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Producing Cocoa in Northern Australia

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Foreword

This report presents the findings of the three stages of the Northern Australian Cocoa Development Alliance project conducted by the Queensland Department of Primary Industries and Fisheries, Northern Territory Department of Regional Development, Primary Industry, Fisheries and Resources and the Western Australian Department of Agriculture and Food.

The project aimed to examine the feasibility of cocoa production in northern Australia in response to commercial concerns about the security of future world cocoa supplies against a backdrop of rising consumption and significant risks to production in major producing countries.

The study included cocoa growing trials in three northern Australian growing regions, investigations of mechanisation opportunities and a clonal introduction program.

The performance of cocoa was demonstrably best at northern Queensland sites where acceptable yields and quality were achieved. Trial performance at sites in other growing regions was either poor or sub-economic.

The economic viability of Australian-based cocoa production was examined and found to depend on good prices (above AU$2,500/t dry bean) and high productivity of harvesting and processing. Mechanised pod splitting and bean separation machinery was successfully developed in the project but has not been commercialised.

A fledgling cocoa industry is now developing in northern Queensland with about 35 ha of plantings established and beginning to come into production.

This research is an important contribution to the potential diversification of horticulture in tropical Australia.

This project was funded by the three partner state/territory primary industry agencies, Cadbury Schweppes and from RIRDC Core Funds which are provided by the Australian Government. There was also a contribution of funding from Timbercorp Ltd.

This report, an addition to RIRDC's diverse range of over 1900 research publications, forms part of our New Plant Products R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

Most of RIRDC's publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

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They included research, administrative and field staff from the state agencies for Primary Industries, the Cadbury representatives who strongly supported the project from its inception, and the co-operator growers on whose properties trials were planted. There was also collaboration with researchers from the University of New South Wales and the Sydney University of Technology through the conduct of two PhDs linked to the NACDA project.

The financial contribution and involvement of Timbercorp Ltd. is also acknowledged. Haigh's Chocolates also kindly assisted with manufacture of the first chocolate samples using the beans from northern Queensland trials.

Finally the oversight of the various RIRDC Program Managers over the life of the project is acknowledged.

Project Participants

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Co-operating Growers

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Rural Industries Research and Development Corporation

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AgWA	Agriculture Western Australia
AQIS	Australian Quarantine and Inspection Service
BCR	Benefit Cost Ratio
BOM	Bureau of Meteorology
CPHRF	Coastal Plains Horticultural Research Farm
CCRI	Cocoa and Coconut Research Institute (Papua New Guinea)
CS	Cadbury Schweppes
CWTA	Centre for Wet Tropics Agriculture
DAFWA	Department of Agriculture and Food, Government of Western Australia
DPI&F	Department of Primary Industries and Fisheries, Queensland Government
DRDPIF&R	Department of Regional Development, Primary Industry, Fisheries and Resources, Northern Territory Government
EVA	Ethyl Vinyl Acetate
FAME	Fatty Acid Methyl Esters
FWRI	Frank Wise Research Institute
GDD	Growing Degree Days
HYET	Hybrid Yield Evaluation Trial
ICCO	International Cocoa Organisation
IRR	Internal Rate of Return
MARDI	Malaysian Agricultural Research and Development Institute
MCB	Malaysian Cocoa Board
MCDB	Moisture Content Dry Basis
NACDA	Northern Australia Cocoa Development Alliance
NPV	Net Present Value
NT	Northern Territory
NTDPIF	Northern Territory Department of Primary Industries and Fisheries
NTU	Northern Territory University
PI	Pod Index
PNG	Papua New Guinea
QDPI	Queensland Department of Primary Industries
QHRS	Quion Hill Research Station
Qld	Queensland
R&D	Research & Development
RIRDC	Rural Industries Research and Development Corporation
SGR	Stock-Grind Ratio
SJ	South Johnstone
WA	Western Australia

Contents

Tables

Figures

Executive Summary

What the report is about

This report documents the implementation and outcomes of an eight-year study which investigated the feasibility of cocoa production in northern Australia.

The study was in response to lobbying in 1998 by Cadbury Schweppes who were subsequently a major supporter of the project. As a major industry player, Cadbury Schweppes were concerned about the security of future world cocoa supplies against a backdrop of rising consumption and significant risks to production in major producing countries.

The study included cocoa growing trials in three northern Australian growing regions, investigations of mechanisation opportunities and a clonal introduction program.

The performance of cocoa trials was demonstrably best at northern Queensland sites where acceptable yields and quality were achieved. No major pest or disease problems were encountered. Trial performance at sites in other states was either poor or sub-economic.

The economic viability of Australian-based cocoa production was examined and found to depend on good prices and high productivity of harvesting and processing. Mechanised pod splitting and bean separation machinery successfully developed in the project has not been commercialised.

A fledgling cocoa industry is now developing in northern Queensland with about 35 hectares (ha) of plantings established and beginning to come into production.

The research is an important contribution to the potential diversification of horticulture in tropical Australia.

Who is the report targeted at?

The report is targeted at researchers, industry, farmers, rural planners and investors interested in the development of an Australian cocoa industry and the diversification opportunities it provides.

The principal beneficiaries of the research are farmers seeking alternative income streams and entrepreneurs or established businesses who can take advantage of access to Australian cocoa beans as processors or confectionery manufacturers and/or retailers.

Background

In 1997, Dr Barry Kitchen, who was at that time Research Director of Cadbury Schweppes (Australia), approached the three northern Australian primary industries agencies regarding the feasibility of a cocoa industry in northern Australia.

In response a steering committee of researchers from the three agencies was formed (Yan Diczbalis – NT, Craig Lemin – Qld and Nick Richards – WA) and undertook a Cocoa Study Tour to Malaysia and Singapore and subsequently prepared a project plan.

At a meeting in Darwin in August 1998, it was decided to develop a project proposal for submission to RIRDC based on industry funding commitments by Cadbury Schweppes and preliminary interest by RIRDC research manager Dr David Evans.

The full research proposal was submitted in 1999 and the Northern Australia Cocoa Development Alliance project was initiated. The project commenced in June 1999 and was conducted over eight years until July 2007 (in three stages).

The rationale for the project was based on several factors:

- the large and well established world cocoa market (2,700,000 tonnes valued at AU$6,750M in 1999) with historical fundamentals of 3% average growth since 1920
- forecasts of sustained increases in demand/consumption of cocoa products against a backdrop of concentrated supply and risks to production
- reviews dating from the 1960s identifying suitable growing regions in Queensland
- some trial work in northern Queensland and the NT which had confirmed that cocoa would grow in these environments and that promising yields were possible
- economic modelling which indicated that cocoa production in Australia may be viable depending primarily on achieving high yields (about 3 tonnes per hectare (t/ha) dry bean) and good prices
- forecasts for increasing 'bulk' cocoa prices combined with potential price premiums for consistently-producing high quality cocoa, which enhanced the case for economic viability
- prospects for 'value adding' Australian produced cocoa in the longer-term through establishment of domestic cocoa grinding, possibly in conjunction with existing sugar mills
- financial and technical support of a major industry player (Cadbury Schweppes) combined with a superior science and technology base in Australia compared to most cocoa producing countries.

Aims/Objectives

The principle aim was to investigate the feasibility and economics of cocoa production in northern Australia. This was based on assessing the agronomic and yield performance of accessible hybrid cocoa in northern Australia using 'best-bet' management practices.

The second major aim was to investigate mechanisation of pod splitting and bean extraction to reduce production costs arising from this traditionally labour intensive operation.

Thirdly, the growing system for cocoa in Australia was to be examined from the perspective of 'mechanised' production to reduce production costs. The results would provide information for further development of an economic model of cocoa production in Australia.

Finally, it was planned to introduce a limited but select pool of elite clonal material into Australia while there was the opportunity to do so and material was publicly available. The aim was to have this material available for any future cocoa selection or breeding program in Australia.

Methods used

Hybrid yield evaluation trials

The primary research and development activities were based around the establishment, management and monitoring of Hybrid Yield Evaluation Trials (HYET) in each of the three potential growing regions.

The work was carried out at three locations, using five accessible hybrid seed lines from the Cocoa and Coconut Research Institute (CCRI) in Papua New Guinea (PNG). The three principle trial sites were:

- Northern Territory – Coastal Plains Horticultural Research Farm (1.1 ha)
- North Queensland – Mossman district (0.9 ha)
- Western Australia – Broome (0.5 ha).

Smaller secondary plantings were also established at the South Johnstone Centre for Wet Tropics Agriculture (CWTA) in northern Queensland and the Frank Wise Research Institute (FWRI) at Kununurra, WA.

All sites were established with natural shade and irrigation. The three primary sites comprised both double and single row planting layouts. Management inputs, pest and disease incidence and climate data were recorded. Yields were measured on the basis of hybrid lines and planting layout. Commercial-scale fermentations were conducted in Queensland once sufficient quantities of beans became available. Beans were recovered and ‘bulked’ for fermentation. Cocoa bean flavour and bean physical characteristics were evaluated against commercial standards with the assistance of Cadbury Schweppes (MacRobertsons, Singapore). There was some experimentation with the methods and techniques for fermentation although this was not a stated aim of the wider Northern Australia Cocoa Development Alliance project. Fermentation was also carried out in association with researchers in an autonomous PhD project (Fermentation of Australian Cultivated Cocoa Beans) funded by Cadbury Schweppes and conducted by the University of New South Wales. Much of the PhD work was conducted by periodic visits to South Johnstone for fermentation trials.

Mechanised pod splitting and bean extraction

This aspect of the Northern Australia Cocoa Development Alliance program was a high priority and commenced early in the project phase. The work was based in northern Queensland and conducted by Craig Lemin.

Technology available from overseas was investigated and found wanting. In light of this, autonomous development work was conducted to produce a working pod splitter machine which was ultimately patented. Attendant machinery for feeding the unit and separating the wet bean and pod fragments afterwards was also developed. Progressively, this was incorporated into a ‘pilot’ pod and bean processing plant at South Johnstone CWTA which was used with harvested material from the trials in northern Queensland.

Farming systems and mechanisation

Trials and activities were conducted to investigate the cocoa planting/management system in the context of allowing mechanisation and reducing production costs. This included:

- comparison of the double and single row planting layouts within the HYETs
- establishing a density trial (double and single row layout) at South Johnstone with densities ranging from about 800 to 2,100 plants/ha
- some trellising of single rows at South Johnstone
- studies of harvest productivity and concepts for harvest aids.

This work contributed significantly to the assumptions and development of a cocoa economic model which was used to assess the likely viability of Australian-based production.

Clonal introduction

A clonal introduction program was conducted with the assistance of Cadbury Schweppes. Budwood was sourced from the Reading University on the basis of recommendations made by Tony Lass (Cadbury, UK). The material was shipped and grafted to rootstock in AQIS quarantine facilities at Darwin from 1999 to 2001.

Results/Key findings

Hybrid yield evaluation trials

Cocoa production of PNG hybrids 1 and 4 reached 3 tonnes per hectare of dry bean in northern Queensland in the third season after planting but fell back to 1.5 t/ha by the fifth season. This yield decline is typical of the yield response experienced in PNG when using SG2 hybrid seed. Seed size and bean physical parameters were acceptable (see Chapter 6 Fermentation for details).

Cocoa at the Mossman site was higher yielding than at South Johnstone for all but one season in which yields were recorded at both sites. Maximum mean yields for all treatments were 27 t/ha of whole pods at Mossman and 20 t/ha of whole pods at South Johnstone. At a 10:1 ratio of whole pods to dry bean equivalent, the usual method of describing cocoa yields, this equates to maximum mean dry bean yields of 2.7 t/ha and 2.0 t/ha for Mossman and South Johnstone respectively. In the last season where data was recorded for both sites the mean yield was approximately 15 t/ha of whole pods or 1.5 t/ha of dry bean equivalent.

Hybrid seed was used to test the concept that cocoa could be grown successfully in far northern Queensland. Hybrid seedlings are known to bear early and can be easily established in large numbers. Higher and more stable yields can potentially be produced by using clonal material; however, this involves a long testing process to identify clones which will perform well in the climatic conditions of far northern Queensland.

Cocoa was successfully established in the Northern Territory despite the harsh NT climate. Tree growth and development was slower then that experienced in Queensland with some of the delayed growth being linked to the use of a vegetatively vigorous shade species (*Acacia mangium*) as companion plantings in the NT trial block. NT cocoa trees were subject to a range of pest pressures. Termites (*Mastotermes dawiniensis*) and longicorn beetle larvae (*Acalolepta mixus*) were major pests which had serious implications for tree growth and survival.

NT cocoa yields (dry bean equivalent) peaked in the 2004/05 season, four years after planting. Mean yields for the four hybrids were 1.68 t/ha and 1.31 t/ha for the double and single row configurations respectively. The hybrid PNG1 was the best performer yielding 2.17 t/ha and 1.56 t/ha for the double and single row configurations respectively. The production peaks occurred during the wet season from November to March. Pod size and bean size were small and below industry acceptable standards. The yields, pod and bean size characteristics suggest that the NT environment is not ideal for commercial cocoa production.

In Broome (WA), major problems were experienced with seed viability and seedling establishment. The cause of this was not fully resolved during the study. Post-planting growth of seedlings was poor due the harsh growing environment (low winter night temperatures, low winter day humidity and high summer day temperatures). As a result of these problems the decision was made to discontinue the WA component of the trial early in the program.

A PhD study, ‘The Environmental Constraints on Cocoa (*Theobroma cacao*) Production in Northern Australia’, funded by Cadbury and which ran parallel to the Northern Australia Cocoa Development Alliance project, demonstrated that assimilation rates were low for cocoa grown in Kununurra (WA) and Coastal Plains (NT) compared to the two Queensland sites (Leibel 2008).

Mechanised pod splitting and bean extraction

The laborious nature of pod processing is likely to have been a major factor inhibiting any previous development of cocoa growing in Australia. Inventions and even commercial machinery for pod splitting and bean extraction have been previously developed overseas but none have been very successful or had any significant adoption. Excessive breakage of the pod husk leading to difficulties in obtaining a clean sample of wet bean is the major problem. Also, there has not been any compelling reason for smallholder cocoa producers to mechanise their operations.

To overcome this, the autonomous development of a pod splitter was undertaken in the Northern Australia Cocoa Development Alliance project from 2001 and a successful design was developed, tested and patented. The unit splits pods longitudinally into two halves in a continuous process without the need for complex mechanical manipulation of pods for cutting or splitting. Demonstrated capacity of the Northern Australia Cocoa Development Alliance pod splitter is in the range of 2,400 to 4,000 pods/hr (20,000 to 30,000 pods/day). A wide range of pods sizes can be handled by the machine but for optimum performance it is proposed that pods be graded into two size ranges prior to splitting.

Some further refinement of the machine components and a new space-frame design are now required to ensure an acceptable reduction in contamination of the wet bean sample with pod husk.

Subsequent to splitting, a mechanical means of separating the resultant mix of pod husk and wet bean was also developed. A bean separation trommel obtained from Brazil was used as a basis for designing a larger and improved unit. The unit performed satisfactorily and is suitable for commercialisation with minor improvements to the design (screens, cleaning and optimum choice of construction materials to reduce corrosion). The capacity of 3,000 to 4,000 pods/hr was reasonably matched to the Northern Australia Cocoa Development Alliance pod splitter.

Delivery of pods to the Northern Australia Cocoa Development Alliance pod splitter requires that they be dropped into the machine in an endwise orientation (long axis parallel to the direction of fall). For commercial application, a mechanised delivery system is required.

A conveyor for delivery of pods to the Northern Australia Cocoa Development Alliance pod splitter was also developed in conjunction with the general development of the pod splitter. Further development of a ‘front-end’ system for segregating pods individually and achieving 100% alignment of pods prior to delivery to the Northern Australia Cocoa Development Alliance pod splitter is required. This is not seen as particularly difficult and several avenues would be available to fully resolve the issue.

The report provides a recommended process for a mechanised, commercial cocoa pod processing system along with priorities for further development.

Fermentation

Commercial-scale fermentations were successfully conducted using Australian grown cocoa beans (sourced from Northern Australia Cocoa Development Alliance trials in Queensland) which resulted in acceptable flavour characteristics.

The process involved was more difficult than anticipated to achieve consistent and acceptable cocoa flavour characteristics. This is attributed to inexperience with the method and techniques for fermentation rather than any deficiency in the beans themselves. Further refinement of fermentation and drying techniques is required to develop proven methods which work under local conditions.

The primary physical characteristics of beans (bean size, fat content, shell content) met International Cocoa Standards for commercial acceptability and were comparable with cocoa from Ghana and Indonesia. Meeting standards for other attributes such as tolerable levels of defects and chemical residues will depend on the application of good production management practices and appropriate secondary processing technology.

It is concluded that it would be entirely possible to commercially produce good quality Australian-grown cocoa for sale into the world market. This will depend on bedding down a reliable method for fermentation and drying, applying appropriate technology for post-drying processing and successful commercialisation of the mechanised pod splitting and bean separation technology.

Farming systems

The farming systems trial covered a range of factors influencing the productivity of cocoa orchards in Australia.

The role of tree density was examined with four densities ranging from 800 to 2,100 trees/ha in both single row and double row configurations. Single rows tended to out-perform double rows and the highest yields were achieved at the highest densities in both row arrangements. Density had less of an impact in the single row arrangement with mean yields at the three lowest densities only being marginally lower then that achieved at the highest density. In the double row plots, yields tended to decline with decreasing density.

Although trellising and pruning combinations were not formally tested, observation-based trials indicated that the labour requirements of trellised trees were high and should not result in any significant advantage over non-trellised trees. The trellised trees were damaged just as severely as non-trellised trees during Cyclone Larry in 2006.

Results indicated that manual commercial harvest productivities are likely to be about 3,000 pods/person/day for an eight-hour working day. There was not a strong relationship between crop load and harvest productivity. Cocoa is comparable with other tree fruit crops in terms of harvest rates. However, the unit value of a cocoa pod on the basis of its equivalent quantity in dried and fermented bean is typically less than for crops like mangoes or avocados. Therefore cocoa needs to be harvested and transported with maximum efficiency to enable achievement of an economic return.

Cocoa is normally removed manually from the tree using cutting implements. Pods once removed do not require careful handling. A mechanised cocoa harvest aid could be based on the concept of a towed or self-propelled device. This would facilitate the efficient collection and transport of pods to a bulk storage container. Three concept proposals for mechanised harvesting are discussed. Recovery from the ground (similar to macadamia harvesters) is not recommended due to compromised operational flexibility. In-field mobile pod splitting is also not recommended since its capacity would be well in excess of the highest rates of harvesting achievable.

Clonal introduction

Eleven cocoa clones were successfully introduced into Australia from the University of Reading's cocoa clonal repository centre. The clones consist chiefly of Forastero material with one clone being of Trinitario origin. The eleven clones were selected on the basis of quality, yield and disease resistance.

The material has not been formally evaluated but the collection has been maintained by the Department of Primary Industries and Fisheries (Qld) Centre for Wet Tropics Agriculture in South Johnstone and by the Northern Territory Department of Regional Development, Primary Industries, Fisheries and Resources' Coastal Plains Horticultural Research Farm. The material has also been established on private grower properties in the Innisfail area.

Economic modelling

A gross margin model of cocoa production prior to commencement of the project (Ngo 1998) estimated that a yield of 4.2 t/ha dry bean would be required just to recover the variable production costs. This was based on the prevailing cocoa price of AU$2,811/t at July 1998. Alternatively the cost of production had to be further reduced (which was seen as more achievable). At projected future cocoa prices of up to $8,650/t, the yield required to recover the variable production costs was 2 t/ha dry bean. On the other hand, if a yield of 3 t/ha dry bean could be achieved; there was a substantial gross margin available to cover fixed production costs and provide a return on investment.

Modelling was also conducted by AgTrans as part of the project justification in 1999. AgTrans acknowledged that modelling to determine the investment returns from cocoa production in northern Australia was largely based on unconfirmed information and there was considerable uncertainty associated with the key variables (yield, price and major production costs).

Using a base case model of an assumed 50 ha cocoa plantation, the investment returns were negative based on historical prices and also for an assumed regime of increasing prices. However, assuming the combined impacts of 'expected' benefits from research and development (R&D) into cocoa production could be realised, a favourable investment return could be generated based on anticipated increasing prices.

The principle driving variable was the future cocoa price. Cocoa prices averaged $2,700 over the previous 10-year period. The break-even price regime required prices to increase linearly from $2,700 in 2000 to $3,873 in 2010 and remain at that level. This was quite an optimistic price regime.

An economic model was also developed within the Northern Australia Cocoa Development Alliance project culminating in its use by Invetech in late 2004 for modelling various establishment scenarios and investigating sensitivities to price, yield and farm size.

The model now requires review for the currency of input cost assumptions, likely yields and prices and the various management options. It would also benefit from simplification by reducing detail and/or redevelopment into a more user-friendly format.

A gross margin analysis estimated reasonably favourable margins over the expected range of prices and yields. For the production of pods (as compared to dried bean) the gross margins at comparable yields are more favourable. Since there is considerable uncertainty about the actual costs of bean processing (which is a major input cost) then there would be less risk to the grower in the production of pods. The extra risk would instead be borne by processors.

The alternative is for growers to produce dried and fermented beans themselves (or on a co-operative basis). This has more inherent risk and has lower theoretical margins to pod production. It is also less attractive in comparison to other horticultural crops. However, significant opportunities at higher margins exist for growers who can establish a good reputation for quality and continuity of supply. They could also develop partnerships with value chain participants to extract extra returns through branding and marketing. The world cocoa market is also very large, is expected to grow and has sophisticated trading instruments to reduce risk. As a fall-back, growers should always be able to sell dried beans no matter what scale of production is attained in Australia.

Commissioned by RIRDC and the Queensland Department of Primary Industries and Fisheries, Invetech conducted a preliminary assessment of the value proposition for Australian cocoa production in late 2004. Their findings were as follows:

- Growing cocoa in Australia is technically feasible? – Yes
- Quality standards for 'bulk' cocoa can be achieved? – Yes
- Growing cocoa in Australia would be economically attractive? – No
- Profitability is insensitive to major variables such as price and yield? – No
- There is strong demand from potential end users? – Possibly

Invetech also conducted a risk analysis to identify the technical and commercial risks. The technical risks were seen as manageable but were dependent on attaining sustainable, acceptable yields (4 t/ha dry bean). The commercial risks were considerable and required entrepreneurial and investment activities which were outside the scope of the Northern Australia Cocoa Development Alliance research program.

Invetech concluded that the value proposition presented by Australian cocoa production for commodity cocoa markets was marginal. Nonetheless, Invetech considered that an integrated business model aimed at premium or value-added chocolate products was realisable. This was being pursued by start-up company 'Cocoa Australia' who were facilitating and supporting industry establishment and standing in the marketplace as a buyer of Australian cocoa for eventual use in high value products.

Situation post-Northern Australia Cocoa Development Alliance

As expected, cocoa prices trended upwards over the eight years of the Northern Australia Cocoa Development Alliance project. Cocoa production and consumption also increased at about the rate previously forecast.

Recent strong cocoa prices and the May 2008 projections by the International Cocoa Organisation (ICCO) for continuing growth in consumption at about 3% per annum lend support to the development of a cocoa industry in northern Australia. Additionally, prices offered for speciality and origin cocoa beans are generally significantly above the bulk cocoa price. This would improve the investment fundamentals of an Australian cocoa industry catering to such markets. However, presuming an inherent price premium for Australian produced cocoa at the outset is highly optimistic.

The formation and activities of Cocoa Australia and continued support of Cadbury Schweppes, are encouraging for the current fledgling industry which is focussed on producing a high quality 'Australian' chocolate.

Implications for relevant stakeholders

Industry

The project has clearly demonstrated that cocoa production is feasible in northern Australia. The wet tropical coast of northern Queensland (Cardwell to Daintree) is environmentally suited to the production of high yields (up to about 3 t/ha dry bean) which meet commercial requirements in terms of size and physical/chemical characteristics. The economics of cocoa production is mostly dependent on yield, costs of harvesting and processing, and world price.

At demonstrated yields (about 2 t/ha long-term, based on the germplasm used) and current world prices commercial cocoa production in Australia for the commodity market is likely to be a marginal undertaking. It is estimated that prices consistently above $3,000 /t are required for sustained viability. Alternatively, yields must be increased to at least 3 t/ha via improved genetics and management.

However, viability may also be predicated on production for particular markets which provide price premiums or capture additional value from the downstream supply chain. This includes producing high quality, product differentiated beans for particular manufacturers or vertically integrating growing and processing. Additionally, significant agro-tourism opportunities exist.

Notwithstanding the above, a compelling case for cocoa production in Australia is still evident based on the presence of significant risks to world supply and continuing world growth in consumption.

Accordingly the Queensland Department of Primary Industries and Fisheries has produced a Cocoa Growers Manual to capture the findings from the Northern Australia Cocoa Development Alliance program in a format which can readily be transferred to potential industry participants.

Although Australia does not have a significant cocoa grinding industry, one advantage is the existence of a well established cocoa confectionary industry producing product for domestic consumption and export. This is not typical of most cocoa growing countries.

Communities

In northern Queensland, many growers are seeking diversification opportunities. Cocoa provides a potential new crop to support the sustainability of the existing cropping and horticultural enterprises in the region. A suggested suitable production model for northern Queensland is 3 to 10 ha plantings supplying whole pods to a central fermentary.

Cocoa appears well-suited to this scale of planting and Australian owner-grower management regimes may exploit the advantages of smallholder and estate-style production systems. A point worth noting would be the management flexibility in drawing upon labour from other farming activities since the major cultural operations (pruning and harvesting) are not particularly time critical. Commercial plantings are being established in the Mossman and Innisfail districts.

The related pod and bean processing provides a significant opportunity for rural communities where cocoa can be grown. Currently, Cocoa Australia is the only commercial entity offering to purchase product from growers for its own fermentary and processing. Opportunities for other entrants may exist depending on the success of initial commercial plantings and the strength of their business case.

Researchers and government

Should the embryonic industry become established and grow, further support and research will be required. Currently the principle risk lies with successful establishment of facilities for pod and bean processing. Optimum economic benefit is dependent on the production of consistent high quality dried bean. Optimising the fermentation process for Australian grown cocoa beans is a priority. This requires specialist input based on further investigation and finalisation of the parallel project on fermentation funded by Cadbury Schweppes and the University of New South Wales. It also requires further development of the technology for pod splitting and bean extraction and its incorporation into a commercial setting.

Recommendations

The highest priority for further industry development is for government, research and commercial interests to combine resources to fund and support the development of a research/commercial fermentary which:

- enables the further development and commercialisation of the pod processing technology
- finalises and implements fermentation research to enable the production of consistent high quality beans
- develops drying technologies which ensure the production of premium quality dried beans.

There is also a need to further investigate the potential of alternative genetic material from overseas with regard to achieving higher long-term yields in the Australian environment. This would be based on exploring alternative hybrid seed lines and/or cost-effective production of clonal material.

Finally there is an urgent need for registration of agricultural chemicals used in cocoa for pest and disease control. Currently a summary list of chemical requirements has been forwarded to the Australian Pesticide and Veterinary Medicines Association.

Whilst there are many other agronomic and production issues worthy of investigation (e.g. pruning management) these are best addressed following further industry development. By default, the developing industry would identify the most important issues. The appropriate funding mechanisms for such research and development would be dependent on industry and government inputs based on the perceived private versus community benefit.

1. Introduction

1.1 About cocoa

1.1.1 The crop

Cocoa (*Theobroma cacao*) is a tropical tree crop originating from either South or Central America. The pods borne by cocoa trees contain seeds (beans) which are fermented and eventually used in the manufacture of chocolate and cocoa products.

Cultivated since 650BC, cocoa production only increased rapidly in the 20^{th} century after the Swiss developed milk chocolate manufacturing and material was planted in West Africa. Cocoa is now a major world commodity crop and is the seventh most traded food commodity.

Climatic requirements place cocoa in the tropical regions of the world generally within 15^{o} of the equator. This region is predominantly underdeveloped and densely populated and cocoa production has evolved with access to cheap, plentiful labour.

1.1.2 Growing cocoa

Cocoa is usually field-planted from seedlings raised in nurseries. Hybrid seeds are increasingly being used from various national breeding programs although the resulting plants are highly variable in growth and performance. More costly vegetative propagation is used where selected characteristics are desired and the growth and performance characteristics will be much more uniform.

Cocoa is field planted after 3 to 6 months, usually under shade. Traditionally the shade is provided by remnant forest, but planted shade is also used and cocoa is also intercropped with other commercial species which provide the shade (Figure 1.1b). Most importantly, the shade provides wind protection and a micro-climate which is necessary for good establishment. In Malaysia and Indonesia, cocoa has been grown in full-sun with the shade progressively removed after establishment.

The growth habit of seedlings is a single upright stem to a height of 1 to 2 m. The bud then forms the *jorquette* with 3 to 5 spreading branches (Figure 1.1a). Further adventitious suckers (*chupons*) emerge below the jorquette and grow up through the branches to form higher jorquettes and further whorls of fan branch growth. In this way the tree becomes higher eventually reaching up to 20 m.

When cultivated, cocoa is pruned to limit height to 3 to 5 m. Only the initial jorquette and subsequent branching growth is retained. Further chupons are continually removed to restrict the eventual vertical growth. Internal pruning of fan branches is carried out to develop a good structure and for cultural management.

Trees take about two years to begin bearing. Flowers arise from '*cushions*' in the wood of the main trunk and branches. Only 1 to 5% of flowers are successfully pollinated and form pods. Even so, cocoa has a fruit thinning mechanism whereby many young pods (*cherelles*) stop growing and shrivel, but do not immediately detach from the tree. The remaining pods take 5 to 6 months to ripen after pollination. Ripe pods remain attached to the tree and will eventually rot or mummify.

As pods ripen they change colour from green or deep red to yellow or orange. Internally, the beans develop and a mucilaginous pulp is formed. The harvest is usually spread throughout the year with one or two peak cropping periods. Pods are cut from trees by hand using knives or machetes since attempting to pull pods from trees will tear the bark and damage the flower cushions.

The timing of harvest is not critical. While only ripe pods should be harvested, under-ripe pods will ferment satisfactorily and ripe pods can be left on the tree for 1 to 2 weeks but with increasing risk of beans germinating and rots developing.

a. b.

Figure 1.1 a. Cocoa tree with maturing pods. b. Commercial cocoa planting in Papua New Guinea with Gliricidia and coconut for shade.

1.1.3   Processing cocoa

After harvest, the pods are opened to extract the *wet bean* and this can be done immediately or delayed for up several days. Traditionally, this is a manual operation. Fermentation of the wet bean is essential for the later development of chocolate flavours. Poor fermentation can severely compromise quality.

With traditional fermentation, the wet bean is bulked and gradually heats up as a result of exothermic chemical reactions in the mucilaginous pulp caused by microorganisms. Initially the mucilage is broken down and drains off as *sweatings*. After two to three days the beans are killed and a series of chemical changes take place which continue when the beans are dried.

Although chemically complex, the methods used for fermentation are straight forward. Batch sizes of at least 50 to 100 kg (to limit heat loss) are placed in wooden boxes, trays, baskets or 'heaps' with banana leaves. Fermentations are usually completed in five to seven days with one to two *turns* during this period for aeration of the fermenting mass.

Fermented beans are traditionally sun dried to about 6 to 7% moisture content (dry basis) which is safe for storage and transport. Mechanical dryers are also used however drying too quickly can result in acidic beans and downgraded quality. Ideally, the dried and fermented beans are cleaned prior to sale to remove defective beans and debris.

1.1.4 Grinding and chocolate manufacturing

Dried and fermented cocoa beans are processed into the raw ingredients for chocolate manufacturing. Principally this involves roasting and winnowing to separate the shell and *nib*. The nibs are then ground and pressed to produce *cocoa liquor* and *cocoa butter*, with *cocoa powder* a by-product. Collectively these operations are generally referred to as *grinding*. More than half world cocoa grinding occurs in the developed world outside the producing countries. It is mostly the domain of several large companies with multinational operations.

To manufacture chocolate, cocoa liquor and cocoa butter are combined with sugar, milk solids and minor ingredients. This is a specialist undertaking requiring industrialised equipment and there are many recipes and techniques. Most chocolate confectionary manufacturers do not own or operate grinding facilities but purchase cocoa liquor and butter to specification.

1.1.5 The cocoa supply chain

Cocoa has a long history and a complex marketing system has evolved. Selling and buying actual consignments of cocoa on the *physical* market is usually on terms negotiated directly between growers, marketing boards or trading companies and grinders or chocolate manufacturers. A much larger *terminal* or *futures* market also exists, in which contracts are traded prior to a delivery date. Trading in cocoa futures provides a hedge for producers and buyers against potentially unfavourable future prices.

The stock-grind ratio (SGR) is an industry measure of the estimated world stocks relative to annual world grindings. Low SGRs (usually as a result of tight supply conditions) often signals higher cocoa prices.

History of supply, demand and prices

World usage of cocoa has increased steadily over many decades averaging about 3.5% per annum since 1920. Production in 2006/07 was 3,360,000 t valued at US$5,945M (Source: ICCO Quarterly Bulletin of Cocoa Statistics XXXIV No.3).

Cocoa prices are cyclical, depending on supply and demand. In real terms cocoa prices have generally declined – mirroring a trend for many agricultural commodities. Figure 1.2 shows the history of cocoa production, grindings, prices and stocks from 1960/61 to 2000/01. In the 1970s high prices stimulated industry expansion which led to oversupply in the following decade. Despite low buffer stocks in the 1990s, prices remained low partly due to economic crises in Europe and Asia. A more recent price history (1971 to 2008) is shown in Figure 1.3 includes the Australian dollar price based on conversions from historical exchange rates.

Production and consumption statistics published in August 2008 are shown in Table 1.1.

Table 1.1 World cocoa bean production, grindings and stocks (Source: ICCO Quarterly Bulletin of Cocoa Statistics, Vol. XXXIV, No. 3).

Crop Year	Gross Crop ('000t)	Year on Year Variance (%)	Grindings ('000t)	Year on Year Variance (%)	Surplus or Deficit ('000t)	End of Season Stocks ('000t)	SGR
1998/99	2,808	4.3	2,744	-0.3	46	1,494	54.5
1999/00	3,077	9.6	2,960	7.9	97	1,591	53.8
2000/01	2,858	-7.1	3,064	3.5	-225	1,367	44.6
2001/02	2,867	0.3	2,885	-5.8	-37	1,330	46.1
2002/03	3,169	10.5	3,078	6.7	70	1,400	45.5
2003/04	3,541	11.7	3,237	5.2	282	1,682	52.0
2004/05	3,381	-4.5	3,364	3.9	-17	1,665	49.5
2005/06	3,767	11.4	3,518	4.6	211	1,876	53.3
2006/07	3,380	-10.3	3,639	3.4	-293	1,583	43.5
2007/08^	*3,646*	*7.9*	*3,698*	*1.6*	*-88*	*1,495*	*40.4*

^ forecast

Production characteristics

A feature of the world cocoa market is the concentration of supply – with about 70% of world production from West Africa.

Cocoa is mostly produced by smallholders on a low input, low output basis typically using family or village labour at low cost. Trees are individually tended; traditional methods of fermentation are employed and quality is generally good. As a rule of thumb, one person can manage about 2.5 ha of cocoa under traditional production systems.

Only recently has large-scale production of cocoa been carried out by plantation companies. However, cocoa has not offered the advantages of other crops grown under estate style management systems like coffee, oil palm and coconuts. To be competitive with smallholder production, higher yields are required based on higher inputs. Also, labour productivities are low relative to other crops and the quality of beans produced using industrial style fermentation.

Table 1.2 shows production characteristics of the major producing countries from 2000/01 to 2007/08. Previously Brazil was in the top three producing countries but production was decimated by fungal disease in the late 1980s. Malaysia rose to some prominence as a producer during the 1990s; however production declined rapidly as cocoa was replaced by more profitable oil palm. Indonesia has had sustained production increases; however the quality of Indonesian cocoa is generally poor and insect pests are causing problems.

Some salient points regarding world cocoa production are:

- concentration of production in three major countries
- supply vulnerability due to social and political factors
- marketing liberalisation reducing quality
- predominantly grown by smallholders
- high average age of farmers
- old plantings, particularly in West Africa
- losses from pests and diseases (estimated at 10% to 30% of gross crop)
- low average yields (<1 t/ha dry bean)
- competition from more profitable crops.

Consumption characteristics

Chocolate consumption is highly correlated with GDP with high per capita consumption in developed economies. The well established markets in Europe and the USA account for 60% of world consumption (Australia = 1.5%).

Some characteristics of world cocoa consumption are:

- sustained consumption growth throughout the 20th century
- traditional major markets remain important, i.e. Europe and North America
- growth in emerging markets of Asia, eastern Europe and Latin America
- good and bad health attributes.

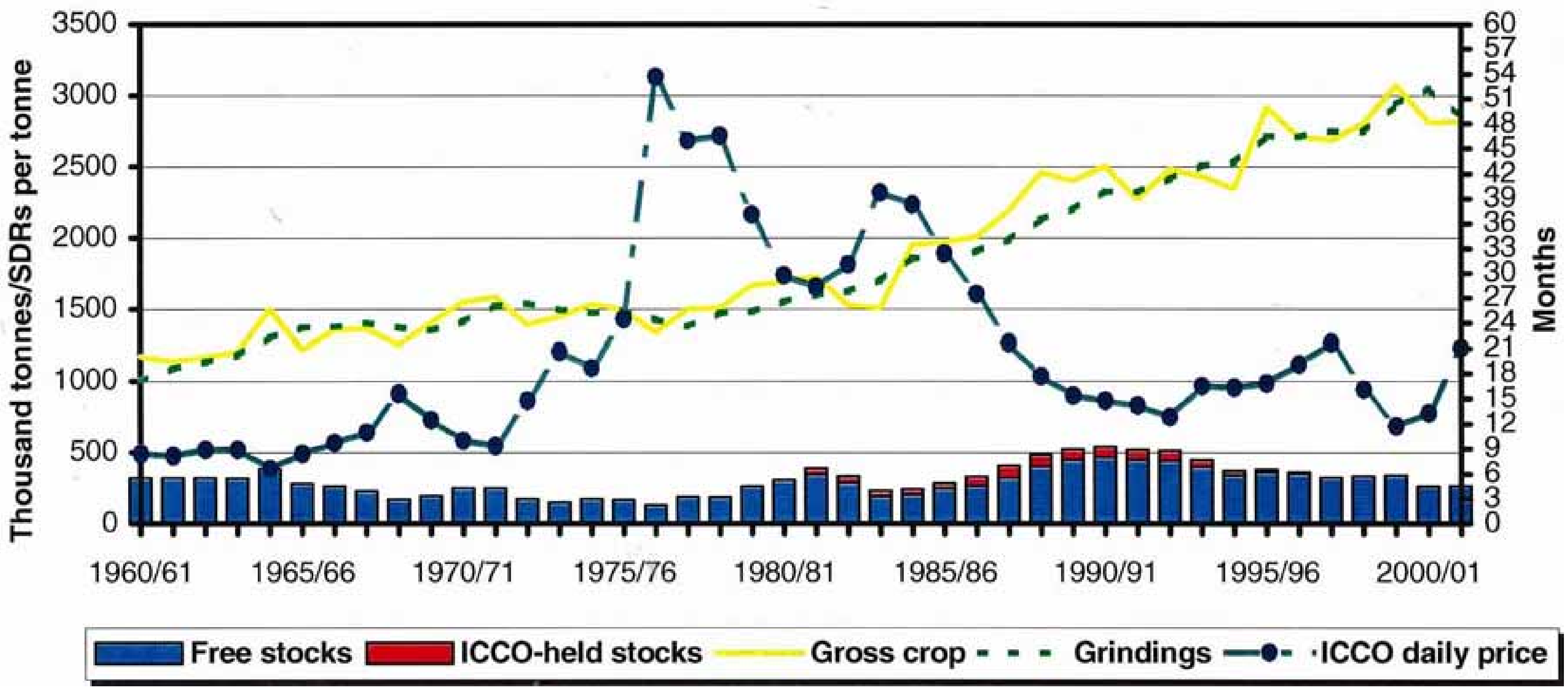


Figure 1.2 World cocoa production, grindings, prices and stocks 1960/61 to 2000/01 (Source: ICCO Annual report for 2001/02).

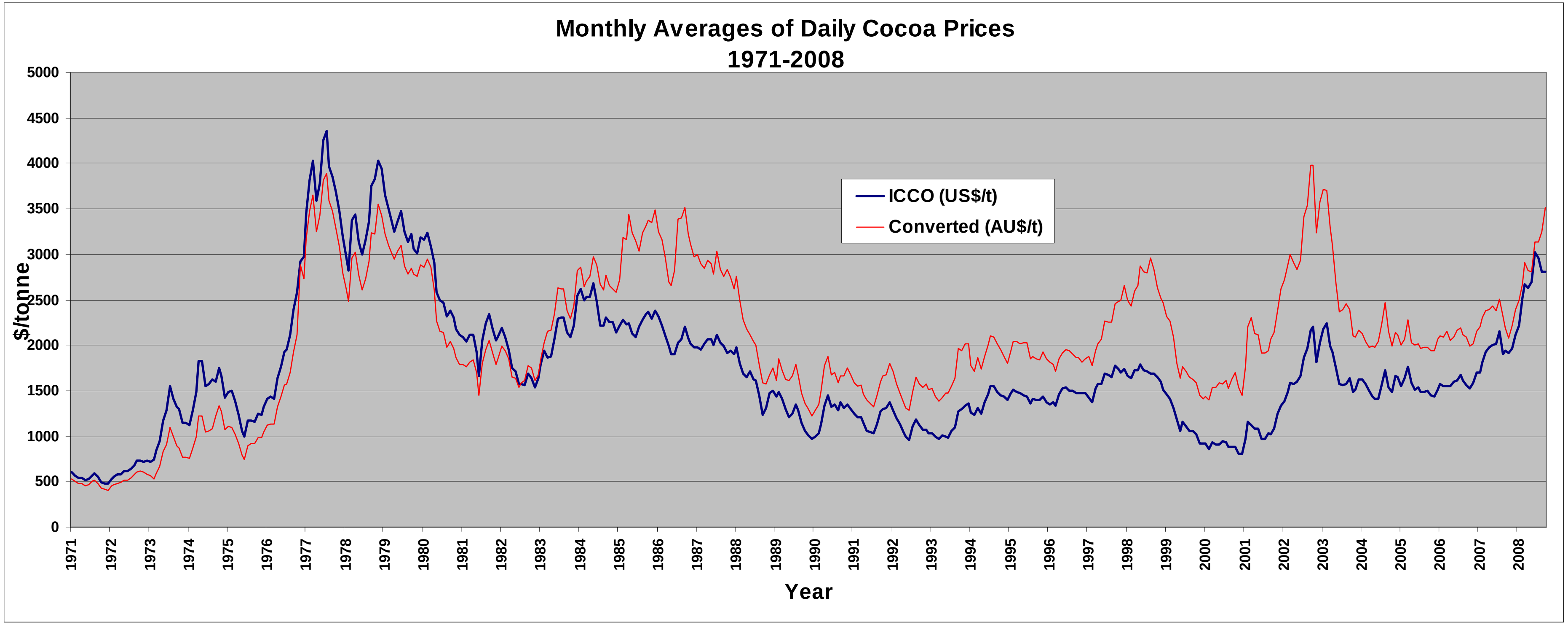


Figure 1.3 World cocoa prices (US$/t) 1971 to 2008 and Australian dollar equivalent price (Source: ICCO).

Table 1.2 World cocoa bean production by region and country 2000/01 to 2007/08 (Source: ICCO Quarterly Bulletin of Cocoa Statistics).

Region Country	000/01		2001/02		2002/03		2003/04		2004/05		2005/06		2006/07		2007/08 forecast		Change Over Previous Decade
	('000t)	(%)	('000t)	(%)	('000t)	(%)	('000t)	(%)	('000t)	(%)	('000t)	(%)	('000t)	(%)	('000t)	(%)	
Africa	1948	68	1952	68	2229	70	2544	72	2309	70	2646	70	2336	69	2613	72	
Cameroon	133		131		160		162		180		169		168		200		flat
Cote d'Ivoire	1212		1265		1352		1407		1273		1408		1229		1380		large increase
Ghana	395		341		497		737		586		740		615		700		increase
Nigeria	177		185		173		175		190		200		190		200		flat
Others	31		30		47		63		80		129		134		133		
Americas	423	15	378	13	428	14	461	13	445	14	450	12	410	12	448	12	
Brazil	163		124		163		163		171		162		126		165		large decrease
Others	260		254		265		298		274		288		284		283		
Asia/Oceania	487	17	539	19	510	16	516	15	534	16	670	18	634	19	585	16	
Indonesia	392		455		410		420		435		560		530		480		major increase
Malaysia	35		25		36		34		33		no data		no data		no data		large decrease
Others	60		59		64		62		66		110		104		105		
World	2858		2869		3167		3521		3288		3766		3380		3646		30% increase

1.2 Background to project

In late 1997 Dr Barry Kitchen who was at that time Research Director of Cadbury Schweppes (Australia), approached the three northern Australian primary industries agencies regarding their interest in the feasibility of a cocoa industry in northern Australia. At a meeting convened in Darwin (March 1998), representatives from Cadbury Schweppes (CS), DPI&F (Qld), DRDPIF&R (NT), DAFWA and ACIAR met for the first time. International cocoa supply, demand and price forecasts were reviewed together with the current constraints and advantages for an Australian industry. A steering committee of researchers from DRDPIF&R (Yan Diczbalis), DPI&F (Craig Lemin), and DAFWA (Nick Richards) was formed to develop a feasibility project plan.

Members of the steering committee undertook a Cocoa Study Tour of cocoa plantations and processing facilities in Malaysia (Sabah) and Singapore in June 1998 with funding from CS ($5,000) and RIRDC ($5,000).

