within PNG, although in world terms PNG's disease incidence is still relatively low. The disease and its causal organism *Ganoderma boninense* are complex and the exact nature and length of the disease cycle is not yet fully known. The need to determine this in order to develop effective disease control forms the basis of ongoing investigations into the epidemiology of this disease in different areas of PNG. The primary mode of spread of the disease has been established previously (*by PNGOPRA scientists*) as being the result of spore dispersal. Evidence for, and characterization of, secondary spread of *Ganoderma* in mature palm stands is part of our on-going research programme. The extended disease cycle makes this a long-term project and continuity is vital for the future management of this disease. Current collections and storage of fungal isolates will allow infections found in future plantings to be identified and associated with previous infections, thereby providing an understanding of the selection and evolution of the pathogen (*Ganoderma*) with its host (*oil palm*). This ongoing study of the epidemiology of *Ganoderma* is one of the most comprehensive of any crop pathogen and emphasizes the importance of these investigations in future disease control.

A second broad area of research concerns the biological control of *Ganoderma*, mainly through the application of naturally occurring antagonistic fungi. Pilot field trials for the rapid degradation of palm trunks with a candidate fungus has yielded mixed results. Clearly, more work is needed on the micro-environmental conditions required for rapid breakdown of palm wood. Under ideal conditions, it has been shown that portions of the trunk can be totally degraded within a several days after inoculation with the candidate fungus. Further small-scale field trials will continue to determine if all trunk tissue, including the bole can be degraded. If so, this will eliminate the need to remove bole tissue and thus reduce the costs for short-term control.

Our evidence to date suggests that pruned frond bases may be the main point of entry for *Ganoderma* spores in both young and mature palms. By using a specific molecular marker for *G. boninense* (*developed as part of our research programme*), the presence of *Ganoderma* in young cut fronds bases continues to be detected. As a result of this, another fungus is being investigated as a potential antagonist of *Ganoderma* in the early stages of palm growth. Candidate isolates have been collected and are awaiting export and identification. It is envisaged that laboratory investigations will start in 2003 and, depending on the results of laboratory assays and molecular marker work, field application will subsequently be tested. These studies will be carried out in collaboration with the Royal Botanical Gardens at Kew and Birkbeck College, London.

The third, and most important, area of research is the production of a viable pathogenicity assay that will enable the selection of more resistant or tolerant planting material. This is the only route to effective long-term control of *Ganoderma* infections. Initial testing using wooden dowels has been shown to be unreliable and results have indicated that alternative means of infection must be investigated. Over 200 palms have already been inoculated using various techniques and these are awaiting assessment after a suitable period of incubation.

Field trials are also being planned to test the resistance of different seed lines. These will be necessary to complement the results of the nursery and laboratory tests.

Training and extension within the industry still comprise a significant portion of the Plant Pathology section's activities. It is envisaged that short-term student attachments will be introduced in the near future.

Technical Services

The personnel within PNGOPRA represent an invaluable knowledge resource for its Members. 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 in place 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 for Members and formulate the annual fertiliser recommendations for most Members. PNGOPRA staff also spend a significant amount of their time in providing technical training to plantation staff and extension officers.

Since its formation, PNGOPRA has had an enormous impact upon the productivity and profitability of PNG's oil palm industry, and there is still more scope for further advancement. The current research programme aims at producing maximum crop yields in an economically and environmentally sustainable manner. The Members of PNGOPRA have a scientific service that they can be proud of and one that reflects the commitment and professionalism of the industry it serves.

Ian Orrell
Director of Research
June 2003

1. AGRONOMY RESEARCH

SUMMARY

(P. Nelson)

The highest returns on investment in the oil palm industry are those made on the purchase and application of fertiliser. While returns are high, the potential for losses or increased gains are also enormous.

As with all investments, the key to maximising return is to understand the nature of the investment; in this case the processes that underlie response of oil palm to fertilisers. Considering the sums involved, our understanding of these processes is not yet what it should be. In addition to the bottom line of profitability, the industry is increasingly committing itself to protecting the environment. One of the major potential areas for minimising impacts on the environment is nutrient loss from plantations. Understanding nutrition and developing appropriate management strategies is the main task of PNGOPRA's Soil Science and Crop Nutrition Section.

In the early days of OPRA, the first priority of the Agronomy research program was to understand the nutrient requirements of palms in different areas and to determine the response to nutrient inputs. That phase of research, consisting of straightforward fertilizer trials, has been carried out to a large extent, but it must still continue as production moves into new areas and as soils change. What has now become clear is that there may be large potential gains in efficiency of fertiliser use. Also, the fertiliser trials have thrown up a number of questions. For example, what is the best way to apply nitrogen fertiliser to maximise uptake and response in the varied climates and soils of the industry? And why doesn't kieserite (magnesium sulphate) eliminate the symptoms of magnesium deficiency widespread in West New Britain? Underpinning all the questions about improving nutrient use efficiency is the issue of the long-term sustainability of agricultural management - how can we best maintain or improve soil fertility and avoid degradation?

In 2002, the Agronomy program underwent a large change in direction in order to find solutions to these problems.

Nutrient Cycling and Soil Fertility

In this last year several major projects commenced. The first two concentrate on the retention and losses of nitrogen and magnesium on volcanic ash soils and have both attracted donor funding.

Minimising nitrogen losses on volcanic ash soils

The aim of the 'N losses' project is to identify the major mechanisms of nitrogen loss and to develop management practices that reduce losses and improve the benefit/cost ratio of fertilizer application. The project is being carried out in collaboration with Massey University, New Zealand and with financial support from the European Union, and is the project in which Murom Banabas is undertaking his PhD. 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. Success in the project could have an enormous impact on the economics of oil palm production in PNG.

The water balance is critical in determining the amount of runoff and leaching and most of the work so far has concentrated on quantifying the water balance. We have determined that the distribution of rainfall under the canopy is very non-uniform, with stem flow varying from 1-7% of rainfall and much of the remainder falling at the intersection of two palm canopies. Infiltration capacity of the soil is also not uniform, being highest under the frond pile and lowest in the harvest path and weeded circle. Surface infiltration rates are generally very high. Surface runoff must therefore be generated in the harvest paths and weeded circles or when hydraulic conductivity of deeper layers is exceeded and the soil profile fills with water. We have measured runoff in several large plots on the Higaturu soil type. It varies from about 1% of rainfall in small events (of around 5 mm) to 36% in large events (around 100 mm). Knowledge of the surface infiltration characteristics of soils will allow us to predict runoff at other sites with similar slope. We are now commencing to measure the generation of mineral N in the soil profile (mineralisation) and the concentration of N in runoff and leachate water. Putting these results together will allow the first estimate of N losses by leaching and runoff.

Cation nutrition on volcanic ash soils

Widespread and serious magnesium deficiency symptoms have been identified in oil palm growing on the young, coarse-textured, volcanic ash soils in West New Britain and some arts of Oro. The problem occurs on plantations, village oil palm and land settlement schemes. The ‘Magnesium nutrition’ project is being carried out in collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia and with financial support from the Australian Centre for International Agricultural Research (ACIAR).

Recent member-funded research found a large and general imbalance between exchangeable calcium on the one hand, and exchangeable magnesium and potassium on the other. Calcium dominates throughout the soil profile, frequently exceeding the soil cation exchange capacity. This may explain why surface applications of soluble amendments such as kieserite have been largely ineffective. A possible solution will be to introduce protected ‘hot spots’ of magnesium- and potassium-containing materials into the soil to allow some roots to access and take up these elements. The project will focus on the type of amendments to apply and methods of placement to overcome the cation deficiencies. Field studies in PNG will be supported by laboratory-based work in Australia aimed at; 1) determining the properties of soils that will allow us to predict where various management practices should be used, and 2) identifying the processes that have caused the problem so as to determine whether it will increase or decrease in these rapidly weathering soils.

Four field trials with alternative amendments and placement methods have been designed and will commence in 2003. The most promising amendments have been obtained and characterized. Preliminary results have already given pointers to the origin of cation imbalance. The soils are dominated by Ca-rich weatherable primary minerals, and they have a very low selectivity for Mg due to the nature of their cation exchange sites. A water/solute transport model, HYDRUS 2D has been purchased to predict the best management options under various soil, climate, palm and ameliorant conditions, and Agronomy staff have been trained in its use.

Poor responses in fertiliser trials in WNB

Over the last decade, an area of increasing concern has been the anomalous and poor responses to fertilizers in trials in West New Britain, with control plots yielding as much as fertilised plots. Over that period considerable effort has gone into ensuring that experimental designs were suitable for measuring responses. ‘Systematic’ trials have recently been re-introduced to overcome the problem, and they are expected to be successful if the problem is due to movement between adjacent plots. The first results from the systematic trials are discussed in the ‘Fertiliser Response Trials’ section. However, if nutrient movement is occurring on a larger scale, from the surrounding plantation, systematic trials may not provide the answer. The apparent movement of nutrients has implications not just for experimental design, but also for management of nutrition in plantations. We have commenced several experiments aimed at determining whether nutrients are moving in shallow groundwater or by other means.

We have established two large 'Omission trials' (Trial 141), in which a large circle of palms has fertilizer with-held. Yield and tissue nutrient contents will be monitored to determine is nutrients are moving into the area and if so, how far and from what direction. The trial has been set up in two locations at Haella, one at the top edge of the plantation and one down on the floodplain, surrounded by plantation. In two areas where fertilizer trials have not responded as expected (Trials 125 and 402), we are monitoring of shallow perched water tables. Through the 2002-2003 wet season groundwater was occasionally detected at about 1-1.5m below the surface, within reach of the roots. The rapid response of the watertable to rainfall suggests that it may be a conduit for nutrients. The groundwater monitoring will not detect transient lateral flow in shallower layers, so lysimeters were set up at Dami to measure lateral flow. A significant amount of water was collected moving laterally at 20 cm depth. Another approach taken has been to determine if there is a gradient in fertility downslope of a well-fertilised plantation into less well fertilized smallholder areas. A possible area has been identified and samples taken for analysis. In addition to these experiments, several fertiliser trials with very large plots have been set up (142, 148 and 149). They are described in the 'Response to Fertilisers' section.

Maintaining soil fertility

Our research now focuses on understanding the ways in which nutrients are retained and lost from the system, and how retention and losses are influenced by management. The ability of soils to retain and supply nutrients varies enormously within plantations and between different soil types, and is also influenced by management. From recent results it is becoming clear that soil organic matter and soil pH are the key to nutrient retention in most of our soils. For example, one of the negative impacts of using ammonium-based fertilisers is a decrease in soil pH, which is significantly reducing the capacity of our soils to retain and supply cations such as potassium and magnesium. Soil pH and soil organic matter are both amenable to management- what we need to know is the critical processes and the economics of influencing them.

Nutrient budgets and nutrient use efficiency

We have commenced routine sampling of trunk tissue and FFB in fertilizer trials in 2003 in order to estimate nutrient uptake and efficiency. Distribution of nutrients in the trunk were measured so that the amount of nutrient in the trunk can be estimated from a single sample.

Fertiliser Response Trials

West New Britain (NBPOL)

In West New Britain, most factorial fertilizer trials have not been responding as expected over the last decade or so. In 2001 it was decided to close trials 125, 126 and 129. In Trial 129 (fertilizer placement), treatments have continued as effects on the soil may still take some years to develop. Those trials were closed at the end of 2002. The systematic N trials commenced recently and were designed to overcome problems with possible plot-to-plot movement of nutrients. Of the systematic trials, 138a (Haella) was closed at the end of 2002 as it is a 2-row trial and will provide no extra information than the adjacent 4-row trial 138b. Trial 137 (Kumbango) and 138b (Haella) commenced treatments in 2003 and Trial 403 (Kaurausu) has provided its second year of results. An additional series of fertilizer trials has commenced in 2003. They have plots that are much larger than in the previous and current trials and are imposed on breeding trials, so progeny effects are controlled. Trial 142 (Kumbango and Bebere) is an N trial with each plot being an entire block and an entire breeding trial replicate. Trial 148 (Mg, Kumbango) and Trial 149 (B, Kumbango) are slightly smaller but follow the same principle.

In Trials 125 and 129 there were again no significant effects of fertilizers (N in 125, N + Mg in 129). In Trial 126 (Malalimi), there were responses to SOA, TSP and NaCl but not SOP, showing that the effect of MOP in previous trial 119 was due to Cl rather than K. In Trial 136 (monthly tissue sampling), peaks in leaflet N corresponding to N fertiliser application were noticed for the first time. In Trial 138a (Systematic N, Haella), a response to N was noted in this the first year of yield recording. The optimum dose was around 4 kg AMC/palm. We expect that trial 138b will provide similar results, although in its first 6 months there was not yet a response. Trial 403 (systematic N, Kaurausu) has produced its second year of yield results with as yet no response to N. If the trial does not respond in 2003 we will suspect that nutrients are moving between plots. The only alternative explanation is that the soil is supplying sufficient N.

West New Britain (Hargy)

The factorial trials 204, 205 and 209 continued to show similar results to previous years. In Trial 204 yield is starting to recover from the Sexava outbreak and one more year will make clear what is the optimum fertilizer strategy for enhancing recovery. At this stage the recommendation for this area would be to continue with AMC application only according to the normal recommended rate. In 205 progenies again had the biggest effect on yield, but the ranking of progenies changes from year to year. In 209 yield was greatest at the highest rates of SOA, MOP and TSP. In factorial trial 213 (N, P on high ground) treatments commenced in 2003. This year we report on the first results for the systematic N trials 211 and 212. There was not yet a response in either trial.

Oro

In Oro, a series of trials has recently been completed and another series has just commenced. The final report for Trials 305 and 306 is complete, and final reports for Trials 309, 310, 311 and 312 have yet to be written. When Trial 312 was felled, trunk and roots samples were taken, and the distribution of nutrients in these will allow us to estimate nutrient content of palm biomass from limited samples and hence to calculate nutrient use efficiency. There were distinct gradients in nutrient distribution within the trunk.

2002 was the second year of results for Trial 324 (N sources, Sangara). There was not yet any clear effect of fertilizer type although some trends appear to be emerging. High rates of fertilizer slowed trunk elongation. 2002 was the first year of results for Trial 326 (N x EFB, Sangara) and 329 (Factorial, Mamba), and there were not yet any significant treatment effects in either trial. Trial 330 (N x S, Grasslands) was delayed due to high variability; blanket SOA is being applied to the site.

Milne Bay

In Milne Bay the three factorial fertiliser trials continued. In Waigani, the trial on the good Plantation soils (502b), SOA, MOP and EFB continue to have positive effects, with EFB proving to be an effective source of N and K. TSP has no effect. On the poorer Hagita (buckshot) soils (511), there are large positive effects of SOA, TSP and EFB, especially in good years. MOP has had no effect. In Sagarai (504), the positive effects of SOA and MOP are increasing with time.

New Ireland

In the factorial fertilizer trials 251 and 252, the effects of fertilisers on yield and tissue nutrient contents in these trials were similar in 2002 to previous years. MOP had a major effect on yield in both trials. SOA has had no effect in Trial 251 but has had an increasing effect in Trial 252. Fertiliser application, especially MOP has had a large beneficial effect on decreasing the incidence of Ganoderma. Trial 254 (B trial) commenced in 2002.

Other Factors

Most of our research is in the area of nutrition. However, we have some research on spacing and thinning for mechanical in-field collection, and research on the interaction between agronomic and socio-economic factors affecting smallholder productivity.

Spacing/thinning trials have not yet produced yield data. Yield recording in Trial 139 (Kumbango) and 331 (Ambogo) commenced in 2003 and Trial 513 (Padipadi) was planted in 2003. A range of cover crops was planted in all three trials in 2002/2003, and preliminary results from 331 are presented.

Agronomic aspects of the ACIAR-funded smallholder socio-economic project are presented here. Unfortunately it was impossible to obtain accurate measures of yield. However, tissue analyses showed large effects of soil type and little or no relationship with any of the survey responses, including fertilizer use. Although the main limitations to smallholder productivity are socio-economic, the results show that important interactions with soil type must be considered when designing extension programs.

Predictions and Recommendations

All our research aims at improving predictions and recommendations for the industry. However, we are also carrying out some work to improve the way we can translate research results into improved recommendations. In the ‘Soil Resource Information’ project we aim to make 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 soil types, we will be able to extend management recommendations from detailed experimental sites to all areas of the industry. We are in the process of incorporating all available soil maps into a GIS.

Results are also starting to flow from our yield monitoring and prediction studies. The gross effect of annual rainfall on annual yield 2 years later has been evident in trials in all four provinces.

BACKGROUND INFORMATION

STAFF

Senior Agronomist

Dr. Paul Nelson

Agronomists

Mr. Murom Banabas (conducting PhD)
Mr. James Kraip, Islands Region Agronomist (commenced June 2003)
Mr. Thomas Betitis, Islands Region Agronomist (departed May 2003)

Assistant Agronomists

Ms. Rachael Pipai, Dami (commenced February 2003)
Mr. Peter Tarramurray, Bialla (departed December 2002)
Mr. Winston Eremu, Bialla (moved from Poliamba in March 2003)
Mr. Steven Nake, Higaturu (commenced March 2003)
Ms. Jojo Papah, GIS, Higaturu

Field Supervisors

Mr. Paul Simin, Dami (moved from Higaturu in Dec 2002)
Mr. Jeren Okka, Kapiura (commenced March 2003)
Mr. Graham Bonga, Higaturu (moved from Dami in Dec 2002)
Mr. Wawada Kanama, Milne Bay
Mr. Kelly Naulis, Poliamba (moved from Kapiura in April 2003)

ABBREVIATIONS

AMC	Ammonium chloride (NH_4Cl)
AMN	Ammonium nitrate (NH_4NO_3)
ANOVA	Analysis of variance (statistical test used for factorial trials)
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	Muriate of potash, or 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 2002

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Total**
West New Britain Province													
Navo	650	1325	467	386	391	155	189	35	84	300	202	147	**4331**
Bialla	480	964	712	212	216	194	63	46	51	174	184	143	**3438**
Dami	672	845	617	304	81	292	181	4	64	215	161	149	**3586**
Garu	537	1272	744	360	95	137	221	0	37	121	262	225	**4011**
Oro Province													
Mamba	333	225	588	298	276	238	164	127	277	265	470	854	**4111**
OPRA Embi	194	157	406	230	150	105	55	73	38	286	393	239	**2326**
Milne Bay Province													
Waigani	208	128	194	152	172	212	164	58	58	144	201	84	**1773**
New Ireland Province													
Poliamba	377	474	447	198	275	403	62	11	9	102	368	124	**2849**

Monthly and annual sunshine hours in 2002

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Total**
West New Britain													
Navo	123	84	80	126	88	164	254	292	316	263	123	-	**1923***
Bialla	189	112	233	247	251	211	316	264	328	235	223	264	**2873**
Dami	129	70	99	190	186	127	183	229	224	186	164	178	**1964**
Oro Province													
Mamba	164	46	101	159	183	131	118	165	208	202	197	196	**1868**
OPRA	188	84	132	203	225	170	179	185	214	228	171	205	**2183**
Milne Bay Province													
Sagarai													
New Ireland													
Poliamba	158	115	143	185	181	159	223	245	246	209	176	199	**2238**

* Data missing for December.

NUTRIENT CYCLING AND SOIL FERTILITY

NITROGEN LOSSES FROM OIL PALM ON VOLCANIC ASH SOILS (EU STABEX 4.22)

(Results and discussion of work done to date, M. Banabas)

INTRODUCTION

Leaching and removal of N by surface lateral flow are associated with soil water balance. Losses of nitrogen by these 2 processes occur when precipitation is greater than evapotranspiration. Surface lateral flow occurs when rate of precipitation is greater than infiltration. Nitrogen is lost in either dissolved or particulate or both forms.

Water balance of an oil palm agro – ecosystem can be defined as the flux of water into and out of the system and the storage of water within the system. The major part of the precipitation stored within an area is held as soil moisture. Water is lost from an area in 2 ways: 1) evaporation and transpiration and 2) deep percolation and surface runoff. Preliminary studies reported here were done to quantify some of the water balance components under an oil palm growing agro ecosystem and model soil water balance.

Under an oil palm, soils vary and for this study, areas under palms were divided into 4 zones; frond piles, between palms, weeded circle and harvest path (the zones are defined under methods and materials section). The zones are different because of the canopy structure of oil palms and management practices. Study of water balance components and chemical characteristics were done in the 4 zones. Studies done included infiltration measurements, through fall measurements, surface runoff measurements, exercises with FAO 56 using available climatic to determine potential evapotranspiration and soil chemical properties.

Potential concentration of N forms in seepage water, bore hole and creeks in oil palm plantations are also reported.

METHOD AND MATERIALS

Sites of Preliminary Water Balance Studies and Soils Sampling

Preliminary measurements of water balance components, soil and water sampling were done in Oro and West New Britain Provinces on volcanic ash derived soils. Work was done in these 2 provinces because 85 – 90% of oil palm is produced in these 2 provinces, however, results will be extrapolated to other Provinces. Sites were also selected on the basis of response pattern to N fertilizers and different P retention values. Sites in Oro Province showed significantly strong responses to N fertilizers and have P retention values of 20 – 30%. In WNB at Dami and Haella, poor to moderate responses to N fertilsers were reported and they have 60 – 75% P retention values while no to poor responses were reported in Bialla in Hargy Plantations on soils with > 90% P retention values. The differences between the different sites at Popondetta are, soils at OPRA are fine sandy clay loam while at Ambogo Estate the soils have coarser sandy loam structure. Samples were taken at 312 to see differences between fertilized and non fertilized plots. The difference between Dami and Haella is differences between a coarser sandy material at Dami and finer material at Haella. In depth studies were, however planned to be done in only 2 sites, Dami and Popondetta because of proximity to weather stations and convenience of management.

Soil samples were taken all sites, infiltration measurements were done at Popondetta, Ambogo, Dami and Haella and through fall and surface runoff measurements at Popondetta. All soil sampling and measurements except surface runoff were done in the 4 locations under the oil palm trees; frond piles, between palms, weeded circle and harvest path.

Frond piles are areas between 2 rows of palms where pruned fronds are placed. In plantations they are also have windrows after every 4th row. Windrows are areas where logs and felled palms are piled as part of land preparation prior to planting. In replanted palms, this will be fallen palm trunks 4th planting row. Fertilizers are spread onto frond piles for palms greater than 5 years of age. Frond piles are usually 2 m wide and cover 10 – 15% of a hectare of plantation.

Between palms is location between 2 adjacent palms in a row. This area also receives fertilizers and empty fruit bunches. In plantations frond tips are also placed here to cover bare soil and encourage undergrowth. The area is 4.5 m wide and 4 m long and makes up about 10 – 15% of a ha. Legume cover crops and under storey plants grow in the between palms and frond pile areas and these 2 areas are usually not sprayed.

The weeded circle is an area of 2 m radial band from the edge of palm base. This zone is manually and or chemically weeded. This is where harvested bunches fell. This zone at immature phase (<3 years of age) is fertilized area and makes up 15% of a hectare.

The harvest path or the wheelbarrow path ranges from 0.5 m for smallholder blocks to 3.5 m in width in plantations where mechanical infield fruit collection is practiced. In smallholder blocks and plantations that do not mechanically collect infield fruits, harvest path makes up 3 – 4% of a hectare while in plantations that practice mechanical infield collection, it makes up about 15%. The paths run between 2 rows of palms from 1 side of the blocks to the other side.

Soil Sampling

Soil samples were taken from each of the locations under the palms and at 0 –20 cm, 20 – 40 cm and 40 – 60 cm depths. At each site there were 5 sampling points and soil samples from each of the sites for each location and depth were compounded. The samples were collected along a single path across blocks in PNGOPRA Popondetta, Dami and Haella sites. At Ambogo and Bialla, samples were collected from 2 adjacent rows. The sampling site at Bialla was in non-experimental palms in a trial with shorter paths while at Ambogo the other half of the row was in soils with a finer texture material.

Trial 312 was a fertilizer trial that was closing. The trial ran for 15 or so years with NxKxEFB treatments. N rates were 0, 2, 4 and 6 kg/plm.yr. Samples were collected from plot 22 which was receiving 6 kg SOA and MOP per palm per annum and 500 kg EFB per palm every 2years. Soil samples were collected from the 4 corners and center points totaling 5 sampling points and were treated like samples collected at other sites except as different plots.

In addition to taking soil samples, soil pit description was done for each of the sites. The soil samples were then brought to New Zealand for analysis.

Infiltration Measurements

Four 3.0 mm thick steel sheets were rolled and welded to form ring cylinders with internal diameters of 45 cm and 25cm height. One end of the rings were sharpened from outside in.

The rings were driven into the soil to a depth of about 5 cm. A bund of soil was then pressed firmly against the outside of the rings to prevent any seepage from the edges. A piece of cloth was then placed in the ring on the soil surface. This was done to stop water directly contacting the soil surface. A strip of shortened tape measure of 20 cm long was inserted into the soil surface from inside of the side of the ring and the top edge pegged to the top end of the ring with a cloth hanging wooden peg. Water was then poured into the rings directly onto the piece of cloth until it reached a height 3-4 cm from the top when pouring was stopped and timing was started with a stop watch. The height drop at 2 minutes intervals were recorded for 8 to 10 minutes and when speed at which the height dropped slowed, the time interval was increased to 5 minutes and eventually to 10 and 15 minutes intervals. When water levels reached the lowest height without exposing the soil surface, the ring was topped up with water and timed. Recording continued for 30 minutes to 1 hr depending on water availability and rate at which water height dropped Exception to above was for measurements done in frond piles at Dami and Haella. The initial drop in height for the whole rings were less than 1 minute so timing was recorded when water level reached the lowest height and water was poured in to the top for the new timing and measurements here was done for between 20 and 30 minutes.

At Popondetta and Ambogo, measurements were done at 10 palm points while 5 for Dami and Haella. At all sites, measurements were done in all 4 locations under the palms.

For Popondetta and Ambogo, rainwater stored in tank at Igora OPIC station was used. Because measurements at Dami and Haella were done during the dry season, ground water was used. Total dissolved solids for water used at Dami and Haella were 42 and 36 ppm for the 2 sites respectively. At Haella where there was a compact ash layer at 10 – 20 cm depth, the surface layer was removed and infiltration measurement was done. Measurement was done at 2 points and at between palms location.

Through Fall Measurements

Through fall measurements was done only at PNGOPRA Popondetta site and at where soils were sampled and infiltration measured. To collect through fall, half 200 l drums of 57 cm internal diameter were used. The drums were cut in half and painted to stop rusting. The half drums were placed from the palm base up to center of 2 adjacent palms. The edge of the first drum was 40 cm from the palm base and the other 4 were 30 cm apart up to the center of the 2 palms. Another half drum was placed in the center of 3 palms. This was replicated 3 times. Two half drums were placed in the open next to rain gauge.

To collect stem flow, bud ends around a palm trunk at 1.5 m height were removed. A glued gutter was placed around the stem. Plastics were pinned against the stem and stem flow water were collected into the gutter then into the 200 l drum The gutter had an opening at the lower end which led to a 200 l drum. The top of the 200 l drum was covered with a plastic to stop through fall into the drum. This was replicated 3 x on neighbouring palms.

Amount of through fall collected in the drums were measured first thing in the morning. During rain events, the drums collecting stem flow when filled up, they were tipped over and the number of drums tipped were counted. The drums were calibrated with buckets and buckets were also calibrated with a measuring cylinder. Smaller amounts were measured with measuring cylinder. Measurements on the half drums were done first thing in the morning.

Surface Runoff.

Surface runoff was measured only at PNGOPRA, Popondetta. Measurements were done from 3 plots. The plots were 30 – 50 m from the weather station and from where other measurements were done. Each plot had 4 palms and a trapezium shape of 18 m dimension on all 4 sides. A bund of 30 cm high was made around the plots and a spade blade deep trench was dug around each of the plots to remove excess water from coming in from surrounding area. The bunds were then covered with black polythene plastic to stop rain drip water from spoiling the bunds. At the lowest end of the plots, an outlet was cemented to stop water from cutting through the plots. The lowest ends of the plots were determined with a dumpy level. A pvc pipe was connected from this end to collection point. The collection point was dug at an elevation lower than the plot. Plastic drums were placed for collecting surface runoff water. Each of the plots had 3 plastic drums. A shelter was built over the collection point to stop rainwater and through fall from being collected in the drums. Drums were calibrated and when surface runoff water filled the drums they tipped and counted during the rain events.

Rainfall Data Compilation for Potential Evapotranspiration Determination

Rainfall data was collected from 2 stations; PNGOPRA offices at Popondetta and Dami and OPRS office at Dami. At both stations, weather is recorded both with auto electronically and by observation.

At Dami, pan evaporation is also measured. Weather observation is done twice a day, at 0900 and 1500 hours.

Soil pH Measurements

Duplicate samples of 10 g of air dry soil (<2 mm) was weighed into 50 ml plastic cups. 25 ml water was then added and stirred vigorously with a glass rod. The suspension was then left to stand overnight. pH was then measured the next morning with a pH meter.

Soil moisture factor.

A known amount of soil between 10 and 20 g air dried soil from each of the soil sample was weighed into an aluminum dish. The soil samples were then dried in an oven at 105 C for 12 hours. After the 12 hours, the samples were removed and weighed while still hot but cool enough to handle.

Moisture factor was then determined as weight of air dried sample/weight oven dried sample.

Total C and N

Total C and N were determined by LECO analysis.

Water Samples Analysis

Water samples were collected from various sites in plantations in Oro and WNB Provinces. The first set of samples was collected in August-September 2002 and the second set was collected in January 2003 in both Provinces.

At each sampling point, 3 replicates of water samples were collected in 60 mls polyethylene tubes and 3-4 drops of 1M HCl acid was added. The acid was added to stop microbial growth.

At Popondetta, water samples were collected from bore water tanks at Iriambo and Sumbiripa and seepage water near OPRA Base and double cross compound. In WNB, water samples were collected at Dami Creek, a running creek at Haella, bore water at Haella and still water also at Haella. The second set of samples were stored in freezer. The samples were then taken to NZ for analysis.

In NZ, the water samples were analysed for ammonium and nitrate N using auto analyzer.

Lysimeter Water Samples

Three lysimeters, L1, L2 and L3 were inserted into the soil at Dami at 180 cm, 100 cm and 20 cm depths. Collecting funnels at L1 and L2 had diameter width of 30 cm while L3 had 15 cm. Water samples collected from the lysimeters were also analysed for ammonium and nitrate N in NZ with auto analyzer.

RESULTS AND DISCUSSION

Infiltration Measurements

Results of infiltration measurements are presented in Table 1 and figure 1. A check on the data suggested the infiltration rates were normally distributed and therefore were not required for transformation.

Statistical tests on the infiltration rates indicated significant differences between locations under the palms and between the 2 provinces at $p<0.001$. Infiltration rates in the frond piles were higher than in the other locations under the palms except for Oro Province where the rates under the frond piles and between palms were comparable (Table 1 and Figure 1). Infiltration rates in the weeded circles and harvest paths were low. The high infiltration rates in the frond piles suggest active biological activities under the frond piles increasing the sizes and number of pores in the soil matrix. The low rates of infiltration in the weeded circle and harvest path were due to compacted soil surface. In the weeded circle, the soil surface is cleared either manually or by herbicide spray or both and receives falling harvested bunches. A single fresh fruit bunch weighs between 15 and 25 kg for mature palms. Workers also walk around in the weeded circle during harvesting, pruning and when spreading fertilizers. As a result, weeded circles are compacted. At the harvest path, fruit bunches are wheel barrowed out from the field. At Ambogo and Dami, tractors are also driven along the path to remove harvested bunches to the roadsides and distribute fertilizers and these cause compaction at the soil surface in the harvest path. The harvest path as was with weeded circle is also cleared from any vegetation either manually or with herbicides and therefore less biological activities to create pores for water transmission. Soil compaction results from increased soil bulk density and reduces pore numbers and sizes causing low infiltration rates.

The infiltration rates in the frond piles in West New Britain (Dami and Haella) were higher than in Oro Provinces. In both Provinces, about similar quantity of pruned fronds are placed in the frond piles every year. Therefore, difference in infiltration rates in the frond piles between the 2 provinces is not likely due to biological activities under the pruned fronds. Difference in infiltration rates was most likely due differences soil texture and nature of the parent materials. In West New Britain, soil parent materials though volcanic as in Oro, were pumice, coarser and lighter while in Oro were smaller and heavier ash materials.

Summary

- Infiltration rates in West New Britain Province are higher in the frond piles than in the other locations under the palms.
- Infiltration rates in the frond piles in Oro Province are comparable to between palms but higher than the rates in the weeded circle and harvest path.
- Infiltration rates in the oil palm plantations appear to be a function of management practice

Table 1. Infiltration rates (mm/hr) in different locations under the palms.

Province	Site	Palm	Infiltration rates (mm/hr) in different location under palms			
			Frond piles	**Betw. palms**	**Weed. circle**	**Harv. path**
WNB	Dami	1	8340	900	220	50
		2	3640	2090	200	90
		3	4580	1910	780	60
		4	18520	1230	370	160
		5	7350	550	340	40
		Mean	**8486**	**1336**	**382**	**80**
WNB	Haella	1	4189	1678	648	74
		2	7821	4728	1422	155
		3	1162	817	413	160
		4	5307	2211	1104	125
		5	12484	2312	918	101
		Mean	**6193**	**2349**	**901**	**123**
Oro	OPRA	1	413	363	138	256
		2	1472	699	410	327
		3	1247	1250	245	115
		4	2538	747	357	115
		5	1455	1247	274	481
		6	1683	1637	375	274
		7	781	655	266	194
		8	1153	2888	159	296
		9	1910	1498	187	429
		10	779	684	423	28
		Mean	**1343**	**1167**	**283**	**251**
Oro	Ambogo	1	1236	999	895	222
		2	1747	2925	1019	113
		3	1755	506	262	93
		4	662	936	354	155
		5	1734	616	330	94
		6	1164	1746	363	204
		7	1343	408	196	123
		8	925	842	339	118
		9	1813	1181	417	170
		10	1808	311	608	169
		Mean	**1419**	**1047**	**478**	**146**

Grand mean = 1622
se = 1603
$p<0.001$ between locations and provinces

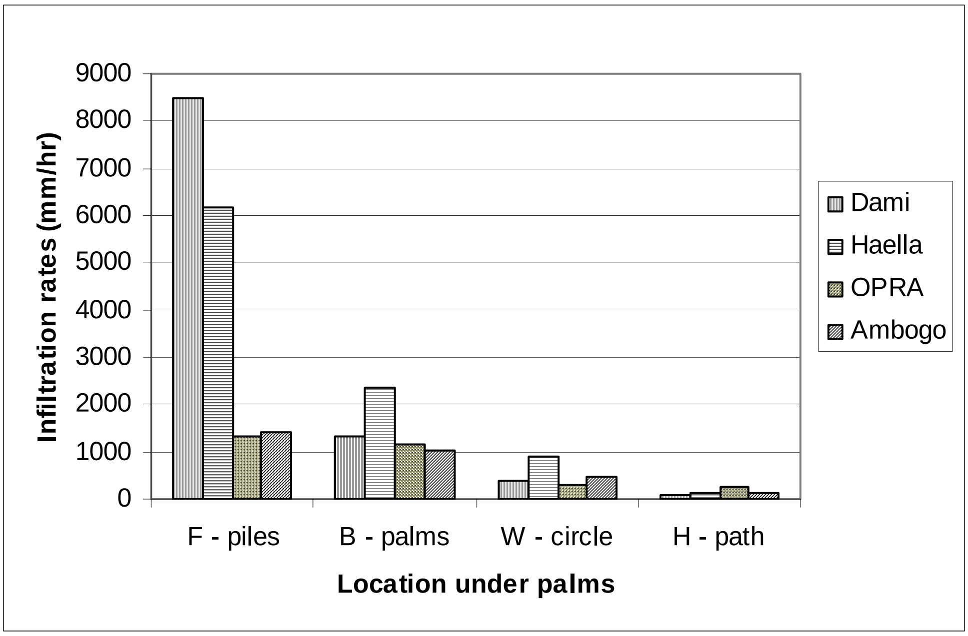


Figure 1. Mean infiltration rates (mm/hr) for different locations at different sites

Rain through fall in different zones under the oil palms

Proportion of rain collected in the different zones under the palms as a % of total rain collected per area of a palm are discussed (Table 2). There were 5 zones and they covered different radial areas from the base of the palms up to the center of 2 adjacent palms. Volume of water measured in the drums for individual rain events were increased by ratio of area of drum to area of the respective zone, which gave the volume collected in the zone. The proportion of through fall received in a zone was determined by dividing the volume collected in the zone by volume collected per area of the palm. Volume collected per area of a palm was determined by multiplying amount of rain measured in the rain gauge in the open by the area of the palm.

Proportion of rain received per area of a palm as stem flow ranged from 1 – 7% for rain events with < 5 mm but increased to 10 – 20 % for events greater > 5mm. Variation between individual palms for any one event also appeared to increase with size of rain events and this was most probably due to differences in the geometry of frond attachments to the main trunk. Stem flow at palm 1 for all rain events was higher than palms 2 and 3. Palm 1 had only 2 black bunches and the fronds were more erect than on palms 2 and 3. Palms 2 and 3 had a lot of ripening bunches which push the subtending fronds down making them more flat than palm 1. Therefore less intercepted rain was channeled to the stem as stem flow in palms 2 and 3. Most of the stem flow are concentrated and flow into the between palm and or the harvest path locations.

Proportion of through fall under different zones increased with distance from the stem. Proportion of through fall in the different zones also increased with rain events but did not affect the increasing trend with distance from palm base. The highest proportion of through fall was collected in zones 4 and 5. Zones 4 and 5 cover some frond piles, between palms and harvest path. Zone 5 is also an overlap zone between neighbouring adjacent palms.

If the distribution of through fall is affected by the geometry of the frond attachments, then the distributions of proportion of through fall and stem flow are a function of the number of bunches on a palm. This will mean that during the low crop, the fronds are more erect and more intercepted rainwater is directed to the stem as stem flow while during the peak crop season, less is diverted to the stem and the volume reaching zones 4 and 5 are high. The changes in distribution of rainwater with time reaching the different zones under the palms can have significant effect on the loss of N from the various zones under the palms at different times during the crop cycle.

The proportion of rain per area of a palm intercepted by the oil palm canopy, fruit, male inflorescence, dead frond buds and epiphytes ranged from 26 to 62 % when rain events were <5 mm. For rain events >5mm, interception ranged from 0 to 24 %. The proportion of interception depends on the wetness of above ground portion of the palm. Where there was rain the previous day, the above ground portion of the palms were still wet, therefore most of the rain came through mostly as stem flow.

Summary

- Proportion of rainfall intercepted per area of a palm as stem flow is 1 – 7 % when rain events are < 5mm but 10 – 20 % when rain events are > 5mm.
- Proportion of through fall increase with distance from palm stem
- Intercepted rainwater range from 26 to 62% when rain events are < 5mm but 0 – 24 % when rain events are > 5mm.

Table 2.Mean through fall collection under different zones under palms

Date	Rainfall (mm)	Proportion (%) of total volume collected under different zones						
		Stem	1	2	3	4	5	Total
17-Jan-03	1.4	6	1	3	13	14	48	84
18-Jan-03	1.2	1	0	0	5	7	24	38
19-Jan-03	4.2	7	1	3	13	10	35	68
20-Jan-03	2.4	6	0	1	11	10	30	58
21-Jan-03	2.8	5	0	3	8	8	22	46
22-Jan-03	1.6	7	1	5	11	17	41	81
29-Jan-03	2.6	4	2	4	10	14	33	65
12-Jan-03	7	10	1	6	13	13	44	87
15-Jan-03	7.2	13	1	3	8	14	45	83
27-Jan-03	6.2	9	1	3	10	15	39	76
11-Jan-03	28.6	19	2	4	8	16	49	97
13-Jan-03	38.6	20	2	5	12	13	44	96
14-Jan-03	36.8	18	2	3	8	17	50	97
16-Jan-03	34.6	15	2	5	10	15	51	98
23-Jan-03	29.2	19	2	5	11	21	47	105
25-Jan-03	24.4	12	1	3	9	14	51	91

Surface Runoff

Proportion (%) of rainwater received in the 4 palm plots as surface runoff increased with daily rainfall amounts showing a linear relationship (Table 3 and Figures 2 and 3). For rain events <10 mm, surface runoff was less than 1% of rain received in the plots and increased to 35% for events greater than 50 mm. When individual plots are considered, plot 2 had higher surface runoff for all rain events than plots 1 and 3. Various factors may have been responsible for this but cannot be determined now. The R squared for daily rainfall amounts and surface runoff was improved when only plots 1 and 3 were considered.

There was a rain event that had 52 mm daily rainfall but only recorded a mean surface runoff of 7 %. The range of surface runoff for rain events for daily rainfall of 20 mm ranged from 1.4 % to 17 %. The differences in the surface runoff for a particular daily rainfall amount is most likely due to differences in the intensity of rainfall. Intensity of rainfall was not measured, however, it will be measured in the next rainy season. Another factor is the soil water content which is determined by rain received in previous days. The soil moisture content also will vary for the 4 different locations under the palms. Soil moisture content will be measured in the next season because of its importance in surface runoff and leaching.

Surface runoff recorded on the 17-04-03 in plot 2 was 90%. This does not look right and when omitted, the new mean was 20%.

Summary

- Surface runoff increase with size of daily rainfall amount in a linear fashion.
- Plot 2 will need to be checked.
- Differences in surface runoff for a certain amount of daily rainfall are most probably due to differences in rainfall intensity.
- Rainfall intensity and soil moisture content will be measured because they influence surface runoff and leaching.

Table 3. Proportion of daily rainfall received in 4 palm plots as surface runoff

			Proportion (%) of rain as surface runoff			
Date	**Rain (mm)**	**Hrs rain**	**Plot 1**	**Plot 2**	**Plot 3**	**Mean**
22-02-03	20.2	1	7.02	0.00	7.12	7.07
23-02-03	27		4.06	11.79	3.51	6.45
04-03-03	6.4	2	0.00	0.87	0.79	0.55
06-03-03	52.4	4	5.09	13.04	3.76	7.29
08-03-03	42	7	13.16	21.92	10.88	15.32
13-03-03	6.6	0.5	0.22	1.43	0.42	0.69
15-03-03	102.6	2	36.53	43.13	27.73	35.80
18-03-03	7.8	0.75	0.06	1.94	0.30	0.77
19-03-03	21	1.5	7.51	21.39	8.45	12.45
20-03-03	21.4	3	11.30	30.93	11.32	17.85
29-03-03	8.2	2	0.73	0.75	0.43	0.64
01-04-03	10.2	2	1.38	4.32	0.57	2.09
02-04-03	6.6	2	1.13	3.40	0.58	1.71
04-04-03	19	6	1.89	3.62	2.05	2.52
05-04-03	74.4	9	26.17	56.80	23.43	35.47
15-04-03	16.4	1	9.00	32.61	12.72	18.11
17-04-03	53	6	21.12	90.79*	19.40	43.77
23-04-03	19.8	2	1.77	2.64	0.52	1.64
24-04-03	19.8	3	5.63	4.86	4.28	4.92
25-04-03	16.4	3	7.76	7.76	7.76	7.76
26-04-03	30.4	1	6.28	9.89	4.19	6.79

*Unusual measurement

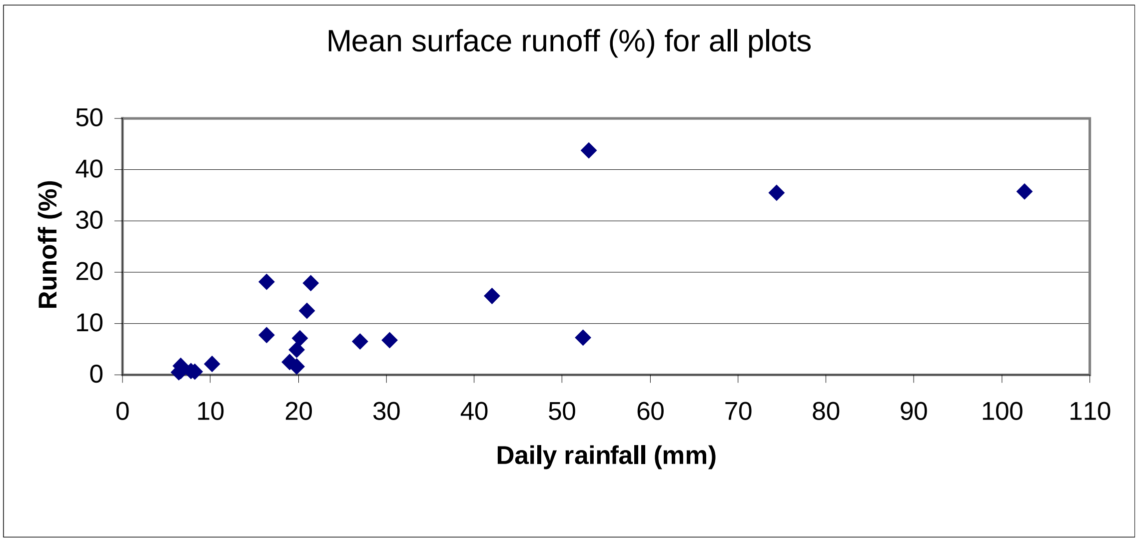
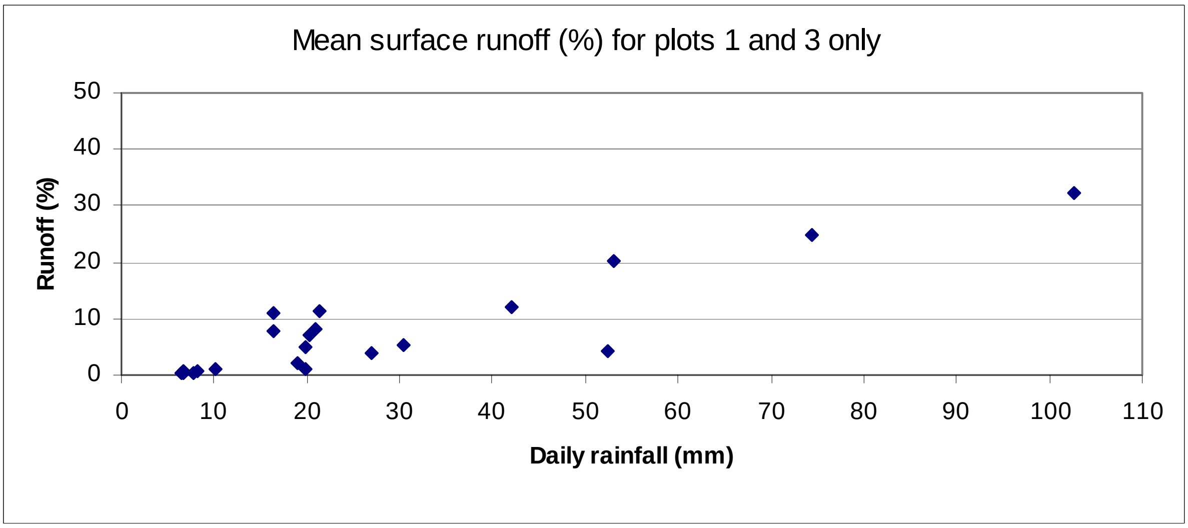


Figure 2. Mean surface runoff (%) for all plots during various rainfall events. $y = 0.4168x - 0.6077$, $r^2 = 0.6517$



$y = 0.3137x - 1.1169$ R squared = 0.80
Figure 3. Mean surface runoff for plots 1 and 3 during various rainfall events.

Calculation of water surplus/deficit using FAO 56

The calculated maximum and mean daily water surplus and deficit amounts for months with data for Dami station are presented in Table 4. Surplus is defined as drainage plus surface runoff water. Deficit is defined as how dry the soil profile is calculated to have got relative to field capacity, assuming evaporation continued as if the palms were well watered.

The number of days that had surplus water ranged from 46 in 1997 when there was a long dry season to 123 days in 1999 as a normal year. In normal years, the number of days with surplus water ranged between 70 and 100. For the 6 years, there was a mean of 1838 mm surplus water and a mean maximum daily surplus of 132 mm. Daily maximum deficit was 118 mm for the 6 years.

Monthly water surplus and rainfall and maximum daily deficit in a month amounts for Dami in 1997 and 1998 are presented in figures 4 and 5 respectively. In all normal years, there was surplus water throughout the year but mostly in the first 3 – 4 months. The only exception was in 1997 when it was a dry year due to effects of El Nino. During 1997, there was significant surplus water in only 3 months. The daily water deficit reached a maximum of 300 mm in November. In all other years, maximum daily water deficit did not exceed 120 mm.

Summary

- There is daily mean surplus water of 22 mm in 90 – 100 days in a year.
- There is mean of 254 days with deficit water in a year.
- There is surplus water throughout the years but mostly in the first 3 – 4 months.
- 1997 was an unusual year because of the effect of El Nino.

Table 4. Water surplus and deficit calculated for 1996-2001 by FAO 56 procedure

Year	**Surplus water (mm)**			**Maximum daily water deficit (mm)**	**Missing months**
	No. of days	**Max daily**	**Total annual**		
1996	80	136	1743	80	Nil
1997	46	130	526	305	March/July
1998	123	128	2882	114	June/Oct
1999	73	186	1883	54	Nov
2000	88	98	1649	66	May
2001	103	117	2344	88	August
Mean	**86**	**132**	**1838**	**118**	

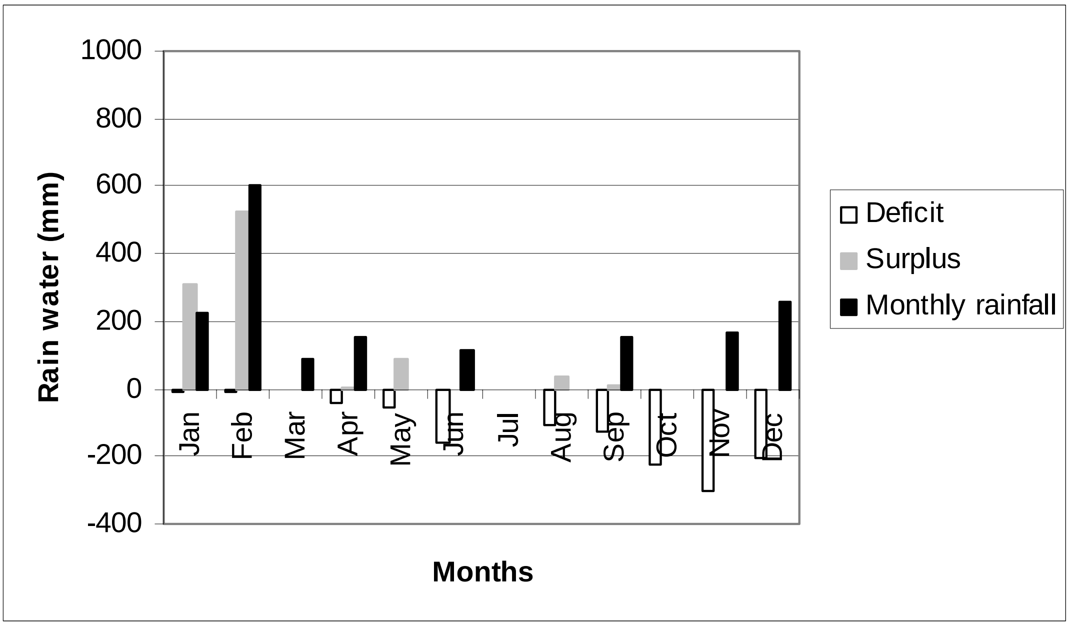


Figure 4. Monthly rainfall, water surplus and maximum daily deficit at Dami in 1997.

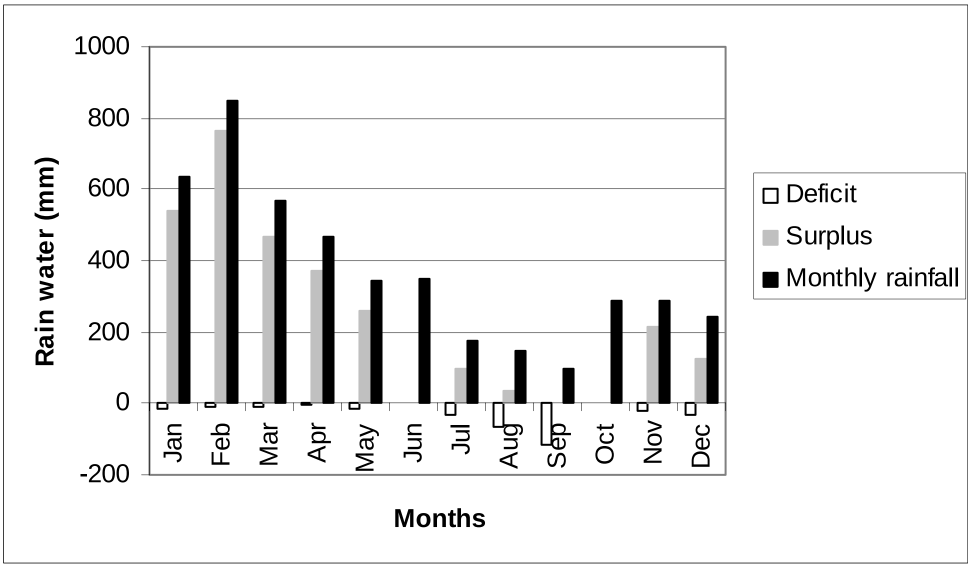


Figure 5. Monthly rainfall, water surplus and maximum daily deficit at Dami in 1998.

Soil pH

At all sites and locations, pH increased with depth (Table 5). pH in the weeded circle and between palms were lower than the other 2 locations in 5 of the 7 sites. This was most likely due to concentrated N fertilizing in these 2 locations. Weeded circle though does not receive fertilizers in the mature phase, it is the fertilizing zone for immature palms. There appears not much difference in pH values for the different locations at different depths at Bialla because the palms are only 5 – 6 years old and were planted from cleared rainforest. Continuous cropping of 2 generations of oil palm without changing the planting alignment has resulted in lowering the pH to 60 cm depth at Dami in the between palms and weeded circle. This also happened in the weeded circle at Ambogo which has palms >15 years old.

Summary

- pH increase with depth at all sites and locations.
- Fertilised areas have low pH.

Table 5. Soil pH (H_2O) for different sites in Oro and West New Britain Provinces

Site	Depth (cm)	Location under palms			
		Frond piles	Betw. palms	Weeded circle	Harvest path
OPRA	0 - 20	5.34	5.53	4.68	5.55
	20 - 40	6.24	6.18	6.27	6.47
	40 - 60	6.35	6.16	6.47	6.58
Ambogo	0 - 20	5.13	4.70	5.17	5.36
	20 - 40	6.09	5.91	5.33	5.97
	40 - 60	6.33	6.18	5.78	6.13
312 0N	0 - 20	5.71	5.30	5.10	5.64
	20 - 40	5.93	5.94	5.88	6.21
	40 - 60	6.25	6.27	6.19	6.62
312 HN	0 - 20	4.90	5.07	5.60	5.34
	20 - 40	5.58	6.39	5.88	6.08
	40 - 60	5.99	6.58	6.09	6.55
Haella	0 - 20	5.71	6.17	5.63	6.08
	20 - 40	5.96	6.35	6.17	6.43
	40 - 60	6.28	6.43	6.26	6.47
Dami	0 - 20	6.18	4.64	4.87	5.52
	20 - 40	6.12	5.39	5.31	5.96
	40 - 60	6.26	5.62	5.88	6.27
Bialla	0 - 20	5.72	5.62	5.88	5.78
	20 - 40	6.37	6.33	6.27	6.24
	40 - 60	6.41	6.42	6.35	6.46

Total C and N

Total C and N contents decreased with depth in the frond piles at both OPRA (Popondetta) and Dami (Table 6). Total C and N in the frond piles at Popondetta were slightly higher than in the other 3 locations. There was little difference between the location because at replanting, the linings were changed and also time has not allowed for accumulation to show up in the frond piles and between palms. At Dami where there was no change in the linings at second planting, there were significantly higher contents of total C and N in the frond piles than in the other 3 locations. Total C and N were higher at Bialla and Dami than at Popondetta in the frond piles. The high C and N contents in the Bialla soils are most likely due to the soil type than to management practice because the palms were only 5 - 6 years old. At all locations and depths, C:N ratio was <15 suggesting rapid mineralisation in these environment.

The surface humus layer was removed for sampling but this is the main biologically active zone in terms of nutrient storage and supply. Sampling will be done in this zone in future.

Summary

- Frond piles and between palms are main areas of nutrient accumulation.
- C and N contents in the different locations are a function of soil type and management practice.

Table 6. Total C and N under different locations for 3 sites

Site	Depth (cm)	Total C (%) Frond piles	Total C (%) Betw. palms	Total C (%) Weed. circle	Total C (%) Harv. path	Total N (%) Frond piles	Total N (%) Betw. palms	Total N (%) Weed. circle	Total N (%) Harv. path	P ret (%)
OPRA	0 - 20	2.85	2.32	2.11	2.41	0.24	0.20	0.20	0.23	25 - 30
(Popn)	20 - 40	0.74				0.07				
	40 - 60	0.52				0.05				
Dami	0 - 20	6.19	3.81	3.24	2.27	0.55	0.40	0.33	0.24	60 - 70
	20 - 40	1.41				0.14				
	40 - 60	0.25				0.03				
Bialla	0 - 20	7.15				0.71				>90
	20 - 40									
	40 - 60									

Ammonium and Nitrate Nitrogen in Water Samples

Mean ammonium and nitrate N contents of water samples from various sites in Oro and WNB Provinces are presented in Table 7. Ammonium N levels in all the water samples were low and inconsistent within the replicates. The inconsistency in ammonium values probably resulted from silt and clay particles in the samples. The values however, were very low and lower than the lowest standard value of 0.25 μg N/ml. The data suggests most of the N in the water samples were in nitrate forms. In Oro Province, nitrate N levels in spring water were higher than in bore water samples. The spring water samples were from springs that were coming out from a seepage zone at a lower terrace. The higher terrace is planted with oil palm. There was no effect of time of sampling on the nitrate N levels in the bore water samples in Oro Province and samples from Dami Creek in WNB. However, nitrate N levels in Garu bore water samples taken in February 2003 were higher than in samples taken in August 2002. The maximum ammonium and nitrate N contents in Oro Province were 0.25 and 1.11 μg N/ml respectively. In WNB, the maximum contents were 0.42 and 3.04 μg N/ml for ammonium and nitrate N respectively.

Water samples from lysimeters from WNB had no replicates and results are presented as single values (Table 8). There were both ammonium and nitrate N forms in the water samples suggesting both N forms have been leached through the soil profile. Nitrate N concentration was higher at 180 cm than at 20 cm depths.

Summary

- Most of the N in the water samples was in nitrate forms.
- Ammonium N contents were generally low and inconsistent.
- The range of nitrate N forms in the bore and spring water were between 0.50 and 3.04 μg N/ml.
- Nitrate N concentration was higher at 180 cm than at 20 cm depths.

Table 7. NH_4 – N and NO_3 – N content of water samples

Sampling Month	**Province**	**Site**	**Type**	**N content** (μg/ml)	
				NH_4 - N	**NO_3 - N**
Aug-02	Oro	Iriambo	Bore water	0.04	0.58
Feb-03	Oro	Iriambo	Bore water	0.03	0.57
Aug-02	Oro	Sumbiripa	Bore water	0.13	0.65
Feb-03	Oro	Sumbiripa	Bore water	0.03	0.60
Feb-03	Oro	OPRA DC	Spring	0.01	1.12
Feb-03	Oro	OPRA GW	Spring	0.09	0.71
Aug-02	WNB	Haella	Still water	0.25	0.03
Feb-03	WNB	Haella	Still water	0.06	1.12
Aug-02	WNB	Haella	Creek	0.06	0.06
Feb-03	WNB	Haella	Creek	0.29	0.43
Sep-02	WNB	Dami	Creek	0.16	0.29
Feb-03	WNB	Dami	Creek	0.11	0.26
Aug-02	WNB	Garu	Bore water	0.12	1.34
Feb-03	WNB	Garu	Bore water	0.18	2.76

Table 8. NH_4 – N and NO_3 – N content (μg/ml) of lysimeter water samples

Date	Rainfall (mm)	Lysimeter 1		Lysimeter 3		Lysimeter 3	
		NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
17-2	75.4						
18-2	0.0			0.46	1.36	0.83	1.43
19-2	36.8					0.24	0.35
20-2	60.4						
21-2	37.4					0.12	0.46
22-2	17.6					0.41	0.16
23-2	42.4						
24-2	60.4					0.32	0.17
25-2	18.6						
26-2	31.0						
27-2	0.0	0.08	0.18				
28-2	3.6			0.69	1.23		
1-3	0.4						
2-3	0.6						
3-3	26.4						
4-3	2.4						
5-3	1.6						
6-3	4.0						
7-3	56.0						
8-3	89.4						
9-3	27.6						
10-3	56.2	0.09	2.86				
11-3	43.6	0.28	2.17				
26-3	15.0	0.17	0.24			0.35	0.45
27-3	13.4						
31-3	7.0	1.24	0.30			0.58	0.38
3-4	2.4	0.32	1.77				
4-4	60.6	0.28	1.55			0.25	0.75
5-4	130.4	0.61	1.89			0.14	0.32
Total		**3.07**	**10.96**	**1.15**	**2.59**	**3.24**	**4.47**
Mean		**0.38**	**1.37**	**0.58**	**1.30**	**0.36**	**0.50**
% of total N		**22**	**80**	**32**	**68**	**32**	**68**

SUMMARY

Frond piles and between palms are very important locations under the palms in relation to the study. These 2 areas are areas where fertilizers are applied and have high total C and N contents (areas of nutrient accumulation/supply). These 2 locations also receive the highest rain through fall and have very high infiltration rates compared to weeded circle and harvest paths. Therefore frond piles and between palms are very important in nutrient storage and supply to the palms but at the same time are also probably important zones of nutrient loss via leaching because of the high amount of through fall received and very high infiltration rates.