The group met again in Darwin in August 1998 together with representatives from Cadbury UK, CSIRO, NTU and AQIS. The steering committee presented a feasibility project plan for review and reported findings from the Cocoa Study Tour (Lemin et al. 1998). The steering committee proposals were endorsed and there was significant enthusiasm for advancement of the project from all parties. At the conclusion of the meeting, David Evans of RIRDC communicated that RIRDC would seriously consider cocoa research and development given the significant level of industry support and potential benefits for northern Australia.

The decision was taken to advance a full project proposal for submission to RIRDC based on a significant commitment by CS of cash funding and in-kind technical support. Additionally, in view of CS's desire to progress field evaluation of cocoa in northern Australia as soon as possible, Barry Kitchen immediately committed $25,000 funding for the remainder of the 1998 calendar year and a further $50,000 for the first six months of 1999. This funding enabled preparation works for the establishment of a significant cocoa trial block at the Coastal Plains Horticultural Research Farm (CPHRF) in the NT.

1.3 Project rationale

In 1999 world cocoa bean production was around 2,700,000 t, valued at AU$6,750M. The scenario presented by CS at the March 1998 meeting was that within five years, world cocoa consumption would be approximately 3,260,000 t. Typical market forecasts were for growth in cocoa consumption of 3% per annum from the emerging and re-emerging markets of Asia and Central and Eastern Europe, and 1.5 to 2% for the mature markets of Western Europe and North America.

At such consumption levels, forecast supplies (2,973,000 t) would potentially be exceeded and cocoa stocks would be reduced to almost nil. Given such a situation, forecast cocoa prices were in the range of £1,450 /t (conservative) to £3,200 /t (high) by 2001/02, from levels of about £1,000 /t (March 1999). A similar situation had been forecast by the Australian Confectionary Manufacturers Association and various world commodity market analysts (e.g. USDA, LMC International). A precedent for this situation was set in the mid-1970s when declining production resulted in cocoa prices of £3,000 /t.

Additionally, there were other factors in play such as continuing problems with cocoa quality and supply from Africa, Brazil and Asia. Primarily these were due to:

- political instability
- disease (Witches Broom in Brazil; Cocoa Pod Borer and Vascular Streak Dieback in Malaysia and Indonesia)

- domestic trade and industry issues in West Africa
- lower quality assurance due to liberalisation of marketing arrangements in some countries.

In Malaysia and Indonesia currency devaluations were reducing commitments to accepted levels of plant husbandry on large cocoa estates, and in many areas cocoa production had been dramatically reduced in favour of oil palm. In the longer-term, chronic labour shortages in West African producing countries were looming on the basis of downgraded population growth forecasts for the region by the World Health Organisation (due to HIV-AIDS).

As a major end user of cocoa, CS Australia was concerned about this situation and believed there was a compelling case for investigating an Australian cocoa industry. There was unease amongst chocolate manufacturers worldwide, about continuity of cocoa supply and quality.

The potential for cocoa in northern Australia had been reviewed as early as 1960 and suitable growing areas were identified. Limited trial work in northern Queensland and the NT demonstrated that promising yields were possible. However, the combination of low world prices and the labour intensive nature of cocoa production had discouraged cocoa research and development in Australia.

However, at the prices forecast it was perceived that cocoa production in Australia could be economically viable assuming modest reductions in labour requirements through mechanisation and attainment of yields in the range of 3 to 4 t/ha dry bean.

CS were of the view that the superior science and technology base in Australia (compared to other countries where cocoa is grown) could provide the means by which Australian cocoa would be competitive with low labour cost countries. In the lead up to the project proposal, Tony Lass (Cadbury UK) also made the observation that cocoa may be well suited to Australian management systems. Successful cocoa production by smallholders is attributed to ‘individualised’ tree management and close attention to traditional style fermentations. These aspects have not translated to large scale cocoa plantings which have not offered the advantages of other crops grown under estate style management systems. However, Australian production based on medium-sized plantings and skilled management by educated grower/owners may well offer the advantages of both the smallholder and large scale models while avoiding the pitfalls.

Additionally, there was the opportunity to produce a ‘clean and green’ product. In particular, some traditional cocoa producing countries had experienced long-term use of pesticides and this was raising concerns amongst international toxicology bodies.

Finally, the opportunity could be maximised by value adding (in the longer-term) Australian cocoa through a domestic grinding facility. There could be complimentary benefits through investing in cocoa processing facilities in association with sugar mills in northern Queensland (many chocolate products contain over 50% sugar). Alternatively, a grower co-operative or business structure that vertically integrated growing with processing, manufacturing and marketing would capture the full value of product.

1.4 Summary of prior Australian cocoa agronomic reviews and research

Previous reviews of the potential for cocoa in Australia (Urquhart and Stephens 1960; Cull 1973; Watson 1987; Watson 1992) suggest that production is feasible and that the crop has potential in northern Queensland. In 1999 cocoa trees were growing on private properties in northern Queensland from Tully to Daintree (none were commercially cultivated). Additionally, cocoa trees were successfully grown at the Coastal Plains Horticultural Research Farm (CPHRF) about 50 km east of Darwin since 1987. Richards (pers comm. 1998) had reviewed climatic conditions in north Western Australia and concluded that cocoa trees could be grown under irrigation in the Broome district.

Small plot yield data suggested that yields in excess of 2.5 t/ha dry bean are possible in northern Queensland (Watson 1992). This material is now dispersed (with the closure of Kamerunga Horticultural Research Station) but much of it was accessible through private gardeners and tropical tree fruit producers. At CPHRF, yields from three-year old cocoa trees were recorded at 2.0 t/ha dry bean under irrigated conditions with predictions that yields could exceed 2.5 t/ha by year 5 (Diczbalis and Richards pers comm. 1998). Cocoa yields worldwide range from 0.2 to 3.7 t/ha with the bulk of production yields less than 2.0 t/ha. Yields of up to 4.9 t/ha are reported in Malaysia.

1.4.1 Preliminary viability analyses for Australian production

Preliminary analysis of production and investment costs for Australian cocoa growing (Agtrans Research, Section 9.3) suggested that at a lower price of AU$2,702 /t, yields in excess of 7.25 t/ha dry bean were required to justify investment. Clearly this was unachievable, however under an assumed regime where prices increase by AU$270 /t/yr (£100 /t/yr) to a maximum of AU$5,404 /t (£2,000 /t) returns were increasingly attractive at yields greater than 2.6 t/ha.

These returns were based on the assumption of reductions in labour requirement achieved through mechanisation (with reference to traditional production systems). In the analysis, it was assumed that labour required for pruning could be reduced by 33%, labour required for pod harvesting could be halved and labour required for pod splitting and bean extraction could be reduced by 75%. Further labour savings through mechanisation of operations such as pruning, spraying and fertilising were also envisaged. Additionally, an outcome of cocoa research and development would be confirmation of increased yields. Using the price and labour assumptions, investment in cocoa was estimated to be economic at yields in the range of 3 to 4 t/ha.

A complete discussion of the Agtrans economic modelling of investment in Australian cocoa production as well as other economic analyses are presented in Chapter 9.

1.5 Conclusion

Researchers and industry had been interested in cocoa production in northern Australia since the 1960s. However, a combination of fluctuating world prices and the traditionally labour intensive nature of cocoa production had inhibited any industry development in Australia. Projected cocoa price increases based on world production and demand trends suggested that cocoa production in Australia could be economically viable based on reduced production costs from mechanisation and high yields. Viability would be improved if a premium market for brand differentiated or 'origin' cocoa could be achieved with Australian produced beans. It was hypothesised that a price premium of about 10% might be achieved on this basis. Alternatively, Australian grown beans would need to establish a reputation for high quality and reliable supply to command any price premiums.

The combination of projected cocoa price rises, declining and unreliable world production and industry support from CS provided a significant opportunity to more thoroughly investigate the agronomic and economic potential for cocoa production in northern Australia and address current constraints to production.

Such a project would benefit strongly from CS's knowledge and contacts in the cocoa industry from their long association with cocoa growing and processing. The transfer of this information, initially through the project and subsequently to Australian cocoa growers as part of a communication and commercialisation package, was seen of significant value. Also, CS stated they could further support an Australian cocoa industry as a potential buyer of beans by entering supply agreements with producers as appropriate.

At the time of the project inception, Australia imported approximately 40,000 t/yr of cocoa (dry bean equivalent) for its chocolate, beverage and confectionery requirements. To replace half of this requirement at an average yield of 2.5 t/ha would require 8,000 ha of producing trees. At the prevailing prices, the value of this production was about AU$50M per annum. The absence of domestic cocoa bean processing facilities was not seen as constraint to development of a northern Australian cocoa industry, however there would be significant advantages for producers and manufacturers should such investment occur.

In conclusion, the above factors were viewed as a significant incentive to investigate development of a northern Australian cocoa industry.

2. Objectives

The major objective of the project was to examine the feasibility and economics of cocoa production in northern Australia. Principally this relied on demonstrating the successful growing and yield potential of cocoa in Australia and determining the likely production costs based on ‘best-bet’ management practices.

The following sub-programs were conducted within a *Stage 1* research and development strategy to investigate the constraints to cocoa production in northern Australia:

- Hybrid Yield Evaluation Trial (HYET)
- Mechanisation of pod splitting and bean extraction
- Farming Systems Trial (FST)
- Clonal introduction.

The aims of these sub-programs were as follows:

1. To investigate the yield potential of accessible hybrid cocoa in three potential growing regions (tropical Northern Territory, northern Queensland and northern Western Australia). Agronomic aspects of production in northern Australia were recorded and management guidelines developed.
2. Investigate and develop as necessary technology for mechanisation of pod splitting and bean extraction with the objective of significantly reducing labour inputs relative to traditional manual methods.
3. Investigate the cocoa growing system (plantation layouts, planting density and tree management strategies) with regard to yield, mechanisation and harvesting. The results from these studies would provide information to further develop an economic model of cocoa production in Australia. The objective was to provide a decision tool for assessing the economic viability of an Australian cocoa growing industry.
4. Introduce elite clonal material into Australia for later evaluation and to provide a starting point for any future cocoa breeding or selection program in Australia.

A *Stage 2* strategy was proposed to later evaluate the introduced clonal material under Australian growing environments under the Stage 1 program. This would include the yield potential, bean quality and growth habit. It was envisaged that this material could be utilised for any future selection and/or breeding program in Australia. The Stage 2 strategy was not carried out.

3. Methodology

Detail of the research and development methodology conducted within the Northern Australia Cocoa Development Alliance (NACDA) project is discussed in sections of the report dealing with each of the sub-programs.

The following is a general description of the work within each sub-program trial and some background information. This provides the rationale for the structure of the research and development program.

3.1 Hybrid yield evaluation trial and quality testing

A critical factor in assessing the viability of cocoa production for northern Australia is the question of yields. Limited information from pilot plots in northern Queensland and the CPHRF suggested that yields in the vicinity of 2.0 to 2.5 t/ha dry bean were achievable. Preliminary modelling (Ngo 1998) suggested that yields of 4.5 to 5.0 t/ha were required to recover variable production costs. However, the available yield data was from small plots and the variable production costs were only estimates of Australian production regimes. It was crucial that larger scale plantings be established under a range of growing conditions, so that more reliable yield and costs of production data could be determined.

This work was carried out at three locations, using accessible hybrid seed. Plant density and agronomic inputs were based on best practice information from traditional cocoa growing regions.

The trials were situated as follows:

- Northern Territory – CPHRF
- Northern Queensland – Mossman region and South Johnstone CWTA
- Western Australia – Broome region and FWRI at Kununurra.

The principal trial was at CPHRF (1.1 ha), with smaller trials proposed at the northern Queensland and Broome sites to reduce project costs. CPHRF is about 50 km ESE of Darwin and was the site of some former smaller-scale cocoa plantings.

In northern Queensland two trial sites were evaluated due to significant local climatic differences. This also mitigated the risk of having a single site only and would reveal any useful genotype x climate interactions. A site in the Mossman district was selected on a private grower property (commercial sugar cane growers John and Melanie Goodman) which offered a more 'assured' climatic regime. This site became the principle HYET in Queensland and an area of 0.9 ha (including guard rows) was planted. A smaller secondary planting at South Johnstone (0.2 ha) was planted to provide information on the suitability of the Innisfail district as a growing environment. Although perceived as marginal (the South Johnstone (SJ) site had the disadvantage of lower winter temperatures and higher rainfall), the Innisfail district in general offered significant scope for industry establishment.

In the Broome district, two growers were approached at alternative sites. Due to a marked climatic change some 15 km from the coast, it was decided to try and evaluate a 0.25 ha site in each of these zones. In the end only the inland site was developed at Skuthorpe approximately 20 km from Broome (commercial banana growers Steve and Kylie Grey) with a smaller second planting established instead at FWRI Kununurra.

The CPHRF, Mosman and Broome sites all incorporated double sites and single row planting layouts. The double row layout was premised on enabling mechanised farming operations whilst the single row layout was a compromise between the same and mimicking 'traditional' block plantings of cocoa (for reference to overseas data).

All sites were established using natural shade of species appropriate to the sites with the intention of progressive removal over a three- to four-year period. Irrigation was supplied and soil water monitored for optimum inputs. Weed control, pruning, shade removal and fertiliser inputs were based on good practise information from overseas and cocoa references. Pest and disease incidence was monitored and documented with control measures carried out as necessary in consultation with entomology and pathology staff. Detailed yield data was collected and management inputs recorded. Weather data was monitored at relevant sites using automatic weather stations or by reference to nearby Bureau of Meteorology (BOM) stations.

Cocoa quality aspects and bean characteristics were evaluated by CS who provided access to the technical staff and facilities. This occurred once fermentable quantities of beans were available. Fermentation was carried out principally in Queensland when it became apparent that yield and bean quality from the CPHRF site was inferior to production from South Johnstone and Mossman. Initial fermentation and drying procedures were conducted after consultation with CS. Later they were refined in collaboration with the CS sponsored PhD project conducted with University of New South Wales.

3.2 Mechanised pod splitting and bean extraction

Provided that acceptable yields can be achieved, a significant risk to viable cocoa production in Australia is the successful mechanisation of pod splitting and bean separation. The productivity of traditional manual methods for pod splitting and bean extraction is in the range of 250 to 400 pods/person/hour. At a typical yield of 75,000 pods/ha, the requirement for pod splitting and bean extraction would be 25 to 40 man-days. Clearly this would not be viable in Australia.

Therefore this aspect of the feasibility study was deemed high priority and it was proposed that development work should be commenced as early in the project phase as possible.

The project was based in northern Queensland and conducted by Craig Lemin. Initially, investigations were focussed on reviewing overseas technology for its performance and suitability. There were several references in cocoa literature to previous attempts at mechanisation of cocoa pod splitting and bean extraction including by manufacturers Pinhalense (Brazil), Zinke (Costa Rica), Christy and Norris (UK), Zumex (Spain) and Cocoaette (France). As well, Tony Lass (Cadbury UK) was able to provide some contacts. An overseas study trip was proposed to examine the technology and performance of existing machines and investigate opportunities for collaboration. However, since no working set-ups could be found and contacts with manufacturers were generally unfruitful, this trip was not undertaken.

In some cases commercial equipment had been developed, however there had been no significant adoption by industry. The problem, apparently common to most of the machines, was excessive contamination of bean with small pieces of broken pod requiring laborious hand sorting to remove pod fragments prior to fermentation.

Additionally, CS was a participant in an AusAid funded project examining mechanisation of pod opening and bean extraction. Technically, this project had some success, and CS was willing to share the information, however there were some intellectual property issues. These were eventually resolved, but the technology was found to be deficient.

In lieu of this, autonomous development work was initiated within the NACDA project based on the concept of discrete opening of individual pods. A working prototype was constructed and tested using the initial production from the NACDA trials and locally available material. At about the same time a working machine was obtained through liaison with Pedro Alcantara (Paulinin and Alves, Brazil). For pod splitting, this unit was unsatisfactory however it did have a useful means for separating bean which provided the basis for development of a larger and more efficient version within the NACDA project. Meanwhile the NACDA prototype pod splitter was progressively developed and improved.

This machine was used extensively for processing pods from the NACDA trials in Queensland. The technology is now patented.

The project also considered the most appropriate implementation of this technology considering product handling logistics and waste disposal. Options included:

- mobile unit located on a harvest aid so that processing is carried out within the plantation in conjunction with harvesting
- relocatable unit with pods brought to a temporary processing station in-field for batch processing
- fixed plant with pods transported to a central processing factory for batch or continuous processing.

3.3 Farming systems and mechanisation

Because field labour for pruning and harvesting was considered to be the major variable cost for cocoa production in Australia, three principle work areas to improve the efficiency of field operations were proposed in the original project methodology. These were:

- plantation layouts for machinery access
- pruning management and tree/flowering manipulation
- harvest mechanisation and management for harvest synchronisation.

From the outset, this work was not perceived as essential to the development of a cocoa industry in Australia should the ability to grow economic yields be proven. Such issues would necessarily be addressed by the pioneering growers and investors of an emergent industry. However, CS representatives were enthusiastic about the prospects from such work which had not been well examined elsewhere in the world. They saw a unique opportunity for innovative approaches to cocoa plantation layouts and tree management which would allow mechanisation and reduce labour inputs.

To varying degrees, the work areas above were all addressed in the project. However, the resources required maintaining the pre-eminent hybrid yield trials and ramp-up of development work on pod processing and fermentation meant that the ‘farming systems’ investigations were not conducted with the rigour or follow-through that was originally envisaged.

The trials and activities which were conducted to investigate cocoa farming system efficiencies were as follows:

- double versus single row planting layouts for the hybrid yield trials at Mossman and Darwin and for the density trial at South Johnstone
- trellising of two single rows in the density trial at South Johnstone and associated pruning/training treatments
- adaptation and use of appropriate tools for harvesting the hybrid yield and density trials and subsequent ‘mimicking’ of commercial harvesting to determine expected harvest productivities
- concepts for mechanised harvest aids (no prototypes constructed)
- development of a cocoa economic model based on alternative production regimes with attendant production costs estimates using data from the above work and the wider program.

No work was conducted on crop manipulation strategies for canopy management or harvest synchronisation. There may be significant benefits from the use of growth regulators for control of jorquetting and chupon growth as well as productivity benefits from synchronisation of harvesting. Techniques to exert control over timing and duration of harvest through irrigation and/or nutrition management were not investigated.

3.4 Clonal introduction

The Cocoa Study Tour to Malaysia (Lemin et al. 1998) conducted prior to the NACDA project application confirmed the superior performance of clonal cocoa over hybrid material in terms of higher yield potential (up to 30%) and reduced vigour. Use of such material in future Australian plantings would offer significant advantages.

Therefore, a clonal introduction program was conducted to establish selected material in Australia whilst it was readily accessible. This would enable later evaluation of the material under Australian conditions should the feasibility study confirm the economic potential of cocoa in northern Australia.

The importations were made from 1999 to 2001 under AQIS protocols. The material was imported from Reading University with the advice and assistance of Tony Lass (Cadbury, UK). Ultimately, eleven clones were successfully introduced and established in-field, initially at CPHRF and later at South Johnstone. No subsequent evaluation program was intended or conducted.

It was originally proposed to also import material from the Malaysian Department of Agriculture (Sabah) but no arrangement was able to be reached with the Malaysian Cocoa Board (MCB).

4. Hybrid yield evaluation trials

4A. Queensland

4A.1 Introduction

Hybrid yield evaluation trials were established in two locations in far northern Queensland. Sites selected included the Centre for Wet Tropics Agriculture (CWTA), South Johnstone (17.61^{o}S, 146.00^{o}E) and a private farm approximately 10 km south of Mossman (16.48^{o}S, 145.46^{o}E). The more northern location of Mossman was chosen for its warmer/dryer conditions as the CWTA site is characterised by mean minimum temperature near 15^{o}C from June to August with the lowest temperature recorded being 3.3^{o}C in July 1965. Climate data collected during the trial period (2000 to 2007) by the Bureau of Meterology showed that the mean monthly minimum temperatures during winter are cooler in South Johnstone by approximately 2.2^{o}C.

The main trial site was established near Mossman and included four hybrid lines from Papua New Guinea (PNG) planted in two row configurations (single versus double row). The secondary trial site at CWTA included all five PNG hybrids obtained in the double row configuration.

The aim of the study was to monitor tree establishment, growth, flowering and fruiting phenology and yields over a seven-year period while also recording inputs of fertiliser, irrigation and pesticide. The data collected was used to calculate the cost of production and crop gross margins. Row layout and hybrid performance were also quantified.

4A.2 Materials and methods

4A.2.1 Seed source

After initial inquiry with the PNG Coconut and Cocoa Research Institute (CCRI), five moderate vigour SG2 hybrid crosses were selected. Efron et al. (2003) report that the SG2 hybrid is the most widely grown in PNG and was originally released as a poly-cross hybrid of 15 different crosses. In 1994 the SG2 was modified to include ten crosses in two groups of five crosses each based on their potential vigour. The five selected hybrids are based on Upper Amazonian female parents (KEE5, KEE12, KEE23, KEE43) and local Trinitario clones K82 and KA2-106 used as males. The hybrids identified in Australia as PNG1, PNG2, PNG3, PNG4 and PNG5 are based on the following male-female combinations:

- PNG Hybrid 1 – KA2-106 x KEE12
- PNG Hybrid 2 – K82 x KEE5
- PNG Hybrid 3 – K82 x KEE43
- PNG Hybrid 4 – KA2-106 x KEE23
- PNG Hybrid 5 – K82 x KEE12

Seeds sufficient for trials at all sites were ordered in December 1999 and received during January 2000. However, germination failed at all sites due to non-viability of seed (it is suspected that this seed was either frozen and/or subject to excessive heat whilst in transit from CCRI to Cairns).

A second lot of seed was received late February 2000. Germination from the second shipment of CCRI hybrid seed (planted 28 February) was in excess of 95%. Seed was placed with prepared and sterilised potting medium in individual seed tubes (forestry pots) and germinated under glasshouse conditions. Seedlings were transferred to 5 litre bags at 4 to 8 weeks post emergence. Plants were then raised under shade-house conditions for a further 11 to 18 weeks prior to field planting. Prior to field planting seedlings were sun-hardened for approximately 3 weeks.

4A.2.2 Trial design and field planting

Mossman

Cocoa seedlings were field planted at the Mossman trial site in the week commencing 17 July 2000. Seedlings (about 1,100) were transported 150 km to the trial site in a enclosed flat bed truck. Ripping was carried out along the plant rows immediately prior to planting and a pre-plant irrigation was applied. Planting holes were dug manually.

The soil at the Mossman site is described as Mission series (red massive earth formed on alluvial fans) with a reddish brown loamy fine sand A horizon (CSIRO Division of Soils, Divisional Report No.102).

Treatments consisted of single rows and double rows and the four hybrids (PNG1, PNG2, PNG4 and PNG5) selected for formal yield evaluation as for the Darwin and Broome sites. The remaining hybrid PNG3 (K82 x KEE43) was planted to the end of the trial rows and to the two southern guard rows. Cocoa seedlings from local northern Queensland trees and selections from existing NT trial block were planted to the two northern guard rows. The trial site was designed to be commercially realistic and to allow for continuous row access. Hence the row configurations were not correctly randomised to allow for true statistical analysis. Data from the two replicate hybrid blocks was averaged and standard error of the means calculated. The trial layout is shown in Appendix A2.1.

CWTA

Cocoa seedlings were field planted at the CWTA trial site in August 2000. Seedlings were transported 100 m to the trial site in a open trayed vehicle. Four months prior to planting the plantings rows had been mounded and allowed to stabilise. Planting holes were dug manually and trees planted.

The trial design was a completely randomised block consisting of the five hybrids (PNG1, PNG2, PNG3, PNG4 and PNG5) planted in the double row configuration in three replicate blocks (Appendix A2.4).

4A.2.3 Trial maintenance and management

Nutrition

Trees were fertilised regularly to maintain growth and production. All inputs were recorded. The nutrition input data and production data were used to construct a nutrition budget based on nutrition in and nutrition which exits the system through crop removal or alternative pathways. Tree fertiliser management practices and a simple nutrition budget for Queensland grown cocoa are documented in Section 4A.5.

Irrigation

The Mossman site is generally drier than South Johnstone and required daily irrigation applications during trial establishment. An automatic irrigation controller was installed to sequentially irrigate the single, double and guard rows. The co-operator switched the system off when significant rainfall occurred. Irrigation schedules were based on tensiometer readings in conjunction with rainfall and evaporation figures. Flow meters were installed in the single and double rows to monitor water usage and aid in equal application of water across the two layouts. Early irrigation inputs are documented in Section 4A.6.

Grass and weed control

The inter-rows were mowed to maintain ground cover and reduce erosion. Spot spraying was used mainly to control the wild passion vine and ipomea. Additionally the immediate area around sprinklers was kept clear to allow even irrigation distribution. The application of herbicide was restricted to the first 24 months as the competition from grass and dicotyledonous weeds was the most severe during the early development stages of cocoa.

Shade management

Natural shade development was provided by planting two species. Gliricidia (*Gliricidia sepium*) cuttings were planted out at 5m spacings in single rows and the middle of the double rows during February 2000 at both sites. Although the initial strike was excellent, about 50% of these subsequently died and this required replacement cuttings to be planted out on further occasions through to May 2000. This process was hampered by a shortage of planting material (obtained from limited tree stock growing at South Johnstone). Additionally, development of the original surviving plants in Mossman was slow compared to material planted around the same time at South Johnstone. It took until June 2000 to achieve complete establishment across the trial block and for the original material to gain vigour. It was hypothesised that residual herbicides may have caused these problems however this was not investigated.

In late 2000 native rainforest trees, locally called purple quandong (*Eleaocarpus angustifolius*) were inter-planted at spacings of 15 x 15 m to provide longer-term light shade for the trial. Purple quandong, despite being a fast growing species, has commercial value as mill timber. Hence the rationale behind selection of this species is that it could provide light long-term shade as well as have commercial value at the end of the cocoa orchard's life in 20 to 30 years time.

Due to inadequate development of the shade trees at the time of planting cocoa, shade-cloth enclosures were erected around each tree. These enclosures were constructed using 50% woven shade-cloth (about 1,000 mm high) erected around 3 wooden stakes spaced in a triangular arrangement around each cocoa plant (at about 350x350x350 mm). These enclosures afforded excellent sun and wind protection. They remained in place until mid-2001. Whilst considered expensive to use commercially, the enclosures were considered necessary to ensure successful trial establishment because the shade trees progressed more slowly than desired. The Gliricidia required regular pruning to help establish a canopy and to maintain a clear inter-row and minimise interference with the developing cocoa trees.

The shade-cloth enclosures assisted early plant development by reducing wind and sun exposure. From observation they may also afford protection from insect damage. The upper leaves of plants (which receive maximum sun exposure) hardened well despite the lack of natural shade.

Pest and disease control

Insect control was carried out on an 'as required' basis. Insect pests which required regular management during early cocoa development include swarming beetle (*Rhyparida* spp. and *Monolepta* spp.), leaf eating caterpillars (loopers etc), cane beetle larvae and mealy bug. Spot spraying was used for control where broad scale insecticide applications were not required.

A weather station was installed to monitor soil and air temperature, relative humidity, rainfall, soil moisture and solar radiation. Climatic averages are presented in Appendix A4.

Pruning

Pruning operations to maintain internal branch tree height and to prevent overshading within the canopy were carried out on a regular basis once trees reached maturity. Recorded pruning events included:

- February 2002 – pruning plagiotropic branches above the jorquette
- December 2002 – minor internal canopy prune to remove branches within 50 cm of the jorquette and branches which cross the canopy internally
- December 2003 – major height and internal branch prune to reduce canopy size prior to the cyclone season

- August 2004 – major height and internal branch prune to reduce canopy size prior to the cyclone season
- January 2005 – height and internal prune to improve light penetration
- September 2005 – large upright branch removal where required
- November 2005 – skirt the side of canopy and major large upright branch removal to reduce canopy height. This latter pruning was relatively severe, reducing tree height to 2.5 to 3.0 m from 5 to 6 m in some individual trees.

4A.3 Results

4A.3.1 Mossman

Early growth measurements

Tree height

The analysis did not record a significant difference in early growth between hybrids (Table 4A.1). The mean jorquette height was 134.5 cm and trees had reached a mean height of 242 cm in 22 months after planting.

Table 4A.1. Mean jorquette height, height change and final tree height for young cocoa hybrid seedings grown at Mossman.

Hybrid	Mean Jorquette Height at 12/7/01 (cm)		Height Change 3/7/00 – 15/5/02 (cm)		Final Height at 15/5/02 (cm)	
	S row (12/7/01)	D row (8/1/02)	S Row	D row	S Row	D row
PNG1	130 a	132	208	206	248	240
PNG2	134 ab	127	245	207	277	242
PNG4	136 b	130	229	227	272	267
PNG5	138 b	138	209	191	237	217
	P=0.05	n.s.	n.s	n.s.	n.s	n.s

Stem diameter

Tree diameter was not significantly different between hybrids at each of the three measurement occasions (Table 4A.2). The mean tree diameter at 30 cm above ground in May 2002 was near 50 mm.

Table 4A.2. Mean tree diameter measurements on three occasions for young cocoa hybrid seedlings grown in Mossman.

Hybrid	Diameter at 8/8/01 (mm)		Diameter at 8/1/02 (mm)		Diameter at 15/5/02 (mm)	
	S row	D row	S row	D row	S row	D row
PNG1	21	20	33	32	49	50
PNG2	24	23	41	36	56	53
PNG4	22	24	38	38	56	54
PNG5	20	19	34	32	48	42
	n.s.	n.s.	n.s	n.s.	n.s	n.s.

Yield

Harvestable yields commenced in 2002/03 two years after planting. Mean pod yield (kg/ha) increased with time peaking at 28,134 kg/ha in the 04/05 season, four years after planting. Yield in the subsequent two seasons, 05/06 and 06/07 declined sharply to 16,637 kg/ha and 14,815 kg/ha respectively (Figure 4A.1).

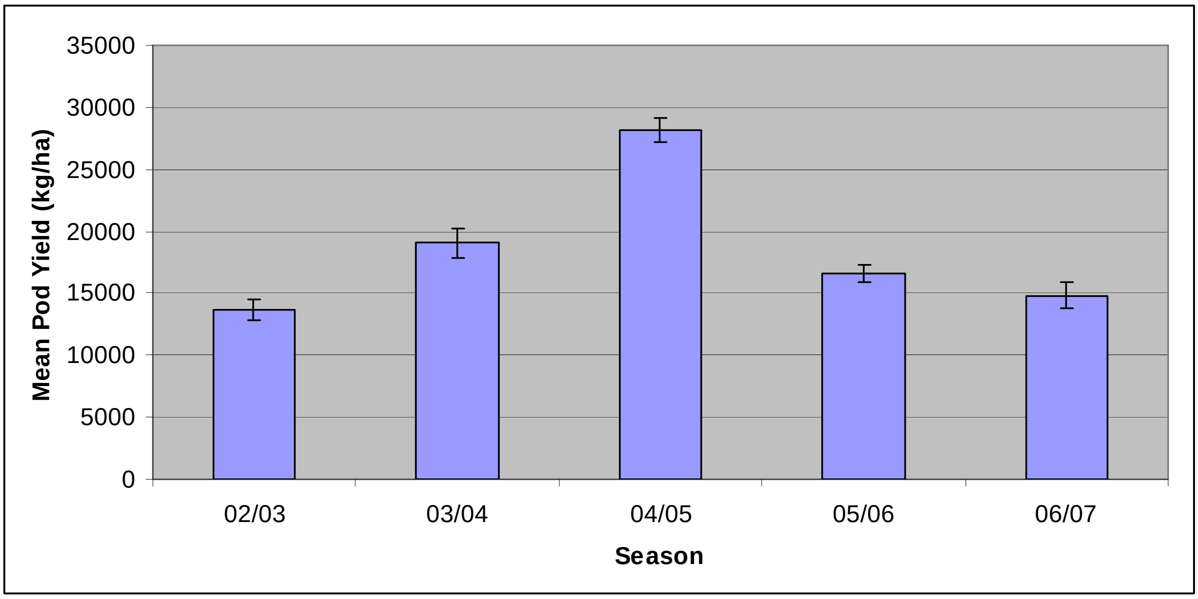


Figure 4A.1. Mean pod yield (kg/ha) at Mossman over five seasons. Treatment SE is represented by the error bars for each season.

Hybrids performed similarly with PNG4 peaking at 30,301 kg/ha of whole pods in the 04/05 season. All of the seasonal means are within the range of standard errors for the hybrids suggesting that within the limitations of the experimental design there is no significant difference in hybrid performance. The drop in production in the last two seasons was consistent across all hybrids (Figure 4A.2).

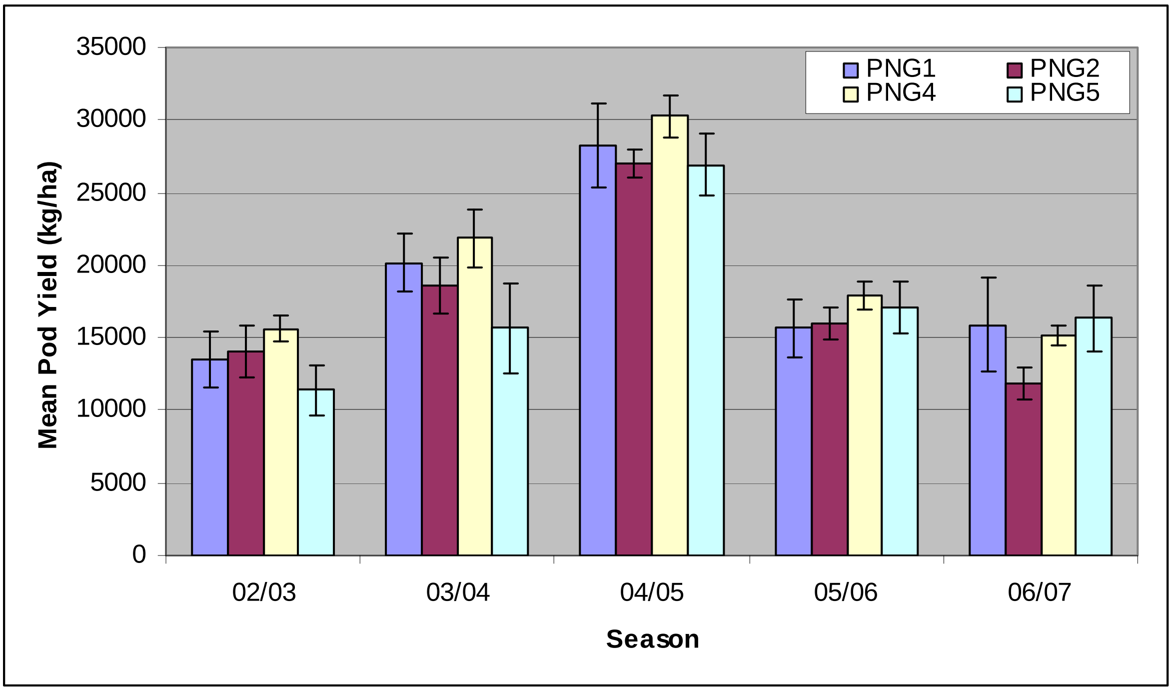


Figure 4A.2. Mean pod yield (kg/ha) for the four hybrids over five seasons at Mossman. Treatment SE is represented by the error bars for each hybrid.

Row configuration, single versus double row, means varied. Plants in the single row arrangement out performed those in the double row in the first two seasons. In the peak production season (2004/05) and the subsequent two seasons the mean pod yields for both row configurations were similar (Figure 4A.3).

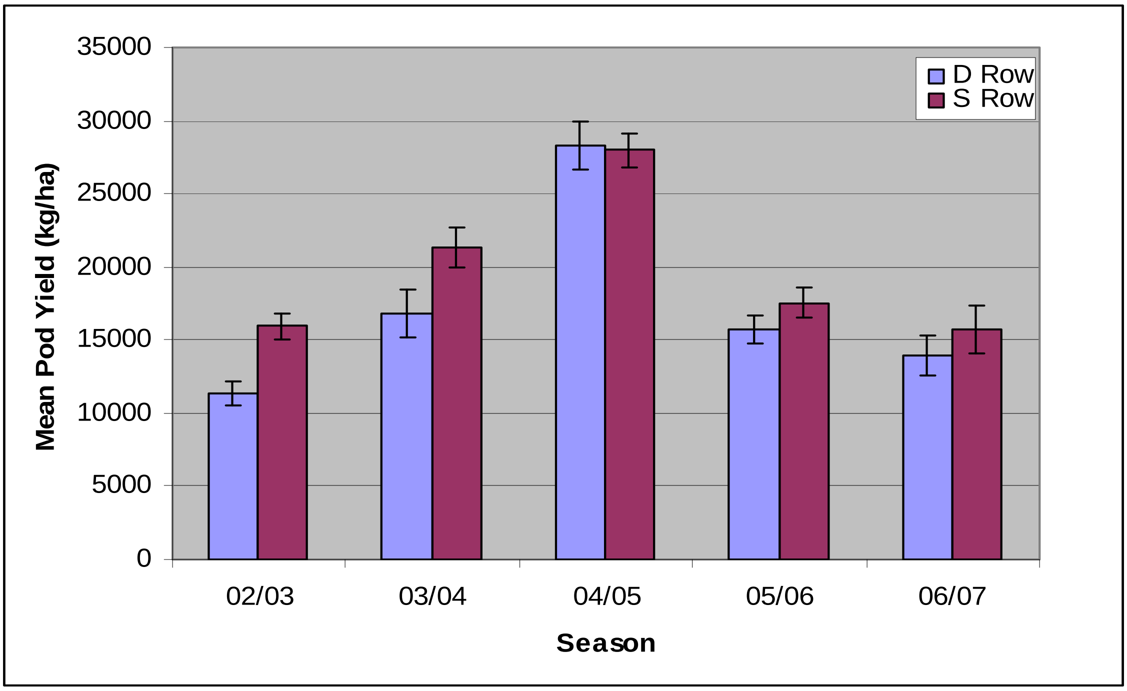


Figure 4A.3. Mean pod yield (kg/ha) for single (S) and double (D) row configurations over five seasons at Mossman. Treatment SE is represented by the error bars for each hybrid.

Mean pod yield/ha for the treatment combinations are shown in Figure 4A.4. Hybrid 4 (PNG4) in a single row configuration is generally the best performer over the five seasons.

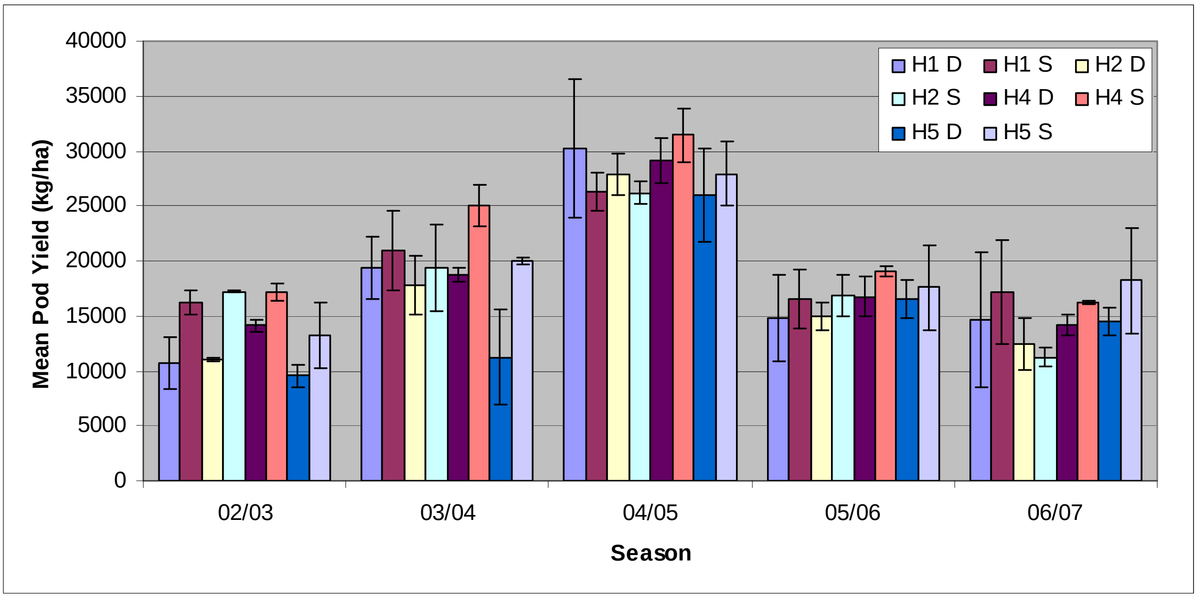


Figure 4A.4. Mossman hybrid mean pod yield (kg/ha) for PNG hybrids H1, H2, H4, and H5 grown in single (S) or double row (D) configurations. Treatment SE is represented by the error bars.

This observation is reflected in the accumulative yield calculation shown in Figure 4A.5. Hybrid 4 (PNG4) in a single row configuration has the best accumulated yield over the five seasons whereas Hybrid 5 (PNG5) in a double row configuration has the least accumulated yield.

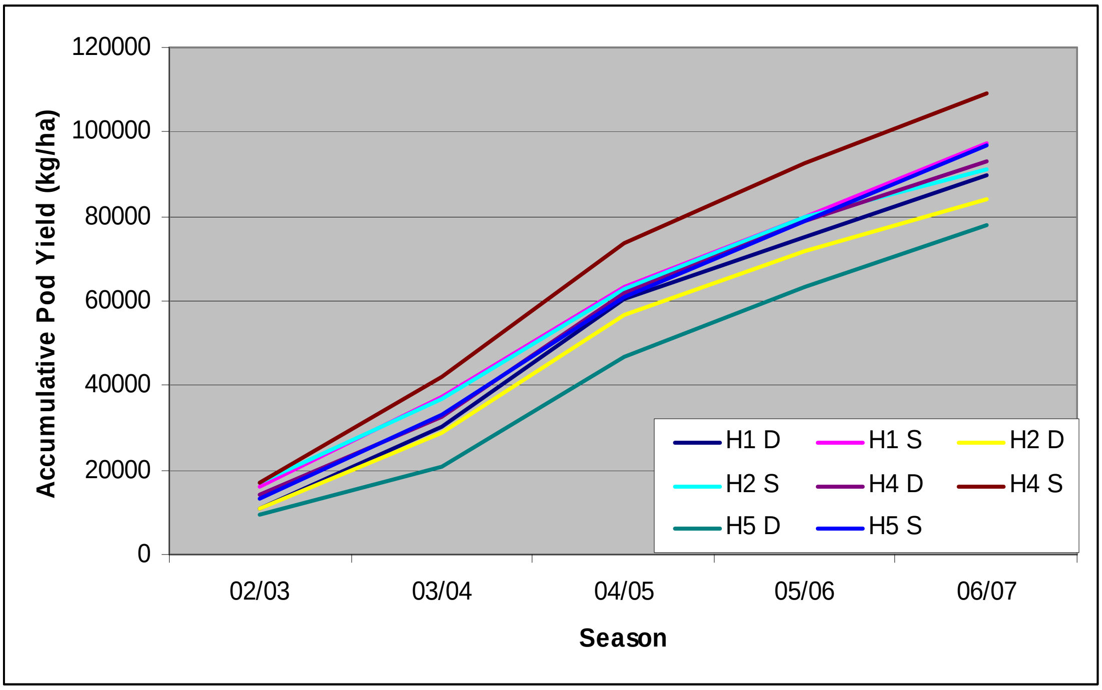


Figure 4A.5. Accumulative pod yield (kg/ha) for the hybrid row configuration combinations at Mossman.

Yield distribution

Cocoa trees flower and set pods throughout the year. The yield distribution was calculated and shown as the percentage of the total annual (seasonal) harvest for each month. The yield distribution changed with season and became more distinct as the trees aged. The peak monthly distribution were in the vicinity of 25% of total production and occurred from August to October (Figure 4A.6).

The highest mean yield distribution for all treatments over the five seasons was 21% and occurred in October (Figure 4A.7). December to March was the period with the least crop produced with monthly yield distributions ranging from 4 to 5% of annual production. For the remaining seven months of the year, monthly pod production exceeded 5% of annual production with August to November being the peak pod producing months.

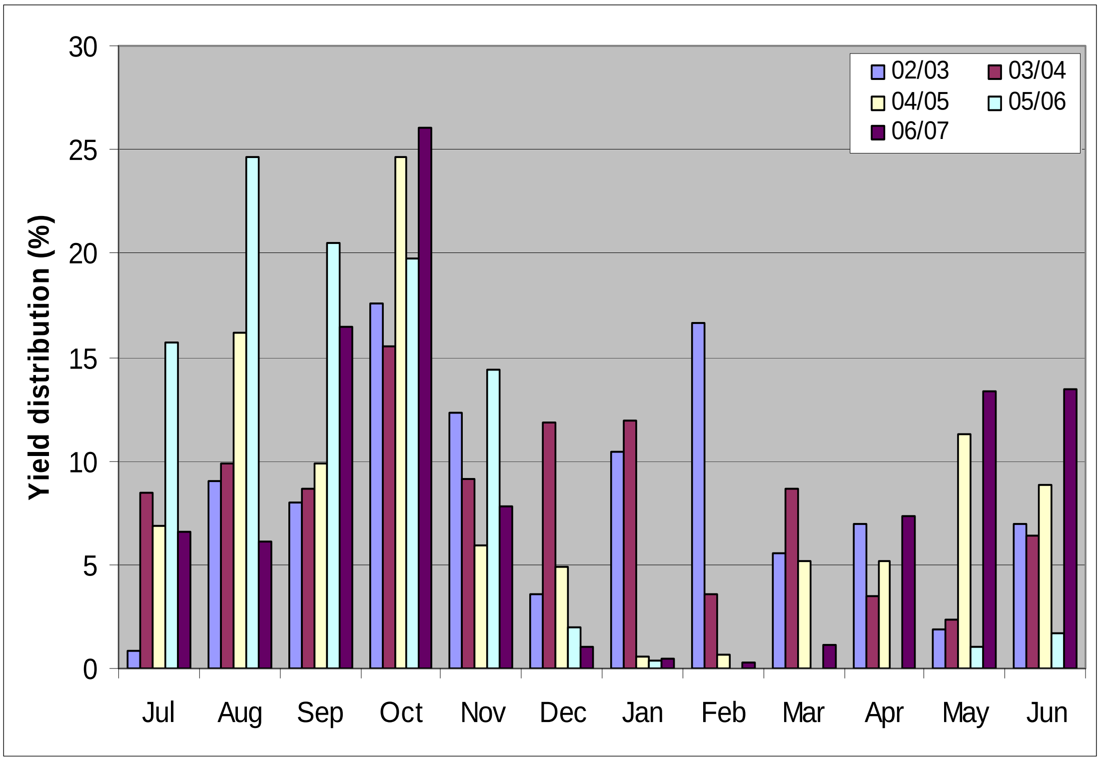


Figure 4A.6. Seasonal yield distribution for cocoa produced in Mossman.