Results from water samples indicate there is loss of N in the system mostly in nitrate forms.

The next phase of work will verify through fall and surface runoff measurements, measure rainfall intensity and lysimeter studies.

OVERCOMING MG DEFICIENCY ON VOLCANIC ASH SOILS (ACIAR LWR2/2002/046)

The proposal for this project was given in the 'Agronomy Research Proposals for 2003'. The project commenced in October 2002.

Objective 1. Assessment of Slow-Release Ameliorants

Four field trials have been designed and will commence in 2003. The field trials (144, 145, 146 and 333) are described in the 'Fertiliser Response Trials' section. Trial 144 is designed to test the interaction between Mg and K. Trial 145 is a Mg source trial designed to test less soluble sources of Mg and compare them to kieserite. Trial 146 is designed to test novel placement methods and slow-release sources of Mg. Trial 333 is designed to test slow-release sources of Mg and K in the low CEC soils of the Ilimo-Mamba area of Oro.

Objective 2. Assessment of Spatial Extent of Problem

Soil samples collected during the smallholder surveys in Hoskins and Oro and for the initial assessment of cation exchange properties by Gillman are being analysed for a range of parameters related to the Mg nutrition problem.

Objective 3. Properties of Soils, Amendments and Palms

A) Soil properties

Soil samples are being examined to determine why they are super-saturated in Ca and do not retain Mg. The work will involve mineralogical analysis and cation exchange selectivity analysis. Initial studies have been carried out and results are given below.

Samples from the Dami profile were examined by XRD and were dominated in weatherable primary minerals that are high in Ca. The patterns were typical of poorly developed (recent) soils, with no ordered clay minerals present. The best fits for the peaks were as follows:

0-20 cm	Anorthite, Quartz
60-70 cm	Anorthite, Quartz, Forsterite
130-190 cm	Anorthite, Quartz, Actinolite

The strongest peaks for each depth were for a feldspar. Of the feldspars tried (microcline and orthoclase – K rich; albite – Na rich; and anorthite – Ca rich), anorthite fitted most peaks best. For the 60-70cm samples, the olivine material, forsterite explained a minor peak. For the 130-190 cm sample the amphibole mineral, actinolite explained a minor peak. These two minerals are also rich in Ca and both tend to occur in metamorphosed limestones.

A protocol for measuring cation exchange selectivity in Ca-saturated systems has been devised and initial results for a Bialla topsoil show high selectivity for Ca over Mg. This selectivity is due to the nature of exchange sites in the soil; because Ca and Mg have the same charge, they would be adsorbed in similar proportions in soils whose exchange sites have no selectivity.

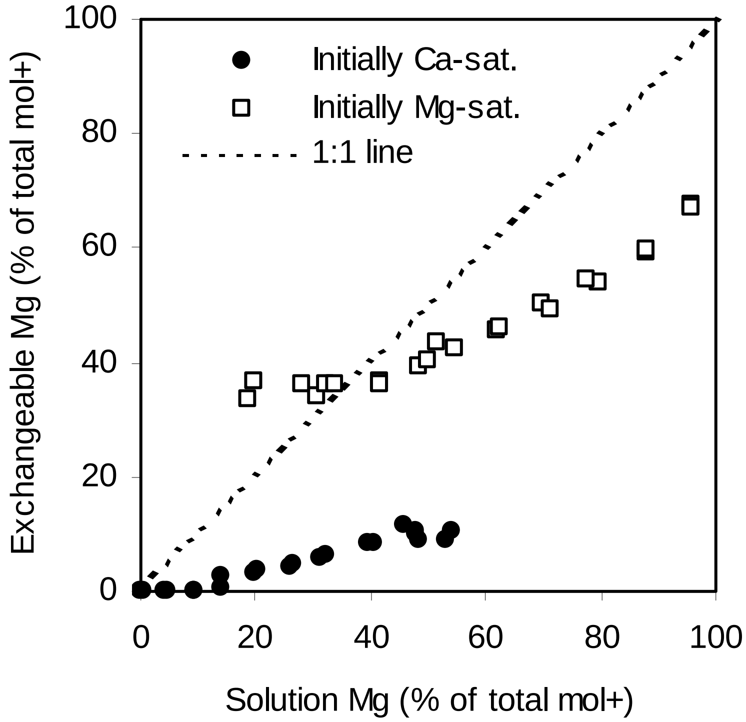


Figure 6. Magnesium/Calcium adsorption isotherm. The slope of the relationship is the selectivity coefficient.

B) Ameliorant properties

Magnesium-containing products were obtained from QMag, a subsidiary of the Australian Magnesium Corporation. They mine magnesite ($MgCO_3$) and produce MgO by calcination. They supply fertilizer products to SE Asia and have donated products for our field trials. Results of our analyses are shown in Table 9. The results conformed well with the specifications given by the supplier. The MgO is slightly more soluble than the $MgCO_3$, but both are far less soluble than kieserite.

Table 9. Characteristics of Mg sources to be used in field trials.

Product	Kieserite	Magnesite FO1	M30	EMAG45	EMAG500
Main constituent	$MgSO_4.H_2O$	$MgCO_3$	$MgCO_3$/MgO	MgO	MgO
Mg content (%)	17	26	42	55	55
S content (%)	20	0.0	0.0	0.0	0.0
Ca content (%)	0.3	1.0	1.2	1.8	1.7
K content (mg/kg)	<100	<100	<100	<100	<100
Na content (mg/kg)	446	100	300	200	300
Mn content (mg/kg)	58	400	900	600	600
Cd content (mg/kg)	<20	<10	<10	<10	<10
Pb content (mg/kg)	<100	<100	<100	<100	<100
Co content (mg/kg)	<20	<10	<10	<10	<10
Cu content (mg/kg)	<20	13	21	19	21
Mo content (mg/kg)	<20	<10	<10	<10	<10
Zn content (mg/kg)	<20	<10	<10	<10	<10
B content (mg/kg)	<100	<100	<100	<100	<100
<300 µm (%)	-	44	99	100	96
Mg dissolved (%)*	>50	0.91	2.29	2.60	2.53
Neutralising value (%)**	~0	113.8	4.9	6.5	5.8

* 1g added to 100 ml water, stirred for 4 days
** Compared to $CaCO_3$

C) Palm physiology

Leaf samples have been taken from throughout the canopies of palms with and without deficiency symptoms to determine the partitioning of Mg and its relationship with symptoms.

D) Pot trials

Nutrient omission pot trials have been set up in Townsville and Dami to determine which elements are deficient in WNB soils. All essential elements are being tested.

Objective 4. Predict Treatment Efficacy

In June 2003, Murom Banabas, James Kraip, Mike Webb and Paul Nelson were trained in use of the HYDRUS-2D model, which calculates water and solute movement through soil and which has been purchased for the project. We will use the model to predict uptake and loss of Mg from the various ameliorants applied in various ways. We are in the process of measuring the soil, climate, palm and ameliorant parameters that are necessary for the predictions. Murom Banabas was sponsored to the training session by a Crawford scholarship obtained by Mike Webb. He will be able to use the model to predict N leaching loss under various environmental and management scenarios.

POOR RESPONSES IN FERTILIZER TRIALS IN WEST NEW BRITAIN

BACKGROUND

Over the last decade or more, control plots in WNB fertiliser trials have been yielding as much as fertilised plots. We suspect that this is due to nutrients moving into the control plots from surrounding areas, despite guard rows and trenching between plots. ‘Systematic’ trials have been introduced to overcome the problem, and they are expected to be successful if the problem is due to movement between adjacent plots. However, if nutrient movement is occurring on a larger scale, from the surrounding plantation, systematic trials may not provide the answer. In order to test whether nutrients are moving at larger scales, we are carrying out the following activities in 2003: ‘Omission trials (Trial 141)’, ‘Monitoring of shallow perched water tables’, ‘Tissue sampling transects’ and a preliminary study to measure movement of water and nutrients through the soil profile using ‘lysimeters’ at Dami. In addition to these trials, several fertiliser trials with very large plots have been set up (142, 148 and 149). They are described in the ‘Response to Fertilisers’ section.

TRIAL 141. LARGE FERTILISER OMISSION TRIAL, HAELLA

Purpose

To improve fertiliser recommendations in West New Britain by determining yield under control conditions, and to determine how far nutrients move from fertilised into unfertilised areas.

This trial is one of the ‘omission trials’. In a related trial (Trial 142), we plan to use the existing CCPT trials in a similar way, but to include a moderate and high level of N application as well.

Site, Palms

Top of slope site: Haella Plantation, Field 1323-10, Roads 3-4, Avenues 1-2

Bottom of slope site: Haella Plantation, Field 1322-10, Roads 6-7, Avenues 13-14

It is intended to duplicate this trial at a similar pair of sites at Kapiura.

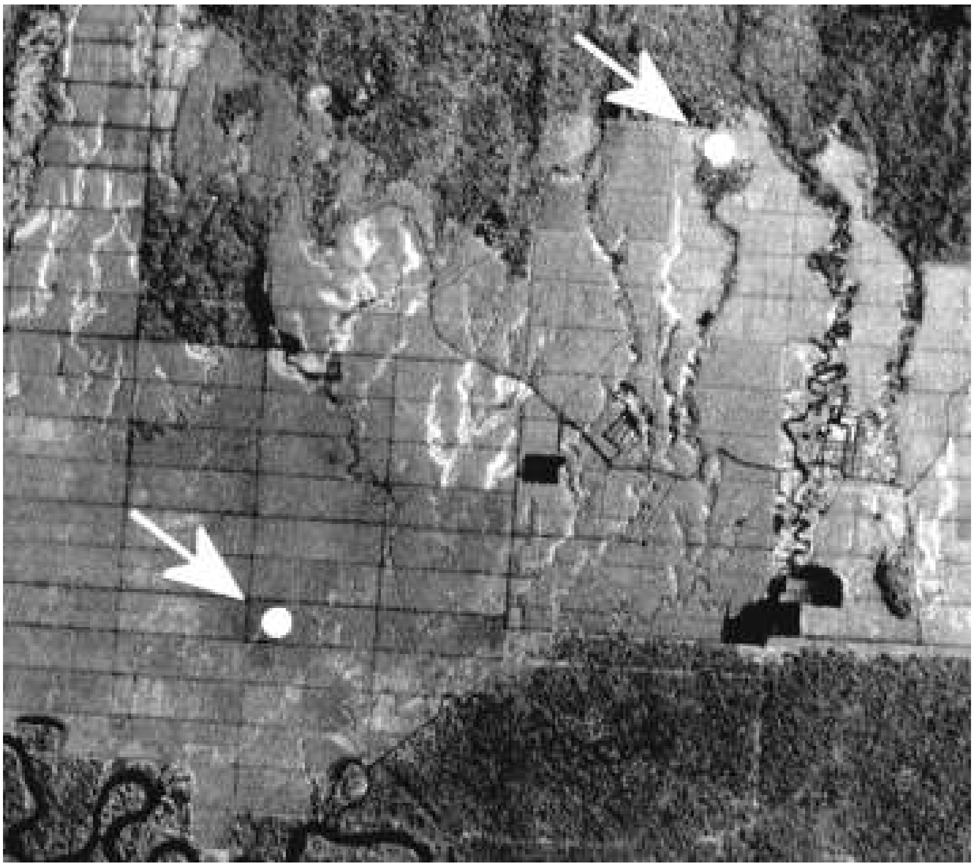


Figure 7. White circles show the position of the two omission trial sites in Haella Plantation.

Design

The trial consists of a circle, about 24 palms in diameter, to which no fertiliser is applied. Fertiliser will be applied normally to the area outside the circle. Measurements will be carried out on palms in 12 transects (1-3 palms wide) radiating from the central palm out into the fertilised area.

Statistical design is regression of yield or other parameters on distance from the central palm. At each distance, the mean of the palms will be used in the regression. The number of palms at each distance is shown in Table 10. Directional effects can be tested by combining groups of the 12 transects. The slope of the line is expected to change with time.

The trial was marked out and commenced in 2003.

Table 10. Number of palms (N) at each distance from the central palm. Distance units are the equilateral distance between palms. Distance 15 only applies to downslope site (Div II).

Dist.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	1	6	6	12	15	12	15	12	15	12	15	12	18	15	12	15

MONITORING OF SHALLOW PERCHED WATERTABLES

Purpose

To determine the depth of shallow perched groundwater tables in two fertiliser trials in WNB that had not shown responses, to determine whether lateral water movement through the soil might be responsible for moving nutrients between experimental plots.

Site, Design

Piezometers were installed in August 2002 in every second plot in Trials 125 (Kumbango) and 402 (Bilomi). Piezometers consisted of 50 mm diameter PVC pipe, slotted every 25 mm to allow water entry. The piezometers were inserted to a depth of about 1.5 m, with about 0.3 m protruding from the soil surface. During times of rainfall, the depth of water in the piezometers was measured.

Results

In Trial 402, ground levels have not yet been determined, so the only data we have at this stage is depth of water below the top of the tube (Table 11). Water levels were deeper than 1.5 m most of the time and only in 2 piezometers were depths <1 m occasionally recorded.

In Trial 125, ground levels have been taken, so groundwater levels could be determined and flow directions inferred. Figure 8 shows the ground level at each piezometer, and Figure 9 shows mean groundwater levels for days when groundwater was detected. All the measured levels during the 2002/03 wet season are shown in Table 12.

In Trial 125, groundwater was more than 1.5 m deep over most of the site most of the time. The piezometers that held water most often (8, 22, 23, 24 and 28, Table 2) were mostly on the eastern and southern sides of the site, close to the Dagi River, which is adjacent to the site. The pattern of groundwater levels showed that water tended to follow the surface contours (Figures 8 and 9). However, the pattern of groundwater depths changed from observation to observation, suggesting that movement was quite rapid and the levels encountered depended on when the observations were made relative to the rainfall event. The low area around piezometer 8 was inundated by several metres of water on 9/3/03 when the Dagi burst its banks.

Water was not observed to move laterally through the thin pumice layer at 30-40 cm depth, but the watertable that was observed was within reach of the roots and may have been a means for nutrients to move between plots. The pumice layer may be transmitting significant volumes of water laterally, and this will be determined by modeling using the measured soil properties and rainfall scenarios.

Figure 8. Diagram showing approximate positions of Trial 125 plots and of piezometers (bold). The height of the ground surface above an arbitrary datum (m) is shown at each piezometer. Shading shows ground height in increments of 0.5m.

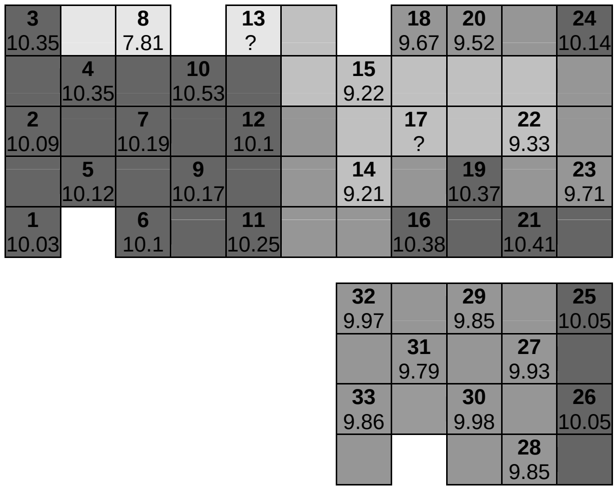


Figure 9. Mean measured ground water levels (m above arbitrary datum) in Trial 125 over period 22/1/03-31/3/03.

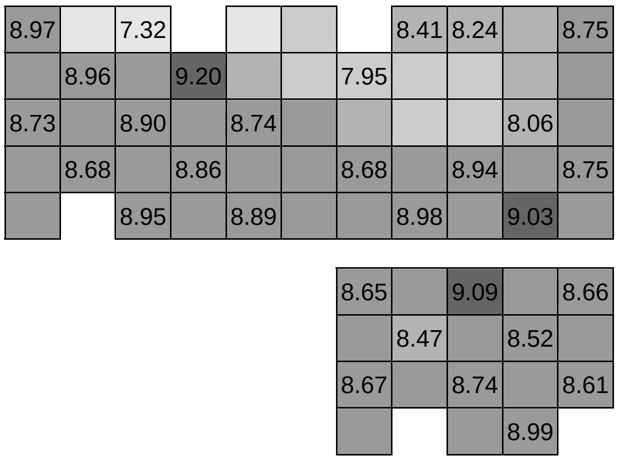


Table 11. Depth of groundwater below top of piezometer (cm) in Trial 402.

Date.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	35	36	37	38	39	40
26/1/03																																								
27/1/03																																								
31/1/03	165	167	164		172	145	153		153	173	166	163	110	173	167		172	168	167			160	170	169					174			173	164	168	164			164	170	
16/2/03	168	167											159																											
23/2/03	150	158													162																									
25/2/03	150	158													162																									
27/2/03	166	165	162		169	127	142		149	169	162	151	59	168	164		159	158	160			149	163	165					165			163	152	160	160					
14/3/03	167	165	162		169	127	142		149	169	161	151	60	168	165		159	162	162			151	165	167					167			167	158	162	165					
8/3/03	166	165	162		169	127	142		149	169	161	151	59	168	164		159	160	160			149	165	165					165			165	156	160	163					
10/3/03	150	158													162																									
11/3/03	145	155	150	125	132	143	150	167	167	169	165	155	107	140			167	169	167	170	170	167	166	167				168	169			172	160	166	169					167
17/3/03	123	123	149	130	124	126	150			130	152			132		133	142	146	152	160	132	128		130	139		118	126	132		126	147	162	135	142		130	160		125
26/3/03	160	162																																						
27/3/03	155	164																																						
28/3/03	155	153																																						
31/3/03	135	145	164																																					
3/4/03	134	145	164			160			153			167					160			150															170					
4/4/03	131	143	154			132											153			132																				
5/4/03	115	128	146			159			148	133	155	150					133		62			168											159	150	146					
7/4/03	89	105	120																	138																				

Table 12. Level of groundwater (m above an arbitrary datum) in Trial 125. Zero value means no water in piezometer (watertable below hole bottom).

Piezometer	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Ground level	10.09	10.35	10.35	10.12	10.10	10.19	7.81	10.17	10.53	10.25	10.10	9.21	9.22	10.38	9.67	10.37	9.52	10.41	9.33	9.71	10.14	10.05	10.05	9.93	9.85	9.85	9.98	9.79	9.97	9.86
Hole bottom	8.69	8.91	8.82	8.76	8.75	8.75	7.01	8.85	9.19	8.86	8.40	7.78	7.76	8.68	8.30	8.94	8.11	8.97	7.90	8.28	8.76	8.65	8.61	8.48	8.45	8.30	8.62	8.37	8.56	8.16
22/1/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.31	0	0	8.30	0	0	0	0	0	0	0	0	0	0
26/1/03	0	8.94	8.90	8.66	9.02	0	6.97	0	0	0	0	0	0	8.98	8.61	8.94	8.28	8.97	7.94	0	8.69	0	0	0	0	9.86	0	0	8.56	0
27/1/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.94	0	0	7.94	0	0	0	8.61	0	8.70	8.71	0	0	0	0
29/1/03	0	0	0	0	0	0	0	0	9.20	0	8.73	0	7.79	0	8.33	0	8.13	9	0	8.33	0	8.67	0	0	8.43	0	0	8.43	8.60	0
31/1/03	8.74	8.99	9.06	8.69	8.91	0	7.31	0	0	0	8.72	0	0	0	8.29	0	0	9.01	8.27	8.34	0	8.66	8.61	8.52	9.76	8.46	0	8.45	8.79	0
5/2/03	0	0	0	0	9.12	0	7.41	0	9.20	0	8.77	0	0	0	0	0	8.13	9.15	8.28	8.30	0	8.66	8.62	0	9.81	0	0	0	0	0
6/2/03	0	0	0	0	8.78	0	6.91	0	0	8.90	0	0	0	0	0	0	0	0	7.96	0	0	0	0	0	8.42	0	0	0	0	0
7/2/03	0	0	0	0	0	0	6.91	0	0	0	0	0	0	0	0	0	0	0	7.96	0	0	0	0	0	0	0	0	0	0	0
19/2/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.68	0	0	0	0	0	0	0	0	0
26/2/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/3/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/3/03	8.71	0	0	0	9.17	0	7.25	0	0	0	0	0	0	0	0	0	0	0	0	8.42	0	0	0	0	9.82	0	0	0	0	0
9/3/03	0	0	0	0	8.81	0	7.76	0	9.22	0	0	0	0	0	0	0	0	0	7.97	8.37	0	0	0	0	0	0	0	0	0	0
10/3/03	0	0	0	0	0	8.90	7.74	8.86	0	0	8.72	0	8.19	0	8.41	0	8.33	0	8.03	8.35	8.66	0	0	0	8.40	8.57	0	0	0	0
11/3/03	8.75	0	0	8.70	0	0	7.82	0	0	0	0	8.68	8.16	0	8.41	0	8.28	0	8.24	8.38	8.98	0	0	0	8.55	9.86	8.74	8.53	0	8.67
24/3/03	0	0	8.92	8.68	8.80	0	0	0	0	0	0	0	7.83	0	0	0	0	0	0	0	8.79	0	0	0	0	0	0	0	0	0
26/3/03	0	0	0	0	0	0	7.10	0	0	0	0	0	7.79	0	0	0	0	0	0	0	8.73	0	0	0	0	0	0	0	0	0
28/3/03	0	0	0	0	0	0	7.33	0	0	0	0	0	0	0	0	0	0	0	0	0	8.71	0	0	0	0	0	0	0	0	0
31/3/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.24	0	0	0	8.71	0	0	0	0	0	0	0	0	0
Mean	8.73	8.97	8.96	8.68	8.95	8.90	7.32	8.86	9.20	8.89	8.74	8.68	7.95	8.98	8.41	8.94	8.24	9.03	8.06	8.35	8.75	8.66	8.61	8.52	8.99	9.09	8.74	8.47	8.65	8.67

TISSUE SAMPLING TRANSECTS

Purpose

To determine if there is a gradient in tissue nutrient contents (especially N) in smallholder blocks downslope of a plantation that receives recommended rates of fertiliser.

Site

A site was sought in which smallholder blocks were situated downslope of a plantation, and were not separated from the plantation by a road or watercourse. One possibility was the Kumbango-Dagi area, but there were insufficient oil palm blocks in the Dagi smallholder area. The only other such area that was identified was the area where the Mamota smallholder scheme abuts Karausu Plantation (Figure 10). The plantation area was not as large and the topographic gradient not as pronounced as desired, but the site has been sampled nonetheless.

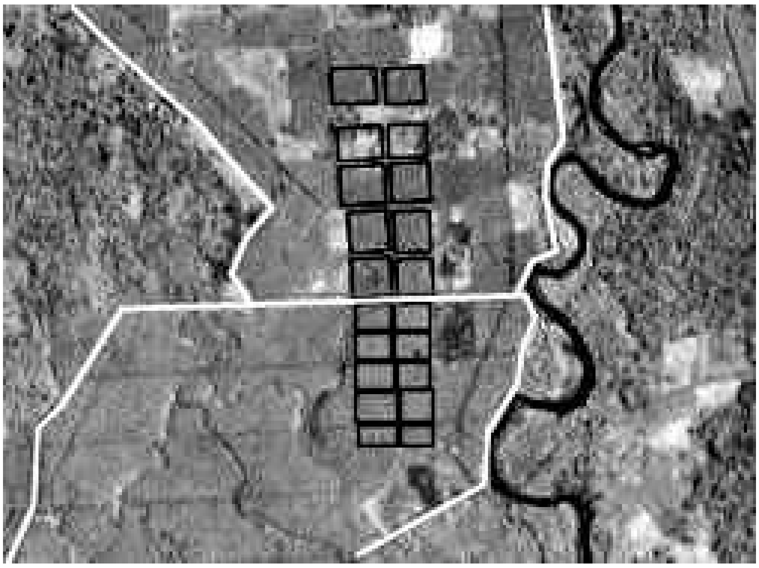


Figure 10. Location of the tissue sampling transect at Karausu-Mamota. The white lines delineate Mamota smallholder area (top, north) and Karausu Plantation (bottom, south). The black boxes indicate the tissue sampling blocks.

Design

The trial consists of a tissue sampling transect made up of 10 smallholder blocks and 10 ‘blocks’ within the plantation. Tissue samples were taken in June/July 2003 and the slope will be surveyed. The history of fertilizer use on the smallholder blocks was determined by surveys.

WATER AND NUTRIENT MOVEMENT THROUGH THE SOIL PROFILE

- Lysimeters, Pits, Hydraulic Conductivity and Water Balance Calculations

Background

We suspect that nutrients applied in fertilizers are moving below the root zone and possibly transported laterally through the soil. Losses via these pathways potentially cost the industry large sums. In the ‘N losses’ and ‘Mg nutrition’ projects we are starting to quantify these losses. Associated with those major studies, and also to address the question of whether or not nutrients are moving laterally through the soil profile, several lysimeters were set up at Dami and monitored through the 2002/03 wet season. Saturated hydraulic conductivity was also measured at several sites at several depths so that water fluxes could be estimated.

Purpose

To determine how much water and nutrient move downwards through and beyond the rootzone, and sideways through soil layers.

Design

Lysimeters

Three lysimeters (Figure 11) were set up in the northernmost block at Dami. The sampling depth distance from soil surface to top of funnel), was 1.8 m for Lysimeter 1, 1.0m for Lysimeter 2 and 0.2 m for Lysimeter 3. The funnel diameters were 30 cm (Lysimeters 1 and 2) or 15 cm (Lysimeter 3). See Table 15 for description of the relevant soil layers. The soil surface was then covered by a sheet of plastic measuring 1.5 x 1.5 m, to ensure that water moving into the lysimeters had moved laterally to some degree. If more water was collected in the lysimeter below the pumice layer than in the one above the pumice layer, then we could deduce that water was moving laterally through that layer. The lysimeter design results in water only being collected when flow is occurring under saturated or almost-saturated conditions. Over the period November 2002 to the end of March 2003, water was removed from the lysimeters daily using a pump, and the volume of water was measured. Several samples were analysed for ammonium and nitrate concentrations.

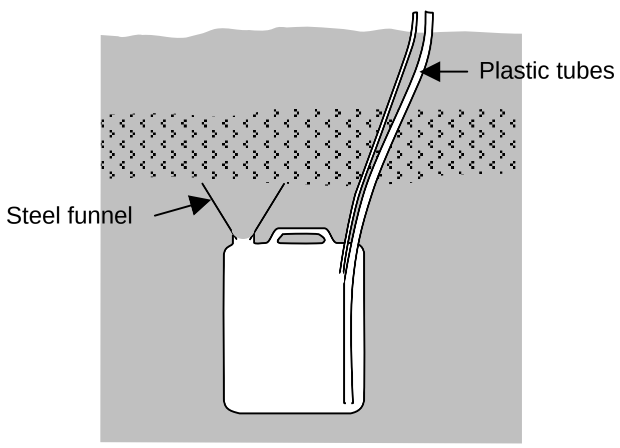


Figure 11. Cross-section showing lysimeter design.

Soil pits

Observation pits were dug in the northern-most corner block of Dami (1 pit in September 2002 and a subsequent one downslope in Feb 2003) and in Trial 125 at Kumbango (2 pits). The soil profiles at the two sites are described below. The pits were observed during heavy rainfall events during the wet season to detect possible lateral flow out of the profile into the pit.

Saturated hydraulic conductivity

Saturated hydraulic conductivity approximates the maximum rate at which water can move through the soil. If saturated hydraulic conductivity of any particular layer is less than the rate of water entering that layer, then water will either pond above that layer or move laterally above it. Saturated hydraulic conductivity was measured using ponded ring infiltrometers. The infiltration rate at various depths was measured by excavating pits to the required depth. For slower layers the steady state rate was assumed to be reached after about 60 minutes and for faster layers it was assumed to be reached at about 30 minutes.

Water balance calculations

A tipping bucket water balance model was constructed to determine under what conditions water would move laterally. The input parameters were as follows:

Dimensions

- Density
- Radius of Weeded circle
- Width of Harvest path
- Width of Frond pile
- Depth of layers A, B, C and D

Rainfall and saturated hydraulic conductivity

- Event period
- Rainfall
- K_{sat} of layer A in Weeded circle
- K_{sat} of layer A in Harvest path
- K_{sat} of layer A in Inter-palm area
- K_{sat} of layer A in Frond pile
- K_{sat} of layers B, C and D

Soil water content and water holding capacity

- Water holding capacity of layers A, B, c and D
- Initial water content of layers A, B, C and D

Results

Lysimeters

Figure 12 shows rainfall and the flow measured in the lysimeters during the wettest part of the year at Dami. Water only collected in the deepest lysimeters (1.0 and 1.8 m depth) on several occasions but was collected quite regularly at the shallowest depth (0.2 m). The collected water had been moving laterally, as the soil surface was covered with plastic above the lysimeters. However, only on one day did the amount collected exceed the amount of rainfall, and there may well have been a contribution from rainfall in the previous day. This result suggests that water was not moving long horizontal distances, as if that were the case, the amount of water collected would have well exceeded rainfall. Therefore, the permeability of the soil below 0.2 m was low enough to cause some lateral flow, but high enough for significant infiltration to be occurring through it during events.

Analysis of the throughflow samples showed that while ammonium concentration was fairly low and constant with soil depth, whereas nitrate and hence total mineral N concentration were higher in the water moving through the deepest layer (Table 13). This suggests that N from fertiliser had been taken up, lost or immobilised before the wet season, and the nitrate at depth was generated by mineralisation in the overlying soil.

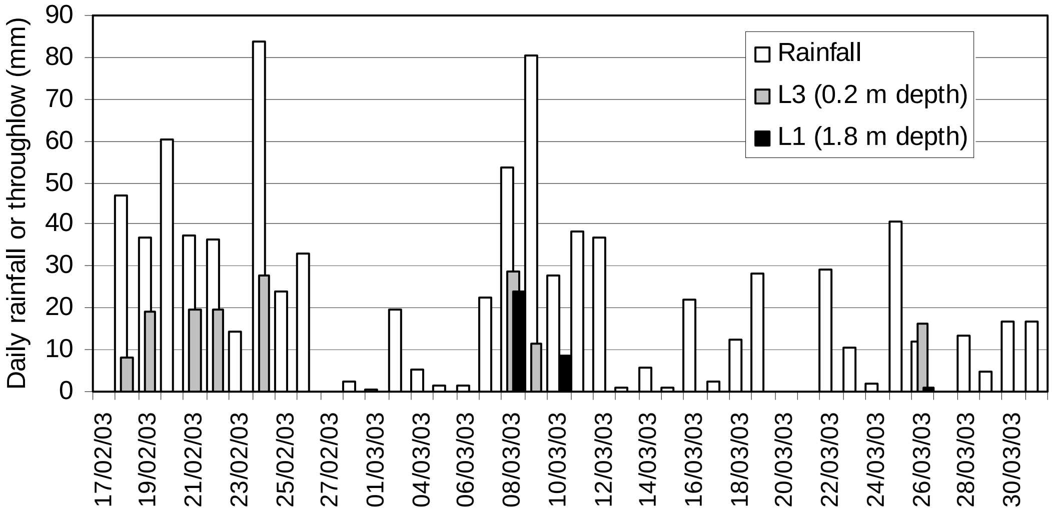


Figure 12. Daily rainfall and flow through the soil profile during February-March 2003 at Dami. L2 (1.0 m depth) only collected water on 18/2/03 (2.4 mm) and 28/2/03 (0.2 mm).

Table 13. Concentration of mineral N in the lysimeter samples.

L1 (1.8 m depth)				L2 (1.0 m depth)				L3 (0.2 m depth)			
Date	NH_4 N	NO_3 N	Min N	Date	NH_4 N	NO_3 N	Min N	Date	NH_4 N	NO_3 N	Min N
27/02/03	0.08	0.18	0.26	18/02/03	0.46	1.36	1.82	18/02/03	0.83	1.43	2.26
10/03/03	0.09	2.86	2.95	28/02/03	0.69	1.23	1.92	19/02/03	0.24	0.35	0.59
11/03/03	0.28	2.17	2.45					21/02/03	0.12	0.46	0.58
26/03/03	0.17	0.24	0.41					22/02/03	0.41	0.16	0.57
31/03/03	1.24	0.30	1.54					24/02/03	0.32	0.17	0.49
3/04/03	0.32	1.77	2.09					26/03/03	0.35	0.45	0.80
4/04/03	0.28	1.55	1.83					31/03/03	0.58	0.38	0.96
5/04/03	0.61	1.89	2.50					4/04/03	0.25	0.75	1.00
								5/04/03	0.14	0.32	0.46
Mean	*0.38*	*1.37*	*1.75*		*0.58*	*1.30*	*1.87*		*0.36*	*0.50*	*0.86*

Soil pits and other observations

See Table 15 for profile descriptions. During heavy rainfall events in January and February 2003, no lateral seepage of water from the profile was evident at Kumbango or Dami. No water collected in the bottom of the Dami pit but at Kumbango water did collect in the pits. Measurements in adjacent piezometers showed the water was watertable rather than simply surface runoff that collected in the pits. At Dami there was only transient surface ponding of water in weeded circles and short surface flows along harvest paths in that block during all the periods of rain from 20 Jan –6 Feb 2003. By observations during rainfall, it is obvious that at Kumbango (Trial 125 area) lateral water movement is mostly along the surface and in the shallow water table, which discharges into the Dagi River. At

Dami, significant surface runoff is only generated on paths and roads; most water moves through the profile, presumably mostly to the watertable below 2 m depth, and discharges near the beach.

Saturated hydraulic conductivity

Saturated hydraulic conductivity values for the various layers in the Dami and Kumbango profiles are shown in Table 14. Values were generally higher than 200 mm/hr in all layers, greater than rainfall intensities that we have measured and therefore unlikely to cause lateral flow within the profile. The lateral flow that was measured in the lysimeters at Dami is most likely due to water flowing at or near saturation through the A horizon, with movement into the underlying horizon (22-33 cm) being restricted by its coarse texture. Under unsaturated conditions water will not move from a fine textured layer into an underlying coarser textured layer.

Further work

A new array of lysimeters is about to be installed at Dami. There will be 5 replicate sets of lysimeters in the inter-palm area and 5 replicate sets under the frond pile. Each set will consist of lysimeters at 3 depths.

Table 14. Saturated hydraulic conductivity (mm/hour) of layers in the profile at Kumbango and Dami. Surface values are included for Kumbango. For Dami they can be found in the 'Nitrogen losses' report.

Kumbango					
Depth (cm)	Texture	Rep. 1	Rep. 2	Rep. 3	**Mean**
3-5	clay loam	385	109	208	**234**
30-40	sand	1574	1677	5571	**2941**
45-50	medium clay	351	344	368	**354**
85-95	heavy clay	148	327	137	**204**
Harvest Path		50	44	47	**47**
Weeded Circle		86	246	163	**165**
Frond Pile		2332	454	639	**1142**
Dami					
Depth (cm)	Texture	Rep. 1	Rep. 2	Rep. 3	**Mean**
20	clay loam	265	330	973	**523**
40-50	sandy clay	321	323	625	**423**
75-80	sandy clay loam	560	426	680	**555**
100-150	gravel	4320	10800	7714	**7611**

Table 15. Colour (wet) and texture of soil layers at the Kumbango and Dami sites.

Site		**Kumbango**, Trial 125, plot 26
Parent material		Tephra: airfall and alluvially redeposited
Author		T. Betitis, 17/11/02

Horizon	Depth (cm)	Description
Ao	0-5	Brown (10YR 4/3); silty clay loam; gradual diffuse boundary
AC	5-17	Light olive brown (2.5Y 5/4); sandy clay loam; smooth clear boundary
BC	17-30	Brown (10YR 4/3) to dark yellowish brown (10YR 4/4); sandy clay; smooth clear boundary;
C	30-40	Light yellowish brown (2.5Y 6/4); sand; smooth clear boundary;
Bw	40-66	Brown (10YR 4/3) clay; smooth clear boundary
C2	66-73	Dark yellowish brown (10YR 4/6), medium fine sand; smooth clear boundary;
Bw2	73-100	Brown (10YR 4/3); clay
C3	100-120	Light yellowish brown (2.5Y6/4); medium sand mixed with medium coarse pumice; smooth clear boundary;
C4	120-150	Light brownish gray (2.5Y6/2); loamy sand intermixed with pumice;; smooth clear boundary;
C5	150-200	Brown (10YR 5/3) to yellowish brown (10YR 5/4); medium to coarse sand intermixed with ash;

Site		**Dami**, LSU 302, OPRS Trial 239
Parent material		Tephra: airfall and alluvially redeposited
Author		M. Banabas, 23/8/02

Horizon	Depth (cm)	Description
Ap	0 – 10	Very dark brown (10YR 2/2) sandy loam; diffuse and smooth boundary to
AB	10 – 22	Dark brown (10YR 3/3) sandy loam; distinct wavy boundary to
BC1	22 – 33	Dark yellowish brown (10YR 3/4) sandy gravelly loam; distinct smooth boundary to
C1	33 – 50	Light olive brown (2.5Y 5/4) sand - sandy loam; diffuse boundary to
C2	50 – 60	Light olive brown (2.5Y 5/4) coarse sandy loam; diffuse boundary to
Bw1	60 – 72	Dark yellowish brown (10YR 4/6) sandy loam; distinct smooth boundary to
C3	72 – 87	Brownish yellow (10YR 6/6) sandy/pumice/gravel; distinct smooth boundary to
C4	87 – 128	Light yellowish brown (2.5 Y 6/4) pumice gravel; distinct straight boundary to
ABC2	128 – 137	Yellowish brown (10YR 5/8) sandy loam; distinct straight boundary to
bA?	137 – 153	Light brownish gray (10YR 6/2) sandy loam; distinct straight boundary to
C5	153 – 163	Yellowish brown (10YR 5/4) sandy loam (ash); distinct straight boundary to
BC2	163 – 178	Dark yellowish brown (10YR ¾) sandy loam with pumice gravel inclusions (weathered pumice layer); diffuse straight boundary to
C6	178 – 200	Yellowish brown (10YR 5/8) pumice gravel,

MAINTENANCE OF SOIL FERTILITY

Why be concerned?

Fertilisers are making up an increasing proportion (about 60-70%) of the costs of oil palm production. The amounts of fertiliser required to maintain production also appear to be increasing with time, as soil fertility declines. The amount of fertiliser required, and the effectiveness of fertilisers that are applied rely to a large extent on the ability of the soil to retain nutrients and then make them available to the palm. In order to maintain profitability in the long-term it is essential to manage for sustained soil fertility. In order to do that, we need to know how management is currently affecting soil fertility.

What determines the ability of soils to retain and supply nutrients?

One of the major aspects of soil fertility is the ability of the soil to supply nutrients to plants in the required quantities. Nutrient supply depends on soil reserves becoming available, and also on the ability of the soil to retain and supply nutrients added in fertilisers, crop residues and biological fixation. The ability of soils to retain and supply N and S depends almost entirely on their organic matter content. The same is true for P, with the additional proviso that the presence of minerals that bind P are also important. The ability of soils to supply K, Mg and minor nutrients depends largely on the types and quantities of weatherable minerals, and on cation exchange capacity. Cation exchange capacity in turn depends mostly on the content and type of clay and organic matter, and soil pH. So organic matter content, clay content, cation exchange capacity, weatherable mineral content, pH and P retention are critical attributes of soil fertility.

The other critical soil factor influencing fertility is the ability of soils to accept, retain and transmit water and air. This factor interacts with climate and topography to determine water and oxygen supply to plant roots. The movement and storage of water and air in soil is determined by the size distribution and continuity of pores. In oil palm, the main management factors influencing pore size distribution are management of cover crops and crop residues, which influences organic matter content and biological acitivity, and mechanised traffic, which tends to reduce porosity. The maintenance of optimum pore size distribution is very important for fertility, but this discussion will focus on chemical rather than physical fertility.

Initially, the young, originally forested soils of the oil palm growing areas of PNG tend to have high organic matter content, and moderate cation exchange capacity and P retention and high contents of weatherable minerals. However, with the change from forest to plantation vegetation, erosion, the application of acidifying fertilisers, and the natural processes of weathering and leaching, there is likely to be a reduction in fertility with time. This applies especially to the recent volcanic ash soils of West New Britain and Oro, but also to the alluvial soils of Milne Bay, and to some extent to the coral soils of New Ireland.

Management effects on soil organic matter content

The decline in soil organic matter content following clearing of forest and conversion to agriculture has been clearly established in many situations. However it is not as drastic in plantations as in cultivated systems. Soil organic matter content tends to decline because inputs of organic matter are generally less under agriculture than under rainforest. Oil palm is unusual in that it produces organic matter, or fixes carbon, at a similar rate to rainforest, around 20 t C/ha.year[1]. However, about half of that is exported as FFB. While conversion of forest to agriculture tends to reduce inputs of organic matter, it can also increase losses. Where the soil is cultivated or where the soil is drained,

[1] Soil C content is approximately half the value of soil organic matter content.

decomposition rates tend to increase. Erosion can also cause very significant losses of soil organic matter in agriculture. Any disturbance of the surface tends to increase losses of the top-most soil layers, which are rich in organic matter. The net result of lower inputs and higher rates of loss is a lower soil organic matter content. Rapid decomposition of soil organic matter following conversion to agriculture is one of the main reasons soil fertility is high initially, as large quantities of nutrients become available. However, eventually the soil organic matter content reaches equilibrium with the new system and the supply of nutrients slows. Organic matter contents of some virgin vs plantation soils sampled in a recent PNGOPRA project did not show consistent differences between forest and plantation soils (Figure 13b). However, these comparisons are not particularly robust, because of the other soil differences between sites. Results from Trial 305 suggest a rapid initial decline in soil organic matter content in the early stages of an oil palm plantation. Over the trial site, organic matter content of the 0-30 cm layer was 5.5% in 1981 and 2.3% in 1986. That is a massive drop in organic matter content and is equivalent to a loss of 4,800 kg/ha of N. However, the way those samples were collected was not recorded, so the comparison may not be entirely valid. Using the example in Figure 1a, the organic C content of the 0-30 layer was 2.90% in the virgin soil and 1.92% in the plantation soil. That represents a loss of approximately 2,940 kg/ha of N. Those N loss figures should be compared to the current N inputs, which are about 100 kg/ha per year.

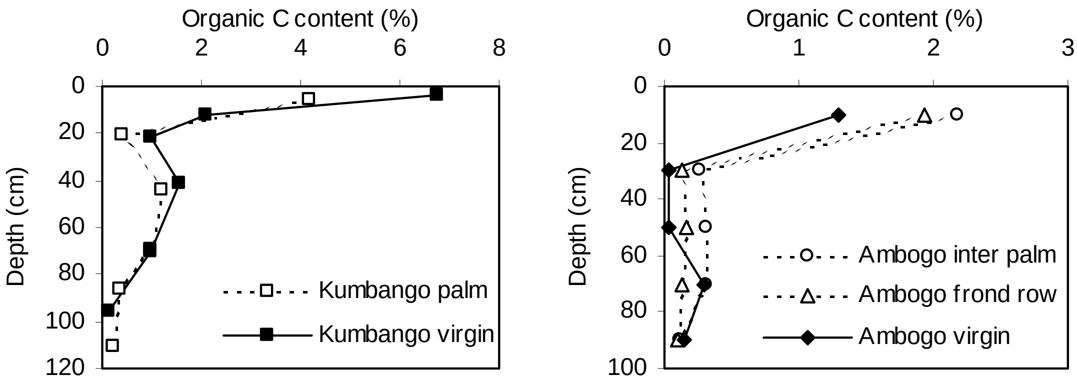


Figure 13. Organic C contents of a) forested and oil palm profiles at Kumbango, and b) forested and oil palm (inter-palm and frond pile) profiles at Ambogo.

Management within the plantation also affects soil organic matter content, as shown in results from trial 306. In 1998, after the trial had been running for 19 years, organic C content of a plot receiving no N fertiliser (0-10 cm depth) was 0.81%, whereas that of plots receiving N fertiliser was 2.07-2.96%. Within the plantation, soil organic matter content could also be expected to vary between frond piles, weeded circles and the general inter-palm areas. However, limited analyses carried out in a recent project did not confirm that hypothesis (Figure 13b).

A large proportion of the CEC of surface soils is in the organic matter, so changes in organic matter have a large impact on CEC. Therefore, continuing the examples above, in trial 305, the CEC of the 0-30 cm layer fell from 19.9 $cmol_c$/kg in 1981 to 11.8 $cmol_c$/kg in 1986. In the 306 example, CEC of the 0-10 cm layer was 9.6 $cmol_c$/kg in the plot not receiving N fertiliser, and 11.9-22.1 $cmol_c$/kg in the plots receiving N fertiliser.

Organic matter also plays an important role in soil pH buffering capacity (Figure 16), so a decrease in organic matter content reduces the ability of a soil to resist acidification.

Management effects on Soil Acidification

Soil pH is important because it affects the availability and uptake of nutrients in several ways. Most soils, especially those in the tropics, tend to acidify with time. At low pH: roots become less active; mineralisation of organic matter slows, reducing the supply of N, S and P; cation exchange capacity decreases, reducing the ability to retain and supply K and Mg; P retention tends to increase; and the concentration of toxic Al increases. Having evolved in a wet tropical environment, oil palm is naturally tolerant of soil acidity and high Al levels. However, the factors described above will eventually reduce productivity.

Acidification of the root zone is the net effect of many natural and man-induced processes, which are listed below. The last two tend to be the major processes in production agriculture.

- Acid rain
- Leaching of cations
- Production of weak acids by plants and microbes
- Oxidation reactions
- Accumulation of organic matter
- Plants absorbing different amounts of cations and anions
- Removal of cations in harvested crop
- Fertiliser application and nitrogen cycling

Acid Rain

Acid rain is usually associated with industrial areas, but in volcanic areas, rain can contain significant amounts of nitric, hydrochloric and sulphuric acid.

Leaching of Cations

This is a natural process that is quite rapid in the wet tropics due to high rainfall. The cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ are pH-neutral. However Al^{3+} is an acid due to the reaction below (Equation 1). Any reaction that produces H^+ ions or protons is acidifying.

$$Al^{3+} + H_2O \rightarrow Al(OH)^{2+} + \mathbf{H^+} \qquad [1]$$

The cations with lowest charge (Na^+ and K^+) are lost most easily by leaching. The cations Ca^{2+} and Mg^{2+} have higher charge and leach out more slowly. The cation with the highest charge, Al^{3+}, is held most strongly. Therefore, with time the proportion of Al^{3+} becomes higher and the soil becomes more acid. Another factor that contributes to this process is that the solubility of Al depends on soil pH. All soils contain large amounts of Al in their minerals, but at neutral pH the Al is not soluble and the concentration of Al^{3+} is negligible. As pH descends below 5.5, the concentration of Al in solution (as Al^{3+}, $Al(OH)^{2+}$ and $Al(OH)_2{}^+$) increases exponentially.

Production of Weak Acids by Plants and Microbes

Plants and microbes produce weak organic acids and exude them from their roots for a number of reasons. All organisms in soil also respire and produce carbon dioxide, which is a weak acid. However, these acids are so weak that they only contribute to acidification in alkaline soils.

Oxidation Reactions

Two oxidation reactions can be significant sources of acid in particular situations. The first is the oxidation of pyrite or iron sulphide (Equation 2). The main situation in which his reaction occurs is where acid-sulphate soils are drained. Acid-sulphate soils occur mostly in ex-tidal areas. Under the waterlogged, high organic matter conditions of tidal mudflats, pyrite forms from the sulphate in the seawater and iron dissolved from soil minerals. When the soils are aerated by drainage, the pyrite is oxidised to huge amounts of sulfuric acid. Conversion of acid sulphate soils to agriculture by drainage is causing massive and costly problems in South East Asia and elsewhere. The problem has not yet occurred to any extent in PNG. The best management option by far is to leave acid sulphate soils in their natural state.

$$FeS \text{ (pyrite)} + O_2 + H_2O \rightarrow Fe(OH)_3 + \mathbf{2H^+} + SO_4^{2-} \quad [2]$$

$$NH_4^+ + O_2 \rightarrow H_2O + \mathbf{2\ H^+} + NO_3^- \quad [3]$$

The second important oxidation reaction is the oxidation of ammonium to nitric acid (Equation 3). That reaction tends to occur where ammonium fertilisers are applied, and is discussed further in the section on nitrogen cycling.

Accumulation of Organic Matter

This mechanism has been most pronounced in infertile soils that have been sown to pasture and fertilised (eg. with P) but not limed. As organic matter content increases, the build-up of negative charge must be balanced with cations, and if Ca, Mg or K are not applied, soil Al will dissolve and produce Al^{3+} to balance the charge. As mentioned above, Al^{3+} is acidic.

Plants Absorbing Different Amounts of Cations and Anions

This is probably significant under oil palm due to the relatively large supply and uptake of N. It is likely that the palms take up a significant proportion of their N as NH_4^+ rather than NO_3^-. When roots take up a large amount of NH_4^+ they excrete H^+ to compensate the charge imbalance.

Removal of Cations in Harvested Crop

As mentioned under leaching, the removal of Ca, Mg, K and Na will lead to soil acidification. A crop of 25 t/ha FFB removes a net amount (allowing for return of EFB) of approximately 35 kg K, 15 kg Mg and 20 kg Ca per ha. When the soil pH is low enough for Al^{3+} concentration to increase, that loss of cations is equivalent to a potential annual acid input of 1.1 kmol H^+/ha. The amount of lime required to neutralise that amount of acidification would be 157 kg/ha of calcium carbonate.

Fertiliser Application and Nitrogen Cycling

Use of ammonium fertilisers almost inevitably acidifies soil, as can be seen in Figure 14. Net acid production would be zero if the fertiliser N applied as ammonium was nitrified, taken up by the plant or soil organisms and mineralised back to ammonium. However, that never occurs in practice; some N always leaves the system in the harvested product or by leaching of nitrate. When N leaves the system, there is a net production of acid. The potential amounts of acid produced when various fertilisers are used are shown in Table 16. The actual amounts of acid produced are probably between the two situations shown in the table (all N taken up or all N lost by leaching). Initial estimates suggest that about 50% of the N applied is being lost by leaching. When N is applied as ammonium chloride or sulphate, the ammonium is nitrified or taken up, leaving the anion available for leaching together with a cation. Therefore ammonium fertilisers can increase the leaching loss of cations described above.

Leaching of N that is derived from mineralisation of soil organic matter also has a net acidifying effect. That effect becomes significant under good stands of legumes. If we assume that the legume cover crop fixes 150 kg N/ha.year for the first 5 years of a 25 year crop rotation, then the average annual amount fixed over the life of the oil palm crop is 30 kg N/ha. That amounts to a potential acid production of 2.1 kmol H^+/ha if all the N is lost by leaching.

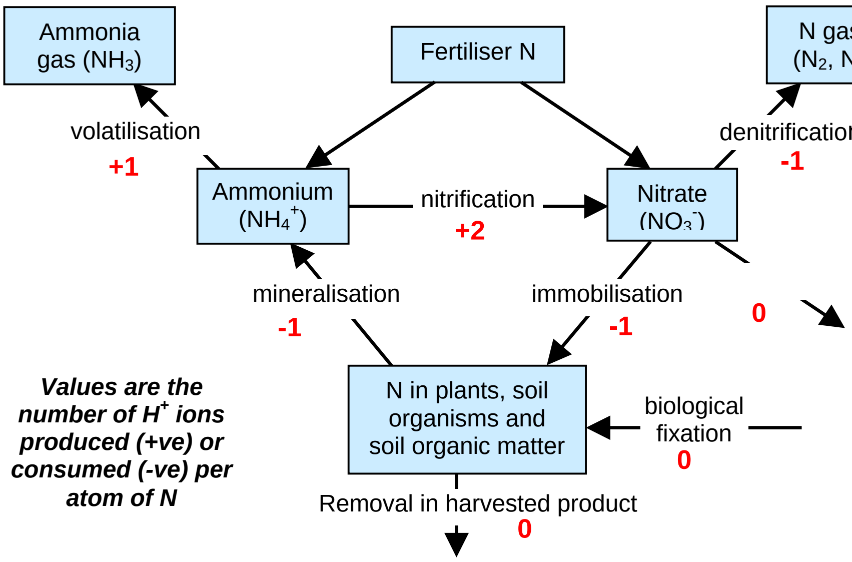


Figure 14. Production and consumption of acid in N cycling processes.

Table 16. Potential acid production using different N fertilisers, all at an equivalent rate of N application (100 kg N/ha).

Fertiliser	Fertiliser application rate at 135 palms/ha and 100 kg N/ha (kg/palm)	Acid production if all N taken up by palms (kmol H^+/ha)	Acid production if all N lost by leaching (kmol H^+/ha)
Ammonium sulphate	3.5	7.1	14.3
Ammonium chloride	3.0	7.1	14.3
Ammonium nitrate	2.1	0.0	7.1
Urea	1.6	0.0	7.1
Diammonium phosphate	4.1	3.6	10.7

Capacity of Soil to Resist Acidification

All the processes described above are acidifying in that they reduce the acid neutralising capacity of the soil. Their effect on pH depends on the pH buffering capacity of the soil; the higher the pH buffering capacity of the soil, the smaller the reduction in pH per unit of acid applied. However, continual acidification eventually reduces the pH buffering capacity of the soil, so eventually all soils in the wet tropics become acidic.

Most of the soils under oil palm in PNG have a desirable pH and relatively high pH buffering capacity due to their young age; they have high contents of easily weatherable minerals, variable charge minerals and organic matter. The actual pH and pH buffering capacity depend on the mixture of materials making up the soil. In New Ireland soils the presence of calcium carbonate buffers pH at around 7. In the volcanic ash soils of West New Britain and Oro, variable charge minerals and organic matter buffer pH at around 6 The large amount of exchangeable Ca, presumably supplied from weathering minerals, probably plays an important role in pH buffering of these soils. In the older weathered ash soils of Mamba, pH is buffered around 5 by organic matter. Soil pH does not normally descend below about 4, because dissolution of the main soil minerals buffers it there.

Several pH buffer curves are shown in Figure 15. The flatter the curve, the higher the pH buffering capacity of the soil. The topsoils tend to have higher buffering capacity, because of their high organic matter content. The effect of organic matter on buffering capacity of a large number of volcanic ash soils is shown in Figure 16. It is clear that a decrease in soil organic matter content will also decrease pH buffering capacity.

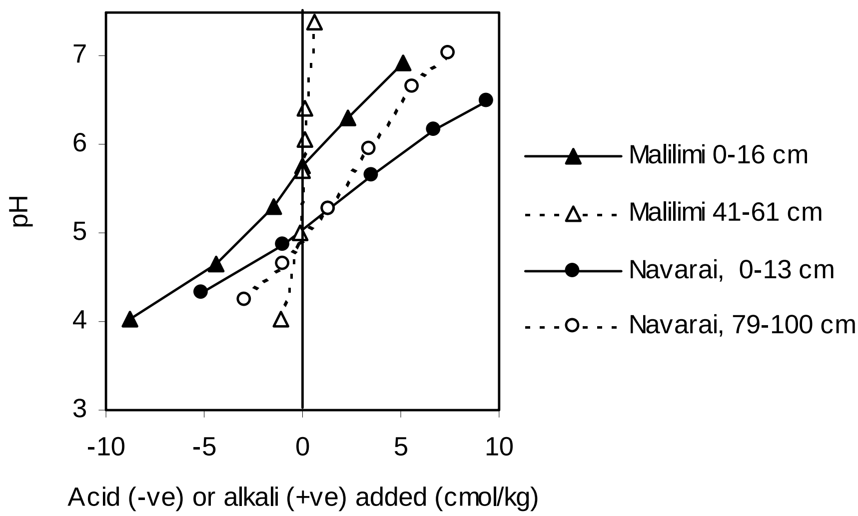


Figure 15. pH buffer curves of soils from selected sites and depths in West New Britain.

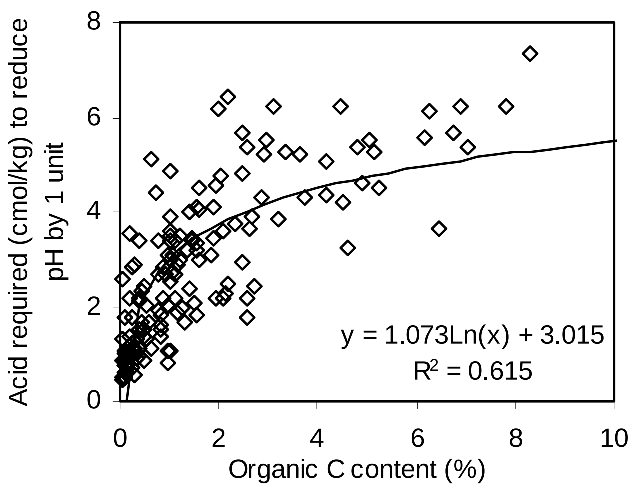


Figure 16. Relationship between soil pH buffering capacity and soil organic matter content in volcanic ash soils from oil palm growing areas of West New Britain and Oro Provinces. Soils came from 27 profiles, in which all horizons to a depth of approximately 1m were sampled, giving a total of 150 samples.

Effect of Soil Acidification on Cation Exchange Capacity

Volcanic ash soils are variable charge soils, which means that their cation exchange capacity varies with soil pH and ionic strength. The relationship between pH and CEC for a typical soil is shown in Figure 17. Using the information given in the sections above, we can estimate the effects of soil acidification on CEC.

Assuming 33% of the N applied in fertilisers (ammonium sulphate or ammonium chloride) and fixed by the cover crop is lost by leaching, the acid input will be approximately10 kmol H^+/ha. We will ignore the acid input from cation removal, which only becomes significant once the exchangeable Ca starts to become depleted. If we take the top 50 cm of soil, where most of the roots are, and say that is the zone where the acidification occurs, then we are talking about 5,000 t of soil per ha (assuming a bulk density of 1 t/m^3). Acid input is therefore 0.2 cmol H^+/kg soil. Averaging pH buffer curves for the 0-50 cm depth layer of 27 soil profiles, including the samples shown in Figure 3, the average drop in pH per cmol H^+/kg added is 0.5. Therefore, the annual drop in pH will be 0.10 units per year, and over a 20 year period will be 2 units.

That estimate correlates reasonably well with results from Trial 306. In 306, soil pH in the top 30 cm dropped by 1.2 units over a period of 16 years (0.075 units/year) in the plots receiving SOA. In the 0-50 cm layer of the 27 soil profiles mentioned above, the average drop in CEC per unit of pH is 2.5 $cmol_c$/kg. Therefore, going back to the hypothetical example, the drop in CEC over a 20-year period will be 5 $cmol_c$/kg. That is a substantial drop in CEC, and means that the soil will be able to retain 9.75 t/ha less of K (equivalent to 19.5 t/ha of MOP), or 3 t/ha less of Mg (equivalent to 30 t/ha of kieserite). These calculations do not take into account any decreases in organic matter content, which would have a large impact on CEC, both directly, and through decreased pH buffering capacity (Figure 16). The effect of N and K fertilisers on exchangeable K and soil pH in Trial 309 in Oro are shown in Figure 18. The recent change from ammonium sulphate or ammonium chloride to ammonium nitrate in most of the industry is likely to have slowed the rate of acidification by up to two thirds.

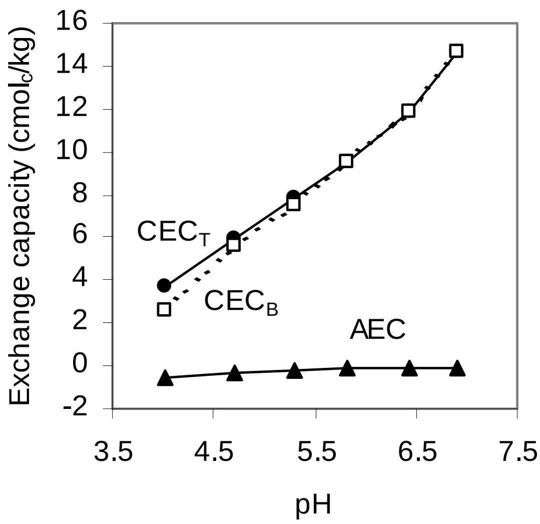


Figure 17. Relationship between exchange capacity and pH for a typical volcanic ash topsoil (Bialla Area 9, LSU 2, 0-20 cm depth). CEC_T is the total cation exchange capacity and CEC_B is the ability of the soil to retain 'basic' cations such as Ca, K and Mg. The difference between the two is due to exchangeable Al that cannot be replaced by 'basic' cations. AEC is anion exchange capacity. The soil has a pH_{BaCl2} of 5.6.