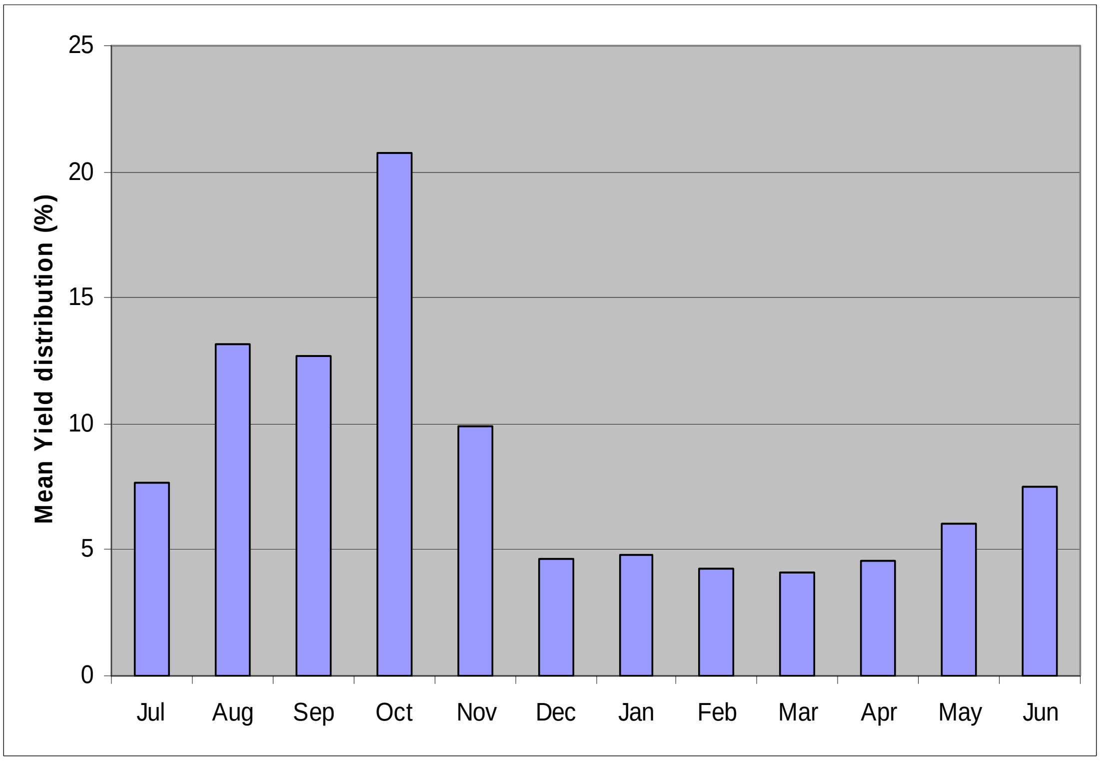


Figure 4A.7. Mean yield distribution % for cocoa produced in Mossman.

Individual tagged trees

144 trees were tagged at Mossman and individual harvest records maintained over four years. Individual tree yield records were added to the bulk plot yields for the analysis of yield total plot data as described above. Nine trees were randomly tagged in each combination of hybrid, row type and block. Hence each hybrid was represented by a total of 36 individual trees. At each harvest pods from these tagged trees were individually marked, collected and tree yields recorded.

The performance of individual trees varied enormously with accumulated pod yields over four seasons (2002 to 2005) ranging from 7 to 145 kg per tree (Figure 4A.8).

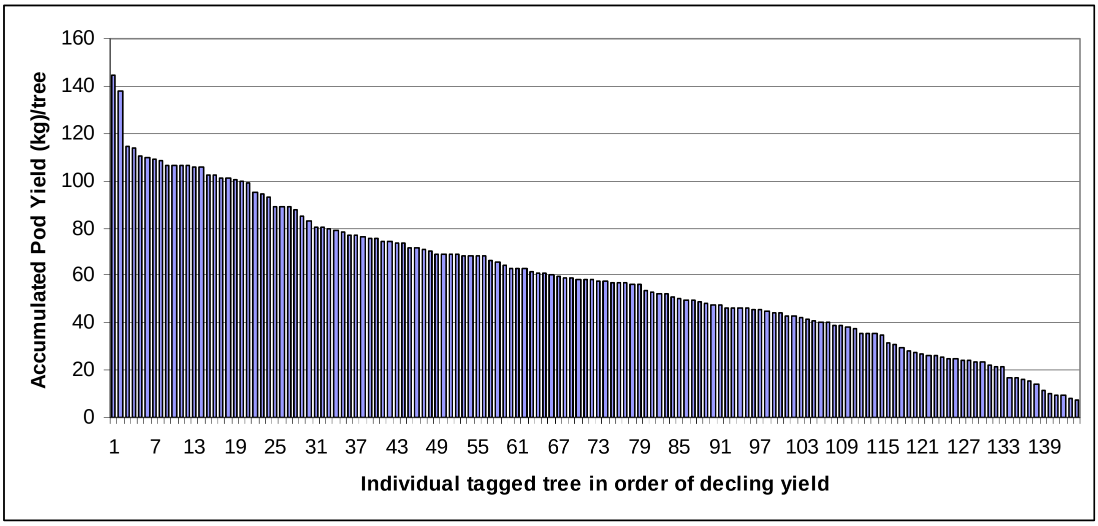


Figure 4A.8. Accumulated yield over four years for individual tagged trees in the Mossman HYET.

Mean yields ranged from 42.7 kg/tree to 81.7 kg/tree for PNG1 single row configuration and PNG4 double row configuration respectively (Table 4A.3).

Table 4A.3. Mean total yields (kg/tree) for tagged trees for the four seasons with associated CV%.

Row Configuration	Hybrids			
	PNG1	PNG2	PNG4	PNG5
Double – Mean Yield (kg/tree)	65.6	54.6	81.7	61.7
Double – CV%	44	46	31	44
Single – Mean Yield (kg/tree)	42.7	49.3	66.4	54.6
Single – CV%	54	69	46	50

Analysis of the frequency of accumulated yields using 20 kg increments shows that 27.8% of the tagged trees had an accumulated pod yield in the 40 to 60 kg bracket and 23.6% of tagged trees had an accumulated pod yield in the 60 to 80 kg bracket. Only 22.3% of trees had an accumulated yield in excess of 80 kg per tree (Table 4A.4).

Table 4A.4. Frequency of accumulated pod yield (kg) per tree over four years for all tagged trees at Mossman.

Accumulated Pod Yield by Category (kg/tree)	Frequency	Percentage of Total
0–20	11	7.6
>20–40	27	18.8
>40–60	40	27.8
>60–80	34	23.6
>80–100	13	9.0
>100–120	17	11.8
>120–140	1	0.7
>140–160	1	0.7
Total	**144**	**100**

An analysis of the hybrids involved in the top 22.3% of individuals, or those producing an accumulated yield greater than 80 kg, shows that 55% of the individuals were PNG4, 19% PNG5 and the remaining 26% being equally distributed among hybrids PNG1 and PNG2. An analysis of individuals with an accumulated yield greater then 60kg per tree showed a more equal distribution of hybrids with PNG4 representing 31.8% of individuals with the remainder being equally distributed among hybrids PNG1, PNG2 and PNG5.

The interest in high yielding seedling individuals is for potential production of uniform clonal production blocks. There is evidence that selecting high yielding individuals to use as clones for new plantings will result in higher yields. However, Eskes (2004) in his summary of the cocoa breeding for improved production systems conference highlights the fact that conflicting data exists on this issue.

4A.3.2 South Johnstone

Early growth measurements

Tree height

Two height measurements were made during the early growth stage on 26 Feb 2001 and 21 May 2002 to allow a growth increment to be made. The height change and the final height were both analysed. The change in height over the 15 months was not significantly different between hybrids. Analysis of the final height measurement showed evidence of a significant hybrid effect at P=0.075 with PNG2 significantly taller than the remaining hybrids and PNG3, PNG4 and PNG5 significantly taller than PNG1. The jorquette height was not significantly different with a mean height of 133 cm (Table 4A.5).

Table 4A.5. Mean jorquette height (cm), height change and final height for five PNG hybrid grown at South Johnstone.

Hybrid	Mean Jorquette Height at 14/1/02 (cm)	Height Change 26/2/01 – 21/5/02 (cm)	Final Height at 21/5/02 (cm)
PNG1	129	135	175a
PNG2	135	212	274c
PNG3	135	175	214b
PNG4	134	181	229b
PNG5	130	193	233b
	n.s.	n.s.	P=0.075

Stem diameter

Stem diameter measurements were made over four occasions (26 Feb 2001 to 21 May 2002). The analysis of the diameter showed that at the initial measurement there was a significant different in stem diameter between hybrids at $P \leq 0.05$ with the hybrid PNG2 having the largest diameter and PNG1 the least. At the remaining three measurement occasions there were significant differences between hybrids and at the last two measurements PNG5 had a significantly larger diameter then the other hybrids (Table 4A.6).

Table 4A.6 Average stem diameter of young cocoa seedling at four occasions during the first two years of growth at South Johnstone.

Hybrid	Av. Diameter at 26/2/01 (mm)	Av. Diameter at 26/8/01 (mm)	Av. Diameter at 14/1/02 (mm)	Av. Diameter at 21/5/02 (mm)
PNG1	**10.3a**	**22.1a**	**32.3**	**36.3**
PNG2	**18.3c**	**31.5c**	**37.5**	**45.8**
PNG3	**13.5b**	**27.3bc**	**37.5**	**45.9**
PNG4	**13.3ab**	**26.5abc**	**38.0**	**47.6**
PNG5	**12.3ab**	**24.8ab**	**47.2**	**56.9**
	P=0.003	**P=0.028**	***Lsd(10%)=8.1***	***Lsd(10%)=11.2***

Yield

Harvestable yields (5,476 kg/ha) commenced in 2002/03, two years after planting. Mean pod yield (kg/ha) increased rapidly and peaked at 22,819 kg/ha in the 03/04 season, three years after planting. Yield in the subsequent season (04/05) remained at a similar level (20, 607 kg/ha). The yield for the last season, 05/06, of collection declines sharply to 11,293 kg/ha principally because of the loss of four months data due to tree destruction caused by Cyclone Larry in March 2006 (Figure 4A.9). The full season yield is estimated to be 13,817 kg/ha based on the proportionate data changes from the preceding season's data. Hence yield decline was most likely occurring in the fourth season.

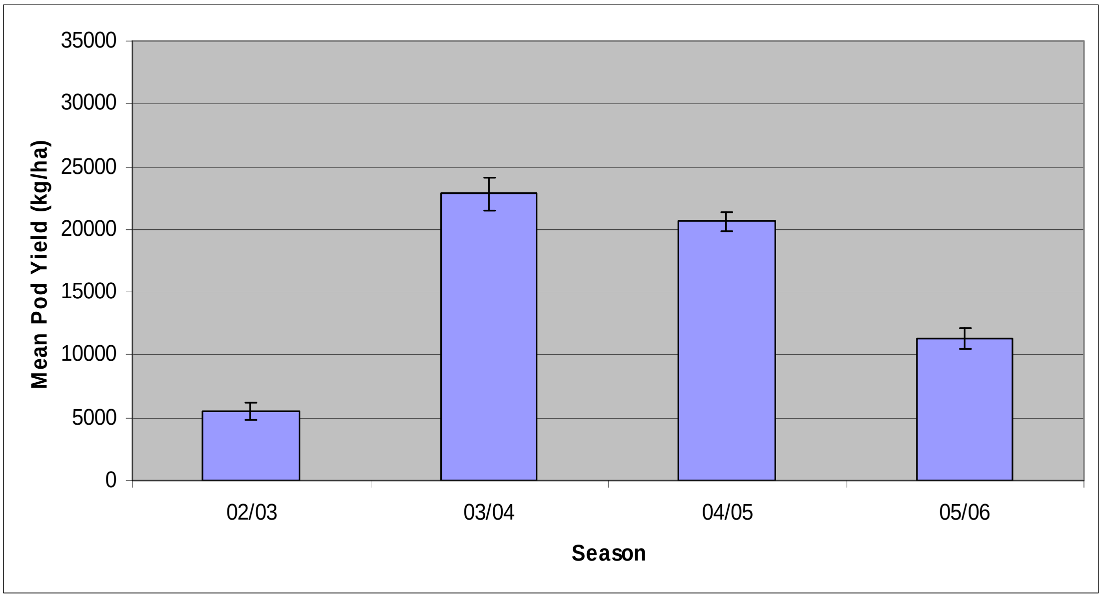


Figure 4A.9. Mean pod yield (kg/ha) at South Johnstone over four seasons. Treatment SE is represented by the error bars for each season.

Hybrids performed similarly with PNG3 peaking at 26,746 kg/ha in the 03/04 season. All of the seasonal means were within the range of standard errors for the hybrids suggesting that within the limitations of the experimental design there is no significant difference in hybrid performance. The drop in production in the last seasons was consistent across all hybrids due to the fact that four months of production data was lost due to the crop destruction by Cyclone Larry (Figure 4A.10)

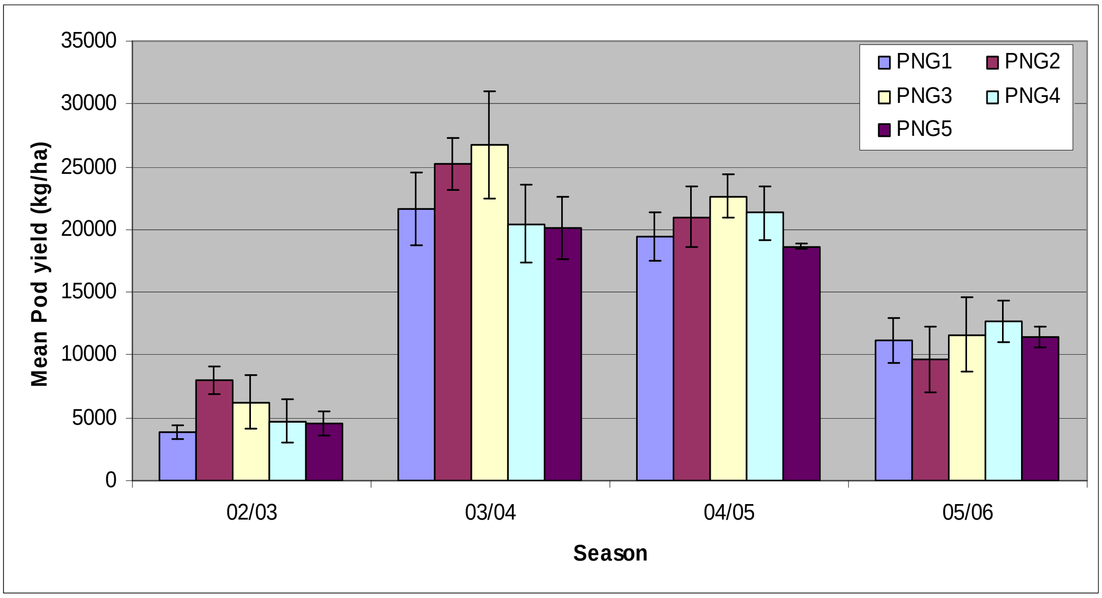


Figure 4A.10. Mean pod yield (kg/ha) for five hybrids over four seasons at South Johnstone. Treatment SE is represented by the error bars for each hybrid.

This trial presented an opportunity to compare the performance of all five PNG hybrids. PNG3, the hybrid which was excluded from the Mossman, Darwin and Broome trials produced the highest mean yield over all seasons and the highest yield in the peak producing season (03/04). However, the difference was insufficient to statistically confirm that PNG3 was superior to the other hybrids (Figure 4A.11).

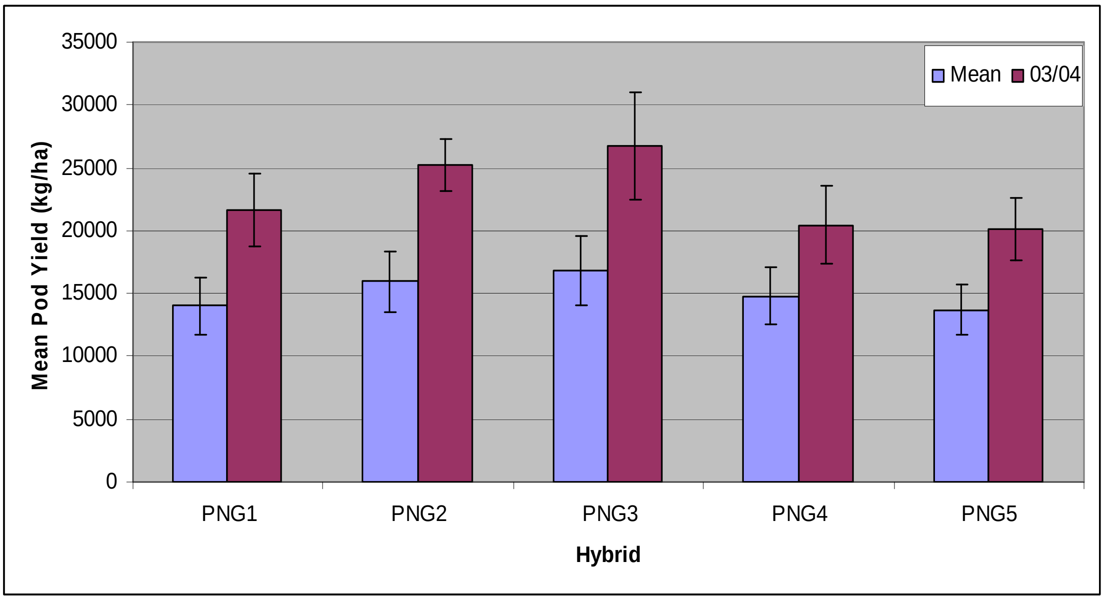


Figure 4A.11. Mean pod yield (kg/ha) for five hybrids at South Johnstone. Treatment SE is represented by the error bars for each hybrid.

The accumulated yield over the four seasons indicates that PNG3 and PNG2 performed similarly reaching a production total of approximately 65,000 kg/ha. Hybrids PNG1, PNG4 and PNG5 preformed similarly with the accumulate yield at the end of the trial reaching 56,600 kg/ha (Figure 4A.12).

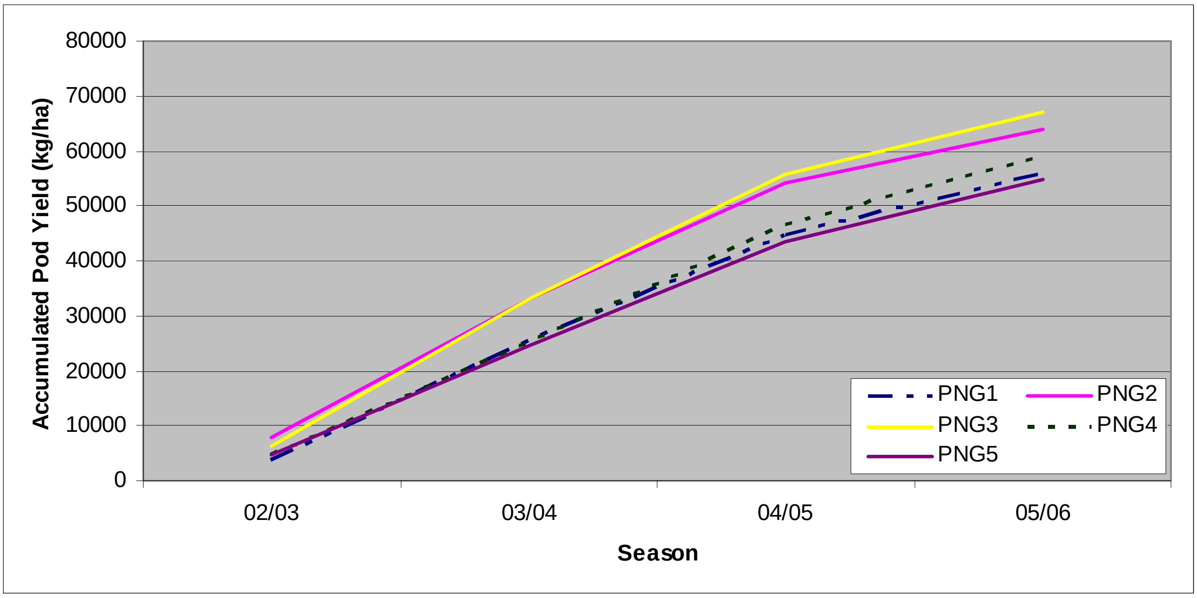


Figure 4A.12. Accumulative pod yield (kg/ha) for the hybrid row configuration combinations at South Johnstone. Note; the accumulated seasonal yield is based on a partial yield recording for the 2005/06 season due to the loss of trees following Cyclone Larry.

Yield distribution

The yield distribution at South Johnstone was similar to that which occurred at Mossman. There was considerable variation over the four seasons (Figure 4A.13). The mean distribution (Figure 4A.14) shows that most of the pods were produced from July to November with peak production occurring in October. At South Johnstone there was negligible production in February and low production (< 2% of total in March. Pod production commenced from April and increased monthly until October.

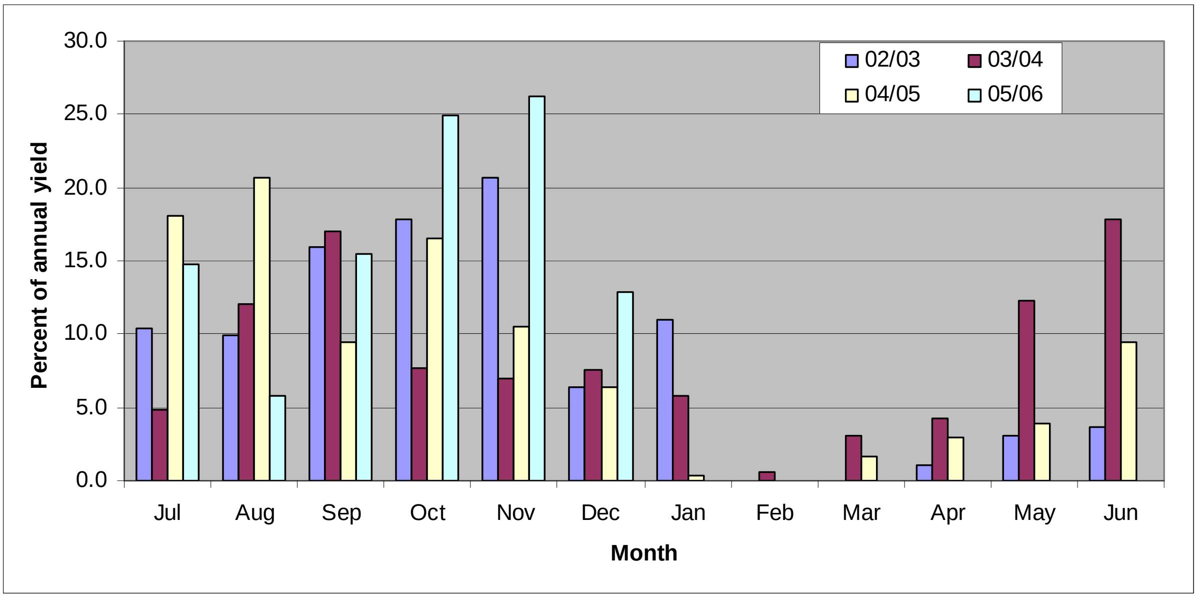


Figure 4A.13. Seasonal yield distribution for cocoa produced in South Johnstone.

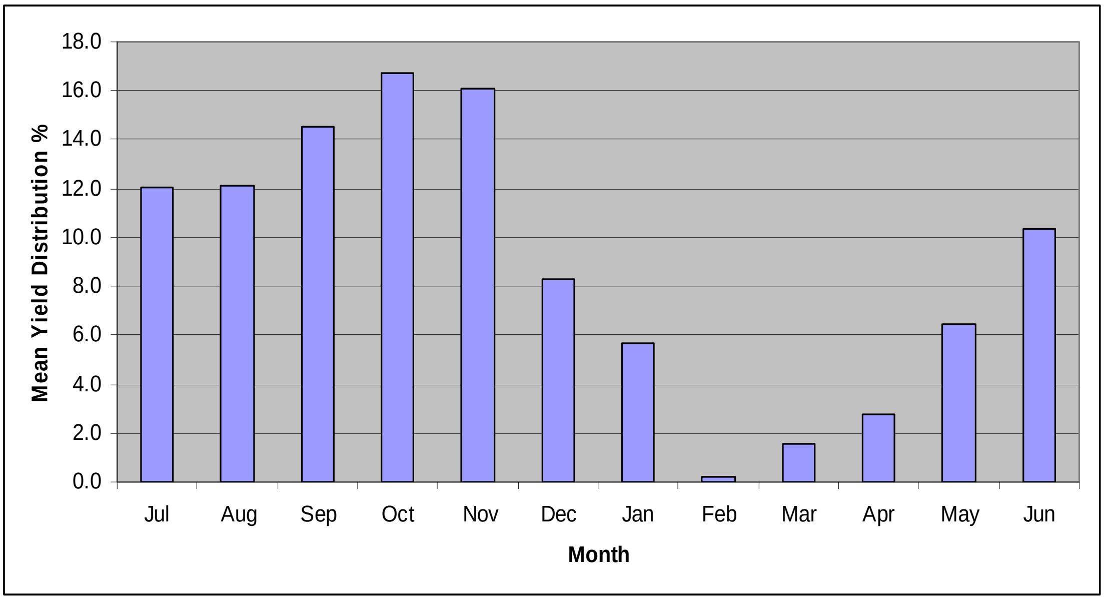


Figure 4A.14. Mean yield distribution % for cocoa produced in South Johnstone.

Individual tagged trees

The accumulated pod yield of tagged trees at South Johnstone varied from a high of 89 kg to 0 kg over the three seasons in which yields were recorded (Figure 4A.15).

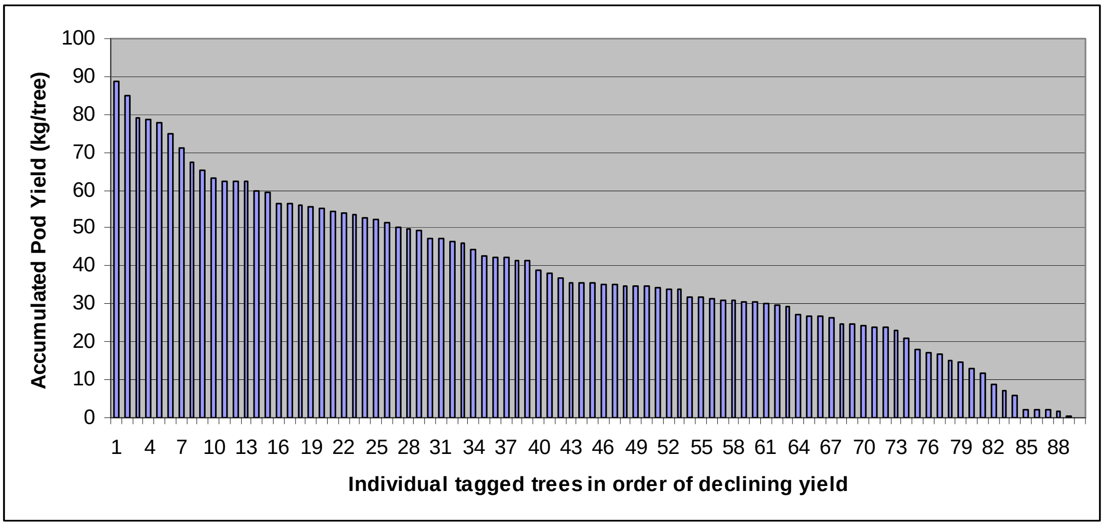


Figure 4A.15. Accumulated yield over four years for individual tagged trees in the South Johnstone HYET.

The bulk of trees (67.8%) had an accumulated pod yield between 20 and 60 kg/tree. Only 13 (14.4%) of the trees had an accumulated pod yield greater than 60kg/tree (Table 4A.7). These high performing trees consisted of the following hybrids; six (46.2%) PNG3 trees; four (30.8%) PNG2 trees; and one tree each of PNG1, PNG4 and PNG5.

The trees are no longer available, regardless of the performance of individual trees, due to the destruction of the plot following Cyclone Larry.

Table 4A.7 Frequency of accumulated pod yield (kg) per tree over three seasons for tagged trees at South Johnstone.

Accumulated Pod Yield by Category (kg/tree)	Frequency	Percentage of Total
0–20	16	17.8
>20–40	35	38.9
>40–60	26	28.9
>60–80	11	12.2
>80–100	2	2.2
TOTAL	90	100.0

4A.4 Growth and yield summary

Cocoa at the Mossman site was higher yielding then at South Johnstone for all but one season in which yields were recorded at both sites (Figure 4A.16). Maximum mean yields for all treatments was 27,000 kg of whole pods per ha at Mossman and 20,000 kg of whole pods/ha at South Johnstone. At a 10:1 ratio of whole pods to dry bean equivalent, the usual method of describing cocoa yields, this equates to a maximum mean dry bean yield of 2.7 t/ha and 2.0 t/ha for Mossman and South Johnstone respectively. In the last season where data was recorded for both sites the mean yield was approximately 15,000 kg/ha of whole pods or 1.5 t/ha of dry bean equivalent. Queensland trial results compare favourably with performance data for the same hybrids in PNG. Efron et al. (2003) report that the average dry bean yields of three- to four-year old hybrid trees ranged from 1.0 t/ha for PNG1 to 1.6 t/ha for PNG2.

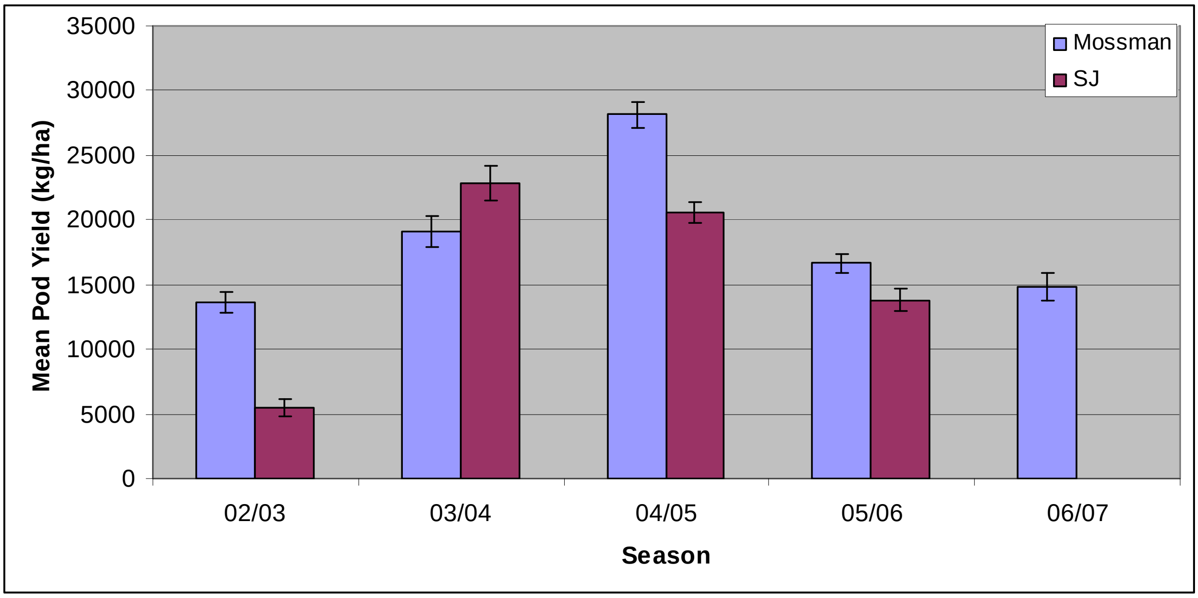


Figure 4A.16. Annual mean pod yields at Mossman and South Johnstone.

The use of hybrid seed was to prove the concept that cocoa could be grown successfully in far northern Queensland. Hybrid seedlings are known to bear early and can be easily established in large numbers. Higher and more stable yields can potentially be produced by using clonal material; however, this involves a long testing process to identify clones which will perform well in climatic conditions in far northern Queensland.

4A.5 Queensland nutrition management

4A.5.1 Introduction

All living plants require a range of essential nutrients to allow them to function, grow and in the case of agricultural crops produce an economic yield, whether it is leaf, root, stem, grain, or fruit. The criteria for essentiality were set in the 1930s (Salisbury and Ross 1969) as:

i. The element must be essential for normal growth and reproduction, neither of which can occur in its absence.

ii. The requirement for the element must be specific and cannot be replaced by some other element.

iii. The element must act inside the plant and not simply cause some other element to be more readily available or antagonise a toxic effect of another element.

The essential nutrients are classified as either, macronutrients (those required in greatest concentrations and usually expressed as a percentage of plant dry matter) or micronutrients (those required in the least concentrations and commonly expressed in mg/kg of plant dry matter).

In modern horticulture, plant nutrition management is the result of interaction among growers, research and extension horticulturists, plant and soil analysis laboratories, fertiliser manufacturers and suppliers. The aim of all these industry participants, although being profession specific, is to optimise the productivity of the crop in question. Plant analysis was developed to provide information on the nutrient status of plants to be used as a guide to nutrient management. Plant analysis data are used in various ways. The three most common are:

- diagnose nutrient problems (deficiencies or toxicities)
- predict nutrient problems likely to occur between sampling and harvest
- monitor crop nutrition status with a view to optimising production.

To act on any of the above the crop manager, researcher or extension officer requires information on plant analysis criteria pertinent to the crop in question. In tree fruit crops, this base level of information is generally gathered through a process of surveying commercial orchards, rather than by a research process as occurs in annual vegetable and grain crops where nutrients are added at varying levels and the differences in yield measured. This is, in a large part, due to the high cost of running traditional nutrition trials in tree crops and the fact that climate and other management variables can play a greater role in flowering and subsequent yield than nutrition management alone. The nutrient survey approach is based on the following:

- determination of the ideal sampling time (when nutrient concentrations are most stable)
- sampling a wide range of commercial orchards and documentation of yields
- identification of leaf standards based on orchard yields and tree health.

Cocoa grown under shade in the traditional method, with little or no inputs, produces a yield of 200 to 500 kg/ha of dry bean. Hybrid cocoa trees grown under full sun (zero shade condition) and high inputs (irrigation and fertiliser) will produce yields of 2000 to 3000 kg/ha of dry bean. Research has shown that cocoa trees grown under full sun require higher inputs of water and nutrients then trees grown under shaded conditions (Wessel 1985).

Snoeck (1984) reports that the first publication on cocoa leaf analysis occurred in 1935 (Hardy et al. (1935). The paper reported that there was a strong correlation between leaf composition and yield and that the highest yields were obtained with a high potassium (K) content relative to nitrogen (N) and phosphorus (P).

This project did not allow for nutrition management to be studied hence a fertiliser management regime based on previously reported work was used. The aim of fertilising is to maintain leaf and soil nutrient levels within specified optimum ranges and avoid losses of fertiliser through leaching or runoff, which can cause environmental problems.

This section documents inputs and leaf and soil nutrient data collected at the Mossman and South Johnstone trial sites over the course of the project.

4A.5.2 Materials and methods

Cocoa leaf selection for sampling

Loue (1961) determined that in cocoa the third leaf on the youngest mature flush with a partly brown peduncle (mainly near the pulvinus) is the ideal sample leaf. This leaf, or as near as possible, was selected throughout the study.

Leaf sampling

Approximately 50 leaves matching the above description were sampled throughout the block and bulked for leaf analysis. Samples were packed in a ‘Pivot’ leaf sampling bag, labelled and dispatched within 24 hours of sampling to Pivot Laboratories in Werribee, Victoria, for analysis. The samples were washed, dried, oven dried at 65^{o}C and ground to < 1 mm. Nutrient analysis for N (nitrogen), P (phosphorus), K (potassium), Ca (calcium), Mg (magnesium), Na (sodium), Cl (chlorine), S (sulphur), Mn (manganese), Fe (iron), Cu (copper), Zn (zinc), B (boron) and Al (aluminium) using inductively coupled plasma technology (ICP) spectrometry. Procedures carried out meet NATA standards.

Soil sampling

The samples was placed in a ‘Pivot’ soil analysis bag, labelled and dispatched within 24 hours to Pivot Laboratories in Werribee, Victoria, for analysis. The samples were air dried, ground to <2 mm and analysed for pH (1:5 water and 1:5 $CaCl_2$), electrical conductivity (1:5 water), Colwell extractable P, nitrate N, organic carbon, K (NH_4Ac), labile S (KCl), extractable B ($CaCl_2$), DTPA extractable Cu, Zn, Mn, Fe, exchangeable Na, Al, K, Ca and Mg. All methods were those described in Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson 1992).

Fertiliser inputs

Fertiliser inputs varied over the seven years and are documented in Table 4A.8. Elemental Nitrogen inputs commenced at 17 kg/ha in the year of planting and rose to 198 kg/ha in years 4 and 5 and settled at 125 kg/ha in years 6 and 7. Elemental K inputs commenced at 18 kg/ha in the year of planting and rose quickly to 360 kg/ha by year 4. Elemental phosphorus inputs were confined to the first three years from planting.

Table 4A.8 Fertiliser inputs from planting

Year	Fertiliser	Rate	Total Fertiliser Inputs (kg/ha/yr)	Elemental Inputs (kg/ha)						
				N	P	K	Ca	Mg	Zn	B
2000	Monsoon plant tablet	1–10g tablet at planting	12	2.4	0.5	1.0	0.5	0.0	0.1	0.0
2000	Nitrophoska	100 g/tree	120	14.4	6.2	16.9	6.0	1.4	0.0	0.0
2000				**16.8**	**6.7**	**17.9**	**6.5**	**1.4**	**0.1**	**0.0**
2001	**Nitrophoska**	**100g/tree 6weekly**	**1040**	**124.8**	**54.1**	**146.6**	**52.0**	**12.5**	**0.1**	**0.2**
2002	Nitrophoska	100g/tree 6weekly	520	62.4	27.0	73.3	26.0	6.2	0.1	0.1
2002	CAN 655	100g/tree 4 weekly	780	105.3	0.0	195.0	31.2	0.0	0.0	0.0
2002				**167.7**	**27.0**	**268.3**	**57.2**	**6.2**	**0.1**	**0.1**
2003	KNO_3	Added fortnightly	947	125.0	0.0	359.9	0.0	0.0	0.0	0.0
2003	Urea	Added fortnightly	158	72.7	0.0	0.0	0.0	0.0	0.0	0.0
2003				**197.7**	**0.0**	**359.9**	**0.0**	**0.0**	**0.0**	**0.0**
2004	KNO_3	Added fortnightly	947	125.0	0.0	359.9	0.0	0.0	0.0	0.0
2004	Urea	Added fortnightly	158	72.7	0.0	0.0	0.0	0.0	0.0	0.0
2004				**197.7**	**0.0**	**359.9**	**0.0**	**0.0**	**0.0**	**0.0**
2005	**KNO_3**	Added fortnightly	**947**	**125.0**	**0.0**	**359.9**	**0.0**	**0.0**	**0.0**	**0.0**
2006	**KNO_3**	Added fortnightly	**947**	**125.0**	**0.0**	**359.9**	**0.0**	**0.0**	**0.0**	**0.0**
2007	**KNO_3**	Added fortnightly	**947**	**125.0**	**0.0**	**359.9**	**0.0**	**0.0**	**0.0**	**0.0**

Pod analysis and nutrient budgeting

Twenty whole pods were sampled for pod nutrient content; ten pods from each of the two growing locations (Mossman and South Johnstone). Within each location, pods were sampled by hybrid (PNG1 to 5).

At the laboratory, pods were split and the wet bean separated. The wet bean and husk were individually weighed. Pod husk and wet bean were then dried at 60^{o}C for approximately 7 days until there was no further reduction in weight indicating that the samples were oven dry. Oven dry samples were re-weighed prior to grinding. Ground samples were forwarded to Pivot Incitec for nutrient sampling.

4A.5.3 Results

Leaf and soil nutritional status

The leaf and soil data is presented in Tables (4A.9 to 4A.14) for individual sampling occasions. The tables also present the calculated mean and median values over the sampling period with associated standard deviation and standard error.

Mossman

Leaf macronutrient concentrations (N, K, Ca, Mg) were stable or slightly increased over the seven-year sampling period with fluctuations above and below the trend line. Leaf P concentrations, however, declined steadily with time from 0.24 mg/kg to 0.16 mg/kg (Table 4A.9). Corresponding soil macronutrient concentrations decreased for NO_3 and Collwell P and increased for K, Ca and Mg (Tables 4A.10 and 4A.11).

Leaf micronutrients concentrations for Cu and Zn remained stable over the seven-year sampling period with fluctuations above and below the trend line. Whereas concentration trends for Mn, Fe, and B declined slightly over the seven-year sampling period. Soil micronutrient concentration trends were in decline for Mn, Fe, Cu, Zn and B (Table 4A.10).

Soil nutrient concentrations trends for most nutrients (NO_3, P, Mn, Fe, Cu, Zn and B) decreased over the seven-year sampling period. For the cations K, Ca and Mg there was an increasing trend in soil concentrations. Changes were small and well within the seasonal fluctuations recorded during the sampling period (Table 4.10 and 4.11).

South Johnstone

Leaf macronutrient concentrations (N, K, Ca, Mg) were relatively stable or increased slightly over the six-year sampling period with fluctuations above and below the trend line. Leaf P concentration trend declined with time (Table 4A.12). Corresponding soil macronutrient concentrations decreased for NO_3 but increased for Collwell P and increased for K, Ca and Mg (Tables 4A.13 and 4A.14).

Leaf micronutrients concentrations for Mn, Fe, Cu, Zn and B remained stable or increased slightly over the six-year sampling period with fluctuations above and below the trend line (Table 4A.12).

Mean soil micronutrient concentration trends remained relatively stable over the same time period with fluctuation above and below the trend line. Soil nutrient concentration trends were positive for P, K, Ca, Mg, and Zn, negative for NO_3, Mn, Fe and B and steady for Cu over a six-year monitoring period. Changes were small and well within the seasonal fluctuations recorded during the sampling period (Tables 4A.13 and 4A.14).

Pod nutrient content and nutrient removal

Pod nutrient concentration analysis indicates that the median macronutrient nutrient concentrations of whole pods is N – 1.68%, P – 0.25%, K – 1.11%, Ca – 0.26%, Mg – 0.32%, S- 0.16%. Median micronutrient concentrations are Zn – 46 mg/kg, Fe – 38 mg/kg, Cu – 21 mg/kg, Mn – 68 mg/kg, B – 23 mg/kg. The analysis of bean and husk as separate entities shows that nitrogen concentration in beans (2.31%) is over twice that found in husk (1.08%). Similarly the concentration of phosphorous in bean (0.48%) is four times that found in husk (0.12%). Whereas, the converse occurs for potassium where the concentration in husk (1.60%) is over double that found in bean (0.69%). There are similar concentration differences between bean and husk for the remaining macro- and micronutrients (Table 4A.15).

Mean and median whole pod nutrient concentrations also vary with growing location although not statistically for the macronutrients. There were statistical differences in micronutrient concentrations between pods from the two growing locations (Table 4A.15).

Nutrient loss via pod removal was calculated using the mean nutrient content on a dry weight basis and the fresh weight to dry weight basis calculated for whole pods. Nutrient loss based on a 30,000 kg of fresh whole pod per hectare per annum (≈ 3 t of dried bean/ha) is N = 134.2 kg, P = 24.5 kg, K = 95.7 kg, Mg = 25.7 kg, Ca = 24.4 kg, Cu = 0.16 kg, Fe = 0.35 kg, Mn = 0.74 kg, B = 0.18 kg, Zn 0.38 kg (Table 4A.16).

Table 4A.9 Cocoa leaf samples for Mossman trial site from 22 January 2001 to 14 April 2007 with mean, median, SD and SE calculations.

Sample Date	Total N (%)	NO_3 (mg/kg)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
22-Jan-01	1.60		0.24	2.10	0.21	0.57	0.53	0.00	0.00	340.00	55.00	7.20	50.00	39.00
14-May-01	1.90		0.23	2.20	0.25	0.59	0.43	0.04	0.05	1050.00	55.00	9.30	30.00	42.00
15-Aug-01	2.30	155	0.31	2.50	0.26	0.64	0.47	0.02	0.04	694.00	116.00	11.00	37.00	36.00
19-Nov-01	2.00		0.25	2.10	0.24	0.81	0.52	0.01	0.04	858.00	68.00	9.40	30.00	39.00
26-Feb-02	2.20	88	0.25	1.90	0.20	0.76	0.51	0.01	0.06	584.00	39.00	8.30	31.00	39.00
20-May-02	2.00	125	0.27	2.10	0.25	1.30	0.56	0.04	0.05	714.00	50.00	9.40	27.00	46.00
13-Aug-02	2.20	96	0.24	1.90	0.24	1.50	0.57	0.03	0.06	902.00	176.00	8.90	26.00	45.00
08-Nov-02	1.50		0.19	1.80	0.23	1.50	0.58	0.03	0.05	1000.00	110.00	5.90	30.00	39.00
16-Feb-03	2.70	180	0.23	1.90	0.25	1.40	0.56	0.01	0.07	678.00	51.00	8.90	29.00	39.00
21-May-03	2.30	135	0.24	2.30	0.24	1.00	0.54	0.02	0.05	768.00	41.00	8.70	30.00	34.00
08-Sep-03	1.80	40	0.20	1.90	0.23	1.70	0.67	0.05	0.06	1500.00	84.00	9.00	25.00	33.00
15-Dec-03	1.90	75	0.17	2.00	0.19	0.94	0.43	0.02	0.05	560.00	59.00	11.00	30.00	30.00
15-Apr-04	2.00	51	0.20	1.90	0.27	1.60	0.47	0.04	0.05	1100.00	44.00	9.10	70.00	39.00
09-Aug-04	2.20	160	0.19	2.30	0.24	1.20	0.50	0.04	0.07	750.00	63.00	15.00	28.00	33.00
06-Nov-04	1.90	53	0.15	2.00	0.25	1.80	0.42	0.03	0.02	1100.00	120.00	6.20	76.00	36.00
03-Feb-05	1.90	250	0.22	2.90	0.24	0.81	0.49	0.02	0.07	400.00	38.00	9.90	26.00	34.00

Sample Date	Total N (%)	NO_3 (mg/kg)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
23-May-05	1.80	95	0.17	2.20	0.21	1.40	0.68	0.04	0.08	610.00	51.00	8.90	29.00	36.00
08-Sep-05	2.00	75	0.15	2.00	0.21	1.30	0.66	0.06	0.12	800.00	61.00	7.70	22.00	33.00
14-Feb-06	2.40	250	0.23	2.30	0.23	0.58	0.43	0.01	0.05	370.00	48.00	12.00	34.00	33.00
06-Jun-06	2.30	160	0.19	2.10	0.21	1.10	0.49	0.03	0.10	550.00	55.00	8.60	29.00	41.00
03-Sep-06	2.00	280	0.20	2.40	0.22	1.10	0.54	0.03	0.08	740.00	80.00	9.70	33.00	30.00
14-Dec-06	1.80	160	0.19	2.90	0.18	0.66	0.45	0.02	0.05	280.00	41.00	10.00	27.00	33.00
14-Apr-07	1.70	45	0.16	1.90	0.24	1.30	0.69	0.02	0.07	540.00	36.00	7.70	25.00	44.00
Count	23.00	19.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00	23.00
Mean	**2.02**	**130.16**	**0.21**	**2.16**	**0.23**	**1.11**	**0.53**	**0.03**	**0.06**	**734.26**	**67.00**	**9.21**	**33.65**	**37.09**
Median	**2.00**	**125.00**	**0.20**	**2.10**	**0.24**	**1.10**	**0.52**	**0.03**	**0.05**	**714.00**	**55.00**	**9.00**	**30.00**	**36.00**
SD	**0.28**	**72.60**	**0.04**	**0.30**	**0.02**	**0.39**	**0.08**	**0.01**	**0.02**	**288.01**	**34.10**	**1.90**	**13.58**	**4.56**
SE	**0.06**	**16.65**	**0.01**	**0.06**	**0.00**	**0.08**	**0.02**	**0.00**	**0.01**	**60.05**	**7.11**	**0.40**	**2.83**	**0.95**

Table 4A.10 Soil chemical, electrical conductivity, organic carbon and pH for Mossman trial site from January 2001 to April 2007 with mean, median, SD and SE calculations.

Sample Date	NO_3 (mg/kg)	Colwell (P) (mg/kg)	K (mg/kg)	S (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	B (mg/kg)	Cl (mg/kg)	EC (ds/m)	EC sat (ds/m)	OC (%)	pH H20	pH $CaCl_2$
22-Jan-01	5.60	54.00	65.00	3.70	0.67	1.08		8.51	0.18	24.00	0.03	0.30	1.10	5.50	4.50
14-May-01	8.00	120.00	88.00	16.00	1.13	1.14	180.00	11.00	0.32	7.80	0.05	0.50	1.30	5.00	4.20
15-Aug-01	43.00	110.00	120.00	40.00	0.74	0.72	150.00	12.00	0.27	30.00	0.15	1.50	0.87	4.80	4.20
19-Nov-01	12.00	41.00	55.00	16.00							0.07	0.70	1.00	5.40	4.70
26-Feb-02	4.90	65.00	57.00	17.00	0.64	0.98	125.00	7.28	0.22	9.00	0.05	0.50	0.93	5.60	4.80
20-May-02	16.00	59.00	73.00	52.00	0.47	0.89	155.00	8.21	0.20	21.00	0.11	1.10	0.91	5.10	4.60
13-Aug-02	4.40	55.00	55.00	27.00	0.43	0.70	110.00	5.97	0.17	34.00	0.08	0.80	1.00	5.70	5.20
08-Nov-02	36.00	63.00	155.00	31.00	0.61	0.72	77.00	8.55	0.27	105.00	0.17	1.70	1.10	5.40	5.00
16-Feb-03	16.00	110.00	160.00	33.00	0.52	0.86	130.00	9.41	0.29	44.00	0.12	1.20	1.10	5.10	4.50
24-May-03	20.00	260.00	200.00	14.00	0.61	1.19	140.00	7.50	0.37	51.00	0.11	1.54	1.20	4.90	4.30
08-Sep-03	5.40	44.00	71.00	4.00	0.61	0.96	120.00	7.10	0.16	21.00	0.04	0.04	1.10	5.80	4.90
15-Dec-03	3.60	35.00	86.00	4.30	0.55	0.76	120.00	5.60	0.17	47.00	0.06	0.60	1.20	5.70	4.90
15-Apr-04	6.10	36.00	120.00	1.80	0.44	0.80	80.00	5.40	0.11	19.00	0.03	0.30	1.10	5.90	4.70
09-Aug-04	1.80	19.00	102.00	1.90	0.29	0.82	160.00	4.40	0.10	10.00	0.02	0.20	0.87	6.00	4.80
06-Nov-04	4.50	32.00	123.00	1.80	0.38	0.74	97.00	5.40	0.11	22.00	0.04	0.40	0.96	5.70	4.70
03-Feb-05	5.80	22.00	154.00	1.10	0.32	0.67	95.00	6.50	0.11	10.00	0.03	0.30	0.97	6.60	5.40
23-May-05	9.00	24.00	207.00	2.50	0.59	0.64	45.00	6.80	0.20	16.00	0.07	0.70	1.50	6.70	6.00
08-Sep-05	9.00	21.00	208.00	1.60	0.42	0.85	63.00	8.50	0.16	20.00	0.05	0.50	1.40	6.50	5.50
14-Feb-06	12.00	180.00	269.00	4.40	0.46	0.94	100.00	4.40	0.17	17.00	0.07	0.70	1.40	6.20	5.30
06-Jun-06	2.70	27.00	208.00	1.80	0.22	0.66	45.00	6.40	0.09	10.00	0.03	0.30	1.10	6.30	5.20
30-Aug-06	4.00	18.00	228.00	7.90	0.33	0.74	45.00	7.10	0.15	13.00	0.06	0.60	1.20	6.40	5.50
14-Apr-07	4.60	28.00	183.00	3.60	0.33	0.85	77.00	6.10	0.18	10.00	0.04	0.40	1.20	6.20	5.20
Count	22.00	22.00	22.00	22.00	21.00	21.00	20.00	21.00	21.00	21.00	22.00	22.00	22.00	22.00	22.00
Mean	**10.65**	**64.68**	**135.77**	**13.02**	**0.51**	**0.84**	**105.70**	**7.24**	**0.19**	**25.75**	**0.07**	**0.68**	**1.11**	**5.75**	**4.91**
Median	**5.95**	**42.50**	**121.50**	**4.35**	**0.47**	**0.82**	**105.00**	**7.10**	**0.17**	**20.00**	**0.06**	**0.55**	**1.10**	**5.70**	**4.85**
SD	**10.53**	**59.78**	**64.87**	**14.67**	**0.20**	**0.16**	**40.29**	**1.97**	**0.08**	**22.20**	**0.04**	**0.46**	**0.17**	**0.57**	**0.46**
SE	**2.25**	**12.74**	**13.83**	**3.13**	**0.04**	**0.03**	**9.01**	**0.43**	**0.02**	**4.84**	**0.01**	**0.10**	**0.04**	**0.12**	**0.10**

Table 4A.11 Soil total CEC and cation exchange concentrations and cation ratios for Mossman trial site from January 2001 to April 2007 with mean, median, SD and SE calculations.

Sample Date	CEC (meq/100g)	Al (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	K (meq/100g)	Ca:Mg	K:Mg
22-Jan-01	2.41	0.66	1.10	0.43	0.05	0.17	2.54	0.38
14-May-01	2.39	1.10	0.80	0.23	0.04	0.23	3.56	1.00
15-Aug-01	2.22	1.22	0.45	0.15	0.09	0.31	3.00	2.05
19-Nov-01	2.55	0.64	1.40	0.23	0.14	0.14	6.22	0.63
26-Feb-02	2.95	0.48	2.00	0.27	0.06	0.05	7.52	0.55
20-May-02	2.51	0.68	1.35	0.20	0.09	0.19	6.75	0.94
13-Aug-02	3.50	0.32	2.65	0.25	0.13	0.14	10.60	0.56
08-Nov-02	4.21	0.30	3.10	0.26	0.15	0.40	12.02	1.54
16-Feb-03	2.98	0.86	1.60	0.07	0.05	0.41	24.24	6.21
24-May-03	2.97	1.33	1.00	0.08	0.04	0.51	12.05	6.17
08-Sep-03	2.59	0.18	1.95	0.15	0.13	0.18	13.09	1.22
15-Dec-03	2.95	0.33	2.23	0.04	0.14	0.22	63.71	6.31
15-Apr-04	2.65	0.53	1.55	0.26	0.06	0.25	6.01	0.96
09-Aug-04	2.53	0.40	1.40	0.37	0.10	0.26	3.83	0.71
06-Nov-04	2.64	0.49	1.45	0.28	0.11	0.32	5.12	1.11
03-Feb-05	3.35	0.13	2.05	0.62	0.16	0.39	3.33	0.64
23-May-05	6.95		4.90	1.42	0.11	0.53	3.46	0.37
08-Sep-05	4.97		3.35	0.92	0.17	0.53	3.66	0.58
14-Feb-06	4.90	0.13	2.55	1.33	0.20	0.69	1.91	0.52
06-Jun-06	3.81	0.17	2.20	0.83	0.07	0.53	2.64	0.64
30-Aug-06	4.52		2.80	1.00	0.13	0.58	2.80	0.58
14-Apr-07	3.64	0.12	2.05	0.92	0.08	0.47	2.24	0.51
Count	22.00	19.00	22.00	22.00	22.00	22.00	22.00	22.00
Mean	**3.37**	**0.53**	**2.00**	**0.47**	**0.10**	**0.34**	**9.10**	**1.55**
Median	**2.96**	**0.48**	**1.98**	**0.27**	**0.11**	**0.32**	**4.48**	**0.68**
SD	**1.15**	**0.37**	**0.98**	**0.41**	**0.05**	**0.17**	**13.28**	**1.94**
SE	**0.24**	**0.09**	**0.21**	**0.09**	**0.01**	**0.04**	**2.83**	**0.41**

Table 4A.12 Cocoa leaf nutrient samples for the South Johnstone trial site from 22 January 2001 to 14 Dec 2006 with mean, median, SD and SE calculations.

Sample Date	N (%)	NO_3 (mg/kg)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
22-Jan-01	2.60		0.23	2.40	0.24	0.90	0.42	0.04	0.06	510.00	80.00	5.70	55.00	30.00
14-May-01	2.40	520.00	0.34	2.90	0.25	0.62	0.43	0.01	0.03	470.00	70.00	11.00	50.00	29.00
21-Aug-01	2.60	630.00	0.41	2.90	0.29	0.55	0.42	0.02	0.06	590.00	76.00	18.00	68.00	31.00
19-Nov-01	2.50		0.30	2.50	0.28	0.79	0.45	0.02	0.06	460.00	99.00	11.00	57.00	35.00
26-Feb-02	2.00	88	0.24	2.20	0.21	0.72	0.38	0.01	0.03	356.00	43.00	8.40	50.00	34.00
20-May-02	2.00	140.00	0.25	2.00	0.23	1.50	0.38	0.04	0.06	634.00	91.00	9.80	49.00	38.00
13-Aug-02	2.10	125.00	0.21	1.90	0.24	1.70	0.34	0.05	0.09	966.00	80.00	7.50	64.00	36.00
08-Nov-02	2.10		0.23	2.30	0.27	1.30	0.46	0.02	0.04	762.00	228.00	9.50	71.00	37.00
16-Feb-03	2.40	200.00	0.21	1.50	0.23	1.60	0.56	0.02	0.07	916.00	77.00	9.40	59.00	40.00
25-May-03	2.40	120.00	0.23	2.00	0.23	1.40	0.40	0.02	0.06	810.00	56.00	8.40	51.00	34.00
08-Sep-03	1.90	89.00	0.17	1.90	0.30	2.00	0.45	0.06	0.09	2200.00	190.00	10.00	92.00	34.00
15-Dec-03	2.10	110.00	0.21	1.90	0.22	0.87	0.35	0.01	0.03	410.00	71.00	11.00	68.00	30.00
15-Apr-04	2.30	100.00	0.24	2.50	0.24	0.89	0.50	0.02	0.04	680.00	43.00	10.00	37.00	38.00
09-Aug-04	2.10	100.00	0.16	1.90	0.28	2.10	0.45	0.05	0.11	1500.00	96.00	16.00	98.00	37.00
06-Nov-04	1.90	53.00	0.15	2.00	0.25	1.80	0.42	0.03	0.02	1100.00	120.00	6.20	76.00	36.00
11-Feb-05	2.00	250	0.22	2.60	0.25	1.10	0.50	0.02	0.43	560.00	40.00	8.50	58.00	35.00
23-May-05	1.80	76.00	0.22	2.20	0.26	1.10	0.48	0.04	0.09	940.00	74.00	37.00	86.00	37.00
08-Sep-05	1.90	94.00	0.14	1.60	0.26	2.40	0.65	0.07	0.16	1500.00	140.00	22.00	99.00	40.00
14-Feb-06	2.10	120.00	0.23	2.40	0.25	0.68	0.45	0.01	0.05	360.00	46.00	11.00	65.00	33.00
14-Dec-06	2.50	560.00	0.18	2.50	0.22	1.20	0.50	0.05	0.12	810.00	150.00	11.00	70.00	34.00
Count	20	17	20	20	20	20	20	20	20	20	20	20	20	20
Mean	**2.19**	**198.53**	**0.23**	**2.21**	**0.25**	**1.26**	**0.45**	**0.03**	**0.09**	**826.70**	**93.50**	**12.07**	**66.15**	**34.90**
Median	**2.10**	**120.00**	**0.23**	**2.20**	**0.25**	**1.15**	**0.45**	**0.02**	**0.06**	**721.00**	**78.50**	**10.00**	**64.50**	**35.00**
SD	**0.25**	**184.15**	**0.06**	**0.39**	**0.02**	**0.54**	**0.07**	**0.02**	**0.09**	**463.00**	**50.00**	**7.03**	**17.05**	**3.18**
SE	**0.06**	**44.66**	**0.01**	**0.09**	**0.01**	**0.12**	**0.02**	**0.00**	**0.02**	**103.53**	**11.18**	**1.57**	**3.81**	**0.71**

Table 4A.13 Soil chemical, electrical conductivity, organic carbon and pH for the South Johnstone trial site from January 2001 to February 2006 with mean, median, SD and SE calculations.

Sample Date	NO_3 (mg/kg)	P (mg/kg)	K (mg/kg)	S (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	B (mg/kg)	Cl (mg/kg)	EC (ds/m)	EC sat (ds/m)	OC (%)	pH water	pH $CaCl_2$
22-Jan-01	8.60	40.00	150.00	4.70	1.51	1.29		45.00	0.39	11.00	0.05	0.50	1.00	6.10	5.20
14-May-01	15.00	115.00	290.00	66.00	1.93	1.23	63.00	49.00	0.66	11.00	0.13	1.30	1.30	5.20	4.60
14-Aug-01	38.00	76.00	250.00	30.00	1.49	1.23	47.00	42.00	0.48	15.00	0.13	1.30	1.10	5.60	5.00
19-Nov-01	12.00	67.00	230.00	18.00							0.08	0.48	1.30	6.40	5.70
26-Feb-02	5.60	79.00	200.00	20.00	1.94	1.99	60.00	40.00	0.40	15.00	0.07	0.70	1.10	6.30	5.60
20-May-02	4.70	73.00	190.00	8.40	1.34	1.19	37.00	37.00	0.47	12.00	0.07	0.70	1.20	6.70	6.10
13-Aug-02	66.00	170.00	390.00	80.00	1.50	1.23	68.00	55.00	0.70	25.00	0.23	2.30	1.20	5.50	4.90
08-Nov-02	54.00	83.00	300.00	38.00	1.62	1.35	45.00	44.00	0.46	82.00	0.19	0.14	1.20	5.80	5.40
16-Feb-03	56.00	200.00	540.00	75.00	2.01	1.18	84.00	74.00	0.93	105.00	0.26	2.60	1.10	4.60	4.20
25-May-03	26.00	240.00	480.00	67.00	1.84	1.50	73.00	58.00	0.85	39.00	0.17	1.70	1.20	4.80	4.30
08-Sep-03	7.30	55.00	215.00	7.80	1.60	1.30	41.00	38.00	0.38	18.00	0.08	0.80	1.10	6.90	6.30
15-Dec-03	8.20	63.00	217.00	11.00	1.70	1.70	52.00	42.00	0.39	27.00	0.06	0.60	1.30	6.20	5.60
15-Apr-04	6.40	72.00	280.00	4.30	1.80	1.30	38.00	25.00	0.31	12.00	0.06	0.60	1.20	7.10	6.40
09-Aug-04	4.70	57.00	230.00	3.30	1.30	1.10	31.00	28.00	0.25	11.00	0.05	0.50	1.10	6.80	5.90
06-Nov-04	7.10	49.00	229.00	4.50	1.40	1.20	36.00	40.00	0.25	17.00	0.06	0.60	1.10	6.80	6.10
03-Feb-05	14.00	50.00	245.00	7.70	1.10	1.00	27.00	36.00	0.22	10.00	0.07	0.70	1.00	7.10	6.30
23-May-05	5.40	62.00	273.00	5.40	2.40	1.40	41.00	39.00	0.31	13.00	0.05	0.50	1.20	7.00	6.10
08-Sep-05	8.70	120.00	333.00	31.00	1.80	1.60	66.00	55.00	0.45	10	0.09	0.90	1.40	5.50	4.80
14-Feb-06	8.30	300.00	356.00	26.00	2.40	1.40	80.00	37.00	0.55	10.00	0.09	0.90	1.40	5.60	4.80
Count	19	19	19	19	18	18	17	18	18	18	19	19	19	19	19
Mean	**18.74**	**103.74**	**284.11**	**26.74**	**1.70**	**1.34**	**52.29**	**43.56**	**0.47**	**24.61**	**0.10**	**0.94**	**1.18**	**6.11**	**5.44**
Median	**8.60**	**73.00**	**250.00**	**18.00**	**1.66**	**1.30**	**47.00**	**41.00**	**0.43**	**14.00**	**0.08**	**0.70**	**1.20**	**6.20**	**5.60**
SD	**19.66**	**72.32**	**99.40**	**26.25**	**0.35**	**0.23**	**17.58**	**11.48**	**0.20**	**26.46**	**0.06**	**0.64**	**0.12**	**0.78**	**0.70**
SE	**4.51**	**16.59**	**22.80**	**6.02**	**0.08**	**0.06**	**4.26**	**2.71**	**0.05**	**6.24**	**0.01**	**0.15**	**0.03**	**0.18**	**0.16**

Table 4A.14 Soil total CEC and cation exchange concentrations and cation ratios for the South Johnstone trial site from January 2001 to February 2006 with mean, median, SD and SE calculations.

Sample Date	CEC (meq/100g)	Al (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	K (meq/100g)	Ca:Mg	K:Mg
22-Jan-01	5.95	0.06	4.20	1.25	0.06	0.38	3.36	0.31
14-May-01	5.46	0.33	3.50	0.83	0.05	0.74	4.20	0.89
14-Aug-01	5.89	0.19	3.90	1.08	0.08	0.64	3.60	0.59
19-Nov-01	7.60	0.13	5.60	1.21	0.07	0.59	4.64	0.49
26-Feb-02	7.38	0.17	5.50	1.13	0.07	0.51	4.89	0.46
20-May-02	8.02	0.09	6.30	1.08	0.06	0.49	5.82	0.45
13-Aug-02	7.06	0.37	4.95	0.69	0.06	1.00	7.16	1.45
08-Nov-02	7.17	0.11	5.30	0.92	0.08	0.77	5.79	0.84
16-Feb-03	5.66	1.39	2.55	0.26	0.08	1.38	9.88	5.36
25-May-03	5.32	1.39	2.15	0.52	0.03	1.23	4.17	2.13
08-Sep-03	8.10		6.30	1.18	0.07	0.55	5.33	0.47
15-Dec-03	6.81		5.10	1.07	0.09	0.56	4.78	0.52
15-Apr-04	9.75	0.08	7.50	1.50	0.05	0.62	5.00	0.41
09-Aug-04	7.75		5.50	1.58	0.08	0.59	3.47	0.37
06-Nov-04	8.53		6.50	1.33	0.11	0.59	4.88	0.44
03-Feb-05	7.97		6.00	1.25	0.10	0.63	4.80	0.50
23-May-05	8.83		6.00	2.00	0.13	0.70	3.00	0.35
08-Sep-05	5.85	0.43	3.30	1.17	0.10	0.85	2.83	0.73
14-Feb-06	7.12	0.32	4.25	1.50	0.13	0.91	2.83	0.61
Count	19	13	19	19	19	19	19	19
Mean	**7.17**	**0.39**	**4.97**	**1.13**	**0.08**	**0.72**	**4.76**	**0.91**
Median	**7.17**	**0.19**	**5.30**	**1.17**	**0.08**	**0.63**	**4.78**	**0.50**
SD	**1.24**	**0.46**	**1.42**	**0.39**	**0.03**	**0.26**	**1.68**	**1.16**
SE	**0.28**	**0.13**	**0.33**	**0.09**	**0.01**	**0.06**	**0.39**	**0.27**

Table 4A.15 Whole pod, bean and husk nutrient concentrations on a dry weight basis.

Location	Pod Component	Stats.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	B (mg/kg)	Na (%)	Al (mg/kg)
All[1]	Whole	Mean	1.67	0.30	1.19	0.30	0.32	0.16	47.45	43.24	20.34	92.49	22.16	0.003	13.85
		Median	**1.68**	**0.25**	**1.11**	**0.26**	**0.32**	**0.16**	**45.95**	**37.60**	**21.20**	**68.05**	**22.50**	**0.003**	**10.90**
		SE	0.15	0.05	0.11	0.05	0.02	0.01	3.11	5.04	2.14	12.24	1.37	0.000	1.48
All[2]	Bean	Mean	2.28	0.49	0.73	0.11	0.34	0.15	44.17	54.62	28.03	46.89	17.17	0.002	12.59
		Median	**2.31**	**0.48**	**0.69**	**0.11**	**0.34**	**0.15**	**43.35**	**43.50**	**28.95**	**45.10**	**16.65**	**0.002**	**9.75**
		SE	0.04	0.02	0.03	0.01	0.01	0.00	2.53	7.99	1.84	2.71	0.91	0.000	1.44
All[3]	Husk	Mean	1.06	0.11	1.65	0.49	0.30	0.18	50.72	31.86	12.64	138.09	27.15	0.004	15.10
		Median	**1.08**	**0.12**	**1.60**	**0.52**	**0.29**	**0.19**	**61.20**	**27.60**	**12.60**	**141.50**	**26.85**	**0.004**	**11.55**
		SE	0.08	0.01	0.08	0.03	0.03	0.01	5.66	3.83	1.69	12.79	1.26	0.000	2.62
Mossman[4]	Whole	Mean	1.62	0.27	1.11	0.31	0.34	0.15	38.24	39.74	16.45	89.25	21.08	0.003	10.45
		Median	**1.81**	**0.25**	**1.06**	**0.23**	**0.33**	**0.14**	**35.75**	**29.80**	**15.85**	**67.90**	**20.05**	**0.003**	**9.00**
		SE	0.22	0.06	0.13	0.07	0.02	0.01	3.59	8.25	2.70	18.11	1.80	0.000	1.02
SJ[5]	Whole	Mean	1.72	0.34	1.27	0.29	0.30	0.18	56.65	46.74	24.22	95.73	23.24	0.003	17.24
		Median	**1.68**	**0.30**	**1.24**	**0.27**	**0.30**	**0.17**	**58.80**	**41.75**	**25.95**	**82.90**	**24.25**	**0.003**	**15.65**
		SE	0.20	0.07	0.19	0.06	0.02	0.01	3.01	6.04	2.95	17.39	2.11	0.000	2.38

Note: Numbers of data points used to create the statistics are 1 = 20, 2, 3, 4 & 5 = 10

Table 4A.16 Mean cocoa pod nutrient concentration and nutrient loss a.) g/tree and b.) kg/ha at 1,200 trees/ha due to pod removal.

	Macronutrients							Micronutrients					
	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	S (%)	Na (%)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	B (mg/kg)	Al (mg/kg)	Zn (mg/kg)
Mean Pod Nutrient Con. (dwt basis)	1.67	0.30	1.19	0.32	0.30	0.16	0.0031	20.34	43.24	92.49	22.16	13.85	47.45

a.) Nutrient Loss via pod removal (g/tree)

kg/tree	FW/DW	N	P	K	Mg	Ca	S	Na	Cu	Fe	Mn	B	Al	Zn
5	3.73	22.4	4.1	15.9	4.3	4.1	2.2	0.04	0.03	0.06	0.12	0.03	0.02	0.06
7	3.73	31.3	5.7	22.3	6.0	5.7	3.0	0.06	0.04	0.08	0.17	0.04	0.03	0.09
10	3.73	44.7	8.2	31.9	8.6	8.1	4.4	0.08	0.05	0.12	0.25	0.06	0.04	0.13
12	3.73	53.7	9.8	38.3	10.3	9.8	5.2	0.10	0.07	0.14	0.30	0.07	0.04	0.15
15	3.73	67.1	12.2	47.8	12.8	12.2	6.5	0.12	0.08	0.17	0.37	0.09	0.06	0.19
17	3.73	76.0	13.9	54.2	14.6	13.8	7.4	0.14	0.09	0.20	0.42	0.10	0.06	0.22
20	3.73	89.5	16.3	63.8	17.1	16.3	8.7	0.17	0.11	0.23	0.50	0.12	0.07	0.25
22	3.73	98.4	17.9	70.2	18.8	17.9	9.6	0.18	0.12	0.26	0.55	0.13	0.08	0.28
24	3.73	107.4	19.6	76.6	20.5	19.5	10.4	0.20	0.13	0.28	0.60	0.14	0.09	0.31
25	3.73	111.8	20.4	79.7	21.4	20.3	10.9	0.21	0.14	0.29	0.62	0.15	0.09	0.32
30	3.73	134.2	24.5	95.7	25.7	24.4	13.1	0.25	0.16	0.35	0.74	0.18	0.11	0.38

b.) Nutrient Loss via whole pod removal at a tree density of 1,200 trees per ha (kg/ha)

kg/tree	kg/ha	N	P	K	Mg	Ca	S	Na	Cu	Fe	Mn	B	Al	Zn
5	6000	26.8	4.9	19.1	5.1	4.9	2.6	0.05	0.03	0.07	0.15	0.04	0.02	0.08
7	8400	37.6	6.8	26.8	7.2	6.8	3.7	0.07	0.05	0.10	0.21	0.05	0.03	0.11
10	12000	53.7	9.8	38.3	10.3	9.8	5.2	0.10	0.07	0.14	0.30	0.07	0.04	0.15
12	14400	64.4	11.7	45.9	12.3	11.7	6.3	0.12	0.08	0.17	0.36	0.09	0.05	0.18
15	18000	80.5	14.7	57.4	15.4	14.6	7.8	0.15	0.10	0.21	0.45	0.11	0.07	0.23
17	20400	91.3	16.6	65.1	17.5	16.6	8.9	0.17	0.11	0.24	0.51	0.12	0.08	0.26
20	24000	107.4	19.6	76.6	20.5	19.5	10.4	0.20	0.13	0.28	0.60	0.14	0.09	0.31
22	26400	118.1	21.5	84.2	22.6	21.5	11.5	0.22	0.14	0.31	0.65	0.16	0.10	0.34
24	28800	128.8	23.5	91.9	24.7	23.4	12.5	0.24	0.16	0.33	0.71	0.17	0.11	0.37
25	30000	134.2	24.5	95.7	25.7	24.4	13.1	0.25	0.16	0.35	0.74	0.18	0.11	0.38
30	36000	161.0	29.3	114.8	30.8	29.3	15.7	0.30	0.20	0.42	0.89	0.21	0.13	0.46

4A.5.4 Discussion

Ahenkorah *et al*. (1987) reported in Ghana that no shade plus fertiliser gave superior cocoa yields than did shaded and fertilised treatments. In earlier evaluation trials in northern Queensland, Watson (1992) suggested that shade was only required for the establishment phase and bananas could be used as a shade and cash crop. In our trials cocoa was established with the use of artificial shade and living shade. The living shade density was reduced markedly by year 2 of growth; however, a light shade cover remained provided by low density plantings of silver leaf quandong. Fertiliser inputs were maintained throughout the trial period.

The interpretation of the data must take into consideration that there is no ideal leaf age for every nutrient. Essential nutrients have been characterised as mobile, immobile or variably mobile, that is they vary in their ability, once deposited in leaf or other plant parts, to be remobilised and transported to other plant parts (Smith and Longeragan 1997). Remobilisation generally occurs via the phloem (food conducting tissue) rather than the xylem (water conducting tissue). Nutrients that are considered as phloem mobile from leaves include nitrogen, phosphorus and potassium. The phloem sap concentration of these elements is high and they are recycled rapidly throughout the plant. Young leaves retain the cycling nutrients at the expense of older leaves. Non-phloem mobile nutrients include calcium, boron, manganese and iron. These elements do not move from where they were initially deposited to new growth regions where they may be deficient. Sufficiency levels in new growth can only be maintained by a continuous supply from root acquired or externally applied (foliar application) sources. Variably phloem mobile nutrients include sulphur, copper and zinc. These elements are not remobilised rapidly as they become deficient in new growth, but are able to rapidly remobilise once leaf senescence begins. Young immature leaves are generally the most sensitive for nutrients that are immobile or variably mobile while older leaves are the most sensitive for those, which are phloem mobile (Smith and Longeragan 1997).

In most cases, the decision as to what plant part to collect for nutrient analysis is based on several important considerations: the best correlation between plant appearance or performance with elemental content; ease of identification of the plant part and its collection; and the stability of the element across similar sampled material (Jones 1985). In many cases the youngest fully expanded leaf has been used successfully for many nutrients in many plant species. In a number of tree crops (lychee, mango, passionfruit) the suggested sampling regime is based on sampling the youngest mature leaf at a time when vegetative flushing activity is low. This often coincides with late autumn/early winter months when the trees or vines are vegetatively dormant and early flowering is commencing. In cocoa the third leaf of the youngest mature flush was used as the index leaf.

Soil and leaf analyses should be taken before the whole plantation is in full flower. Samples of the leaves will give an indication of what the plant has actually taken up from the soil. It is recommended that once the plantation has started to bear annual leaf, soil samples should be taken prior to the major flowering just after the wettest months (April/May) or twice per year just before the production peaks, generally around September and March.

Macronutrients

Macronutrients are those nutrients needed in greatest quantities by the plant. In the case of cocoa, nitrogen and potassium are major macronutrients required during pod development. The northern Queensland trial levels presented in Table 4A.17 are mean levels of both the South Johnstone and Mossman plots from 2001 to 2007. Nutrient sampling ceased for the South Johnstone site following Cyclone Larry in March 2006.

Mean leaf macronutrient concentrations recorded in the trial can be compared to results recorded in previous work by a range of authors (Table 4A.17). Leaf macronutrient concentrations were within the optimum/normal range when compared to data published by Incitec Pty Ltd and Murray (1967) or within or above the adequate range suggested by Bergmann (1992). Trial nitrogen concentrations were below those considered normal by Loue (1961). This suggests that the macronutrient concentrations of the trial trees were maintained at optimum levels.

Table 4A.17 Mean cocoa leaf macronutrient and associated confidence intervals (CI) (95%) for northern Queensland trial sites (2001–2007) and adequacy levels presented by various authors.

	N %	NO_3 mg/kg	P %	K %	S %	Ca %	Mg %	Na %	Cl %
NQ trial sites									
Mean	**2.08**	**160**	**0.22**	**2.20**	**0.24**	**1.15**	**0.49**	**0.03**	**0.07**
CI (95%)									
Incitec Ltd (1999)									
Deficient	<2.00	[#]na	<0.12	<1.10	n.a.	<0.50	<0.30	n.a.	n.a.
Low	2.00-2.30	n.a.	0.12-0.16	1.10-1.60	n.a.	0.50-0.80	0.30-0.40	n.a.	n.a.
Optimum/normal	2.30-3.00	n.a.	0.16-0.30	1.60-2.60	n.a.	0.80-2.00	0.40-1.00	n.a.	n.a.
High	>3.00	n.a.	>0.30	>2.6	n.a.	>2.00	>1.00	n.a.	n.a.
		n.a.							
Bergmann (1992))			n.a.						
Adequate range	1.90-2.20	n.a.	0.15-0.18	1.70-2.00	0.17-0.20	0.90-1.20	0.40-0.70	n.a.	n.a.
		n.a.							
Loue (1961)		n.a.							
Normal	2.35-2.50	n.a.	>0.18	>1.2	n.a.	n.a.	n.a.	n.a.	n.a.
Mod deficient	1.80-2.00	n.a.	0.10-0.13	1.00-1.20	n.a.	n.a.	n.a.	n.a.	n.a.
Severely deficient	<1.80	n.a.	0.08-0.10	<1.00	n.a.	n.a.	n.a.	n.a.	n.a.
		n.a.			n.a.				
Murray (1967)		n.a.			n.a.				
Normal	>2.00	n.a.	>0.2	>2.00	n.a.	>0.40	>0.45	n.a.	n.a.
Low	1.80-2.00	n.a.	0.13-0.20	1.20-2.00	n.a.	0.30-0.40	0.20-0.45	n.a.	n.a.
Deficient	<1.80	n.a.	na n.a.	<1.20	n.a.	<0.30	<0.20	n.a.	n.a.

Fertiliser practices utilised in the northern Queensland cocoa trials were sufficient to maintain leaf macronutrient levels near adequate as determined by overseas research nutrition monitoring. Nitrogen levels may have been a little lower than that considered ideal by some authors.

Micronutrients

Leaf micronutrient concentration data is less available then macronutrient data. However two authors have published data on a limited range of micronutrients. Mean leaf micronutrient concentrations recorded in the trial are compared to results recorded in previous work by these authors (Table 4A.18). The concentrations recorded in the northern Queensland trial sites did not cause any growth or yield restrictions to our knowledge.

Table 4A.18. Mean cocoa leaf micronutrient and associated confidence intervals (CI) (95%) for northern Queensland trial sites (2001–2007) and adequacy levels presented by various authors.

Source	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	B (mg/kg)
NQ Trial Sites					
Mean	**765**	**76**	**10**	**46**	**36**
CI (95%)					
min range	642	62	9	39	34
max range	888	90	12	53	37
Bergmann (1992)					
Adequate range	150–200	n.a.	10–15	70–80	30–40
Wood and Lass (1985)					
Normal range	n.a	65–175	n.a	30–65	25–75
Deficiency	n.a	50	n.a	15–20	8.5–11.0

Micronutrients are those nutrients required in least amounts by the plant to function properly however, they are still vital for the maintenance of normal plant growth and development. Deficiencies in micronutrients can occur in some situations. Sandy soils are prone to boron, copper and zinc deficiencies, while poorly drained soils are prone to iron deficiency. Alkaline soils are prone to zinc, iron and manganese deficiencies.

The most effective, long-term solution to micronutrient deficiency is to apply fertilisers to the soil. This provides a reserve of nutrients in the soil, which the tree can take up as required. Foliar applications may produce faster relief of chronic symptoms in the tree, but only small amounts of nutrient are absorbed and improvement will be temporary. As soon as the nutrients applied to the leaf are metabolised, the deficiency will reappear.

Timing of fertiliser applications

The trials' harvest cycle occurred every two to three weeks. The fertigation schedule was set to coincide with the removal of pods. The implications of fertiliser timing are not fully understood, but our aim was to replace the nutrients removed at harvest.

Nitrogen and potassium were applied fortnightly via fertigation. The annual totals are shown in Table 4A.19. In the wet season, fertiliser may need to be applied in the solid form although fertigation can occur during the wet as long as the pre- and post-injection phases are kept to a minimum. Avoid losing the application through leaching from badly timed applications.

Table 4A.19 Nutrient inputs used for mature pod bearing trees.

Elemental Nutrient	Inputs from Years 2 to 4 (kg/ha/yr)	Inputs from Years 5 to 7 (kg/ha/yr)
Nitrogen	**125–198**	**125**
Potassium	**147–359**	**359**

Fertilisers used were potassium nitrate and urea from years 2 to 4 and potassium nitrate from years 5 to 7.

The timing of micronutrient application is not likely to influence tree performance given the almost continuous bearing capacity of cocoa. Soil application of micronutrients is generally best, since uptake of micronutrients through the leaves is limited. Tailor micronutrient applications to replace what the crop has removed, basing this on the results of soil and leaf analyses.

Virtually all nutrients can be applied through fertigation. Although the more expensive soluble forms of the fertiliser are used, this is balanced by the reduced amount required. Application costs are also less for fertigation, because of minimal machinery and labour costs for preparation and mixing in the fertigation tank. Fertigation is a more efficient method of applying fertilisers and results in reduced losses, which has direct environmental benefits.

Pod nutrient content and crop nutrient removal

Pod nutrient content measured in this study differs from that reported in other studies (Wessel 1985). Nutrient removal in northern Queensland pods was higher for N, P, Ca and Mg but lower for K (Table 4A.20).

Table 4A.20. Nutrient removal in kg of nutrient per 1,000 kg of dried bean (Wessel 1985) and for northern Queensland grown cocoa based on dry bean equivalent (10,000 kg of whole pods).

Source	Nutrient Removal (kg/1,000 kg of dry bean)				
	N	**P**	**K**	**Ca**	**Mg**
Wessel (1985)					
Nigeria	39.8	6.3	85.6		
Nigeria	38.3	5.7	76.9		
Cameroon	34.2	6.3	72.6	8.2	6.8
W Malaysia	31.0	4.9	53.8	4.9	5.2
Mean	**35.8**	**5.8**	**72.2**	**6.6**	**6.0**
North Queensland					
based on 10,000 kg pod/ha	44.7	8.2	31.9	8.1	8.6

Nutrient removal by pod removal is a major nutrient sink. Further losses of nutrients would occur due to deep percolation, runoff, volatilisation and fixation.

Slack and Dirou (2002) used the following ‘other loss’ factors in their subtropical fruit crop fertiliser requirement program (Excel® spreadsheet) for northern NSW coast orchards.

- N – 30–40% (volatilisation, runoff and leaching)
- P – 80–100% (fixation and runoff)
- K – 30% (leaching and runoff)
- Ca – 10% (leaching and runoff)
- Mg – 25% (leaching and runoff)

These rates compare favourably with the 30–50% fertiliser N loss reported to occur in bananas in northern Queensland (Moody et al. 1996; Rasiah and Armour 2001). Similarly work carried out on the effect of nitrogen applications in cashew orchards in northern Queensland suggest that fertiliser N can be rapidly leached from the root zone with high nitrate concentrations (128 mg N/L) found in leachate at a depth of 1 m (O’Farrell et al. 1999). Any estimate of nutrient loss via volatilisation, leaching, runoff and fixation will remain a generalisation because of the specific interactions between loss, soil type, climate and irrigation management (Moody pers comm. 2001).

Nutrient replacement can be partly determined by using crop removal data, despite the limitations of determining ‘other’ losses. Leaf and soil analysis information with crop removal data provides the best tools to determine nutrient management.

4A.5.5 Nutrition management summary

Leaf nutrient concentrations during the trial were within the range deemed adequate as determined by most overseas research references. Leaf nitrogen concentrations were lower than what was considered ideal by some authors, particularly during the latter stages of the trial.

Nitrogen inputs ranged from 125 to 198 kg/ha from years 2 to 4 and was decreased to 125 kg/ha from years 5 to 7 in an attempt to reduce the vegetative vigour of the crop. Whereas potassium inputs ranged from 147 to 359 kg/ha from years 2 to 4 and were maintained at 359 kg/ha from years 5 to 7. Minimal phosphorous applications were made in the first three years of crop development; they were 6.7, 54 and 27 kg/ha/ha respectively.

Nutrient removal via pod removal was calculated as 44.7 kg of N, 8.2 kg of P, 31.9 kg of K, 8.1 kg of Ca and 8.6 kg of Mg per 10 tonnes of pods (≈1 tonne of dry bean). Environmental losses via volatialisation, leaching, runoff or fixation would increase this amount with up to 40% losses being recorded in other situations. However, the regular application of small amounts of fertiliser by fertigation is an ideal method of application which minimises field losses.

Nutrient management should ideally be based on crop removal data, despite the limitations of determining ‘other’ losses, and leaf and soil analysis information.

4A.6 Queensland irrigation management

4A.6.1 Introduction

Cocoa is a crop from the wet tropics. Wood (1985) reports that under ideal temperature and wind conditions cocoa grows well in environments where rainfall varies from 1,500 to 2,000 mm per year with no more than three months with less than 100 mm per month. In northern Australia, rainfall although high is relative seasonal and in many locations monthly evaporation exceeds rainfall for three or more months per year (Table 4A.21).

Table 4A.21 Mean annual rainfall, number of months in which mean evaporation exceeds rainfall and the number of months where the mean rainfall is less than 100 mm/month for a range of locations in northern Queensland and Darwin, NT.

Location	Mean Annual Rainfall (mm)	Number of Months where Evaporation Exceeds Rainfall	Number of Months where Rainfall <100mm
Cooktown	1628	7	7
Mossman	1992	7	6
South Johnstone	3287	4	3
Ingham	2020	6	6
Darwin	1665	8	7

The data in Table 4A.21 shows that in most growing locations supplementary irrigation is required to meet the water requirements of cocoa.

4A.6.2 Materials and methods

Trials in all locations were established with irrigation, utilising under-tree sprinkler technology commonly used for orchard crops in Australia. Sprinkler flow rates ranged from 30 L/hr to 120 L/hr depending on site and row layout. At both Mossman and South Johnstone row configurations were either single or double row.

At Mossman in the single row block sprinklers (Plastro Gvat 30 L/hr) were positioned between cocoa trees (2.5 m apart) in the row, whereas in the double rows sprinklers (Watermark 90 L/hr) were positioned along the centreline at 5 m intervals. At the South Johnstone site sprinklers were positioned at 2.5 m intervals in single row plantings and at 5.0 m intervals in double row plantings.

At both sites irrigation inputs were monitored with inline Amiad watermeters. Readings were taken at weekly to monthly intervals and the irrigation inputs expressed as liters per m^2 per day.

At Mossman soil moisture was monitored using watermark tensiometers (Irrometer Co., Riverside, CA) located at 20, 40 and 80 cm depth connected to a Campbell data logger. The historical tensiometer data was used to a certain extent to determine irrigation scheduling, however, other inputs such as rainfall history and surface soil moisture were also used to determine irrigation frequency. At South Johnstone soil moisture was not monitored and irrigation scheduling was determined by experience. Detailed monitoring was carried out from September 2000 to September 2002 for the Mossman block and September 2000 to November 2001 for the South Johnstone block. During the monitoring period the cocoa trees and accompanying shade trees were young and growing rapidly and canopy cover was less then 50%.

4A.6.3 Results and discussion

Trial site irrigation input data

Irrigation inputs varied considerably during the monitoring period and increased during periods of little or no rainfall and decreased during periods of heavy rain (Figures 4A.17 and 4A.18). Table 4A.22 summarises the irrigation inputs (L/m^2/day) and the irrigation to evaporation ratio. Mean irrigation inputs at Mossman were 1.68 mm per m^2/day which resulted in a mean irrigation to evaporation ratio of 0.39. At South Johnstone the mean irrigation inputs were 1.86 mm per m^2/day resulting in a mean irrigation to evaporation ratio of 0.48.

Table 4A.22 Summary of irrigation inputs (L/m^2/day) and irrigation to evaporation ratio for the cocoa trial sites at Mossman and south Johnstone.

	Irrigation Inputs Mossman # (L/m^2/day)	Irrigation Inputs South Johnstone * (L/m^2/day)	Irrigation:Evaporation Ratio Mossman	Irrigation:Evaporation Ratio South Johnstone
Minimum	0.06	0.05	0.01	0.01
Maximum	4.04	15.96	1.18	3.90
Mean	1.68	1.86	0.39	0.48

- inputs calculated during monitoring from Sep 2000 to Sep 2002
* - inputs calculated during monitoring from Sep 2000 to Nov 2001

At Mossman the soil moisture response, as depicted by the tensiometer data in Figure 4A.17 appears not to be directly related to irrigation and rainfall. This may have been due to placement issues. Cocoa tree development, flowering and fruiting did not appear to be limited during this period with the first trees producing harvestable pods within 17 months of planting. Similarly tree growth was excellent at South Johnstone. This suggests that soil moisture was not limiting at either site and that the combination of rainfall and supplementary irrigation was not limiting to growth.