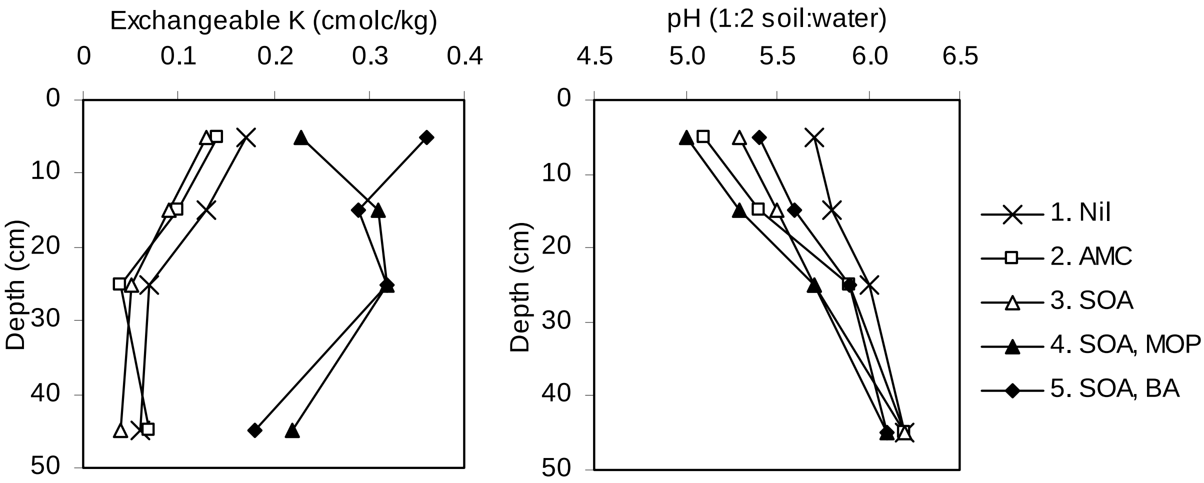


Figure 18. Effect of N and K fertilisers on soil exchangeable K and soil pH over the course of Trial 309 in Oro.

Summary and Implications

Our limited research on this subject suggests that the ability of soils to retain and supply nutrients is falling under current oil palm management. Accelerated soil acidification is almost certainly occurring and there is quite good evidence that leaching losses of N and cations are a major contributor. The N loss and cation projects, which are just commencing, will provide much of the essential information for management strategies for mitigating those losses. However, the actual current rates of acidification are not known, and we need to come up with cost-effective strategies to counter the problem. The effects of management on soil organic matter are even less well understood and we need to determine what is happening and what the best management strategy is. Erosion is likely to be a significant loss mechanism for organic matter. The N loss project will provide the first measurements of erosion losses in oil palm in PNG. The problem of soil fertility decline and its management is the subject of a proposal outlined below.

The other major gap in our ability to provide rational and cost effective management solutions for soil fertility is our ability to link the processes in a predictive sense. For example, fertiliser type, frequency and means of application, uptake and loss of N and cations, growth and productivity of the palm all influence each other. If we recommend a practice that influences one of these factors, we need to know how all the others will be affected. This problem is the subject of another research proposal (see ‘Predictions and Recommendations’ section).

NUTRIENT BUDGETS AND NUTRIENT USE EFFICIENCY

Fertilizer trials have given information about yield responses to fertilisers, but with a little extra information we will also be able to calculate the efficiency with which fertilizers are taken up (Uptake efficiency) and converted to yield (Conversion efficiency). Those parameters are calculated as shown below.

Uptake efficiency (UE) = extra uptake / amount applied

Conversion efficiency (CE) = extra yield / extra uptake

Yield efficiency = extra yield / amount applied (UE x CE)

We know the amount of nutrient applied in fertilizer and we know the extra yield, but in order to calculate efficiency we need to estimate the extra uptake, which we get by measuring the biomass and nutrient content of the palm. Our routine vegetative measurements give us the biomass, and routine measurements of nutrient contents in Frond 17 give us nutrient content of the canopy (when used together with information we have on nutrient distribution throughout the canopy). The gap in information is our knowledge about nutrient content of the trunk and roots. We have commenced routine sampling of the trunk in fertilizer trials that are showing responses. The trunk samples are taken at a standard position. In order to estimate the amount of nutrient in the trunk we need to know the distribution of nutrients throughout the trunk. In late 2001 4 palms in Ambogo were dissected and their trunks and roots analysed for nutrients. Figure 19 shows that nutrients are distributed non-uniformly but predictably through the trunk. The information will be used to extrapolate nutrient contents from routine samples taken from the outside 0-20cm at 1.5m height. Table 17 shows the nutrient content of the roots.

Table 17. Mean nutrient content of primary and secondary roots in mature palms felled at Ambogo, October 2001 (% DM).

	Ash	N	P	K	Mg	Ca	Cl	S
Primaries	6.04	0.30	0.03	0.60	0.10	0.11	0.35	0.10
Secondaries	8.85	0.55	0.06	0.68	0.18	0.19	0.44	0.12

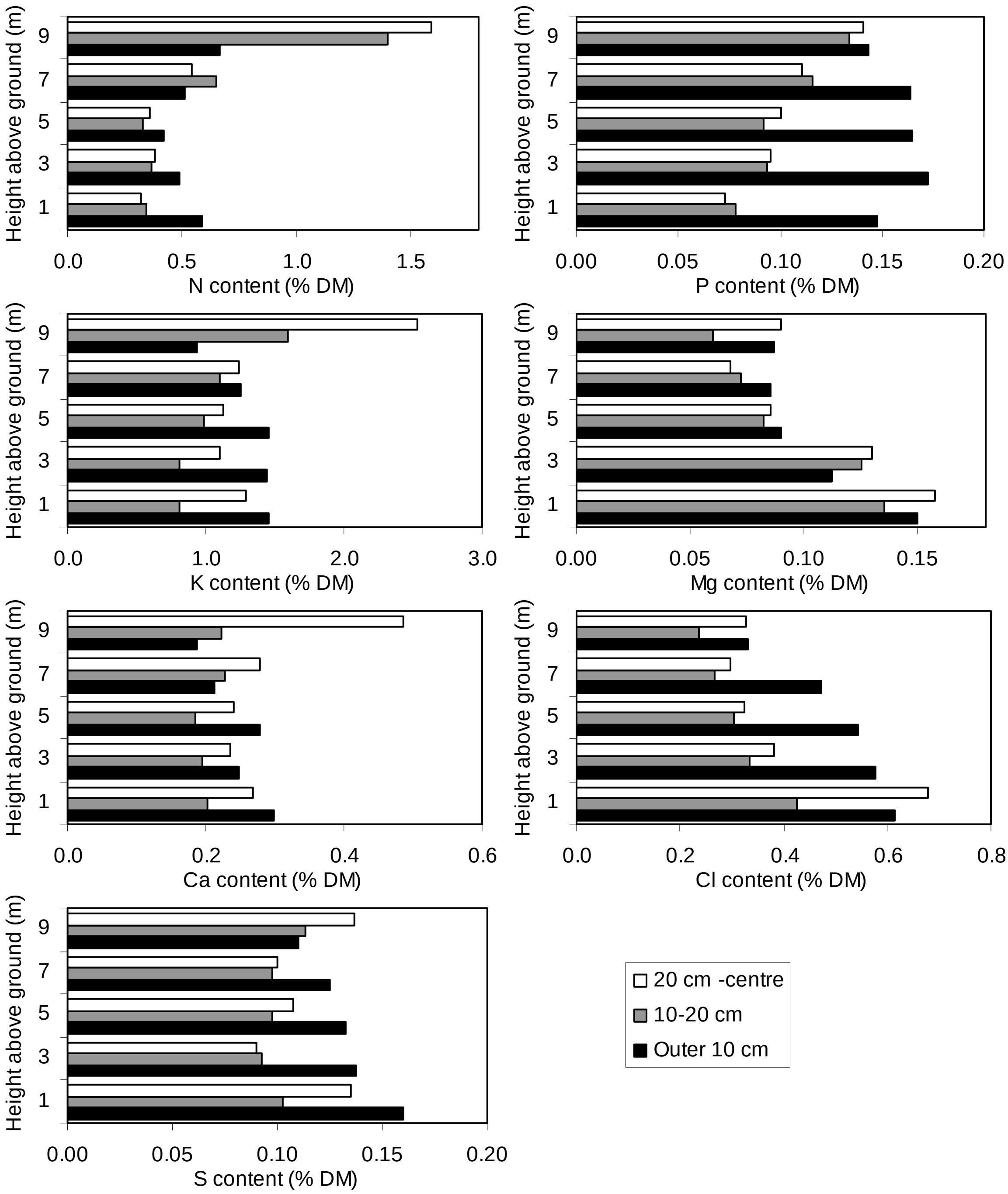


Figure 19. Nutrient content throughout trunks of palms felled at Ambogo, October 2001.

FERTILISER RESPONSE TRIALS IN WEST NEW BRITAIN (NBPOL)

(P. Nelson, J. Kraip)

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 Trial 324 in Oro Province.

Results

There were no significant effects of fertiliser type, fertiliser rate or their interaction on yield or its components in 2002 (Table 2). The means for the main effects and their interaction are shown in Tables 3 and 4. Looking at tissue nutrient contents, the treatments had significant effects on leaflet P and Cl contents only (Table 5). DAP increased leaflet P content and AMC increased leaflet Cl content (Tables 6, 7 and 8). However, neither P nor Cl contents were particularly low in the controls (Table 6).

Figure 1 shows the yields at maximum N rate throughout the course of the trial, indicating that there have been no consistent effect of treatments, and that control plots are yielding at a similar level to fertilised plots. The issue was discussed at the 2001 SAC meeting and it was decided to close Trial 125 at the end of 2002, which is what has happened. Most of the fertiliser trials in NBPOL plantations over the last decade or so have shown similar results, with little or no response and high yields in the control plots. We are now investigating why this is so.

Table 2. Effects (p values) of treatments on FFB yield and its components in 2000-2002 and 2002 (Trial 125). p values <0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Rate	**0.091**	0.127	0.820	0.977	0.696	0.676
Type	0.575	0.581	0.701	0.731	0.920	0.619
Rate.Type	0.432	0.875	0.408	0.369	0.900	0.575
CV %	*8.9*	*11.0*	*7.3*	*12.4*	*9.7*	*14.7*

Table 3. Main effects of treatments on FFB yield (t/ha) and its components (Trial 125). Effects with p<0.1 are shown in bold. The control values were not used in the ANOVA.

	2000-2002			2002		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Control	28.6	1727	16.8	22.5	1280	18.2
sd	*2.40*	*183*	*0.86*	*3.14*	*225*	*2.01*
Rate 1	**28.5**	1622	18.0	24.1	1259	19.6
Rate 2	**30.2**	1736	17.7	24.2	1307	19.1
Rate 3	**28.7**	1646	17.9	24.3	1304	19.4
s.e.d.	*1.06*	*58.0*	*0.41*	*0.95*	*60.0*	*0.60*
AMC	30.2	1710	18.2	24.0	1299	19.1
SOA	28.8	1651	17.9	23.7	1266	19.4
Urea	29.4	1722	17.4	25.2	1361	19.1
AMN	28.7	1627	18.0	24.4	1282	19.7
DAP	28.8	1630	17.9	23.7	1243	19.5
s.e.d.	*0.82*	*74.9*	*0.53*	*1.23*	*77.5*	*0.77*

Table 4. Effect of interaction between fertiliser type and rate on FFB yield (t/ha) in 2002 (Trial 125). The interaction was not significant. $Lsd_{0.05}$ = 4.3.

	AMC	SOA	Urea	AMN	DAP
Rate 1	24.1	25.3	23.5	25.9	21.6
Rate 2	23.5	23.4	26.4	23.7	24.0
Rate 3	24.4	22.5	25.7	23.5	25.5

Table 5. Effects (p values) of treatments on frond 17 nutrient concentrations in 2002 (Trial 125). P values less than 0.1 are indicated in bold.

	Leaflet								Rachis	
Source	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
Rate	0.300	0.613	0.446	**0.036**	0.497	0.134	0.783	0.776	0.633	0.399
Type	0.275	0.326	**<.001**	0.129	0.210	0.167	0.664	**<.001**	0.476	0.278
Rate.Type	0.740	0.595	**0.021**	0.871	0.197	0.933	0.551	0.504	0.924	0.619
CV %	*5.9*	*3.5*	*2.9*	*5.7*	*9.7*	*8.6*	*9.5*	*15.4*	*11.2*	*11.5*

Table 6. Main effects of treatments on frond 17 nutrient concentrations in 2002, in units of % dry matter, except for B (mg/kg) (Trial 125). Effects with p<0.1 are shown in bold. The control values were not used in the ANOVA.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
Control	15.2	2.50	0.148	0.81	0.173	0.80	13.6	0.380	4.3	1.41
sd	*1.28*	*0.090*	*0.0039*	*0.010*	*0.0096*	*0.015*	*1.65*	*0.0616*	*0.39*	*0.186*
Rate 1	14.9	2.55	0.149	**0.79**	0.166	0.79	12.9	0.44	4.6	1.56
Rate 2	15.2	2.53	0.149	**0.75**	0.172	0.82	13.2	0.44	4.6	1.57
Rate 3	15.4	2.56	0.151	**0.78**	0.169	0.78	13.0	0.43	4.7	1.63
sed	*0.28*	*0.028*	*0.0014*	*0.014*	*0.0052*	*0.022*	*0.39*	*0.0213*	*0.16*	*0.058*
AMC	14.7	2.55	**0.150**	0.75	0.164	0.84	12.7	**0.54**	4.8	1.68
SOA	15.4	2.52	**0.146**	0.78	0.162	0.78	13.3	**0.41**	4.6	1.55
Urea	14.9	2.52	**0.148**	0.79	0.174	0.80	12.8	**0.43**	4.6	1.60
AMN	15.5	2.56	**0.149**	0.79	0.171	0.78	13.2	**0.39**	4.5	1.52
DAP	15.3	2.58	**0.156**	0.77	0.174	0.80	13.2	**0.42**	4.7	1.59
sed	*0.37*	*0.036*	*0.0018*	*0.018*	*0.0067*	*0.028*	*0.51*	*0.028*	*0.21*	*0.075*

Table 7. Effect of interaction between fertiliser type and rate on leaflet P content (% DM) in 2002 (Trial 125). The interaction was significant (p=0.021). $Lsd_{0.05}$ = 0.0062.

	AMC	SOA	Urea	AMN	DAP
Rate 1	0.150	0.145	0.148	0.149	0.154
Rate 2	0.153	0.141	0.149	0.151	0.154
Rate 3	0.147	0.152	0.148	0.148	0.160

Table 8. Effect of interaction between fertiliser type and rate on leaflet Cl content (% DM) in 2002 (Trial 125). The interaction was not significant. $Lsd_{0.05}$ = 0.0962.

	AMC	SOA	Urea	AMN	DAP
Rate 1	0.5475	0.4125	0.4125	0.3625	0.4550
Rate 2	0.5450	0.3800	0.4633	0.3950	0.4375
Rate 3	0.5225	0.4350	0.4075	0.4100	0.3700

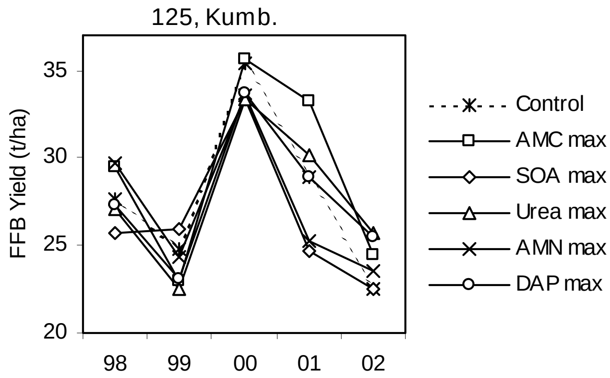


Figure 1. Effect of different N fertilisers (at rates equivalent to 2.08 kg N/palm.year) on yield in Trial 125

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 amoung 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

Over the 2000-2002 period, SOA, TSP and NaCl have each significantly increased yield, mainly thought their effect on bunch weight (Tables 2 and 3). There were few interactions between fertilisers, except for a significant interaction between TSP and kieserite (Table 2 and 4). Where kieserite was applied, TSP had no significant effect on yield. This interaction between kieserite and TSP appears to be quite common, but the reasons are not yet clear.

The positive effect of NaCl and absence of response to SOP shows fairly clearly that the response to MOP in Trial 119 was due to Cl rather than K. The response to Cl appears to have been present throughout the life of the trial, whereas the responses to SOA and TSP have developed with time (Figure 1).

This trial was closed at the end of 2002 to allow resources to be directed to the new work in West New Britain.

Table 2. Effects (p values) of treatments on FFB yield and its components in 2000-2002 and 2002 (Trial 126). p values less than 0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.012**	0.753	**0.006**	0.160	0.880	**0.002**
SOP	0.151	0.118	0.402	0.353	0.389	0.234
TSP	**0.072**	0.964	**0.013**	**0.052**	0.551	**0.007**
KIE	0.403	0.885	0.263	0.860	0.466	0.137
NaCl	**0.061**	0.923	**0.018**	**0.031**	0.258	**0.063**
SOA.SOP	0.616	0.967	0.461	0.278	0.327	0.155
SOA.TSP	0.512	0.710	0.680	0.915	0.741	0.666
SOP.TSP	0.656	0.746	0.488	0.598	0.697	0.518
SOA.KIE	0.419	0.834	0.455	0.214	0.450	0.608
SOP.KIE	0.496	0.838	0.100	0.539	0.683	**0.043**
TSP.KIE	**0.052**	0.967	**0.008**	**0.021**	0.608	**0.004**
SOA.NaCl	0.765	0.569	0.557	0.808	0.590	0.213
SOP.NaCl	0.406	0.654	0.985	0.980	0.921	0.947
TSP.NaCl	0.250	0.252	0.685	0.600	0.502	0.538
KIE.NaCl	0.351	0.482	0.625	0.108	0.161	0.653
SOA.SOP.TSP	0.206	0.486	0.463	0.281	0.343	0.375
SOA.SOP.KIE	0.138	0.444	0.951	0.507	0.576	0.355
SOA.TSP.KIE	0.182	0.136	0.396	0.814	0.245	**0.081**
SOP.TSP.KIE	0.548	0.943	0.382	0.388	0.632	0.544
SOA.SOP.NaCl	0.159	0.903	0.194	0.383	0.816	**0.099**
SOA.TSP.NaCl	0.471	0.474	0.530	0.798	0.686	0.926
SOP.TSP.NaCl	0.102	0.402	0.087	0.112	0.240	0.332
SOA.KIE.NaCl	0.293	0.450	0.995	0.967	0.879	0.647
SOP.KIE.NaCl	0.996	0.864	0.786	0.711	0.548	0.424
TSP.KIE.NaCl	0.940	0.318	0.172	0.814	0.183	**<.001**
CV %	*8.9*	*10.4*	*6.7*	*13.0*	*14.0*	*6.1*

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

	2000-2002			2002		
	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
SOA0	**27.3**	1148	**24.2**	25.9	1107	**23.77**
SOA1	**29.3**	1173	**25.2**	27.7	1128	**25.18**
SOA2	**29.6**	1167	**25.9**	27.6	1111	**25.45**
sed	*0.74*	*34.9*	*0.49*	*1.01*	*45.1*	*0.434*
SOP0	28.9	1188	24.7	27.0	1128	24.43
SOP1	29.4	1181	25.4	27.8	1138	25.20
SOP2	27.9	1119	25.2	26.3	1079	24.76
sed	*0.74*	*34.9*	*0.49*	*1.01*	*45.1*	*0.434*
TSP0	**28.2**	1162	**24.6**	**26.2**	1104	**24.26**
TSP1	**29.3**	1164	**25.7**	**27.9**	1126	**25.33**
sed	*0.60*	*28.5*	*0.40*	*0.83*	*36.9*	*0.355*
KIE0	28.5	1161	24.9	27.1	1129	24.52
KIE1	29.0	1165	25.3	27.0	1102	25.07
sed	0.60	28.5	0.40	0.826	36.9	0.355
NaCl0	**28.1**	1162	**24.6**	**26.06**	1094	**24.45**
NaCl1	**29.3**	1164	**25.6**	**27.98**	1137	**25.15**
sed	*0.60*	*28.5*	*0.40*	*0.826*	*36.9*	*0.355*

Table 4. Effect of the significant interactions between TSP and kieserite on single bunch weight and FFB yield in 2002 (Trial 126). $Lsd_{0.05}$ = 0.096 for bunch weight and 2.43 for yield.

	Bunch wt. (kg)		FFB yield (t/ha)	
	KIE 0	KIE 1	KIE 0	KIE 1
TSP 0	23.4	25.1	25.2	27.1
TSP 1	25.6	25.0	29.0	26.8

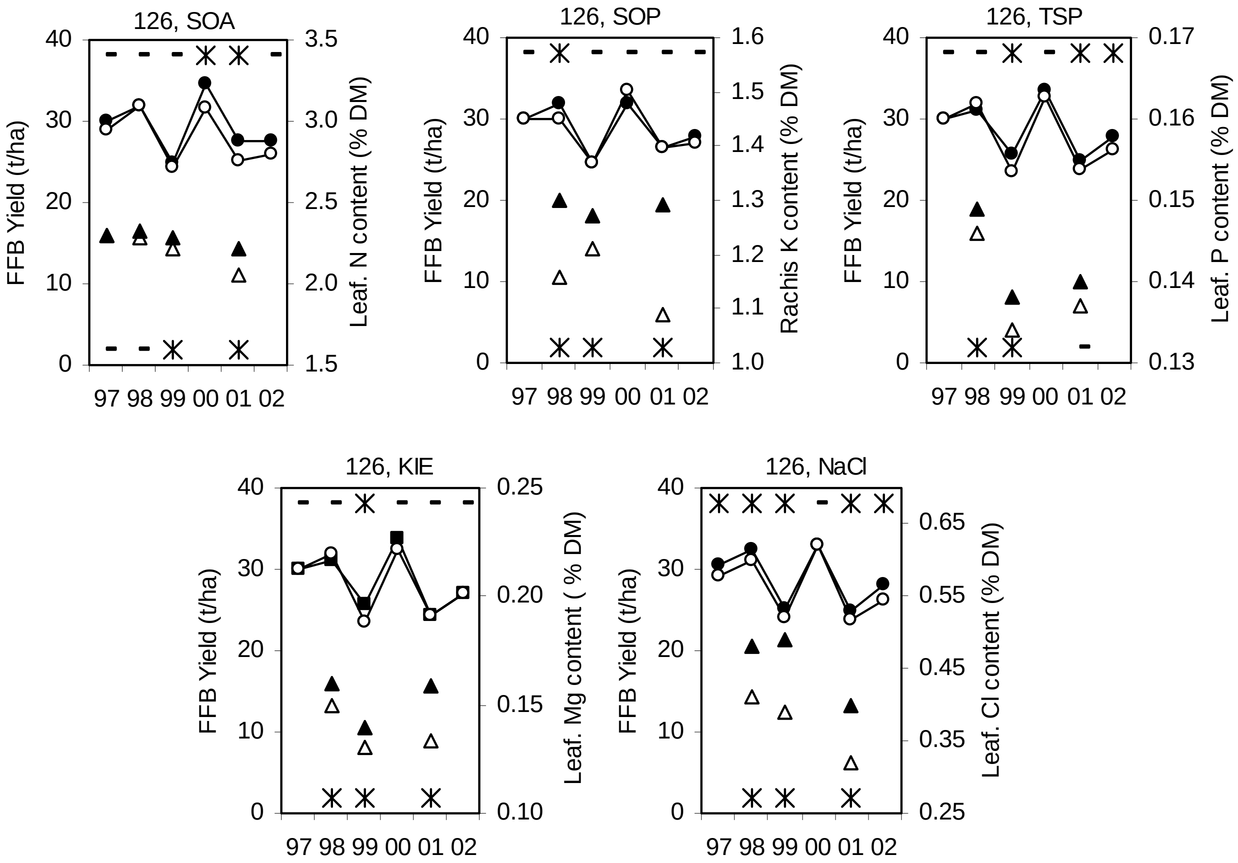


Figure 1. Main effects of SOA, SOP, TSP, KIE and NaCl over the course of Trial 126. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance 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 2002 was the fourth year of yield recording for trial 129. Results of trial a and b were analysed together. Similar to last year's results, there was no significant effect of fertiliser application or placement on yield (Table 4). This is one of the trials that at the 2002 SAC meeting were discussed for closure due to lack of response to fertiliser application. Yield recording stopped at the end of 2002. However, treatments continue, as expected effects on nutrient retention and supply by the soil may take some years to develop.

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	8	1 EFB

Table 4. Effects of treatments on FFB yield and its components (Trial 129). Effects with $p<0.1$ are shown in bold. s.e.d. and l.s.d. are for max-min.

	2000-2002			2002		
Treat. Code	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
0 0	28.5	1848	15.7	23.9	1327	18.4
0 Weed	30.2	1946	16.0	26.7	1512	18.1
0 Frond	29.2	1927	15.6	24.0	1371	18.0
1 0	29.8	2055	14.9	25.0	1464	17.9
1 Weed	29.2	1965	15.3	25.1	1432	18.3
1 Frond	29.9	1957	15.7	26.2	1429	19.2
1 EFB	29.1	1988	15.0	24.9	1416	18.4
GM	29.5	1973	15.4	25.2	1430	18.4
p	*0.469*	*0.213*	*0.209*	*0.370*	*0.599*	*0.361*
s.e.d.	*0.84*	*78.1*	*0.51*	*1.32*	*84.8*	*0.91*
lsd	*1.69*	*156.9*	*1.02*	*2.65*	*170.5*	*1.49*
CV %	*4.9*	*6.9*	*5.7*	*9.1*	*10.3*	*7.0*

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

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 10th palm in every 10th 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 2. K and Mg contents generally appeared to be low and Ca contents high. Of the 5 locations, Haella, the most recently planted site, consistently has the highest leaflet N, P, K, and Cl contents of the five sites. Kumbango has the highest leaflet Ca and rachis K and the lowest leaflet Mg and B. Malalimi has the lowest leaflet N and P and rachis K. Kautu and Haella have the highest Mg contents and Kautu has the lowest Ca and Cl. Over the 5 year period, there has been a consistent downward trend for P at most sites. Other nutrients have not shown consistent trends over the period.

During the year, there was a noticeable peak in leaflet N content in the month following N fertiliser application at most sites (Tables 3-7, Figure 1). That peak was accompanied by a peak in rachis K at Bilomi, Kumbango and Haella and leaflet ash at Kumbango and Haella. At Haella, the August peak in ash, N, B and rachis K also corresponded with a very dry period. The tissue concentrations of nutrients other than N, K and B stayed fairly constant through the year.

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 nutrient concentrations in Frond 17 for the five sites in 1998 – 2002. Nutrient contents are for leaflets except where rachis is specified. For each year, the highest value of each parameter for the 5 locations is highlighted in bold.

Site	Nutrient	1998	1999	2000	2001	2002
Haella	Ash			14.2	14.4	14.9
Kumbango	(% DM)			15.8	**16.1**	**16.9**
Malilimi				15.3	15.0	15.4
Bilomi				**15.9**	15.7	15.5
Kautu				14.3	13.7	13.6
Haella	Nitrogen	**2.62**	**2.42**	**2.61**	**2.56**	**2.58**
Kumbango	(% DM)	2.38	2.38	2.42	2.37	2.38
Malilimi		2.26	2.38	2.33	2.24	2.19
Bilomi		2.37	2.34	2.34	2.36	2.26
Kautu		2.46	2.38	2.42	2.42	2.38
Haella	Phosphorus	**0.160**	**0.158**	**0.158**	**0.153**	**0.153**
Kumbango	(% DM)	0.146	0.143	0.146	0.142	0.141
Malilimi		0.141	0.138	0.137	0.136	0.131
Bilomi		0.148	0.138	0.140	0.139	0.134
Kautu		0.157	0.153	0.150	0.150	0.148
Haella	Potassium	**0.81**	**0.81**	**0.80**	**0.75**	**0.77**
Kumbango	(% DM)	0.69	0.76	0.68	0.69	0.72
Malilimi		0.67	0.73	0.69	0.73	0.69
Bilomi		0.66	0.79	0.69	0.70	0.70
Kautu		0.72	0.74	0.72	0.73	0.73
Haella	Calcium	0.92	0.88	0.85	0.87	0.85
Kumbango	(% DM)	**0.97**	**0.89**	**0.92**	**0.98**	**0.90**
Malilimi		0.91	0.85	0.83	0.88	0.88
Bilomi		0.93	0.82	0.86	**0.98**	0.89
Kautu		0.79	0.70	0.68	0.75	0.73
Haella	Magnesium	**0.26**	**0.23**	**0.21**	0.21	0.20
Kumbango	(% DM)	0.17	0.14	0.14	0.14	0.14
Malilimi		0.16	0.15	0.15	0.16	0.15
Bilomi		0.18	0.17	0.15	0.16	0.14
Kautu		0.24	**0.23**	0.19	**0.23**	**0.22**
Haella	Chlorine	**0.69**	**0.71**	**0.63**	**0.59**	0.51
Kumbango	(% DM)	0.59	0.62	0.59	0.56	**0.52**
Malilimi		0.46	0.48	0.44	0.45	0.49
Bilomi		0.57	0.61	0.50	0.54	0.50
Kautu		0.49	0.50	0.44	0.44	0.43
Haella	Boron		**13.4**	14.0	14.9	15.0
Kumbango	(mg/kg DM)		11.4	11.9	13.2	12.9
Malilimi			12.4	15.0	17.4	15.1
Bilomi			11.9	14.6	**17.8**	14.6
Kautu			12.9	**15.5**	16.9	**15.2**
Haella	Rachis K	1.34	1.43	1.50	1.42	1.41
Kumbango	(% DM)	**1.50**	1.47	**1.57**	**1.59**	**1.62**
Malilimi		1.05	1.15	1.07	1.24	1.22
Bilomi		1.48	**1.49**	1.39	1.51	1.51
Kautu		1.22	1.04	1.09	1.05	1.25

Table 3. Rainfall, fertiliser applications and tissue nutrient concentrations at Kautu in 2002.

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	605		14.6	2.34	0.148	0.71	0.24	0.75	15.5	0.38	0.93
Feb	576		14.3	2.37	0.149	0.71	0.21	0.75	13.7	0.40	1.22
Mar	467		13.4	2.33	0.156	0.77	0.24	0.77	14.4	0.39	1.12
Apr	295		13.1	2.30	0.150	0.83	0.21	0.74	13.8	0.32	1.50
May	137	AMN (1.2)	13.0	2.58	0.156	0.75	0.23	0.74	16.0	0.42	1.12
Jun	248		12.8	2.37	0.148	0.73	0.25	0.74	15.6	0.40	0.99
Jul	262		11.6	2.41	0.156	0.85	0.25	0.76	15.8	0.48	1.46
Aug	7	AMN (1.0)	12.7	2.37	0.148	0.73	0.26	0.72	16.5	0.50	1.26
Sept	82		12.8	2.25	0.134	0.69	0.22	0.67	14.5	0.51	1.58
Oct	212		14.2	2.35	0.141	0.71	0.19	0.74	13.0	0.51	1.26
Nov	321		14.7	2.44	0.145	0.67	0.20	0.69	14.9	0.38	1.26
Dec	278		16.5	2.42	0.142	0.65	0.19	0.74	18.5	0.42	1.26
Total:	**3490**	**Mean:**	**13.6**	**2.38**	**0.148**	**0.73**	**0.22**	**0.73**	**15.2**	**0.43**	**1.25**

Table 4. Rainfall, fertiliser applications and tissue nutrient concentrations at Bilomi in 2002.

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			15.8	2.23	0.132	0.73	0.14	0.86	13.9	0.52	1.26
Feb			15.2	2.20	0.134	0.65	0.14	0.88	13.9	0.50	1.46
Mar			16.6	2.15	0.132	0.63	0.14	0.99	16.1	0.42	1.46
Apr		AMN (2.0)	16.1	2.29	0.133	0.67	0.13	1.00	15.8	0.46	1.12
May			14.0	2.43	0.148	0.75	0.17	0.91	14.2	0.53	1.66
Jun			14.3	2.22	0.132	0.67	0.15	0.95	13.5	0.47	1.62
Jul		AMN (2.0)	14.0	2.23	0.133	0.69	0.14	0.87	13.9	0.52	1.66
Aug			13.8	2.34	0.139	0.81	0.15	0.82	13.2	0.61	1.70
Sept			15.5	2.28	0.136	0.75	0.14	0.93	15.3	0.59	1.58
Oct			16.3	2.32	0.129	0.69	0.11	0.79	13.8	0.48	1.54
Nov			17.1	2.29	0.128	0.67	0.11	0.80	14.4	0.44	1.42
Dec			17.7	2.19	0.126	0.67	0.12	0.89	16.8	0.48	1.58
Total:		**Mean:**	**15.5**	**2.26**	**0.134**	**0.70**	**0.14**	**0.89**	**14.6**	**0.50**	**1.51**

Table 5. Rainfall, fertiliser applications and tissue nutrient concentrations at Malilimi in 2002.

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			15.4	2.20	0.130	0.69	0.15	0.87	14.6	0.43	1.26
Feb			15.8	2.23	0.132	0.67	0.14	0.86	15.2	0.43	1.03
Mar			15.9	2.25	0.135	0.73	0.15	0.91	16.4	0.48	1.03
Apr			15.9	2.28	0.135	0.67	0.15	0.94	15.8	0.49	1.26
May			15.1	2.20	0.134	0.63	0.16	0.96	18.8	0.46	1.30
Jun			14.5	2.27	0.132	0.73	0.17	0.85	14.7	0.47	1.34
Jul			15.6	2.20	0.139	0.63	0.18	0.96	15.1	0.46	1.12
Aug			15.4	2.11	0.127	0.73	0.15	0.84	14.8	0.48	1.26
Sep			14.7	2.19	0.132	0.73	0.15	0.84	12.9	0.52	1.14
Oct			15.0	2.18	0.123	0.69	0.16	0.80	13.5	0.52	1.26
Nov			15.7	2.10	0.124	0.69	0.13	0.85	13.4	0.58	1.38
Dec			16.4	2.09	0.124	0.71	0.12	0.86	15.5	0.52	1.26
Total:		**Mean:**	**15.4**	**2.19**	**0.131**	**0.69**	**0.15**	**0.88**	**15.1**	**0.49**	**1.22**

Table 6. Rainfall, fertiliser applications and tissue nutrient concentrations at Kumbango in 2002.

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	450		16.3	2.32	0.138	0.69	0.14	0.85	12.2	0.52	1.42
Feb	764		17.4	2.35	0.142	0.63	0.14	0.98	13.4	0.46	1.58
Mar	662		15.1	2.39	0.140	0.69	0.16	0.89	12.7	0.52	1.34
Apr	259		16.1	2.55	0.153	0.77	0.14	0.94	13.1	0.55	1.74
May	119		14.8	2.46	0.142	0.75	0.15	0.90	13.7	0.56	1.74
Jun	184	AMN* (2.2)	14.7	2.31	0.144	0.79	0.17	0.84	12.5	0.54	1.58
Jul	202		15.2	2.34	0.142	0.75	0.15	0.92	10.9	0.55	1.74
Aug	4	KIE* (2.0)	19.8	2.58	0.162	0.85	0.15	1.04	13.8	0.43	1.95
Sep	74		18.8	2.32	0.135	0.73	0.12	0.90	13.0	0.58	1.46
Oct	178		17.9	2.27	0.129	0.63	0.10	0.82	13.2	0.52	1.74
Nov	253		18.5	2.30	0.134	0.63	0.12	0.91	12.1	0.47	1.58
Dec	104		18.1	2.35	0.133	0.71	0.13	0.86	13.6	0.51	1.54
Total:	**3280**	**Mean:**	**16.9**	**2.38**	**0.141**	**0.72**	**0.14**	**0.90**	**12.9**	**0.52**	**1.62**

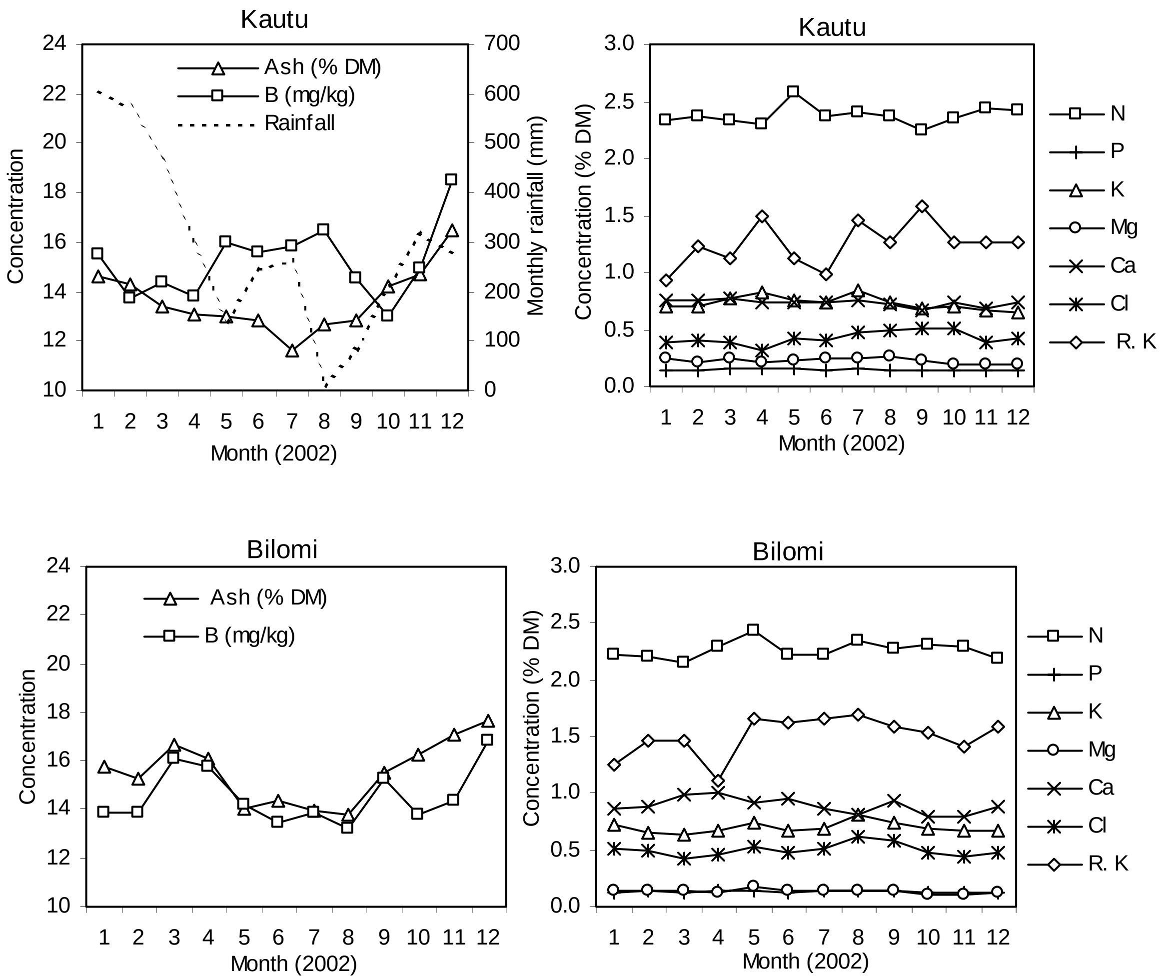
**AMN 30/6/02, KIE 9/8/02*

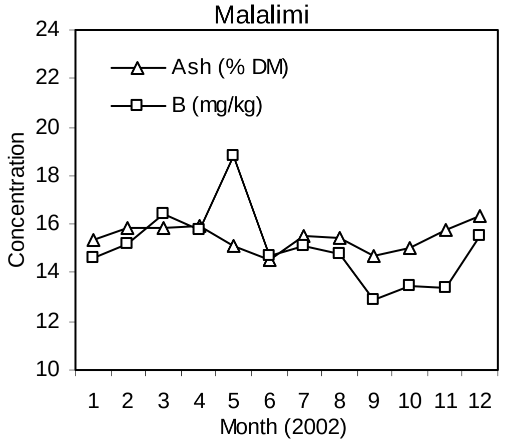
Table 7. Rainfall, fertiliser applications and tissue nutrient concentrations at Haella in 2002. Rainfall figures are from Garu.

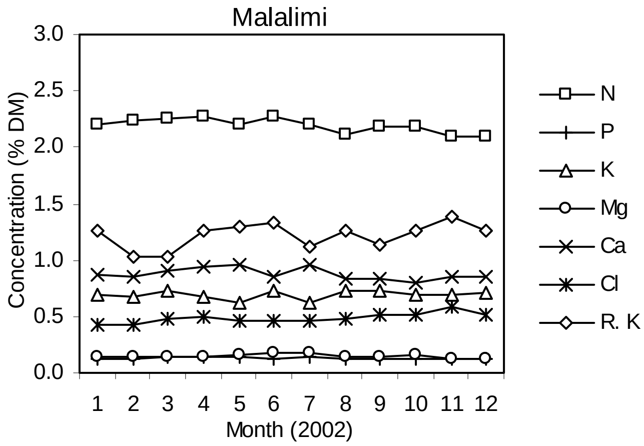
Month	Rainfall (mm)	Fertiliser (kg/palm)	Nutrient content (% DM, except B, in mg/kg)								
			Ash	N	P	K	Mg	Ca	B	Cl	Rachis K
Jan	537		14.8	2.68	0.147	0.71	0.17	0.76	12.3	0.50	1.30
Feb	1272		15.5	2.56	0.152	0.73	0.21	0.87	13.0	0.50	1.46
Mar	744		13.9	2.60	0.154	0.75	0.20	0.84	12.1	0.47	1.42
Apr	360		13.2	2.64	0.157	0.79	0.19	0.84	14.1	0.57	1.42
May	95		13.0	2.69	0.158	0.79	0.22	0.88	15.2	0.63	1.54
Jun	137		12.9	2.56	0.152	0.75	0.22	0.88	15.9	0.56	1.50
Jul	221	AMC* (2.0)	13.1	2.49	0.152	0.79	0.22	0.88	13.9	0.56	1.30
Aug	0		17.2	2.84	0.175	0.83	0.23	1.04	20.8	0.35	1.58
Sep	37		16.0	2.48	0.158	0.83	0.22	0.88	17.2	0.57	1.30
Oct	121		15.9	2.49	0.147	0.75	0.21	0.82	15.2	0.48	1.38
Nov	262		16.2	2.45	0.140	0.79	0.16	0.75	14.3	0.49	1.26
Dec	225		17.0	2.43	0.139	0.75	0.18	0.78	15.8	0.47	1.46
Total:	**4011**	**Mean:**	**14.9**	**2.58**	**0.153**	**0.77**	**0.20**	**0.85**	**15.0**	**0.51**	**1.41**

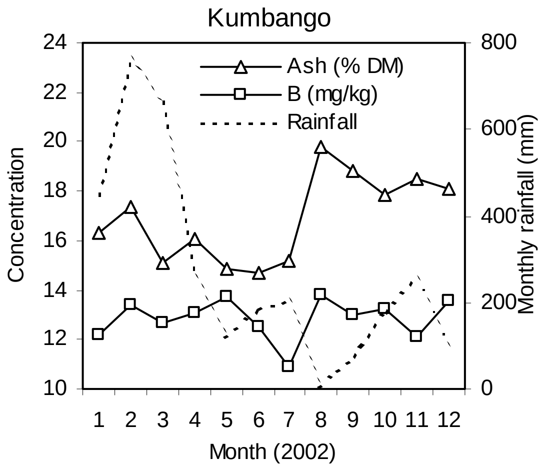
** 15/7/02*

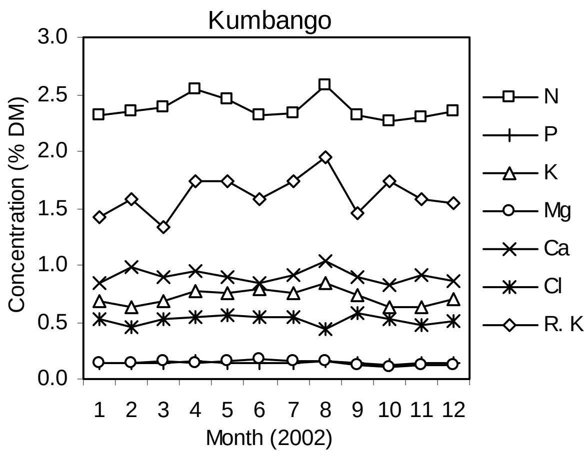
Figure 1. Graphs of monthly rainfall, leaflet nutrient contents and rachis K content during 2002 (Trial 136).

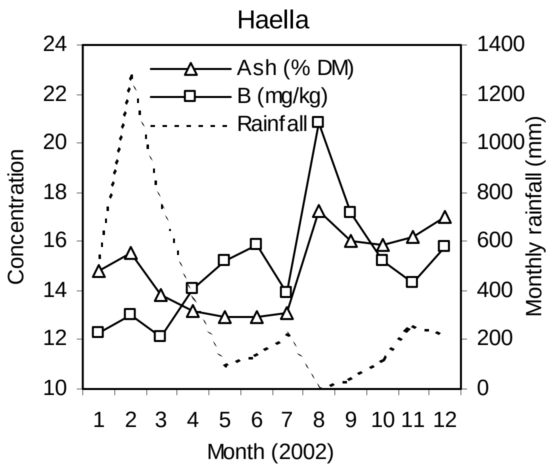


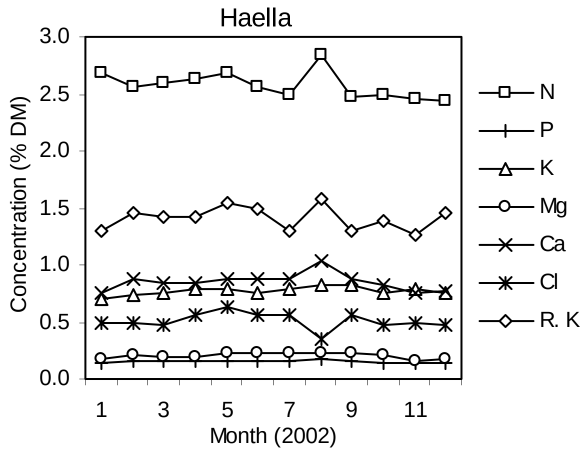

Malalimi
Concentration
Ash (% DM)
B (mg/kg)
Month (2002)


Malalimi
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2002)


Kumbango
Concentration
Monthly rainfall (mm)
Ash (% DM)
B (mg/kg)
Rainfall
Month (2002)


Kumbango
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2002)


Haella
Concentration
Monthly rainfall (mm)
Ash (% DM)
B (mg/kg)
Rainfall
Month (2002)


Haella
Concentration (% DM)
N
P
K
Mg
Ca
Cl
R. K
Month (2002)

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 15-17 palms. N rates (N0 – N8) vary systematically along the trial. Fertiliser is applied in 4 doses per year.

RESULTS

Treatments and yield recording commenced in December 2001 so this is the first year of results for the trial. A response, although not significant, appears to be developing, with an optimum fertiliser rate around 4 kg AMC/ha (Figure 1). In the 2002 SAC meeting it was decided that this trial would not provide any useful additional information to Trial 138b, which is adjacent to this one and which consists of 4-row rather than 2-row plots. This trial was therefore closed at the end of 2002 so that efforts to be redirected to other research work.

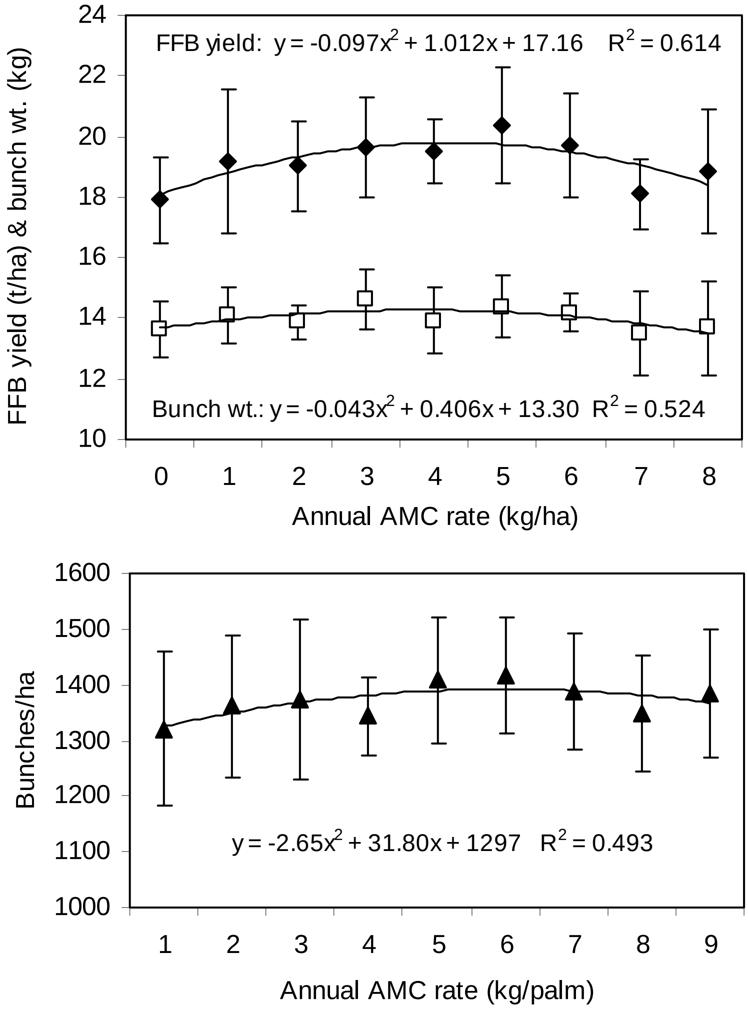


Figure 1. The relationship between yield and its components and the application rate of ammonium chloride in 2002 (Trial 138a). Bars show ± s.d.

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 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 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. Plots were marked in February 2001 and treatments and yield recording commenced in July 2002. Fertiliser is applied in 2 doses per year.

RESULTS

There was no response to N fertiliser in the first half year of the trial (Table 1., Figure 1). Of the 288 32-palm rows that were harvested 13 times in the half- year period (total of 3744 row-harvests), 32 or about 1% were missed. The distribution of these missed harvests was fairly random, so they were ignored when analysing the results.

Table 1: Regression parameters for the effect of fertiliser application rate (kg/palm/year) on FFB yield and its components in 2002 (Trial 138b).

	Intercept	Slope	Slope p	r^2
Yield (t/ha)	3.2	0.030	0.316	0.014
Bunches/ha	262.3	2.89	0.239	0.020
Bunch wt. (kg)	12.3	-0.055	0.429	0.009

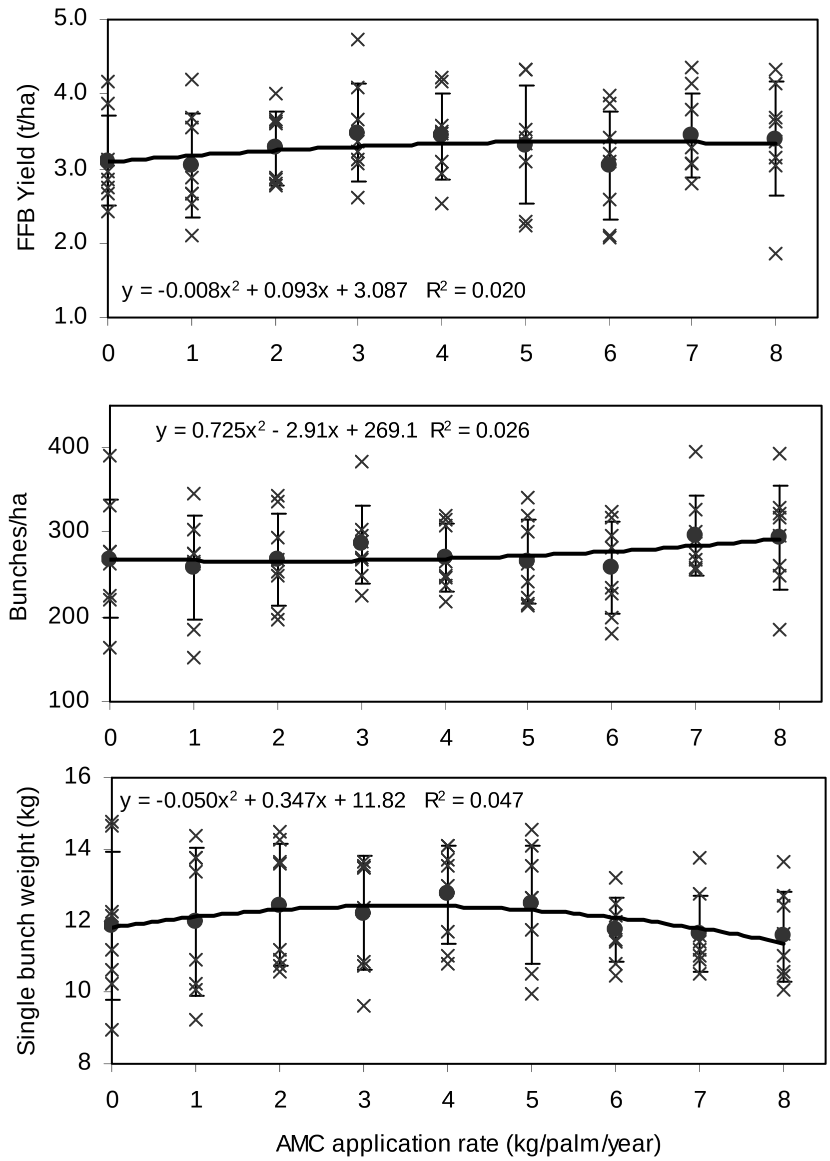


Figure 1. Effect of fertilizer rate (annual) on FFB yield, bunch numbers and single bunch weights for the second half of 2002 (Trial 138B). Crosses show values for each 128-palm plot (4 rows of 32), circles show means for treatment, and bars show sd. Quadratic equations are shown as they fitted slightly better than the linear model described in Table 1.

TRIAL 142. N RESPONSE USING LARGE PLOTS IN OPRS PROGENY TRIALS, KUMBANGO AND BEBERE

BACKGROUND

Over the last decade or more, control plots in WNB fertiliser trials have been yielding as much as fertilised plots. We suspect that this is due to nutrients moving into the control plots from surrounding areas, despite guard rows and trenching between plots. Systematic trials have been introduced to overcome the problem, and they are expected to be successful if the problem is due to movement between adjacent plots. However, if nutrient movement is occurring on a larger scale, from the surrounding plantation, systematic trials may not provide the answer. In order to test whether nutrients are moving at larger scales, OPRA is carrying out the following activities in 2003: 'Omission trials', 'Monitoring of shallow perched water tables' and 'Tissue sampling transects'. The initial idea of the omission trials was to stop applying fertiliser to a large area in the plantations in an attempt to obtain a true control. That will be the purpose and design of Trial 141. In this trial (142), we plan to use the existing CCPT trials in a similar way, but to include a moderate and high level of N application as well. We expect a substantial interaction between progeny and response of vegetative growth parameters to N. The trial is a joint one between OPRA and OPRS.

PURPOSE

To establish a response curve to N fertiliser, using a large number of known progeny, and large plots to overcome suspected problems with nutrient movement in trials with conventional size plots. The purpose of the response curve is to improve N fertiliser recommendations in WNB.

SITE, PALMS

CCPT Trial 256, Reps II, III and IV, Kumbango Division II
    110 plots (progenies) of 16 palms each, planted 1993 at 135 palms/ha
DxP Trial 266, Reps I, II and III, Kumbango Division II
    118 plots (progenies/clones) of 16 palms each, planted in 1998 at 120 palms/ha
DxP Trial 260, Reps I, II and III, Bebere, Division I (reps I and II) and II (rep III)
    155 plots (progenies) in reps I and II and 154 plots in replicate II, planted in 1995 at 135 palms/ha

DESIGN

The trial will test 3 levels of N fertiliser (ammonium nitrate) at the three sites, as shown in Table 1. Other fertilisers will be applied as a blanket across the trial, at recommended rates. Treatments will commence in 2003. Fertiliser application will be split into 2 doses, the first in May, and the second in October. The estates will not apply any fertiliser in these blocks in 2003 or thereafter.

The whole trial will be analysed as a one-way ANOVA of N level with 3 replicates (each progeny trial being a replicate). It will not be possible to test the interaction between N level and progeny as only one progeny occurs in all three progeny trials. Possible movement of N into zero plots from surrounding areas may be analysed spatially if the same progeny is repeated within that plot.

Table 1. Locations of fertiliser treatments (annual rates of ammonium nitrate) in Trial 142. Each breeding trial replicate becomes a plot of the fertiliser trial.

CCPT Trial No.	Level 0 (0 kg/palm)	Level 1 (3 kg/palm)	Level 2 (6 kg/palm)
256 (Kumbango)	Rep III	Rep II	Rep IV
266 (Kumbango)	Rep II	Rep III	Rep I
260 (Bebere)	Rep I	Rep II	Rep III

TRIAL 144 – MAGNESIUM AND POTASSIUM RESPONSE, WAISISI

Background

Symptoms of Mg deficiency are common in West New Britain. However, given the low CEC of the soils, their high Ca contents and their low Mg and K contents, it is surprising that the palms would be Mg-deficient but not K-deficient. Cation nutrition is affected by interactions between the cations, so this trial is aimed at determining the effect of Mg and K, alone and in combination, on symptoms and yield. The experimental site chosen, Waisisi 'Mini-Estate', has a young planting and is likely to show severe Mg and possibly K deficiency as palms grow. Symptoms tend to be expressed most strongly around the age of 4-5 years. This trial is part of the ACIAR-funded Mg project.

Purpose

To determine if there is a response to Mg or K or both, on a site that does not have a history of fertiliser application and is in an area where Mg deficiency symptoms are common.

Site and duration

The site is a young planting (2001) at Waisisi Mini-estate. Trial will continue for about 10 years.

Design

A factorial of 2 Mg treatments (nil and plus Mg) by 2 K treatments (nil and plus K) with 4 replicates. Where applied, both nutrients to be added as frequent surface application, slow release form in holes, and foliar spray. Surface and foliar applications will consist of kieserite ($MgSO_4.H_2O$) or K_2SO_4. Slow release applications will consist of large applications of QMAG product M30 (partially calcined magnesite, containing $MgCO_3$ and MgO) or K_2SO_4 in inverted coconut shells to prevent leaching loss. Ammonium chloride will be added as a basal fertiliser. See Table 1 for treatment rates.

To minimise chances of nutrient movement between plots, each plot of 16 palms will be surrounded by 2 guard rows, the inner one treated as per the plot, and the outer one untreated. No Mg or K fertiliser will be applied to the blocks surrounding the trial. Measurements will focus on uptake of Mg and K by the canopy, and expression of symptoms. As palms start to produce, yield will be measured.

The trial has been marked out and will commence in 2003.

Table 1. Fertiliser types and rates

Nutrient	Application method	Nutrient appl. rate (kg/ha)	Fertiliser	Nutrient cont. of fert. (%)	Fert appl. rate (kg/palm/yr)	Number of appl.
Mg	Surface	50/yr	kieserite	17	2.45	6/yr
K	Surface	50/yr	K_2SO_4	42	0.99	6/yr
Mg	Slow-release	150	$MgCO_3$/MgO*	46	2.72	1
K	Slow-release	150	$K_2SO_4^+$	42	2.98	1
Mg	Foliar	6/yr	kieserite	1% solution	0.05	6/yr
K	Foliar	6/yr	K_2SO_4	1% solution	0.05	6/yr

* QMAG M30
$^+$ K_2SO_4 in inverted half coconuts

TRIAL 145 – MAGNESIUM SOURCE TRIAL

Background

Magnesium deficiency of oil palm is common on the young volcanic ash soils of West New Britain (WNB). Kieserite is currently used to correct the deficiency. Kieserite is highly soluble and has the potential to be rapidly lost by leaching due to high rainfall and saturation of the soil cation exchange capacity with Ca. By using magnesium fertilisers with lower solubility than kieserite, it is envisaged that roots will have more chance of accessing the magnesium before it is lost by leaching. This trial is part of the ACIAR-funded Mg project.

Purpose

To compare the effects on oil palm growth and yield of a range of magnesium fertilisers.

Site and duration

A site will be chosen in mature palms in WNB in an area showing deficiency symptoms, probably Walindi Plantation. The trial is expected to continue for 10 years, with ACIAR support for the first 5.

Design

Three rates (0, standard, 2 times standard) by four sources (kieserite, and the QMAG products Magnesite FO1, EMAG M30 and EMAG 45) factorial with 4 reps. The current industry standard for kieserite in WNB is around 2 kg kieserite per palm per year. The other fertilisers will be applied on an equivalent magnesium basis (Table 1). All fertilisers will be surface-applied. Ammonium nitrate will be added as a basal fertiliser and other nutrients will be added as a basal application as required.

The 12 treatments will be set out as a randomised complete block design of 4 reps. Each plot will consist of 36 (6*6) palms with the inner 16 (4*4) being the recorded palms. Trenches will be dug around each plot to prevent root poaching.

Fortnightly measurements of yield will be carried out. Nutrient analysis of frond 17 and standard vegetative measurements will be carried out at time zero and regularly thereafter. The fate of magnesium in the soil and palms may be examined after several years of treatment.

The trial will commence in 2003.

Table 1. Fertiliser types and rates.

Product	Main component	Mg content (%)	Mg appl. rate (kg/plm.yr)	Product appl. rate (kg/palm.yr)	Number of appl. /yr	Amount per applic. (g/palm)
Kieserite	$MgSO_4$	17	0.34	2.00	2	1000
Kieserite	$MgSO_4$	17	0.68	4.00	2	2000
Magnesite FO-1	$MgCO_3$	26	0.34	1.31	2	654
Magnesite FO-1	$MgCO_3$	26	0.68	2.62	2	1308
EMAG M30	$MgCO_3$/ MgO	46	0.34	0.74	2	370
EMAG M30	$MgCO_3$/ MgO	46	0.68	1.48	2	739
EMAG45	MgO	56	0.34	0.61	2	304
EMAG45	MgO	56	0.68	1.21	2	607

TRIAL 146 – MAGNESIUM PLACEMENT AND SOURCES

Background

Mg deficiency symptoms persist in West New Britain, despite applications of kieserite. It is suspected that the cation exchange capacity of the soil is swamped with Ca, preventing Mg from being retained. It was proposed that adding Mg fertiliser in concentrated zones, or with barriers to leaching, or as less soluble sources might solve the problem of competition with Ca and loss by leaching. This trial is part of the ACIAR-funded Mg project.

Purpose

To determine if the placement and type of Mg fertilisers influences growth and yield of palms in an area that appears to be Mg-deficient.

Site and design

Site will be Kumbango or Bebere plantation, to be run for 10 years, with ACIAR support for the first 5.

Mg sources will be kieserite, MgO (QMAG EMAG 45) and $MgCO_3$ (QMAG Magnesite FO-1).

Application methods will be twice per year on the surface, or buried in the soil in concentrated zones in a quantity sufficient for 8 years: in trenches without any cover, in trenches covered with plastic, or in inverted coconut shells.

There will be two control treatments, one with zero Mg, and the other a positive control with multiple sources of Mg: regular surface applications of kieserite, MgO and $MgCO_3$ (QMAG M30,) in trench (sufficient for 8 years), and trunk injection with $MgSO_4$ solution.

Design is a factorial of source (3) and application method (4) plus controls (2) = 14 treatments times 4 reps = 56 plots. Layout will be randomised complete block. Nitrogen will be applied as a basal fertiliser applied at standard rate.

Vegetative growth, yield and nutrient uptake will be measured. The trial will commence in 2003.

Table 1. Fertiliser types and rates

Fertiliser	Placement	Mg appl. Rate (kg/palm)	Mg cont. of fert. (%)	Fert. Appl. rate (kg/palm)	Number of appl.	Amount per applic. (g/palm)
Kieserite	Surface	0.34	17	2	2/yr	1,000
Kieserite	Trench	2.72	17	16	1	16,000
Kieserite	Trench/P*	2.72	17	16	1	16,000
Kieserite	Coconuts	2.72	17	16	1	16,000
$MgCO_3$	Surface	0.34	26	1.3	2/yr	654
$MgCO_3$	Trench	2.72	26	10.5	1	10,462
$MgCO_3$	Trench/P*	2.72	26	10.5	1	10,462
$MgCO_3$	Coconuts	2.72	26	10.5	1	10,462
MgO	Surface	0.34	56	0.6	2/yr	304
MgO	Trench	2.72	56	4.9	1	4,857
MgO	Trench/P*	2.72	56	4.9	1	4,857
MgO	Coconuts	2.72	56	4.9	1	4,857
Positive control (all fertilisers below applied together in same plot)						
Kieserite	Surface	0.34	17	2.0	2/yr	1000
M30**	Trench	3.40	46	7.4	1	7394
Kieserite	Injection	0.24	(1Molar)	(10L/palm)	Continuous	

* Trench with plastic cover. ** A mixture of $MgCO_3$ and MgO

TRIAL 148. MG RESPONSE USING LARGE PLOTS IN OPRS PROGENY TRIALS, KUMBANGO

BACKGROUND

The characteristic symptoms of magnesium deficiency are marked and widespread in WNB. However, fertiliser trials over the last few decades have shown little or no response to kieserite (magnesium sulphate). Recent research has shown that the soils have very low cation exchange capacity and are saturated with calcium, which competes with magnesium for cation exchange sites. Therefore, we suspect that in this high rainfall environment, magnesium from soluble fertilisers like kieserite is being leached out of the soil profile before the roots can take it up. The OPRA/CSIRO/ACIAR Mg project is addressing this issue. Another possible explanation for the lack of response to Mg in WNB is movement of nutrients into the control plots from surrounding areas. That possibility has led to a change in direction for N trials in WNB. One of the approaches being used for N is to have very large plots in progeny trials, and this trial does the same with Mg. We suspect a strong interaction between progeny and Mg fertiliser effects, especially on oil extraction rate. The trial is a joint one between OPRA and OPRS.

PURPOSE

The trial has two purposes:

1. To establish a yield response curve to magnesium fertiliser, using a large number of known progeny, and large plots to overcome suspected problems with nutrient movement in trials with conventional size plots. The purpose of the response curve is to improve magnesium fertiliser recommendations in WNB.

2. To measure the effect of magnesium nutrition on yield, tissue magnesium contents and oil extraction rates of several contrasting progeny.

SITE, PALMS

Breeding Trials 282, 283 and 284, Kumbango Division II.
Planted 2001 at 128 palms/ha
Each breeding trial has 84 plots/progeny of 12 palms each

DESIGN

The trial will test 3 levels of Mg fertiliser (Table 1). Kieserite will be applied under OPRA/OPRS supervision in 2 doses (June and October). Treatments will commence in 2003. Nitrogen fertiliser will be applied by the plantation at recommended rates (blanket application across the trial). Borate will be applied (under OPRA/OPRS supervision) as a blanket across the trial, at 80 g/palm. This trial is adjacent to a similar trial on boron (Trial 149). Treatments will vary in a systematic rather than random way across the trial, so that plots with high rates are not adjacent to control plots.

Table 1. Fertiliser rates (kg/palm per year) in trial 148. The replicates shown are Breeding trial replicates. Each breeding trial is a replicate of the fertiliser trial.

Breeding Trial 282			Breeding Trial 283			Breeding Trial 284		
Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
0	2	4	4	2	0	0	2	4

The whole trial will be analysed as a one-way ANOVA of kieserite level with 3 replicates (each progeny trial being a replicate). Two-way ANOVA of kieserite (3 levels) x progeny (3 progeny) with 3 replicates will be carried out for those progeny that occur in all three trials (635.607 x 742.207, 714.814 x 742.316, and 5035.216 x 742.316). Progeny 714 has a low OER and 635 has high OER and is being used in much Dami seed.

TRIAL 149. B RESPONSE USING LARGE PLOTS IN OPRS PROGENY TRIALS, KUMBANGO

BACKGROUND

Boron deficiency is suspected of being involved in problems of fruit set and maturation in WNB and elsewhere. We suspect a strong interaction between progeny and B fertiliser effects, and therefore plan to carry out a trial testing the interaction between the two. The trial is a joint one between OPRA and OPRS. It complements factorial trials with boron and other nutrients that OPRA has recently started in Haella and Poliamba.

PURPOSE

To determine the effect of progeny, B nutrition and their interaction on yield and its components.

SITE, PALMS

Breeding Trials 285, 286, 287 and 288, Kumbango Division II. Each trial has 75 plots/progeny of 9 palms each
Planted 2001 at 128 palms/ha

DESIGN

The trial will test 3 levels of B fertiliser (Table 1). Ca borate will be applied by OPRA in June. Treatments will commence in 2003. Nitrogen fertiliser will be applied by the plantation at recommended rates (blanket application across the trial). Kieserite will be applied by OPRA as a blanket across the trial, at an annual rate of 1 kg/palm, applied as one dose in June and a second in October. Blue paint will be applied to palms around the perimeter of the whole area (OPRS trials 285-288), to remind plantation workers not to enter the blocks with kieserite or borate. Every 5th palm around the perimeter of the whole area will be labelled 'No kieserite or borate'. Fertiliser applications by OPRA will be carried out with joint supervision by OPRS supervisor.

Table 1. Locations of fertiliser treatments (annual rates of Ca borate in g/palm) in Trial 149. The 'replicates' referred to below are replicates of the breeding trials and are plots of the fertiliser trial

OPRS Trial:	285			286			287			288		
Replicate:	1	2	3	1	2	3	1	2	3	1	2	3
Treatment:	0	80	160	160	80	0	0	80	160	160	80	0

The whole trial will be analysed as a one-way ANOVA of B level with 4 replicates (each progeny trial being a replicate). Two-way ANOVA of B (3 levels) x progeny (3 progeny) with 4 replicates will be carried out for those progeny that occur in all three trials (635.607 x 742.207, 714.814 x 742.316, and 5035.216 x 742.316). Progeny 714 has a low OER and 635 has high OER and is being used in much Dami seed.

TRIAL 403 SYSTEMATIC N TRIAL, KAURAUSU

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

Kaurausu 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 the beginning of 2003, fertiliser is being 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 in fact individual palms), rather than plots.

RESULTS

There was no response of yield or its components or tissue nutrient contents to N fertiliser in this the second year of the trial (Tables 1 and 2, Figures 1 and 2). A linear response model only was fitted, but it is evident from looking at the graphs that there was no curvilinear response either. Of the 288 15-palm rows that were harvested 27 times in the year (total of 7776 row-harvests), 253 or 3.3% were missed. The distribution of these missed harvests was fairly random, so they were ignored when analysing the results.

Table 1. Regression parameters for the effect of fertiliser application rate (kg/palm.year) on FFB yield and its components in 2002 (Trial 403).

	Intercept	Slope	Slope p	r^2
Yield (t/ha)	23.48	0.082	0.348	0.013
Bunches/ha	964.2	2.4	0.542	0.005
Bunch wt. (kg)	24.41	0.02	0.719	0.012

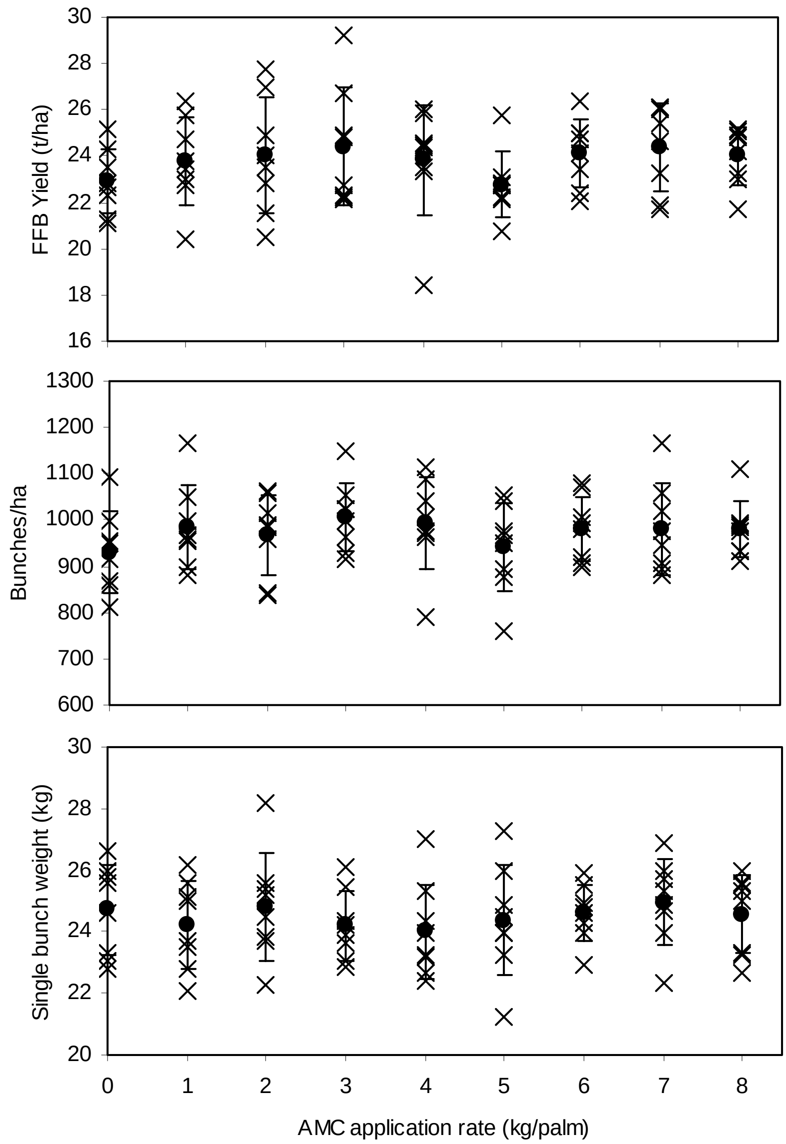


Figure 1. Effect of fertilizer rate (annual) on FFB yield, bunch numbers and single bunch weights in 2002 (Trial 403). Crosses show values for each 60-palm plot (4 rows of 15), circles show means for treatment, and bars show s.d.

Table 2. Regression parameters for the effect of fertiliser application rate (kg/palm.year) on tissue nutrient contents (% DM, except for B, in mg/kg DM) in 2002 (Trial 403).

	GM	Intercept	Slope	Slope p	r^2
Leaflet					
Ash	15.3	15.15	0.026	0.466	0.008
N	2.32	2.33	-0.002	0.406	0.010
P	0.138	0.1387	-0.00019	0.417	0.010
K	0.66	0.662	-0.0013	0.449	0.008
Mg	0.18	0.183	-0.0014	0.180	0.026
Ca	0.83	0.827	-0.0003	0.908	0.000
B	15.1	14.99	0.0154	0.781	0.001
Cl	0.50	0.507	-0.0013	0.517	0.006
Rachis					
Ash	4.7	4.74	-0.008	0.686	0.002
K	1.48	1.49	-0.001	0.934	0.000

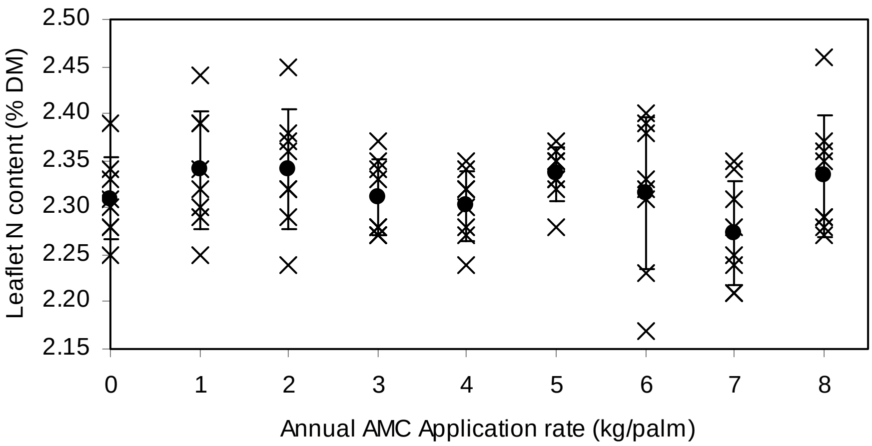


Figure 2. Effect of fertilizer rate on leaflet N content in 2002 (Trial 403). Crosses show values for each 60-palm plot (4 rows of 15), circles show means for treatment, and bars show s.d.

FERTILISER RESPONSE TRIALS IN WEST NEW BRITAIN (Hargy)

(P. Nelson, J. Kraip)

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.

RESULTS

Yield is starting to pick up again in this trial, following the crash in 2001 due to Sexava damage. The increase is mainly due to bunch numbers. Previous to the Sexava damage AMC had a large positive effect on yield in this trial (Figure 1). In 2001 yield was low irrespective of fertiliser treatment. In 2002, fertilisers are again beginning to have an impact on yield. AMC decreased bunch numbers but increased bunch weight (Tables 2 and 3). The net effect of AMC on yield depended on TSP and KIE application. Overall, yield was highest at the highest rate of AMC with no added TSP or kieserite (Table 2 and 4), similar to 2001. TSP generally decreased yield at 2 kg/palm and had no effect at 4 kg/palm (Tables 4 and 5). Addition of MOP also had a positive effect on yield (especially with no TSP), mainly through its effect on bunch number (Tables 2 and 5). Variation in bunch numbers across the trial increased markedly in 2001, probably due to patchiness of the Sexava damage, and it remained high in 2002 (see CV in Table 2). At this stage the recommendation for this area would still be to apply AMC and no other fertilisers, but another year of results should make the effects of fertilisers on recovery from Sexava damage clear.

Table 2. Effects (p values) of treatments on FFB yield and its components in 2000-2002 and 2002 for the block*units stratum (Trial 204). p values <0.1 are indicated in bold. CV% is for the interaction of block x plot.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
AMC	**<.001**	0.511	**<.001**	0.891	**0.078**	**<.001**
MOP	0.247	0.240	0.851	0.117	**0.082**	0.772
TSP	0.134	0.147	0.658	0.115	0.143	0.748
KIE	0.544	0.546	0.695	0.557	0.423	0.425
AMC.MOP	0.686	0.702	0.960	0.522	0.523	0.939
AMC.TSP	0.171	**0.077**	0.563	**0.087**	**0.054**	0.422
MOP.TSP	0.895	0.941	0.682	0.743	0.637	0.654
AMC.KIE	0.379	0.553	0.711	0.260	0.446	0.298
MOP.KIE	0.951	0.861	0.899	0.181	0.430	0.318
TSP.KIE	0.669	0.274	0.469	0.354	0.186	0.965
AMC.MOP.TSP	0.853	0.922	0.548	0.677	0.775	0.463
AMC.MOP.KIE	0.629	0.309	0.475	0.238	0.197	0.629
AMC.TSP.KIE	**0.028**	**0.006**	0.520	**0.068**	**0.029**	0.380
MOP.TSP.KIE	**0.063**	**0.098**	0.505	**0.086**	0.175	0.312
AMC.MOP.TSP.KIE	0.480	0.415	0.586	0.352	0.467	0.183
CV %	17.3	15.9	6.3	21.9	21.6	7.6

Table 3. Main effects of treatments on FFB yield (t/ha) and its components (Trial 204). Effects with p values <0.1 are shown in bold.

	2000-2002			2002		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
AMC0	**13.8**	661	**21.0**	15.6	**771**	**20.6**
AMC1	**16.3**	680	**24.2**	15.2	**692**	**22.1**
AMC2	**16.9**	698	**24.2**	15.1	**672**	**22.5**
s.e.d.	*0.78*	*31.1*	*0.42*	*0.97*	*44.4*	*0.47*
MOP0	15.3	665	23.2	14.7	**679**	21.8
MOP1	16.0	695	23.1	15.9	**744**	21.7
s.e.d.	*0.64*	*25.4*	*0.34*	*0.79*	*36.2*	*0.39*
TSP0	16.4	709	23.4	16.4	758	21.9
TSP1	14.8	647	23.0	14.3	668	21.7
TSP2	15.7	684	23.1	15.2	710	21.5
s.e.d.	*0.78*	*31.1*	*0.42*	*0.97*	*44.4*	*0.47*
KIE0	15.9	687	23.2	15.5	726	21.6
KIE1	15.5	672	23.1	15.1	697	21.9
s.e.d.	*0.64*	*25.4*	*0.34*	*0.79*	*36.2*	*0.39*
GM	15.7	680	23.1	15.3	712	21.7

Table 4. Effect of interaction between AMC, TSP and KIE on FFB yield ($lsd_{0.05}$ = 4.80) and bunch number ($lsd_{0.05}$ = 221) in 2002 (Trial 204).

Yield (t/ha)						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
AMC0	14.1	17.3	16.8	14.0	15.2	15.9
AMC1	14.8	15.5	18.1	12.8	16.4	14.0
AMC2	20.2	16.4	11.2	13.1	13.1	16.6
Bunches/ha						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
AMC0	679	889	879	680	728	769
AMC1	659	685	815	572	742	681
AMC2	925	708	496	564	614	726

Table 5. Effect of interaction between MOP, TSP and KIE on FFB yield ($lsd_{0.05}$ = 3.92) and bunch number ($lsd_{0.05}$ = 180) in 2002 (Trial 204).

Yield (t/ha)						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
MOP0	15.4	15.7	14.4	12.5	16.5	13.5
MOP1	17.3	17.1	16.3	14.1	13.3	17.5
Bunches/ha						
	TSP0		TSP1		TSP2	
	KIE0	KIE1	KIE0	KIE1	KIE0	KIE1
MOP0	697	722	678	575	750	654
MOP1	812	799	782	636	640	797

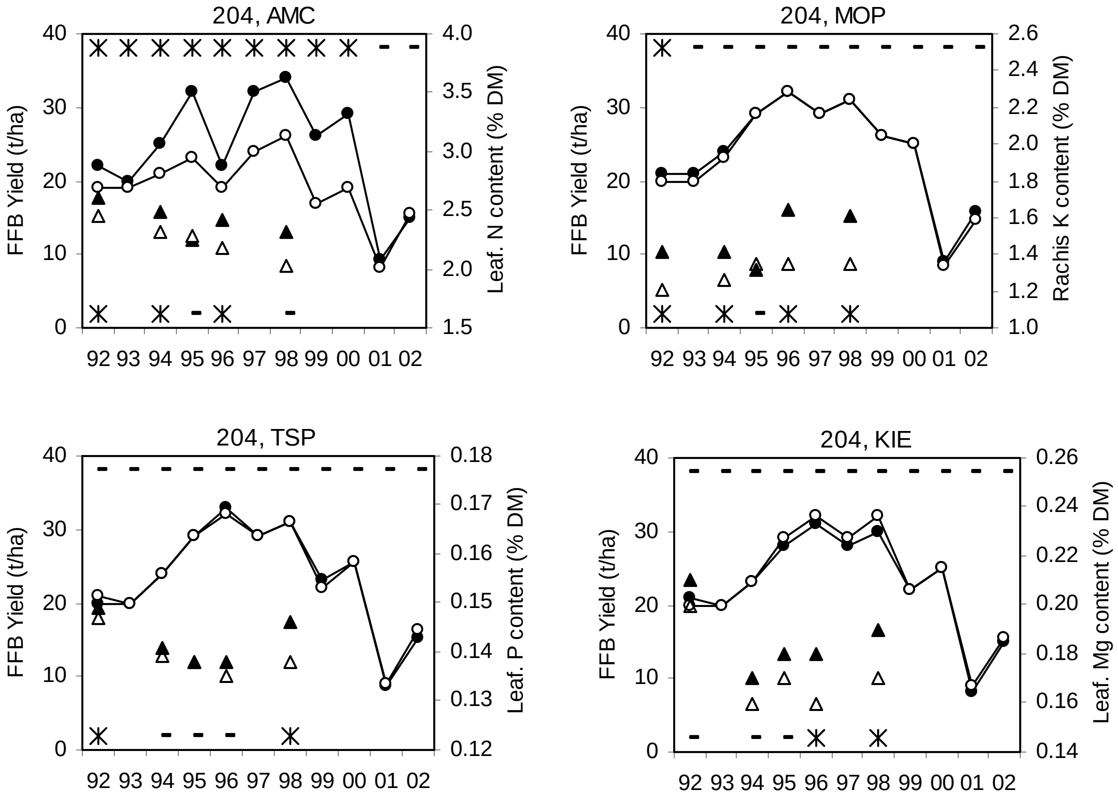


Figure 1. Main effects of SOA, MOP, TSP and kieserite over the course of Trial 204. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance 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

Progenies again had the largest effect on yield in this trial, and fertilisers and EFB only had small effects. The progenies that yielded best in 2002 were different to those that yielded best in 2001, but two of the poorest performers were the same in the two years. Kieserite was the only amendment that significantly increased yield in 2002 (Tables 3 and 4). Kieserite was particularly effective when no EFB was applied, and EFB was only effective where no kieserite was applied (Table 5).

The fertilisers and EFB significantly increased tissue P, K and Mg contents (Tables 6 and 7), but the values were in the adequate ranges even with no fertiliser addition.

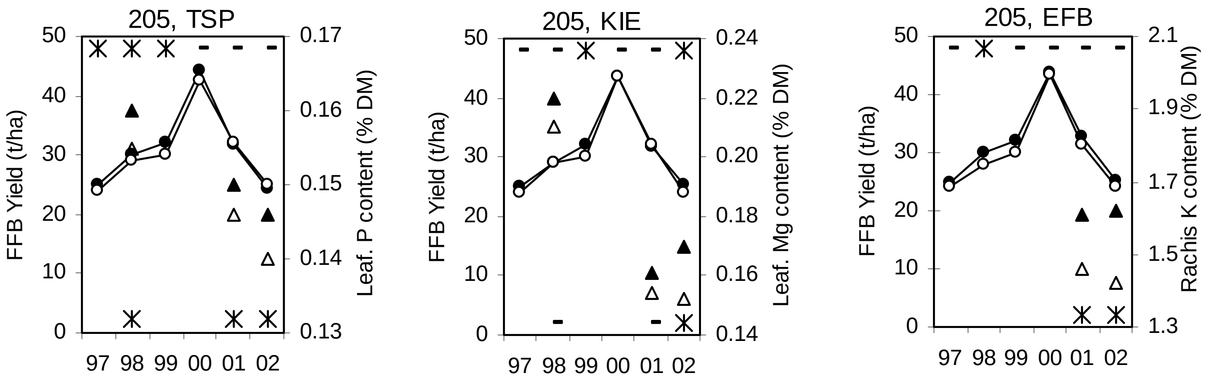


Figure 1. Main effects of TSP, kieserite and EFB over the course of Trial 205. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance 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 2000-2002 and 2002 (Trial 205). p values <0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
Rep.Plot stratum						
TSP	0.355	0.786	**0.068**	0.346	**0.064**	**0.062**
KIE	0.608	0.680	0.685	**0.040**	0.233	0.460
EFB	0.147	0.991	**0.040**	0.186	0.520	0.355
TSP.KIE	0.497	0.436	**0.037**	0.189	0.886	0.199
TSP.EFB	0.177	0.347	0.323	0.168	0.342	0.157
KIE.EFB	0.183	**0.048**	0.574	**0.002**	**0.004**	0.949
TSP.KIE.EFB	0.654	0.436	**0.032**	0.611	0.911	**0.090**
CV%	*5.5*	*5.3*	*3.4*	*10.4*	*11.8*	*6.0*
Rep.Plot.Progeny stratum						
Prog	**<.001**	**0.013**	**<.001**	**0.016**	0.184	**<.001**
TSP.Prog	0.198	0.388	0.260	0.199	0.228	0.353
KIE.Prog	0.705	0.683	0.220	0.867	0.915	**0.066**
EFB.Prog	0.995	0.769	0.401	0.511	0.617	0.568
TSP.KIE.Prog	0.344	0.187	0.173	0.355	0.298	0.658
TSP.EFB.Prog	0.910	0.300	0.448	0.547	**0.045**	**0.040**
KIE.EFB.Prog	0.953	0.877	0.372	0.868	0.705	**0.032**
TSP.KIE.EFB.Prog	0.330	0.375	0.140	0.580	0.749	0.210
CV %	*20.1*	*20.1*	*12.6*	*40.7*	*41.5*	*18.9*

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.

	2000-2002			2002		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
TSP0	33.3	2097	**16.0**	25.0	**1429**	**17.9**
TSP1	33.8	2088	**16.3**	24.3	**1339**	**18.5**
KIE0	33.4	2086	16.1	**23.9**	1356	18.1
KIE1	33.7	2099	16.2	**25. 5**	1413	18.3
EFB0	33.1	2093	**16.0**	24.2	1369	18.1
EFB1	33.9	2092	**16.3**	25.2	1399	18.4
Fert. s.e.d.	*0.54*	*31.9*	*0.16*	*0.74*	*47.1*	*0.32*
A	**35.2**	**2095**	**16.8**	**28.4**	1500	**19.3**
B	**34.0**	**1993**	**17.3**	**25.5**	1299	**19.9**
C	**33. 9**	**2134**	**16.1**	**24.8**	1406	**18.0**
D	**32.1**	**2016**	**16.0**	**22.6**	1263	**18.0**
E	**30.6**	**2050**	**15.1**	**22.2**	1392	**16.8**
F	**30.9**	**1984**	**15.7**	**23.8**	1311	**18.5**
G	**31.8**	**2045**	**15.6**	**22.1**	1351	**17.0**
H	**35.7**	**2210**	**16.3**	**23.9**	1372	**17.7**
I	**35.7**	**2201**	**16.4**	**26.6**	1451	**19.0**
J	**35.0**	**2035**	**17.4**	**26.3**	1358	**20.1**
K	**32.2**	**1994**	**16.2**	**21.6**	1216	**17.8**
L	**33.2**	**2085**	**16.1**	**24.3**	1382	**18.1**
M	**34.3**	**2114**	**16.3**	**27.1**	1434	**19.2**
N	**32.8**	**2090**	**15.8**	**24.7**	1432	**17.6**
O	**33.8**	**2154**	**15.8**	**23.5**	1358	**17.4**
P	**35.1**	**2281**	**15.5**	**27.2**	1619	**17.0**
Prog. s.e.d.	*1.38*	*86.1*	*0.42*	*2.05*	*117.3*	*0.70*
GM	*33.5*	2093	*16.15*	*24.7*	*1384*	*18.2*

Table 5. Effect of interaction between KIE and EFB on FFB yield (t/ha) in 2002 (Trial 205). p= 0.002 and $lsd_{0.05}$ = 2.12.

	EFB0	EFB1
KIE0	22.1	25.6
KIE1	26.2	24.7

Table 6. Effects (p values) of treatments on frond 17 nutrient concentrations in 2002 (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	0.123	0.972	**<.001**	**<.001**	0.178	**<.001**	0.111	0.203	0.407	**0.009**
KIE	0.880	0.481	0.277	**0.093**	**<.001**	**0.006**	0.736	0.203	0.355	0.836
EFB	0.318	0.621	0.882	0.180	0.560	0.333	0.436	0.709	**0.028**	**0.002**
TSP.KIE	**0.014**	0.379	0.745	0.319	0.334	**0.019**	0.119	0.343	0.972	0.416
TSP.EFB	0.679	**0.026**	**0.018**	0.117	0.125	0.466	0.831	0.433	0.262	0.114
KIE.EFB	0.618	**0.053**	0.393	0.518	0.560	0.309	0.436	**0.040**	0.908	0.590
TSP.KIE.EFB	0.668	0.418	0.616	0.953	0.438	0.922	0.570	0.152	0.589	0.401
CV%	*4.4*	*3.4*	*3.4*	*6.7*	*9.2*	*5.7*	*11.9*	*6.2*	*11.6*	*13.6*

Table 7. Main effects of treatments on frond 17 nutrient concentrations in 2002, 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	13.8	2.39	**0.140**	**0.76**	0.158	**1.00**	13.2	0.56	4.7	**1.61**
TSP1	14.1	2.39	**0.146**	**0.69**	0.164	**1.07**	13.9	0.57	4.5	**1.44**
KIE0	13.9	2.40	0.143	**0.71**	**0.152**	**1.06**	13.6	0.56	4.7	1.53
KIE1	13.9	2.38	0.142	**0.74**	**0.170**	**1.01**	13.5	0.57	4.5	1.52
EFB0	13.8	2.38	0.142	0.71	0.162	1.04	13.4	0.56	**4.4**	**1.42**
EFB1	14.0	2.39	0.143	0.73	0.160	1.02	13.7	0.56	**4.8**	**1.62**
sed	*0.18*	*0.023*	*0.0014*	*0.014*	*0.004*	*0.017*	*0.47*	*0.010*	*0.015*	*0.060*

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

Yields in 2002 were similar to 2001. Over the 2000-2002 period, SOA, TSP and MOP all significantly ($p<0.07$) increased yield (Tables 2 and 3). In 2001 the effect of TSP was most significant. There were significant interactions between SOA.TSP.MOP and SOA.MOP.KIE (Tables 4 and 5). The highest yields were obtained at the highest rates of SOA, TSP and MOP (Table 4). The effects of the fertilisers appear to be increasing with time (Figure 1).

CONCLUSION

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

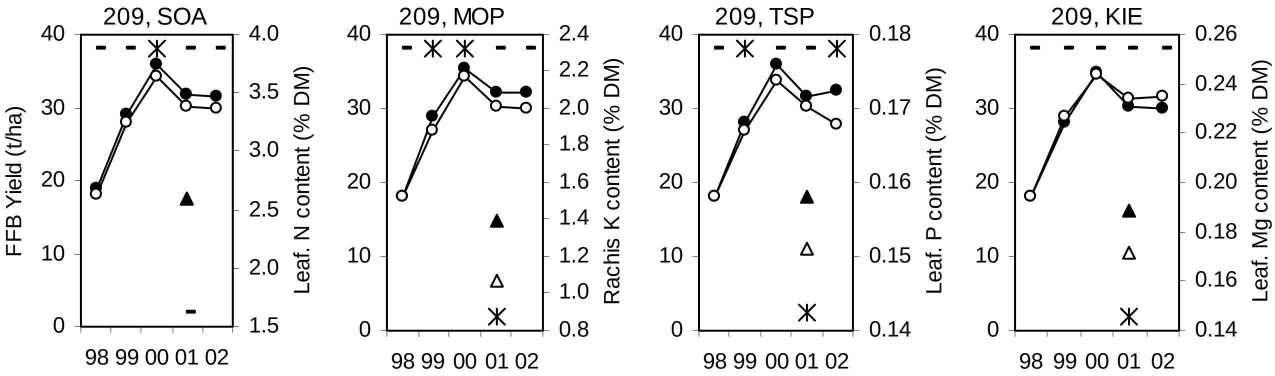


Figure 1. Main effects of SOA, MOP, TSP and KIE over the course of Trial 209. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols the lowest level. Symbols along the top of the graph indicate significance of the main 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 2000-2002 and 2002 (Trial 209). p values <0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.070**	0.325	**0.019**	0.207	0.325	**0.018**
TSP	**0.002**	**0.044**	0.211	**<.001**	**0.003**	0.347
MOP	**0.052**	0.546	**0.002**	**0.093**	0.296	**<.001**
KIE	0.337	0.295	0.582	0.288	0.268	0.602
SOA.TSP	0.915	0.923	0.758	0.979	0.997	0.404
SOA.MOP	0.589	0.612	0.303	0.840	0.868	0.441
TSP.MOP	0.474	0.795	0.661	0.504	0.541	0.816
SOA.KIE	0.196	0.177	0.155	**0.064**	**0.013**	**0.034**
TSP.KIE	0.806	0.616	0.764	0.135	**0.070**	0.512
MOP.KIE	**0.046**	0.164	0.973	0.141	0.319	0.622
SOA.TSP.MOP	**0.001**	**0.018**	0.419	**0.005**	**0.014**	0.326
SOA.TSP.KIE	0.376	0.714	0.920	0.316	0.366	0.189
SOA.MOP.KIE	**0.082**	0.217	0.454	**0.016**	**0.037**	0.466
TSP.MOP.KIE	0.600	0.450	0.591	0.381	0.448	0.771
CV %	*7.7*	*9.3*	*5.1*	*11.6*	*13.1*	*5.7*

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

	2000-2002			2002		
	Yield (t/ha)	Bun./ha	kg/bun.	Yield (t/ha)	Bun./ha	kg/bun.
SOA1	**31.3**	2329	**13.5**	29.8	1918	**15.9**
SOA2	**32.1**	2422	**13.3**	31.0	2026	**15.5**
SOA3	**33.0**	2383	**13.9**	31.6	1985	**16.4**
TSP0	**30.5**	**2285**	13.4	**27.9**	**1807**	15.8
TSP1	**32.6**	**2402**	13.7	**32.2**	**2058**	16.0
TSP2	**33.3**	**2446**	13.7	**32.3**	**2064**	16.1
MOP0	**31.4**	2399	**13.2**	**30.1**	2008	**15.2**
MOP1	**31.8**	2339	**13.7**	**30.2**	1910	**16.2**
MOP2	**33.1**	2396	**14.0**	**32.1**	2010	**16.4**
KIE0	32.5	2402	13.6	31.5	2018	15.9
KIE1	32.4	2410	13.5	31.0	2003	15.9
KIE2	31.5	2322	13.7	29.9	1908	16.1
s.e.d.	*0.67*	*60.2*	*0.19*	*0.98*	*70.6*	*0.25*
GM	*32.1*	*2378*	*13.6*	*30.8*	*1976*	*16.0*

Table 4. Effect of SOA.TSP.MOP interaction on FFB yield (t/ha) in 2000-2002 (Trial 209). P= 0.001, $lsd_{0.05}$ = 4.27. Yields >35 t/ha are highlighted.

		MOP0	MOP1	MOP2
SOA1	TSP0	28.9	26.9	32.2
	TSP1	29.1	31.4	34.1
	TSP2	32.3	34.2	32.4
SOA2	TSP0	30.5	28.5	33.2
	TSP1	33.6	34.6	30.0
	TSP2	32.6	32.1	34.1
SOA3	TSP0	31.9	34.3	28.3
	TSP1	34.2	29.8	**36.6**
	TSP2	29.7	34.8	**37.3**

Table 5. Effect of SOA.MOP.KIE interaction on FFB yield (t/ha) in 2000-2002 (Trial 209). P= 0.082, $lsd_{0.05}$ = 4.27. Yields >35 t/ha are highlighted.

		KIE0	KIE1	KIE2
SOA1	MOP0	30.2	32.1	28.0
	MOP1	30.4	32.1	30.0
	MOP2	**35.7**	33.1	29.9
SOA2	MOP0	31.7	34.7	30.2
	MOP1	32.4	28.0	34.7
	MOP2	32.6	32.7	32.1
SOA3	MOP0	32.6	32.7	30.4
	MOP1	34.8	31.3	32.8
	MOP2	31.8	34.5	**35.8**

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

There was no response to N fertiliser in this the first year of the trial (Table 1., Figure 1). Of the 288 15-palm rows that should have been harvested, 272 were harvested 23 times in the year (total of 6256 row-harvests), 368 or 5.6 % were missed. The distribution of these missed harvests was not random. Only treatments 1 and 9 recorded 2 plots each of missed harvests during the entire trial year so these plots were omitted when analysing the results. Of the 6256 harvested rows in the year, some rows had missed harvests. However, the distribution of these missed harvests was fairly random so they were ignored when analysing the results.

Table 1. Regression parameters for the effect of fertiliser application rate (kg/palm/year) on FFB yield and its components in 2002 (Trial 211).

	Intercept	Slope	Slope p	r^2
Yield (t/ha)	22.0	0.055	0.688	0.003
Bunches/ha	2433	2.4	0.852	0.001
Bunch wt. (kg)	9.0	0.014	0.515	0.006

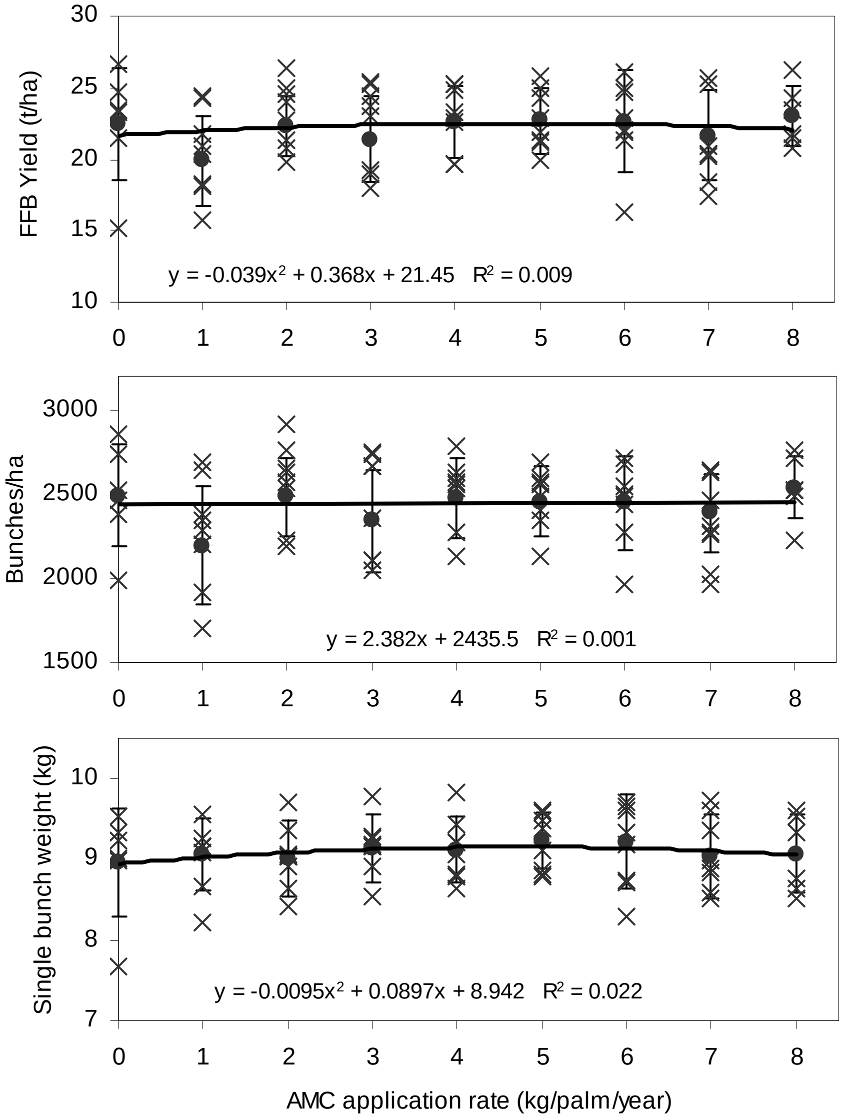


Figure 1. Effect of fertilizer rate (annual) on FFB yield, bunch numbers and single bunch weights in 2002 (Trial 211). Crosses show values for each 60-palm plot (4 rows of 15), circles show means for treatment, and bars show sd. Quadratic equations are shown as they fitted slightly better than the linear model shown in Table 1.

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 2 rows of 15 palms. N rates vary systematically along the trial. The site was chosen in 2001 and treatments commenced in 2002. From 2003, fertiliser application frequency will be 2 doses/year in replicates 1, 3, 5, & 7 and 10 doses/year in replicates 2, 4, 6 & 8.

RESULTS

There was no response to N fertiliser in this the first year of the trial (Table 1., Figure 1). Of the 144 15-palm rows that were harvested 17 times in the year (total of 2448 row-harvests), 60 or 2.5 % were wheeled out and no weights recorded. The distribution of these wheeled out harvests was fairly random, so they were ignored when analysing the results.

Table 1. Regression parameters for the effect of fertiliser application rate (kg/palm/year) on FFB yield and its components in 2002 (Trial 212).

	Intercept	Slope	Slope p	r^2
Yield (t/ha)	20.8	0.032	0.735	0.002
Bunches/ha	1616	-9.38	0.232	0.020
Bunch wt. (kg)	12.9	0.084	0.86	0.042

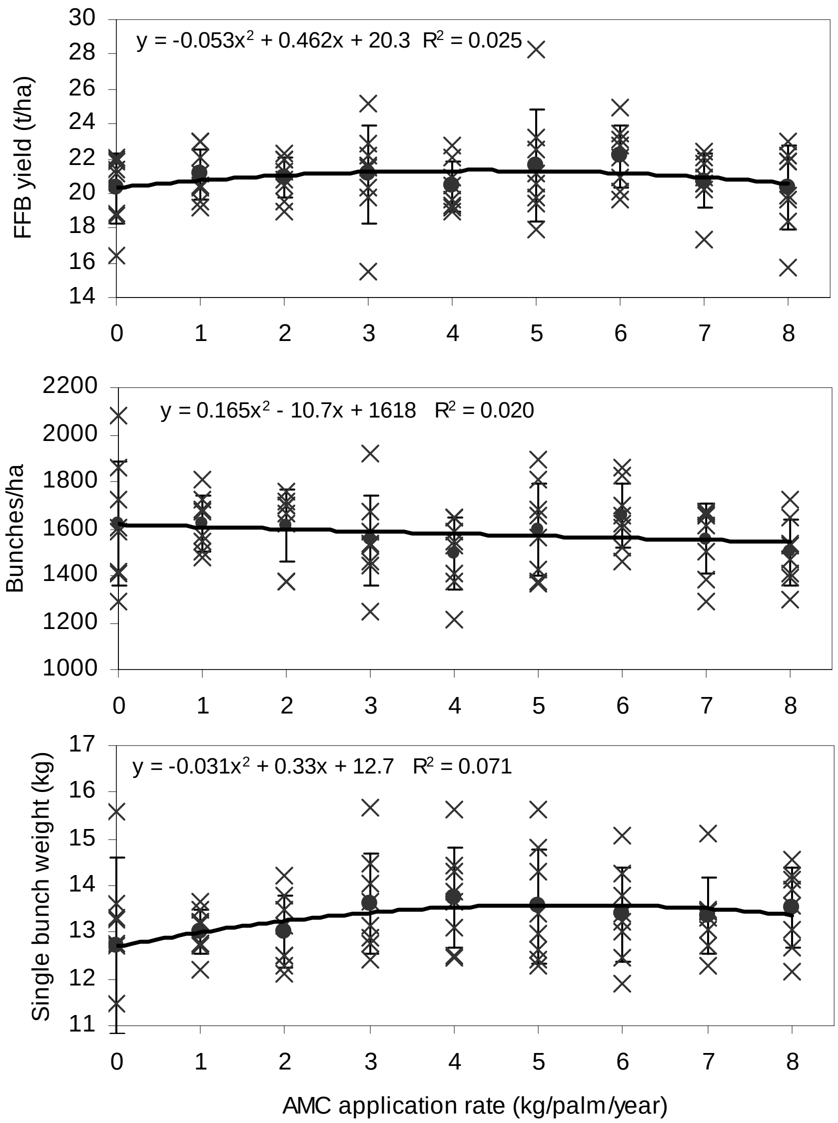


Figure 1. Effect of fertilizer rate (annual) on FFB yield, bunch numbers and single bunch weights in 2002 (Trial 212). Crosses show values for each 30-palm plot (2 rows of 15), circles show means for treatment, and bars show sd. Quadratic equations are shown as they fitted slightly better than the linear model shown in Table 1, especially for bunch weights and yield.

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

The site was marked out in 2002. Treatments and yield recording commenced at the beginning of 2003.

FERTILISER RESPONSE TRIALS IN ORO PROVINCE

(S. Nake, P. Nelson)

TRIAL 324 NITROGEN SOURCE TRIAL ON HIGATURU SOILS, SANGARA ESTATE

PURPOSE

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

SITE and PALMS

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

Treatment effects on yield

Similar to 2001, fertiliser type and rate had no significant effect on the FFB yields in 2002 (Table 3). However, the effect of fertiliser type on bunch number, bunch weight and yield was more pronounced in 2002 than in 2001. Bunch numbers were particularly affected by fertiliser type, being highest with DAP and lowest with urea (Tables 3 & 4).

The yields and bunch numbers in 2002 were lower than in 2001 and bunch weights were higher. Palms receiving zero fertilizer yielded less than those that received nitrogen fertilizer in 2002 (Table 4). In 2002, DAP gave the highest FFB yield of 35.8 t/ha. The interaction between fertiliser type and rate, though not significant, showed increasing DAP fertilizer rate increased yields. AMC and SOA are also starting to show some responses but were not statistically significant at this stage. FFB yields from the control plots, although lower than from fertilised plots, were still reasonably high (Table 4).

Treatment effects on frond 17 nutrient concentrations

The effects of the treatments on Frond 17 leaflet and rachis nutrient contents are presented in tables 6 and 7. Fertiliser type significantly affected leaflet Cl content only. Fertiliser rate and the interaction between type and rate had no significant effects on nutrient contents of the leaflets or rachis (Table 6).

The leaflet nitrogen content of palms in the zero N plots (2.27 % DM) appeared to be in the deficient range. Palms with nitrogen applied had leaflet nitrogen levels within the optimum range. Urea and DAP had the highest and second highest level of leaflet nitrogen respectively. The interaction between fertiliser type and rate showed increasing SOA rate decreased leaf and rachis nitrogen content (Table 8).

Treatment effects on height increments

Increments made in the height of the palm between 2001 and 2002 were significantly influenced by the fertilizer rates as well as the interaction between the rate and fertilizer type (Table 9). The greatest increase in height was in the palms fertilized with DAP (especially the lowest rate) followed by AMN (Tables 10 and 11). In general, the increase in height was reduced as the rates of the fertilizer increased. Palms from the control plots (zero N) had the least increment in height between 2001 and 2002. The interaction showed increasing SOA, urea and DAP rates slowed down the increase in palm height.

Table 3. Effects (p values) of treatments on FFB yield and its components in 2002 (Trial 324). P values <0.1 are shown in bold.

	2001			2002		
Source	Yield	BNO	SBW	Yield	BNO	SBW
Type	0.256	0.279	0.300	0.134	**0.059**	0.190
Rate	0.402	0.331	0.372	0.851	0.196	0.146
Type. Rate	0.451	0.279	0.852	0.416	0.107	0.128
CV %	*8.3*	*9.9*	*8.7*	*7.7*	5.5	*6.6*

Table 4. Main effects of treatments on FFB yield and its components in 2001 and 2002 (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.

	2001			2002		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
Zero N	(32.3)	(2947)	(11.0)	(30)	(2611)	(12.0)
AMC	34.4	3075	11.5	33.1	2798	12.0
AMN	37.2	3274	11.7	34.6	2844	12.4
DAP	35.6	3070	12.0	35.8	2914	12.6
SOA	35.6	3157	11.5	33.7	2769	12.3
Urea	35.9	3012	12.3	34.1	2734	12.7
sed	*1.22*	*125.5*	*0.42*	*1.07*	*63.3*	*0.33*
Level 1	36.5	3182	11.7	34.0	2856	12.1
Level 2	35.3	3133	11.6	34.5	2813	12.5
Level 3	35.5	3038	12.0	34.2	2766	12.5
sed	*0.94*	*97.2*	*0.32*	*0.83*	*49.0*	*0.26*

Table 5. Effect of interaction between fertiliser type and rate on FFB yield (t/ha) in 2002 (Trial 324). The interaction was not significant. $Lsd_{0.05}$ = 3.74.

	AMC	SOA	Urea	AMN	DAP
Rate 1	32.5	32.1	35.1	35.5	35.1
Rate 2	33.7	35.5	34.7	33.4	35.3
Rate 3	33.2	33.4	32.6	34.9	37.1

Table 6. Effects (p values) of treatments on frond 17 nutrient concentrations in 2002 (Trial 324). p values less than 0.05 are indicated in bold.

	Leaflet							Rachis	
Source	Ash	N	P	K	Mg	Ca	Cl	Ash	K
Type	0.123	0.761	0.921	0.120	0.865	0.891	**0.016**	0.764	0.936
Rate	0.219	0.775	0.590	0.508	0.869	0.278	0.938	0.447	0.753
Type.Rate	0.655	0.278	0.364	0.176	0.987	0.342	0.145	0.861	0.501
CV %	3.5	3.7	2.1	4.6	10.5	5.9	8.7	7.8	10.5

Table 7. Main effects of treatments on frond 17 nutrient concentrations in 2002, 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	Ash	K
Zero N	(13.6)	(2.27)	(0.14)	(0.71)	(0.19)	(0.84)	(0.41)	(4.5)	(1.4)
AMC	13.9	2.41	0.14	0.71	0.20	0.88	**0.51**	4.7	1.5
AMN	13.9	2.39	0.15	0.74	0.20	0.87	**0.47**	4.6	1.5
DAP	14.3	2.40	0.15	0.73	0.20	0.87	**0.49**	4.8	1.5
SOA	14.3	2.38	0.14	0.72	0.20	0.89	**0.46**	4.7	1.5
Urea	13.9	2.42	0.14	0.72	0.20	0.88	**0.47**	4.8	1.5
sed	*0.200*	*0.037*	*0.001*	*0.013*	*0.009*	*0.021*	*0.017*	*0.14*	*0.06*
Level 1	14.2	2.40	0.14	0.72	0.20	0.88	0.48	4.8	1.5
Level 2	14.1	2.41	0.15	0.72	0.20	0.89	0.48	4.7	1.5
Level 3	13.9	2.39	0.14	0.73	0.20	0.86	0.48	4.7	1.5
sed	*0.16*	*0.028*	*0.001*	*0.010*	*0.006*	*0.016*	*0.013*	*0.116*	*0.050*

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

Leaflet N (% DM), $lsd_{0.05}$ = 0.12

	AMC	AMN	DAP	SOA	Urea
Rate 1	2.43	2.38	2.39	2.43	2.36
Rate 2	2.39	2.42	2.38	2.37	2.51
Rate 3	2.43	2.38	2.43	2.33	2.40

Rachis K (% DM), $lsd_{0.05}$ = 0.23

	AMC	AMN	DAP	SOA	Urea
Rate 1	1.46	1.52	1.56	1.59	1.49
Rate 2	1.45	1.40	1.48	1.55	1.61
Rate 3	1.51	1.56	1.50	1.44	1.42

Table 9. Effects (p values) of treatments on increments made in the height between 2001 and 2002 (Trial 324). Significant effects are shown in bold ($P<0.05$).

Source	Increment in Height
Type	0.104
Rate	**<0.001**
Type.Rate	**0.003**
CV %	*20.1*

Table 10. Main effects of treatments on palm height in 2002 (Trial 324). Values for plots receiving zero N (in brackets) were not included in the analysis of variance.

Treatment	Increment in Height (cm)
Zero N	(72.1)
AMC	74.2
AMN	77.2
DAP	80.0
SOA	75.2
Urea	76.9
sed	*2.28*
Level 1	80.5
Level 2	78.4
Level 3	71.2
sed	*1.77*

Table 11. Effect of interaction between fertiliser type and rate on palm height increment (cm) between 2001 and 2002 (Trial 324). The interaction was significant (p=0.003). Lsd0.05 = 7.75.

	AMC	SOA	Urea	AMN	DAP
Rate 1	76.1	80.8	83.4	74.6	87.8
Rate 2	79.4	72.0	80.9	81.1	78. 6
Rate 3	67.1	72.8	66.3	76.1	73.7

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

SITE and PALMS

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 ammonium sulphate (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. Treatments and yield recording commenced in 2002.

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	-

RESULTS

The application of treatments and yield recording commenced in 2002. The main effects of the treatments as well as the interactions between the treatments showed no significant effects ($p>0.05$) on yield and its components (Table 2). There were no significant effects on the rachis width x thickness measurements either (Table 2). The coefficient of variation was reasonably low. SOA, although not significant, appeared to have increased yields (Table 3). Table 4 shows the effects of the treatment interactions on FFB yield.

The leaf and rachis nutrient contents were not affected by either SOA or EFB treatments ($p>0.05$). However, the treatment interaction significantly affected the rachis ash and K contents in 2002 (Table 5). The effect of SOA treatment on the nutrient contents of the leaf and the rachis was almost significant. Table 6 shows the main effects of the treatments on Frond 17 leaflet and rachis nutrient contents. Zero SOA and EFB provided the highest dry matter percentage of rachis ash (4.86%) compared to the other combinations (Table 7). SOA2 had a consistent drop in rachis ash content with increases in the EFB level. Similar to the rachis ash content, the lowest level of SOA and EFB (SOA0 & EFB0) produced the highest content of potassium (1.65 % DM).

Table 2. Effects (p values) of treatments on FFB yield, its components and rachis width x thickness in 2002 (Trial 326).

Source	Yield	Bun./ha	kg/bun.	WxT
SOA	0.713	0.670	0.906	0.740
EFB	0.616	0.209	0.950	0.431
SOA.EFB	0.509	0.642	0.401	0.462
CV %	*11.8*	*9.0*	*8.2*	*11.5*

Table 3. Main effects of treatments on FFB yield and its components and rachis width x thickness in 2002 (Trial 326).

	Yield (t/ha)	Bun./ha	kg/bun.	WxT (cm^2)
SOA0	17.9	2249	7.99	15.0
SOA1	18.0	2294	7.99	14.4
SOA2	18.3	2314	7.88	14.8
SOA3	18.8	2340	8.05	15.0
sed	*0.79*	*75.2*	*0.23*	*0.62*
EFB0	18.5	2343	7.95	15.2
EFB1	15.3	2322	7.97	14.6
EFB2	17.9	2233	8.01	14.6
sed	*0.68*	*65.1*	*0.21*	*0.54*

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Table 4. Effect of the interactions between SOA and EFB on FFB yield (t/ha) in 2002 (Trial 326). The interaction was not significant, $Lsd_{0.05}$ =2.74

	SOA 0	SOA 1	SOA 2	SOA 3
EFB 0	18.9	17.9	17.7	19.5
EFB 1	16.7	18.4	19.1	19.1
EFB 2	18.1	17.6	18.1	17.7

Table 5. Effects (p values) of treatments on frond 17 nutrient concentrations in 2002 for Trial 326. p values <0.1 are indicated in bold.

	Leaflet							Rachis	
Treatment	Ash	N	P	K	Mg	Ca	Cl	Ash	K
SOA	0.946	0.098	0.731	0.999	0.751	0.224	**0.062**	**0.099**	**0.061**
EFB	0.526	0.698	0.860	0.750	0.830	0.778	0.367	0.856	0.933
SOA.EFB	0.517	0.286	0.932	0.880	0.350	0.951	0.118	**0.007**	**0.005**
CV %	4.7	3.7	2.5	5.2	9.0	4.8	12.1	9.3	10.8

Table 6. Main effects of treatments on frond 17 nutrient concentrations in 2002 (% dry matter), Trial 326.

	Leaflet							Rachis	
	Ash	N	P	K	Mg	Ca	Cl	Ash	K
SOA0	11.97	2.68	0.159	0.80	0.30	0.97	0.48	4.65	1.58
SOA1	11.89	2.59	0.158	0.80	0.31	0.93	0.44	4.27	1.41
SOA2	11.85	2.64	0.159	0.80	0.30	0.95	0.49	4.49	1.51
SOA3	11.91	2.67	0.157	0.80	0.30	0.95	0.45	4.51	1.51
sed	*0.205*	*0.036*	*0.001*	*0.015*	*0.009*	*0.017*	*0.021*	*0.152*	*0.059*
EFB0	11.94	2.64	0.159	0.80	0.31	0.95	0.48	4.47	1.49
EFB1	11.98	2.66	0.158	0.81	0.30	0.95	0.45	4.45	1.50
EFB2	11.79	2.63	0.158	0.80	0.30	0.95	0.47	4.52	1.51
sed	*0.178*	*0.031*	*0.001*	*0.013*	*0.008*	*0.014*	*0.018*	*0.132*	*0.051*

Table 7. Effects of interaction between SOA and EFB on rachis Ash and rachis K content

Rachis Ash (% DM), $lsd_{0.05}$ = 0.007

	SOA0	SOA1	SOA2	SOA3
EFB0	4.86	4.23	4.60	4.18
EFB1	4.55	3.84	4.57	4.84
EFB2	4.55	4.73	4.29	4.53

Rachis K (% DM), $lsd_{0.05}$ = 0.005

	SOA0	SOA1	SOA2	SOA3
EFB0	1.65	1.39	1.54	1.40
EFB1	1.54	1.24	1.57	1.63
EFB2	1.53	1.60	1.40	1.51

TRIAL 329 NITROGEN, P, K AND MG TRIAL ON MAMBA SOILS, MAMBA ESTATE

PURPOSE

To provide information for fertiliser recommendations for estates and smallholders in the Kokoda Valley and Ilimo/Papaki areas on soils that are unlike soils of the Popondetta plains, being acidic, with low cation status and 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 factorial with a single replicate and 54 plots, which are arranged in 3 blocks of 18. 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

RESULTS

The first yield data for the trial since establishment is hereby presented. The yields were high but not affected by the treatments and their combinations (p>0.05) as shown in Table 2. Kieserite had the largest effect on yield. Fertiliser effects were not expected in this the first year of the trial, but we expect to see effects in the future.

Table 2. Effects (p values) of treatments on FFB yield and its components in 2002 (Trial 329).

Source	Yield	Bun./ha	kg/bun.
SOA	0.985	0.835	0.565
TSP	0.940	0.888	0.687
MOP	0.758	0.943	0.797
KIE	0.728	0.596	0.804
SOA.TSP	0.807	0.871	0.250
SOA.MOP	0.716	0.721	0.174
TSP.MOP	0.906	0.505	0.239
SOA.KIE	0.621	0.977	0.262
TSP.KIE	0.986	0.989	0.916
MOP.KIE	0.990	0.963	0.767
SOA.TSP.MOP	0.745	0.519	0.723
SOA.TSP.KIE	0.370	0.460	0.993
SOA.MOP.KIE	0.257	0.234	0.530
TSP.MOP.KIE	0.141	0.141	0.410
CV %	13.5	15.2	7.1

Table 3. Main effects of treatments on FFB yield and its components in 2002 (Trial 329).

	Yield (t/ha)	Bun./ha	kg/bun.
SOA1	22.86	1993	11.77
SOA2	22.85	2011	11.63
s.e.d.	*0.843*	*83.0*	*0.227*
TSP0	22.65	1982	11.67
TSP1	22.99	1993	11.83
TSP2	22.92	2030	11.59
s.e.d	*1.032*	*101.6*	*0.278*
MOP0	22.69	1984	11.77
MOP1	22.57	2003	11.59
MOP2	23.30	2018	11.74
s.e.d	*1.032*	*101.6*	*0.278*
KIE0	22.39	1947	11.79
KIE1	22.95	2004	11.70
KIE2	23.21	2054	11.60
s.e.d	*1.032*	*101.6*	*0.278*

TRIAL 330 GRASSLAND SULPHUR TRIAL ON OUTWASH PLAINS, PARAHE MINI ESTATE

PURPOSE

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

SITE, PALMS

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

A ‘factorial’ design with 4 rates of ammonium nitrate (0.7, 2.0, 3.3 and 4.6 kg/palm per year) and 3 rates of elemental S (0, 0.1 and 0.30 kg/palm per year), with 3 replicates, resulting in 36 plots. Each of the 36 plots has 16 recorded palms plus 2 guard rows, resulting in a total of 64 palms/plot. Double guard rows were used to avoid the use of trenches for preventing 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.