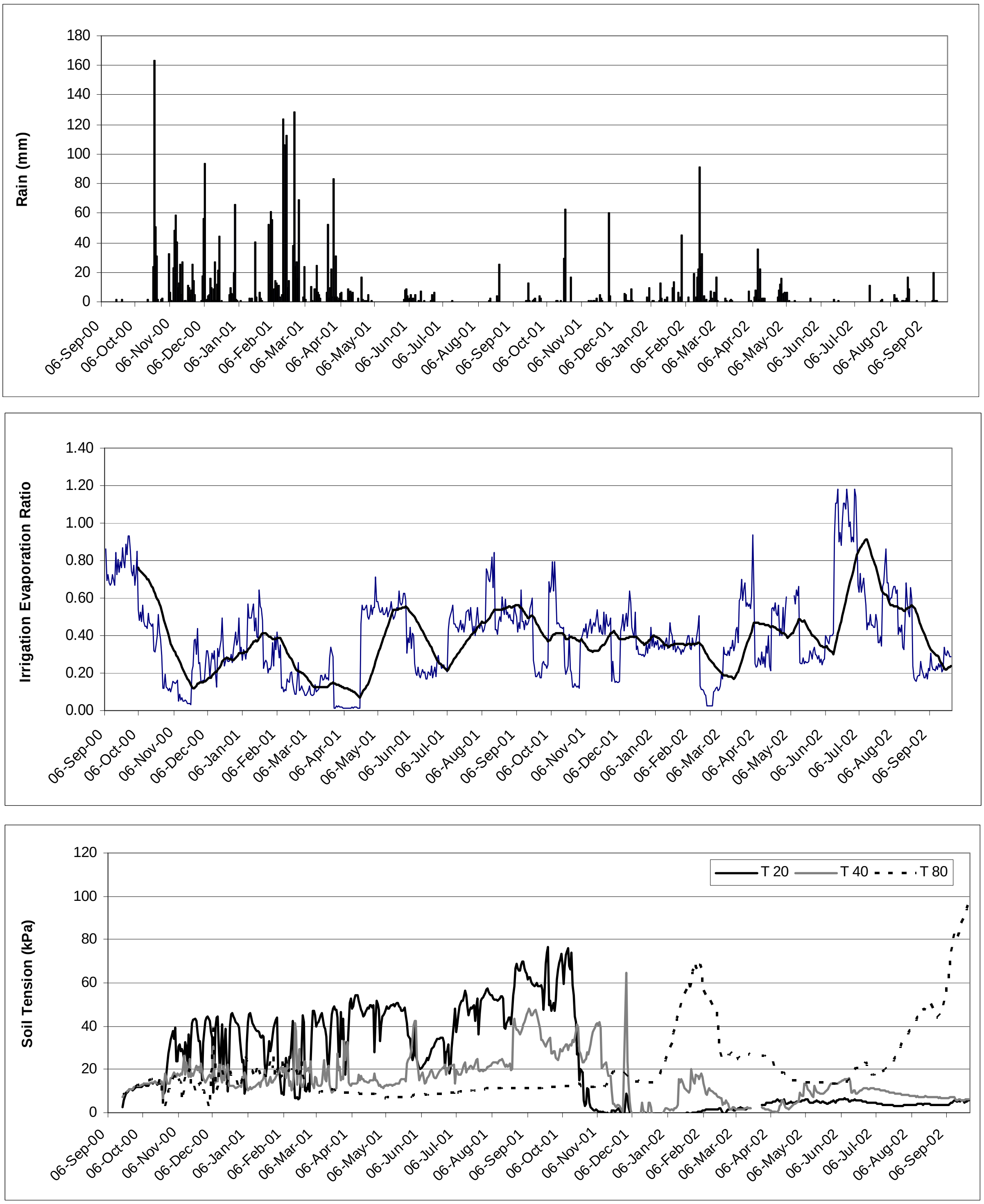
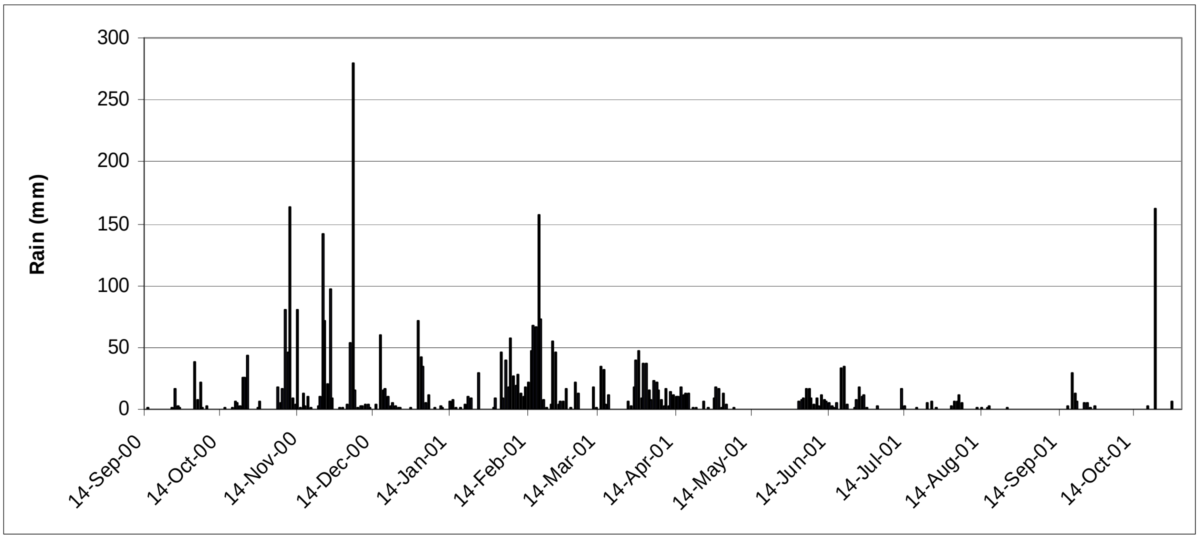


Figure 4A.17 Rainfall, irrigation:evaporation ratio and soil tension at 20, 40 and 80 cm for the Mossman cocoa trial site from September 2000 to September 2002. Note; in the irrigation:evaporation ratio graph a 20 day weighted average line is displayed in an attempt to clarify the data.



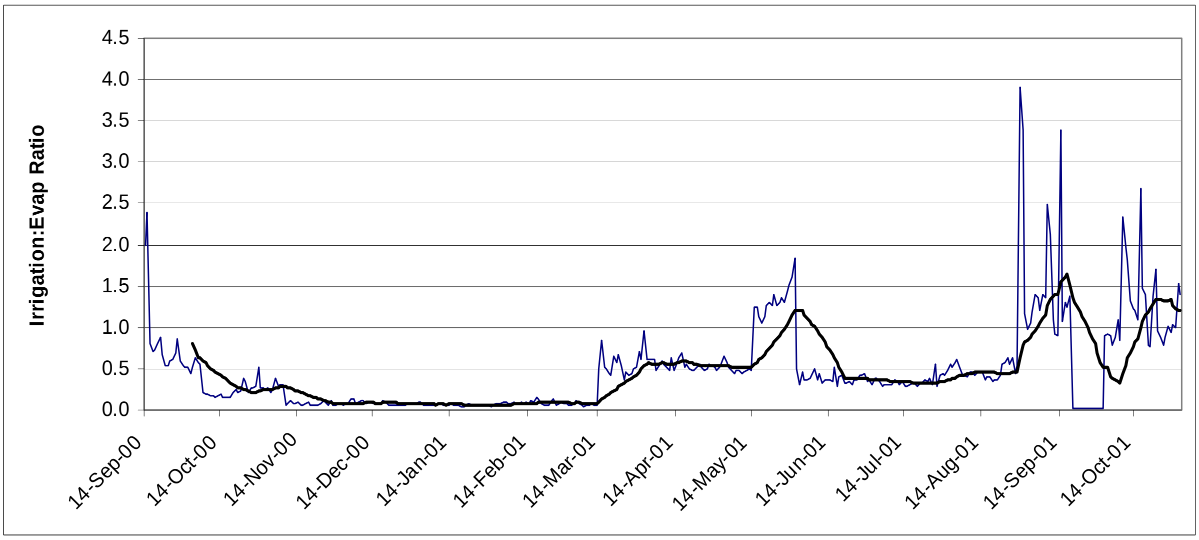


Figure 4A.18 Rainfall and irrigation:evaporation ratio for the South Johnstone cocoa trial site from September 2000 to November 2001. Note; in the irrigation:evaporation ratio graph a 20 day weighted average line is displayed in an attempt to clarify the data.

Predicted water requirements

Mean annual rainfall for many coastal northern Queensland growing locations is near the ideal required for cocoa production. However, rainfall distribution is seasonal with many months in which evaporation exceeds rainfall. Hence the use of supplementary irrigation is necessary to grow cocoa. Water monitoring during early growth in northern Queensland trial sites suggests that the mean irrigation to evaporation ratio is less than 0.5. However, older trees near full canopy cover will require higher irrigation inputs for sustained growth to occur.

Evaporation-based models can be used to predict maximum water requirements based on known average climate data (rainfall and evaporation), tree canopy cover and crop factor (tree water use relative to evaporation).

Assumptions made in the model used to generate water requirement figures for cocoa grown in northern Australia were as follows:

- tree density – 1250 trees/ha
- crop factor – 0.8 for all months of the year
- irrigation efficiency – 0.85
- maximum canopy cover of a mature crop – 85%.

Annual water use requirements were calculated using the assumptions above with local long-term mean rainfall and evaporation data as supplied by the Bureau of Meteorology. The model calculated that annual irrigation requirements varied from 0.9 ML/ha/annum in South Johnstone to 11.5 ML/ha/annum in Darwin (Table 4A.23).

Table 4A.23 Cocoa irrigation requirements (annual (ML/ha/year), maximum inputs (L/tree/week) at peak month and average weekly inputs (L/tree/week)) for cocoa grown in various northern Queensland environments and Darwin, NT.

Growing Location	Mean Annual Rainfall (mm)	Mean Annual Evaporation (mm)	Annual Irrigation Requirement (ML/ha/year)	Maximum Irrigation Requirements in Peak Month (L/tree/week)	Average Irrigation Inputs (L/tree/week)
Cooktown	1628	1703	4.7	216 (Oct)	75
Mossman	1992	1552	3.8	174 (Oct)	61
South Johnstone	3287	1573	0.9	90 (Oct)	14
Ingham	2020	1523	2.2	114 (Oct)	35
Darwin – NT	1665	2686	11.5	343 (Sep)	184

Mean irrigation input data collected at the early stages of cocoa development in northern Queensland support the calculations in Table 4A.23. This data should ideally be used for irrigation planning and design purposes and irrigation scheduling should be carried out using one of the many devices (tensiometers, Watermark sensors, Capacitance probes) available on the market.

4A.6.4 Irrigation management summary

Mean annual rainfall for many coastal northern Queensland growing locations are near the ideal required for cocoa production. However, rainfall distribution is seasonal with many months in which evaporation exceeds rainfall. Hence the use of supplementary irrigation is necessary to grow cocoa. Irrigation management was adequate throughout as reflected by rapid tree growth and prolific pod production.

Long-term evaporation and rainfall data for the trial sites was used to calculate irrigation requirements using a simple water requirement model. Annual irrigation requirements for a mature crop (85% canopy cover) range from 0.9 ML/ha for South Johnstone to 4.7 ML/ha for Cooktown in Queensland whereas, annual irrigation requirements in Darwin are 11.5 ML/ha.

The use of soil moisture sensing equipment is recommended for commercial cocoa production to ensure the efficient utilisation of water and nutrients.

4B. Northern Territory

4B.1 *Introduction*

This section discusses the cocoa hybrid evaluation work carried out in the NT from 1998 to 2005.

4B.2 *Materials and methods*

The data sampling and orchard management practices were aligned as much as possible with the practices described in the 'Best Practice' manual developed by the Australian research team in April 2000.

The site chosen in the NT for the study was at the Northern Territory Government's Coastal Plains Horticulture Research Farm (CPHRF) approximately 50 km south-west of Darwin. The climate is Dry Monsoonal with approximately 1,600 mm of rain falling in four months only. Figure 4B.1 shows the monthly climate averages for a BOM site close to CPHRF.

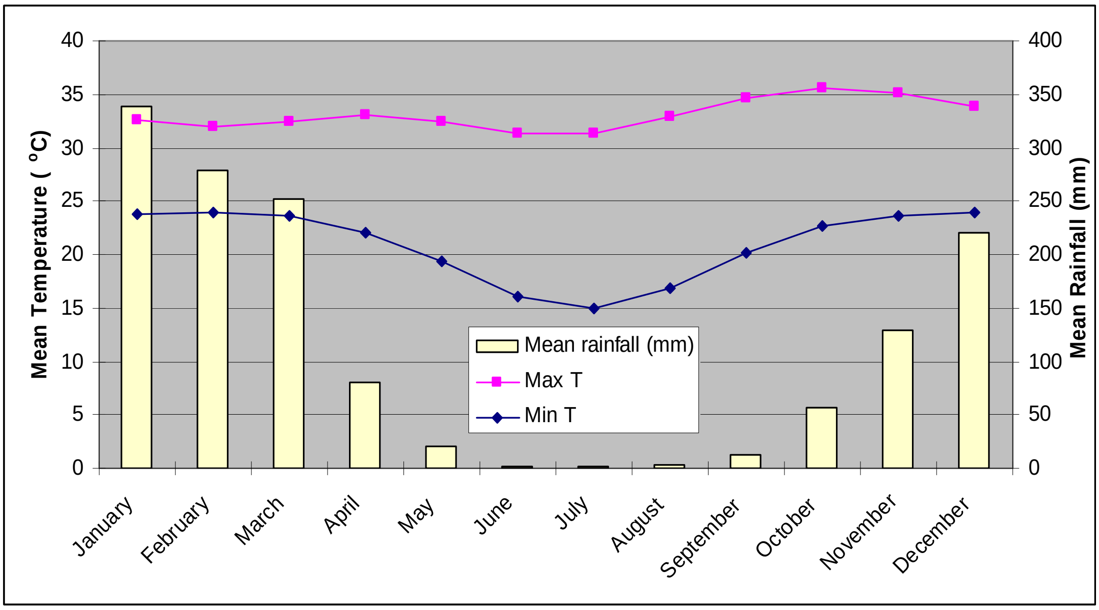


Figure 4B.1 Monthly climate averages for Middle Point Meteorology Station located 1 km from CPHRF. Average annual rainfall = 1,399 mm (Source: Australian Bureau of Meteorology).

4B.2.1 Trial layout and shade management

Acacia mangium seedlings were planted in early 1999. The seeds were of PNG provenance from near Lae. This provenance was recommended by NTDPIF agro forestry researchers on the basis of their fast straight growth and the similar growing conditions to those expected in the NT. The planting holes were prepared by hand using a shovel. The base of each hole had a 20 g Monsoon® tablet and a handful of gypsum placed in it. The nutrient analysis of a Monsoon® tablet is N=20%, P=4.4%, K=8.2%, Ca=4%, S=6%, Mg=0.2%, Cu=0.33%, Zn-0.5%, Fe=0.33%, Mn=0.16%, B=0.01% and Mo=0.01%.

The trial design layout is shown in Appendix A2.2. The planting density was the same as described for the Mossman HYET. In the single rows the shade trees were planted in the same line as the planned cocoa rows so that there was 2.25 m between each shade tree. In the double rows the shade trees were planted down the centre of each double cocoa row at the same spacing (2.5 m) as the cocoa trees.

The shade trees were watered and fertilised to ensure rapid growth. The trees were also strategically pruned to ensure straight clean growth. Unfortunately this pruning was a non-essential and time-consuming process as the trees did not display the single straight clean trunk required.

In early 2000 (a few months before the cocoa was to be planted), the shade trees were thinned by 50%. The arrangement after this thinning was as follows:

- single rows: two cocoa trees then a single shade tree then two cocoa trees etc.
- double rows: shade tree spacing increased from 2.5 m to 5 m.

In early 2001 50% of the remaining shade trees were ringbarked to facilitate death. In late 2001 the dead shade trees were removed leaving only 25% of the original planting. Figure 4B.2 shows the cocoa block before and after shade tree removal in 2001.

a.

b.

Figure 4B.2 Photographs of the hybrid cocoa block at CPHRF in 2001 a. before b. and after shade tree removal.

Unfortunately, a severe storm in December 2001 brought down most of the remaining Acacias resulting in some damage to the cocoa and a reduction in the final shade cover to less than 10%. The impact upon the cocoa of this dramatic shade removal can be seen in Figure 4B.3 where leaf scorching is clearly evident.

Figure 4B.3 Scorched leaves on cocoa trees planted at CPHRF after the removal of almost all shade trees in late 2001 due to storm damage.

During 2002 the cocoa block underwent extensive rejuvenation in response to the storm damage. In early 2003 extra shelter was planted along all edges of the block as well as inside the block (20 m spacing). The shelter were a combination of *Maranthes* spp. and *Terminalia* spp. sourced from local provenances and were all well over 2 m tall when planted.

4B.2.2 Timing of major activities

Table 4B.1 shows the chronology of major tree planting and shade management activities for the CPHRF hybrid cocoa block.

Table 4B.1 Timing of major planting and shade management activities at CPHRF hybrid cocoa block.

Activity	Timing
Ground preparation	**Oct-Nov 1998**
Shade tree planting	**Jan-Feb 1999**
Remove shade trees to get 50% coverage	**May 2000**
Plant cocoa trees	**July-Aug 2000**
Kill 50% shade trees to get 25% coverage	**Feb 2001**
Remove dead shade trees	**Nov 2001**
Storm damage reduces shade to <10% coverage	**Dec 2001**
Gaps in cocoa planting filled with clonal trees	**Feb 2003**
Shade trees planted to get 20% coverage	**April 2003**

4B.2.3 Pot size and potting mix

The planting pot used was a 'T7' which were just less than 1L in capacity. They were filled with a potting mix prepared on site which comprised Pine Bark, German Peat and River Sand in the ratio 3:2:2 as well as 350 g/100 L of Osmocote® and 100 g/100 L of lime. The sand used was Mary River Sand which is commercially available fine sand sourced from the fresh water section of the Mary River in the Northern Territory. The German Peat is by Plantfor Co., Vechta, Germany.

4B.2.4 Planting method

The cocoa seeds sourced from CCRI (Rabaul, East New Britain Provenance, Papua New Guinea) were planted directly into the T7 pots with one seed per pot. The seedlings were germinated under 75% shade before being moved to 50% shade two months before planting out.

The cocoa was planted as a randomised complete block with four hybrids and in two row configurations (single and double). Single row blocks consisted of four rows 3.3 m apart with 2.25 m between plants in the row. The central two rows were used for data collection. Double row blocks consisted of three rows 6.5 m from centre to centre with plants in the twin row 2.5 m apart. An offset planting arrangement was used for the rows within each double row. The trial design was as shown in Appendix A2.2.

The field planting bed was prepared before planting the shade trees by clearing native vegetation (the site was virgin ground) followed by deep ripping to 0.5 m and then primary cultivation with a chisel plough both along and across the direction of the planting rows.

The planting holes for the cocoa were prepared using a planting-hole auger attached to a bobcat (with initial holes in the first few cocoa rows prepared by hand using shovels). As planting occurred in the middle of the dry season with strong prevailing winds, it was necessary to protect both the block and the cocoa trees with hay bales and hay mulch respectively. This can be seen in Figure 4B.4 where the mulch piles around the young trees are clearly evident.

Figure 4B.4 Hay mulch protecting young cocoa plants just after planting at CPHRF.

The requirement for the wall of hay bales as seen in Figure 4B.5 was to act as a shelter band against the strong and dry winds. This wall was in place until such time as a living shelter band had matured. The live band consisted of an outer high density row of Jackfruit and an inner row of native *Terminalia* spp. The live shelter band can be seen in Figure 4B.6.

Figure 4B.5 The wall of hay required to provide a windbreak for the cocoa block just after the cocoa was planted at CPHRF.

Figure 4B.6 The live shelter band planted around the cocoa block at CPHRF.

In early 2003, the spare clonal trees were planted into gaps within the hybrid plots. There were 60 trees available with most of them needing root pruning before planting out.

4B.2.5 Irrigation and water

Irrigation was supplied from an aquifer via a tank that fed a variable speed pump such that water supply at the hydrant to the hybrid cocoa block was on-demand at a pressure of 350 kPa. Initial irrigation was conducted using Aquajets® at 60 L/hr and 4 m spacing within planting rows. In early 2002 when recovering the block from the dramatic loss of shade (due to storm damage), Winfield Orbitors® (90 L/hr) were placed down the middle of the double and single rows at 2.25 to 2.5 m spacing such that each sprinkler was irrigating three and four cocoa trees in the double and single rows respectively.

The irrigation schedule was managed using a TBOS Rainbird® 2-station stand-alone controller. The schedule was determined from the phenological status and average tree size as well as from soil moisture determined using tensiometers (set at 200 and 400 mm depth) and a Diviner 2000® probe (Sentek, Australia) that measured to a depth of 700 mm.

As would be expected the water requirements increased with age and dropped slightly each dry season as the ‘cold’ reduced tree activity. An indicative schedule is provided in Table 4B.2. The double irrigations carried out in 2000 and 2001 were after the cocoa was planted when the trees still had small root systems. The reduction after the wet season of 2001/02 was due to there being no need to water the (non-existent) shade trees. It should be noted that during the wet season (especially during the monsoon) irrigation would be turned off for up to a week.

Table 4B.2 Indicative irrigation schedule for cocoa grown at CPHRF.

Year	Irrigation Schedule (mins/day)	
	January	**July**
1999	30	30
2000	30	1 x 15 + 1 x 30
2001	2 x 30	75
2002	60	60
2003	90	90
2004	75	60
2005	75	60
2006	75	60

4B.2.6 Fertiliser management

In the first three years after planting, the cocoa trees were given a fertiliser regime as shown in Table 4B.3. This macro element regime was administered by broadcasting solid fertiliser around the base of the cocoa trees.

In the first year, ‘Complete Mineral Mix’ (NPK 10:5:5+trace elements) was applied at 200 g/tree every eight weeks. In the second and third years ‘Nitrophoska Special’ (NPK 12:5.2:14+trace elements) was applied every six to eight weeks (300 to 350 g/tree in year 2 and 450 to 500 g/tree in year 3). The exception to this regime was for calcium which was applied twice during this period using a gypsum spreader at 3.5 t/ha of gypsum.

Table 4B.3 Macro element application to cocoa grown in the NT during the first three years after planting.

	Macro Element Inputs (g/tree/annum – elemental)			
Year	**N**	**P**	**K**	**Mg**
1	175	77	58	28
2	275	121	91	44
3	137	60	46	22

After year 3, the macro elements were applied via fertigation. The fertilisers were applied weekly via a venturi system attached to a 100 L tank. The annual elemental requirements and the weekly applications of fertiliser can be seen in Table 4B.4. The exception to this regime was for calcium which was applied once after year 4 by hand at a rate of approximately 1.5 kg/tree of gypsum.

Initially the micro elements were applied by foliar application three times per year. In the first three years, foliar spray was by hand with application until leaf drip. In the fourth and fifth years an orchard sprayer was used which put out 2,000 L/ha. The timing of spraying was aimed to ensure new vegetative flush received the elements. The elements sprayed usually were zinc as sulphate heptahydrate at 2 g/L, iron as iron chelate at 1 g/L and boron as Solubar at 1 g/L though on occasion Wuxal® was sprayed at 3 g/L.

Table 4B.4 Weekly macro element fertigation to cocoa grown in the NT after the third year of growth.

Macro Element	Requirement (g/tree/yr)	Product Applied	Amount of Product for Entire Block (kg/week)
		Potassium Nitrate	2.6
N	137	Urea	4.5
		Mono-ammonium Phosphate	4.9
P	60	Mono-ammonium Phosphate	4.9
K	46	Potassium Nitrate	2.6
Mg	22	Magnesium sulphate	5.1

Once the canopy was too dense for tractor travel (around mid-2004), the micro elements were applied through a fertigation system. The elements listed in Table 4B.5 were applied every four to six weeks to the block.

Table 4B.5 Monthly micro element fertigation to cocoa grown in the NT after the fourth year of growth.

Micro Element	Application Rate (g/m^2 of tree area)	Product	Amount Applied to Entire Block per Fertigation (kg)
Fe	2	Iron chelate	0.7
Mn	2	Manganese sulphate	1.7
Cu	2	Copper Hydroxide	1.4
B	4	Solubar	1.7
Zn	2	Zinc sulphate	1.9

4B.2.7 Management

Pruning

Pruning was the major management exercise required for the cocoa block. This was mainly due to extensive chupon growth that occurred for the entire period the trees were in the ground. This was especially the case in 2003 as the trees recovered from the lack of shade and grew rapidly. At times, chupon removal was a fortnightly exercise of up to four hours for two people. Chupon removal was usually done by hand or with a pair of secateurs.

Once the trees had jorqueted, tree shaping was also required. Initially this was mainly removal of unwanted or cross-over growth. Later, once the trees had reached a height of 3 m, topping and major limb reduction (by hand) was also required. The timing for this major pruning was either late wet season or late dry season after a major pod harvest. This timing was to reduce the amount of sunburn to the limbs and new growth.

Herbicide

Grass and weed control was maintained via slashing (using a tractor-mounted slasher) of the inter-rows and the use of Basta® (active ingredient Glufosinate-ammonium) at recommended rates intra-row. In the first few years the use of Basta® was extensive (once per month). As the trees grew and the covered more of the inter-row, weed growth reduced dramatically. Eventually only twice yearly herbicide applications were required so long as monthly mowing (using a ride-on mower) was undertaken. The difference in weed and grass cover between early in the crop life and at maturity can be seen in Figure 4B.7.

a. **b.**

Figure 4B.7 a. Grass and weed cover in early stages of block life. b. Grass and weed cover in later stages of block life.

Pesticides

The following chemicals were used (at recommended rates) throughout the life of the block:

- Carbaryl
- Chlorpyrifos
- Dimethoate
- Fenthion
- Mirex

Initially most foliar chemicals were applied by hand to knock out early infestations. When the trees became too large (year 3) the orchard sprayer was used. Towards the latter stages of the trial, the canopy density was too high for tractor access and so foliage-based insect pests were controlled via backpack application.

The Mirex was applied to *Mastotermes* termite infestations using the drum aggregation technique developed by NTDPIF. An example of this can be seen in Figure 4B.8.

Figure 4B.8 The drum aggregation technique and use of Mirex to control *Mastotermes* termites.

4B.3 Results and discussion

4B.3.1 Climate

The climate during the life of the project was typical of the region though rainfall was above average in every year. Climate details can be found in Section 4D.

4B.3.2 Tree establishment and mortality

As shown in Table 4B.6, there was an 80% survival rate across the blocks. The majority of the deaths occurred while the trees were still juvenile or occurred as a result of storm damage when mature. The major causes of death for the juvenile trees were environmental stress, termites and longicorn. For mature trees, damage was incurred when the shade trees came down during a severe storm.

The environmental stress was caused by the late planting in the dry season. The young trees were planted at the beginning of the windiest and then hottest times of the year. It is clear that in the NT, cocoa needs to be planted early in the wet season after the first decent rains or close to the end of the wet season when conditions of overcast skies and high humidity are typical.

Table 4B.6 Survival rate of cocoa planted at CPHRF in July-August 2000.

Hybrid	Survivability (%)						Average
	Block						
	1		2		3		
	Double	Single	Double	Single	Double	Single	
1	76	56	84	79	78	81	**76**
2	76	83	76	69	92	85	**80**
4	84	81	89	79	71	65	**78**
5	92	81	83	90	76	85	**85**
Average	**79**		**81**		**79**		**80**

4B3.3 Jorquetting

The first jorquettes developed in early 2001 approximately six months after planting. Figure 4B.9 shows that a large number of trees had jorquetted by May 2001. The data also shows a significant difference in behaviour between the cocoa trees in the ‘Single’ and the ‘Double’ rows.

However by April 2002 the differences had disappeared with completion of jorquetting seen by November 2002. This completion was over 15 months after planting which is up to three months later than typical with the ‘Single’ density trees particularly slow.

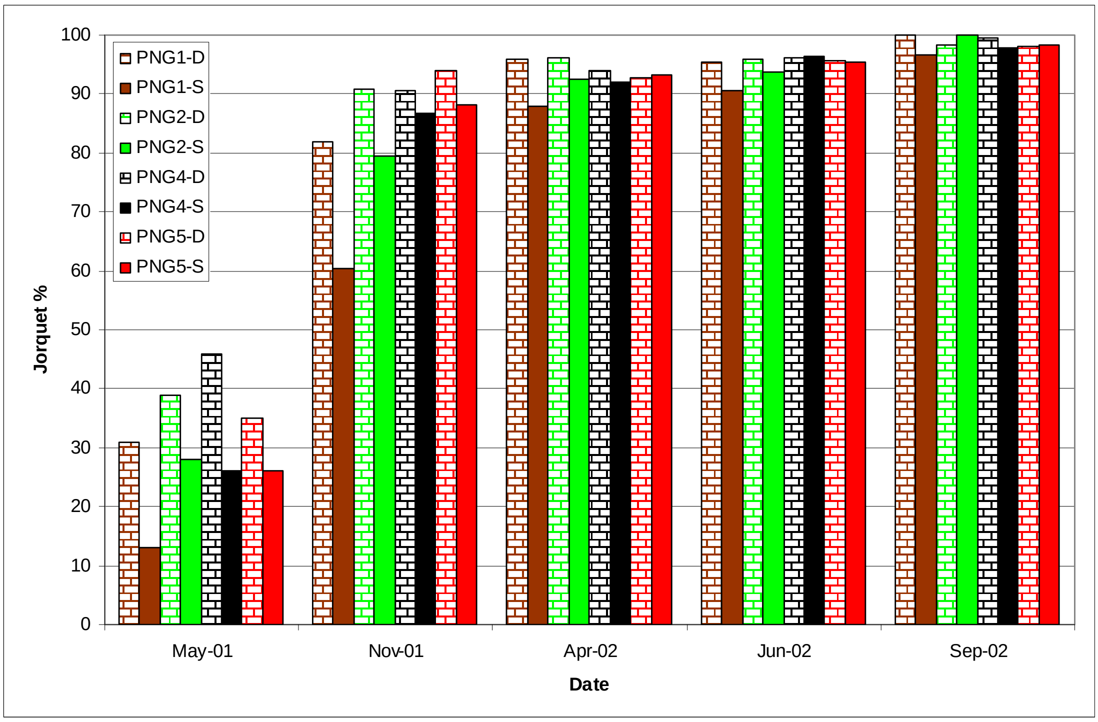


Figure 4B.9 Jorquette development in cocoa trees planted at CPHRF.

When looking at the jorquette data shown in Table 4B.7 it can be seen that despite the differences in jorquette timing there was no significant difference between densities or between hybrids. Nonetheless, these jorquette heights are up to 300 mm less than is typical for cocoa. This is attributed to either an overall affect of the environment or competition from the shade trees.

Table 4B.7 Average height of jorquette in cocoa grown at CPHRF.

Hybrid	Jorquette Height (m)	
	Row layout	
	Double	Single
1	1.12 +/- 0.09	1.08 +/- 0.06
2	1.18 +/- 0.09	1.14 +/- 0.05
4	1.12 +/- 0.05	1.16 +/- 0.06
5	1.09 +/- 0.06	1.10 +/- 0.05

4B.3.4 Flowering

The first flowers developed in mid-2001 but significant flowering did not occur until early 2002. A large number of trees in the double rows had jorquetted by November 2001 (Figure 4B.10). The trees in the single rows took up to six months longer to commence flowering than did the double row trees. However, by September 2002 most of the differences had disappeared with only two hybrids still showing significant differences in flowering between planting layouts. By November 2002, the majority of trees had commenced flowering. This was over nine months after jorquetting which was up to three months later than is typical for cocoa. This was more apparent in the single rows with flowering being particularly slow.

When considered with the significant difference in flowering between planting layouts, it can be inferred that there is some affect of the increased number of shade trees relative to the number of cocoa trees per block. Another factor is the closer proximity of the cocoa trees to each other in the single rows. However, the effect was initially attributed to the shade trees having a detrimental effect. However an assessment in 2006 of cocoa tree size relative to the distance from an *Acacia* shade tree did not confirm this theory conclusively.

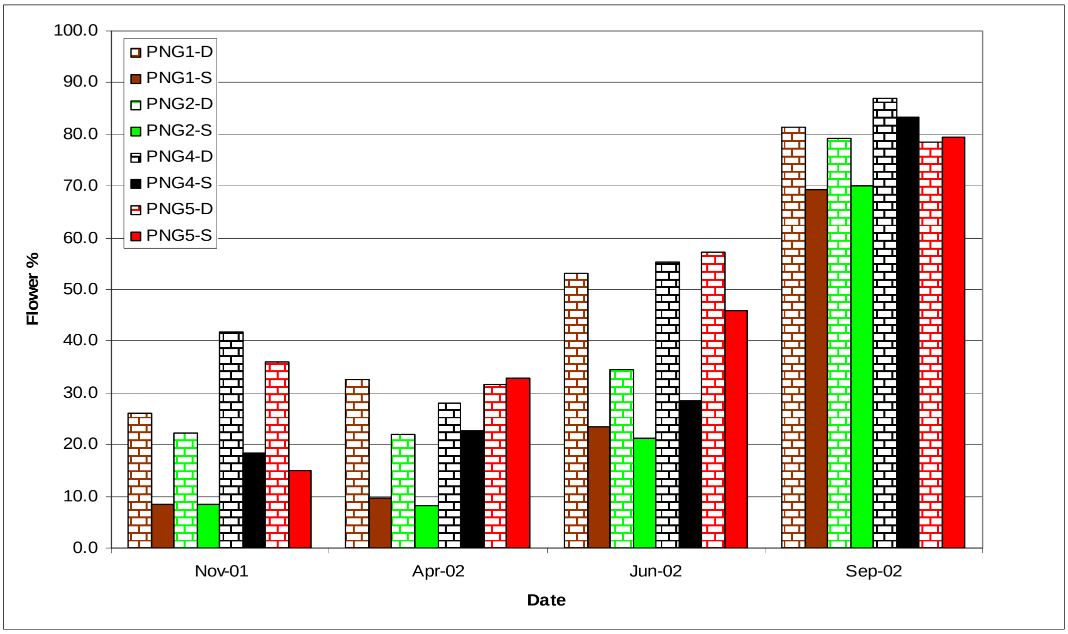


Figure 4B.10 Juvenile flowering behaviour of cocoa trees planted at CPHRF.

4B.3.5 Tree size

Both tree height and trunk diameter increased with time. Tree height increased to greater than 3.5 m (Figure 4B.11), however potential height was never reached as pruning operations ensured that the trees remained relatively compact and easy to harvest and manage.

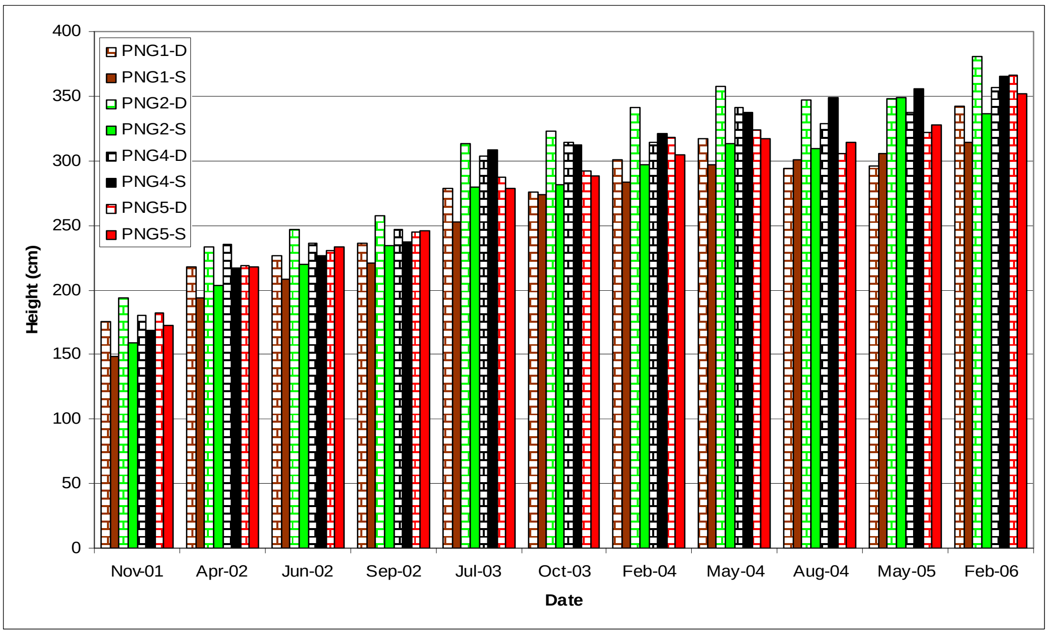


Figure 4B.11 Cocoa tree height (cm) over time in the NT. Note that major pruning operations commenced mid-2004.

Regardless of pruning operations, trunk diameter increased continually. Trunk diameter increased to greater than 100 mm by the end of the trial (Figure 4B.12).

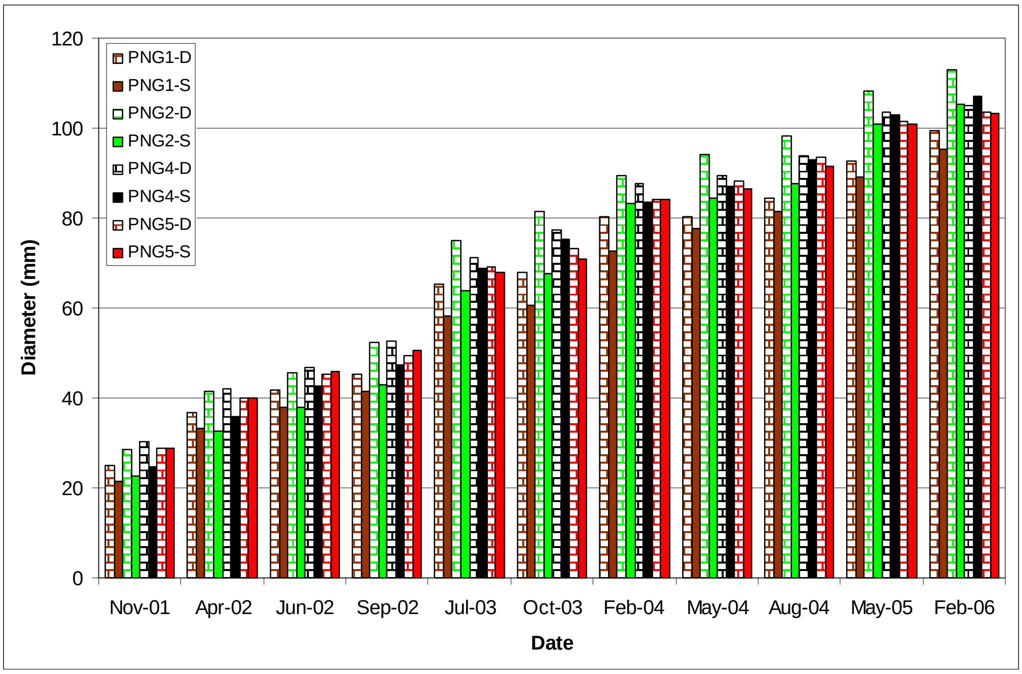


Figure 4B.12 Cocoa trunk diameter (mm) over time in the NT. Note that major pruning operations commenced mid-2004.

An interesting observation was that in almost every case, trees in the double rows were taller and thicker than the same hybrids in the single rows. This is especially apparent from the height data where the height differential is maintained until pruning operations commenced in mid-2004. Even so, the differential in trunk diameters can still be seen post-pruning. This suggests that the effects of the shade trees were still being felt.

4B.3.6 Yield and pod index

From the yield data summarised in Appendix A1, NT yields were consistently lower than those in Queensland. Furthermore, there was a clear difference in yields between the two row layouts with the double row trees producing more pods. While it is not conclusive, Hybrid 1 (PNG1) produced the most pods in the NT and could be a likely candidate for a commercial planting or for further evaluation and development.

A graphical representation of monthly production can be seen in Figure 4B.13. This illustrates that the double row trees produced much more crop than the single row trees during the peak production period. Figure 4B.13 also shows that the peak of production occurs in the wet season. While there is production throughout the year, it is questionable if the work required during the dry season could sustain a full harvest crew.

The NT Pod Indexes never approach commercial levels (<30). This is due to the small size of the beans which could not be improved regardless of shading, nutrition or irrigation. Other work conducted on cocoa in the NT, indicate that the environmental impacts are greater than the plant can cope with and still maintain commercial production.

It is concluded that the commercial production envelope for cocoa does not extend to the NT climate and environment.

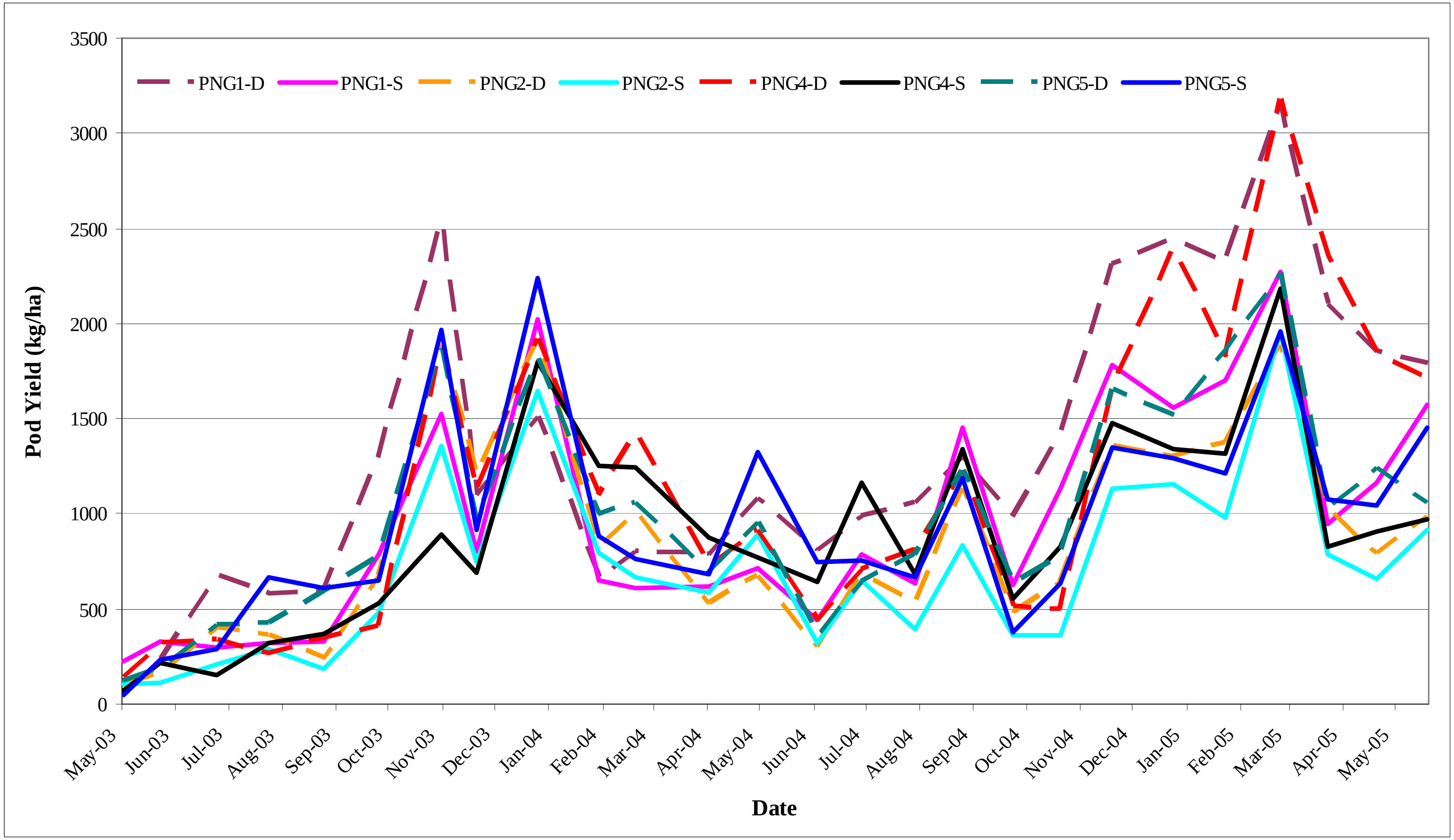


Figure 4B.13 Cocoa pod yield over time from the HYET at CPHRF.

4B.3.7 Pests

The pressure by insects on cocoa at CPHRF was manifested more by tree deaths than by yield reductions. As has been discussed previously, there was significant tree loss due to termites and longicorns as well as physical damage from winds and falling branches from shade trees. However some yield decline on surviving trees was seen though the level of loss was not measured.

The pests seen in the cocoa in the NT are as follows:

- Termites *(Mastotermes darwiniensis*) were a problem during initial crop establishment and maturation. Often the first symptom of this pest is tree death. Control was finally achieved using Fipronil® via the recommended drum aggregation method.
- Longicorn beetles (*Acalolepta mixtus)* were a major pest throughout the life of the trial. The larvae of the beetle would ringbark the trees (regardless of age). The only effective control for this pest was regular inspection of the stems and trunks of the cocoa with either physical removal of the grub or local spraying with dimethoate at recommended rates.
- Fluted scale (*Icerya* spp.) were present throughout the life of the planting. However, damage from this pest was light and consisted of leaf and fruit damage/distortion but not loss. Control for this pest was only undertaken rarely using either Fenthion or a soap or petroleum product. Spraying for other pests also gave some control to this pest.
- Redbanded thrips (*Selenothrips rubrocinctus*) often appeared during the dry season and once during a very long break in the monsoon (three weeks). The symptoms included bronzed and desiccated leaves. Leaf loss could become dramatic which limited production and encouraged sunburn of newly exposed branches. Control was affected using dimethoate or a soap product at recommended rates.
- Aphids and mites were often an issue when the plants were young. Leaf loss/degradation was the main concern. Control was achieved using chlorpyrifos at recommended rates where a full orchard spray was required or using a soap or petroleum product when requiring local control only.
- Swarming beetles (*Monolepta australis*) damaged trees during the late dry season and early wet season through mass emergence after rain and attack of leaves. Control when required was provided by spot spraying of Carbaryl at recommended rates.
- Fruit Spotting Bug (*Amblypelta lutescens lutescens)* was a minor pest. Some fruit damage did occur but not at levels that warranted overall control. When required, a local spray with Carbaryl controlled the pest.