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

Treatments and yield recording were planned to commence in 2003, but high variability lead to continuation of the blanket treatment with SOA and MOP. The variability is due to poor management (especially lack of fertiliser application) of some areas. The variability is illustrated by the WxT values shown in Figure 1. Application of treatments will probably commence in 2004. We have tried to start yield recording in 2003, but continuing disputes between the landowners and the company have prevented most harvests being recorded properly.

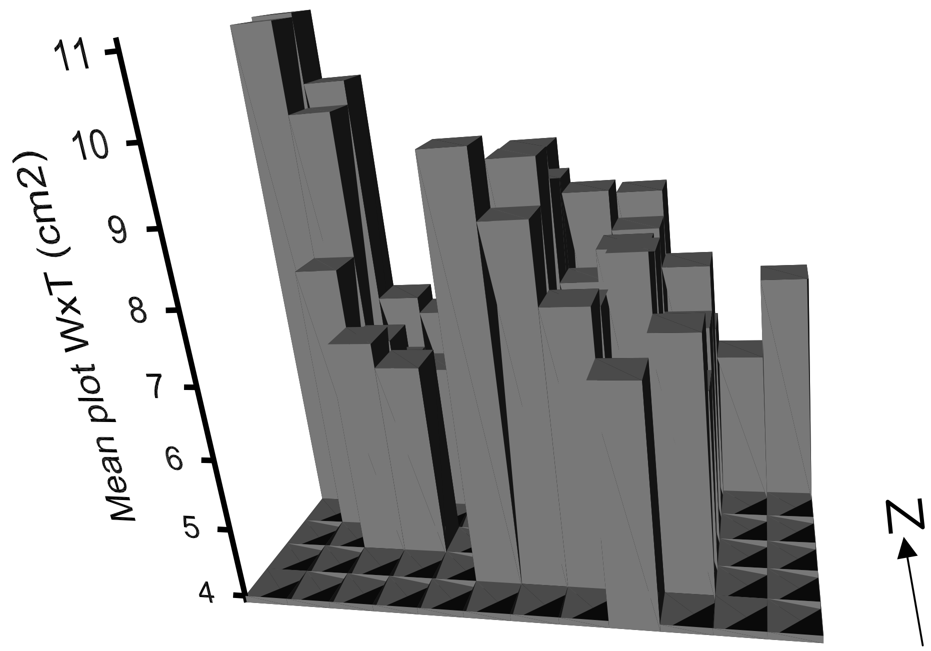


Figure 1. Rachis width x thickness values for each plot, measured in September 2002 (Trial 330).

TRIAL 333 – Mg AND K SOURCES IN ORO

BACKGROUND

The soils of the Ilimo-Mamba area of Oro Province are acidic and have very low CEC. Magnesium and K deficiency symptoms are common. Kieserite and MOP are applied, but we expect that their effectiveness will be limited because of the high potential for leaching losses due to high rainfall and low CEC. Therefore, this experiment is designed to test less soluble sources. Less soluble fertilisers such as $MgCO_3$, MgO and boiler ash have the added advantage of being likely to increase soil pH, which will increase CEC of these variable charge soils. Empty fruit bunch (EFB) is included as a source of K, because of its high K content, but it has the added advantage of increasing soil organic matter content. This trial is part of the ACIAR-funded Mg project.

PURPOSE

To determine if slow-release options for supplying Mg and K to palms are more effective than the current use of soluble fertilisers, on the acidic, low CEC soils of the Ilimo-Mamba area of Oro province.

SITE

Mamba Estate, in 1993 planting.

TREATMENTS

The treatments fall into 3 groups. Fertiliser rates for the various treatments are given in Table 1. Nitrogen will be applied across the trial as ammonium nitrate at a standard rate.

Group 1, Mg sources in the presence of adequate K: The following 4 Mg sources will all be added individually at an equivalent rate of Mg, and all be applied in 2 doses per year: 1) kieserite, 2) magnesite (QMAG Magnesite FO1), 3) MgO (QMAG M45) and 4) dolomite.

Group 2, K sources in the presence of adequate Mg: The following 3 sources of K will be added individually. 1) MOP (2x per year, on surface). 2) MOP in trenches covered with plastic, applied once at a rate equivalent to 3x the surface MOP rate. 3) EFB at an equivalent rate of K to the surface MOP treatment (applied in 1 dose per year).

Group 3, Potential response to Mg or K: The adequate Mg treatment will comprise of kieserite + magnesite + MgO, applied together in 2 doses per year. The adequate K treatment will be MOP applied to the surface 2x annually + MOP in trenches covered with plastic (see Group 2). An extra treatment will be boiler ash, which contains Mg and K in approximately the correct ratio.

STATISTICAL DESIGN AND LAYOUT

The 11 treatments are replicated 4 times, giving a total of 44 plots. The field layout will be a completely randomised design. The trial can be analysed as 3 separate experiments by treating the treatment groups as separate experiments, or as one single experiment with 11 treatments. Plots will consist of 36 (6*6) treated palms, of which the central 16 (4*4) are recorded.

PROGRESS

The site was mapped in 2003 and the trial will commence in 2003.

Table 1. Fertiliser types and rates

Fertiliser	Nutrient	Nutrient appl. rate (kg/palm)	Nutrient cont. of fert. (%)	Fert. appl. rate (kg/palm)	Number of appl.	Amount per applic. (g/palm)
Group 1 (Mg sources)						
Kieserite	Mg	0.425	17	2.5	2/yr	1,250
Magnesite	Mg	0.425	26	1.6	2/yr	817
Dolomite	Mg	0.425	10	4.3	2/yr	2,125
MgO	Mg	0.425	56	0.8	2/yr	379
Basal (all plots)						
MOP	K	1.25	50	2.5	2/yr	1,250
MOP trenches & plastic	K	3.75	50	7.5	1	7,500
Group 2 (K sources)						
MOP surface	K	1.25	50	2.5	2/yr	1,250
MOP trenches & plastic	K	3.75	50	7.5	1	7,500
EFB	K				1/yr	
Basal (all plots)						
Kieserite	Mg	0.14	17	0.8	2/yr	417
Magnesite	Mg	0.14	26	0.5	2/yr	272
MgO	Mg	0.14	56	0.3	2/yr	126
Group 3 (Mg and K factorial)						
MOP	K	1.25	50	2.5	2/yr	1,250
MOP trenches & plastic	K	3.75	50	7.5	1	7,500
Kieserite	Mg	0.14	17	0.8	2/yr	417
Magnesite	Mg	0.14	26	0.5	2	272
MgO	Mg	0.14	56	0.3	2	126
Boiler Ash	Mg & K	0.425 & 1.39	1.5 & 4.9	28.3	2	14,167

FERTILISER RESPONSE TRIALS IN MILNE BAY PROVINCE

(S. Nake, P. Nelson)

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 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

Figure 1 shows the main effects of the treatments on the fresh fruit bunch (FFB) yield and the tissue nutrient concentrations over the course of the trial. In 2002, SOA and EFB significantly increased the FFB yield (Table 2 & 3). The effect of the two-way interactions on FFB yield in 2000-2002 are given in Table 4. The most significant interaction was that between MOP and EFB. Where EFB was applied, yield was high and MOP had no effect. Without EFB application, MOP increased yield. The effect of the interaction between SOA, MOP and EFB on FFB yield is given in Table 5. Without EFB, yield was highest at SOA2 and MOP3. With EFB, high yields were obtained with SOA1 and MOP0, with additional SOA and MOP having little or no effect.

The results of the tissue analysis are presented in Table 6 & 7. SOA significantly increased leaflet ash and N but reduced leaflet Mg and Ca. MOP increased leaflet K content and decreased leaflet Mg. EFB application had a positive effect of the levels of leaflet N and K and decreased leaflet Mg and Ca.

SOA increased rachis N levels while decreasing rachis levels of P, Mg and Cl. MOP increased rachis concentrations of ash, K, P and Mg. TSP positively affected rachis concentrations of P and Mg. EFB significantly increased rachis levels of ash, N and K and decreased rachis Mg and Ca.

CONCLUSION

SOA, MOP and EFB all had positive effects on the FFB yield. Without EFB the highest FFB yield is being obtained with annual applications of 4.0 kg SOA/palm and 7.5 kg MOP/palm. EFB is proving to be an effective source of N and K at this site. When EFB is applied, no MOP and low rates of SOA (2 kg/palm instead of 4 kg/palm) are required for maximum yield. TSP continues to have no significant effect on yield.

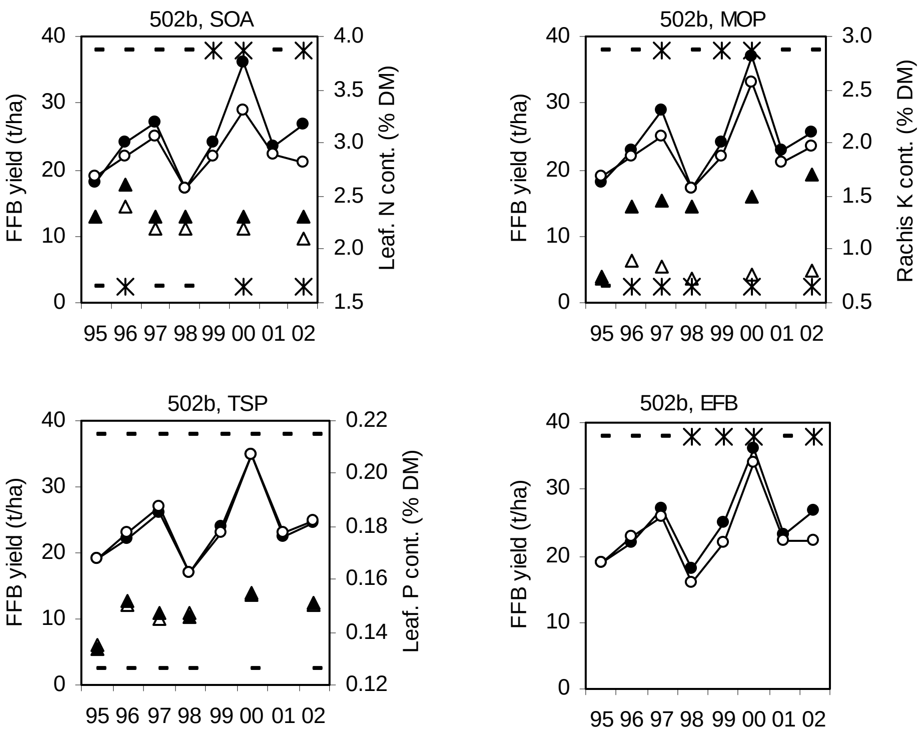


Figure 1. Main effects of SOA, MOP and TSP over the course of Trial 502b. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect 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 2000-2002 and 2002 (Trial 502b). p values less than 0.1 are indicated in bold. CV value is for the Block.Plot interaction.

	2000-2002			2002		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<0.001**	**<0.001**	**<0.001**	**0.002**	**0.036**	**<0.001**
TSP	0.134	0.549	**0.046**	0.716	0.675	0.673
MOP	**0.022**	0.184	**0.010**	0.212	0.354	**0.005**
EFB	**<0.001**	**0.010**	**<0.001**	**<0.001**	**0.004**	**<0.001**
SOA.TSP	0.500	0.631	0.381	0.235	0.271	**0.044**
SOA.MOP	0.639	0.338	0.146	0.658	0.411	**0.081**
TSP.MOP	0.172	**0.090**	0.222	0.126	0.292	**0.027**
SOA.EFB	0.106	0.122	0.111	**0.084**	0.255	**0.007**
TSP.EFB	0.314	0.316	0.916	0.755	0.510	0.414
MOP.EFB	**0.029**	0.546	**0.002**	0.170	0.258	**0.040**
SOA.TSP.MOP	0.164	**0.068**	**0.066**	0.505	0.196	**0.061**
SOA.TSP.EFB	0.332	0.434	0.269	0.319	0.525	0.120
SOA.MOP.EFB	0.674	0.511	0.110	0.564	0.769	**0.003**
TSP.MOP.EFB	0.845	0.884	0.646	0.392	0.256	0.128
CV %	6.1	5.5	2.7	11.8	11.1	3.0

Table 3. Main effects of treatments on FFB yield and its components (Trial 502b). Significant effects (p<0.1) are shown in bold.

	2000 - 2002			2002		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**24.4**	**1079**	**22.7**	**21.1**	**959**	**21.8**
SOA1	**28.3**	**1178**	**24.1**	**24.8**	**1018**	**24.3**
SOA2	**28.9**	**1211**	**24.1**	**25.2**	**1033**	**24.4**
SOA3	**28.5**	**1218**	**23.8**	**26.9**	**1105**	**24.3**
sed	*0.59*	*22.9*	*0.23*	*1.02*	*40.3*	*0.26*
MOP0	**26.3**	1145	**23.1**	23.5	1011	**23.1**
MOP1	**27.4**	1177	**23.6**	24.9	1053	**23.5**
MOP2	**27.6**	1164	**23.9**	24.0	993	**24.1**
MOP3	**28.7**	1200	**24.1**	25.7	1057	**24.2**
sed	*0.59*	*22.9*	*0.23*	*1.02*	*40.3*	*0.26*
TSP0	27.8	1177	**23.8**	24.7	1035	23.7
TSP1	27.2	1166	**23.5**	24.4	1022	23.7
sed	*0.42*	*16.2*	*0.16*	*0.72*	*28.5*	*0.18*
EFB0	**26.1**	**1145**	**22.9**	**22.2**	**973**	**22.7**
EFB1	**29.0**	**1198**	**24.4**	**26.8**	**1084**	**24.8**
sed	*0.42*	*16.2*	*0.16*	*0.72*	*28.5*	*0.18*

Table 4. Effect of two-way interactions on FFB yield (t/ha) in 2000-2002 (Trial 502b).

SOA.MOP, p=0.64 , lsd=2.68

	SOA0	SOA1	SOA2	SOA3
MOP0	23.5	27.8	27.0	27.0
MOP1	23.3	28.3	29.3	28.9
MOP2	24.7	27.9	28.6	29.4
MOP3	26.2	29.1	30.5	28.9

MOP.TSP, p=0.172 , lsd=1.89

	TSP0	TSP1
MOP0	26.9	25.7
MOP1	27.0	27.8
MOP2	28.7	26.6
MOP3	28.9	28.5

SOA.TSP, p=0.500, lsd=1.89

	SOA0	SOA1	SOA2	SOA3
TSP0	24.7	28.7	28.7	29.3
TSP1	24.1	27.9	29.0	27.7

EFB.TSP, p=0.314 , lsd=1.34

	TSP0	TSP1
EFB0	26.6	25.5
EFB1	29.1	28.8

SOA.EFB, p=0.106 , lsd=1.89

	SOA0	SOA1	SOA2	SOA3
EFB0	21.9	27.0	28.1	27.2
EFB1	26.8	29.5	29.6	29.9

MOP.EFB, p=0.029 , lsd=1.89

	EFB0	EFB1
MOP0	23.6	28.1
MOP1	25.9	28.9
MOP2	26.8	28.4
MOP3	27.9	29.4

Table 5. Effect of interaction between SOA, MOP and EFB on FFB yield (t/ha) in 2000-2002 (Trial 502b). P=0.674, s.e.d. = 1.68 and l.s.d.(0.05) =3.79 CV (block.units)= 6.1%. Yields > 29 t/ha are highlighted in bold.

	EFB0					EFB1			
	SOA0	SOA1	SOA2	SOA3		SOA0	SOA1	SOA2	SOA3
MOP0	20.2	24.2	24.4	25.5	MOP0	26.8	**31.3**	**29.6**	28.5
MOP1	20.2	27.4	28.9	27.3	MOP1	26.4	**29.2**	**29.8**	**30.4**
MOP2	23.3	27.5	28.6	27.8	MOP2	26.1	28.3	28.5	**30.9**
MOP3	24.3	28.9	**30.4**	28.1	MOP3	28.0	**29.4**	**30.7**	**29.7**

Table 6. Significance (p values) for effects of the fertilizer treatments on Frond 17 leaflet and rachis nutrient concentrations in 2002, 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				
SOA	**0.023**	<**0.001**	0.573	0.215	**0.003**	**0.003**	0.751	0.065
MOP	0.911	0.363	**0.001**	0.117	**<0.001**	0.644	0.332	0.120
TSP	0.859	0.559	0.297	0.171	0.383	0.102	0.806	0.438
EFB	0.182	**0.001**	**<0.001**	0.193	**<0.001**	**<0.001**	0.192	0.476
CV %	5.9	2.9	7.4	2.1	5.8	5.2	14.4	6.4
				Frond 17 rachis				
SOA	0.275	**<0.001**	0.082	**<0.001**	**0.004**	0.141	0.696	**0.075**
MOP	**<0.001**	0.877	**<0.001**	**0.017**	**<0.001**	**0.001**	0.269	**<0.001**
TSP	0.725	0.458	**0.853**	**<0.001**	**<0.001**	0.960	0.713	0.183
EFB	**<0.001**	**0.008**	**<0.001**	0.203	**<0.001**	**<0.001**	0.713	0.082
CV %	7.5	9.5	11.3	20.7	5.8	7.3	10.9	12.6

Table 7. Main effects of treatments on frond 17 leaflet and rachis nutrient concentrations in 2002. All nutrients are in units of % dry matter except B which is expressed in ppm (Trial 502b). Significant effects ($p<0.05$) are shown in bold.

Treatments	Ash	N	K	P	Mg	Ca	B	Cl
				Frond 17 leaflets				
SOA0	**12.9**	**2.1**	0.62	0.15	**0.37**	**0.81**	10.7	0.57
SOA1	**13.2**	**2.2**	0.62	0.15	**0.36**	**0.78**	10.5	0.58
SOA2	**13.8**	**2.3**	0.64	0.15	**0.33**	**0.75**	10.4	0.56
SOA3	**13.8**	**2.3**	0.63	0.15	**0.34**	**0.74**	10.9	0.59
s.e.d	*0.28*	*0.02*	*0.02*	*0.001*	*0.01*	*0.01*	*0.54*	*0.01*
MOP0	13.4	2.2	**0.57**	0.15	**0.39**	0.77	11.3	0.55
MOP1	13.4	2.3	**0.62**	0.14	**0.35**	0.78	10.5	0.57
MOP2	13.4	2.2	**0.66**	0.15	**0.34**	0.77	10.3	0.59
MOP3	13.6	2.2	**0.66**	0.15	**0.33**	0.76	10.4	0.59
s.e.d	*0.28*	*0.02*	*0.02*	*0.001*	*0.01*	*0.01*	*0.54*	*0.01*
TSP0	13.4	2.2	0.63	0.15	0.35	0.76	10.7	0.57
TSP1	13.5	2.2	0.62	0.15	0.35	0.78	10.6	0.58
s.e.d	*0.19*	*0.01*	*0.01*	*0.001*	*0.01*	*0.01*	*0.38*	*0.01*
EFB0	13.6	**2.1**	**0.58**	0.15	**0.38**	**0.80**	10.9	0.58
EFB1	13.3	**2.3**	**0.68**	0.15	**0.33**	**0.73**	10.4	0.57
s.e.d	*0.19*	*0.01*	*0.01*	*0.001*	*0.01*	*0.01*	*0.38*	*0.01*
				Frond 17 rachis				
SOA0	4.4	**0.24**	1.4	**0.15**	**0.14**	0.32	5.9	**0.74**
SOA1	4.3	**0.25**	1.4	**0.12**	**0.14**	0.34	6.1	**0.70**
SOA2	4.2	**0.28**	1.3	**0.10**	**0.13**	0.33	6.0	**0.67**
SOA3	4.2	**0.31**	1.3	**0.09**	**0.13**	0.34	6.1	**0.65**
s.e.d	*0.11*	*0.009*	*0.05*	*0.009*	*0.003*	*0.009*	*0.23*	*0.03*
MOP0	**3.5**	0.27	**0.8**	**0.09**	**0.18**	**0.36**	6.2	**0.49**
MOP1	**4.2**	0.27	**1.3**	**0.12**	**0.14**	**0.33**	5.8	**0.71**
MOP2	**4.6**	0.27	**1.6**	**0.13**	**0.11**	**0.31**	6.2	**0.76**
MOP3	**5.0**	0.27	**1.7**	**0.13**	**0.11**	**0.31**	5.9	**0.70**
s.e.d	*0.11*	*0.009*	*0.05*	*0.009*	*0.003*	*0.009*	*0.23*	*0.03*
TSP0	4.3	0.27	1.3	**0.09**	**0.13**	0.33	6.0	0.71
TSP1	4.3	0.27	1.3	**0.14**	**0.14**	0.33	6.1	0.68
s.e.d	*0.08*	*0.006*	*0.04*	*0.006*	*0.002*	*0.006*	*0.16*	*0.02*
EFB0	**4.0**	**0.26**	**1.1**	0.11	**0.16**	**0.35**	6.1	0.67
EFB1	**4.6**	**0.28**	**1.6**	0.12	**0.11**	**0.31**	6.0	0.71
s.e.d	*0.08*	*0.006*	*0.04*	*0.006*	*0.002*	*0.006*	*0.16*	*0.02*

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.

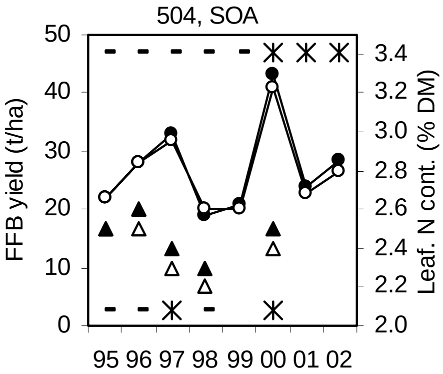
	Amount (kg/palm.year)			
	Level 0	Level 1	Level 2	Level 3
SOA	0	2.0	4.0	6.0
MOP	0	2.5	5.0	7.5
Vacant Treatment	-	-	-	-

RESULTS

Figure 1 depicts the main effects of the fertiliser treatments on the FFB yield and tissue nutrient contents. SOA and MOP continued to have significant positive effects on FFB yield, with no significant interaction between them (Tables 2 & 3). Over the 2000-2002 period, the highest yield was achieved with 4.0 kg/palm SOA and 5.0-7.5 kg/palm MOP (Table 4).

CONCLUSION

Both SOA and MOP have shown to have significant effects on the FFB yield over the last 3 to 5 years respectively. The highest FFB yield was reached at 4.0 kg/palm of SOA and 5.0 kg/palm of MOP.



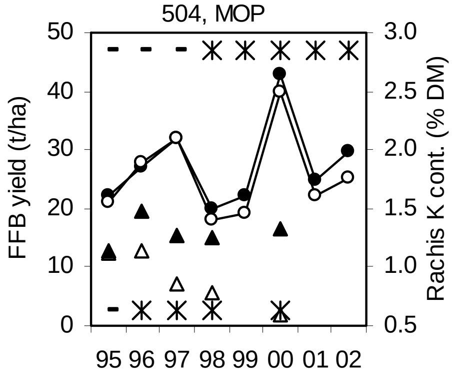


Figure 1. Main effects of SOA and MOP over the course of Trial 504. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect on 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 2000-2002 and 2002 (Trial 504). p values less than 0.05 are indicated in bold.

	2000-2002			2002		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<0.001**	**<0.001**	0.417	**0.050**	0.087	0.677
MOP	**<0.001**	**0.007**	**0.011**	**<0.001**	**0.016**	**0.042**
SOA.MOP	0.307	0.121	0.713	0.550	0.395	0.584
CV %	6.0	5.2	4.3	11.7	10.5	6.2

Table 3. Main effects of treatments on FFB yield and its components (Trial 504). Significant effects ($p<0.05$) are shown in bold.

	2000-2002			2002		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**29.9**	**1415**	21.4	**26.5**	1201	22.5
SOA1	**31.9**	**1476**	21.9	**28.5**	1259	23.0
SOA2	**33.0**	**1534**	21.7	**29.8**	1323	23.1
SOA3	**31.9**	**1487**	21.6	**28.5**	1278	22.8
sed.	*0.67*	*27.1*	*0.33*	*1.17*	*46.8*	*0.50*
MOP0	**29.5**	**1421**	**21.0**	**25.3**	**1176**	**21.9**
MOP1	**31.6**	**1477**	**21.7**	**28.2**	**1261**	**23.0**
MOP2	**33.1**	**1512**	**22.1**	**30.1**	**1314**	**23.3**
MOP3	**32.6**	**1501**	**21.9**	**29.7**	**1310**	**23.1**
sed	*0.67*	*27.1*	*0.33*	*1.17*	*46.8*	*0.50*

Table 4. Effect on SOA.MOP interaction on FFB yield (t/ha) in 2000-2002 (Trial 504). Yields >30 t/ha are highlighted in bold.

SOA.MOP, p=0.921, lsd=2.99				
	MOP0	MOP1	MOP2	MOP3
SOA0	24.8	24.4	29.5	27.2
SOA1	25.0	28.5	29.5	**30.8**
SOA2	25.8	28.9	**32.1**	**32.4**
SOA3	25.3	**30.9**	29.3	28.5

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 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

Figure 1 presents the main effects of the treatments from 1995 to 2002. SOA, EFB and TSP all showed significant effects on FFB yield, with SOA having the greatest effect. The effects of MOP were not significant, although the high rate of MOP increased FFB yield by 2.2 t/ha in 2002 (Table 3). The yield was greatest at the highest rates of SOA, TSP and EFB (6 kg SOA/palm, 2 kg TSP/palm and 300 kg EFB/palm) (Table 2, 3 & 5). There were 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. The effect of the interaction between SOA, EFB and TSP on yield is shown in Table 5.

The effects of the treatments on tissue nutrient contents are given in Tables 6, 7, 8 and 9. Leaflet N and P were raised by SOA, TSP and EFB. SOA and EFB also increased leaflet K and Mg contents, and reduced Ca levels. MOP increased ash and Cl contents of the leaflets and rachis leaflets and rachis. Most of the leaflet nutrient levels (Ash, N, P, K, Cl, S) responded positively to EFB. Rachis nitrogen level was increased by SOA and EFB applications. The highest rate of SOA (6 kg/palm) with EFB application produced the highest of N. TSP alone raised rachis P content.

CONCLUSION

SOA, TSP and EFB continued to have substantial effects on yield in 2002. EFB substantially increases yield in the absence of SOA or TSP, and enhances yield when they are present.

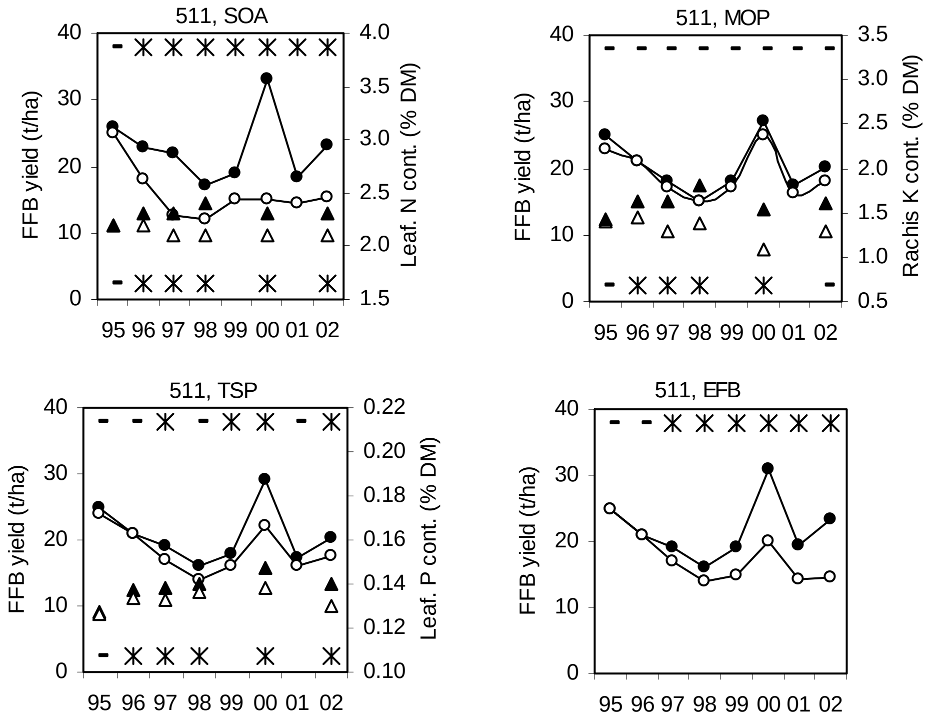


Figure 1. Main effects of SOA, MOP and TSP over the course of Trial 511. Lines are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate significance of the main effect 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 2000-2002 and 2002 (Trial 511). p values less than 0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	BNO	SBW	Yield	BNO	SBW
SOA	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.011**	**<0.001**
MOP	0.424	0.664	0.506	0.337	0.747	0.526
TSP	**<0.001**	**0.005**	**0.003**	**0.006**	0.284	**<0.001**
EFB	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
SOA.MOP	0.846	0.860	0.399	0.417	0.723	0.192
SOA.TSP	0.409	0.520	**0.032**	0.574	0.742	**0.010**
MOP.TSP	0.609	0.670	0.252	0.674	0.747	0.435
SOA.EFB	**0.037**	0.125	**0.003**	0.186	0.455	**<0.001**
MOP.EFB	0.914	0.917	0.659	0.563	0.444	0.331
TSP.EFB	**0.051**	0.142	**0.050**	0.258	0.588	**0.037**
SOA.MOP.TSP	0.761	0.792	0.640	0.515	0.551	0.396
SOA.MOP.EFB	0.583	0.645	0.157	0.719	0.739	**0.083**
SOA.TSP.EFB	0.449	0.745	0.329	0.756	0.795	0.164
MOP.TSP.EFB	0.818	0.920	0.691	0.914	0.998	0.448
CV %	14.5	14.0	7.0	17.4	19.9	6.4

Table 3. Main effects of treatments on FFB yield and its components (Trial 511). Significant effects (p<0.05) are shown in bold.

	2000-2002			2002		
	Yield (t/ha)	BNO (/ha)	SBW (kg)	Yield (t/ha)	BNO (/ha)	SBW (kg)
SOA0	**15.0**	**802**	**18.4**	**15.3**	**819**	**18.4**
SOA1	**19.3**	**919**	**20.9**	**16.8**	**793**	**21.0**
SOA2	**22.8**	**1015**	**22.5**	**20.6**	**941**	**22.1**
SOA3	**25.2**	**1130**	**22.4**	**23.2**	**1043**	**22.6**
sed	*1.06*	*47.8*	*0.52*	*1.16*	*63.2*	*0.48*
MOP0	19.8	934	20.9	18.0	880	20.6
MOP1	20.2	964	20.6	18.6	881	21.1
MOP2	20.8	975	21.1	19.0	894	21.1
MOP3	21.6	993	21.4	20.2	941	21.3
sed	*1.06*	*47.8*	*0.52*	*1.16*	*63.2*	*0.48*
TSP0	**18.7**	**904**	**20.3**	**17.5**	874	**19.9**
TSP1	**22.5**	**1029**	**21.8**	**20.4**	925	**22.2**
sed	*0.75*	*33.8*	*0.37*	*0.82*	*44.7*	*0.34*
EFB0	**16.5**	**840**	**19.1**	**14.6**	**773**	**18.7**
EFB1	**24.7**	**1093**	**22.9**	**23.3**	**1025**	**23.3**
sed	*0.75*	*33.8*	*0.37*	*0.82*	*44.7*	*0.34*

Table 4. Effect of two-way interactions on FFB yield (t/ha) in 2000-2002 (Trial 511). Significant ($p<0.05$) interactions are shown in bold.

SOA.MOP, p=0.846, lsd=4.78

	SOA0	SOA1	SOA2	SOA3
MOP0	14.6	18.9	21.9	24.0
MOP1	15.6	17.2	22.6	25.3
MOP2	14.7	20.3	23.7	24.4
MOP3	15.0	20.9	23.1	27.2

MOP.TSP, p=0.609, lsd=3.38

	TSP0	TSP1
MOP0	18.7	21.0
MOP1	18.3	22.1
MOP2	18.1	23.4
MOP3	19.6	23.5

SOA.TSP, p=0.409, lsd=3.38

	SOA0	SOA1	SOA2	SOA3
TSP0	13.9	17.7	20.4	22.6
TSP1	15.9	20.9	25.3	27.9

*EFB.TSP, **p=0.05**, lsd=2.39*

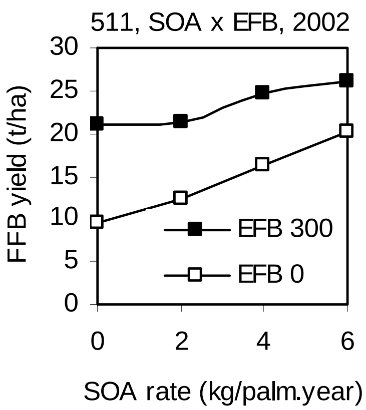
	TSP0	TSP1
EFB0	**13.7**	**19.2**
EFB1	**23.6**	**25.8**

*SOA.EFB**, p=0.037**, lsd=3.38*

	SOA0	SOA1	SOA2	SOA3
EFB0	**9.1**	**14.8**	**18.9**	**23.2**
EFB1	**20.8**	**23.8**	**26.8**	**27.3**

MOP.EFB, p=0.914, lsd=3.38

	EFB0	EFB1
MOP0	15.3	24.4
MOP1	16.3	23.9
MOP2	16.8	24.7
MOP3	17.4	25.7



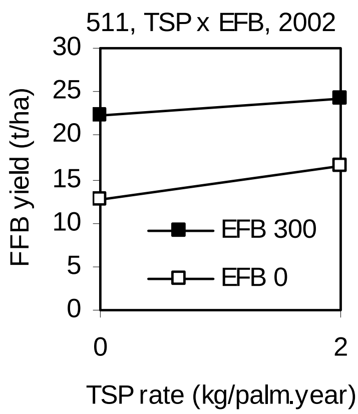


Figure 2. Effects of the interaction between SOA and EFB, and between TSP and EFB on FFB yield in 2002 (Trial 511).

Table 5. Effect of the SOA x EFB x P interaction on FFB yield (t/ha) in 2000-2002 (Trial 511). P=0.449, s.e.d. = 2.11 and l.s.d.(0.05) =4.78, CV (block.units)= 14.5%. Yields > 26 t/ha are highlighted in bold.

	TSP0			TSP1	
	EFB0	EFB1		EFB0	EFB1
SOA0	7.9	20.0	SOA0	10.3	21.5
SOA1	13.0	22.4	SOA1	16.6	25.3
SOA2	15.0	25.9	SOA2	22.7	**27.8**
SOA3	19.0	**26.1**	SOA3	**27.3**	**28.5**

Table 6 : Effects (p values) of treatments on frond 17 leaflet nutrient concentration in 2002. p values less than 0.05 are indicated in bold. Nutrient content in % DM, except B, in ppm DM.

Source	Ash	N	P	K	Mg	Ca	Cl	S	B	SO_4	Na
SOA	**0.045**	**<0.001**	**0.050**	**0.026**	**0.012**	**0.005**	0.946	0.164	0.168	0.131	0.880
MOP	**0.005**	0.641	0.313	0.070	0.338	0.158	**<0.001**	0.313	0.990	0.237	0.327
TSP	**<0.001**	**0.037**	**<0.001**	0.954	0.500	0.602	**0.006**	0.217	**0.026**	0.267	0.629
EFB	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.009**	**0.008**	**0.013**	**0.010**	**0.013**	**0.002**
SOA.MOP	**0.026**	0.692	0.490	0.622	0.947	0.414	0.993	0.397	0.302	0.396	0.575
SOA.TSP	**<0.001**	0.390	0.937	**0.018**	0.822	0.176	0.922	0.897	0.611	0.890	0.167
MOP.TSP	0.348	**0.016**	0.994	0.543	0.956	0.791	0.996	0.202	0.799	0.105	0.785
SOA.EFB	0.064	0.125	0.963	0.768	0.561	0.689	0.777	0.065	0.130	0.053	0.880
MOP.EFB	0.336	0.196	0.355	**0.010**	0.250	0.756	0.651	0.639	0.134	0.690	0.117
TSP.EFB	**<0.001**	0.197	**0.032**	0.292	0.258	0.383	0.135	0.399	0.770	0.267	0.168
SOA.MOP.TSP	**0.050**	0.925	0.328	0.796	0.325	0.150	0.772	0.567	0.451	**0.500**	0.906
SOA.MOP.EFB	**0.023**	0.392	0.485	0.075	0.528	0.507	0.989	0.239	0.505	0.295	0.400
SOA.TSP.EFB	**0.002**	0.512	**0.050**	0.410	0.853	0.809	0.415	0.678	0.265	0.601	0.176
MOP.TSP.EFB	**0.009**	0.874	0.814	0.768	0.959	0.218	0.692	0.332	0.645	0.186	0.238
CV %	*2.5*	*3.9*	*3.4*	*6.2*	*13.6*	*6.7*	*10.3*	*7.3*	*10.3*	*6.9*	*11.2*

Table 7 : Effects (p values) of treatments on frond 17 rachis nutrient concentration in 2002. p values less than 0.05 are indicated in bold.

Source	Ash	N	P	K	Mg	Ca	Cl	S	B	SO_4	Na
SOA	0.203	**0.002**	**0.009**	0.614	0.195	0.991	0.946	0.317	0.960	0.832	**0.031**
MOP	**0.019**	0.185	0.283	0.144	0.852	0.160	**<0.001**	0.209	0.187	0.697	0.253
TSP	0.547	0.210	**<0.001**	0.632	0.844	0.694	**0.006**	0.064	0.182	**0.006**	**0.004**
EFB	0.302	**<0.001**	0.150	0.116	**0.009**	**0.039**	**0.008**	0.194	0.841	0.264	**0.011**
SOA.MOP	0.157	0.485	0.910	0.279	0.802	0.811	0.993	0.232	0.538	0.676	0.084
SOA.TSP	0.681	0.186	0.054	0.700	0.889	0.306	0.922	0.410	0.200	0.897	0.733
MOP.TSP	0.217	0.525	0.361	0.200	0.676	0.936	0.996	0.645	0.689	0.758	0.369
SOA.EFB	0.199	0.786	0.948	0.580	0.259	0.577	0.777	0.265	0.908	0.397	0.825
MOP.EFB	0.152	0.177	0.573	0.091	0.281	0.988	0.651	0.085	0.387	0.183	0.157
TSP.EFB	0.900	0.425	0.491	0.572	0.715	0.184	0.135	0.734	**0.027**	1.000	0.166
SOA.MOP.TSP	0.854	0.637	0.827	0.849	0.904	0.936	0.772	0.477	0.304	0.206	0.546
SOA.MOP.EFB	0.573	0.587	0.661	0.709	0.927	0.973	0.989	0.303	0.654	0.168	0.449
SOA.TSP.EFB	0.926	0.949	0.949	0.984	0.738	0.360	0.415	0.777	0.242	0.934	0.409
MOP.TSP.EFB	0.678	0.831	0.822	0.466	0.854	0.745	0.692	0.890	0.655	0.553	0.521
CV %	*14.6*	*8.0*	*15.7*	*25.3*	*38.8*	*14.8*	*10.3*	*14.2*	*8.1*	*22.1*	*7.4*

Table 8. Main effects of treatments on frond 17 leaflet nutrient concentrations in 2002, in units of % dry matter except for B which is expressed as mg/kg DM (Trial 511). Significant effects ($p<0.05$) are shown in bold.

Treatments	Ash	N	P	K	Mg	Ca	Cl	S	B	SO_4	Na
SOA0	**13.0**	**2.1**	**0.13**	**0.66**	**0.36**	**0.83**	0.53	0.16	10.9	0.46	0.02
SOA1	**13.4**	**2.1**	**0.13**	**0.67**	**0.33**	**0.82**	0.53	0.15	10.4	0.45	0.02
SOA2	**13.1**	**2.2**	**0.14**	**0.70**	**0.32**	**0.78**	0.54	0.16	10.5	0.47	0.02
SOA3	**13.0**	**2.3**	**0.14**	**0.69**	**0.30**	**0.75**	0.54	0.16	9.9	0.48	0.02
s.e.d	*0.12*	*0.03*	*0.002*	*0.02*	*0.02*	*0.02*	*0.02*	*0.004*	*0.38*	*0.011*	*0.001*
MOP0	**13.0**	2.2	0.14	0.65	0.34	0.77	**0.46**	0.15	10.5	0.45	0.02
MOP1	**13.3**	2.2	0.14	0.68	0.33	0.81	**0.56**	0.16	10.4	0.47	0.02
MOP2	**13.2**	2.2	0.14	0.70	0.33	0.80	**0.56**	0.15	10.5	0.46	0.02
MOP3	**13.0**	2.2	0.14	0.69	0.31	0.81	**0.57**	0.16	10.4	0.47	0.02
s.e.d	*0.12*	*0.03*	*0.002*	*0.02*	*0.02*	*0.02*	*0.02*	*0.004*	*0.38*	*0.011*	*0.001*
TSP0	**13.5**	**2.2**	**0.13**	0.68	0.33	0.79	**0.51**	0.15	**10.8**	**0.46**	0.02
TSP1	**12.8**	**2.3**	**0.14**	0.68	0.32	0.80	**0.56**	0.16	**10.1**	**0.47**	0.02
s.e.d	*0.08*	*0.02*	*0.001*	*0.01*	*0.01*	*0.01*	*0.01*	*0.003*	*0.27*	*0.008*	*0.001*
EFB0	**13.6**	**2.2**	**0.13**	**0.63**	**0.36**	**0.82**	**0.51**	**0.15**	**10.9**	0.45	**0.02**
EFB1	**12.7**	**2.3**	**0.14**	**0.73**	**0.30**	**0.77**	**0.56**	**0.16**	**10.0**	0.47	**0.02**
s.e.d	*0.08*	*0.02*	*0.001*	*0.01*	*0.01*	*0.01*	*0.01*	*0.003*	*0.27*	*0.008*	*0.001*

Table 9. Main effects of treatments on frond 17 rachis nutrient concentrations in 2002, in units of % dry matter except for B which is expressed as mg/kg DM (Trial 511). Significant effects ($p<0.05$) are shown in bold.

Treatments	Ash	N	P	K	Mg	Ca	Cl	S	B	SO_4	Na
SOA0	4.9	**0.22**	**0.13**	1.6	0.13	0.31	0.53	0.05	6.0	0.15	**0.05**
SOA1	4.6	**0.24**	**0.08**	1.5	0.11	0.31	0.53	0.05	5.9	0.14	**0.04**
SOA2	4.3	**0.25**	**0.08**	1.4	0.11	0.31	0.54	0.05	5.9	0.14	**0.04**
SOA3	4.5	**0.26**	**0.06**	1.5	0.10	0.31	0.54	0.05	5.9	0.14	**0.04**
s.e.d	*0.24*	*0.006*	*0.01*	*0.14*	*0.02*	*0.02*	*0.02*	*0.003*	*0.17*	*0.01*	*0.001*
MOP0	**4.0**	0.24	0.07	1.3	0.11	0.29	**0.46**	0.05	5.9	0.15	0.04
MOP1	**4.8**	0.25	0.09	1.6	0.10	0.32	**0.56**	0.05	6.1	0.15	0.04
MOP2	**4.7**	0.23	0.10	1.6	0.12	0.31	**0.56**	0.05	5.7	0.14	0.04
MOP3	**4.8**	0.25	0.08	1.6	0.12	0.33	**0.57**	0.05	6.1	0.14	0.05
s.e.d	*0.24*	*0.006*	*0.01*	*0.14*	*0.02*	*0.02*	*0.02*	*0.003*	*0.17*	*0.01*	*0.001*
TSP0	4.6	0.24	**0.05**	1.5	0.11	0.31	**0.51**	0.05	**5.9**	0.16	**0.05**
TSP1	4.5	0.25	**0.13**	1.5	0.11	0.31	**0.56**	0.05	**6.0**	0.13	**0.04**
s.e.d	*0.17*	*0.004*	*0.01*	*0.09*	*0.01*	*0.01*	*0.01*	*0.002*	*0.12*	*0.008*	*0.0008*
EFB0	4.5	**0.23**	0.08	1.4	**0.13**	**0.33**	**0.51**	**0.05**	**6.0**	**0.14**	**0.05**
EFB1	4.7	**0.26**	0.10	1.6	**0.09**	**0.30**	**0.56**	**0.05**	**6.0**	**0.15**	**0.04**
s.e.d	*0.17*	*0.004*	*0.01*	*0.09*	*0.01*	*0.01*	*0.01*	*0.002*	*0.12*	*0.008*	*0.0008*

FERTILISER RESPONSE TRIALS IN NEW IRELAND

(P. Nelson)

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 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 this write-up FFB yield and its components has been calculated on a ‘per live palm’ basis (the same as for all other trials), using the 2000 palm census data. The effects of the treatments on the number of dead and missing palms has been tested separately.

RESULTS

Yield and tissue nutrient concentrations in Trial 251

In this trial, MOP continued to be the only fertiliser that significantly influenced FFB yield and its components (Tables 2 and 3). Yield was again doubled by the application of 2.5 kg MOP/palm, with 5 kg providing no extra benefit (Table 3). There were no significant interactions between the effects of MOP and the other fertilisers (Table 2). There was still no effect of SOA after 11 years without any addition of N. It is unlikely that the soil is still providing sufficient N; perhaps the cover crop is supplying an adequate amount to maintain yields. The effect of the interaction between SOA and MOP on yield is shown in Table 4. Soil depth did not significantly influence yield or its components (Table 2), nor did it significantly improve the model for most parameters (Efficiency factor <1, Table 3).

Application of MOP influenced tissue contents of all nutrients (Tables 5 and 6). In the leaflets, concentrations of N, P and K increased and ash, Mg, Ca, B and Cl decreased. However, even at the highest MOP application rate, leaflet Mg, Ca, B and Cl contents were well above critical levels. In the rachis, ash and K contents were increased, the increase in K content being enormous. The effects of the interaction between SOA and MOP on leaflet N content and rachis K content are shown in Tables 7 and 8. A comparison between nutrient contents in Frond 3 and 17 is shown in Table 22.

The main effects of the treatments on yield and tissue contents over the course of the trial are shown in Figure 1. The effect of MOP has increased through time and there has been no significant effect of SOA, TSP or kieserite throughout the life of the trial.

Yield and tissue nutrient concentrations in Trial 252

MOP had the largest effect on yield and its components (Tables 9 and 10). SOA and TSP also had significant effects and interactions with MOP. Yields were highest where SOA and MOP were both applied at 5 kg/palm, or where one (either) was applied at 2.5 kg/palm and the other at 5 kg/palm (Table 11). TSP had a positive effect on yield where no SOA or MOP were applied (Tables 12 and 13).

MOP application increased N and P contents of the leaflets and K content of the rachis, and SOA increased N content of the leaflets (Tables 14 and 15). Leaflet N was highest where both SOA and MOP were applied (Table 16), whereas rachis K content was not influenced by SOA (Table 17). A comparison between nutrient contents in Frond 3 and 17 is shown in Table 23.

The main effects of the treatments on yield and tissue contents over the course of the trial are shown in Figure 1. The large effect of MOP has increased through time and SOA has started to have an effect in the last few years.

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

The 2002 results confirm those reported in the previous annual report. The latest census data was from July 2003. If we assume that dead and missing palms were dead or removed due to Ganoderma infection, then MOP application had a large positive influence on the ability of the palms to resist the disease (Tables 18-21). TSP and kieserite also tended to reduce Ganoderma incidence, and SOA tended to increase it. In Trial 251 kieserite had an effect with or without MOP, whereas in Trial 252 kieserite only had an effect when MOP was also applied (Figure 3).

In Trial 251 the effect of the fertilisers was most marked in the 1998-2000 period and in Trial 252 the fertiliser effects were most marked in 1998-2003 (Figure 2). Possible reasons for the decrease in treatment effect over the last 2 years in Trial 251 were discussed in last year’s report.

The effect of soil depth was not significant in 2003. In previous years soil depth was positively correlated with dead/missing palms in 251 and negatively correlated in 252. The difference may be due to the distribution of soil depth in the plots, which is much more variable in 252 than 251 (Figure 4).

Plans for the trial

Yield recording has stopped at the end of 2002, but the treatments are still being applied in 2003, as the site may be useful for a progeny by MOP trial. Soil, trunk and bunch samples are being taken in 2003 for nutrient analyses so that nutrient budgets can be estimated. That will allow assessment of whether the MOP application strategy used in the trial is effective or if there have been significant losses of K and hence the potential for more efficient application methods.

CONCLUSION

The effects of fertilisers on yield and tissue nutrient contents in these trials were similar in 2002 to previous years. MOP had a major effect on yield in both trials. SOA has had no effect in Trial 251 but has had an increasing effect in Trial 252. Fertiliser application, especially MOP has had a large beneficial effect on decreasing the incidence of Ganoderma in these trials.

Table 2. Effects (p values) of treatments and the soil depth covariate on FFB yield and its components in 2000-2002 and 2002 (Trial 251). p values <0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	0.650	0.701	0.997	0.812	0.727	0.743
MOP	**0.004**	**0.016**	**0.002**	**0.014**	**0.090**	**0.003**
TSP	0.948	0.892	0.467	0.534	0.811	0.242
KIE	0.658	0.425	0.333	0.780	0.578	0.375
SOA.MOP	0.691	0.918	0.191	0.881	0.781	0.185
SOA.TSP	0.974	0.916	0.753	0.956	0.989	0.725
MOP.TSP	0.506	0.425	0.831	0.977	0.955	0.941
SOA.KIE	0.940	0.986	0.365	0.928	0.975	0.361
MOP.KIE	0.680	0.753	0.539	0.960	0.870	0.526
TSP.KIE	0.748	0.665	0.893	0.578	0.613	0.531
SOA.MOP.TSP	0.743	0.528	0.866	0.798	0.697	0.759
SOA.MOP.KIE	0.712	0.852	0.832	0.812	0.908	0.764
SOA.TSP.KIE	0.546	0.545	0.767	0.480	0.533	0.844
MOP.TSP.KIE	0.645	0.824	0.233	0.758	0.949	0.222
Soil depth	0.862	0.891	0.676	0.494	0.367	0.934
CV %	17.5	16.1	7.9	24.3	25.6	9.2

Table 3. Main effects of treatments on FFB yield (t/ha) and its components, adjusted for depth covariate (Trial 251). Also shown are the depth covariate coefficient (cm) and covariate efficiency. Effects with p<0.1 are shown in bold.

	2000-2002			2002		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA0	20.0	1044	18.7	21.3	1132	18.5
SOA1	21.0	1066	18.8	20.1	1043	18.4
SOA2	21.7	1115	18.8	21.4	1121	19.0
s.e.d.	*1.51*	*71.4*	*0.62*	*2.11*	*116.2*	*0.71*
MOP0	**11.6**	**791**	**13.8**	**12.8**	**903**	**13.4**
MOP1	**26.1**	**1232**	**21.5**	**26.2**	**1261**	**21.2**
MOP2	**25.1**	**1202**	**21.1**	**23.8**	**1130**	**21.2**
s.e.d.	*1.72*	*80.9*	*0.70*	*2.39*	*131.6*	*0.81*
TSP0	21.0	1074	19.0	21.5	1102	19.1
TSP1	20.8	1077	18.6	20.4	1094	18.2
s.e.d.	*1.27*	*59.8*	*0.52*	*1.76*	*97.2*	*0.60*
KIE0	20.8	1057	19.1	20.5	1045	19.0
KIE1	21.0	1094	18.5	20.4	1151	18.2
s.e.d.	*1.60*	*75.3*	*0.65*	*2.22*	*122.5*	*0.75*
Depth coeff.	0.05	2	0.05	0.30	23	0.01
s.e.	*0.282*	*13.3*	*0.115*	*0.392*	*21.6*	*0.132*
Effic.	*0.76*	*0.76*	*0.80*	*0.90*	*1.03*	*0.75*

Table 4. Effect of the interaction between SOA and MOP on FFB yield (t/ha) in 2000-2000 and 2002 (Trial 251). Yields >26 t/ha are highlighted in bold.

2000-2002, p=0.691, lsd=10.22				2002, p=0.881, lsd=14.21			
	MOP0	MOP1	MOP2		MOP0	MOP1	MOP2
SOA0	12.7	23.6	23.6	SOA0	13.9	**26.1**	23.9
SOA1	10.3	**27.7**	25.1	SOA1	11.4	**26.3**	22.7
SOA2	11.8	**26.9**	**26.6**	SOA2	12.9	**26.3**	24.9

Table 5. Effects (p values) of treatments and the soil depth covariate on frond 17 nutrient concentrations in 2002 (Trial 251). p values <0.1 are indicated in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	0.772	0.735	0.208	**0.011**	0.674	**0.018**	**0.085**	0.538	**0.007**	**0.016**
MOP	**0.073**	**0.096**	**0.061**	**<.001**	**0.002**	**<.001**	**0.001**	**0.057**	**<.001**	**<.001**
TSP	0.829	0.465	0.127	**0.073**	0.723	0.360	0.124	0.458	0.719	0.221
KIE	0.874	0.575	0.518	**0.067**	0.132	**0.011**	1.000	0.381	0.125	0.147
SOA.MOP	0.945	0.924	0.840	0.132	0.924	0.229	0.524	0.647	**0.015**	0.198
SOA.TSP	0.592	0.587	0.796	**0.055**	0.749	**0.024**	**0.015**	0.369	**0.017**	0.480
MOP.TSP	0.988	0.705	0.193	0.117	0.599	0.556	0.222	0.997	0.152	0.382
SOA.KIE	0.909	0.761	0.733	0.502	0.813	**0.078**	0.908	0.734	0.158	0.164
MOP.KIE	0.470	0.498	0.755	0.215	0.901	**0.063**	0.302	0.659	0.141	0.271
TSP.KIE	0.919	0.232	0.341	0.221	0.358	**0.041**	0.633	0.414	0.278	0.808
SOA.MOP.TSP	0.429	0.713	0.388	**0.021**	0.670	**0.037**	0.385	0.830	0.247	0.371
SOA.MOP.KIE	0.949	0.715	0.684	**0.022**	0.966	**0.068**	0.172	0.693	0.383	0.274
SOA.TSP.KIE	0.807	0.806	0.451	0.118	0.898	0.176	0.740	0.818	**0.049**	0.295
MOP.TSP.KIE	0.825	0.412	0.545	**0.032**	0.567	0.127	0.201	0.298	0.792	0.845
Soil depth	0.809	0.342	0.758	0.845	0.972	0.574	0.246	0.591	0.113	0.844
CV %	14.9	8.4	4.5	2.9	17.6	2.6	5.0	12.4	4.0	9.6

Table 6. Main effects of treatments on frond 17 nutrient concentrations in 2002, in units of % dry matter, except for B (mg/kg DM). Values are adjusted for depth covariate (Trial 251). Also shown are the depth covariate coefficient (cm) and covariate efficiency. Effects with p<0.1 are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA0	7.4	2.13	0.143	**0.54**	0.34	**1.30**	**13.8**	0.59	**4.1**	**0.97**
SOA1	7.7	2.19	0.139	**0.49**	0.36	**1.25**	**14.6**	0.62	**3.7**	**0.81**
SOA2	7.7	2.20	0.145	**0.52**	0.34	**1.21**	**13.7**	0.60	**3.6**	**0.77**
s.e.d.	*0.47*	*0.076*	*0.003*	*0.006*	*0.025*	*0.014*	*0.29*	*0.031*	*0.062*	*0.034*
MOP0	**8.6**	**2.00**	**0.137**	**0.28**	**0.54**	**1.42**	**16.7**	**0.68**	**3.3**	**0.15**
MOP1	**7.2**	**2.23**	**0.144**	**0.61**	**0.26**	**1.15**	**12.6**	**0.55**	**3.7**	**0.96**
MOP2	**7.0**	**2.29**	**0.147**	**0.66**	**0.24**	**1.20**	**12.7**	**0.58**	**4.3**	**1.44**
s.e.d.	*0.53*	*0.086*	*0.003*	*0.007*	*0.029*	*0.016*	*0.33*	*0.035*	*0.070*	*0.038*
TSP0	7.6	2.20	0.140	**0.52**	0.35	1.25	14.3	0.59	3.7	0.87
TSP1	7.7	2.14	0.145	**0.51**	0.34	1.26	13.7	0.62	3.8	0.83
s.e.d.	*0.39*	*0.063*	*0.002*	*0.005*	*0.021*	*0.011*	*0.24*	*0.026*	*0.052*	*0.028*
KIE0	7.6	2.17	0.142	**0.52**	0.33	**1.28**	14.1	0.61	3.8	0.87
KIE1	7.7	2.17	0.143	**0.51**	0.37	**1.23**	13.9	0.59	3.8	0.83
s.e.d.	*0.50*	*0.080*	*0.003*	*0.006*	*0.027*	*0.014*	*0.31*	*0.033*	*0.065*	*0.036*
Depth coeff.	0.023	-0.016	-0.000	0.000	0.000	0.002	-0.078	0.004	0.026	0.001
s.e.	*0.087*	*0.014*	*0.000*	*0.001*	*0.005*	*0.003*	*0.054*	*0.006*	*0.012*	*0.006*
Effic.	*0.77*	*1.07*	*0.78*	*0.76*	*0.75*	*0.85*	*1.27*	*0.84*	*1.98*	*0.76*

Table 7. Effect of interaction between SOA and MOP on leaflet N content (% DM) in 2002 (Trial 251). P =0.924 and l.s.d.(0.05) =0.510. The ANOVA was adjusted for depth covariate.

	MOP0	MOP1	MOP2
SOA0	1.97	2.11	2.30
SOA1	1.94	2.34	2.29
SOA2	2.10	2.22	2.27

Table 8. Effect of interaction between SOA and MOP on rachis K content (% DM) in 2002 (Trial 251). P =0.198 and l.s.d.(0.05) =0.228. The ANOVA was adjusted for depth covariate.

	MOP0	MOP1	MOP2
SOA0	0.19	1.11	1.60
SOA1	0.13	0.90	1.41
SOA2	0.12	0.87	1.03

Table 9. Effects (p values) of treatments and the soil depth covariate on FFB yield and its components in 2000-2002 and 2002 (Trial 252). p values <0.1 are indicated in bold.

	2000-2002			2002		
Source	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA	**0.027**	0.123	0.121	**0.033**	**0.002**	0.427
MOP	**<.001**	**0.005**	**0.003**	**0.001**	**<.001**	**0.014**
TSP	**0.098**	0.202	0.180	0.372	**0.051**	0.363
KIE	0.937	0.442	0.284	0.828	**0.017**	0.647
SOA.MOP	**0.070**	0.182	0.205	0.131	**0.002**	0.824
SOA.TSP	**0.059**	0.128	0.270	0.114	**0.005**	0.678
MOP.TSP	**0.075**	0.168	0.186	**0.081**	**0.003**	0.398
SOA.KIE	0.519	0.683	0.575	0.885	0.207	0.886
MOP.KIE	0.402	0.280	0.125	0.601	0.124	0.277
TSP.KIE	0.611	0.749	0.524	0.107	**0.001**	0.938
SOA.MOP.TSP	0.422	0.608	0.375	0.516	**0.011**	0.912
SOA.MOP.KIE	0.258	0.911	0.251	0.551	**0.035**	0.519
SOA.TSP.KIE	0.706	0.876	0.835	0.684	**0.020**	0.600
MOP.TSP.KIE	0.432	0.369	0.718	0.329	**0.011**	0.764
Soil depth	0.918	0.398	0.747	0.390	0.311	0.308
CV %	8.1	9.9	6.9	10.7	2.5	12.0

Table 10. Main effects of treatments on FFB yield (t/ha) and its components, adjusted for depth covariate (Trial 252). Also shown are the depth covariate coefficient (cm) and covariate efficiency. Effects with p<0.1 are shown in bold.

	2000-2002			2002		
	Yield	Bun./ha	kg/bun.	Yield	Bun./ha	kg/bun.
SOA0	**22.4**	1215	17.9	**20.5**	**1117**	18.1
SOA1	**26.7**	1367	19.6	**25.2**	**1294**	19.6
SOA2	**25.8**	1293	19.0	**25.3**	**1259**	19.5
s.e.d.	*0.85*	*53.5*	*0.55*	*1.06*	*12.8*	*0.96*
MOP0	**16.0**	**1013**	**15.1**	**14.3**	**937**	**15.0**
MOP1	**28.8**	**1416**	**20.6**	**27.1**	**1310**	**21.0**
MOP2	**30.1**	**1446**	**20.8**	**29.6**	**1423**	**21.2**
s.e.d.	*0.93*	*58.3*	*0.60*	*1.16*	*13.9*	*1.04*
TSP0	**24.1**	1254	18.4	23.2	**1206**	18.7
TSP1	**25.8**	1329	19.2	24.1	**1241**	19.4
s.e.d.	*0.68*	*42.7*	*0.44*	*0.85*	*10.2*	*0.76*
KIE0	25.0	1314	18.6	23.8	**1250**	18.8
KIE1	24.9	1269	19.1	23.5	**1198**	19.3
s.e.d.	*0.68*	*42.8*	*0.44*	*0.85*	*10.2*	*0.77*
Depth coeff.	-0.008	-4.5	0.017	0.092	1.3	0.101
s.e.	*0.074*	*4.61*	*0.047*	*0.092*	*1.1*	*0.083*
Effic.	*0.75*	*0.99*	*0.78*	*1.00*	*1.12*	*1.12*

Table 11. Effect of the interaction between SOA and MOP on FFB yield (t/ha) in 2000-2002 and 2002 (Trial 252). Yields >30 t/ha are highlighted in bold.

2000-2002, p=0.070, $lsd_{0.05}$=5.12				2002, p=0.131, $lsd_{0.05}$=6.38			
	MOP0	MOP1	MOP2		MOP0	MOP1	MOP2
SOA0	13.9	27.2	26.1	SOA0	13.5	23.6	24.2
SOA1	20.9	28.1	**31.2**	SOA1	16.6	27.2	**31.7**
SOA2	13.2	**31.0**	**33.1**	SOA2	12.8	**30.5**	**32.7**

Table 12. Effect of the interaction between SOA and TSP on FFB yield (t/ha) in 2000-2002 and 2002 (Trial 252).

2000-2002, p=0.059, $lsd_{0.05}$=3.89			2002, p=0.114, $lsd_{0.05}$=4.84		
	TSP0	TSP1		TSP0	TSP1
SOA0	19.6	25.2	SOA0	18.2	22.7
SOA1	26.5	27.0	SOA1	26.1	24.3
SOA2	26.3	25.3	SOA2	25.3	25.4

Table 13. Effect of the interaction between MOP and TSP on FFB yield (t/ha) in 2000-2002 and 2002 (Trial 252). Yields >30 t/ha are highlighted in bold.

2000-2002, p=0.075, $lsd_{0.05}$=3.99			2002, p=0.081, $lsd_{0.05}$=4.97		
	TSP0	TSP1		TSP0	TSP1
MOP0	13.6	18.4	MOP0	12.1	16.5
MOP1	29.2	28.4	MOP1	28.5	25.7
MOP2	29.6	**30.6**	MOP2	29.0	**30.1**

Table 14. Effects (p values) of treatments and the soil depth covariate on frond 17 nutrient concentrations in 2002 (Trial 252). p values <0.1 are indicated in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA	0.518	**0.036**	0.154	0.276	**0.018**	0.946	0.405	0.830	0.549	0.351
MOP	**0.009**	**0.004**	**0.027**	**<.001**	**<.001**	**0.054**	**0.031**	**0.013**	**0.018**	**0.004**
TSP	0.977	0.311	0.203	0.751	**0.020**	0.285	0.976	0.272	0.813	0.936
KIE	0.723	0.247	0.669	0.218	**0.002**	0.171	0.213	0.170	0.330	0.527
SOA.MOP	0.501	0.248	0.639	0.179	0.174	0.474	0.562	0.391	0.696	0.717
SOA.TSP	0.672	0.225	0.946	0.861	0.124	0.348	0.993	0.611	0.527	0.367
MOP.TSP	0.660	**0.032**	0.617	0.268	**0.019**	0.991	0.549	0.090	0.772	0.826
SOA.KIE	0.141	0.475	0.973	0.885	0.161	0.589	0.586	0.582	0.985	0.893
MOP.KIE	0.760	**0.026**	0.539	0.729	**0.051**	0.428	0.811	0.922	0.231	0.530
TSP.KIE	0.810	0.493	0.851	0.424	0.126	0.609	0.625	0.134	0.952	0.805
SOA.MOP.TSP	0.379	0.119	0.445	0.728	**0.074**	0.907	0.429	0.403	0.770	0.804
SOA.MOP.KIE	0.587	0.137	0.536	0.251	0.590	0.915	0.555	0.156	0.866	0.906
SOA.TSP.KIE	0.432	0.233	0.942	0.550	0.917	0.963	0.400	0.202	0.566	0.443
MOP.TSP.KIE	0.528	0.151	0.556	0.320	0.957	0.632	0.449	0.189	0.647	0.579
Soil depth	0.356	**0.011**	0.165	0.720	0.841	0.194	0.761	0.182	0.193	0.216
CV %	7.8	2.4	3.9	6.3	4.9	7.3	8.6	6.0	17.5	35.2

Table 15. Main effects of treatments on frond 17 nutrient concentrations in 2002, in units of % dry matter, except for B (mg/kg DM). Also shown are the depth covariate coefficient (cm) and covariate efficiency. Values are adjusted for depth covariate (Trial 252). Effects with p<0.1 are shown in bold.

	Leaflet								Rachis	
	Ash	N	P	K	Mg	Ca	B	Cl	Ash	K
SOA0	6.5	**2.27**	0.144	0.54	**0.35**	1.23	11.5	0.61	3.8	1.01
SOA1	6.7	**2.37**	0.151	0.58	**0.31**	1.22	11.4	0.62	3.6	0.88
SOA2	6.9	**2.43**	0.151	0.57	**0.31**	1.22	11.0	0.62	3.4	0.78
s.e.d.	*0.218*	*0.024*	*0.002*	*0.015*	*0.007*	*0.038*	*0.41*	*0.016*	*0.27*	*0.132*
MOP0	**7.6**	**2.17**	**0.140**	0.33	**0.49**	**1.30**	**12.2**	**0.67**	**2.9**	**0.20**
MOP1	**6.2**	**2.44**	**0.154**	0.65	**0.25**	**1.22**	**11.3**	**0.59**	**3.5**	**1.01**
MOP2	**6.2**	**2.46**	**0.152**	0.72	**0.23**	**1.15**	**10.5**	**0.59**	**4.4**	**1.47**
s.e.d.	*0.238*	*0.026*	*0.003*	*0.016*	*0.007*	*0.041*	*0.45*	*0.017*	*0.29*	*0.144*
TSP0	6.7	2.35	0.147	0.56	**0.34**	1.21	11.4	0.63	3.6	0.89
TSP1	6.7	2.36	0.150	0.57	**0.31**	1.24	11.3	0.61	3.6	0.89
s.e.d.	*0.174*	*0.019*	*0.002*	*0.012*	*0.005*	*0.030*	*0.33*	*0.012*	*0.21*	*0.105*
KIE0	6.6	2.37	0.149	0.57	**0.30**	1.25	11.5	0.63	3.7	0.94
KIE1	6.7	2.35	0.148	0.55	**0.35**	1.20	11.1	0.61	3.5	0.85
s.e.d.	*0.175*	*0.019*	*0.002*	*0.012*	*0.005*	*0.030*	*0.33*	*0.012*	*0.21*	*0.106*
Depth coeff.	0.020	0.012	0.000	-0.001	0.000	-0.005	-0.012	0.002	-0.038	-0.018
s.e.	*0.019*	*0.002*	*0.000*	*0.001*	*0.001*	*0.003*	*0.035*	*0.001*	*0.023*	*0.011*
Effic.	*1.05*	*8.71*	*1.59*	*0.79*	*0.76*	*1.45*	*0.78*	*1.50*	*1.45*	*1.36*

Table 16. Effect of interaction between SOA and MOP on leaflet N content (% DM) in 2002 (Trial 252). P =0.248, and l.s.d.(0.05) =0.145. The ANOVA was adjusted for depth covariate.

	MOP0	MOP1	MOP2
SOA0	2.16	2.31	2.35
SOA1	2.10	2.54	2.47
SOA2	2.25	2.48	2.57

Table 17. Effect of interaction between SOA and MOP on rachis K content (% DM) in 2002 (Trial 252). P =0.717 and l.s.d.(0.05) =0.792. The ANOVA was adjusted for depth covariate.

	MOP0	MOP1	MOP2
SOA0	0.14	1.22	1.67
SOA1	0.39	0.93	1.34
SOA2	0.05	0.90	1.40

Table 18. Total numbers of dead/missing palms and significance (F probability values) of treatment effects and soil depth covariate on dead/missing palms in Trial 251. p values <0.1 are shown in bold.

	Recorded palms						Recorded + guard row palms			
Factor	1996	1997	1998	2000	2001	2003	1996	2001	2002	2003
No. of palms	*4*	*14*	*13*	*25*	*46*	*65*	*16*	*109*	*138*	*141*
SOA	0.401	0.377	0.157	0.192	0.318	0.801	0.813	0.293	0.478	0.604
MOP	0.512	**0.096**	**0.099**	**0.067**	0.547	0.489	0.486	0.417	0.614	0.419
TSP	0.465	0.121	**0.034**	0.120	0.708	0.627	1.000	0.433	0.272	0.808
KIE	0.504	0.124	**0.078**	**0.028**	0.248	0.386	0.147	**0.094**	**0.026**	**0.061**
SOA.MOP	0.611	0.735	0.178	0.174	0.233	0.864	0.613	0.411	0.455	0.749
SOA.TSP	0.861	0.367	0.280	0.283	0.258	0.654	0.545	0.181	0.264	0.229
MOP.TSP	0.535	0.277	0.101	0.557	0.357	0.957	0.445	0.384	0.367	0.919
SOA.KIE	0.245	0.371	0.280	0.910	0.670	0.754	0.353	0.135	0.208	0.389
MOP.KIE	0.435	0.276	0.280	0.849	0.470	0.730	0.168	0.115	0.113	0.203
TSP.KIE	1.000	0.631	0.208	**0.038**	**0.057**	0.434	0.437	**0.060**	**0.085**	0.346
SOA.MOP.TSP	0.347	0.284	**0.060**	0.549	0.515	0.729	0.348	0.225	0.129	0.252
SOA.MOP.KIE	0.344	0.225	**0.040**	**0.090**	0.228	0.986	0.554	0.549	0.551	0.422
SOA.TSP.KIE	0.604	0.382	0.275	**0.097**	0.277	0.654	0.536	0.380	0.186	0.514
MOP.TSP.KIE	0.490	0.775	0.155	0.636	0.945	0.924	0.980	0.405	0.539	0.616
Soil depth	0.314	**0.068**	**0.015**	**0.032**	0.113	0.589	0.411	0.349	0.225	0.232

Table 19. Main effects of treatments and soil depth on numbers of dead/missing palms (% of palms) 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 row palms			
Factor	1996	1997	1998	2000	2001	2003	1996	2001	2002	2003
SOA 0	0.14	1.56	1.51	3.69	6.31	9.75	1.03	7.14	9.81	9.92
SOA 1	0.53	3.69	3.14	3.66	8.38	12.00	1.39	8.58	10.89	11.36
SOA 2	1.43	2.06	2.13	5.66	9.31	12.13	1.31	9.53	11.28	11.36
s.e.d.	*1.00*	*1.59*	*0.81*	*1.33*	*2.27*	*5.17*	*0.84*	*1.58*	*1.75*	*2.48*
MOP 0	1.51	**3.81**	**3.69**	**4.57**	9.75	15.81	1.47	9.25	12.14	13.94
MOP 1	1.05	**5.25**	**3.68**	**7.34**	9.44	12.00	1.86	9.75	11.61	11.83
MOP 2	-0.48	**-1.75**	**-0.60**	**1.11**	4.75	6.06	0.36	6.25	8.19	6.86
s.e.d.	*1.13*	***1.81***	***0.91***	***1.51***	*2.57*	*5.86*	*0.96*	*1.79*	*1.98*	*2.81*
TSP 0	0.91	3.31	**3.01**	4.98	7.06	9.69	1.22	7.53	9.28	10.08
TSP 1	0.49	1.56	**1.51**	3.70	8.94	12.88	1.22	9.31	12.03	11.69
s.e.d.	*0.84*	*1.33*	***0.68***	*1.12*	*1.90*	*4.33*	*0.71*	*1.32*	*1.46*	*2.08*
KIE 0	0.63	2.31	**1.73**	**4.88**	7.69	12.13	1.58	**8.97**	**12.22**	**12.17**
KIE 1	0.76	2.56	**2.79**	**3.80**	8.31	10.44	0.89	**7.83**	**9.08**	**9.58**
s.e.d.	*1.05*	*1.68*	***0.85***	***1.41***	*2.39*	*5.45*	*0.89*	***1.66***	***1.84***	***2.61***
Depth. Coeff.*	2.25	**8.31**	**7.69**	**9.38**	9.38	5.63	1.50	7.50	11.25	15.63
s.e.	*1.86*	***2.96***	***1.50***	***2.48***	*4.22*	*9.63*	*1.57*	*6.63*	*7.31*	*10.38*
Covar. Effic.	*1.11*	*2.71*	*7.28*	*4.34*	*1.99*	*0.84*	*0.98*	*1.06*	*1.33*	*1.31*

* Units of dead/missing palms (% of recorded) for every 10cm increase in soil depth

Table 20. Total numbers of dead/missing palms and significance (F probability values) of treatment effects and soil depth covariate on dead/missing palms in Trial 252. p values <0.1 are shown in bold.

	Recorded palms						Recorded + guard row palms			
Factor	1996	1997	1998	2000	2001	2003	1996	2001	2002	2003
No. of palms	*0*	*18*	*29*	*33*	*35*	*54*	*4*	*66*	*88*	*102*
SOA	-	0.336	**0.075**	0.202	**0.050**	**0.002**	0.582	**0.042**	0.109	0.201
MOP	-	0.664	0.149	0.417	**0.007**	**0.001**	0.175	**0.010**	**0.013**	**0.039**
TSP	-	0.654	0.139	0.164	**0.006**	**0.023**	1.000	**0.048**	**0.149**	0.545
KIE	-	1.000	**0.023**	0.187	**0.013**	**0.032**	1.000	**0.008**	**0.013**	0.179
SOA.MOP	-	0.818	0.140	0.723	0.113	**0.017**	0.504	**0.074**	0.199	0.280
SOA.TSP	-	0.492	**0.067**	0.310	**0.011**	**0.009**	1.000	**0.028**	**0.012**	**0.088**
SOA.KIE	-	0.443	**0.085**	0.395	**0.033**	**0.008**	1.000	**0.019**	**0.032**	0.118
MOP.TSP	-	0.341	0.585	0.617	**0.097**	0.398	1.000	0.375	**0.053**	0.476
MOP.KIE	-	0.583	0.143	0.503	0.256	**0.078**	1.000	**0.029**	**0.027**	0.258
TSP.KIE	-	0.412	**0.076**	0.368	**0.050**	0.203	1.000	1.000	0.809	0.244
SOA.MOP.TSP	-	0.243	**0.030**	0.195	**0.015**	**0.010**	1.000	**0.016**	**0.061**	0.197
SOA.TSP.KIE	-	0.850	0.460	0.929	**0.054**	**0.037**	0.138	**0.009**	**0.015**	**0.072**
SOA.MOP.KIE	-	0.279	**0.027**	0.185	**0.013**	**0.003**	1.000	**0.008**	**0.013**	**0.096**
MOP.TSP.KIE	-	0.314	**0.040**	0.417	0.124	**0.072**	1.000	**0.011**	**0.073**	0.425
Soil depth	-	0.104	**0.009**	0.251	**0.041**	0.306	**0.085**	**0.009**	0.388	0.931

Table 21. Main effects of treatments and soil depth on numbers of dead/missing palms (% of palms) in Trial 252. 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 row palms			
Factor	1996	1997	1998	2000	2001	2003	1996	2001	2002	2003
SOA 0	0.00	2.25	**4.70**	4.13	**5.08**	**6.38**	0.18	**5.14**	6.13	6.92
SOA 1	0.00	3.19	**4.29**	5.25	**6.30**	**8.35**	0.48	**4.46**	6.73	7.17
SOA 2	0.00	3.94	**6.11**	7.75	**6.85**	**13.40**	0.26	**5.68**	7.51	9.53
s.e.d.	*0.00*	*1.88*	***1.11***	*2.23*	***0.72***	**0.65**	*0.44*	***0.53***	0.70	1.46
MOP 0	0.00	5.56	8.91	8.81	**10.69**	**15.36**	0.36	**8.67**	**10.18**	**12.22**
MOP 1	0.00	3.31	5.00	5.88	**5.33**	**8.37**	0.98	**4.78**	**6.28**	**6.47**
MOP 2	0.00	0.50	1.19	2.50	**2.21**	**4.39**	-0.41	**1.83**	**3.91**	**4.92**
s.e.d.	*0.00*	*2.05*	*1.21*	*2.43*	***0.78***	**0.71**	*0.48*	***0.57***	**0.76**	**1.58**
TSP 0	0.00	3.25	5.60	7.13	**7.88**	**10.38**	0.31	**5.56**	**7.22**	8.19
TSP 1	0.00	3.00	4.47	4.31	**4.28**	**8.37**	0.31	**4.62**	**6.36**	7.56
s.e.d.	*0.00*	*1.51*	*0.89*	*1.78*	***0.57***	**0.52**	*0.35*	***0.42***	**0.56**	1.16
KIE 0	0.00	3.13	**7.30**	7.44	**7.77**	**10.46**	0.31	**6.65**	**8.37**	8.94
KIE 1	0.00	3.13	**2.77**	4.00	**4.38**	**8.29**	0.31	**3.53**	**5.21**	6.81
s.e.d.	*0.00*	*1.51*	***0.89***	*1.79*	***0.57***	**0.52**	*0.35*	***0.42***	**0.56**	1.16
Depth. Coeff.*	0.00	-3.75	**-5.75**	-2.75	**-2.13**	-0.69	**-0.97**	**-6.25**	-1.38	0.25
s.e.	*0.00*	*1.63*	***0.96***	*1.92*	***0.62***	0.56	***0.38***	***1.02***	1.36	2.82
Covar. Effic.	-	*2.08*	*9.66*	*1.25*	*3.72*	-0.69	*2.35*	*10.09*	6.13	6.92

* Units of dead/missing palms (% of recorded) for every 10cm increase in soil depth

Table 22. Comparison of tissue nutrient contents in Frond 3 and 17 in selected plots in 2002 (Trial 251)

	Treatment				Leaflet (% DM except B, in mg/kg DM)								Rachis (% DM)	
Frond	SOA	MOP	TSP	KIE	LAsh	LN	LP	LK	LMg	LCa	LB	LCl	Ash	K
3	0	0	0	0	5.91	2.58	0.166	0.61	0.44	1.02	13.0	0.67	2.79	0.43
3	2	0	1	0	5.93	2.81	0.185	0.61	0.45	1.00	12.0	0.59	2.33	0.22
3	0	1	0	0	6.42	2.52	0.165	0.93	0.35	0.98	11.4	0.81	4.56	1.70
3	0	1	0	1	5.71	2.58	0.167	0.95	0.34	0.99	10.8	0.81	4.29	1.66
3	0	1	1	1	5.48	2.55	0.165	0.91	0.38	0.89	11.2	0.82	4.26	1.58
3	0	2	0	1	5.59	2.56	0.165	0.95	0.35	0.87	11.5	0.74	5.41	1.99
3	0	2	1	0	5.95	2.58	0.175	1.07	0.30	0.98	13.0	0.81	5.68	1.99
3	0	2	1	1	5.72	2.43	0.164	0.99	0.36	0.96	11.4	0.90	4.95	1.99
3	2	2	0	1	5.54	2.49	0.162	0.95	0.32	0.95	10.8	0.82	4.79	1.83
3	2	2	1	0	5.64	2.55	0.165	1.12	0.32	0.88	11.5	0.94	4.54	1.74
3	2	2	1	1	5.52	2.62	0.166	1.24	0.29	0.81	9.6	0.79	4.01	1.54
17	0	0	0	0	7.54	2.03	0.141	0.39	0.45	1.38	12.0	0.62	3.34	0.20
17	2	0	1	0	8.46	2.04	0.141	0.28	0.50	1.38	11.3	0.83	3.03	0.10
17	0	1	0	0	7.82	2.33	0.148	0.71	0.23	1.19	11.5	0.60	3.54	1.07
17	0	1	0	1	6.01	2.31	0.147	0.75	0.22	1.22	10.7	0.55	4.57	1.46
17	0	1	1	1	6.45	2.21	0.149	0.67	0.32	1.05	10.9	0.60	4.25	1.26
17	0	2	0	1	6.99	2.30	0.147	0.77	0.26	1.03	12.0	0.61	5.56	1.99
17	0	2	1	0	6.77	2.29	0.150	0.75	0.17	1.31	12.6	0.59	5.44	1.74
17	0	2	1	1	6.50	2.22	0.148	0.77	0.26	1.15	10.2	0.65	5.29	1.78
17	2	2	0	1	6.59	2.31	0.152	0.75	0.23	1.12	11.0	0.61	4.31	1.38
17	2	2	1	0	7.20	2.35	0.149	0.81	0.20	1.14	11.4	0.63	3.98	1.26
17	2	2	1	1	6.14	2.32	0.147	0.87	0.23	1.09	9.8	0.63	4.01	1.42

Table 23. Comparison of tissue nutrient contents in Frond 3 and 17 in selected plots in 2002 (Trial 252)

	Treatment				Leaflet (% DM, except B, in mg/kg DM)								Rachis (% DM)	
Frond	SOA	MOP	TSP	Kies	Ash	N	P	K	Mg	Ca	B	Cl	RAsh	RK
3	0	0	0	0	6.68	2.16	0.138	0.28	0.46	1.30	10.3	0.74	1.77	0.16
3	2	0	0	0	4.99	3.00	0.192	0.85	0.35	0.69	12.3	0.45	1.74	0.18
3	0	1	0	1	5.31	2.46	0.162	1.34	0.32	0.63	10.3	0.85	4.53	1.70
3	0	1	1	0	5.23	2.57	0.179	1.42	0.28	0.57	9.2	0.81	4.10	1.66
3	1	1	1	0	5.49	2.56	0.179	1.62	0.23	0.67	9.8	0.80	4.37	1.74
3	1	1	1	1	5.40	2.61	0.174	1.32	0.31	0.63	9.9	0.82	4.66	1.62
3	2	1	0	0	5.85	2.57	0.177	1.46	0.31	0.69	11.0	0.88	4.34	1.58
3	0	2	1	0	5.29	2.40	0.170	1.28	0.28	0.74	9.4	0.81	5.83	2.23
3	0	2	0	0	5.30	2.41	0.166	1.32	0.28	0.63	10.3	0.86	4.34	1.78
3	1	2	1	1	5.72	2.41	0.152	0.83	0.25	1.04	10.6	0.61	5.58	2.11
3	2	2	1	0	5.76	2.63	0.183	1.54	0.25	0.69	10.0	0.88	5.13	2.07
17	0	0	0	0	4.84	2.89	0.186	0.65	0.37	0.85	10.5	0.43	2.91	0.10
17	2	0	0	0	8.09	2.27	0.147	0.32	0.48	1.18	11.4	0.68	2.82	0.10
17	0	1	0	1	5.73	2.30	0.143	0.69	0.30	1.05	9.4	0.62	4.82	1.50
17	0	1	1	0	5.54	2.39	0.153	0.71	0.24	0.99	10.5	0.60	2.62	0.77
17	1	1	1	0	5.76	2.37	0.154	0.75	0.22	1.26	11.1	0.64	5.56	1.66
17	1	1	1	1	6.14	2.36	0.150	0.71	0.30	1.00	9.5	0.66	3.64	0.91
17	2	1	0	0	6.85	2.47	0.159	0.81	0.24	1.06	10.0	0.65	3.30	0.83
17	0	2	1	0	5.61	2.30	0.146	0.79	0.21	1.06	9.5	0.58	5.68	1.78
17	0	2	0	0	5.70	2.20	0.142	0.77	0.23	0.99	8.6	0.63	5.71	1.87
17	1	2	1	1	5.49	2.66	0.170	1.50	0.29	0.59	9.0	0.83	5.04	1.62
17	2	2	1	0	6.26	2.47	0.158	0.85	0.19	1.20	9.7	0.64	4.19	1.42

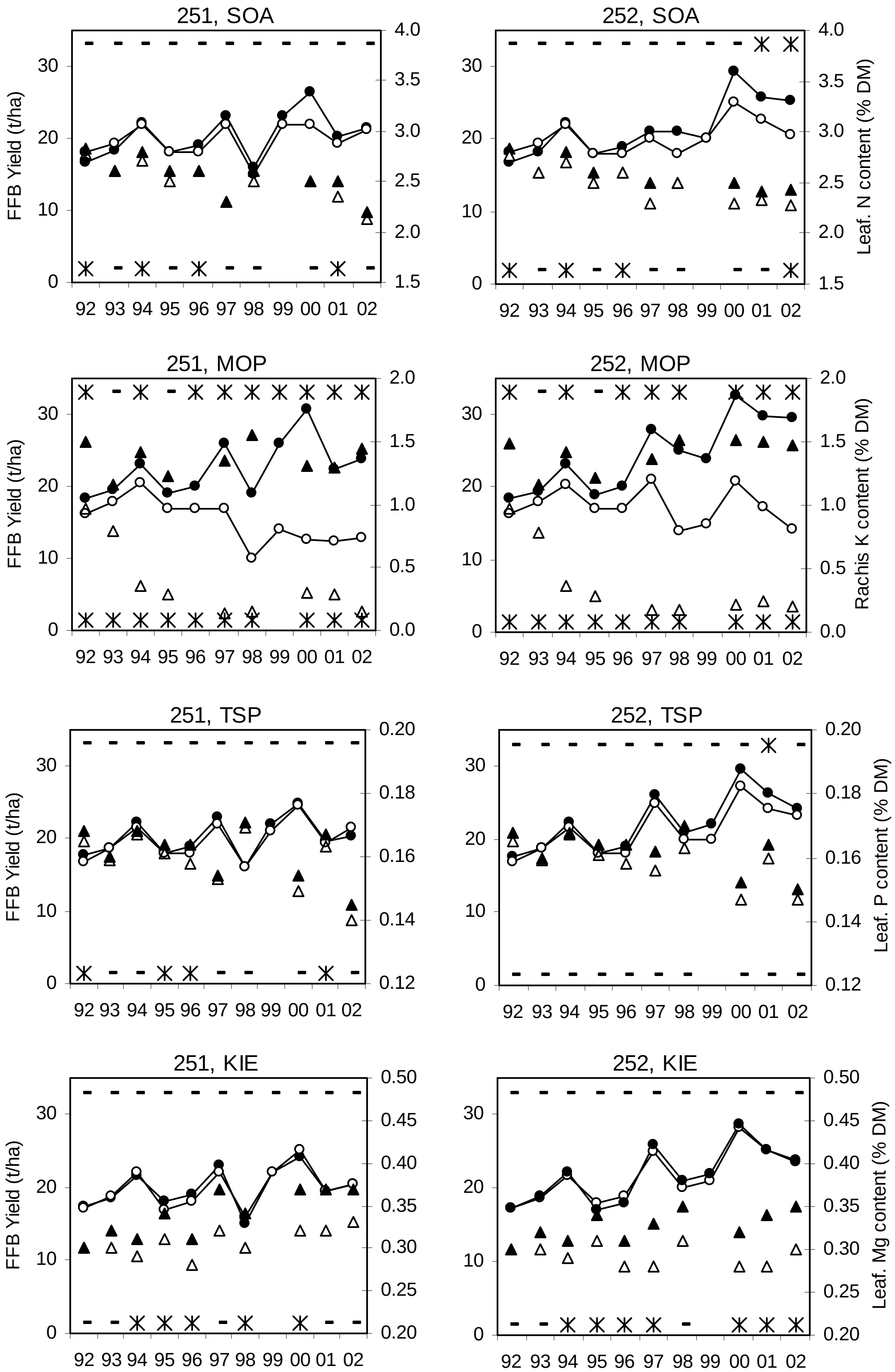


Figure 1. Main effects of SOA, MOP, TSP and kieserite over the course of Trials 251 and 252. Lines with circles are FFB yields and triangles are tissue concentrations. Full symbols represent the maximum level of application, and empty symbols zero application. Symbols along the top of the graph indicate 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.

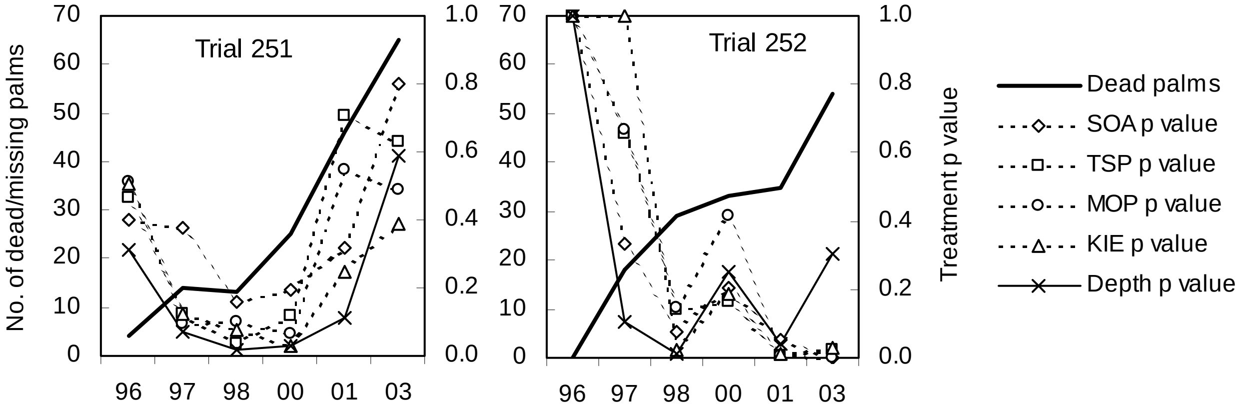


Figure 2. Number of dead and missing palms (out of 576 recorded palms) and significance of treatment main effects and soil depth covariate over the 1996-2003 period in Trials 251 and 252.

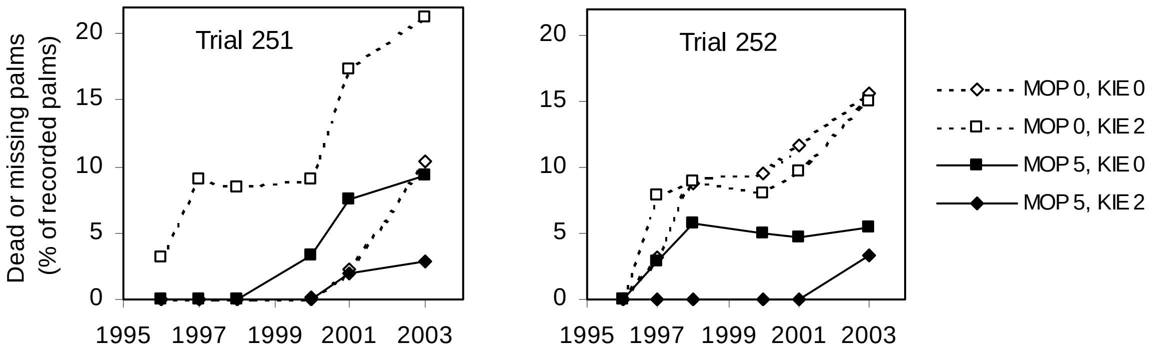


Figure 3. Effect of interaction between MOP (5 kg/palm.year) and KIE (2 kg/palm.year) on the number of dead or missing palms over the 1996-2003 period in Trials 251 and 252.

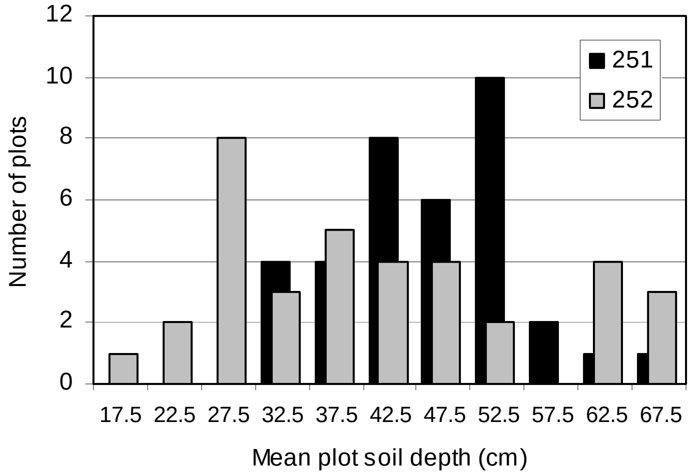


Figure 4. Distribution of mean plot soil depths in Trials 251 and 252.

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.

OTHER FACTORS

SPACING/THINNING TRIALS

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 and weights are are being measured on every palm in every third row.

PROGRESS

Plots were laid out in 2001, yield recording commenced in 2003 and a range of cover crops are being sown in 2003.

TRIAL 331 SPACING AND THINNING FOR MECHANICAL IN-FIELD COLLECTION TRIAL, AMBOGO ESTATE

PURPOSE

To determine the effects of spacing configuration on palms, cover crops and soils, with a view to facilitating mechanical in-field 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 with equilateral triangular spacing (Table 1.). In treatments 4, 5 and 6 every third row will be removed 5 years after planting. Treatments 1, 2 and 3 will remain as planted. The final densities of treatments 4, 5 and 6 will then be the same as treatments 1, 2 and 3 but they will have closely spaced pairs of rows with wide avenues between the pairs. There are 3 replicates of the 6 spacing treatments, giving a total of 18 plots. The trial was planted in 2001. In 2002, 7 cover crops were sown in small plots throughout replicate 2 of the spacing trial in order to assess their performance under the different light and traffic conditions of the different spacing treatments. The cover crops were Pueraria, Calapogonium, Mucuna, Vigna, Desmodium, Centrosema and Stylo.

Table 1. Treatment allocations in Trial 331. ‘Thinning’ involves the removal of every third row 5 years after planting in treatments 4, 5 and 6.

Treatment No	Initial density (palms/ha)	Triangular spacing (m)	Initial number of rows/plot	Density after thinning (palms/ha)	Inter-row width after thinning (m)
1	128	9.50	7	128	8.2
2	135	9.25	7	135	8.0
3	143	9.00	7	143	7.8
4	192	7.75	8	128	13.4 & 6.7
5	203	7.55	9	135	13.1 & 6.5
6	215	7.33	9	143	12.7 & 6.4

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.

RESULTS

The effects of the treatments on the ‘minimum’ and ‘maximum’ spread of the cover crops in 2002 are presented in Tables 2 and 3. ‘Minimum’ spread is the lateral spread of the main sward from the planting line. ‘Maximum’ spread is the length of the longest runners. The spread of the cover crops were affected by the main treatments as well as the treatment interaction (Table 2). Variability was however very high. Three cover crop species out-performed the other species in terms of their spread. They were Calapogonium, Pueraria and Desmodium (Table 3). Apart from measuring the relative spread of each of the cover crops, they were also given scores according to the density of the sward. The effect of the treatments on the cover crop density are presented in Tables 4 and 5. In October 2002, palm density and the interactions significantly had an effect on the density of the cover crops. The cover crop species showed no significant interaction probably because they were not yet fully established. By December 2002, both treatments with their combinations (interactions) affected the density of the cover crops. Table 6 shows the mortality rate of each of the cover crop species after initial planting in the field. Pueraria and Stylo had the lowest mortality rate after initial planting. Mucuna was initially very vigorous, but then died out. Vigna never performed well and eventually died out. Stylo had a very low mortality rate (6.3%) and dense ground cover, but was quite slow in spreading out. Desmodium and Centrosema had reasonably high density, but fairly high mortality rate. Preliminary results therefore suggest Pueraria and Calapogonium to be the best cover crop at this stage because of their high relative spread and lower mortality rate than the others.

We should expect some changes in the results as the palm canopy closes over in the future. What has been presented above are only preliminary results from two sets of data taken in 2002. The performance of the cover crops will still be monitored in 2003.

Table 2. Effects (p values) of treatments on the relative spread of the cover crop in 2002 (Trial 331). p values less than 0. 05 are indicated in bold.

Treatments	Min. Spread (17/10/02)	Max. Spread (17/10/02)	Min. Spread (20/12/02)	Max. Spread (20/12/02)	Min. Spread (2002 mean)	Max Spread (2002 mean)
Palm density	**0.003**	**0.002**	**<0.001**	**<0.001**	**0.022**	0.066
C.crop sp.	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Interaction	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
CV %	*75.5*	*6.09*	*51.8*	*52.0*	*57.9*	*59.8*

Table 3. Main effects of treatments on the relative spread of the cover crops in 2002 (Trial 331).

Treatments	Min. Spread (cm) 17/10/02	Max. Spread (cm) 17/10/02	Min. Spread (cm) 20/12/02	Max. Spread (cm) 20/12/02	2002 min. spread average (cm)	2002 max. spread average (cm)
Density (palm/ha)						
128	154	312	168	239	165	291
135	145	300	157	243	158	287
143	122	247	167	255	144	251
192	136	277	197	301	162	293
203	124	258	171	252	148	262
215	120	252	154	276	139	270
s.e.d	*10.4*	*13.8*	*9.0*	*10.0*	*9.1*	*16.9*
Cover crop						
Calapogonium	188	408	189	306	199	384
Pueraria	179	359	173	278	176	321
Mucuna	103	215	166	247	114	207
Vigna	130	255	124	181	132	241
Desmodium	115	211	208	306	171	281
Centrosema	97	249	157	257	131	260
Stylo	126	228	170	254	145	236
s.e.d	*11.2*	*14.9*	*9.8*	*10.8*	*9.8*	*18.3*

Table 4. Effects (p values) of treatments on cover crop density in 2002. p values less than 0.05 are indicated in bold.

Treatments	October 2002	December 2002
Palm Density	**<0.001**	**<0.001**
Cover crop species	0.104	**<0.001**
Interaction	**<0.001**	**<0.001**
CV%	64	58.7

Table 5. Main effects of the treatments on the cover crop density in 2002. Significant effects are shown in bold. All values in the table are transformed values using Log_{10}.

Treatments	October 2002	December 2002
Density (palm/ha)		
128	**0.74**	**0.62**
135	**0.67**	**0.65**
143	**0.63**	**0.86**
192	**0.65**	**0.75**
203	**0.57**	**0.54**
215	**0.56**	**0.72**
s.e.d	*0.02*	*0.02*
Cover crop species		
Calapogonium	0.62	**0.66**
Pueraria	0.58	**0.67**
Mucuna	0.70	**0.64**
Vigna	0.63	**0.58**
Desmodium	0.68	**0.78**
Centrosema	0.60	**0.72**
Stylo	0.64	**0.79**
s.e.d	*0.03*	*0.03*

Table 6. Mortality rate of cover crop species after field planting in 2002.

Cover crop species	Mortality (%) in 2002
1. Calopogonium	16.7
2. Pueraria	2.4
3. Mucuna	93.7
4. Vigna	95.8
5. Desmodium	22.2
6. Centrosema	37.0
7. Verano stylo	6.3
s.e.d	*6.27*
C.V (%)	30.9

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 and the palms planted in July 2003. The cover crops shown in Table 2 were sown in May 2003 across all spacing treatments in replicate 2 in 2003. Commercial cover crop mix was sown in replicates 1 and 3.

Table 2. Cover crops sown in Trial 513 in 2003.

No.	Treatment	Source
1	Calopogonium (*Calopogonium mucunoides*)	MBE
2	Pueraria (*Pueraria phaseoloides*)	MBE
3	Commercial mix (later to be replaced by Mucuna or Centrosema)	MBE
4	Aztec Atro	Australia
5	Creeping Desmodium (*Desmodium spp.*)	Australia
6	Cooper Glycine	Australia
7	Verano stylo	Australia

AGRONOMIC ASPECTS OF SMALLHOLDER SURVEYS IN ORO AND HOSKINS

(P. Nelson)

Summary

The aim of this work was to determine the relationship between agronomic and socioeconomic factors that influence productivity in the Hoskins and Oro oil palm schemes. In 2001, samples of leaf tissues were taken from each block in order to rate nutrition status, management of the blocks was scored and questions were asked about fertilizer use. Soil profiles were described in selected blocks.

There were clear differences between nutrient status of blocks in Hoskins and Oro, attributable mainly to differences in soils. Differences in nutrient status between VOP and LSS blocks in both provinces were also due mainly to soil type rather than management. Soil properties on these blocks will be examined in more detail, and all soil maps of smallholder areas are being brought into a GIS framework in order to facilitate recommendations based on soil type. Soil profiles in selected blocks have been described. Palm nutrient status was not related to fertilizer use. This was probably due to over-riding effect of soil type and also possibly because the fertilizer use question in the survey was not sufficiently specific.

The information from this survey will be useful in targeting extension messages to the actual factors limiting productivity. Agronomic limitations to productivity are largely related to soil type. While the major limitations to smallholder productivity are in the socioeconomic realm, the important interactions with soil fertility should be taken into account when designing extension programs.

Introduction

Oil palm yields in PNG are usually substantially lower on smallholder blocks than on large plantations. Previous studies of smallholder production have tended to focus on either agronomic or socio-economic factors and not link the two. This lack of integration has hindered efforts to identify and overcome limitations to productivity. This study examined the links between agronomic and socioeconomic factors.

Methods

Choice of blocks

The surveyed blocks were chosen to cover VOP and LSS tenure and a range of locations and soil types across the areas of interest.

Tissue nutrient contents

Tissue nutrient contents were measured by standard sampling and analysis of Frond 17. A bulk sample was used for each block. Leaflet nutrient contents were also examined after correcting for ash content, by adjusting the values to what they would be if ash content were the average value for that group of samples (15.6% for Hoskins and 14.1% for Oro).

Production data

Yields were taken from milling company records. Yields from LSS in Hoskins should be reasonably accurate, but yields from other blocks are unreliable due to shifting of fruit and cards between blocks. Lack of reliable production records for individual blocks pose a major hindrance to research aimed at determining limitations to productivity.

Survey questions

Methods for the survey are given in the main body of the report. Block assessment score (Ass.) was rated 1 for poor, 2 for moderate and 3 for good. Fertiliser use (Fert.) was rated 0 for never, 1 for irregular and 2 for regular. Planting year (Plant.) ranged from 1968-1999 for Hoskins and 1979-1999 for Oro. Population (Pop.) was the population living on the block at the time of survey.

Comparison between Oro and Hoskins

All nutrient contents were higher in Hoskins blocks than Oro blocks, except for leaflet K, which was the same, and leaflet Mg, which was lower in Hoskins (Table 1). It should be noted that Rachis K is a better indicator of K status than leaflet K, which is why it is measured. For the other nutrients, leaflet contents give a good indication of plant nutrient status. In Hoskins, contents of N and Mg ranged from the deficient to sufficient range. P, K, B and Cl were generally sufficient and Ca was present in excess. In Oro, N, K, Mg, S and Cl ranged from deficient to sufficient, B was generally sufficient and Ca was generally in excess.

Table 2 shows the relationship between contents of nutrients in the leaflets. There was a strong correlation between leaflet N and P contents (r^2 0.77 in Hoskins and 0.67 in Oro), illustrated in Figure 1. The leaflet N/P ratio was marginally higher in Oro than Hoskins. Total cation content of the leaflets was fairly similar at the two sites, but Ca made up a higher proportion and Mg a lower proportion in Hoskins than in Oro. This Ca/Mg imbalance in Hoskins is discussed further below.

Table 1. Summary of Frond 17 nutrient contents in surveyed smallholder blocks, and significance (p value) of difference between the two sites.

	Leaflets (% DM, except B, in mg/kg)									Rachis (% DM)	
	Ash	N	P	K	Mg	Ca	B	Cl	S	Ash	K
						Hoskins					
Mean	15.6	2.27	0.142	0.78	0.16	0.93	13.61	0.42		4.3	1.31
sd	1.5	0.21	0.011	0.11	0.04	0.11	2.20	0.10		0.6	0.23
Min	11.7	1.81	0.114	0.61	0.08	0.71	9.80	0.18		2.7	0.81
Max	19.0	2.79	0.168	1.16	0.29	1.17	18.80	0.63		5.9	1.99
						Oro					
Mean	13.8	2.19	0.135	0.78	0.23	0.79	10.7	0.20	0.16	3.4	0.98
sd	1.8	0.25	0.014	0.13	0.05	0.15	1.6	0.08	0.02	0.7	0.30
Min	9.4	1.78	0.111	0.34	0.12	0.52	7.5	0.04	0.12	2.0	0.14
Max	17.4	2.73	0.177	1.18	0.38	1.16	15.2	0.36	0.21	5.0	1.50
p	*<0.001*	*0.009*	*<0.001*	*0.699*	*<0.001*	*<0.001*	*<0.001*	*<0.001*		*<0.001*	*<0.001*

Table 2. Parameters derived from Frond 17 leaflet nutrient contents

	N/P	K/Mg	Ca/Mg	Total cations (% DM)	K (% of cations)	Mg (% of cations)	Ca (% of cations)
				Hoskins			
Mean	16.0	5.0	6.0	1.87	41.4	8.7	49.9
sd	0.7	1.2	1.5	0.19	3.8	1.7	4.3
Min	14.4	2.9	2.9	1.51	31.6	4.9	39.5
Max	19.0	9.2	10.5	2.35	51.3	13.9	59.8
				Oro			
Mean	16.3	3.5	3.5	1.80	43.4	12.9	43.7
sd	1.0	0.8	0.6	0.26	4.8	2.2	4.2
Min	13.9	1.2	2.1	1.32	23.0	8.2	32.7
Max	18.7	6.3	5.0	2.59	55.3	19.8	58.1
p	*0.009*	*<0.001*	*<0.001*	*0.034*	*0.002*	*<0.001*	*<0.001*

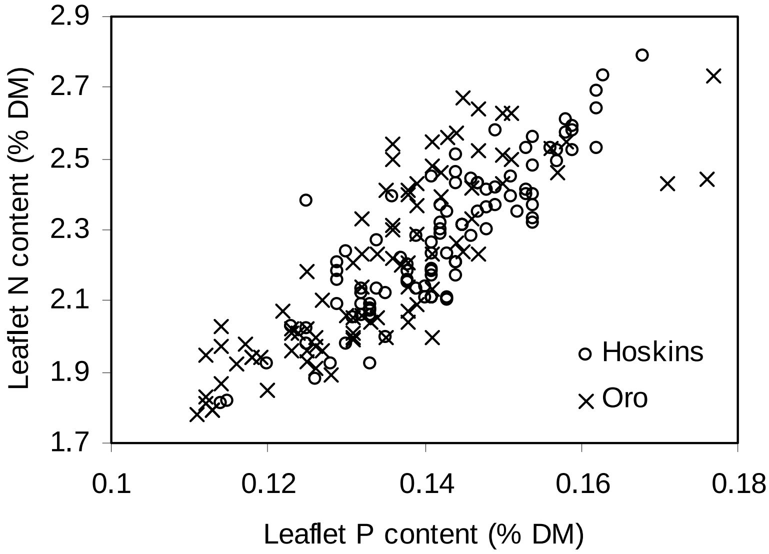


Figure 1. Relationship between conentrations of N and P in leaflets from surveyed smallholder blocks in Oro and Hoskins.

Table 3. Survey parameters

	Population	Planting year	Yield (t/ha)	Management score	Fertiliser use score
			Hoskins		
Mean	12.2		15.1	2.30	1.76
sd	7.3		9.3	0.46	0.43
Min.	1		0.0	2	1
Max.	41		44.5	3	2
			Oro		
Mean	7.63	1986	14.6	2.45	1.31
sd	2.92	7.5	8.7	0.50	0.51
Min.	1	1979	0.3	2	0
Max.	16	1999	55.9	3	2
p	*<0.001*		*0.689*	*0.032*	*<0.001*

Oro: Correlations between parameters

Correlations were carried out between the tissue nutrient content, yield, planting year and the social survey parameters that could be measured or scored; block assessment, fertilizer use and population. Results are shown in Table 4. Correlations were poor (r<0.3) among social survey parameters and between social survey and physical parameters. Particularly interesting is the lack of correlation between 'fertilizer use' and leaflet N content. A likely explanation is that the questions and answers about fertilizer use were not sufficiently specific. Those questions were modified for the more recent survey of growers in Bialla.

There were some significant correlations (r>0.4) among nutrient contents and between nutrient contents and planting year (Table 1). The older the palms, the higher their leaflet ash content and the lower their leaflet N, P and Mg content. Palm age generally fell into one of two groups; those planted around 1980 and those planted around 1995. Leaf levels of nutrients have generally been shown to decrease with time (Hartley, 1977). Slight declines in leaf N with age have been noted in fertilizer trials in Oro (Trials 305, 306, 312), but measurements only started at 8-9 years of age in those trials. The decrease in N, P and Mg contents with age in this survey may have been a simple result of their negative correlation with ash content (Table 4). To test whether or not that was the case, the correlation was performed again using leaflet nutrient contents that had been corrected for the dilution effect of ash content by bringing them to a standard average ash content (Table 5). The fall in leaflet N, P and Mg contents with age was still apparent, showing that it was not a simple dilution with other inorganic leaflet constituents (ash) with time. Possible explanations are a physiological effect of age, a decrease in soil fertility with time, or a difference in soil fertility between the blocks planted at different times. The issue of soil fertility was further examined by comparing the measured parameters between soil types.

Table 4. Correlations (r values) between Oro smallholder block data. Values >0.5 are highlighted in bold.

	Ass.	Fert.	Plant.	Pop.	Yield	LAsh	LN	LP	LK	LMg	RK
Ass.	1.000										
Fert.	0.297	1.000									
Plant.	-0.067	-0.140	1.000								
Pop.	0.143	0.175	-0.214	1.000							
Yield	-0.059	-0.167	-0.113	-0.087	1.000						
LAsh	0.006	0.098	**-0.712**	0.113	0.058	1.000					
LN	0.003	-0.091	**0.643**	-0.057	-0.153	**-0.705**	1.000				
LP	-0.106	-0.046	**0.646**	-0.096	-0.010	**-0.753**	**0.837**	1.000			
LK	-0.097	0.008	0.351	-0.040	-0.032	-0.409	**0.566**	**0.532**	1.000		
LMg	-0.220	-0.013	**0.598**	-0.192	-0.213	**-0.654**	0.448	0.480	0.103	1.000	
RK	-0.073	0.184	-0.301	-0.061	0.214	0.308	-0.341	-0.193	0.226	-0.384	1.000

'L' prefix indicates leaflet nutrient content; 'R' prefix indicates rachis nutrient content

Table 5. Correlations (r values) between Oro smallholder block data. Leaflet N, P, K and Mg contents had been corrected for ash content. Values >0.5 are highlighted in bold.

	Ass.	Fert.	Plant.	Pop.	Yield	LAsh	sLN	sLP	sLK	sLMg	RK
Ass.	1.000										
Fert.	0.297	1.000									
Plant.	-0.067	-0.140	1.000								
Pop.	0.143	0.175	-0.214	1.000							
Yield	-0.059	-0.167	-0.113	-0.087	1.000						
LAsh	0.006	0.098	**-0.712**	0.113	0.058	1.000					
LN	0.002	-0.080	**0.582**	-0.042	-0.161	**-0.591**	1.000				
LP	-0.127	-0.024	**0.571**	-0.084	0.007	**-0.620**	**0.783**	1.000			
LK	-0.104	0.028	0.261	-0.025	-0.023	-0.281	0.499	0.458	1.000		
LMg	-0.231	-0.010	**0.566**	-0.191	-0.216	**-0.596**	0.342	0.360	-0.016	1.000	
RK	-0.073	0.184	-0.301	-0.061	0.214	0.308	-0.318	-0.138	0.286	-0.379	1.000

'L' prefix indicates leaflet nutrient content; 'R' prefix indicates rachis nutrient content

Oro: Differences between soil types

In Oro, soils were grouped into the 5 categories shown in Table 6 and Figure 2. Only one block did not fall into one of these categories, and as no tissue nutrient contents were measured for that block, it was left out.

Table 6. Main characteristics and number of blocks in soil type groups in Oro

Code	No. of surveyed blocks		Total no. of blocks	Landform	Soil texture
	LSS	VOP			
1	21	10	31	Outwash plains	sandy
2	16	9	25	Dissected plain	clayey
3	5	17	22	Lamington slopes	sandy
4	6	6	12	Fluvial plains	clayey
5	6	6	12	Ilimo-Kokoda valley	various

The graphs (Figure 2) show differences between soil types with respect to survey parameters and tissue nutrient contents. On soil type 1, most blocks were planted around 1981, on soil types 2 and 3 plantings were evenly distributed between 1981 and 1995, and on soil types 4 and 5, most were planted around 1995. Block population, management score and regularity of fertilizer application was similar on all soil types. Going from soil type 1 to soil type 5 was generally accompanied by a decrease in ash and rachis K content and an increase in leaflet N, P and Mg content. However, it was still not possible to remove the confounding effect of palm age.

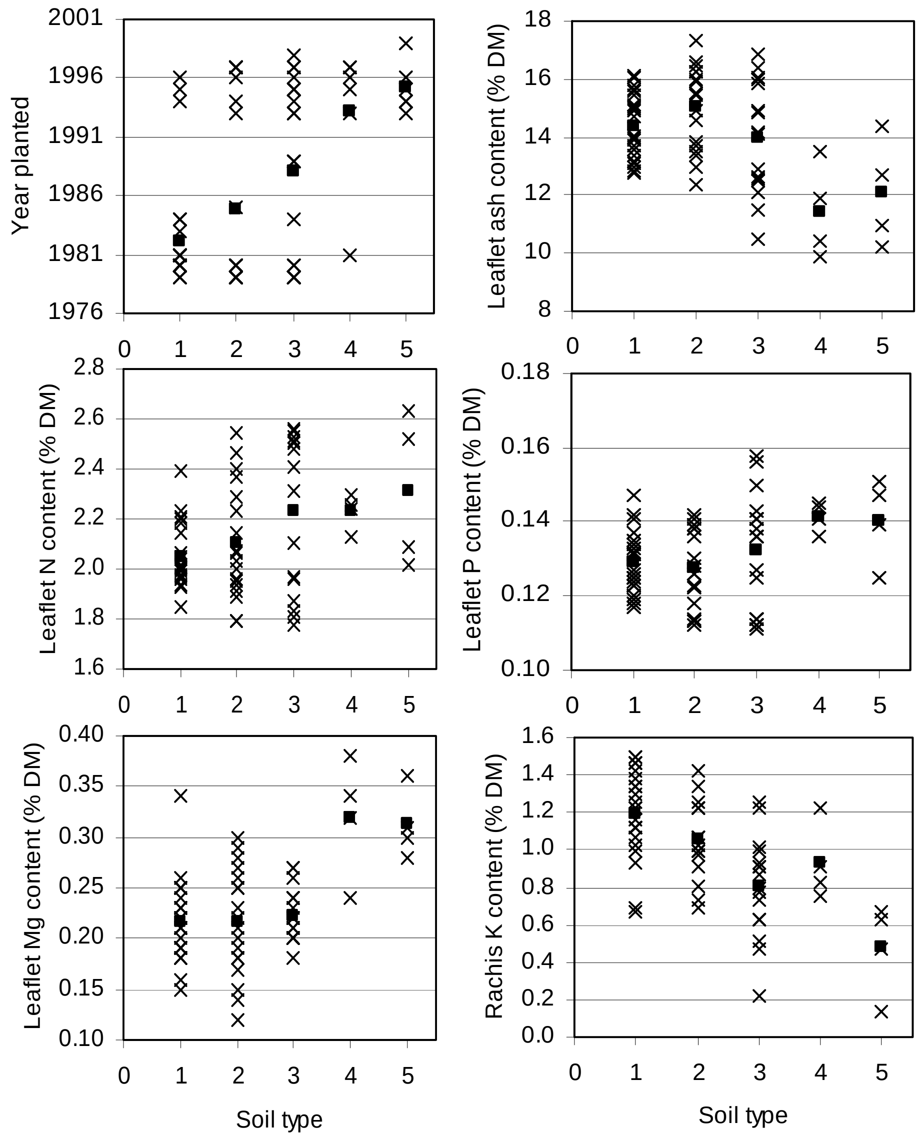


Figure 2. Relationship between palm age and tissue nutrient contents and soil type in Oro smallholder blocks. Soil types are described in Table 6. Squares show the mean for each soil type.

Hoskins: Correlations between parameters

Correlations were poor among the social survey parameters that could be measured or scored (r<0.1, Table 7). All correlations had coefficients <0.5, except for that between leaflet N and P contents (r=0.85), which is shown graphically in Figure 3.

Table 7. Correlations (r values) between Hoskins smallholder block data. Values >0.5 are highlighted in bold.

	Ass.	Fert.	Pop.	Yield	LAsh	LN	LP	LK	LMg	RK
Ass.	1.000									
Fert.	0.089	1.000								
Pop.	-0.025	0.019	1.000							
Yield	-0.069	-0.124	0.048	1.000						
LAsh	-0.099	0.039	-0.165	-0.004	1.000					
LN	-0.051	0.044	-0.189	-0.375	-0.403	1.000				
LP	0.016	0.035	0.091	0.364	0.239	**0.849**	1.000			
LK	-0.074	-0.019	0.023	-0.003	-0.364	-0.030	0.239	1.000		
LMg	0.074	-0.024	-0.013	-0.220	-0.424	-0.179	0.095	0.269	1.000	
RK	-0.072	-0.026	-0.023	0.164	0.008	0.085	-0.192	-0.025	0.089	1.000

Comparison between LSS and VOP blocks

Hoskins

The comparison between LSS and VOP blocks in Hoskins with respect to the measured parameters is shown in Table 8. The LSS blocks generally had a larger planted area, and yields were generally higher. Yields for individual VOP blocks are unreliable because of exchange of fruit and cards between blocks, but it is unlikely (but possible) that there was a net export of fruit from the 46 surveyed blocks. There was a clear difference in cation nutrition between the two groups of blocks. Most oil palm plantations in West New Britain suffer from a magnesium deficiency induced by excessive calcium in the soils. Both the VOP and LSS blocks had magnesium contents in the critical range, but the VOP blocks had significantly higher magnesium contents than the LSS blocks. The VOP blocks had lower potassium status (RK) than the LSS blocks, but in both cases the mean was well above the critical level of 1%. No magnesium or potassium fertilizers are applied to smallholder blocks, so the differences must be due to soil type. There were no soil maps covering the Hoskins area in sufficient detail for

Oro

The comparison between LSS and VOP blocks in Oro is shown in Table 9. As in Hoskins, LSS blocks were generally larger than VOP blocks. They were also generally better maintained and applied fertilizer more regularly than VOP blocks. The LSS blocks had significantly higher leaflet ash contents and lower N, P and Mg contents than the VOP blocks. Rachis K contents and leaflet K as a percent of total cations were however higher in LSS than VOP blocks. No cation fertilizers were applied to smallholder blocks prior to 2002, and the LSS had lower N contents despite receiving more fertilizer. Therefore, the difference in nutrient status between LSS and VOP blocks must have been due to soil type rather than management, as in Hoskins. The influence of soil type in Oro has been discussed above.

Table 8. Comparison between LSS (n=45) and VOP (n=46) blocks in Hoskins. Parameters with p<0.1 are highlighted in bold.

Parameter	LSS mean	VOP mean	p	s.e.d.	CV%
Tissue nutrient contents (% DM)					
LAsh	15.7	15.3	0.170	0.31	9.5
LN	2.27	2.27	0.972	0.045	9.3
LP	0.143	0.141	0.480	0.0023	7.8
LK	0.76	0.79	0.280	0.024	14.6
LMg	**0.156**	**0.176**	**0.024**	0.0089	25.5
LCa	**0.98**	**0.89**	**<0.001**	0.019	9.7
LCl	**0.44**	**0.41**	**0.097**	0.021	23.7
RK	**1.37**	**1.26**	**0.021**	0.047	17.0
Derived parameters					
Total cations (% DM)	1.90	1.85	0.204	0.038	9.7
N/P	15.9	16.1	0.198	0.14	4.2
K/Mg	**5.15**	**4.62**	**0.015**	0.214	20.9
Ca/Mg	**6.68**	**5.27**	**<0.001**	0.287	23.0
K as % of cations	**40.1**	**42.5**	**0.002**	0.74	8.6
Mg as % of cations	**8.10**	**9.44**	**<0.001**	0.337	18.3
Ca as % of cations	**51.8**	**48.1**	**<0.001**	0.83	7.9
Survey parameters					
Area (ha)	**4.80**	**2.41**	**<0.001**	0.191	25.4
Management score	2.27	2.32	0.540	0.097	20.1
Fertiliser use score	1.76	1.74	0.859	0.092	25.1
Yield (t/ha)	**18.7**	**11.6**	**<0.001**	1.77	56.0
Population	13.0	11.5	0.307	1.53	59.4

Table 9. Comparison between LSS (n=42) and VOP (n=49) blocks in Oro. Parameters with p<0.1 are highlighted in bold.

Parameter	LSS mean	VOP mean	p	s.e.d.	CV%
Tissue nutrient contents (% DM)					
LAsh	**15.1**	**13.3**	**<0.001**	0.32	10.9
LN	**2.02**	**2.24**	**<0.001**	0.044	9.7
LP	**0.125**	**0.136**	**<0.001**	0.0022	7.8
LK	**0.74**	**0.79**	**0.027**	0.022	13.9
LMg	**0.205**	**0.253**	**<0.001**	0.010	20.6
RK	**1.14**	**0.85**	**<0.001**	0.057	27.2
Derived parameters					
Total cations (% DM)	**1.63**	**1.91**	**<0.001**	0.043	11.6
N/P	16.2	16.3	0.518	0.21	6.0
K/Mg	**3.74**	**3.33**	**0.024**	0.176	23.7
Ca/Mg	3.47	3.47	0.970	0.131	17.9
K as % of cations	**45.2**	**42.3**	**0.004**	0.98	10.7
Mg as % of cations	12.5	13.2	0.128	0.47	17.4
Ca as % of cations	**42.3**	**44.5**	**0.009**	0.82	8.9
Survey parameters					
Area (ha)	**3.87**	**2.06**	**<0.001**	0.090	14.8
Management score	**2.65**	**2.36**	**0.008**	0.103	19.5
Fertiliser use score	**1.48**	**1.15**	**0.003**	0.107	38.9
Yield (t/ha)	14.2	15.3	0.615	2.03	65.2
Population	8.0	7.0	0.114	0.64	40.9

References

Hartley, C.W.S. (1977) The Oil Palm. 2nd ed. (Longman: London, New York)

PREDICTIONS AND RECOMMENDATIONS

SOIL RESOURCE INFORMATION

In this project we aim to collate all the soil maps for oil –palm growing areas of PNG, compile them into a GIS and use them to improve our management recommendations.