While not an insect, there was some damage by tree rats and their like. These vertebrate pests would eat pods just as they ripened. However the level of damage was small and an active trap and release program provided adequate management of the problem.

4B.3.8 Diseases

There was little evidence of any disease problems or presence in the cocoa. Some anthracnose was observed on leaves on the exterior of the taller trees while typical brown fruit rots were evident on pods that were left too long on the tree.

4B.3.9 Water use

Analysis of crop water use in cocoa in the NT indicates that during the dry season after harvest (April to September) the crop factor (as a factor of evaporation) is between 0.9 and 1.0 while during the rest of the year the range is 1.0 to 1.2. This indicates that cocoa grown in the NT has a high water requirement. This requirement could be up to 1,700 mm per annum in the Darwin region.

As previously discussed, various soil moisture monitoring tools were used on the cocoa block. These included the Diviner 2000® system by Sentek and standard tensiometers made in-house. Figure 4B.14 shows the total soil water content in the first 0.7 m of soil under the cocoa. Figure 4B.15 shows the average soil water tension at 0.4 m under the cocoa. The major finding of this work was that the crop water requirement increased dramatically at the end of the dry season. This increase coincides both with an increase in temperatures and evaporative load and the onset of the major flowering which results in the late wet season crop peak.

Nonetheless, this measured water usage includes usage by the shade trees. It is estimated from other sources that the crop water requirement for the species of trees used in this block could be up to 30% of that of the cocoa. This would especially be the case at the onset of the wet (after a dry season slow-down) when these natives would be at full productivity in a natural setting.

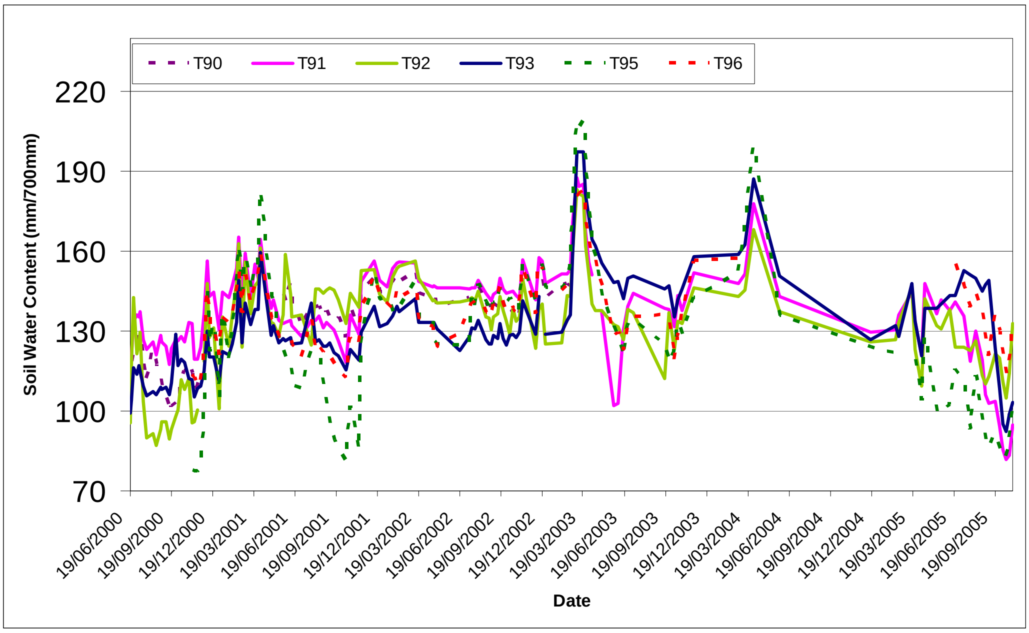


Figure 4B.14 Soil water content (mm) for the first 0.7 m under cocoa grown in the NT (single rows = T90, T95, T96; double rows = T91,T 92, T93).

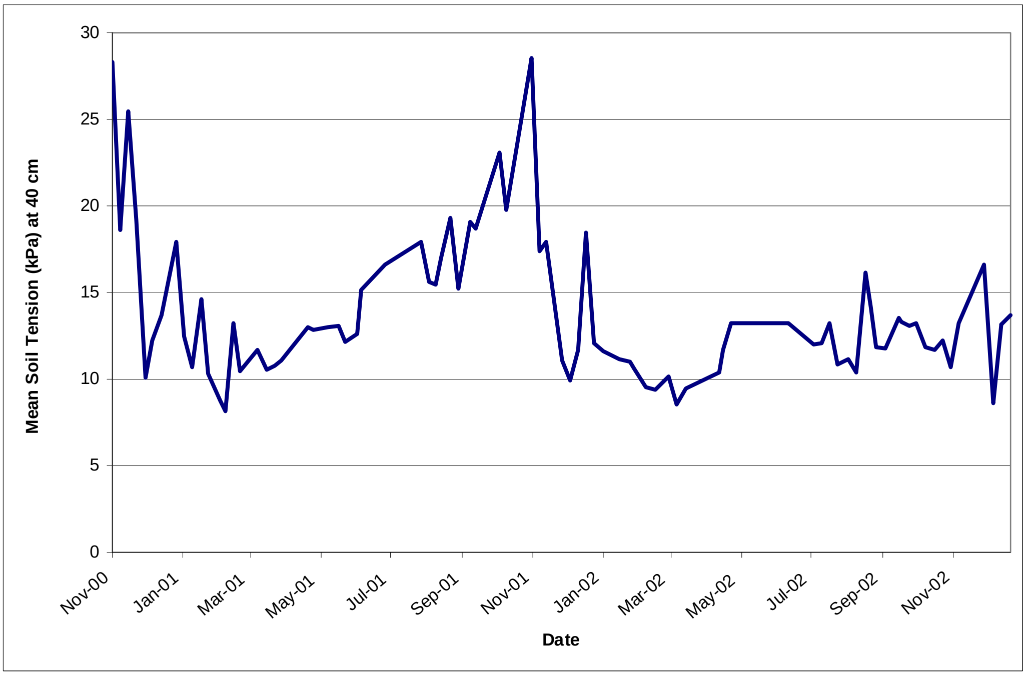


Figure 4B.15 Soil water tension (kPa) at 0.4 m depth under cocoa grown in the NT (average of up to 24 tensiometers at each date).

4B.3.10 Nutrition

Crop nutrition was tracked via regular leaf analyses. In late 2004 an assessment of crop nutrition suggested that more potassium as well as a general increase in nutrient provision was required. The results of this change in management can be seen in Table 4B.8 where a general increase in levels is shown. During this period both sodium and chlorine levels were also tested with sodium levels ranging from 0.006 to 0.014% and chlorine levels never rising above detection level (0.005%). This indicates that production was not inhibited by high 'salt' levels.

Table 4B.8 Leaf nitrogen (N) and potassium (K) concentration of cocoa hybrids grown at Coastal Plains research station in single and double row configurations.

Nutrient	Date	Hybrid and Row Configuration								
		PNG1-D	PNG1-S	PNG2-D	PNG2-S	PNG4-D	PNG4-S	PNG5-D	PNG5-S	Mean
N (%)	Oct-02	2.7	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.6
	Aug-04	1.4	1.5	1.5	1.3	1.2	1.5	1.5	1.5	1.4
	Sep-04	1.8	1.8	1.6	1.7	1.7	1.9	1.7	2.0	1.7
	Jun-05	2.1	2.1	2.1	2.1	2.2	2.2	2.3	2.3	2.2
K (%)	Oct-02	1.7	1.9	1.6	1.7	1.9	2.0	1.8	1.6	1.8
	Aug-04	0.8	0.9	0.7	0.7	0.8	0.8	0.9	0.8	0.8
	Sep-04	1.2	1.2	1.1	1.4	1.1	1.2	0.9	1.2	1.2
	Jun-05	1.6	1.6	2.0	2.0	1.8	1.8	1.6	1.6	1.8

4B.3.11 Bean analysis and size

Generally, bean size was consistently too small in the NT. Another issue was premature germination of beans inside pods which was attributed to high ambient temperatures. There was only limited fermentations conducted and since this was being addressed in Queensland-based trials, it was agreed that this work would not be taken further in the NT.

4B.4 Summary

Cocoa was successfully established despite the harsh NT climate. Tree growth and development was slower than experienced in Queensland. This was partly attributed to the use of a vegetatively vigorous shade species in the NT trial block (*Acacia mangium*).

Cocoa trees were subject to a range of pest pressures. Termites (*Mastotermes dawiniensis*) and longicorn beetle larvae (*Acalolepta mixus*) were major pests which had serious implications for tree growth and survival.

Cocoa yields (dry bean equivalent) peaked in the 2004/2005 season, four years after planting. Mean yields for the four hybrids were 1.68 t/ha and 1.31 t/ha for the double and single row configurations respectively. The hybrid PNG1 was the best performer yielding 2.17 t/ha and 1.56 t/ha for the double and single row configurations respectively.

Peak pod production occurred during the wet season from November to March. Pod size and bean size were small.

The yields, pod and bean size characteristics suggest that the NT environment is sub-optimal for commercial cocoa production.

4C. Western Australia

4C.1 Introduction

At the Broome HYET, the broad objectives were to:

- establish cocoa seedlings for a 0.5 ha block
- evaluate the growth and performance of cocoa trees and yield harvested
- evaluate the quality of cocoa beans and by-products
- provide data and observations for comparative analysis with other program trial sites.

4C.2 Materials and methods

4C.2.1 Site selection

The NACDA HYET site near Broome in WA was selected based on the following factors:

- proximity to established horticultural industry development
- tropical coastal climate
- land and water resources availability with scope for expansion (Waterbank Station Land Use Allocation Plan)
- arid climate of Ord River Irrigation Area thought to be less suitable.

Potential co-operator growers were approached in Broome in 1999 to determine interest and possible involvement. Initially two growers (Coconut Wells and Skuthrope) expressed great interest, but dropped out of contention during negotiations and project development. A third party and commercial banana grower was then approached (Mr S. Gray) and agreed to participate in the project. Mr Gray's property was located at Skuthorpe about 20 km from Broome. The divide between Coastal and Inland Arid climates was thought to be somewhere between 10 and 25 km from Broome, so it was decided to proceed with the trial at Skuthorpe.

4C.2.2 Trial history

The block chosen for trial work was adjacent to commercial banana production blocks, and was on the Pindan soil type (clayey sand, 5–10% clay). The 0.5 ha block selected was cultivated and rows formed in September 1999 with irrigation installed by December 1999. Irrigation was supplied through Dan 2000® micro-sprinklers arranged in a 6 m x 5 m configuration. Soil and potting mix samples for nutrient analysis were collected in November 2000, February 2001, October 2001and June 2002. As expected most nutrients were deficient. Water quality was tested as good with no limitations for cropping and irrigation.

4C.3 Results and discussion

Table 4C.1 lists the events and stages reached over the life of the trial which concluded in June 2002, following the withdrawal of AgWA support for the project and the poor results obtained.

Table 4C.1 Activities completed at the Broome HYET site.

Activity	Month Completed	Outcome
1. Visit and inspect potential trial site and discuss with growers	July 1999	Agreement signed with co-operator grower
2. Trial site clearing, cultivation and marking out.	December 1999	A 0.5 ha site established
3. Construct a nursery for seedlings	December 1999	Nursery of 700 seedling capacity built
4. Obtain access to seed sources; place orders for cocoa seed with suppliers	July 1999 to January 2000	Unsuccessful negotiations with MCB, successful with CCRI of Papua New Guinea.
5. Obtain and plant shade tree seeds	December 1999	*Acacia mangium* seeds obtained and planted into nursery pots.
6. Select shade species; establish seedlings and plant out.	March 2000	*Acacia mangium* seedlings established in single and twin row layouts according to planting plan
7. Irrigation system and pump capacity selected; hardware installation.	January 2000	Micro-sprinkler system installed
8. Receive seed; plant cocoa seeds to nursery.	January 2000 to October 2001	See Table 4C.2
9. Spray planting lines, dig holes, apply fertiliser and plant out seedlings.	First planting March 2001 to single row layout	Half of 0.5 ha site planted, 95% seedlings subsequently died over next few months
10. Water and nutrient management scheduled; pest and disease monitoring and control; weed control; phenology monitoring; soil and leaf nutrient status monitoring.	March 2001 and following.	Soil testing Nov 2000, March 2001, Oct 2001, June 2002 Soil water recording established May 2001. Pest scouting monthly from June 2001. Daily irrigation from planting onwards. Regular application of nutrients.
11. Field planting to double rows	Re-planted February 2002	Very poor growth and development
12. Field planting to single rows	Re-planted March 2002	Very poor growth and development
11. Thin/prune shade		Shade thinned to 75% July 2001 and to 25% in April 2002
12. Install automatic weather station	March 2001	Data collected from April 2001 to June 2002
13. Decision by Director General AgWA to withdraw from the project	May 2002	Final report to stakeholders, July 2002

Figure 4C.1 shows an overview of the Broome trial site in May 2001 with field planted cocoa seedlings (under acacia) shown in Figure 4C.2.

Figure 4C.1 Overview of Broome HYET site (May 2001).

Figure 4C.2 Field planted cocoa at the Broome HYET (May 2001).

4C.3.1 Seed import and germination problems

The decision was taken to source hybrid seed lines from the CCRI in Papua New Guinea (Keravat near Rabaul) in lieu of accessing requested seed lines from the MCB. After initial inquiry, five moderate vigour SG2 hybrid crosses were selected based on Trinitario x Amazonian parents as follows:

- KA2-106 x KEE12
- K82 x KEE5
- K82 x KEE43
- KA2-106 x KEE23
- K82 x KEE12

Seeds sufficient for trials at all sites were ordered at Christmas 1999 and received during January 2000. However, germination failed at all sites due to non-viability of seed. It was suspected that this seed was either frozen and/or subject to excessive heat whilst in transit from CCRI to Cairns.

In May 2000 MCB belatedly agreed to supply seed as per the original request (of about 12 months prior). On receival in Darwin, these seeds were also distributed to WA and Queensland. Germination success at all sites was about 50% however almost all these seedlings died within days of emergence. These losses were generally attributed to the poor (old) condition of the seed and subsequent fungal attack Table 4C.2 summarises the cocoa seed consignments to Broome and outcomes.

Table 4C.2 Cocoa seed imports and outcomes

Date seed planted Broome	Seed Source	Results	Comments
January 2000	CCRI	Failure all sites	
March 2000	CCRI	Germination en-route, problems with enlarged radicles	96% seedlings culled due to distorted roots see Figure 4C.3
May 2000	MCB	40% success germination all sites	Emerged seedlings retarded and poor growing; died or culled
July 2000	CCRI	Germination en route, very poor rates of emergence	Radicle tips blackened and browned, soft seeds; <10% success
October/November 2000	CCRI	75% germination success	Field planted March 2001; poor seedlings; 95% loss.
June 2001	CCRI	100% failure	Cold weather snap during germination
September 2001	CCRI	41 to 56% germination success	Poor seedling development and emergence, post germination; field planted to twin rows February 2002
October 2001	CCRI	55% germination success	Satisfactory seedling development; field planted March 2002 into single rows

Seeds that failed to germinate did not appear to be diseased; but some seeds were soft and rotted.

In total there were eight seed consignments from January 2000 to October 2001. The last two batches were field planted in February and March of 2002. Delays were experienced in sourcing seed from PNG due to non-availability of materials at certain times.

The major problems encountered with the seeds are summarised as:

- high percentage of germination of seeds en-route
- damage and necrosis of the radicles (primary roots) of seeds
- germination failure
- fluctuating conditions during germination as a result of variable temperatures en-route, leading to stop/start germination and possible physiological and biochemical changes in the seeds
- poor rates of seedling emergence.

4C.3.2 Seedling emergence problems

Of the seedlings that successfully germinated, they often had deformed root systems and leaf growth disorders as typified by Figures 4C.3 to 4C.5. Seedlings with grossly distorted root systems (apparently resulting from radicle damage) and deformities were common in Broome. The potting mix used was based on a mix comprising sand, peat moss and pine bark fines in the ratio and 2:2:1 with 1 kg of lime added per cubic meter of mix. Mixes were re-used if no signs of disease were evident in previous seed batches that failed. A view of the nursery is shown in Figure 4C.6.

a.

b.

Figure 4C.3 a. Deformed roots from seedlings (March 2000) with enlarged or damaged radicles at seed planting. b. Close up of deformed primary root.

Figure 4C.4 Example of poor germination and deformed leaves of emergent seedlings.

Figure 4C.5 Close-up of deformed newly emerged seedling with deformation of one cotyledon.

Figure 4C.6 Nursery view showing irregular germination and emergence.

4C.3.3 Field seedling establishment and performance

Field planting was carried out on three occasions – March 2001 (single rows), February 2002 (double rows), and March 2002 (single rows). The seedlings used for the first planting were generally not vigorous and robust at the time of planting. However it was decided to plant them anyway and see if field conditions would allow them to improve. Unfortunately they got worse with more than 95% losses over 3 months. Photos taken in June 2002, of seedlings which survived are shown in Figures 4C.7 to 4C.9. These seedlings were then aged 15 months and the degree of canopy and root development could only be described as poor.

Figure 4C.7 Cocoa seedling field planted March 2001.

Seedlings field planted in February and March 2002 also performed very poorly. Flushing activity was evidenced but the capacity to subsequently develop the new leaves to mature leaves was limited. Some plants excavated in June 2002 showed that root development had generally not extended beyond the potting mix ball, despite there being no restrictions to prevent this (see Figure 4C.10). The soil moisture status was checked with the Gopher® system and found to be acceptable with 10 to 17% volumetric water content.

Figure 4C.8 Cocoa field planted March 2001 with typical poor canopy/foliage development.

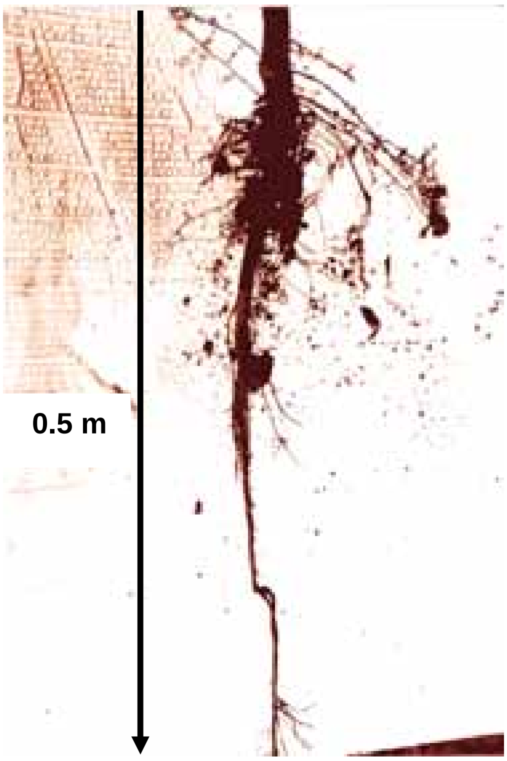


Figure 4C.9 Cocoa field planted March 2001 with typical poor root development.

Fertiliser application history for Feb/March plantings was:

- at planting: Gypflo solution 25 L/ha to base of plants (32%Ca, 25%S)
- at planting and after two months: NPK Nitrophoska Perfect (14 14 12 4 +Trace elements) broadcast around base of plant at 70 g/plant
- after one month: Guano gold (32%Ca, 8%P)
- foliar spraying fortnightly with Wuxal® complete mix and insecticides as required.

Foliar spraying with Wuxal® complete blend and selected insecticides was carried out at two- to three-weekly intervals.

In addition to this (in line with the owners practice for banana management), compost and mulch was applied in an attempt to build soil organic matter and improve overall soil health.

Figure 4C.10 Excavated cocoa seedling photographed June 2002 (field planted in February 2002); note lack of root development from potting mix ball.

4C.3.4 Cocoa root development

Cocoa root development was very poor in all seedlings planted to the field in Broome. This was consistent with observations made on banana plants by the site owner. There is virtually no feeder root activity despite mulching efforts and little root development in general. Figure 4C.10 taken in June 2002 illustrates the lack of root development in the Broome cocoa seedlings.

4C.3.5 Soil management issues

The soil at the trial site is essentially a clayey sand (5 to 10% clay) and belongs to the Pindan soil association. The limitations of this soil are:

- very low available water capacity of 55 mm per 100 cm
- very low cation exchange capacity
- very low nutrient content of all major nutrients
- low organic carbon content.

These properties are demonstrated by reference to Table 4C.3.

4C.3.6 Soil nutrient management

The soil at the outset was a major challenge and required careful management. The initial approach to this was to treat it more or less as a relatively inert hydroponic medium, and to supply most nutrients through fertigation. As the trial progressed and seedling defects in both the nursery and field plantings continued, it was thought that nutrient deficiencies may be the cause and the approach was re-evaluated with additional soil tests conducted. The soil tests did not yield any additional information in either potting mixes or field soil. Potting mixes sampled indicated satisfactory and non-limiting nutrient status.

The soil was generally deficient in most elements as stated and nutrient additions were programmed to deal with this. Typical nursery applications featured Guano Gold® basal application, MicroGyp® solution application Osmocote® granules, and Calcium Ammonium Nitrate (CAN) fertigation. In addition, foliar sprays of complete macro- and micronutrients were applied at three- to four-weekly intervals. Soil nutrient, pH and electrical conductivity pre- and post-trial status is shown in Table 4C.3.

Table 4C.3 Broome site soil nutrient status and conditions pre and post cocoa trial.

Nutrient or Property	Status Pre-trial (February 2001)	Status Post-trial (June 2002)
Nitrate Nitrogen	Low	Low
Phosphorus	Medium	Medium
Sulphur	Low	Medium
pH in water	Medium	High-slightly alkaline
Electrolytic conductivity	Low	Low
Organic carbon	Low	Low
Chloride		Low
Calcium	Low	Low
Magnesium	Low	Low
Sodium	Low	Low
Potassium	Low	Low
Ca sat %	Medium	High
Exch. Na %	Medium	Low

The change in soil pH to an alkaline status resulted presumably form the application of calcium fertilisers. Exchangeable calcium increased over the trial period but there was negligible change in magnesium, potassium or sodium levels. There were slight increases in electrolytic conductivity, available phosphorus and sulphur. Whilst most of the changes were positive the soil was still deficient.

The majority of trace elements in the soil were found to be adequate and not thought to be limiting plant or root growth. However, zinc was found to be very low in the soil and foliar applications were made.

Additional analyses for soil exchangeable aluminium and hydrogen were carried out to determine the extent of exchange site saturation and aluminium availability. The results indicated that aluminium is not a problem in these soils and unlikely to impede root development.

4C.3.7 Soil water and irrigation management

Seedlings in the nursery were irrigated twice daily for 10 minutes, and included a weekly fertigation with CAN at about 20 kg/ha.

Field seedlings were irrigated daily, with pulsed irrigation scheduled for 10 minutes at hourly intervals for 8 hours. This was based on the owners experience with this soil and climate establishing bananas and was in line with best practice following the 'little and often' approach to irrigating sandy soils. Irrigation was applied through 95 L/hr 'Dan' micro-sprinklers, with an effective mean precipitation rate of 4 mm/hr. Soil moisture status was checked regularly during field visits using a Dataflow Systems Soil Gopher®. The instrument was calibrated with the soil and a combined equation developed for the recording depths of 100, 200, 300, 400, 500, 600 and 700 mm. During this calibration process, the soil full and estimated refill points were established using a flooded soil bund and measurements over three days from flooding (Table 4C.4).

Table 4C.4 Soil physical properties at the Broome trial site

Depth (mm)	Bulk Density (g/cm^3)	Field Texture Group	Estimated Full Point (cm^3/cm^3)	Estimated PWP (cm^3/cm^3)	AWC (%)	RAW at 50% AWC (mm)	RAW (mm/40 cm)	RAW (mm/ 100 cm)	Chosen Refill Point (cm^3/cm^3)
100	1.75	clayey sand	0.19	0.09	10	5	20	50	12
300	1.74	clayey sand	0.20	0.09	0	5.5	22	55	12
500	1.74	clayey sand	0.20	0.09	10	5.5	22	55	12
70	1.74	clayey sand	0.20	0.09	10	5.5	22	55	12

PWP – Permanent Wilting Point; AWC – Available Water Content; RAW – Readily Available Water

The irrigation program appears to have been effective and no signs of plant wilting were noted.

4C.3.8 Climatic variables and impact on plant growth

Wood and Lass (2001) summarised cocoa climate limitations as:

- rainfall 1,250 to 3,000 mm/yr, with no dry periods exceeding three months
- mean maximum temperatures 30 to 32°C and mean minimum 18 to 21°C with an absolute minimum of 10°C
- no persistent strong winds.

They also rated sandy soils as being very poor for cocoa growth. Alvim and Kozlowski (1977) discuss the importance of diurnal variation in temperature on plant growth. Extremes of temperature occurring for a period of several days or even a few hours may severely reduce the growth of tropical crops.

Climatic data was recorded at the trial site from May 2001 to June 2002. The site had the following negative aspects for cocoa production:

- low rainfall of <700 mm/year
- low average relative humidity from March to November of 80% or lower and mean values often below 50%
- high daily maximum temperatures exceeding 40°C from October to April, with an annual range of 21°C to 42.5°C

- low daily minimum temperatures below 20°C from May to September, with an annual range of 22.5°C to 2.5°C
- high diurnal fluctuations in air temperatures of 30°C
- strong persistent winds with maximum wind speed of 10 km/hr or higher throughout the year
- a sandy soil of very limited water holding and low nutrient status.

Some of these limitations were known at the commencement of the trial; others have been realised as the trial progressed. The general approach to this trial has been to treat the soil as a medium; to be frequently replenished with nutrients and water delivered via irrigation. It was hoped that microclimate changes created with irrigation could mitigate some of the adverse climatic aspects.

Climate data was collected from two sources; using a fully automated Weathermaster 2000 ® climate recording station on the edge of the trial and inside the canopy and using temperature data loggers (Gemini Tinytalk®) at three sites to measure and record 10 minute temperatures.

The greatest unknown at the outset of the trial in Broome was climate suitability for cocoa growth and development. The data collated indicates an environment which is definitely alien to the conditions under which cocoa is normally cultivated. The periods of greatest stress for plant growth would appear to be November to April having the highest average air temperatures, high wind speeds and highest levels of incident radiation (refer to Section 4D Climate Records).

Additionally, the cooler months from June to August are also stressful to tropical plants. For example, there is little or no plant growth and poor fruit development of bananas during this period. Air temperatures reach minimums of 2.5°C and maximums of 35°C during this period, again highlighting the wide range in temperatures. Cocoa also suffered from cooler temperatures and one batch of cocoa seed planted to the nursery in June completely failed to germinate.

Data loggers installed inside the acacia plant canopy recorded temperatures that were generally lower by a few degrees, than those outside the canopy i.e. from the weather station. Daily data for two periods – May to June 2002 and October to November 2001 – is shown in Figures 4C.11 and 4C.12 which illustrate the large diurnal fluctuations.

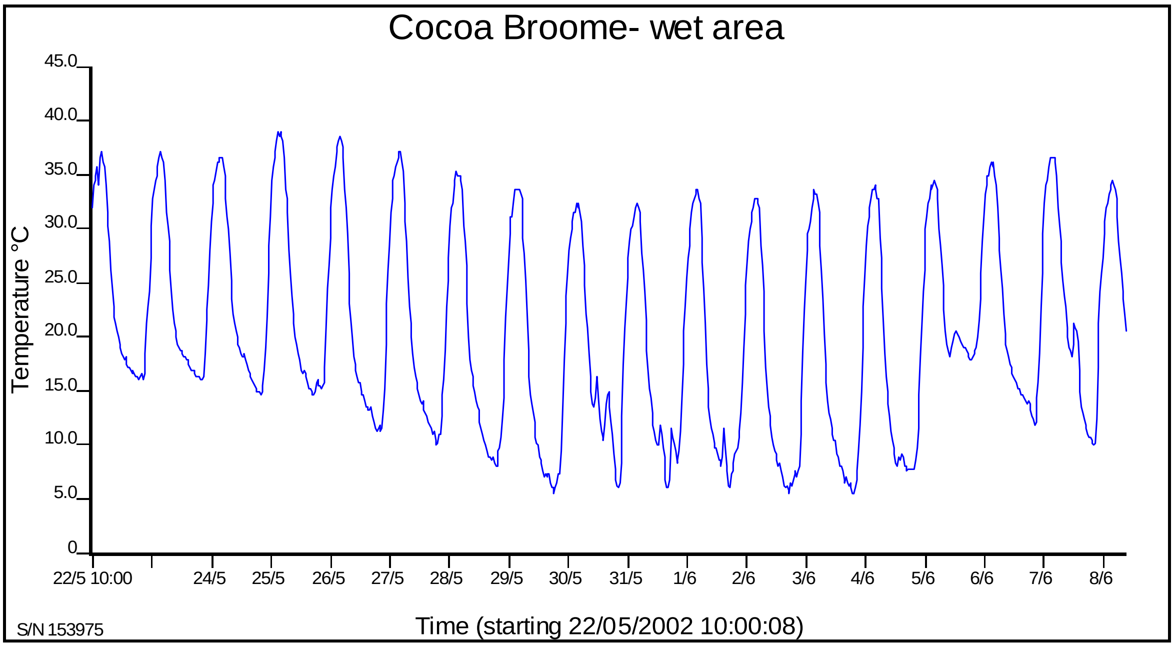


Figure 4C.11 Daily data for air temperature inside the acacia canopy at the Broome trial site – May to June 2002.

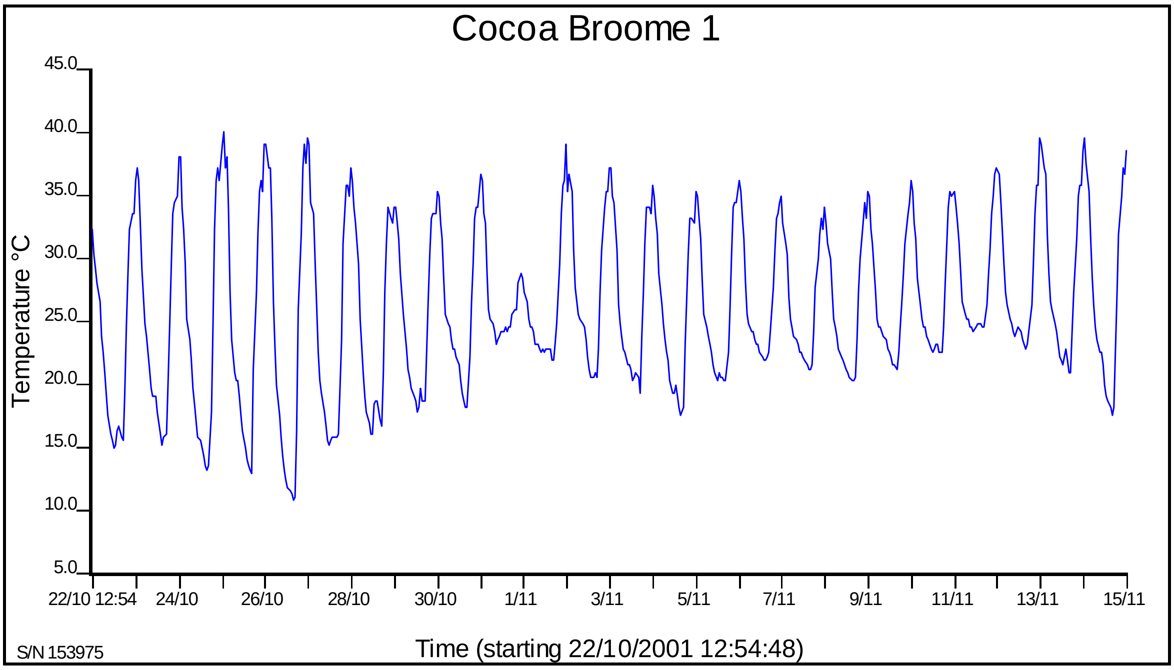


Figure 4C.12 Daily data for air temperature inside the acacia canopy at the Broome trial site – October to November 2001.

4C.4 Kununurra

A small trial was established in Kununurra at the DAFWA Frank Wise Research Institute (FWRI) in 2000, funded independently by DAFWA.

Cocoa trees were field planted to a smaller 0.1 ha site at Kununurra. Field planting was carried out in October-November 2000 utilising seed from the February CCRI delivery. A total of 160 seedlings were planted to the field from September 2000 to January 2001 in four double-rows. These plants did not develop the same root problems as those in Broome. Despite field planting being conducted at the worst time of year in terms of environmental conditions, plants coped well with high daytime temperatures in excess of 40^{o}C.

The environment was alleviated by well-established shade (4 m in height) at time of planting. Some losses were experienced due to termites. Monitoring and control was affected by employing colony attractant drums (refer to Section 4B.2 for details).

In August 2001 seedling growth was satisfactory with 75% of trees jorquetted, with height to jorquette ranging from 0.64 to 1.38 m. In November 2001, five trees had started flowering. Figure 4C.13 shows the field established cocoa at the Kununurra site.

A final set of measurements on tree physical parameters (tree height, tree diameter and jorquette height) and reproductive status (flowering or not flowering) was carried out in January 2003 (Table 4C.5). Mean tree height for the four hybrids ranged from 1.52 to 1.65 m. The associated standard errors of the mean suggest that the differences are not significant. Tree diameter in January 2003 was similar for the four hybrids and ranged from 26.6 to 27.6 mm. The jorquette height ranged from 0.81 to 0.95 m and was significantly less for PNG2.

Table 4C.5 Mean tree height, tree diameter and jorquette height and associated standard errors (n = 32–35) and reproductive status (flowering or not flowering) in January 2003.

Hybrid	Tree Height (m)	Tree Diameter (mm)	Jorquette Height (m)	Flowering (%)
PNG1	1.57±0.08	26.76±1.61	0.95±0.05	74.3
PNG2	1.52±0.05	27.64±1.21	0.81±0.03	67.6
PNG4	1.65±0.07	27.10±1.53	0.95±0.04	68.8
PNG5	1.59±0.06	26.91±1.26	0.93±0.04	71.4

Figure 4C.13 Cocoa trees established at Kununurra FWRI (March 2003).

Tree growth was significantly better in Kununurra than in Broome. In-field temperature data collected at both sites in June/July 2001 (Figure 4C.14) shows that the Broome site was significantly colder at nights with minimums less than 8°C compared to warmer nights at Kununurra where minimums where approximately 12°C.

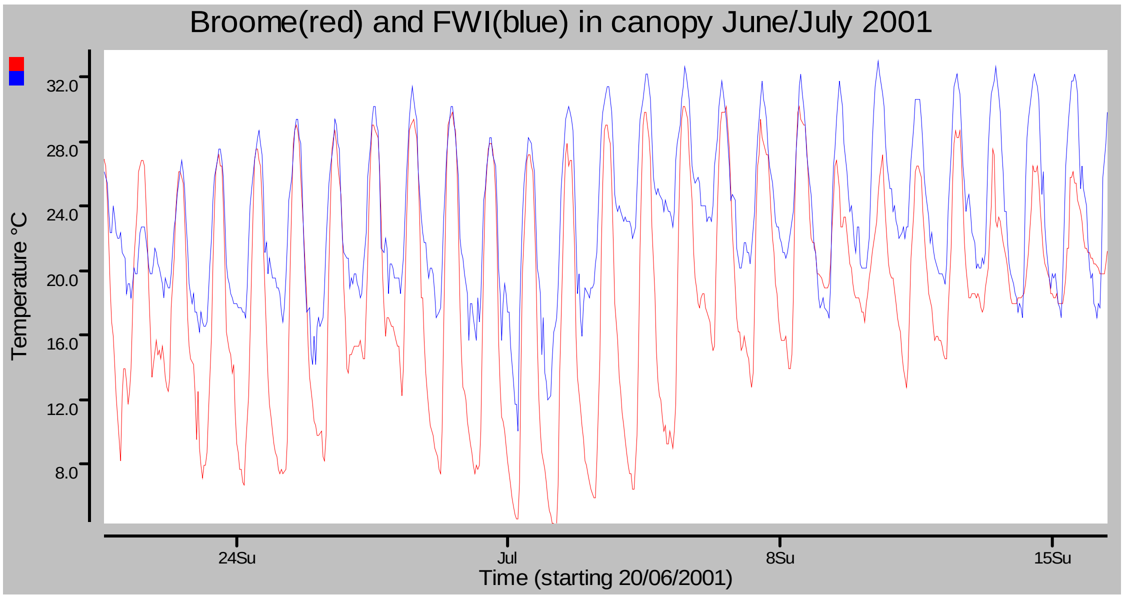


Figure 4C.14 Daily in-field temperature comparisons (June/July 2001) for the Broome and Kununurra cocoa trial sites.

4C.5 General discussion

The principle issue with the Broome trial since the first batch of cocoa seed was received in January 2000 was the inability to obtain a sufficiently high rate of germinated seeds and grow plants to healthy and viable seedlings for transplanting.

Secondary to this was the subsequent poor growth and development of seedlings in the nursery. A large component of the poor growth was most likely related to the conditions that seeds were exposed to pre- and post-germination (in transit form PNG to Broome), most likely associated with significant changes in temperature during air freight.

The third aspect of the poor performance was the post-planting phase of these apparently affected seedlings to the field and their apparent loss of vigour and root development capacity

Compounding all of the above was climatic factors. The physical environment is apparently too variable to sustain cocoa growth and development.

The issue of viable seed delivery is problematical but not insurmountable. For example, it should be possible to raise seedlings in Cairns in sterile medium then road transport to Broome which was the next option for the trial. However, even if a good germination were achieved there is still great cause for doubt as to the subsequent level of successful seedling establishment and vigour, given the climate limitations.

Issues relating to soil nutrient and water management could be managed more easily, possibly by focussing on the soil health perspective. However, the economics of this would need to be evaluated.

In conclusion it appears that the climate experienced some 22 km from the coast near Broome is not coastal but more arid in nature and thus likely to be the greatest limitation for cocoa and other equatorial tropical crops being established here. It is interesting to note that in Kununurra, seedlings have performed much better which may be partly related to an improved temperature environment.

In June 2001, DAFWA decided to cease support for the cocoa trial and withdraw from the NACDA project. Nick Richards visited the trial site in June 2001 and discussed this with the landowners who also decided to discontinue further involvement in the trial. The trial was subsequently terminated.

4D. Climate records

4D.1 Introduction

The bulk of cocoa production occurs within 10^{o} north and south of the equator with production areas in southern Brazil approach 20^{o}S of the equator. These areas are tropical in nature with relative high well-distributed rainfall and warm temperatures year-round (Figure 4D.1).

Wood and Lass (1992) summarise the climatic preferences of cocoa as:

- rainfall: 1,250 to 3,000 mm/yr but with 1,500 to 2,000 mm/yr preferred with no more than three months under 100 mm
- temperature: mean maximum 30 to 32^{o}C, mean minimum 18 to 21^{o}C, absolute minimum > 10^{o}C
- wind: no persistent strong winds.

They state that temperatures well above 32^{o}C can be tolerated for short times and leaf temperatures as high as 46^{o}C were regularly recorded in Trinidad.

As well as the direct effect of climate on tree growth and yield, Alvim and Kozlowski (1977) report that temperature also affects chemical and physical characteristics of cocoa butter, in terms of the percentage of fatty acids and melting point of the butter. These authors conclude that an alternation between dry and wet periods is a major external factor affecting flowering and that hydroperiodicity is the most important exogenous stimulus for enhancing flowering and opening of vegetative buds. The optimal day temperature for dry weight increase and relative growth rates, for 55-day-old cocoa seedlings over 60 days, was found to be 33.3°C (Sena Gomes and Kozlowski 1987).

Cocoa is found growing in far northern Queensland from Cooktown (16°S) to Tully (18°S) and in the vicinity of Darwin (12°S) in the Northern Territory. In the NT crop survival is dependent on irrigation for the long dry season.

This section discusses the climatic averages recorded during the trials with particular reference to temperature, rainfall, rainfall deficit, radiation and relative humidity. Reference is also made to the climatic means in major world production regions.

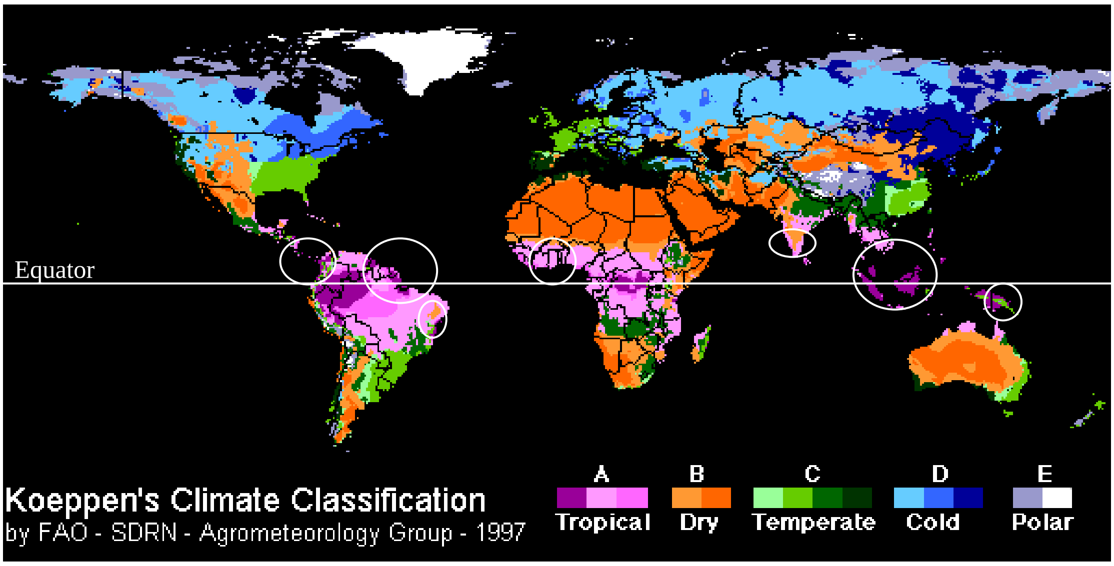


Figure 4D.1 Major cocoa growing regions (circled) in relation to distance from the equator. The authors acknowledge the use of the FAO SDRN agrometeorology group Koeppen's World Climate Classification figure.

4D.2 Materials and methods

Climate data (temperature, rainfall, evaporation, radiation, relative humidity) was obtained from the Bureau of Meterology (BOM) Silo project. The data obtained was patch point data for existing BOM recording stations within the vicinity of trial sites for the periods in which growth and yield data was collected (Table 4D.1). The Patched Point Data set uses original BOM measurements for a particular meteorological station, but with interpolated data used to fill ('patch') any gaps in the observation record (Anon 2008). The relevant Patched Point Data sets for South Johnstone and Port Douglas sites are given in Appendix A4.

Table 4D.1 Cocoa trial sites, associated BOM weather stations, latitude and longitude, distance from station to trial site and the period in which means were calculated.

Trial Site	BOM Weather Station site and Station Number	Latitude/Longitude	BOM Station Distance from Trial Site (km)	Time Period of Data Used to Calculate Means
Coastal Plains Research Farm, NT	Middle Point (14090)	12.58°S; 131.31°E	1.0	January 2000 to December 2006
Skuthorpe (approximately 20 km from Broome, WA)	Broome Airport (3003)	17.95°S; 122.24°E	≈ 20.0	January 2000 to December 2003
DPI&F South Johnstone, Qld	South Johnstone (32037)	17.61°S; 146.0°E	0.0	June 2000 to June 2007
Goodman Farm (approximately 5 km west of Port Douglas, Qld)	Port Douglas (31052)	16.48°S; 145.46°E	5.0	June 2000 to June 2007

Daily data over the time period relevant to the trial sites was obtained electronically from the BOM. The data was entered into Microsoft Excel and monthly means or totals calculated and graphed.

4D.3 Results and discussion

4D.3.1 Temperature

Mean maximum temperatures were the highest for Middle Point in the Northern Territory with monthly means varying from a low of 31.7°C in June to a high of 36.8°C in October. In contrast the mean maximum temperature had a greater seasonal variation for the two far northern Queensland sites. South Johnstone had the coolest mean maximum temperatures with a low of 24.4°C in June to a high of 31.3°C in February (Figure 4D.2).

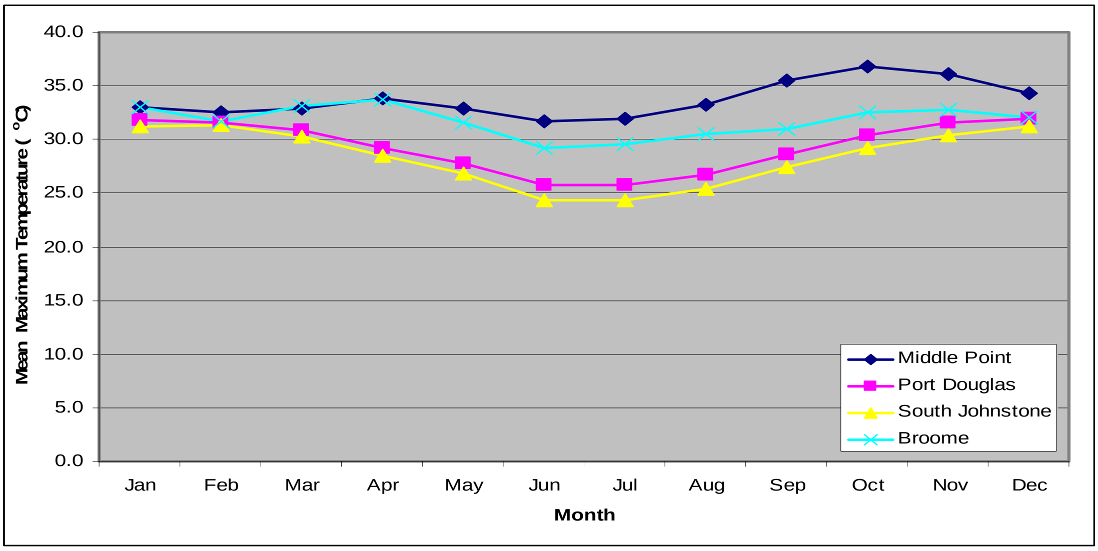


Figure D4.2 Mean maximum temperatures for the trial sites during periods of data collection.