We have identified 107 soil reports and 120 soil maps in oil palm growing areas. Of these we have obtained copies of all the reports and 62 of the maps, 39 as scans. We are in the process of digitising the scanned maps and incorporating them into a GIS. The maps digitised so far are shown in Figure 1.

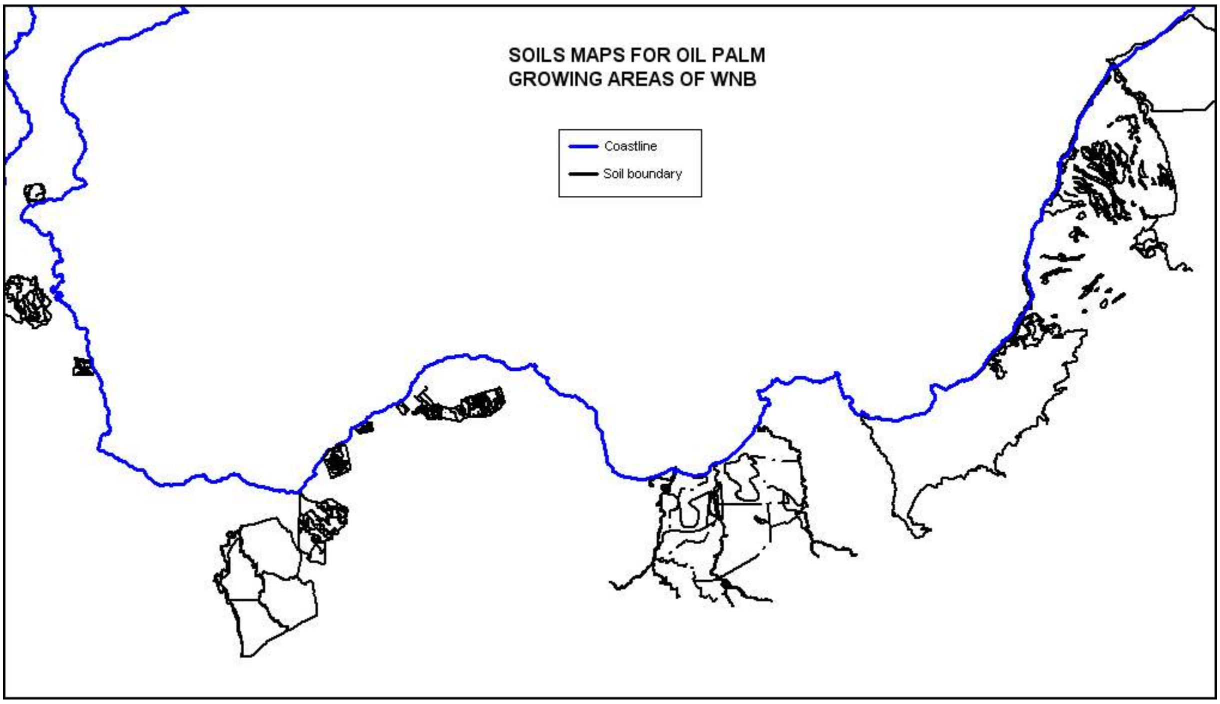


Figure 1. Soil maps that have been digitised.

YIELD PREDICTIONS

It is well known that oil palm yields are influenced by previous rainfall, especially in the critical periods of sex differentiation about 24 months before harvest and fruit maturation and susceptibility to abortion 4-8 months before harvest. It has been widely thought that in PNG the effect would only be evident in drier areas such as Poliamba or in following particularly dry years such as 1997. The fertiliser trials give us an opportunity to determine how well rainfall correlates with yield in the various growing areas of PNG.

Figures 1-4 show that in all provinces there is quite a good agreement between the trends of annual FFB yield of mature palms and annual rainfall 2 years previously. This relationship could form the basis of yield estimates for mature palms on a time scale of 1-2 years.

Various rainfall periods were used, but the annual rainfall in the calendar year 2 years before the annual yield for a calendar yield generally fitted the best over all trials in all areas. The relationship must be due primarily to bunch numbers. Better predictions of yield over shorter time periods will come out of Trials 332 and 514.

At the very least the comparison is instructive in showing that the decline in yields in Oro over the period 1991-2000, which had raised some concern, appears to be related to a decline in rainfall over the 1989-1997 period.

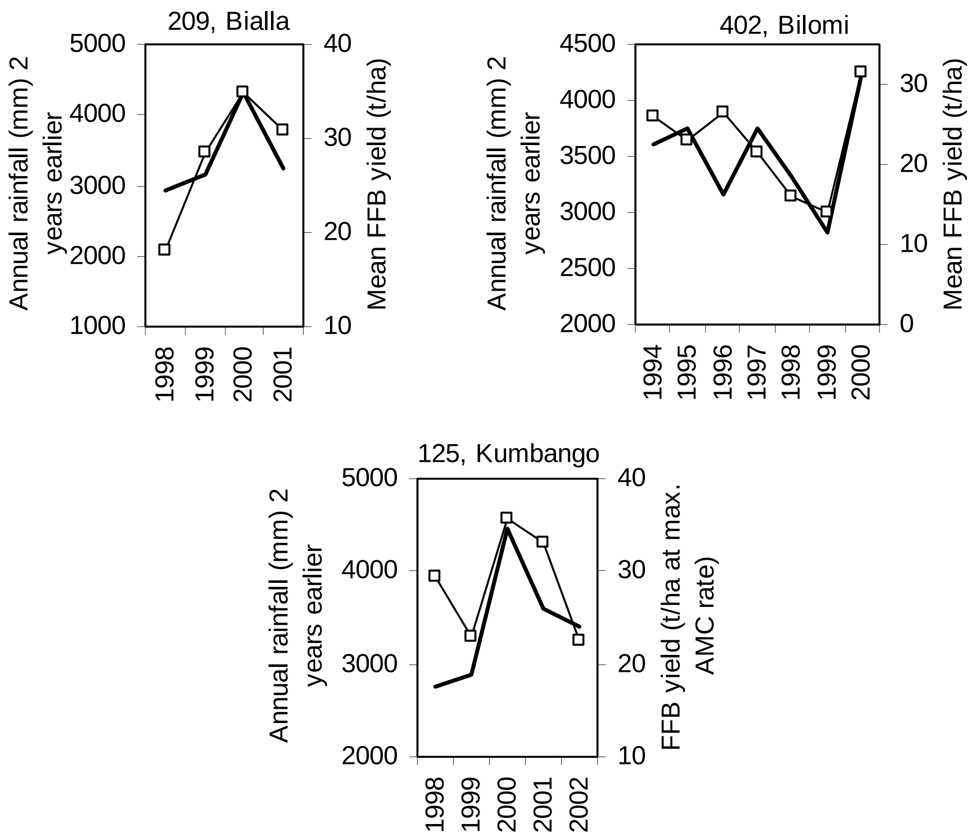


Figure 1. Annual FFB yield and annual rainfall 2 years previously for 3 trials in WNB.

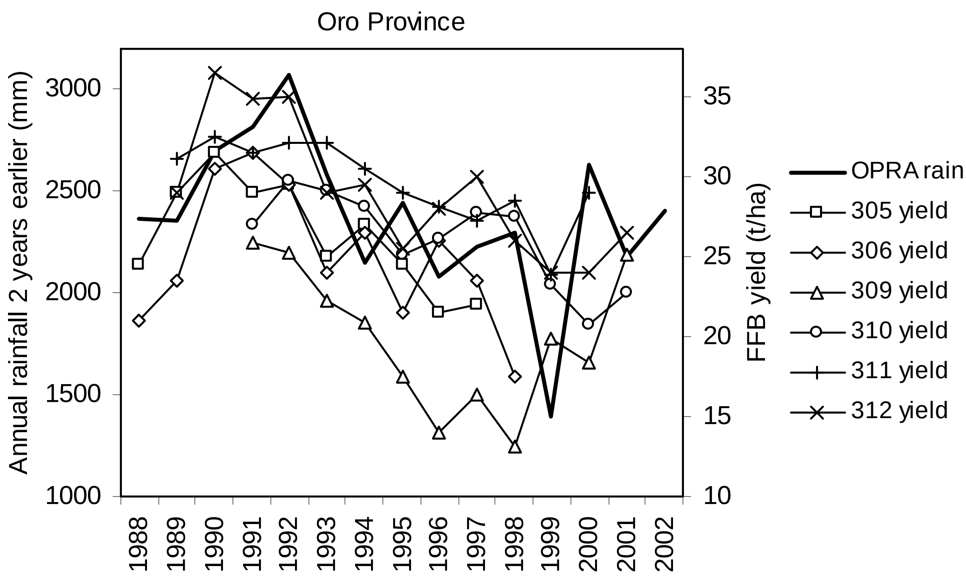


Figure 2. Annual FFB yield and annual rainfall 2 years previously for 6 trials in Oro.

Figure 3. Annual FFB yield and annual rainfall 2 years previously for 3 trials in Milne Bay.

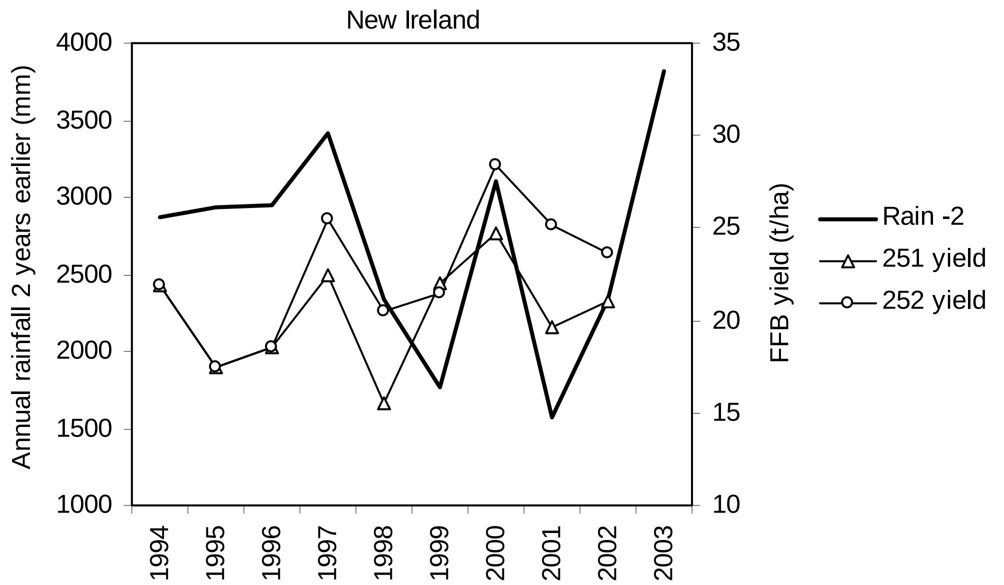


Figure 4. Annual FFB yield and annual rainfall 2 years previously for 3 trials in New Ireland.

Trials 332 and 514. YIELD FLUCTUATION MONITORING

Background

An ability to predict FFB yield several months in advance would be of great benefit to the industry. The purpose of this proposal is to establish FFB yield forecasting models for different oil palm growing agro ecosystems in PNG. Following discussions with PacRim, M. Banabas formulated a proposal for a model to predict yields, using monitoring of a group of palms in each block or soil type. The work has been designated Trial 332 in Oro and 514 in Milne Bay. Fresh fruit bunch yield of oil palm is determined by a wide range of factors from 6 months to 2 – 3 years before a bunch is harvested. Yields also vary from one site to the other because of the heterogeneity in the different agro-ecosystems. Yield at any one particular site is largely determined by factors that are limiting during the development of fruit bunches. The complexity of oil palm flowering cycles to adds to the difficulty of estimating yields 2 – 3 years ahead.

Purpose

- To develop FFB yield forecasting models for different oil palm growing agro ecosystems
- To collect sets of important soil, climate and oil palm physiological growth data that will be useful for FFB yield forecasting

Sites and Design

Sites in plantation blocks Sangara (adjacent to Trial 324) and Mamba (adjacent to Trial 329) in Oro and Waigani in Milne Bay were selected in 2001. At each site 20 palms have been chosen and marked. The 20 palms will be monitored over a number of years and data collected will be used for yield forecasting. Palms along the centre line of blocks (perpendicular to planting rows) were chosen to minimise progeny effects. The plantations will carry out all upkeep on the palms. The following parameters are measured.

- Soil description
- Daily weather data collection from nearby stations (sunshine hours, daily rainfall and maximum and minimum temperatures)
- Weekly production of male and female flowers (flower census)
- Weekly spear leaf count
- Weekly soil moisture determination
- Fortnightly ripe bunch count and weighing
- Monthly black bunch count
- Six monthly leaf production count

Results

Preliminary results are shown in Figure 1. Possible relationships between the parameters will become more evident with time.

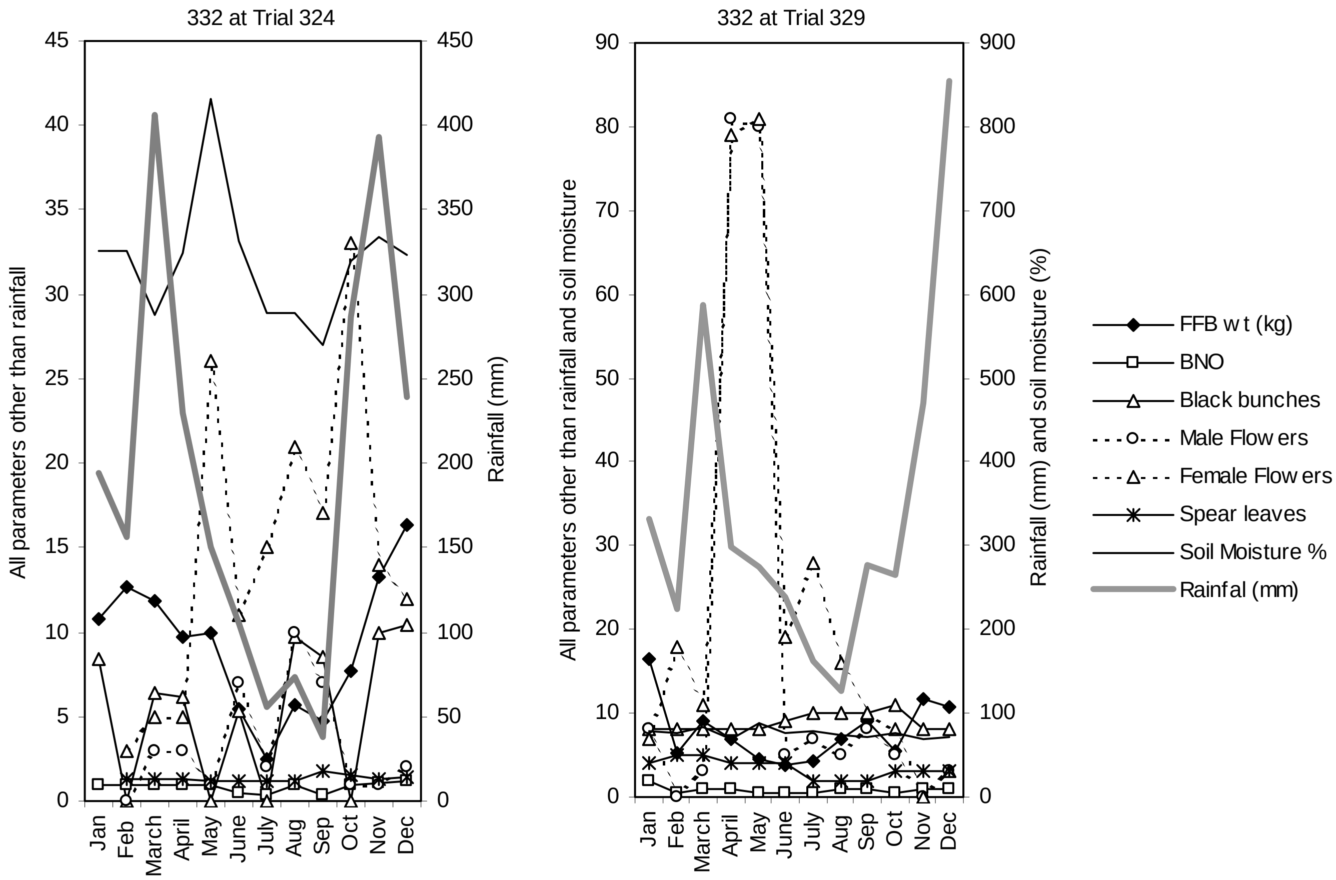


Figure 1. Monthly pattern of the measured parameters in Oro (Trial 332).

2. SMALLHOLDER STUDIES

Improving Productivity of the Smallholder Oil Palm Sector in Papua New Guinea

(G. Koczberski & G. Curry)

Smallholder socio-economic studies have been conducted as a collaborative research project between the PNG Oil Palm Research Association Inc., Curtin University of Technology and the Australian National University. Research funding was provided by the Australian Centre for Agricultural Research (ACIAR)

The main project report, subtitled "*A socio-economic study of the Hoskins and Popondetta schemes*" was released in 2001. As an extension, and final component, of the main project a further study was conducted in 2002 that focussed on the smallholder sector in the Bialla project area. The report of this extended study is available as a separate supplemental report to the PNGOPRA's Annual Research Report for 2002.

3. ENTOMOLOGY RESEARCH

(W.W. Page)

During 2002, Dr R Caudwell left PNGOPRA at the beginning of July and WW Page took over the post of Senior Entomologist in mid October.

1. SEXAVA

Outbreaks

The number of outbreaks for Sexava and other pests reported during 2002 is shown in Table 1. Because of the comparatively poor dry season it was expected that many Sexava eggs that might have been in the ground during that period would have held up development/hatching (diapause) so that when the rains began it was expected that there would be mass emergences of eggs (see Fig 1 for comparison between the rainfall in 2002 and the mean for 1985-2002 at Dami). This appeared to have happened with indications of peak hatching occurring in October (see below).

Date	Area	Pest	Date	Area	Pest
	NBPOL - Mosa			PIC - Bialla	
13/02/02	Togulo Plantation	Sexava	14/03/02	Tiauru LSS	Sexava
25/02/02	Dami Plantation	Sexava	04/04/02	Sege VOP	Sexava
26/02/02	Numundo Plantation	Sexava	18/04/02	Malele VOP	Sexava
28/02/02	Navarai Plantation	Sexava	23/05/02	Barema LSS	Sexava
09/03/02	Navarai Plantation	Sexava	23/05/02	Tiauru LSS	Sexava
07/05/02	Dami Plantation	Leafhoppers	11&18/7/02	Barema LSS & Tiauru LSS	Sexava
17/05/02	Haella Plantation	Sexava	03/10/02	Barema LSS	Sexava
16/07/02	Togulo Plantation	Bagworm	10/10/02	Tiauru LSS & Gomu VOP	Sexava
18/09/02	Garu, Numundo,Walindi Pltns	Poor fruit set			& leafhopper
				Poliamba - Kavieng	
	NBPOL - Kapiura		22-26/1/02	Kapsu,Wanup, Katu, Luburua,	
30/04/02	Bilomi Plantation Div 1 & 2	Sexava		Lakurmau,Maramakas, Baia,	Sexava
30/04/02	Kautu 2 Plantation	Leafhopper		Medina, Piera, Losso	
17/07/02	Malilimi Plantation	Sexava		Plantations	
30/10/02	Malilimi Plantation	Sexava	22-26/1/02	Kafkaf, Fissoa and Toabi VOP	Sexava
			25-27/7/02	Boligila, Medina, Manavai,	Sexava
	OPIC - Hoskins			Sikakui Plantations	
13/02/02	Kavui LSS	Leafhopper	25-27/7/02	Lakaka Plantation	Rhinoceros beetle
08/07/02	Kafori VOP	Sexava	14-19/10/02	Libba Plantation	Sexava
09/08/02	Tamabu VOP	Sexava			
27/09/02	Buvussi LSS	Sexava & stick			

Table 1. Pest outbreaks during 2002, reported, visited and advised on.

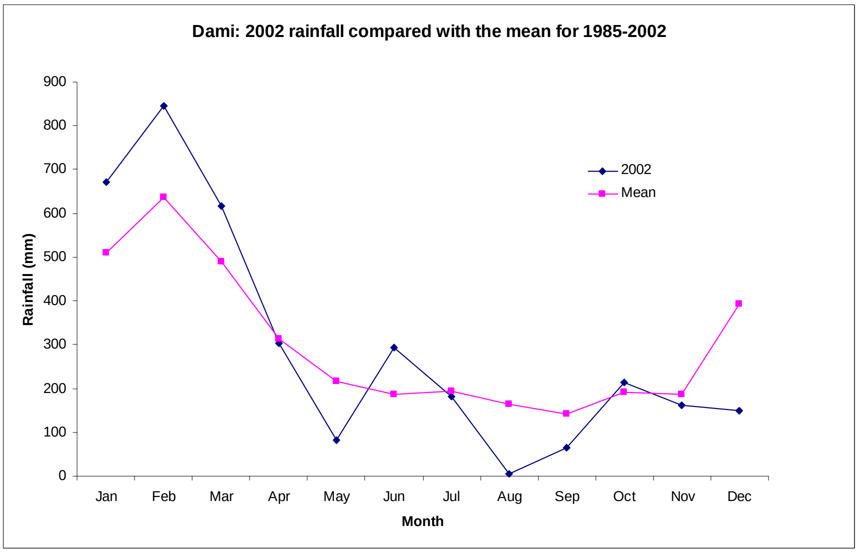


Fig. 1. Rainfall at Dami in 2002 compared with the mean for 1985-2002

Biological Control

Egg parasitoids

Leefmansia bicolor were reared in the laboratory in Sexava eggs and then released into oil palm growing areas where low-level Sexava populations were present. Table 2 gives details of the releases of egg parasitoids during 2002.

Site	No, parasitised eggs released	Estimated No. parasites released
NBPOL - Mosa		
Dami Plantation	1,090	27,250
Bebere plantation	320	8,000
Togulo Plantation	480	12,000
NBPOL - Kapiura		
Bilomi Plantation	240	6,000
Malilimi Plantation	310	7,750
Smallholders - Hoskins		
Kavui	260	6,500
Sarakolok	260	6,500
Tamba	480	12,000
Hargy - Bialla		
Navo Plantation	1,320	33,000
Smallholders - Bialla		
Apupul	210	5,250
Kambyia	240	6,000
Barema	360	9,000
Soi	110	2,750
Malasi	110	2,750
Tiauru	920	23,000
Poliamba - Kavieng		
Boligila Plantation	120	3,000
Piera	120	3,000
Medina	120	3,000
Loburua	120	3,000
Totals	**7,190**	**179,750**

Table 2. Numbers of egg parasitoids (*L. bicolor*) released during 2002

Strepsipteran parasites

The EU-funded Sexava project, which focused on attempts to transfer the strepsipteran parasite, *Stichotrema dallatorreanum,* from Oro to West New Britain and New Ireland Provinces finished at the end of 2001 and the project report submitted. However further releases of *Stichotrema* were made during 2002 and the total of all releases, at more than 20 trial sites, reached 10,878 by September 2002 (see Table 3). Despite this, regular monthly sampling at many of the sites only produced two returns of the parasite during 2002 (Table 4) and there has not yet been any indication of *Stichotrema* successfully infecting *Segestidea gracilis* in the New Ireland. The method used for recording infection, the presence of the dark patches on the underside of the Sexava host produced by the extrusion of the parasite's cephalothorax through the skin of the host, was supplemented after October by the dissection of all specimens collected from release areas to look for the immature stylops inside the hosts. Between October 2002 and the beginning of February 2003, 547 Sexava from *Stichotrema* release areas were dissected and no stylops were found (see Table 5). It is possible that if the Sexava eggs laid in the field during the year held up development (diapause) until the start of the rains at the beginning of October, no or very few Sexava nymphs or adults would have been available for *Stichotrema* to infect and the population cycle of the parasite could have been broken. This would only be expected to happen in a particularly dry season although confirmation of this will not be forthcoming until the egg diapause is fully understood. Work will concentrate on further understanding the sexual/asexual reproduction of *Stichotrema* and the breeding of the parasite through successive generations of *Segestes decoratus* (and later *Segestidea defoliaria*) in the insectary, so that stocks of the parasite can be released from the correct hosts.

Location	Date	Sexava host	Number
Dami Pantation, fields 1c and 15	Feb-Jul	*defoliaria* /*decoratus*	668
Numudo Plantation fields E1 and E2	Feb-Jul	*decoratus*	1,000
Balaha, Hargy, Bialla	Feb	*defoliaria*	85
Sege VOP block 578 Central Nakanai	Feb	*defoliaria*	80
Navo Plantation, Hargy, Bialla	Mar-Jul	*defoliaria*	265
Poliamba Plantation, Kavieng	Mar-Oct	*gracilis*	834
Tiauru block 298, Bialla	Jun-Jul	*defoliaria*	150
Previous releases Feb 2000 to Dec 2001			7,796
Total *Stichotrema* releases			**10,878**

Table 3. Number of *Stichotrema dallatorreanum* released during 2002

Dami Plantation	Sarakolok Smallholders 1
Numundo Plantation	Sarakolok Smallholders 2
Siki Smallholders	Sarakolok Smallholders 3
Kapore Smallholders	Tiauru Smallholders
Kavui Smallholders 1	Barema Smallholders
Kavui Smallholders 2	Sege VOP
Tamba Smallholders	Navo Plantation

Stichotrema recovered during 2002

12/01/02 Kapore block 288 in female *defoliaria*
18/07/02 Barema block 1391 in female *defoliaria*

Table 4. Sites monitored for *Stichotrema dallatorreanum* returns during 2002

Date	Area	Species	No. dissected	No. with stylops
11/11/02	Numondo	*decoratus*	5	0
14/11/02	Dami	*decoratus*	7	0
03/12/02	Siki (block 2235)	*decoratus*	151	0
02/01/03	Dami (field 15)	*decoratus*	172	0
06/01/03	Dami	*defoliaria*	41	0
09/01/03	Siki (block 2235)	*decoratus*	109	0
12/02/03	Numundo	*decoratus*	62	0
	Totals		547	0

Table 5. Sexava from *Stichotrema* release areas dissected to look for infection.

<u>Morphometrics</u>

Introduction

The use of morphometrics to identify insect stages and study changes in populations is well established (i.e. Chapman et al, 1977, Pedgley et al, 1989). In grasshoppers the length of the hind femur can be measured to delineate the instars in a sample and examine the linear increase of mean femur length of a population over time when more than one sample is taken. It is only when a population of insects is under severe conditions and individuals are smaller than they should be, or instars stages are missed out, that the technique is less accurate. This is extremely unlikely in the case of Sexava feeding on oil palm, which provides a constant food source of similar quality. The technique was therefore introduced to look at: (i) whether Sexava populations are overlapping or succinct (ii) the number of instars that *Segestes decoratus* and *Segestidea defoliaria* have in the field (iii) the rate of development in the field (iv) being able to predict when oviposition is beginning to take place and (v) being able to predict the time of eggs hatching in relation to rainfall. Although at a very early stage, with a lot more data needed for the proper delineation of instars and prediction of hatching and oviposition, the initial results are encouraging. These are presented here as an example of what can be done with the data rather than an accurate conclusion on the development of *Segestes decoratus* over time.

Methods

Random samples in excess of 50 (62-145) were taken from outbreaks of *S. decoratus* at Siki, Dami and Numondo on different dates and the femur measured for each individual. All specimens were dissected to look for early stages (stylops) of *Stichotrema* (see above). In addition the elytra (wing) length and stage of oocyte (egg) development were also recorded for each adult (note that for *S. decoratus* found in New Britain there are only females present). The oocyte development dissections can give information on how mature a female is, how many eggs have been laid, and how many times the female has laid eggs. Histograms of the femur length distribution were drawn up and the mean femur length for each sample calculated.

Results and discussion

The linear progression in development over time of a population that has hatched from eggs at about the same time, as measured by changes in the mean femur length, only occurs after moulting begins since no change in the mean will take place before then. Similarly when the majority of a population are becoming adult the increase in the mean will level off. A diagrammatic representation (based on the results) is shown in Fig 2. For this reason, and known differences in the first rainfall of the season, the sample from Numundo (collected 12/2/03, with 71% adults) was excluded from the calculation of linear increase in femur length over time. However the Numundo result is included in the three histograms of the distribution of femur lengths given below that illustrates the variability within the samples collected. The histograms show the presence of only three instars (although other instars in very low numbers could occur), which is typical of a population that has hatched over a short period of time. Overlapping populations that have hatched at different times will show a much broader number of instars being present. The histograms in Figs 3 a, b and c are presented in chronological order and show clearly the shift in the instars (changes in mean femur length) over time and also show that the peak numbers of *S. decoratus* in each femur length category are similar for each instar, i.e. 2.5 for fifth instar, 3.2 for sixth instar and 3.9 for adults despite the samples coming from three different areas.

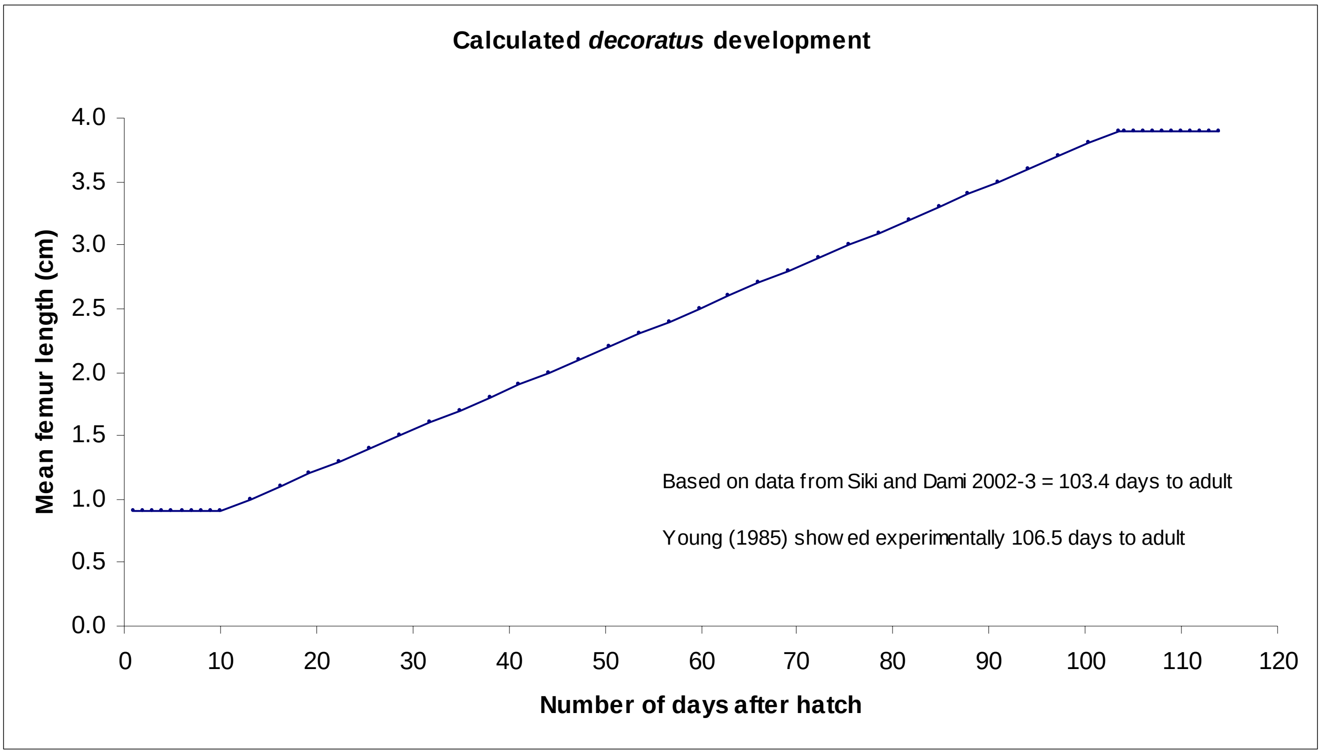
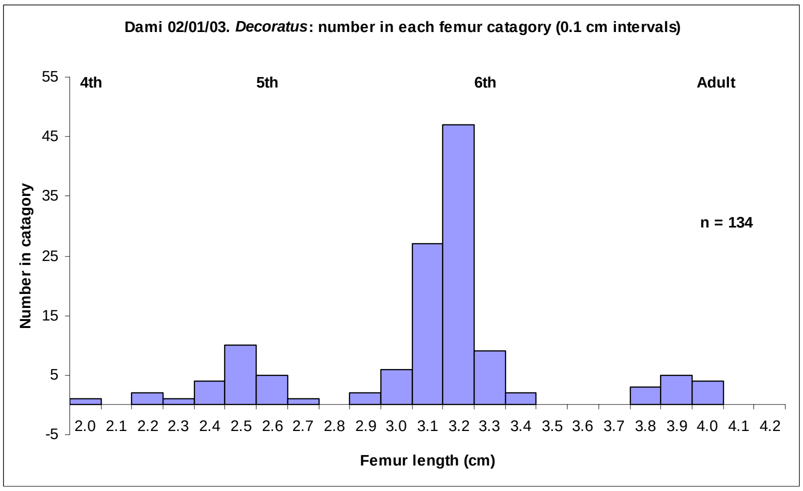
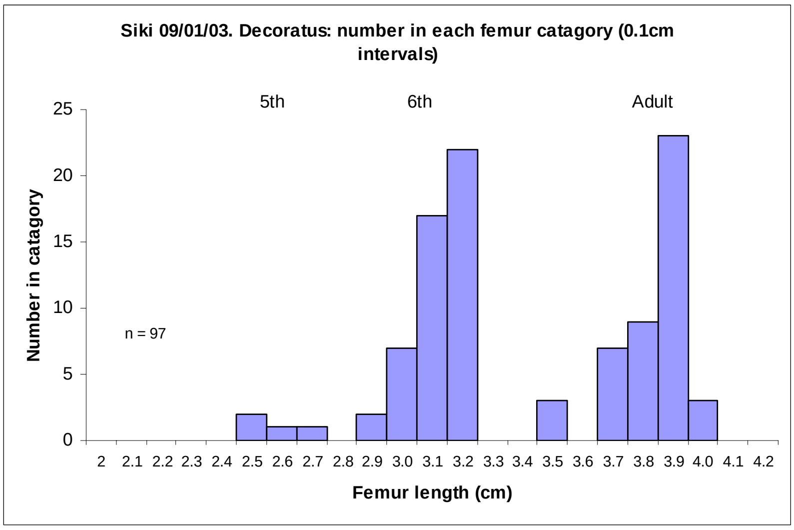


Fig. 2 Diagrammatic representation of the rate of development of *Segestes decoratus* using changes in mean femur length.

(a)



(b)



(c)

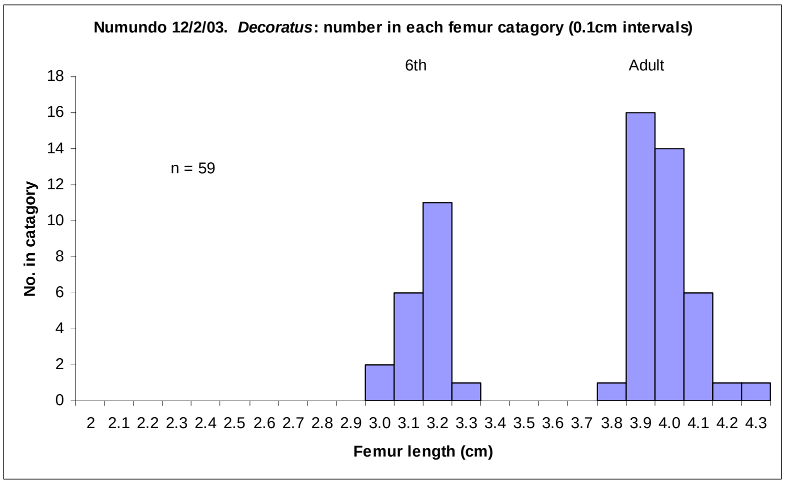


Fig 3 Changes in mean femur length over time of populations of *Segestes decoratus*

By plotting the mean femur lengths of the samples of *Segestes decoratus* from Siki and Dami over time (having to assume that the populations hatched at about the same time) a linear progression of change in femur length appears to be occurring (see Fig 4). By drawing in the trend line and extending it back to the expected mean for first instar nymphs (from hatching eggs) then adding ten days for the length of the first instar (Young 1985) and ten days for the time from when diapausing eggs are watered to hatching (Froggatt and O'Connor, 1940) the projected date of hatching of the populations is related to the first major rains of the season. It is concluded that, based on this small amount of data, hatching occurred around 13/10/03 after the first two heavy showers of the season (30th September and 3rd October). Using the derived equation for the linear progression of $y = 0.0321x + 0.5796$ and the mean femur length for adults of 3.9, the length of time from hatching to adult can be calculated as 103.5 days, which fits well with Young's figure of 106.5 days for caged female *Segestes decoratus* (Young, 1985). With further data this method can be used for delineating from one random sample from an outbreak: hatching dates, when the population will become adult, and when they will begin ovipositing; all of which will be of use in control decisions, both chemical and in the timing of the release of parasitoids.

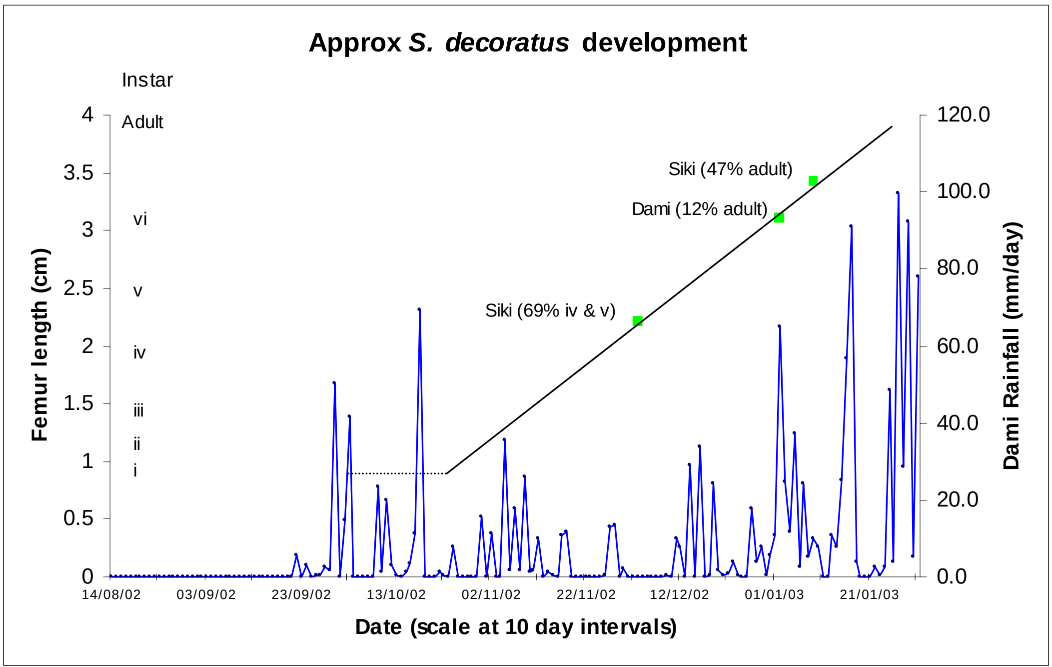


Fig 4 Linear progression in mean femur length of *S. decoratus* in relation to time and projected back to estimated hatching time to compare with rainfall.

Rearing

A major constraint in carrying out experimental work on Sexava in the laboratory has been the difficulty of maintaining stocks of the different species, particularly *Segestes decoratus* and *Segestidea defoliaria* at Dami. Up until October stocks had been kept solely on reject oil palm seedlings of approximately 7 months old. Since Sexava had originally fed on indigenous plants prior to the introduction of oil palm it was decided to try giving the stocks a mixture of young oil palm, young coconut palm and wild *Heliconia* sp. Both *S. decoratus* and *S. defoliaria* showed a particular preference for coconut; with oil palm being the second choice and *Heliconia* last in terms of amount eaten. The stocks showed a considerable improvement in health (reduction in mortality) so it was decided to continue giving a mixture of the food plants. Coconut is now presented using 2-4 cut fronds and keeping them in wet soil. Handling of the Sexava, perceived to be a major cause of mortality, now no longer appears to be a problem.

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2. INSECT POLLINATION

<u>Introduction</u>

The two-year research project on the pollinating weevil *Elaeidobius kamerunicus*, funded by the European Union, was completed by the end of June 2002, other than the conversion of part of the insectary at Dami to a quarantine facility, which was delayed because an inspection report was required from NAQIA. The project report was written up by the end of June and was updated and submitted in early 2003. The main outcomes of the project (reported on in detail in the 2001 annual report) were:

1. There can be a high level of parasitic nematode infection in the pollinating weevil population (*up to 50% infection with high parasite loading*). This level of parasitism must have a considerable impact on weevil survival and reproductive capacity.
2. The PNG population is genetically distinct from the West African and Central American, however the genetic diversity within PNG does not appear to be as restricted as originally feared. Inbreeding may not be so much of a concern.
3. It would be better to supplement the current pollinating weevil population with imports of new genetic material of the same species rather than importing new pollinator species.

The parasitic nematode, which lives in the haemocoel (blood cavity) of the weevils, has been identified as *Elaeolenchus parthenonema* by Poinar et al 2002, who give a brief outline of the stages of this parthenogenetic nematode.

<u>Quarantine facilities</u>

Quarantine facilities to house the introduction of new genetic material of *Elaeidobius kamerunicus* proposed by the pollination project (3 above) were designed in October to fit in the requirements set out by the National Agriculture Quarantine and Inspection Authority in their report of June 2002 "Pre-accreditation Report on Dami Oil Palm Insectary". The plan for the conversion was submitted to NAQIA to ensure that the conversion would meet their requirements and clearance was received at the beginning of December. The building of the facility with high, medium and low security rooms was initiated at that time.

History of the introduction of *Elaeidobius kamerunicus*

In order to understand more fully the genetic diversity of the original stocks introduced into Papua New Guinea (and the rest of the South east Asian oil palm industry) a search was done of the literature and unpublished reports to ascertain how many weevils were used to establish the weevil populations now in existence and how the weevils were distributed. The following summary gives the details that have been gleaned:

1. Weevils (*Elaeidobius kamerunicus*) were collected from various sites in Cameroon by Dr Syed (R Prior, *pers. comm.*) and a colony formed at Lobe Estate, Pamol du Cameroon and reared so that pupae of the same age could be collected.
2. 1044 pupae of the same age were transported by Dr Syed, firstly to CABI UK on 20th July 1980 to check and clean; then on to Kuala Lumpur on 23rd July 1980.
3. Of the original 1044 pupae only 618 survived and the culture for release was established from these pupae. During the establishment of the colony, care was taken to eliminate all nematodes, but these were ectophoretic (external) and it is possible that entomoparasitic (internal) nematodes were not looked for.
4. The two nematodes mentioned by the various authors at the time of the quarantine and releases were: (a) *Cylindrocorpus* sp. This is found all over the world (it is present on the weevils in PNG) and is found on the oil palm florets, the nematode being transported by the adult weevils. These nematodes are associated with decaying organic matter where bacteria, their food source, are abundant. (b) *Aphelenchoides bicaudatus*, which is a fungal feeding species that is found commonly throughout the tropical and subtropical regions. This species has not been recorded in PNG. Neither of these external nematodes cause any apparent harm to the weevils although they can be numerous and readily observed so that their importance may be misinterpreted.
5. The first release of *E. kamerunicus* in Malaysia was on 21st February 1981 and in the subsequent field studies no nematodes (external) were found.
6. The stocks of E. *kamerunicus* for Papua New Guinea were received on 10th November 1980, so they must have come from the quarantined stock held in Malaysia as releases had not occurred by then. The weevils were held at Awilunga where a special facility had been built. No nematodes were observed (external).
7. Stock was taken from the Awilunga quarantined colony to Dami, West New Britain on 2nd April 1981 where it was further quarantined.
8. First releases in PNG were at Bubia, near Lae, Morobe Province on a 4 ha block at the DPI Agricultural Station on 15-16th April 1981 (about 4000 adults). Saturation of flowers had occurred 47 days after release (about 4 generations of the weevil).
9. First releases on New Britain Island were at New Britain Palm Oil Development from 6th June 1981 (Bebere, then Dami) and 100 ha became saturated within 80 days and the whole development covered by October 1981. No nematodes (external) were observed in the laboratory or in the field.
10. Subsequent releases that year were at Higaturu Oil Palms on 24th June 1981 and at Hargy Oil Palms on 22nd July 1981. At Higaturu the palms were young and had a shortage of male inflorescences for weevil redistribution so there was a poor spread of the weevils and another introduction had to be done on 3rd November 1981.
11. In Liau, S.S., 1984 he says, "In 1983, Mr. Tan Yap Pau reported at a meeting that a parasite was extracted from a field-collected weevil but this has not been confirmed".
12. David Hunt (Nematode Taxonomist, CABI Bioscience, UK) pers.comm. says that the entomoparasitic nematode *Elaeolenchus parthenonema* was first reported in 1998, and he first saw it in 1999 from Sabah. The nematode has been reported from Malaysia, Sumatra and Papua New Guinea and could be widespread in the region.

Levels of infection by the internal nematode *Elaeolenchus parthenonema*

Work was initiated in October to study further the infection levels in the pollinating weevils by the internal nematode *E. parthenonema* and to gain further understanding of the population dynamics, life cycle and effect of the nematodes on the weevil population. Initial collections of weevils from anthesing male inflorescences showed a marked difference in the levels of infection between different sites. The initial studies on male and female weevils emerging from their breeding sites (post-anthesing male spikelets) and the levels of nematode infection have shown that:

(i) The majority of females weevils emerge over the first four days whereas males emerge over a period of two weeks or more (Fig 5). The sex ratio reaches about 50:50 if the population is healthy.

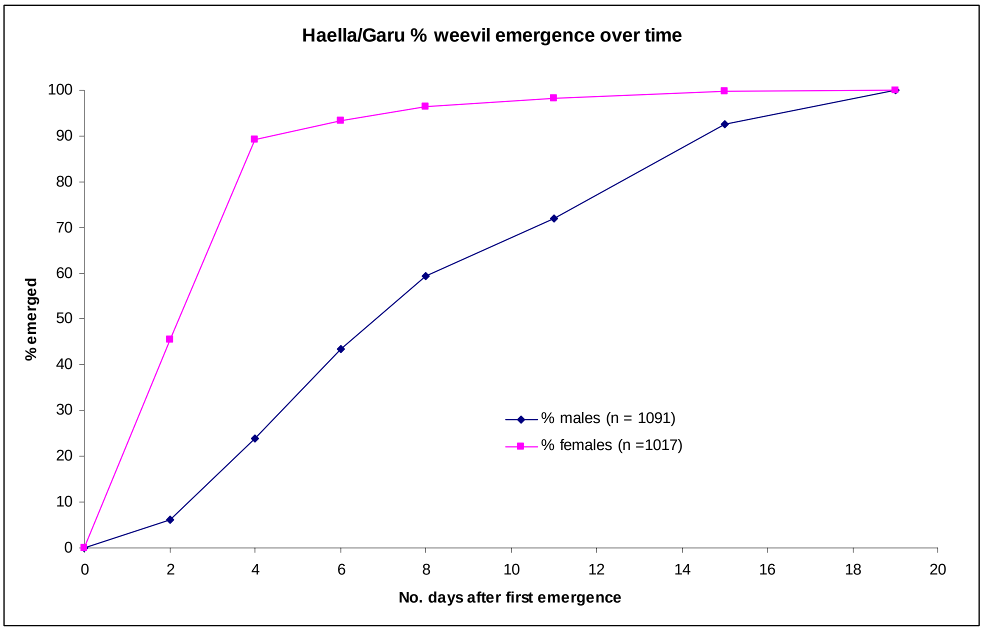

Fig. 5 Percentage of male and female weevils emerging over time from areas with very low levels of nematode infection.

(ii) In areas where weevils have high levels of the internal nematode, there can be a very high variation in infection levels in weevils emerging from different inflorescences sampled within 50m of each other, an example is shown in Table 6.

Inflorescence number	% males emerged	% infected with nematodes
1	60.9	9.8
2	68.1	5.6
3	51.7	31.9
4	35.1	48.0
5	34.1	83.7

Table 6. Variation in the proportion of weevils, emerging from spikelets, infected with internal nematodes sampled from inflorescences collected within 50m of each other at Kautu 2.

(iii) There appears to be mortality caused by the internal nematodes if the numbers of nematodes per infected individual is high, with male emergence affected more than females, the higher the level of infection the higher the male mortality. Initial results from emerging weevils collected in November showed that, at Kapiura where the nematode infections were found to be comparatively high (Kautu 1, Kautu 2, Kaurausu and Bilomi), there was a much lower proportion of male emergence than at Numundo where nematode infections were extremely low (Haella 1 and 2, Garu 1 and 2). Also the proportion of males emerging was related to the difference between expected overall emergence and actual emergence. This is illustrated in Fig 6 where the percentage of males emerging from 20 inflorescences in each area (20 pairs of spikelets per inflorescence) is plotted against the difference between the actual emergence and the expected emergence (based on the ideal of 48 weevils per 5 cm shown by Syed 1980). The results suggested that there might be a link between the nematode infections and numbers emerging, although other factors cannot be discarded.

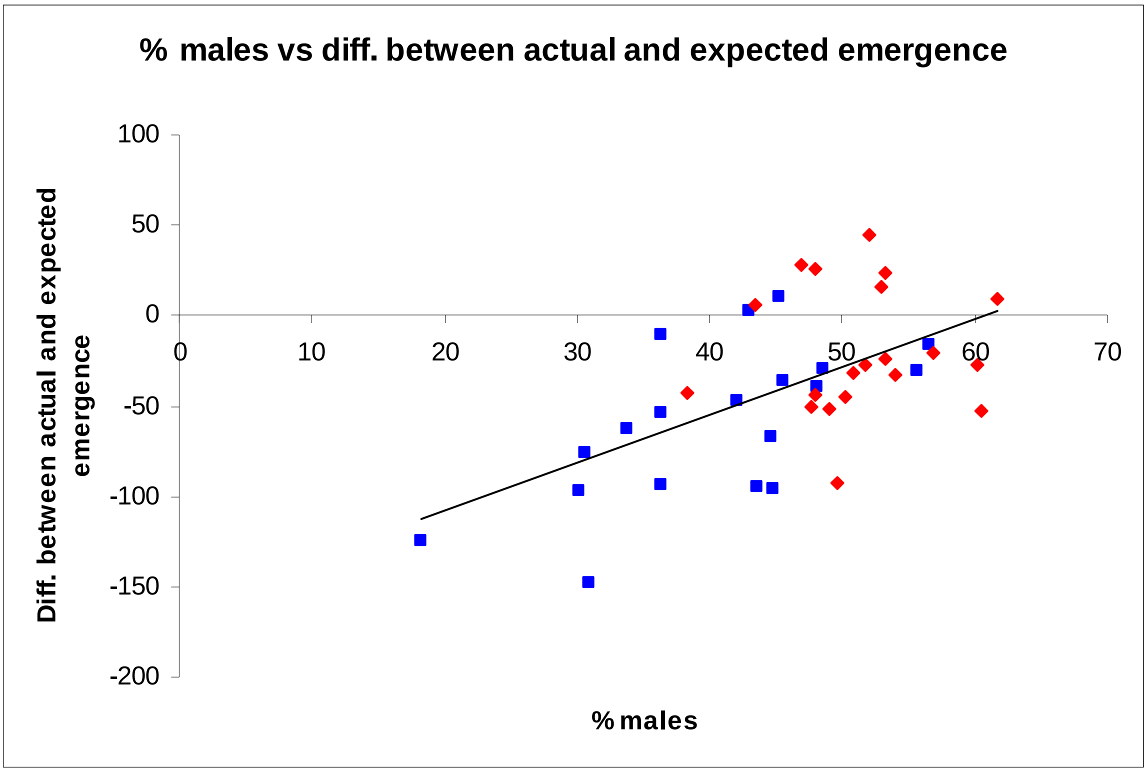

Fig. 6. Percentage of males emerging from 20 inflorescences from Kapiura (■) and Numundo (◆) in relation to the expected emergence for the size of the spikelets sampled.

Samples for emergence from Kapiura and Numundo were looked at more closely in December by dissecting weevils emerging every two days from the spikelets in order to look at any changes of level of infection over the period of emergence. Initial results show that the proportion of males emerging is related to the proportion of infected weevils emerging (Fig. 7) suggesting that some mortality may be taking place before emergence and males may be more affected than females. Since the results in Fig 7 are from the same site, variables such as weevil density in the area, palm age, weather and other factors would be the same.

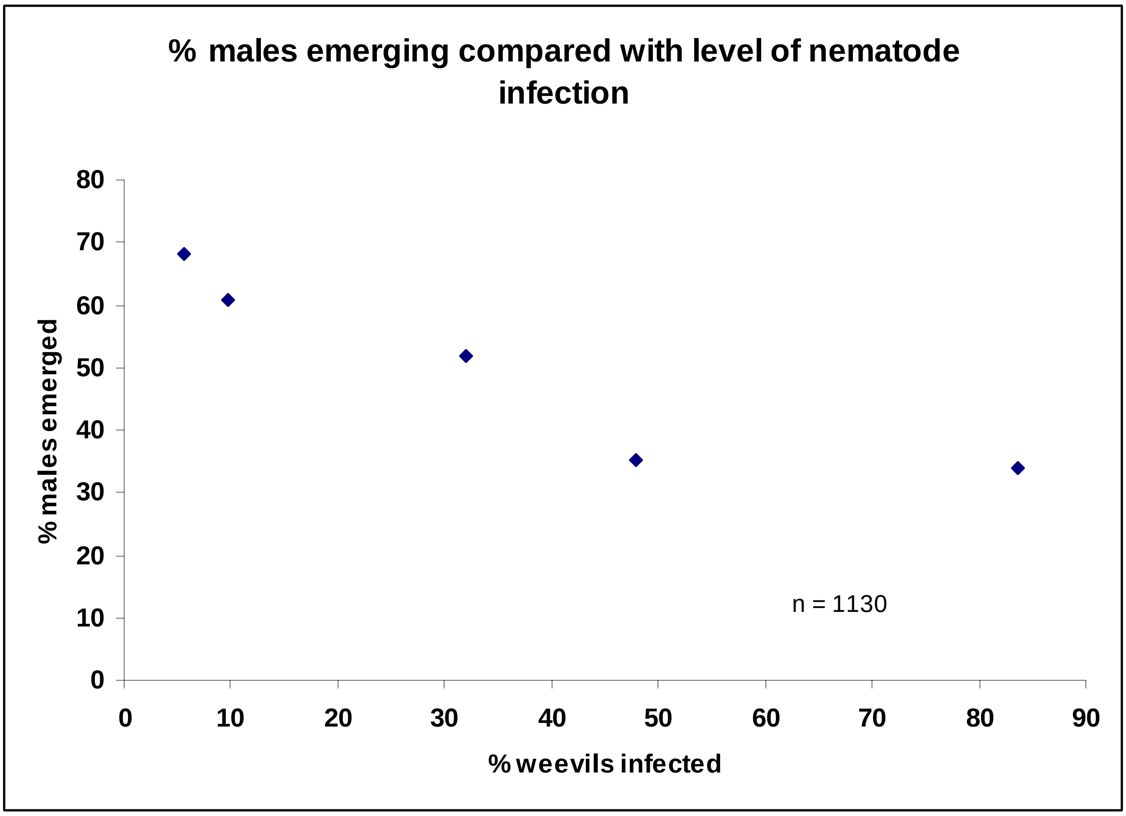

Fig. 7. Proportion of males emerging from 5 different inflorescences (2 spikelets per inflorescence) sampled from Kautu 2 in comparison with the proportion of emerging weevils infected with internal nematodes.

(vi) The internal nematodes are often immature or have not started producing larvae in the first emerging weevils (females) but have by the time the majority of the male weevils are emerging. Nematodes (which are all females) were designated immature if the ovaries were not fully developed or the eggs had not formed fully. When larvae of the nematode hatch, they pass out of the adult nematode into the haemocoel of the weevil, so the presence or absence of larvae in a weevil's haemocoel is another stage in the development of the parasite. Fig 8 shows the proportions of immature adults and larvae in infected weevils over time and shows that nearly 70% of infected weevils have nematodes that are immature inside them when weevil emergence first begins, but this declines so that by day 12 there are only mature nematodes present. Conversely the first infected weevils to emerge do not have nematode larvae inside them but by day 12 the proportion has reached 100%.

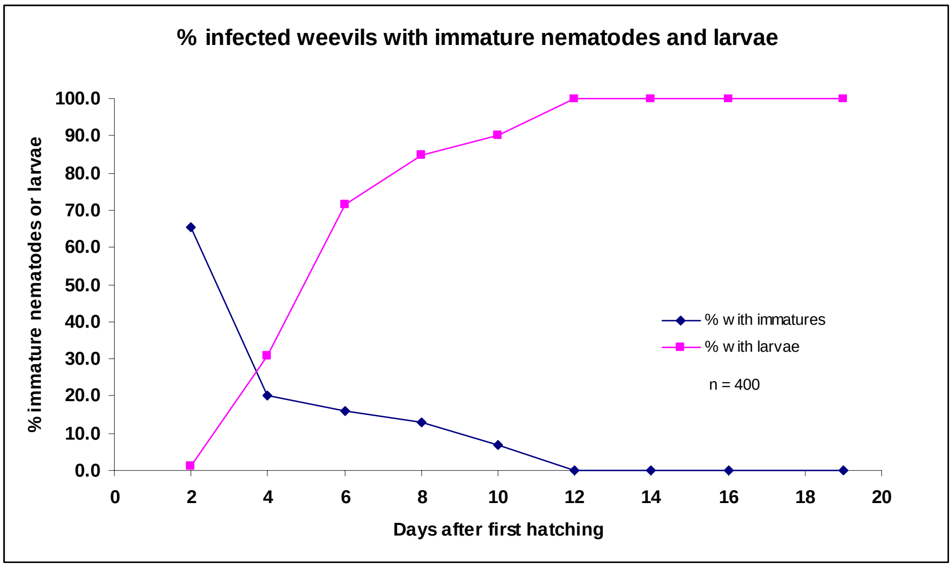

Fig. 8. Comparison of the proportions of immature nematodes and the presence of larvae over time after first emergence of infected weevils.

If the presence of larvae is compared with the proportions of males and females emerging it can be seen that by the time the majority of females (90%) have emerged the proportion of individuals with larvae present is still only around 20%. Whereas by the time a similar proportion of males have emerged the level of larvae present has reached 90% (see Fig. 9).

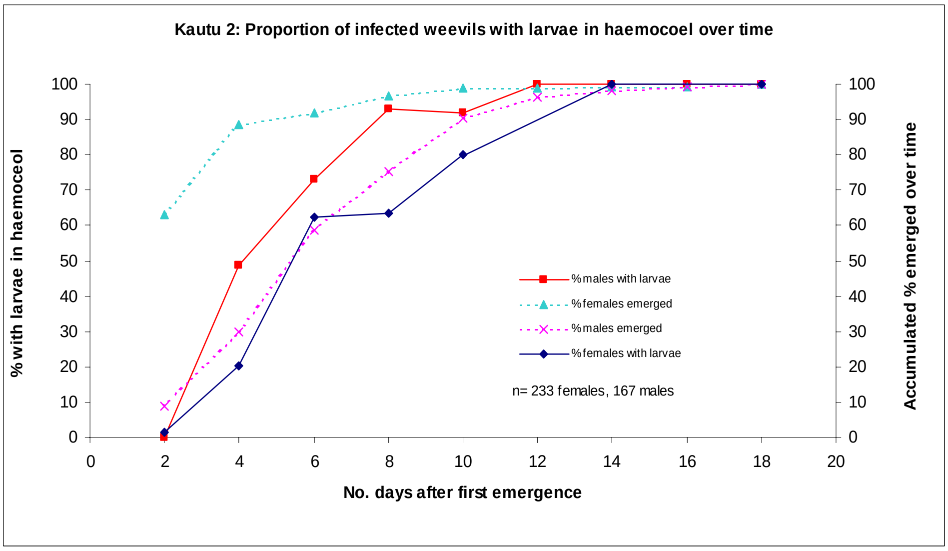

Fig. 9. The proportion of emerging infected male and female weevils with nematode larvae present in the haemocoel over time compared with the proportion of weevils of each sex emerging per day.

When the nematode larvae are present in the haemocoel of the weevils they have to undergo a moult to third instar prior to passing out of the weevil (Poinar et al 2002). It appears also that the third instar larvae may accumulate prior to leaving the weevils (pers. obs.). Since there may be hundreds or even thousands of these larvae, all feeding within the haemocoel along with the adults, the weevils must be put under enormous strain. It is suggested that the higher proportions of males possibly dying prior to emergence could be due to them taking longer to develop (i.e. later emergence) and the feeding nematode larvae and adults causing some mortality. Because the females emerge before most larvae start feeding there is a higher proportion emerging; but if this is so, then some females are likely to die a few days after emergence. This requires further investigation.

(vii) There appears to be a link between the wetness of the inflorescence and the level of infection where the nematodes are occurring, hence the reason why levels of nematode infection are perceived to be higher during the main rains and in areas with higher rainfall. This requires further investigation.

(viii) Up to 100% nematode infection has been found in the emergence samples and up to 57 nematodes in one individual have been found.

Work will continue on the affect of the internal nematodes and other factors on the health of the pollinating weevils and the subsequent affect on pollination and fruitset in oil palm.

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3. FINSCHHAFEN DISORDER

Feeding by a small brown leafhopper (*Zophiuma lobulata* Ghauri) causes Finschhafen disorder. It is probable that the symptoms are caused by a localised toxic reaction to *Z. lobulata* feeding on the fronds, so control of the disorder is therefore dependent on the management of *Z. lobulata* populations. The symptoms of the disorder can be severe and widespread in coconut, but so far the majority of symptoms that have been observed in oil palm appear to be the result of *Z. lobulata* moving onto the oil palms from infested coconut palms, producing damage as an edge effect.

During the year reports of localised occurrences of Finschhafen disorder were reported from Embi, Ambogo, Sumbiripa, Sangara and Igora in Oro Province on the mainland and Kautu, Kavui, Walindi and Buluma in West New Britain.

In order to examine the development of the disorder in oil palms, monitoring plots were established on the mainland at Embi and Igora in Oro Province. The initial results suggest a general decline in the presence and appearance of symptoms over time. This may be because the symptoms are likely to appear several months after attack by *Z. lobulata* and the bulk of the population has disappeared by the time the symptoms have come through. Further studies will be made on the appearance, severity and distribution of the symptoms in relation to estimated leafhopper numbers.

4. QUEEN ALEXANDRA'S BIRDWING BUTTERFLY (*Ornithoptera alexandrae*)

As part of the oil palm industry's commitment to conservation, the Entomology Section have been actively involved in the propagation and planting out of QABB food plant (*Pararistolochia dielsiana*) in areas of forest habitat on Popondetta Plain (i.e. Lejo) and buffer zones in Higaturu Oil Palm plantations. Several thousand of the vines were propagated and planted out during the year. Monitoring of tagged vines was carried out at Lejo and Parahe but no QABB stages were found.

5. OTHER PESTS

a. Bagworms (Lepidoptera: Psychidae)

There were minor outbreaks of bagworm at Kautu, Togulo (WNB) and Ambogo (Oro) during 2002. Chemical treatment was not required for these outbreaks.

b. Rhinoceros beetles (Coleoptera: Scarabaeidae)

There were no outbreaks during 2002.

c. Psyllid (Hemiptera: Psyllidae) on the PNG mainland

Psyllids were released onto patches of the weed pest Mimosa (Leguminosae: Mimosaceae) at Bakito, Heropa, Pingoruta and Watus mini estates. Parahe mini estate was the source of Psyllid collection and a site where Psyllid has had a significant effect on Mimosa. The number of mimosa patches declined in the treated areas.

d. Rats on the PNG mainland

An outbreak of rats was reported at Milne Bay during the year. Visits by Entomology Section personnel in February and November provided recommendations to alleviate the problem.

4. PLANT PATHOLOGY RESEARCH

(Dr. C. Pilotti)

SUMMARY

Phase II of the Ganoderma Stabex project 4.2 ended in April 2002. However, there were still sufficient funds available to enable some basic research activities to continue. Research activities in 2002 involved epidemiological studies, nursery screening tests and biological control experiments.

Survey results for 2002 indicate that annual disease incidence has decreased in most plantations. This is attributed to the natural disease progression and not to control procedures currently in place. On average, after 10 years of age, the decline in live palms accumulates by approximately 1 palm/ha/year from which yield losses can be tentatively predicted. Environmental factors have an influence on disease incidence and where possible every effort must be made to minimise stress on palms.

Studies on the population of *Ganoderma boninense* continue to confirm that isolate variation is due to spore dispersal. However, the number of neighbouring diseased palms is increasing which may indicate secondary spread. Compatibility tests between isolates obtained from neighbouring palms show that the majority of isolates are not identical, ruling out root-to-root spread of *Ganoderma* between palms. Isolates causing both upper stem rot and basal stem rot have been found to have an indirect hereditary relationship. A direct hereditary link between isolates that will prove secondary spread by basidiospores has so far not been detected within the population in Milne Bay. Similar studies in New Ireland show that isolates are of diverse genetic background.

Work on early detection of *Ganoderma* in young oil palm plantings using the GanET primer continued in 2002 with a further 33 samples being analysed. 27% of frond bases sampled gave positive results for *Ganoderma* indicating that the frond bases have been exposed to spores of *G. boninense* but these palms may not develop infection.

Nursery and laboratory screening assays carried out in 2002 have given variable results due to high contamination rates and non-uniform palm stock. Frond base inoculations did not produce disease symptoms in 3-year–old palms after 6-12 months of incubation. Generally, decay was confined to the pruned and inoculated frond base with limited progression into the basal tissue. Several different inoculation techniques were carried out on a large number of nursery palms and these will be assessed in 2003.

Results of pilot field trials using *Ceratocystis paradoxa* have been poor due to dry weather conditions. Indications are that the fungus is not efficient at degrading denser wood in the lower parts of the palm trunk and this may hinder it's effectiveness as a biocontrol agent for *Ganoderma*. In addition, dry weather conditions have an adverse effect on the growth of *Ceratocystis,* which may restrict field application. More intensive trials are planned for 2003.

Other potential biocontrol agents for *Ganoderma* are species of *Trichoderma.* Naturally occurring isolates have been purified in the laboratory and these will be subjected to further tests and identification in 2003.

1. Epidemiological Studies

Objectives: (1) To determine the mechanisms of primary and secondary spread of Ganoderma within plantations in PNG and to apply this data to refine control methods.

(2) To generate models from survey data that will allow growers to make predictions of crop losses

1.1 Disease trends

1.1.1 Milne Bay plantation surveys

On average, disease levels decreased for all estates except for Sagarai in 2002 (Figure 1). The largest decrease occurred for Waigani Estate of >0.6% which is unexpected and may be attributed to missing data for some blocks. Gilgili recorded the lowest decrease while the increase in the Sagarai disease levels is attributed to the apparent decrease in levels in 2001.

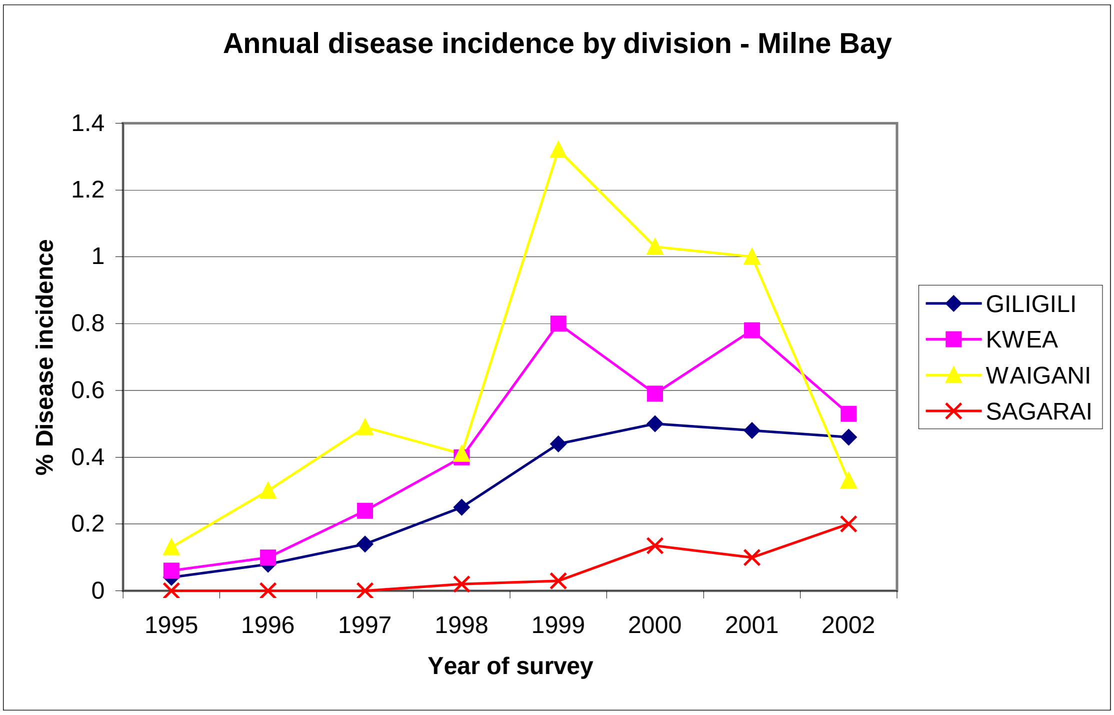

Figure 1. Annual disease incidence in Milne Bay at each survey by division.

The numbers of basal, suspect and upper stem rot palms was predictably variable in all estates in Milne Bay (Figures 2-5) with POME and ex-forest blocks showing the highest number of suspect palms. Particularly high levels of palms with upper stem brackets were observed in Sagarai (Figure 5) but these were recorded on sterile palms that had been poisoned prior to the survey. The total number of palms with upper stem rot did not increase significantly from the previous year (2001). In Kwea the majority of blocks (73%) had higher numbers of suspect palms than palms with brackets present at the time of survey. The same trend was observed for Sagarai with 71% of blocks containing more suspect palms. This may indicate that palms are succumbing earlier to the disease in these areas, probably due to environmental factors that are causing stress on the palms.

Average cumulative disease incidence for each estate in Milne Bay is shown in Figure 6. Disease levels are approaching 5% in Waigani and 0.5% in Sagarai. When viewed by age group it might be expected that disease levels will increase more rapidly from 14-17 yrs of age (Fig. 7). Variation in disease levels in palms of the same age is attributed to site factors and/or genetic background. It is encouraging to note that the average disease levels for 14 year-old palms in Sagarai is lower than that for palms in the other estates at the same age. This may be due to the larger number of ex-forest blocks compared to ex-coconut blocks in Sagarai.

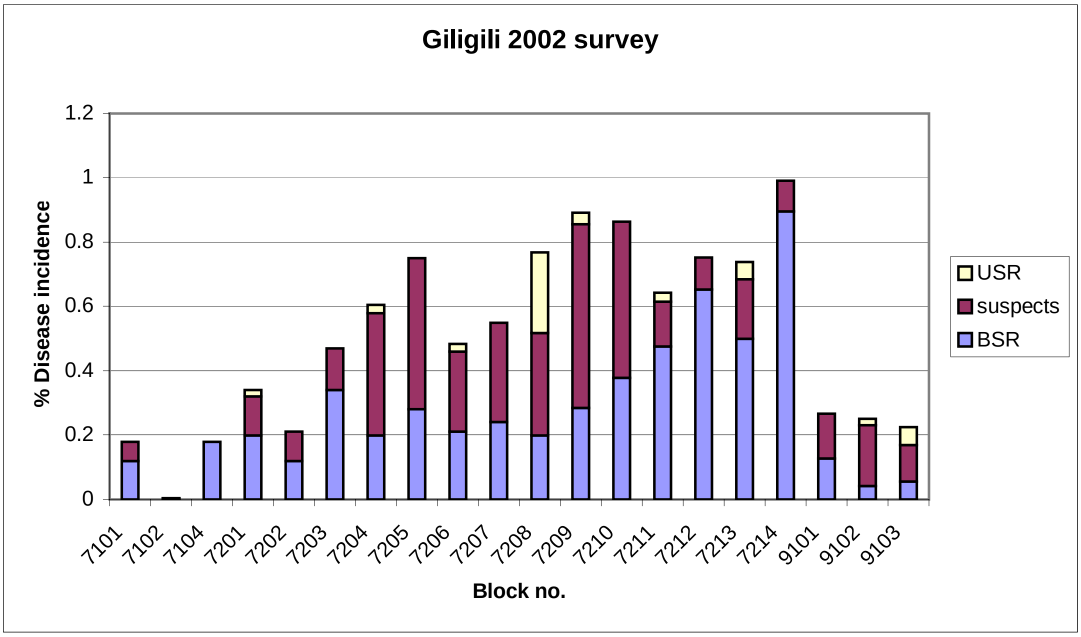

Figure 2. Disease incidence for 2002 in Gligili Division, Milne Bay by category. BSR= basal stem rot; USR = upper stem rot; Suspects= no brackets.

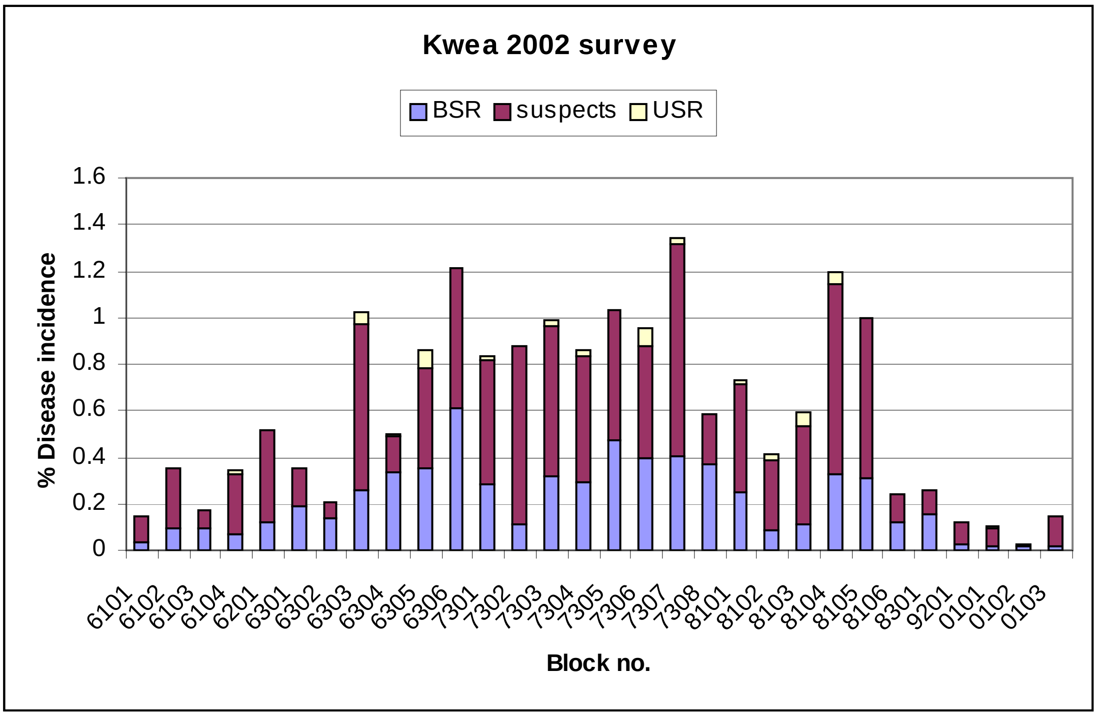

Figure 3. Disease incidence for 2002 in Kwea Division, Milne Bay by category. BSR= basal stem rot; Usr = upper stem rot; Suspect= no brackets

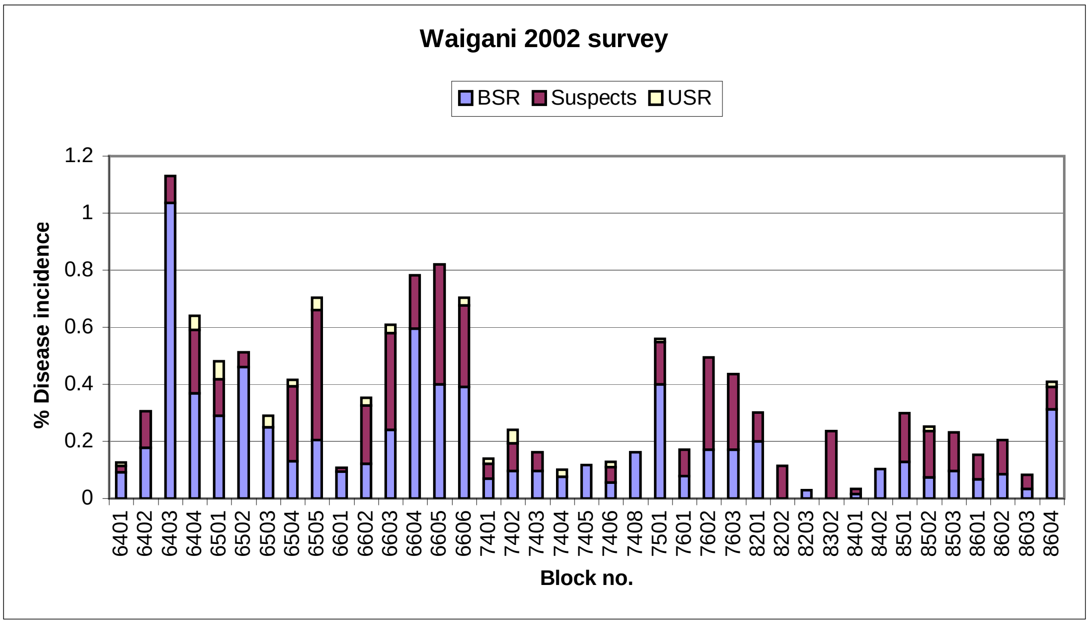

Figure 4. Disease incidence in 2002 for Waigani, Milne Bay by category. BSR = basal stem rot; Usr = upper stem rot; Suspect= no brackets.

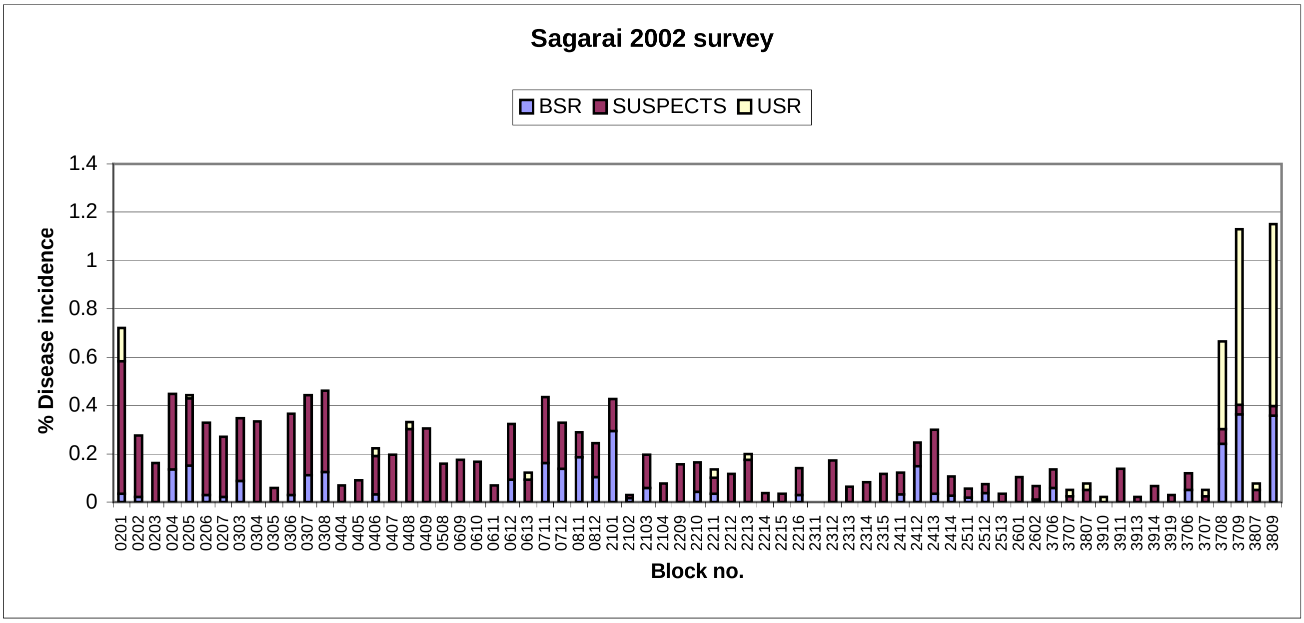

Figure 5. Disease incidence in 2002 for Sagarai, Milne Bay by category. BSR = basal stem rot; Usr=upper stem rot; Suspect = no brackets.

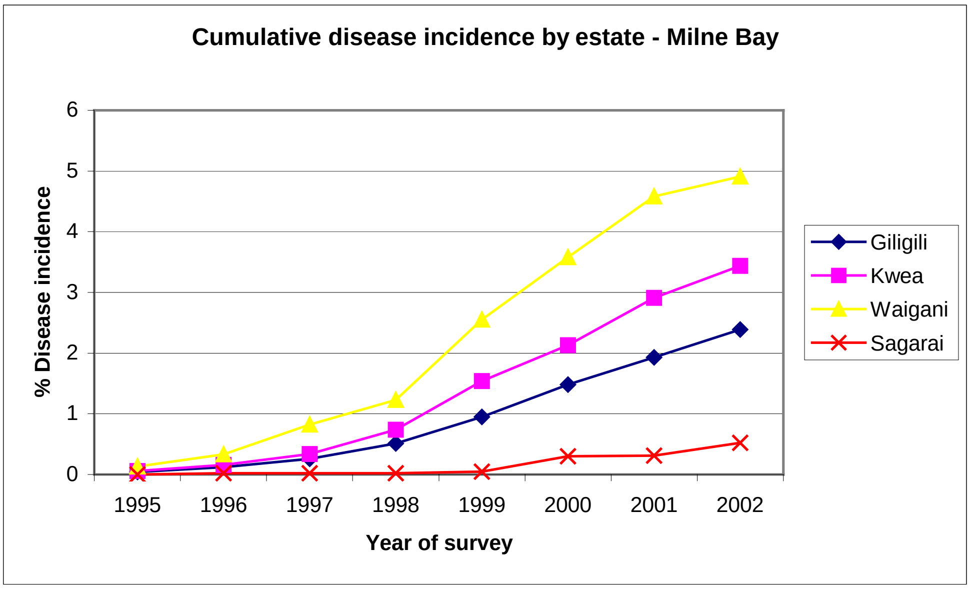

Figure 6. Cumulative disease incidence from 1995-2002 for each division, Milne Bay.

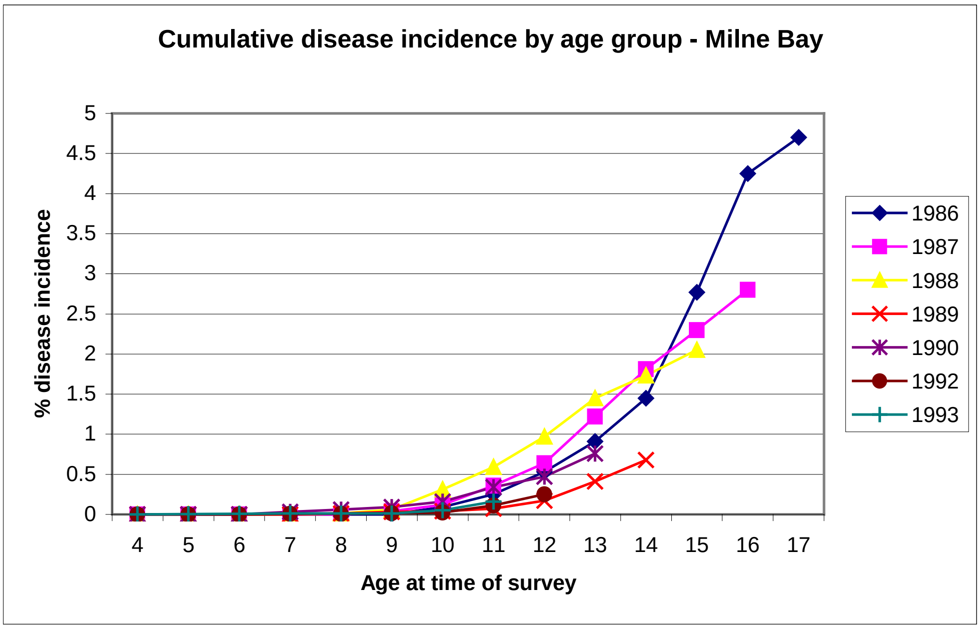

Figure 7. Cumulative disease incidence by age group from 1995-2002, Milne Bay.

1.1.1.1 Environmental effects

The disease incidence in 2002 in blocks that receive POME compared to blocks without POME is shown in Figure 8. As in previous years, disease incidence in the blocks that receive effluent is significantly higher and this trend is more evident in Hagita estate in 2002. It is recommended that some changes be made to application rates or techniques to minimise stress on palms. For example, application to EFB may be better than direct application to soil.

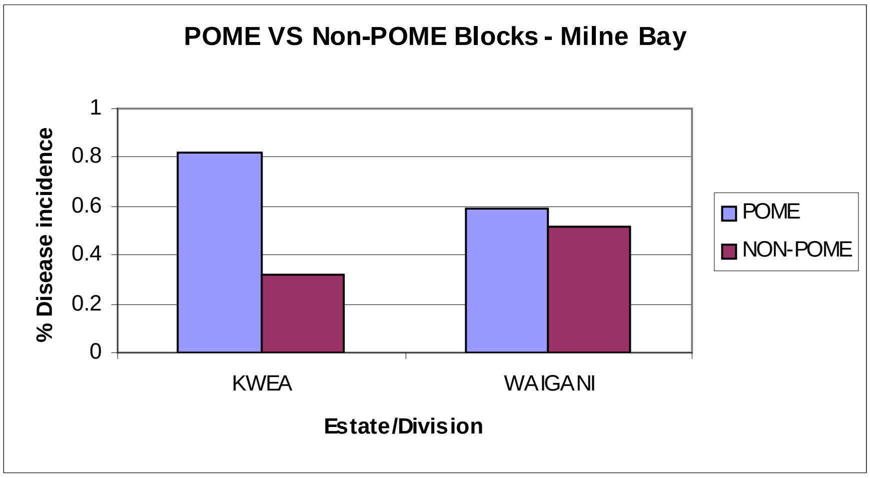

Figure 8. Disease incidence in blocks that receive palm oil mill effluent (POME) and non-POME blocks in two divisions, Milne Bay.

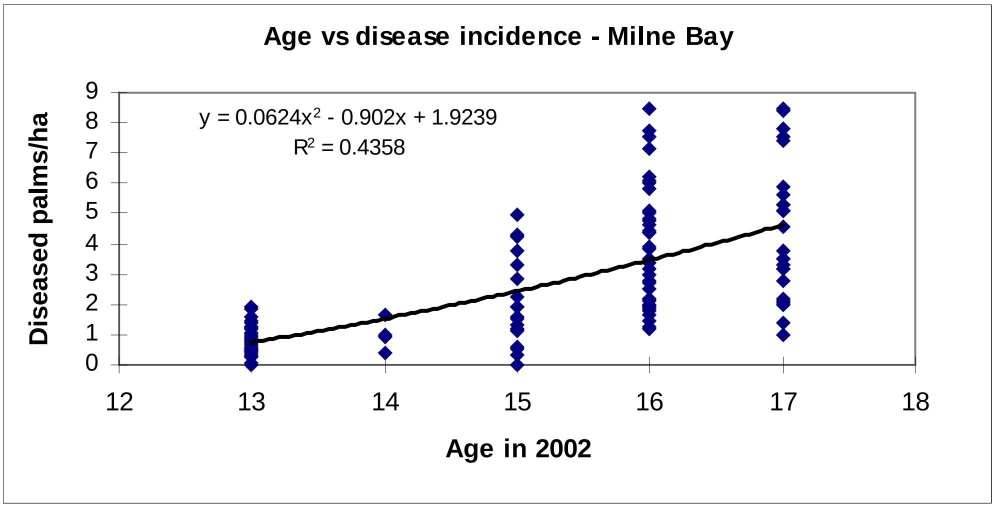

Figure 9. Predicted losses (palms/ha) expected due to Ganoderma disease with age in Milne Bay.

Figure 9 shows that that only 40% of the variation in disease incidence throughout the Milne Bay plantation can be explained by age. Clearly, other factors are influencing disease levels. Figures 10, 11 and 12 show the effects of previous crop on Ganoderma disease incidence. There was generally a low correlation between previous crop and disease levels although ex-coconut and ex-mixed stands (which include rubber) gave a higher level of infected palms per hectare at age 16 compared to ex-forest blocks. On average, a loss of 5-6 palms per hectare per year would be expected for ex-coconut and mixed blocks whereas 3-4 palms/ha/year could be expected for ex-forest blocks at age 16. Further predictions can be made for older palms but these should be made with caution as the data presented is for a relatively short period of time. It must also be emphasised that these predictions are for first generation oil palm plantings and cannot be extrapolated to second-generation plantings. However, if adequate sanitation is maintained throughout the first generation, there is no reason to expect higher disease levels in the second-generation oil palm plantings.

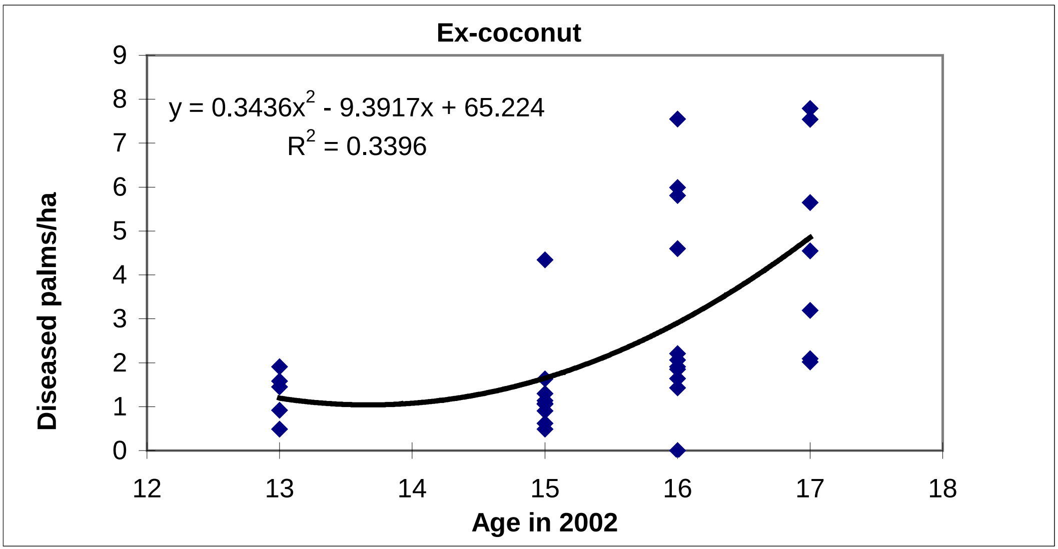

Figure 10. Predicted losses due to Ganoderma disease for ex-coconut areas in Milne Bay.

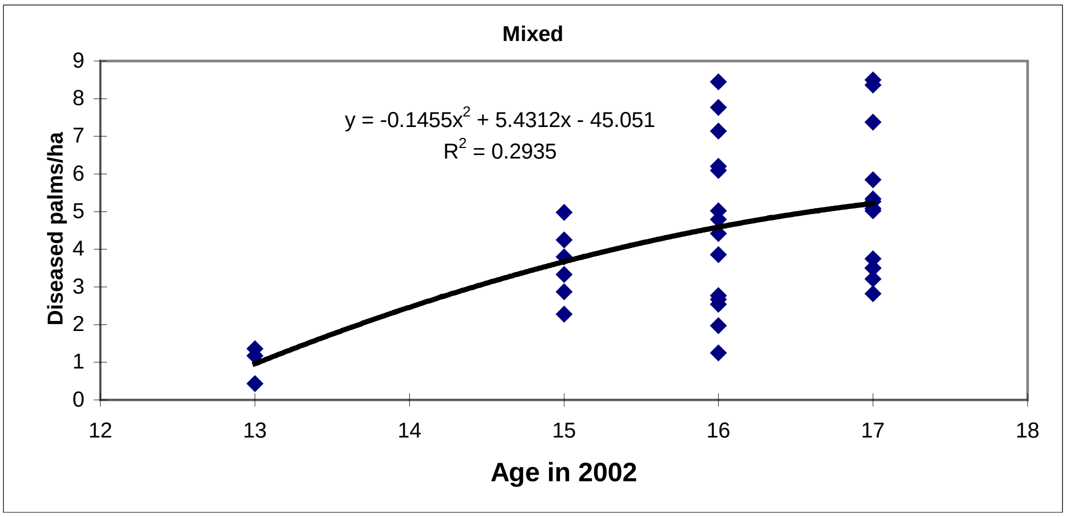

Figure 11. Predicted losses due to disease in areas planted after garden/scrub and rubber.

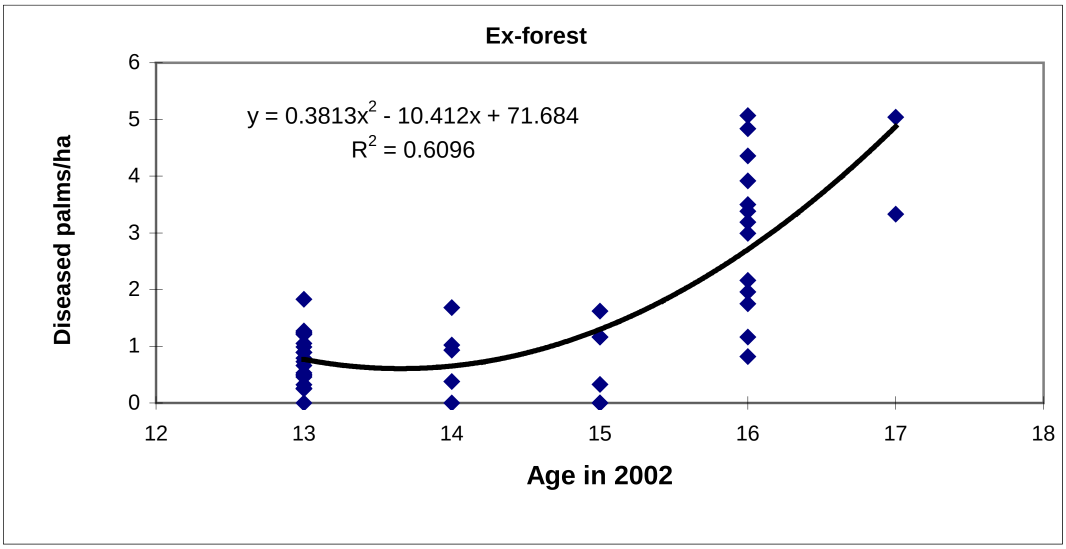

Figure 12. Expected stand losses with age for areas planted after secondary forest.

1.1.2 New Ireland

Disease levels for different sites in New Ireland are shown in Figure 13. The highest cumulative total (to 2002) is 3% for Bolegila. Disease levels are slightly underestimated because data for only 3 surveys has been combined. Data from earlier surveys is missing.

As shown in Figure 14, the annual disease incidence has not declined over the last 4 years in each plantation/division, neither has it increased dramatically which is an indication that disease spread is not spatially dependent. Cumulative losses by age group are shown in Figure 15. This graph indicates that disease trends in palms of the same age group follow a similar pattern although these are average figures and therefore don not reflect site differences.

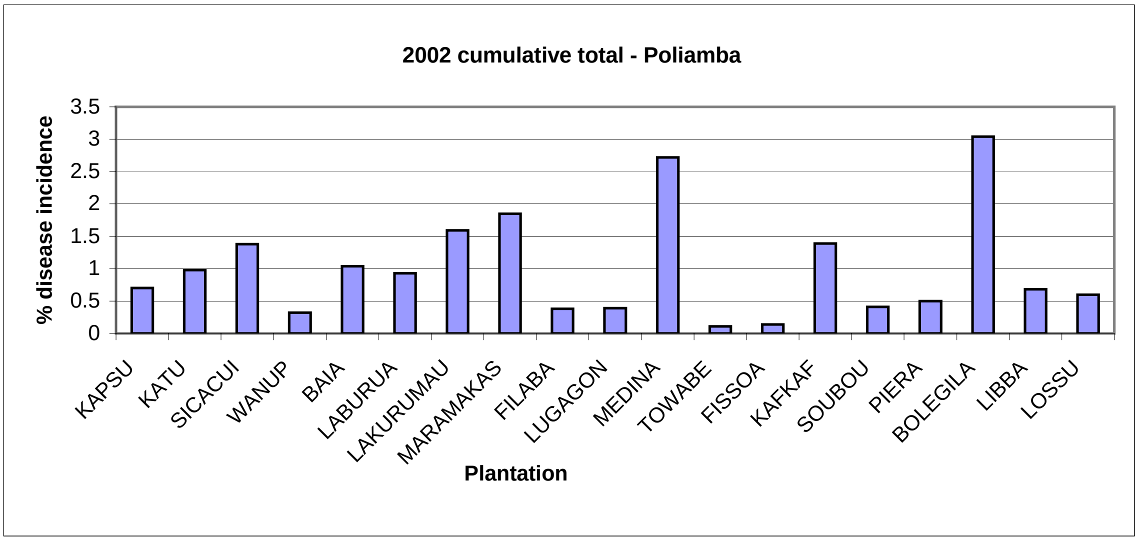

Figure 13. Cumulative disease incidence from 1999-2002 in New Ireland by plantation.

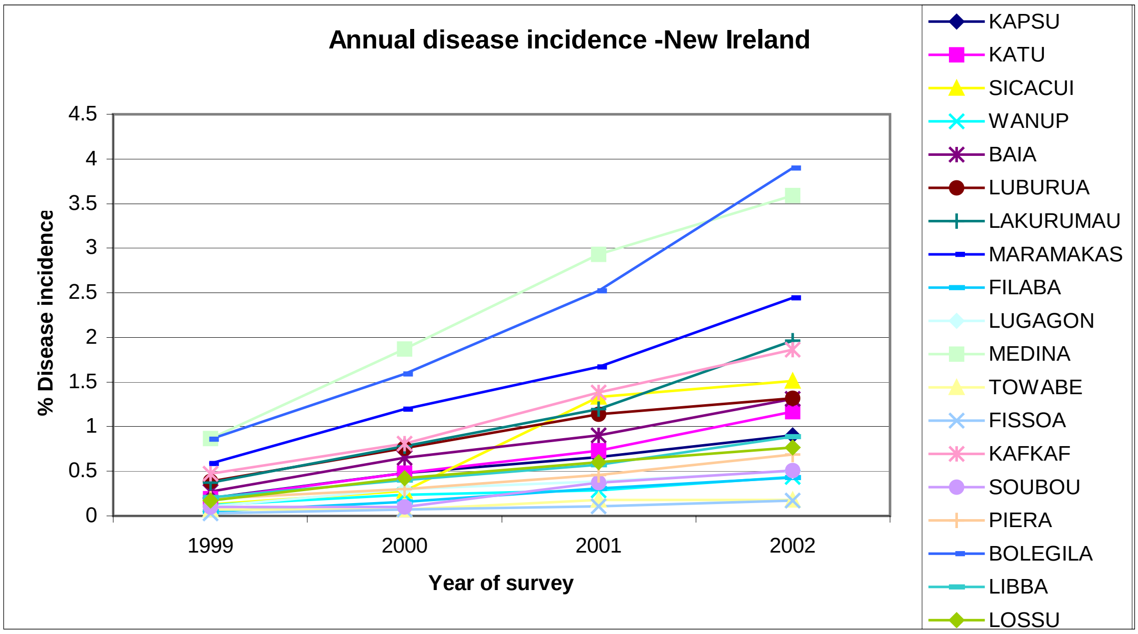

Figure 14. Annual disease losses by plantation in New Ireland since 1999.

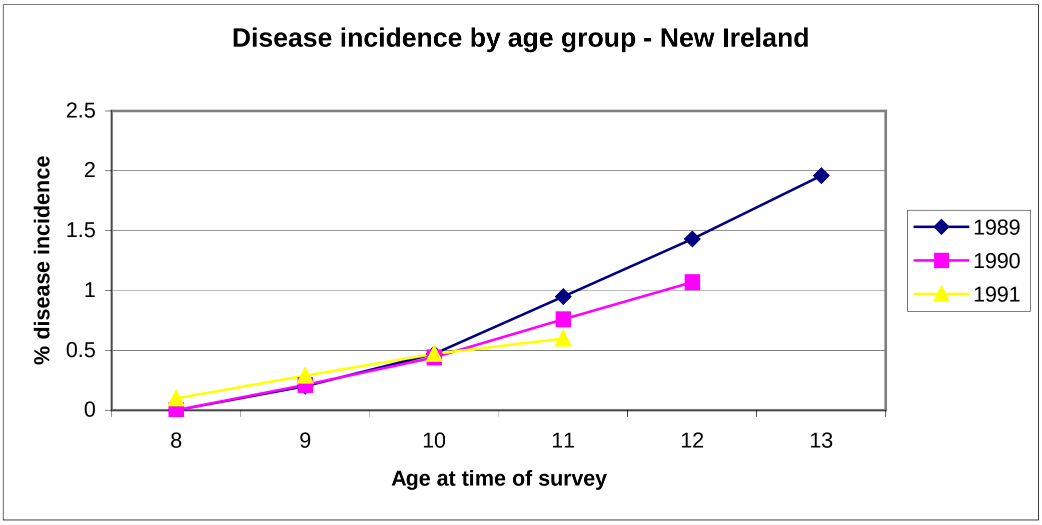

Figure 15. Cumulative disease trends with age, New Ireland.

Figure 16 shows the correlation of disease incidence with age in New Ireland. This is tentative as more data. Although the correlation was poor due to the wide variation between plantations, an average loss of 2-3 palms/hectare/year can be expected for palms at 10yrs of age. Environmental effects are evident in New Ireland where disease levels for 10 year-old palms in some plantations are higher than for older palms in other regions.

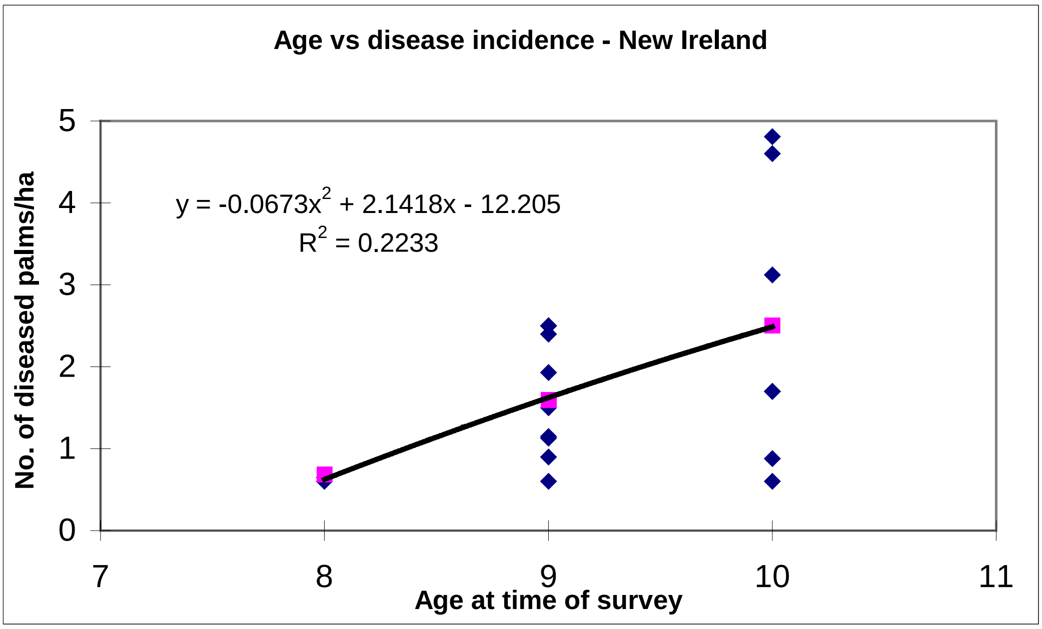

Figure 16. Predicted losses due to Ganoderna with age, New Ireland.

1.1.3 Numundo plantation

Disease levels for 9-10 year-old palms planted in ex-coconut blocks in West New Britain appear to have decreased in most blocks (Figure 17). Disease levels are particularly high in blocks E3, E4 and E5 (Figure 18). It is not known why this is so but could be related to soil or sanitation factors related to the previous crop.

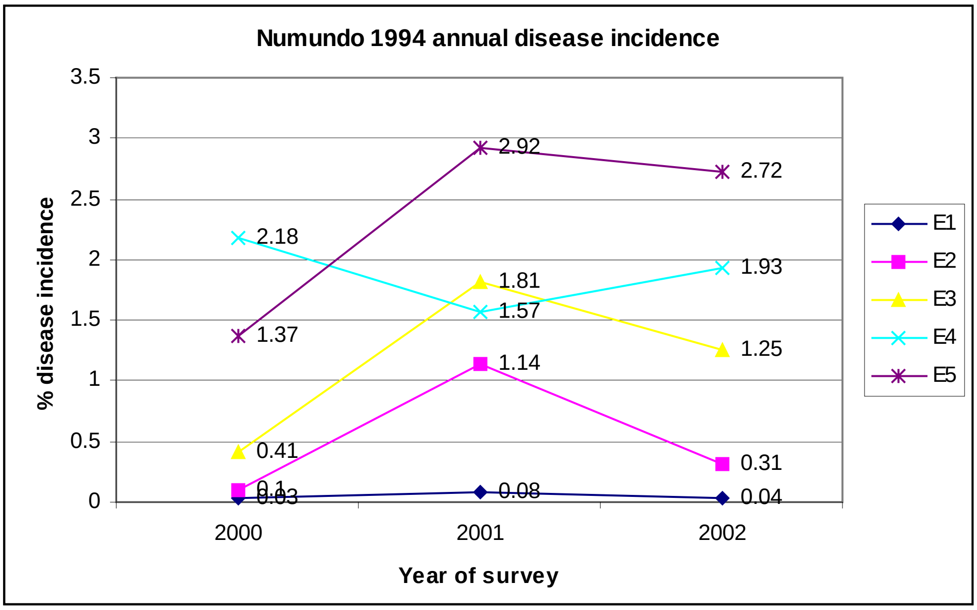

Figure 17. Annual disease incidence at Numundo at each survey.

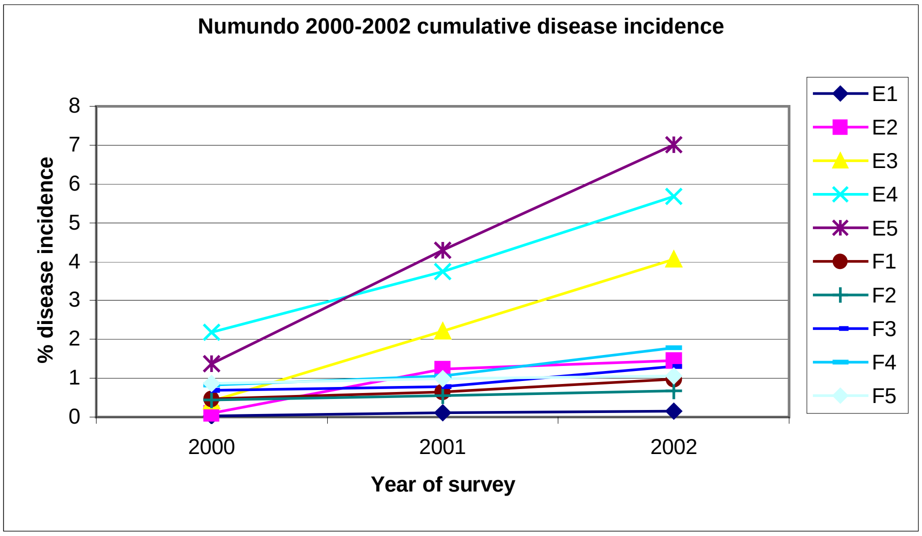

Figure 18. Cumulative losses at Numundo from 2000-2002.

2. Population Studies

2.1 Milne Bay population

One hundred and nine (109) samples were collected from the six blocks under study in Milne Bay in 2002. Mating types for almost all of these samples have been determined. These will be stored and crossed with other isolates from the same block. This year, crosses were concentrated in block 7213 because of the large number of samples to process. The block was also split into 20-row plots on either side of each harvest road and only samples from within these plots will be crossed with each other. Neighbouring diseased palms were targeted as these are becoming more common within the Milne Bay plantation. Table 1 shows the results of some crosses between isolates on neighbouring palms in block 7213. In all except two cases, isolates were different which still indicates that root-to-root spread is not a common occurrence. A large number of other crosses have been completed for the other isolates within this block but the data is not shown here. The majority of spatially separated isolates were different. The total number of mating alleles found in the sampled population from all blocks now stands at 155, which indicates that there are new alleles coming into the population as well as the persistence of certain alleles from previous generations. Current indications are that gene flow within block 7213 has occurred and will continue to occur within the population. This means that there is a real possibility of selection for more aggressive or ‘fit’ isolates and the practice of removing Ganoderma brackets is therefore crucial to prevent the establishment of better adapted strains or isolates to oil palm.

Table 1. Vegetative compatibility tests between neighbouring palms in block 7213 Milne Bay.

	512		437		666		821		881		766
509	vi	**436**	vi	**432**	vc	**146**	vi	**765**	vi	**714**	vi

	145		767		816		816		767		816
670	vi	**670**	vi	**670**	vi	**767**	vc	**145**	vi	**821**	vi

	896		832		725		724		830		893
719	vi	**764**	vc	**721**	vi	**829**	vi	**149**	vi	**898**	vi

vc = vegetatively compatible (*i.e. the same isolates*); vi = vegetatively incompatible (*i.e. different isolates*).

2.2 New Ireland population

Ganoderma isolates have also been collected from fertilizer trial plots in the New Ireland Province. In 2002 and early 2003, a total of 19 isolates were collected from within the two trials. New surveys were also carried out within the two trials in 2002 and January 2003. Isolates collected were subjected to vegetative compatibility tests to determine if they were genetically distinct. Results in Table 2 show that all isolates within each trial so far are of different genetic origin. There is a possibility that some of these isolates are related however as some of the interactions were weak to medium. If time permits, mating tests will be carried out to determine these relationships (if any).

Table 2. Vegetative compatibility tests amongst dikaryons collected from trial 251, New Ireland. Isolates are mated with themselves as a control.

	914	915	916	917	918	919	920	921	923	925
914	vc	vi	vi	vi	vi	vi	vi	vi	vi	vi
915		vc	vi	vi	vi	vi	vi	vi	vi	vi
916			vc	vi	vi	vi	vi	vi	vi	vi
917				vc	vi	vi	vi	vi	vi	vi
918					vc	vi	vi	vi	vi	vi
919						vc	vi	vi	vi	vi
920							vc	vi	vi	vi
921								vc	vi	vi
923									vc	vi
925										vc

vc=vegetatively compatible; vi= vegetatively incompatible

Table 3. Vegetative compatibility tests amongst dikaryons collected from trial 252, New Ireland.

	926	927	928	929	930	931	932	933	934
926	vc	vi	vi	vi	vi	vi	vi	vi	vi
927		vc	vi	vi	vi	vi	vi	vi	vi
928			vc	vi	vi	vi	vi	vi	vi
929				vc	vi	vi	vi	vi	vi
930					vc	vi	vi	vi	vi
931						vc	vi	vi	vi
932							vc	vi	vi
933								vc	vi
934									vc

vc=vegetative compatible; vi=vegetatively incompatible.

3. Collaborative Research

Dr. Paul Bridge made a three week visit to Papua New Guinea in May 2002. This visit was principally to assist with isolation of cultures of *Trichoderma* for potential use in the development of a biocontrol product that could be used against *Ganoderma* on cut frond bases, and to continue the ongoing survey of cut frond bases of young oil palms for the detection of *Ganoderma* with the PCR based GanET method.

3.1 Ganoderma epidemiology in palm plantings

Recent and previously cut frond bases were sampled from 2 blocks of young oil palms in Numundo plantation. These were a block of 1998 plantings previously sampled in 2000 and 2001, and a block of 1999 plantings previously sampled in 2000. Sampling was as in previous years and involved removing small amounts of subsurface tissue from frond bases. These were stored under ethanol on the field, and freeze-dried within 7 days. Freeze dried tissue was ground with either sterile sand or under liquid nitrogen, and total DNA was extracted by the cetrimide/PVPP method used in previous years. Total DNA extractions were used in Polymerase Chain Reactions (PCR) with the universal ribosomal RNA subunit primer ITS3 and the *Ganoderma boninense* specific primer GanET. A PCR product of the expected size was taken as indicative of *G. boninense* DNA in the samples as in previous years. A restricted sampling procedure was adopted as a result of previous findings and single upper and lower frond bases were sampled from palms. Previous results have suggested that positive results from upper frond bases may be indicative of recent exposure to *G. boninense*, and that positive results from lower frond bases are more likely to be indicative of established *Ganoderma* infection. Two rows were selected in the 1998 palms, one of which had previously shown a high level of positive results, and one that had previously shown largely negative results. In the row where previously 4 palms had given positive samples, these palms now showed disease symptoms, with one palm dead and rotted out and the other 3 palms all showing apparent *Ganoderma* rot in the lower frond bases. These observations were confirmed with the GanET primer. In the row where frond bases had previously given negative results there were no apparently infected palms and all samples tested negative.

A further 22 samples were taken from single upper and lower frond bases of palms in the 1999 planting. These included samples from 5 palms that had given positive molecular results in 2001, and 4 palms that had previously given negative molecular results. Of these 2 palms showed positive results, one from a lower frond base on a palm that had previously tested positive in 2001, and one from a frond base from a palm not previously tested.

Table 4. Results of PCR amplification of frond base samples collected in 2002 from Numundo plantation.

Numundo 1998	**Row**	**Palm**	**Frond base**	**Results**
Sample 1	5b	1	upper (8+)	
2		1	lower (ground level)	
3		2	upper	
4		2	lower	positive
5		3	upper	positive
6		3	lower	positive
7		4	upper	
8		4	lower	
9		5	upper	
10		5	lower	positive
11	10a	6	basal debris	positive
12		10	upper	
13		10	lower	
14		11	upper	positive
15		11	lower	
16		13	upper	
17		13	lower	
18		15	upper	
19		15	lower	positive
1999 Plantings				
20	1b	3	upper(5)	
21		3	lower (ground level)	
22		9	upper	
23		9	lower	
24		10	upper	
25		10	lower	positive
26		11	upper	
27		11	lower	
28	2a	7	upper	
29		7	lower	
30		5	upper	
31		5	lower	
32		4	upper	
(marker)33		4	lower	positive
(biro) 33	3b	3	upper	
34		3	lower	
35	3a	3	upper	
36		3	lower	

These results support the theory suggested in previous reports that a positive molecular result indicates that a frond base has been exposed to *G. boninense*, but of these *Ganoderma* infection only develops in some of the palms where lower frond bases were positive. This suggests that the lower frond bases exposed in early pruning and planting out can provide a significant entry site for *G. boninense* infection. These results are however preliminary, and further monitoring of these blocks is required to determine if basal stem rot develops later in any palms.

4. Pathogenicity Trials

Objectives:

1) To develop an effective and rapid pathogenicity screening test for basal stem rot of oil palm.
2) To use this screening test to identify susceptible seed lines.

4.1 Laboratory screening assays

In 2002, five (5) sets of laboratory assays were carried out using both leaf and rachis tissue of different palms. Assays were done in triplicate on rachis tissue from individual palms. Two or three Ganoderma isolates were used as inoculum. A number of variations to the method were tried. These were:

1. Variation of strength of sterilizing solution and length of sterilization
2. Sterile moist filter paper in the base of the Petri-dish as opposed to no filter paper
3. Placement of inoculum on the surface or next to excised leaf tissue

Generally, contamination rates were high which masked the differences between the isolates. Prolonged sterilization in 10% bleach was necessary to minimise contamination. However, the strength of the bleach caused damage to the rachis tissue which may also have affected the results. The final trial did show some differences between isolates.

Leaf tissue has been found to be highly resistant to Ganoderma attack and leaflets will no longer be used for assays.

4.2 Nursery screening assays

Thirty-five palms inoculated in October/November 2001 with Ganoderma-infected wooden dowels were dissected to check the extent of decay after 5 to 6 months. Results were variable but generally, very little activity was observed in the base of the palms with all the different types of wood used. Several samples were taken from the palms in an attempt to isolate Ganoderma in the basal tissue. Ganoderma has not been isolated so far but another basidiomycete appears to be present in the basal tissue. This has not been identified as yet. In January 2003, 89 palms that were inoculated in November 2001 were destructively sampled. Results were extremely variable but more encouraging than earlier samplings. Approximately 50% of the plants showed no evidence of decay in the basal plate compared to the control samples however, in the remainder, slight to significant decay was recorded although not in the region of initial inoculation. Indications are that the fungus does not move directly into the base from the frond but moves laterally, until a ‘weak’ point is found in the frond base structure. At this point some evidence of movement into the base was seen, usually through weakened and decayed roots below the frond base. The presence of Ganoderma will have to be confirmed using the GanET primer.

A further 300, 3 year-old palms were inoculated using 1cm square oblong rods made of oil palm wood in 2002. The inoculation technique was varied. One set of palms was inoculated by drilling into the rachis tissue. A second set of palms were inoculated by splitting the rachis tissue and placing the inoculum into the split tissue without covering and a third set was inoculated in the same way but the rachis was taped to prevent moisture loss. So far, none of the inoculated palms has shown symptoms of Ganoderma infection. Palms will be dissected and examined in 2003.

In another set of experiments, rachis tissue on 50 palms that had been inoculated at the base were also inoculated *in situ* with three isolates of Ganoderma (one on each rachis). Rachis was sterilized and a wound was made using a sterile scalpel. A 1cm agar plug of inoculum was placed onto the wound and sterile, moist filter paper was laid on top. The entire wound and inoculum was covered with clear plastic tape to prevent moisture loss. Each rachis will be excised and examined in 2003 to assess the extent of decay.

5. Biological Control of Ganoderma

Objectives:

1) To develop methods for the rapid degradation of oil palm trunks
2) To utilize Trichoderma as a natural antagonist of Ganoderma to prevent Ganoderma infection on cut frond bases.

5.1. Rapid wood degradation studies

Four sets of pilot trials were carried out in 2002. Ceratocystis isolates were put into liquid culture and sprayed onto freshly cut surfaces of oil palm logs. In another experiment holes were drilled into the logs and liquid culture was pipetted into the hole. After one to two weeks the logs were checked and cut up to observe the extent of degradation. In all four trials, the Ceratocystis failed to colonise further than the surface of the logs. This was attributed to the dry weather conditions experienced at the time of the trials. No advantage was seen in drilling holes into the trunks as the fungus failed to penetrate the woody tissue below. Experiments targeting the basal area of the trunk (left in the ground) were also carried out in one trial. Ceratocystis failed to penetrate the woody tissue despite extra water being applied to the surface to encourage growth. Indications are that Ceratocystis performs better on the less ligninized upper portion of the trunk and this may have practical implications. Further field trials to determine the limitations to rapid colonization of trunk tissue are planned for 2003.

Mating tests were also carried out between isolates to determine the mating types. There appears to be an equal number of A1 and A2 mating types in the field. Some mating types could not be determined as shown in Table 5.

5.2. Trichoderma biological control agents

Samples of palm debris and soil were screened for *Trichoderma* species. Small samples of debris, soil and soil dilutions were plated onto an adapted *Trichoderma* isolation medium, quarter strength Potato Dextrose Agar and Tap Water Agar. Plates were incubated at room temperature for 3-7 days and colonies showing typical *Trichoderma* sporulation structures and green/blue spores were sub-cultured onto $1/10^{th}$ strength Potato Dextrose agar. Initially 25 samples produced colonies that could be presumptively identified as *Trichoderma* sp., and further sub-culture and morphological characterisation identified 2 further culture lines within these samples.

Table 5. Mating type designations assigned to PNG isolates of *Ceratocystis paradoxa*.

ISOLATE	MATING TYPE DESIGNATION
PNG-1	A1
PNG-2	A2
PNG-3	A1
PNG-4	ND
PNG-5	A1
PNG-6	A2
PNG-7	ND
PNG-8	ND
PNG-9	A2
PNG-10	ND
PNG-11	A2
PNG-12	A1
PNG-13	A1
PNG-16	A1
PNG-18	ND
PNG-20	ND
PNG-21	A1
PNG-22	A2
PNG-24	A1
PNG-26	A2
PNG-27	A2
PNG-28	A2
PNG-29	A2
PNG-30	ND
PNG-31	ND (from fruit fly)
PNG-32	ND
PNG-33	ND (from fruit fly)
PNG-34	ND (from fruit fly)

A simple baiting method was also used to isolate active *Trichoderma* cultures in the soil. Detached brackets of *Ganoderma* species were buried at approximately 5-10cm in soil on the plantation. The brackets were recovered after 24 hours and incubated at room temperature in sealed plastic bags to maintain humidity. Fungal growth was evident on brackets after 2-4 days, and isolates of *Trichoderma* were identified by their characteristic morphology. Individual colonies from different parts of different brackets buried at different sites were sub-cultured onto 1/10th strength Potato Dextrose agar. This method resulted in 21 pure cultures that were presumptively identified as *Trichoderma* sp.

The 48 pure cultures presumptively identified as *Trichoderma* sp. were maintained on slopes of 1/10th strength PDA for later screening for bioactivity, growth and sporulation. The screening activity in the UK is currently dependent on the grant of an export licence from the PNG Department of Environment and Conservation.

6. Publications, Conferences and Visits

Pilotti, C. A. & Bridge, P.D. (2002). Basal Stem Rot: Probing the facts, *The Planter Kuala Lumpur*, 78 (916): 365-370.

Pilotti, C. A. Sanderson, F. R. & Aitken, E. A. B. (2002). Sexuality and interactions of monokaryotic and dikaryotic mycelia of *Ganoderma boninense*. *Mycological Research*, 106 (11): 1315-1322.

Pilotti, C. A. (2002). Stem rots of oil palm in PNG: Paper presented at the International Oil Palm Conference, Bali, Indonesia, July 2002.

Prof. Paul Bridge visited Milne Bay and Dami in June 2002.

C. Pilotti visited NBPOL for sampling at Numundo in June.

C. Pilotti visited NBPOL in November, 2002 for Ganoderma training.

C. Pilotti visited Poliamba in November, 2002 for Ganoderma training.