Mean minimum temperatures were the lowest for Broome during the winter months and highest during the summer months ranging from 13°C in July to 26.2°C in December. The least seasonal variation was recorded in Port Douglas with the lowest mean minimum temperature of 17.8°C in July and the highest mean minimum temperature of 24.6°C in February (Figure 4D.3).

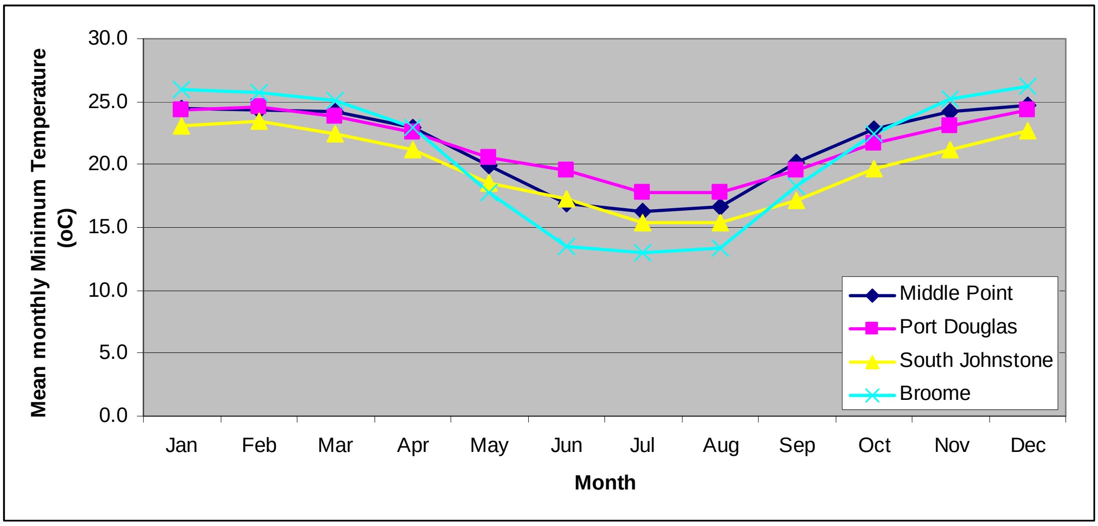


Figure 4D.3 Mean minimum temperatures for the trial sites during periods of data collection.

Temperature is an important factor determining the time taken for biological processes. The time required for pod development is influenced by temperature. The location of cocoa production areas and the mean temperatures in those environments may have a strong influence on productivity.

Pods take approximately five to six months to mature from pollination. Ultimately the aim is to have two full cropping cycles occur per 12 month cycle thus maximising productivity (Lass pers comm.). Alvim et al. (1974) determined that the heat sum for pod development is 2520 growing degree days (GDD). Heat sums can be calculated by adding the daily mean temperature minus the base temperature in this case determined to be 9°C for the period from fertilisation to harvest maturity.

The base temperature is the temperature below which no growth occurs; hence in this case the first 9°C is discounted. This can be expressed in the following formula:

$$\text{Heat sum (GDD)} = \sum((\text{MaxTemp} + \text{Min Temp})/2) - 9^{\circ}\text{C}.$$

Calculated heat sum from fertilisation to maturity

(assuming 2520 GDD, base temp = 9°C, flowering date from mid-month)

The time to pod maturity for each growing location depends on the date of flower fertilisation and the temperature range during pod development. The data in Table 4D.2 shows that warmer growing locations have the shortest mean pod development time over a 12 month production period. The mean pod development time is 135, 144, 153 and 167 days for Middle Point, Broome, Port Douglas and South Johnstone growing environments respectively. The Middle Point location allows for pod development in as little as 123 days and as much as 152 days, a difference of 29 days in time to maturity whereas the South Johnstone location allows for pod development in as little as 142 days and as much as 194 days, a difference of 52 days in time to maturity.

Table 4D.2 Calculated pod maturity date and days from flowering for cocoa grown at four sites in northern Australia (assuming a base temperature of 9^{o}C and a heat sum of 2520 GDD).

Assumed Flower Fertilisation	Calculated Pod Maturity Date							
	Middle Point		Broome		Port Douglas		South Johnstone	
Date	Date	Days	Date	Days	Date	Days	Date	Days
15-Jan	25-May	131	26-May	132	8-Jun	145	21-Jun	158
15-Feb	3-Jul	141	14-Jul	150	22-Jul	158	11-Aug	178
15-Mar	9-Aug	147	28-Aug	166	1-Sep	170	22-Sep	191
15-Apr	14-Sep	152	6-Oct	174	7-Oct	175	26-Oct	194
15-May	12-Oct	150	3-Nov	172	4-Nov	173	22-Nov	191
15-Jun	5-Nov	143	25-Nov	136	28-Nov	166	15-Dec	183
15-Jul	27-Nov	135	14-Dec	152	19-Dec	157	3-Jan	172
15-Aug	20-Dec	127	2-Jan	140	9-Jan	147	22-Jan	160
15-Sep	16-Jan	123	23-Jan	130	1-Feb	139	12-Feb	150
15-Oct	15-Feb	123	18-Feb	126	26-Feb	134	7-Mar	143
15-Nov	20-Mar	125	20-Mar	125	28-Mar	133	6-Apr	142
15-Dec	22-Apr	128	19-Apr	125	30-Apr	136	10-May	146
Mean		**135**		**144**		**153**		**167**
Min		**123**		**125**		**133**		**142**
Max		**152**		**174**		**175**		**194**

The warmer the growing location the more likely it is that two full crops can be produced in a 12 month cycle. At Middle Point two full crops can be grown in 270 days, assuming a fertilisation date of mid-March and mid-October, thus leaving 95 days (approximately three months) for re-flowering. Whereas in South Johnstone two full crops will take 334 days to develop, assuming a fertilisation date of mid-March and mid-October, thus leaving 31 days (one month) for re-flowering to commence after the crop is picked (Table 4D.3). Hence it is most unlikely that two full crop cycles can be completed in a year. In cocoa, flowering occurs throughout the year; however there are peak flowering periods which lead to peak harvest times (refer to Section 4A).

Table 4D.3 Time taken to complete two full pod maturity cycles assuming a mid-March and mid-October fertilisation date.

Location	Assumed Fertilisation Date	Days to Pod Maturity	Remaining Days in the Year
Middle Point	15-Mar	147	
	15-Oct	123	
	Total	270	95
Broome	15-Mar	166	
	15-Oct	126	
	Total	292	73
Port Douglas	15-Mar	170	
	15-Oct	134	
	Total	304	61
SJ	15-Mar	191	
	15-Oct	143	
	Total	334	31

4D.3.3 Rainfall and rainfall surplus and deficit

South Johnstone was clearly the wettest trial site with a mean annual rainfall during the trial period of 2,876 mm, followed by Port Douglas with 1,846 mm, Middle Point with 1,438 mm and Broome with 892 mm. The rainfall pattern for the four sites was seasonal with the bulk of rainfall recorded from December to April. Relatively dry conditions were recorded from May to October (Figure 4D.4).

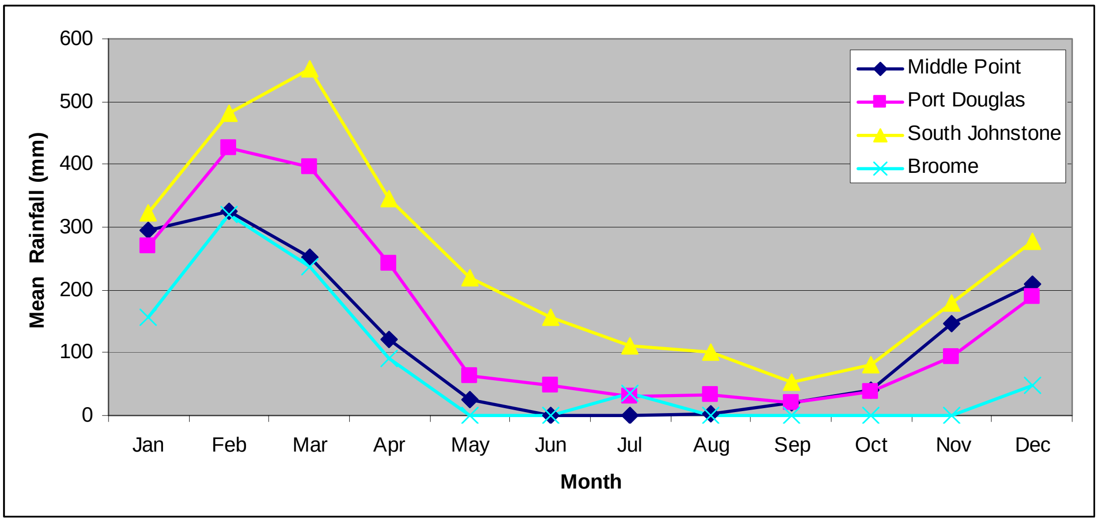


Figure 4D.4 Mean rainfall for the trial sites during periods of data collection.

Rainfall less evaporation data allowed a comparison of periods in which rainfall was in excess of evaporation or in deficit. The rainfall deficit was greatest in north Western Australia and the NT with evaporation exceeding rainfall for ten and eight months of the year for Broome and Middle Point respectively. In far northern Queensland, the Port Douglas site was the driest with evaporation exceeding rainfall for seven months of the year. At South Johnstone evaporation exceeded rainfall for five months with only two of the months producing a serious deficit (Figure 4D.5).

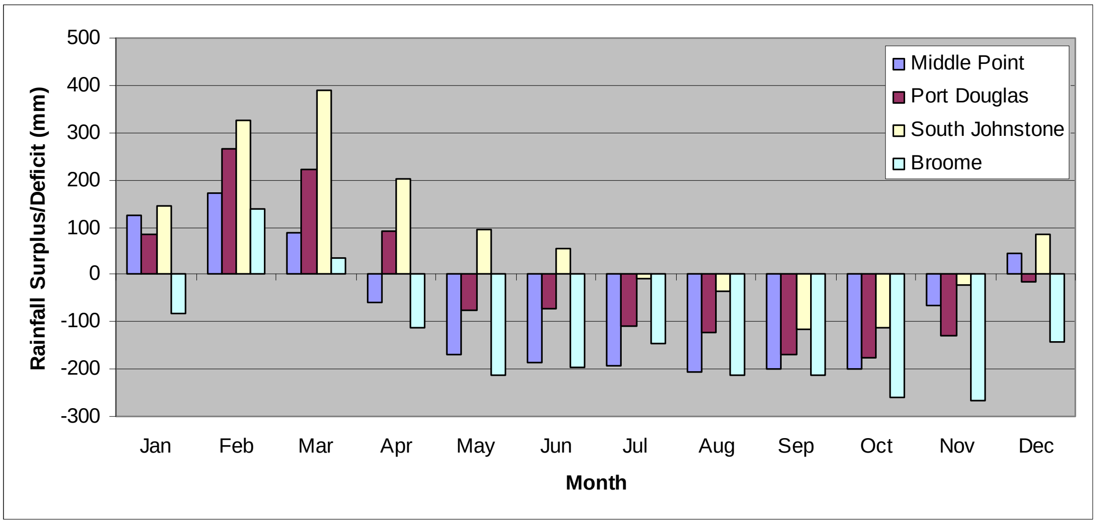


Figure 4D.5 Mean rainfall surplus/deficit for the trial sites during periods of data collection.

4D.3.4 Solar radiation

As shown in Figure 4D.6, solar radiation inputs are a reflection of day length and clear skies. Mean radiation measurements at the four trial sites show that the two northern Queensland sites have the most seasonal change in mean radiation inputs from a low in June of 15 MJ/m^2/day when the day length is at its shortest to a high in October/November of 23 to 24 MJ/m^2/day with longer days and relatively clear skies. Mean radiation levels drop in December and January as cloudy skies reduce incoming sunlight.

Similar patterns occur in WA and the NT. However there is less seasonal variation and less depression in radiation during the winter months. A strong depression in radiation occurs at Middle Point in December, January and February due to the influence of the monsoon.

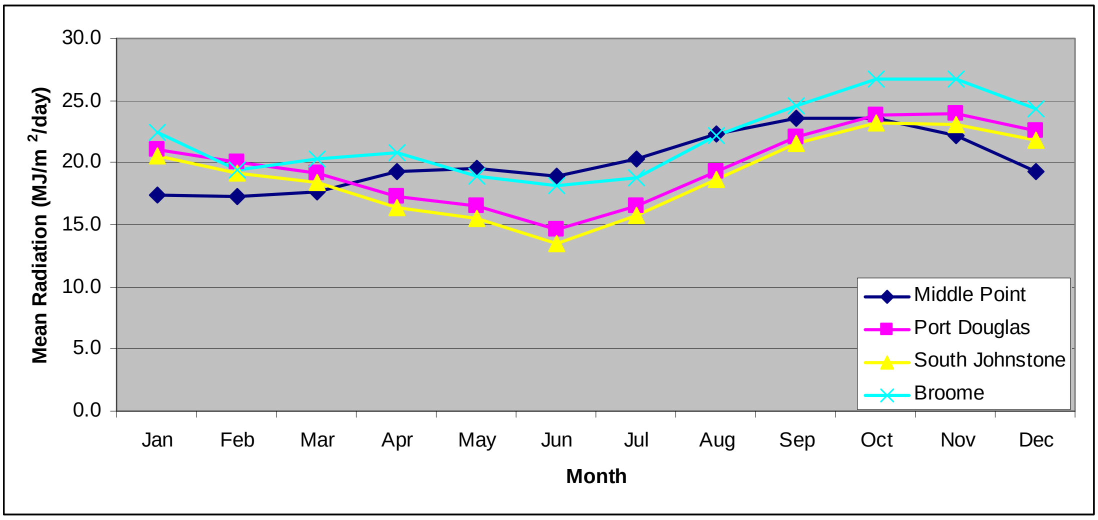


Figure 4D.6 Mean solar radiation for the trial sites during periods of data collection.

4D.3.5 Relative humidity

Relative humidity is an important environmental influence on the performance of cocoa. The cocoa plant prefers high humidity conditions for effective photosynthesis. In all environments monitored the relative humidity (RH) at the minimum daily temperature is between 90 to 100% because RH is the amount of moisture in the air as a percentage of the amount the air can actually hold at that temperature – so for the same air mass the relative humidity drops as the day warms up. RH is relatively constant (50 to 67%) in far northern Queensland but has significant seasonal changes in the NT and north WA. In the NT and north WA the mean monthly RH drops rapidly after March and remains relatively low at 25 to 40% until October (Figure 4D.7).

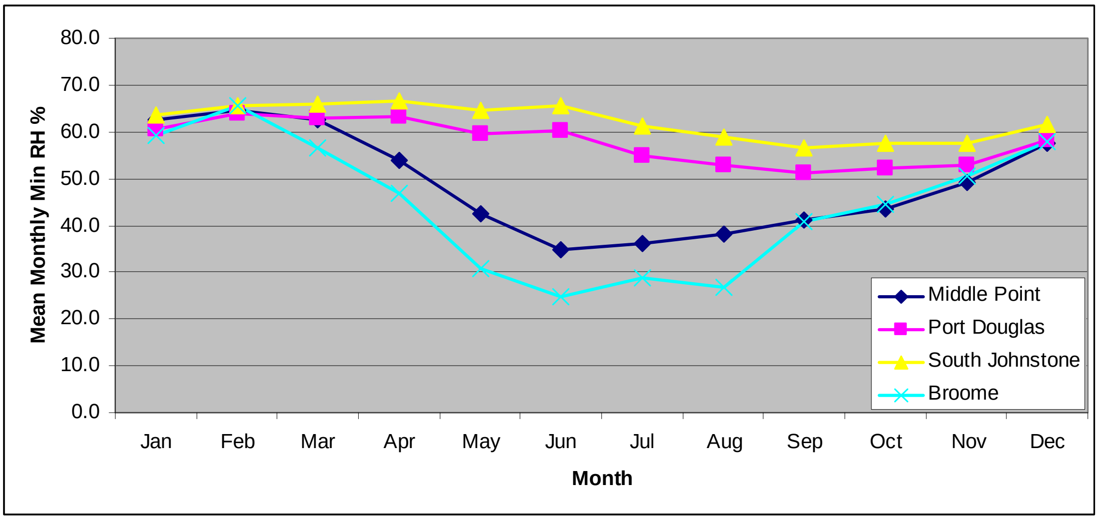


Figure 4D.7 Mean relative humidity for the trial sites during periods of data collection.

The low RH conditions experienced in the NT and northern WA for six to seven months of the year lead to high vapour pressure deficits (VPD) between the internal leaf moisture and the atmosphere. In cocoa a high VPD leads to closure of the stomata and hence a lowering or even cessation of photosynthesis. Leibel (2008) reports a range of workers having shown that carbon assimilation in cocoa decreases once VPD exceeds 1.6 kPa. In the NT dry season VPDs commonly exceeded 4.0 kPa during the dry season. At the corresponding time the VPDs were under 3.0 kPa in South Johnstone.

4D.4 Summary

Climatic conditions are harsh in potential growing areas in the Northern Territory and north-west Western Australia. Temperatures are extreme and the relative humidity, an important environmental factor for cocoa, is low for much of the year. Leibel (2008) in his examination of the ecophysiological function of cocoa in various growing locations in Australia based on the NACDA sites states that the environment at the Mossman site in far northern Queensland offered the most suitable climatic conditions for growing cocoa of the five NACDA locations. The growth and yield data presented in the Hybrid Yield Evaluation Trials indicates that this is the case.

The South Johnstone site in far northern Queensland, despite limitations due its cooler winter climate is suitable for cocoa production. Other growing areas in far northern Queensland may be suitable, however, mean minimum temperatures become an important consideration. Table 4D.4 compares annual rainfall, the number of dry months (rainfall < 100mm), mean maximum temperature range and mean minimum temperature range for three overseas cocoa producing regions (Itabuna – Brazil, Tafo – Ghana, Medan – Indonesia) with four far northern Queensland growing locations (Mossman, South Johnstone, Ingham and Mackay).

The overseas cocoa growing sites are categorised by high evenly spread rainfall, and high mean maximum and minimum temperature ranges. The rainfall in far north Queensland is more seasonal, however, the use of irrigation can overcome this limitation. The minimum temperature range in far northern Queensland has a minimum 2 to 7 degrees cooler then that experienced in Itabuna, Brazil which is the coolest of the commercial overseas growing regions.

Table 4D.4 Climate comparisons (annual rainfall, the number of dry months (rainfall < 100mm), mean maximum temperature range and mean minimum temperature range) for three overseas cocoa producing regions (Itabuna – Brazil, Tafo – Ghana, Medan – Indonesia) with four far northern Queensland growing locations (Mossman, South Johnstone, Ingham and Mackay).

Location	Annual Rainfall (mm)	Dry Months (<100 mm)	Mean Maximum Temperature (^{o}C)	Mean Minimum Temperature (^{o}C)
Ideal	**1,500–2,000**	**3**	**30.0–32.0**	**18.0–21.0**
Itabuna, Brazil (14.5^{o}S)	1,720	1	26.0-30.5	17.0-21.0
Tafo, Ghana (6.2^{o}N)	1,600	4	27.5-32.5	20.0-21.5
Medan, Indonesia (3.4^{o}N)	2,029	1	29.0-32.0	22.0-23.0
Mossman (16.3^{o}S)	1,992	6	27.7-35.4	16.8-23.7
South Johnstone (17.3^{o}S)	3,287	3	23.7-31.2	14.9-22.5
Ingham (18.6^{o}S)	2,019	5	24.9-32.5	13.6-23.2
Mackay (21.1^{o}S)	1,684	7	23.3-31.3	10.2-21.8

5. Pod splitting and bean extraction

5.1 Introduction

5.1.1 Traditional primary cocoa processing

In most traditional cocoa producing countries, harvested cocoa pods are processed into dried, fermented beans on-farm. This 'primary processing' of cocoa involves three steps:

i. opening of the cocoa pods and extraction of the wet bean

ii. fermentation of wet beans

iii. drying of fermented beans.

Typically, harvested pods are gathered together and opened in-field. This is done manually by cutting or breaking the pods and scooping out the beans by hand. The wet beans are then gathered together and fermented using a wide range of techniques. These range from in-field heap fermentations with beans wrapped in banana leaves, through to industrial scale, central fermentaries servicing large production areas. At the small scale, drying is generally carried out by spreading beans in the sun whereas larger-scale central fermentaries use forced hot-air drying.

Pod opening is performed within 0 to 12 days of harvesting and fermentation is started as soon as there are enough wet beans to make a 'batch' (minimum 50 kg). Depending on the method, fermentation takes 3 to 6 days and drying is started as soon as fermentation is completed. Sun drying takes over a week, whereas 'artificial' drying can be achieved in 48 hours.

5.1.2 Implications of primary cocoa processing for Australian cocoa production

At the outset of the NACDA project it was acknowledged that the primary processing of cocoa would pose a significant challenge to viable production in Australia. Indeed the laborious nature of pod processing had in all likelihood been a historical factor inhibiting any development of an Australian-based industry.

This is confirmed by simple calculation based on productivity rates cited in general reading of cocoa literature and confirmed on the Cocoa Study Tour to Malaysia conducted prior to the NACDA project proposal development (Lemin et al. 1998). Typical productivity for manual pod splitting and bean extraction is 250 to 400 pods/person/hr. Assuming a yield of 1 kg dry/bean per 25 pods, this equates to 100 to 62.5 hrs/t dry bean. Assuming a minimum labour cost in Australia of $15 /hr, the cost would be at least $950 /t just for pod opening and bean extraction. Therefore manual pod splitting and bean extraction could not be considered in Australia.

Notwithstanding the above, it was apparent that technology used for fermentation and drying in some cocoa producing regions would be quite appropriate in the Australian context. In particular this was based around the industrial style fermentaries common to Malaysia and some parts of Indonesia. Such set-ups included a range of approaches for 'mechanised' fermentation and drying which could be readily adopted in Australia and indeed offered scope for further development and greater efficiency.

Therefore, investigation and development of mechanisation for cocoa pod processing and bean extraction was seen as a priority in the NACDA project. Work was commenced early in the research program, since any viable agronomic system developed would still be dependant on an economic processing system.

However, at the outset a deliberate decision was taken not to focus on fermentation and drying aspects beyond proving the commercial acceptability of Australia grown cocoa beans using proven techniques from overseas 'industrialised' systems. Likewise no investigation of secondary processing systems was necessary since these technologies were even more highly developed.

5.2 Investigation of existing overseas technology

5.2.1 Introduction

Wood and Lass (1985) cite a number of references in cocoa literature to mechanised pod openers dating back to the 1960s. It is claimed that none of these reached the stage of a commercially successful design because of the difficulty in designing machinery to separate the wet beans from broken pod husk. In general these inventions relied on the principle of crushing pods to break them open with subsequent screening to separate the beans. Descriptions of their design and performance in the literature are only general.

However, there has since been a number of attempts at commercial cocoa pod splitters. These include Pinhalense (Brazil), Zinke (Costa Rica), Christy and Norris (UK), Zumex (Spain) and Cocoaette (France). In some cases commercial equipment was developed, however none has been widely adopted by the industry. The problem, apparently common to most of these machines, is excessive contamination of bean with small pieces of broken pod. The presence of pod fragments is undesirable during the subsequent fermentation of bean and requires that wet bean is hand sorted to remove pod fragments.

Within the NACDA project several initial inquiries turned up some promising leads. Through the 'Question and Answer' forum on the International Cocoa Organization website, the ICCO forwarded some historical references to pod cutting machines including Cacaoette of France, Zumex of Spain and Pinhalense of Brazil (these were also mentioned by Tony Lass of Cadbury Ltd.). Subsequently, contact was established with both Pinhalense and Zumex and the outcomes of this are detailed in Section 5.2.3.

Dr Chris Searle (pers comm. 1999) of DPI&F recalled Unilever engineers working on a cocoa pod splitter in the Solomons in the early 1980s but had no details or contacts. Dr Rob Lockwood (pers comm. 1999) of the Commonwealth Development Corporation confirmed that some such work may have occurred but Unilever were more focussed on developing coconut splitters. Tony Lass (pers comm. 1999) later confirmed that any work which Commonwealth Development Corporation did with cocoa splitters was using 'the Brazilian Pinhalense machine and it was not very pretty or effective'. Cadbury had also made a 'rustic' design at a Cameroon plantation in the early 1970s but there were difficulties separating the pieces of husk covered in mucilage from the bean also covered in mucilage.

Separately, Mr Keith Courte (Torrens Creek Pilot Vehicle Service) made contact in late 1999 claiming to have previously designed and constructed a functioning cocoa pod splitter when formerly managing a cocoa plantation in Papua New Guinea. He supplied a parts/materials list and offered to build a unit for $100 /day plus expenses. However he would not divulge any details of the machine or its performance so his offer was not taken up.

5.2.2 Performance and limitations

In reviewing inventions for mechanical cocoa pod splitters, most were based on the principle of crushing pods with subsequent separation of the pod husk from beans using rotating trommels. Following initial development, none of these inventions appear to have been commercialised or adopted in producing countries. Two reasons are proposed for this:

i. The crushing action causes fragmentation of the pod husks and separation of the placenta which is difficult to efficiently separate from the wet bean sample even with trommels or screens. Since conventional fermentation practices placed importance on excluding husk and placental material, then there was little benefit to be gained if the wet bean sample from mechanised splitting had to be 'hand cleaned' prior to fermentation.

ii. Secondly, even if the performance of these machines was acceptable there was little imperative for smallholder cocoa farmers to adopt such technology since they operate at small scales and there is usually plentiful and cheap labour available. Also, such growers have limited ability to purchase or construct such equipment because of low financial and technical capacity. This is relevant given that more than 70% of world cocoa production is by smallholders.

Alternatively, some inventions (patents) for mechanical pod splitters are premised on mechanisms to discretely open pods such that the beans could (presumably) be cleanly separated from the husks. They are based on mechanically complex mechanisms to manipulate individual pods, but there is no corresponding apparatus proposed to efficiently deliver pods to such equipment. Also, the method to extract beans from open pods is not always apparent. Therefore, few if any of these devices appear to have been proven or progressed beyond design ideas or patent applications.

5.2.3 Prior manufacturers of pod splitting equipment

After commencement of the NACDA project in 1999, initial investigations into mechanised cocoa pod splitting revealed two companies purporting to manufacture commercial pod splitters.

One was Zumex Maquinas y Elementos, S.A. (Spain), a company primarily focussed on design and manufacture of fruit processing/juicing equipment. A commercial cocoa pod splitter was promoted on the company website. Contact was established with Zumex in 1998. They forwarded a commercial video demonstrating a commercial pod splitting and extraction plant with 'pod contamination of bean <5%'. However, follow-up inquiries as to where the technology could be seen working to verify its existence and performance were not answered. It is assumed that no or few sales of this technology ever occurred and it is doubtful that Zumex remains interested in it.

The second company was Pinhalense Maquinas Agricolas (Brazil) who mainly manufacture coffee processing equipment. The author (Craig Lemin) had close involvement with this company during previous work on mechanised coffee harvesting in Brazil (1994/96). However, direct inquiries to Pinhalense about the cocoa pod splitter were thwarted by an intermediate agency that Pinhalense had appointed for product marketing. They could provide no information on any cocoa pod splitting machinery.

5.2.4 Australian-based development – Modra Automation

Prior to the NACDA project, Cadbury Schweppes initiated an AusIndustry project in collaboration with Modra Automation to develop a mechanised pod splitter. At the commencement of the NACDA project the developments and findings were subject to a confidentiality agreement. However subsequent negotiations resulted in the project report being released to DPI&F researchers on the NACDA project in 2000.

The technique tested by Modra was based on extraction of beans through an open end of the pod by inserting a rotating screw device. Initial testing had been done on fresh cocoa imported into quarantine in Australia (since they were not aware of any locally available material). However, the results were not compelling and no technique for removing the pod ends or holding pods during the extraction process was demonstrated (or proposed). Given this, and a subsequent lack of interest by Modra in a joint development, further engagement was not pursued.

5.2.5 Brazilian pod splitter and bean separator

During 1999, Mr John Zentveld (CAPE Australia) communicated with NACDA researchers on a pod splitter previously used commercially in Sumatra. Subsequent follow-up on this development yielded a contact in Brazil, Mr Pedro Alcantara, the export license holder for the company Paulini and Alves who manufactured a full line of coffee processing equipment. Pedro also operated his own engineering company and designed and installed cocoa pod splitting machinery for Askindo in Sumatra, whilst previously working for Pinhalense.

However, efforts by Mr John Aston (CS) to contact Askindo and inspect the equipment were frustrated through a lack of response. Subsequent to this, Pedro visited Australia in September 2000 on coffee business, and met with Craig Lemin while in northern Queensland. As a result of this, Pedro agreed to redesign and build a pod splitting machine, and ship it to Australia for testing and evaluation by NACDA. Whilst no written terms were entered into, it was agreed that the NACDA project would contribute to freight and import costs to facilitate the offer (subsequently AU$3,000). After lengthy shipping delays, this machine arrived in northern Queensland in late November 2001 and was immediately evaluated using locally sourced cocoa pods.

The Brazilian splitter operated on the principle of a pilot-operated pneumatic ram pushing individual pods end-wise down a vertical tube of about 100 mm diameter and onto three radial blades mounted symmetrically across the tube. Spring-loaded vanes mounted inside the tube and just above the blades were designed to centralise the pod prior to it passing over the blades. The unit was operated by manually placing a pod end-wise into the tube and activating the ram pilot control (a method for automating the loading process was claimed by Pedro but no method was actually put forward). On exiting the tube, split pods passed directly into a separating trommel. An overview of the splitting unit is shown in Figure 5.1.

Performance of the splitter was poor due to excessive pod fragmentation (breakage) and unacceptable levels of bean damage (crushing and cutting). This was attributed to the following:

- ineffectual alignment mechanism which only worked with pods having a circumference smaller but close to the tube diameter (many pods were pushed at an angle or even sideways over the cutting blades)
- energy of cutting action: force required and speed of pushing pods over the cutting blades was too great resulting in shattering of the husk
- sharpness of cutting blades resulted in cutting of beans.

Although, Pedro claimed the machine would perform better using correctly sized and freshly harvested pods, this was not achieved in practice. The disadvantages of the set-up were judged too great to warrant further development or extensive testing.

Figure 5.1 Overview of Brazilian pod splitter.

Notwithstanding this, the separating trommel into which pods from the Brazilian splitter were delivered was an effective design. The unit is shown in Figure 5.2 and comprised a horizontal octagonal screen about 800 mm diameter and 1.8 m long rotating at 30 to 50 rpm. The screen was constructed of mild steel rods about 6 mm in diameter and welded to provide an aperture ranging from 9 to 15 mm progressing from the inlet end to the outlet end of the screen. Several flat steel flights were mounted inside the screen and these could be adjusted to provide different angles of 'attack' to material inside the screen and promote or retard its passage from the inlet to the outlet end.

The internal flights inside the screen repeatedly lifted and subsequently dropped material against the flat bottom surface (due to the octagonal shape) with higher energy than if the screen was round. This effectively separated the pod/bean mixture such that dislodged beans could pass through the screen apertures whilst pod husks were retained in the screen and eventually passed out the end.

The performance of the separator was good enough to warrant further investigation and development. Because of this a 'break fee' was negotiated with Pedro to cover his costs of manufacture and shipping of the equipment and also in recognition of the intellectual property embodied in the original bean separator. Full development of the NACDA bean separator is discussed in Section 5.4.

Figure 5.2 Overview of Brazilian pod splitter and trommel.

5.3 Development of the NACDA pod splitter

5.3.1 Background

Because the uncertainties about the performance and suitability of previous pod splitting technology from overseas, independent design of a NACDA pod splitter commenced in early 2001 with firsts test of the prototype machine in about August 2001.

Once the prototype machine had been successfully tested and its potential confirmed, other development work was undertaken. This was aimed at techniques and machinery for mechanised delivery of pods to the pod splitter and subsequent separation of the pod husk, beans and placental material. This work is discussed separately in Sections 5.4 and 5.5.

5.3.2 Basis for development

From the literature on previous pod splitter inventions and from direct experience with the Brazilian pod splitter, it was concluded that these machines had not been adopted commercially because of limitations in their performance and/or design.

In the case of mechanically simple machines based on crushing pods, this resulted in a mix of beans and pod fragments which were difficult to efficiently separate.

In the case of mechanically complex machines based on discrete opening or cutting of pods, they had low throughputs because of stepwise handling procedures. They also required delivery of individual pods in a precise alignment. Since no actual methods for achieving this were developed or proposed, then they presumably relied on manual feeding.

Finally, none of the machines were well adapted to accommodate variable pod sizes whilst maintaining processing efficiency. In the case of crushing machines they would most likely be set-up for the median pod size. This would result in excessive break-up of larger pods and possible failure to break smaller pods. In the case of cutting machines it is likely that they would only accommodate pods within a certain size range. In either case additional units would be required to process pods outside of the optimum size range the machines would be set for. Alternatively, pods would need to be size-graded and batch processed after appropriate machine adjustments.

Therefore the parameters for development of the NACDA pod splitter were broadly identified as follows:

- discrete opening of pods into not more than four pieces for subsequent bean separation
- mechanically simple (suited to use in underdeveloped countries)
- not reliant on precise alignment of pods for processing i.e. ability for mechanical feed
- ability to continuously process pods at a minimum capacity of about 2,500 pods/hr
- ability to accommodate the entire range of pod sizes likely to be harvested.

Initial experimentation using knives to cut open pods demonstrated that beans could be more easily dislodged from opened pods when the pods were cut longitudinally into two halves as shown in Figure 5.3.

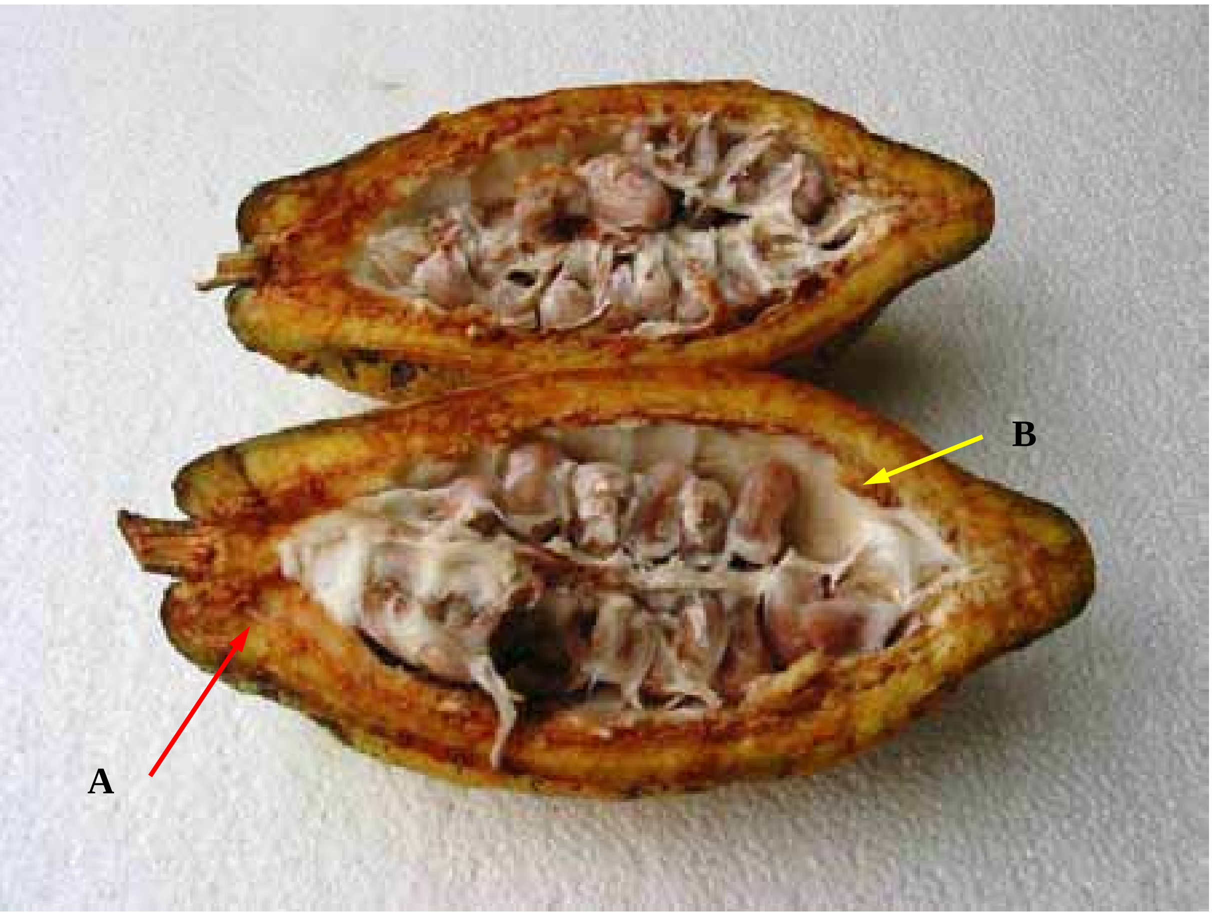


Figure 5.3 Cocoa pod cut longitudinally – note (A) extra thickness of husk particularly at stem end; and (B) tough layer surrounding seed cavity.

This is not easily achieved however because:

i. pod husks vary in thickness based on varietal differences and their ribbed nature – thicknesses in the range of 8 >20 mm were measured

ii. pods are more difficult to cut longitudinally in the 'neck' region (stem end) where the husk is particularly thick

iii. the presence of a tough layer surrounding the seed cavity

iv. the combination of the above three factors makes careful cutting of the pod husk (so as not to accidentally cut beans) very difficult – and erring on the side of an incomplete cut means that the pods will not easily break into two discrete halves.

It was observed however, that by first cutting the ends completely off pods (as shown in Figure 5.4) points ii) and iv) above were significantly mitigated. This was because, the pods could then be broken into two halves by applying a compression force in planes perpendicular to a longitudinal cut even if this cut was incomplete (as shown in Figure 5.5).

With this in mind, a prototype machine was developed to try and cut pods longitudinally. The challenge of cutting the ends from pods (either beforehand or afterwards) and breaking the pods into two halves could be addressed in separate apparatus.

Figure 5.4 Pod with ends cut off to facilitate splitting.

Figure 5.5 Pod cut longitudinally and split by applying a compressive force perpendicular to the plane of the cut.

5.3.3 NACDA Mark I pod splitter

The prototype NACDA pod splitter (Mark I) is shown in Figure 5.6. Its principle of operation was as follows:

- pods were dropped in an endwise orientation (long axis parallel to the direction of fall) into a gap formed between opposed dual pneumatic motorcycle tyres (grabbing wheels)
- the grabbing wheels were mechanically linked to rotate at the same speed toward each other (from the top) at about 60 rpm – the outside diameter of the tyres was about 750 mm
- the gap between the opposed grabbing wheels was set to be smaller than the average diameter of pods; as pods are contacted by the rotating tyres they are centralized (with respect to the gap) in the moment before pods are ‘grabbed’ by the converging tyre surfaces (and thence held firmly)
- the tyres were inflated at low pressure so that they deformed according to the various size and shape of pods
- two opposing cutting discs were mounted in a plane perpendicular to the tyres with the axle centreline of the cutting discs the same as the axle centreline of the tyres – the diameter of the cutting discs was about 200 mm
- the cutting discs had backing plates on each side which limited the depth of cut into the pod husk – a cut depth of about 17 mm was initially selected
- the cutting discs were mounted on pivoted arms which were spring loaded towards each other
- via the pivot arms and a frame stop, the cutting discs were adjustable to a close tolerance in the fully closed (no pod) position
- the cutting discs were mechanically powered to rotate inward (towards each other) when viewed from above i.e. direction of rotation was the same as direction of pod movement through the machine
- the speed of rotation of the cutting discs was adjustable
- as pods contact the cutting discs the spring pressure applied to the pivot arms is sufficient that the discs cut into the pod husk to a depth limited by the disc backing plates bearing on the pod surface immediately adjacent the cutting disc
- pods are held and forced by the grabbing wheels further onto the cutting discs
- the cutting discs (pivot arms) are forced apart by the pod and reach a point of maximum displacement coinciding with the maximum diameter of the pod
- the spring tension causes the cutting discs to close back onto the pod as the pod is forced further downward by the grabbing wheels.

Figure 5.6 Overview of NACDA pod splitter (Mark I).

Testing

Initial testing of the prototype machine was encouraging with relatively accurate longitudinal cuts being achieved and minimal damage to beans.

Results of comparative testing between the NACDA prototype splitter and the Brazilian pod splitter, demonstrated the NACDA splitter to be superior as follows:

i. less contamination of bean sample with pod fragments

ii. higher recovery of wet bean (less lost bean)

iii. less bean damage (cutting).

Figure 5.7 illustrates this difference in performance. The upper photo shows material separated using the Brazilian bean separator after pod splitting in the Brazilian pod splitter. The lower photo is for splitting using the NACDA pod splitter. In both cases the source, time since harvest and number of pods used were the same. Each photo show the amount of beans recovered in the trays below the separator (with any attendant contamination by pod fragments) and the pod material rejected by the separator trommel collected into a box. The photos do not illustrate the proportion of unrecovered beans (i.e. combined with the rejected pod husk) or the level of damaged beans in the recovered sample. The detailed results from this trial are given in Table 5.1. General results from other pod splitting trials are given in Table 5.2.

Figure 5.7 Material samples post-pod splitting by Brazilian pod splitter (top) and NACDA pod splitter (bottom).

Table 5.1 Results of processing trials comparing NACDA and Brazilian pod splitter performance.

Trial 1: Pods harvested 05/12/01, processed 10/12/01 (ex Conti)				
	Weight	Proportion of Total Sample by Weight	Proportion of Pod Components by Total Pod Weight	Proportion of Bean Components by Total Bean Weight
	(g)	(%)	(%)	(%)
Split and Screened in All Coffee Machine (31 pods)				
Recovered bean	1646	16.8		74.0
Damaged (cut) bean	66	0.7		3.0
Misplaced bean	511	5.2		23.0
Misplaced pod fragments	1002	10.2	13.2	
Rejected pod	6570	67.1	86.8	
Total	9795	100.0		
Split in NACDA machine and Screened in All Coffee Machine (31 pods)				
Recovered bean	1879	19.1		92.8
Damaged (cut) bean	1	0.0		0.0
Misplaced bean	145	1.5		7.2
Misplaced pod fragments	546	5.6	7.0	
Rejected pod	7243	73.8	93.0	
Total	9814	100.0		
TRIAL 2: Pods harvested 20/12/01, processed 21/12/01 (ex Conti)				
Split and Screened in All Coffee Machine (54 pods processed)				
Recovered bean	2379	16.2		68.9
Damaged (cut) bean	57	0.4		1.7
Misplaced bean	1018	6.9		29.5
Misplaced pod fragments	2461	16.8	21.9	
Rejected pod	8773	59.7	78.1	
Total	14688	100.0		
Split in NACDA machine and Screened in All Coffee Machine (54 pods processed)				
Recovered bean	3294	22.1		87.8
Damaged (cut) bean	15	0.1		0.4
Misplaced bean	442	3.0		11.8
Misplaced pod fragments	139	0.9	1.2	
Rejected pod	10997	73.9	98.8	
Total	14887	100.0		

Table 5.2 Results of processing trials comparing NACDA and Brazilian pod splitter performance.

Harvest Date	Processing Date	Source	Separator	Bean Weight (kg)		Proportion (% by bean weight)	
				recovered	misplaced	recovered	misplaced
28/08/02	**29/08/02**	**Mossman**	**All-Coffee**				
Trial 1				4.45	0.89	83	17
Trial 2				2.57	0.95	73	27
Trial 3				3.86	0.80	83	17
Trial 4				3.17	0.56	85	15
14/08/03	**26/08/03**	**South J.**	**All-Coffee**	**202.0**	**27.9**	**88**	**12**
28/10/03	**05/11/03**	**South J.**	**NACDA**	**25.6**	**2.2**	**92**	**8**

Capacity

Initially pods were processed through the machine by manual feeding into the machine and manual turning of the grabber wheels. This did not give a true indication of the potential operating capacity. Later (when the grabber wheels were powered) pods were processed through the machine as fast as an operator could keep pods up to the unit (by dropping individual pods into the grabbing wheels). By this method, operating capacities of one pod per 2–3 sec were achieved. (equivalent to 1,200 to 1,800 pods/hr).

5.3.4 Mark I pod splitter development and improvements

Crushing wheels

A limitation of the machine was that only an incomplete cut was achieved at the ends of pods. This was because of the geometry of the cutting wheels with reference to the pods. It was thought that this could be addressed in two ways as previously discussed:

i. cutting the ends from pods in a subsequent or prior operation using a separate apparatus

ii. and/or squeezing the pods perpendicular to the plane of the longitudinal cut.

With the aim of carrying out the second option a modification was made to the prototype unit whereby two opposing ‘crushing wheels’ were mounted directly below and in the same plane as the cutting discs on pivoted cutting arms. These were powered by an extension of the drive belts powering the cutting discs. The crushing wheels were spring tensioned towards each other in the same way as the cutting wheel arms.

The general arrangement of this apparatus in the prototype pod splitter is shown in Figure 5.8 with the crushing wheels shown in Figure 5.9 (disassembled and simulated with a pod). Only brief testing was conducted using this arrangement as not enough pressure could be applied to effectively fracture pre-cut pods without causing feed problems (even when the ends of pods were manually cut off).

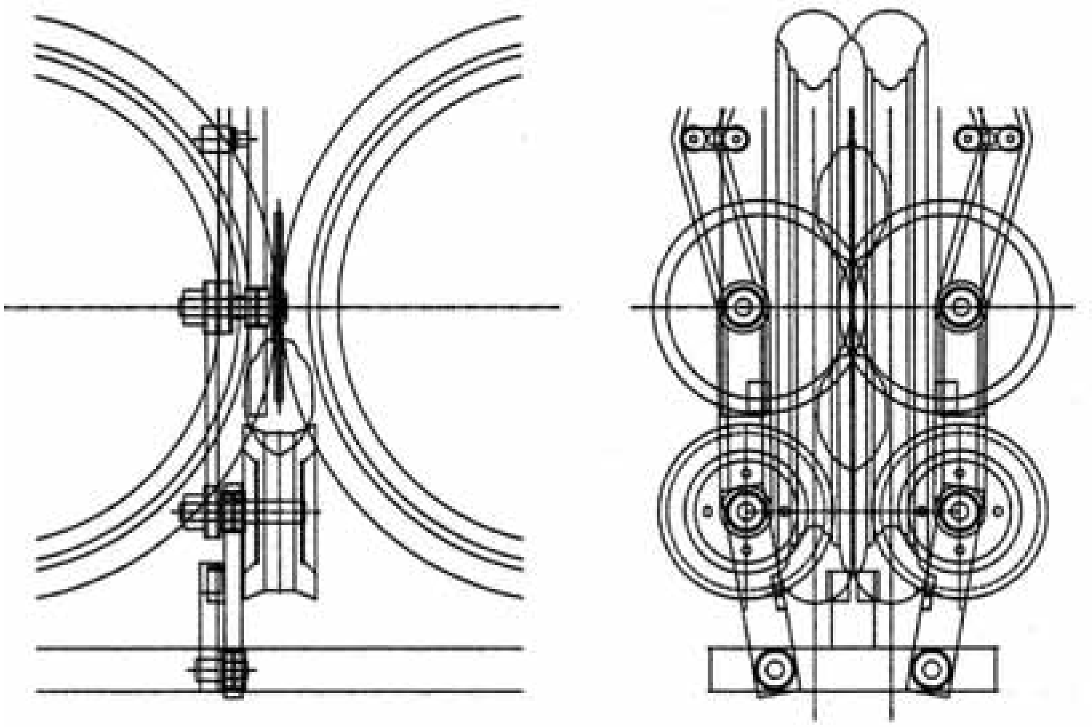


Figure 5.8 Schematic view of crusher wheel arrangement.

a. **b.**

Figure 5.9 Crusher wheels: a. disassembled; b. simulated with pod.

Powered grabber wheel drive

Early in the development and testing of the unit the grabber wheels were powered by fitting an additional electric motor and chain drive. Both the grabber wheel motor and cutter wheel motor had separate variable speed control so that the rotational speed of the cutting wheels and grabber wheels could be adjusted independently. The cutting wheel motor-drive was mounted on top of the mainframe, whereas space limitations required the grabber wheel motor-drive to be mounted below.

Arrowhead splitter

After the failure of the crushing wheel apparatus to effectively split the pods an alternative approach was needed. It was proposed to try splitting the pre-cut pods by mechanically forcing them over a vertical plate mounted immediately below and in the same plane as the cutting wheels. An 'arrowhead' splitter was fabricated and mounted as shown in Figure 5.10. The wedge shape forced the pod halves apart without being so sharp as to damage beans.

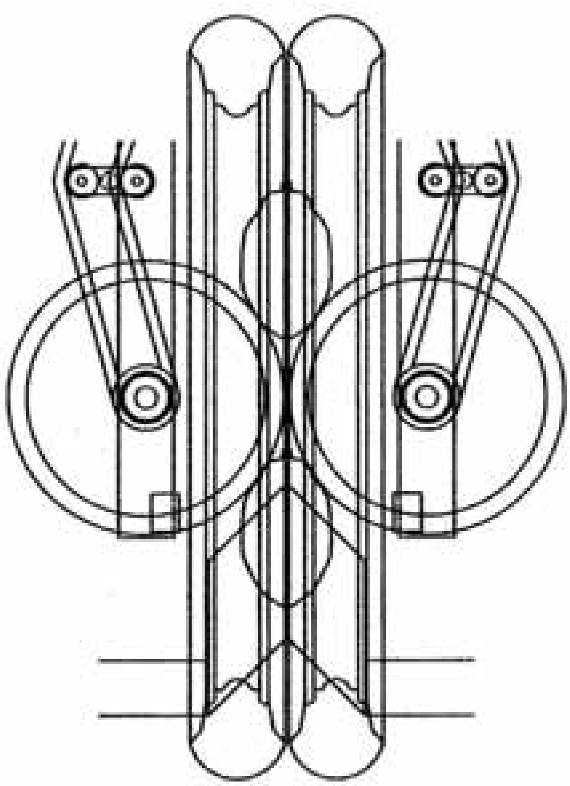


Figure 5.10 Set-up of arrowhead splitter.

Testing this apparatus resulted in effective splitting of pods with very little damage to beans. It was not necessary to first cut the ends from pods which avoided the need to develop a separate process and equipment for this task. Also the technique had the advantage of dislodging the beans from the placenta as the splitting plate passed through the seed sack. A pod passing over the arrowhead splitter is shown in Figure 5.11; split pods (showing seeds) are shown in Figure 5.12.

Figure 5.11 Pod being split by arrowhead plate.

Figure 5.12 Mechanically split pods using the arrowhead splitter.

Cutter wheel feed plates

Despite the initial success of the machine an emergent problem was that pods sometimes became jammed on the cutter wheels. This was due to three factors:

i. on entering the machine, smaller pods often contacted the cutting wheel blades before becoming fully engaged by the grabber wheels

ii. due to low friction, the cutting wheels did not exert sufficient driving force to the pods

iii. the extra force required to push pods over the arrowhead splitter – when passing over the splitter, pods were no longer fully engaged by the grabber wheels so that the following pod effectively pushed the pod in front of it over the splitter plate.

To address this problem a range of profiled backing plates were fabricated to assist driving the pods through the machine. These ranged from rippled plates to more aggressive sawtooth and spiked plates. One of the spiked designs is shown in Figure 5.13 (also note damage to the cutting plates caused by opposing plates contacting each other when returning under spring tension to their central position – this was due to flex in the mounting frame and pivot arms).

Testing showed that all the plate profiles assisted in feeding pods through the machine and reducing blockages with the more aggressive profiles being the most effective. However, an undesirable consequence was that a 'sawdust' of pod husk material was produced which contaminated the bean sample. This was not really reduced by ensuring a good match between the peripheral speeds of the cutting and grabber wheels. There was always some slip between the rotational elements of the machine and the pods passing through.

Figure 5.13 Spiked backing plate on cutting wheel.

V-Plate splitters

A problem with the arrowhead splitter was that pods tended to deflect to either side of the apparatus. This was because of the lesser resistance offered when compared to passing centrally over the apparatus. Wing plates were mounted to the sides of the arrowhead splitter in an attempt to retain pods centrally on the apparatus. However these were necessarily a compromise since the spacing between them had to allow for the largest sized pods – smaller pods could still be pushed to the side before encountering the wing plates.

As a solution a number of V-shaped plates were profiled from 3 mm steel. The range of shapes tested is shown in Figure 5.14. The idea of these plates (with the exception of the conventional pointed plate at top right) was that the sides of the pod encountered the plate apexes before the point of the pod thereby helping to centralise the pod as it passed over the plate. This concept worked well with the profile at top left in Figure 5.14 being the most effective. The splitter plate design also reduced the wedging effect due to its slimmer profile. This had the benefit of reducing blockages in the machine and reducing unwanted pod breakage and fragmentation.

Operational improvements

Other modifications to improve the functionality and safety of the machine included:

i. mesh guarding to prevent accidental operator contact with the grabber wheels, cutting discs or drives

ii. a sub-frame to raise the operating height of the unit

iii. a hopper-chute mounted below the arrowhead splitter.

Figure 5.14 Alternative splitter plate shapes.

5.3.5 NACDA Mark Ib pod splitter

After testing and modification of the original prototype pod splitter, a significant redevelopment and refurbishment of the unit was carried out. This overcame some structural and geometric limitations of the space frame and improved the spatial alignment of the main functional components. A photograph showing the redesigned pod splitter is shown in Figure 5.15. The key design and operational improvements carried out are summarised in Table 5.3.

Figure 5.15 Overview of redesigned pod splitter.

Table 5.3 Design improvements to NACDA Mark1b pod splitter.

Design Improvement	Comment	Benefit
Cutter arm loading	The mainframe was modified to allow relocation of the cutter arm tension springs. The springs were originally mounted between the cutter arms below the cutter arm pivot point. The cutter arms were extended above the pivot points and tension springs attached from the top of each cutter arm outwards to the modified mainframe. Attachment was via threaded rods to allow adjustable pre-loading.	The original cutter arm spring intruded into the space where pods were delivered to the machine – the relocated springs removed this intrusion and allowed unhindered entry of larger pods into the machine. Adjustable spring loading allowed higher restoring force which resulted in better cutting.
Adjustable length of cutter arms (cutter blade position)	Each cutter arms was fabricated with two telescoping sections to provide length adjustment. This allowed optimisation of the height between the plane of the cutter wheel axle and the plane of the grabber wheel axle. This change required that the mounting for the V-splitter plate was also adjustable. The plate was set as close a possible to the bottom of the cutter blades at all times.	In the original machine, larger pods came into contact with the cutter blades before being properly engaged by the grabber wheels. Lowering the cutter wheels with respect to the grabber wheels meant that pods were engaged and centred by the grabber wheels before contacting the cutter blades. This resulted in better pod alignment, more effective pod cutting and less blockages during operation.
Increased cutter arm stiffness	There was considerable flex in the original cutter arms. The adjustable cutter arms were significantly stronger and stiffer.	Excessive cutter arm flex resulted in clashing between the opposing cutter blades when restoring to the closed (no pod) position. This caused blade damage and did not allow adjustment of the cutter blades (via threaded mainframe stops) to a close tolerance. This was not completely resolved.
New tyres	The original tyres were secondhand knobbed tyres with non-uniform wear profiles. New ‘road profile’ tyres were purchased and fitted.	Surface profile irregularity and lack of symmetry in the original tyre did not assist good pod alignment. This was overcome by using consistent tyres with a smooth profile.
Redesigned discharge hopper	Larger hopper fabricated and fitted for discharge into bean separator.	Original hopper had insufficient clearance required between floor of hopper and adjustable V-splitter plate mounts. New hopper allowed full adjustment range for the V-plate splitter and reduced blockages.
Cutter blade guarding	Fixed semi-circular guards fitted to cutter arms around cutter blades.	Safety.
Grabber wheel guarding	Sheet metal guarding to outside of grabber wheels.	Safety.

In addition to the design improvements summarised in Table 5.3, alternative grabber wheel tyres and cutting blade arrangements were trialled as follows.

Overlapped cutting blades

A problem noted with the geometry of the opposed circular cutting blades was failure to achieve effective cutting at the ends of pods. The subsequent cutting sequence is described as follows:

i. the shoulders of the pod (rather than the end) first contact the cutting discs and backing plates
ii. under pressure from the cutting wheels the discs penetrate the pod husk to a depth set by the backing plates on either side of the blade
iii. this means that the ends of the pod are only partially cut through as the cutting discs do not penetrate to full depth
iv. a full depth cut is achieved around the sides of the pod and as the pod tapers off
v. only a partial cut is again achieved at the end of the pod as the pod passes below the cutting blades.

The above sequence means that a full depth cut is achieved around the periphery of pods but tapers off to a zero cut towards the ends of pods. This is exacerbated by larger pods and by rounder shaped pods (less tapered).

Therefore, rather than being prised apart by the V-splitting plate, pods are effectively fractured in the area of the incomplete or non-existent surface cut. This results in some fragmentation of pod husks into smaller pieces rather than two complete halves. The smaller fragments of pod husk then contaminate the wet bean sample since they are not possible to separate by screening. In addition, the extra force required to fragment the pod (rather than split it along the pre-cut planes) contributes to intermittent jamming of pods on the splitter plate and subsequent machine blockages.

One way of reducing this effect is to use smaller diameter cutting wheels. However, the potential for this was limited with the existing machine due to the need to maintain clearance between the cutter wheel drive and the grabber wheels. The blade diameter could only be reduced slightly from 270 to 260 mm.

Another option which was trialled was to mount the cutting wheels in an overlapped configuration. This was implemented by using only one opposite mounted backing plate per cutting blade and using a single bevelled cutting disc (with discs mounted back-to-back) as shown in Figure 5.16.

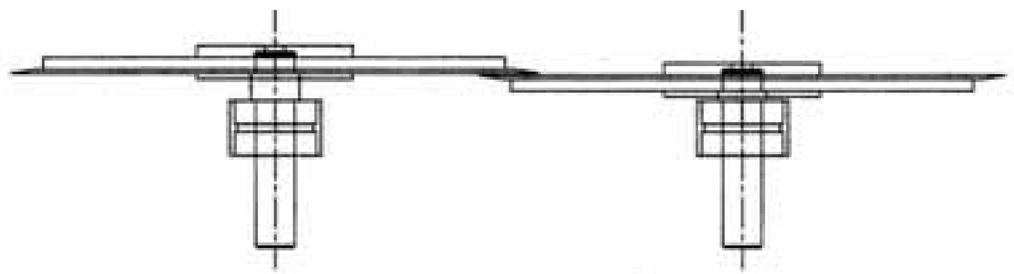


Figure 5.16 Configuration of overlapped cutting discs (plan view).

The geometry of pod cutting is shown schematically in Figure 5.17 based on the set-ups described above. The diagram shows the theoretical area of cut (shaded) for the same size and shape of pod resulting from four different cutting disc arrangements. An almost complete, full depth cut is achieved when using smaller (200 mm) cutting discs in an overlapped configuration.

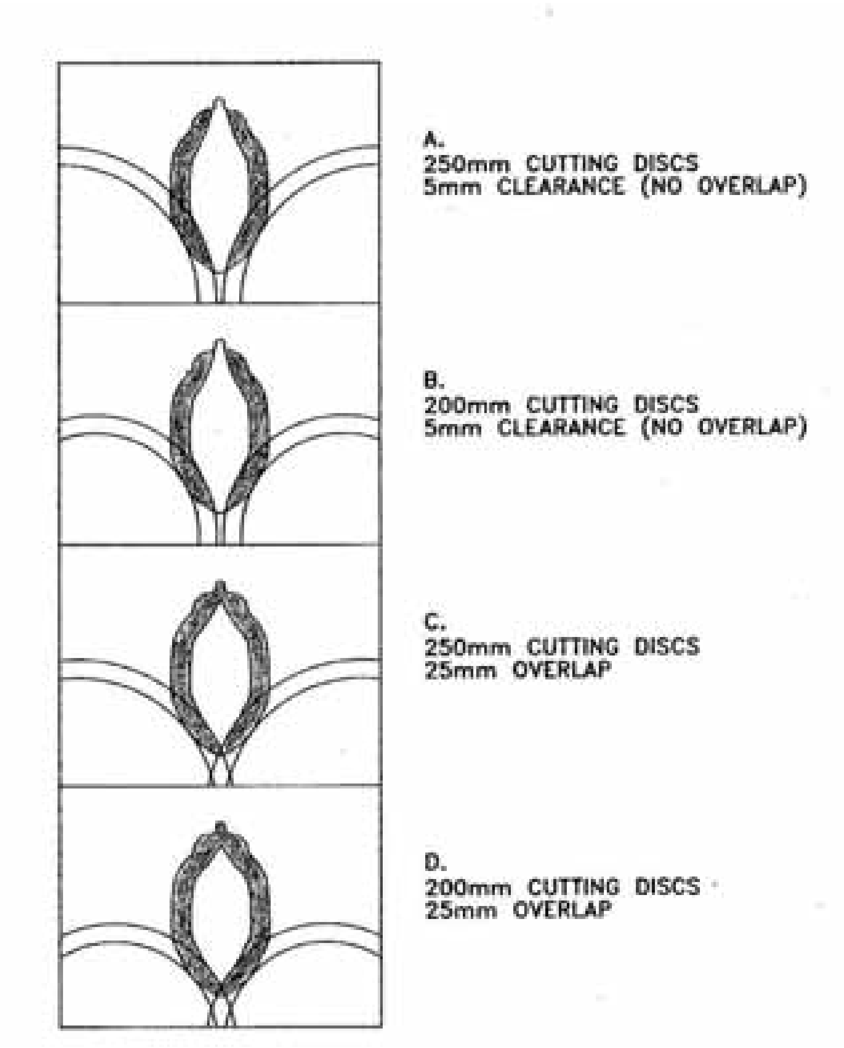


Figure 5.17 Area of cut achieved (shaded) using four alternative cutting disc configurations.

When tested, the overlapped cutting blade arrangement resulted in improved and near complete cutting of pods with subsequent increase in recovery of wet bean and reduction in pod fragmentation. Unfortunately the set-up could not be maintained with the existing machine due to the excessive flex in the cutter arms (as per Table 5.3).

Modified grabber wheels

There were some disadvantages with the dual pneumatic tyres which resulted in excessive fracturing and subsequent breakage of larger pods due to the greater deformation required:

i. the tyre carcass was generally too stiff – even when operating them with no inflation pressure

ii. the geometry of the arrangement meant that maximum deformation was generally required adjacent to the stiffer sidewall rather than at the more flexible centreline of the tyres.

Since a softer compound tyre was not evidently available, it was proposed to use extra heavy duty tubes as a substitute for the tyres themselves. Whilst implemented, the idea was abandoned since the inflation pressure required to seat the tubes on the rims (without the restraint of the tyre carcass) resulted in 'ballooning' of the tubes even at relatively low pressures. This 'ballooning' was attributed to manufacturing inconsistency in the tube wall thickness and resulted in a non-circular and irregular profile.

Another proposal was to use urethane 'tyres' designed specifically for application in the pod splitter. An advantage of urethane was that the material hardness (durometer) could be specified. A number of arrangements using this material were proposed as shown in Figure 5.18. Unfortunately the cost to tool a mould to manufacture any of these options was prohibitive. Also, any changes to the original (experimental) profile would have required a complete new mould to be tooled. Therefore this proposal was not progressed.

Alternatively a more cost-effective option was to use ethyl vinyl acetate (EVA). A pair of profiled EVA 'tyres' was specified and manufactured. They were attached (glued) to a new set of rims built specifically for the purpose. These units are shown in Figure 5.19. They comprise a composite EVA cross section wrapped and glued to the steel rim surface. A 4 mm capping layer (EVA220) was laminated to the thicker, softer and profiled base layer (EV4A5).

Figure 5.19 Profile comparisons of original pneumatic tyres (left) and custom manufactured EVA 'tyres' (right).

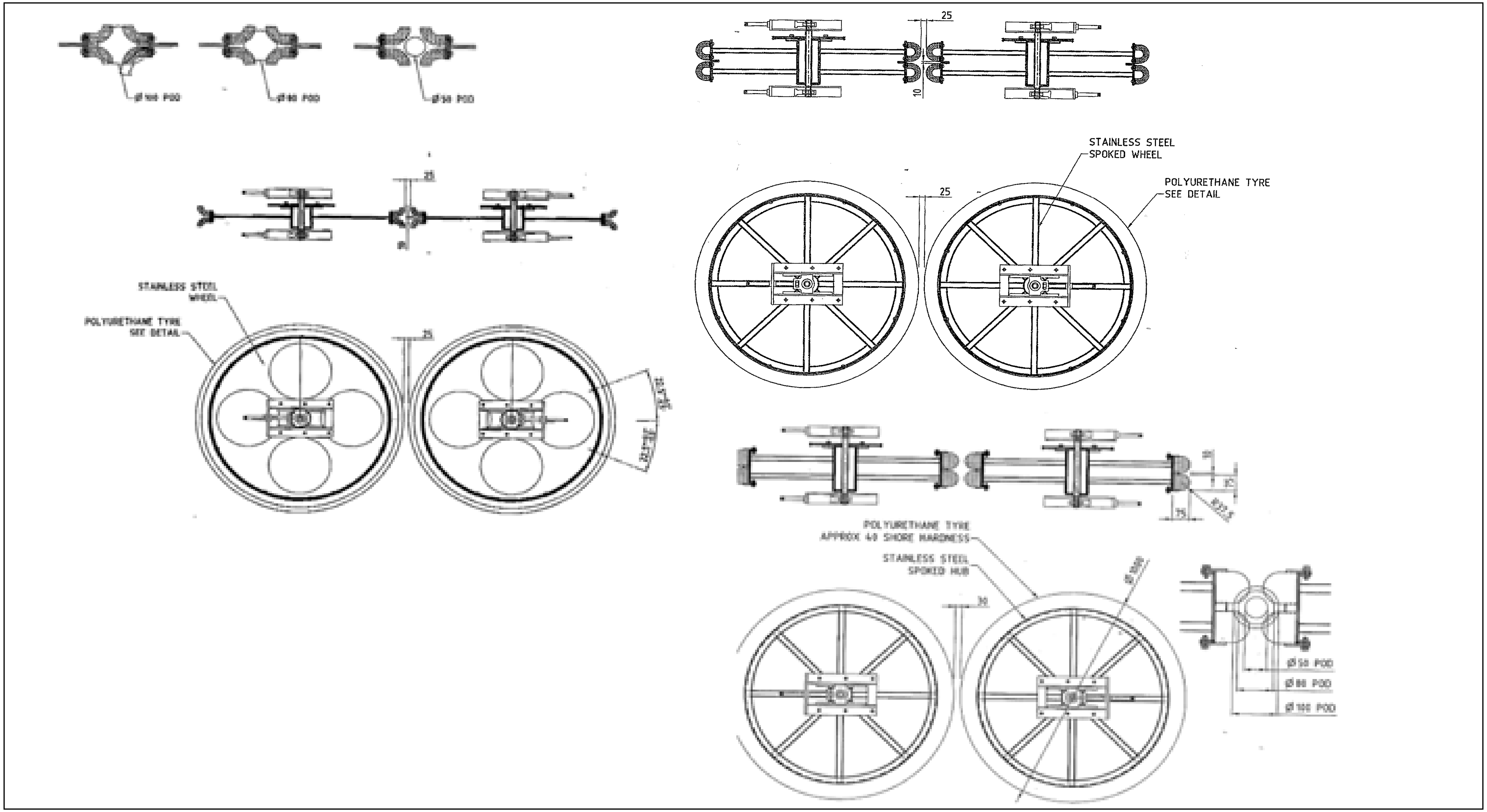


Figure 5.18 Proposed alternative ‘tyre’ arrangements based on moulded urethane construction.

The EVA tyre and rim combination was only fitted to the pod splitter towards the end of the development period and only limited testing was conducted. However the performance was judged to be significantly superior to the original pneumatic tyre set-up with less pod breakage and some further improvement in feeding (less blockages).

Figure 5.20 EVA 'tyres' as fitted to the pod splitter (view from above).

The only issue with the set-up was with the glued join of the EVA cross section. This resulted in a slightly 'harder' section of the material and an irregular profile as shown in Figure 5.21. Whilst this caused no immediate operational issue it did limit the proximity to which the rims could be adjusted towards each other. It was thought that this join could also be a potential failure point either of the glued join itself or the base material due to extra induced stresses. However, such a failure has not occurred after two further years of use.

Figure 5.21 Deformation caused by glued join of EVA tyre.

Specifications and performance of NACDA Mark Ib pod splitter

General specifications and typical performance of the Mark Ib Pod Splitter are given in Tables 5.4 and 5.5. Results of capacity testing are given in Table 5.6 and demonstrate capacity in the range of 2,500 to 4,000 pods/hr.

Table 5.4 Specifications of NACDA Mark Ib pod splitter.

Component/Parameter	Specification	Comment
Grabber Wheels		
Diameter	700 mm dia. ethyl vinyl acetate composite	custom profiled
Speed	variable 35–90 rpm	typically operated at 65 rpm
Drive	0.37 kW electric motor via mechanically linked chains	motor power marginal; mechanically variable reduction gearbox
Cutting Discs		
Speed	electronically variable 250–650 rpm	typically operated at 450 rpm
Blades	260 mm diameter, 2mm thick, 7mm bevel	high carbon steel
Backing plates	230 mm diameter, 6mm thick	mild steel
Drive	1.1 kW electric motor via independent V-belts	motor power excess to requirement; electronic speed controlled

Table 5.5 Typical performance of NACDA Mark Ib pod splitter.

Processing Capacity	
Pods	2,500 to 4,000 pods/hr (20,000 to 30,000 pods/day)
Wet bean	250-500 kg/hr
Maximum pod size	110 mm dia. x 275 mm long approx. (= ~1.2 kg)
Minimum pod size	50 mm dia. x 100 mm long approx. (= ~150 g)
Processing Performance	
Pods split (entire halves; no breakage)	~75%
Pods fragmented (halves with breakage)	~25%
Wet bean recovery	>90% (using NACDA separator)

Table 5.6 Capacity testing of NACDA Mark Ib pod splitter.

Aug 2006	Number of Pods	Total Time to Process (sec)	Processing Rate (pods/hr)	Inferred Capacity* (pods/day)
batch 1	95	88	3,886	31,000
batch 2	646	556	4,183	33,000
batch 3	100	145	2,483	20,000

*based on 8-hr day.

5.3.6 NACDA Mark II pod splitter

The original Mark I pod splitter was progressively improved and modified over a four-year period. During this time, most pods from Queensland trials conducted under the wider research program were processed using the unit which was in excess of 50,000 pods. It became obvious that some components of the prototype machine were compromising performance and required refurbishment or replacement. However, limitations of the existing frame meant that this was either not possible or worthwhile.

Therefore, design of a new 'Mark II' machine was commenced. The objectives during this process were:

i. to incorporate the proven features and principles from the prototype machine

ii. to improve performance by overcoming limitations of the prototype machine

iii. to design a more robust and reliable machine in the context of it being developed as a semi-commercial unit.

The design was taken to the point of a layout and conceptual arrangement with no detail drawings or actual fabrication being completed. This conceptual design is shown in Figure 5.22.

The principle improvements embodied in the design relative to the prototype unit were as follows:

i. more rigid space frame to improve integrity of mounting for critical components (particularly cutter arm pivot point, grabber wheels and splitter plate)

ii. improved rigidity of critical components (particularly cutter arms)

iii. improved adjustability of critical components to encompass optimum geometric relationship (particularly grabber wheels, cutting wheels and splitter plate);

iv. all drive components located at top of the machine to improve ease of clean-down

v. simplified guarding by virtue of larger space-frame

vi. drive components upgraded (larger chain drive for grabber wheels and larger bearings for cutter arm pivot points)

vii. larger diameter grabber wheels (950 mm)

viii. larger area for pod entry above grabber wheels also obstruction-free

ix. improved outlet chute.

As stated previously, the improved unit based on the above design has not been fabricated. Prior to doing so it is recommended that the use of alternative and more appropriate construction materials also be considered. This would include possible use of aluminium or stainless steel for framing and components to improve corrosion resistance.

It would also be advantageous to use lighter material for the construction of the cutter arms to minimise inertia and improve the responsiveness. This would be particularly critical if a significantly higher throughput of pods is to be achieved. The use of cam followers for positive location of the cutter arms throughout their duty cycle was also considered (though not incorporated into the existing conceptual design).

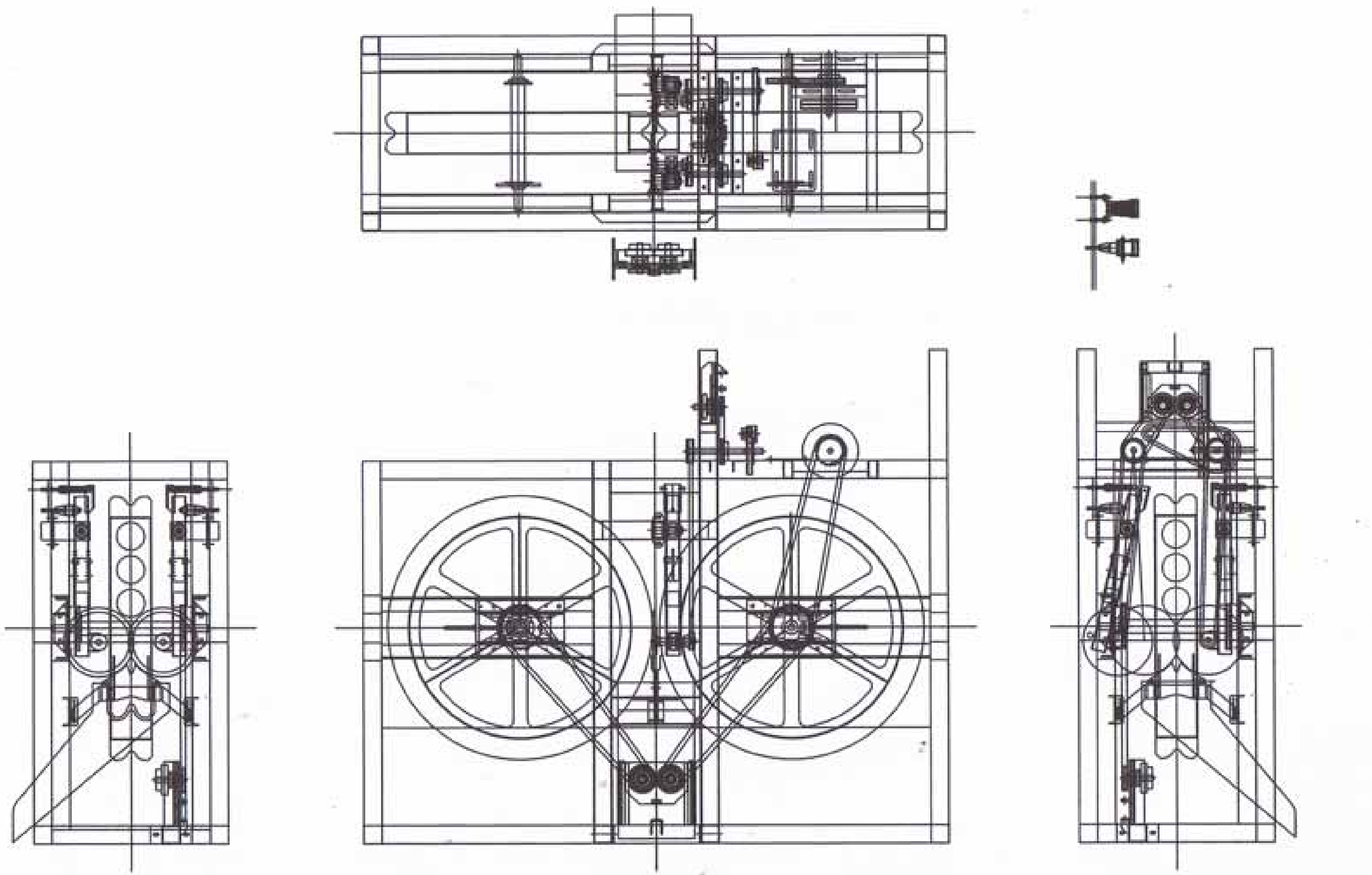


Figure 5.22 Conceptual drawings of NACDA Mark II pod splitter

5.4 Development of an improved bean separator

5.4.1 Background

As discussed in Section 5.2.5 a bean separating trommel obtained in conjunction with the Brazilian pod splitter in December 2001 worked well and it was decided to further develop the concept within the NACDA project. Its key feature was the octagonal construction of the trommel screen. This assisted the dislodgment of beans from pre-split pods to a much greater extent than a round trommel would have done. However due to its relatively small size, the capacity of the existing unit was restricted to about 1,500 to 2,000 pods/hr. It was also envisaged that the separation efficiency of the unit could be improved.

Design of a new NACDA separator was commenced in 2002 and the unit was operational by October 2003. Only minor modifications were subsequently carried out as the unit operated successfully from the outset. It was used exclusively in conjunction with the NACDA pod splitter.

5.4.2 Development and testing

An overview of the NACDA bean separator is shown in Figures 5.23 with the unit in operation in Figure 5.24. The principle points of difference of the NACDA separator compared to the original Brazilian unit are:

i. increased trommel diameter and length

ii. two-stage trommel with the initial section comprised of a smaller aperture screen to remove small pod fragments and the second section to separate bean from the main pod fragments (Figure 5.25)

iii. screen construction from standard mesh profiles to simplify fabrication (Figure 5.25)

iv. removable screen sections to aid in clean-down and possible interchange for different average bean size (Figure 5.25)

v. variable speed drive

vi. collection hoppers to contain separated material

vii. conveyor belts to collect separated bean (Figure 5.26)

viii. pod husk elevator to manage waste product (Figure 5.27)

ix. safety guarding of moving components.

Initial testing confirmed an increase in wet bean recovery from about 88% to 93% compared to the original Brazilian sourced trommel. Pod contamination was also reduced. Further improvement in separation performance could possibly be achieved by experimentation with the screen aperture size. However this was not undertaken and separation efficiency was ultimately limited by the performance of the pod splitter – i.e. getting the pod splitter to perform optimally will maximise wet bean recovery from the separator and minimise contamination of same with pod fragments.

The only significant modification made during development and testing of the separator was an extension of the pod husk elevator to provide additional reach (height).

The machine/concept is sufficiently well developed that a commercial design could be based on the existing unit – with some further enhancements including optimum screen selection, provision of cleaning brushes; elevator/conveyor for wet-bean and construction with aluminium, plastics or stainless steel.

Figure 5.23 NACDA bean separator (side view – top; end view – bottom).

Figure 5.24 NACDA bean separator in operation.

Figure 5.25 NACDA bean separator showing two-stage demountable screens.

Figure 5.26 NACDA bean separator showing wet bean conveyor belt.

Figure 5.27 NACDA bean separator showing pod husk waste elevator.

5.4.3 Specifications and performance of NACDA bean separator

Tables 5.7 and 5.8 details the generic specifications and measured performance of the NACDA pod splitter.

Table 5.7 Specifications of the NACDA bean separator.

Component/Parameter	Specification	Comment
Trommel		
Diameter	1,050 mm (screen face to screen face)	octagonal cross-section
Overall trommel length	3,400 mm	
Speed	variable 10 to 60 rpm	typically operated ~ 20 rpm
Power source	0.55 kW electric motor	with mechanically variable reduction gearbox
Drive	¾” roller chain and sprockets	via sprocket on main shaft
Rubbish Removal Screen		
Length	1 m	
Material	expanded metal	4 x demountable panels
Aperture	~ 11mm x 7 mm	diamond shape
Bean Separator Screen		
Length	2 m	
Material	welded mesh	4 x demountable panels
Aperture	~ 17 x 17 mm	square shape
Wet Bean Conveyor		
Belt	continuous, flat, 1,200 mm wide	~ 0.5 m/s
Power source	~ 0.25 kW electric motor	with reduction gearbox
Drive	½” roller chain and sprockets	via sprocket on roller
Husk elevator		
Belt	continuous, cleated 250 mm wide	~ 0.5 m/s
Power source	trommel drive motor	
Drive	¾” roller chain and sprockets	via sprocket on lower roller shaft

Table 5.8 Typical performance of the NACDA bean separator.

Performance	
Processing Capacity	
Pods	3,000 to 4,000 pods/hr
Wet bean	300 to 400 kg/hr
Recovery	
Wet bean recovery	~95% (using NACDA pod splitter)

5.5 Delivery of pods to the NACDA pod splitter

5.5.1 Background

Delivery of pods to the NACDA pod splitter requires that they be dropped into the machine in an endwise orientation (long axis parallel to the direction of fall). During initial testing of the splitter this was carried out manually. For commercial application, a mechanised delivery system would be required.

A pod delivery conveyor was developed in conjunction with the general development of the pod splitter. Design, fabrication and testing were conducted in late 2002. Initially, the conveyor did not function as anticipated. The unit had to be modified and an additional elevator conveyor constructed, before it could reliably be used in conjunction with the NACDA pod splitter.

5.5.2 Development and testing

A means of continual, automatic delivery of pods to the NACDA splitter in a relatively consistent alignment was required. It also needed to be simple and not rely on a complex mechanical system to manipulate individual pods.

It was not critical that pods had to be delivered in a perfect alignment as the design of the pod splitter grabber wheels resulted in pods being automatically centred as they came into initial contact with the grabber wheels. This is particularly the case for vertical misalignment of pods in the plane parallel to the plane of rotation of the grabber wheels. However, for pods misaligned in the perpendicular plane, the tolerance is much reduced. In this case pods are much more likely to pass through the splitter in a sideways alignment resulting in poor cutting, excessive pod breakage and damage to beans.

Therefore the guiding principle for design of the conveyor was to eliminate misalignment of pods in the plane perpendicular to the plane of rotation of the grabber wheels. With this aim, a belt feeder comprising two angled belts as shown in Figure 5.28 was constructed.

The unit was based on a similar (but smaller scale) conveyor used in avocado packing sheds which is also used to singulate and orientate avocados with their long axis parallel to the direction of travel. There is a slight (about 20%) speed differential between the otherwise identical belts. Avocados dropped randomly onto the moving belts are ‘rotated’ by the faster belt until they attain a lengthwise alignment. They then remain in this alignment as it offers the greatest resistance to additional ‘rotation’ (instead the faster belt slips against the surface of the avocado). So whilst a rotational force is applied, it is insufficient to overcome the rotational inertia of the avocados in this position (due to the low co-efficient of friction with the belt surface).

It was thought that this technique could be also be applied to cocoa pods because of their similar ovoid shape. Furthermore, by aligning the centreline of the belts parallel to the centreline of the grabber wheels, the correctly oriented pods could be ‘dropped’ from the end of the belt and rotate into a vertical alignment as they fell from the end of the belt. Accurate pod placement could then be achieved by altering the position of the end of the conveyor relative to the grabber wheels with further fine-tuning through adjustment of the belt speed.

Figure 5.28 Pods on prototype pod conveyor.

Initial tests carried out in November 2002 showed that pods did behave as expected with the faster belt rotating misaligned pods into a lengthwise orientation parallel with the belts. However, most pods (excepting longer ones) continued to be rotated by the faster belt instead of the belt slipping against the pod surface. So the desired orientation was not necessarily achieved.

Subsequently, the unit was modified so that the belts were running at the same speed. Testing with this set-up in conjunction with the pod splitter demonstrated that provided pods were placed on the conveyor in an end-wise fashion, pods could be dropped into the pod splitter as anticipated. Furthermore, testing also demonstrated that by dropping the pods onto the conveyor from about 200 mm, 90–95% of pods ended up lengthwise on the conveyor anyway – even when dropped in a random alignment. An elevator was therefore proposed – with cleats to lift and segregate pods individually before dropping them onto the conveyor.

A pod elevator designed and fabricated during late 2003 and used in conjunction with the pod conveyor is shown in Figure 5.29. It operated well and greatly improved the efficiency of pod handling and processing associated with the research program at South Johnstone. Whilst it still relied on manual feeding, this could be done more carelessly than was previously required when manually feeding pods to the pod splitter itself. However, it did not fully address the issue of segregating pods individually or achieving 100% alignment of pods unless the pods were manually placed onto the elevator with more care.

Further development of the ‘front-end’ delivery system was clearly required but this was not seen as an insurmountable issue. Indeed it is expected that several avenues are available to fully resolve this issue by applying materials handling techniques and machinery already commonly utilised in industry and agriculture.

Figure 5.29 Pod elevator.

5.6 As-built NACDA pilot processing system – 2006

A summarized flowchart of the NACDA pilot processing system (with accompanying photos) is given in Figure 5.30. This is based on the system components previously described and which had been developed up until the start of 2006. After this time no further development of the system was carried out, and only maintenance, repairs and provision of some guarding was performed.

Details of the apparatus and methods used for fermentation and drying have not been described in the foregoing but are detailed in Section 6.

A recommended arrangement for a fully-developed, ‘commercial cocoa pod processing system’ is outlined in Section 5.7.4 together with related priorities for further research and development.

1. ***Pod Storage***
(in bulk bins for up to 10 days)

↓

2. ***Pod Delivery***
(manual transfer of pods to pod elevator)

↓

3. ***Pod Elevator***
(elevates pods to pod conveyor)

↓

4. ***Pod Conveyor***
(orientates pods and delivers pods to pod splitter)

↓

5. ***Pod Splitter***
(cuts and splits pods @ 2,500–5,000 pods/hr)

↓

6. ***Chute***
(split pods delivered to bean separator)

↓

7. ***Bean Separator***
(separates beans from pods)

↓

8. ***Wet bean Conveyor***
(collects wet bean)

9. ***Pod Husk Elevator***
(collects, elevates and dumps pod husks)

↓

10. ***Fermentation Bins***
(fermentation of wet bean)

↓

11. ***Sun-Drying***

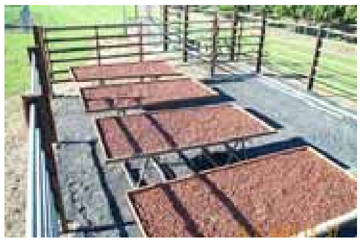


Figure 5.30 Flowchart of NACDA pilot cocoa processing system.

5.7 Summary

The laborious nature of pod processing is likely to have been a major factor inhibiting any development of cocoa growing in Australia. Investigation and development of mechanisation for cocoa pod processing and bean extraction was a priority in the NACDA project. However, in-depth investigation of technology for fermentation, drying and secondary bean processing was not conducted since it was presumed technology could readily be adapted from overseas.

5.7.1 Pod splitting

A number of inventions for pod splitting and bean extraction have been previously developed overseas but none has been widely adopted including some commercially manufactured equipment. Excessive breakage of the pods husk leading to difficulties in obtaining a clean sample of wet bean is the major problem with most designs. Additionally, there has not been any compelling reason for smallholder cocoa producers to mechanise their operations.

Due to this, autonomous development of a pod splitter was undertaken in the NACDA project from 2001 and a successful design was developed, tested and ultimately patented.

The unit splits pods longitudinally into two halves. Pods need to be delivered to the machine individually in an endwise orientation, however processing through the machine is a continuous operation without complex mechanical manipulation of pods for cutting or splitting.

Demonstrated capacity of the NACDA pod splitter is in the range of 2,400 to 4,000 pods/hr (20,000 to 30,000 pods/day). A wide range of pod sizes can be handled by the machine ranging in length from about 100 to 275 mm with corresponding diameters of 50 to 100 mm without the need for adjustment. For optimum performance it is proposed that pods would be graded into two size ranges prior to splitting with each size range processed through individual pod splitters adjusted appropriately.

5.7.2 Bean separation

A bean separation trommel obtained from Brazil was used as a basis for designing a larger and improved NACDA bean separator. The improved machine incorporated two-stage screening, and wet bean and pod waste conveyors.

The unit performed satisfactorily and is suitable for commercialisation with minor improvements to the design (screens and cleaning) and optimum choice of construction materials to reduce corrosion). The capacity of 3,000 to 4,000 pod/hr was reasonably matched to the NACDA pod splitter.

5.7.3 Pod delivery

Delivery of pods to the NACDA pod splitter requires that they be dropped into the machine in an endwise orientation (long axis parallel to the direction of fall). For commercial application, a mechanised delivery system is required.

A pod delivery conveyor was developed in conjunction with the general development of the pod splitter. Initially the conveyor did not function as anticipated. The unit had to be modified and an additional pod elevator constructed, before it could be reliably used in conjunction with the NACDA pod splitter. However, these units did not fully address the issue of segregating pods individually or achieving 100% alignment of pods prior to delivery to the pod splitter (unless a degree of manual handling was introduced).

Further development of the 'front-end' delivery system is required but is not seen as an insurmountable issue. It is expected that several avenues would be available to fully resolve the issue. One probable solution would be to interpose a roller conveyor between the pod elevator and the pod delivery conveyor to singularise pods with a long-axis orientation parallel to the delivery conveyor.

5.7.4 Commercial pod processing system

A recommended process for a mechanised, 'commercial cocoa pod processing system' is outlined in Table 5.9 together with probable technology options and corresponding priorities for further research and development.

Table 5.9 Suggested processes and implementation for mechanised cocoa pod processing with development priorities.

Operation/ Process	Function	Equipment Options	Development Priority/ Task
Receival	Short-term pod storage prior to feeding into system	Tipping bin; or fixed bin with 'live' or inclined floor	Medium: could readily adopt from other industries or similar products
Elevator	Elevate pods for entry to system with possible concurrent singulation	Cleated, inclined belt conveyor	Low-Medium: existing unit performs satisfactorily
Size grading	Grade into three categories as follows: 1 – undersized to waste 2 – small-medium 3 – medium large	Two-stage rotating trommel	Medium: could readily adapt principle from other industries or similar products. Not absolutely necessary.
Singulator	Singulation of pods with concurrent orientation of long axis parallel to delivery conveyor travel	Roller conveyor mounted under/after sizing trommel	High: adapt from other industries or similar products, necessary for optimum pod delivery and some technical risk
Delivery conveyor	Deliver pre-oriented pods to pod splitter/s	Improved version of existing V-conveyor	Low-Medium: existing unit satisfactory
Pod splitting	Pod splitting/opening	NACDA pod splitter (one or two units based on size grading)	High: evolution of current prototype, some technical risk
Bean separator	Agitate bean from pod husks and separate wet bean from pod husks and pod husk fragments	NACDA bean separator (one unit only with any separate size streams ex splitting recombined)	Medium: evolution of current unit
Bean conveyor	Elevate wet bean to sorting table	Flat or cleated, inclined belt conveyor	Low: in conjunction with separator development
Bean clean-up	Sorting table for efficient (manual) cleaning of bean and direct transfer to fermentation vessel	Stainless steel ergonomic table	Medium: low technical risk and priority depends on contamination levels

6. Fermentation

6.1 Introduction

At the outset of the NACDA project, a deliberate decision was taken not to investigate fermentation and drying beyond proving the commercial acceptability of Australian grown cocoa beans. The intention was to use proven methods from overseas on the assumption that the chemistry and microbiology of fermentation could readily be repeated with Australian produced beans and in the Australian environment.

There was also an expectation (which is still valid) that the technology used for fermentation and drying in some cocoa producing regions would be quite appropriate in the Australian context. In particular this was based around the industrial style fermentaries common to Malaysia and some parts of Indonesia. Such set-ups included a range of approaches to 'mechanised' fermentation and drying which could be readily transferred to Australia. There was also scope for further evolution of these systems to deliver greater efficiencies and improved product quality.

Nonetheless, there was some need during the NACDA program, to increase the effort and resources devoted to fermentation work. This arose because initially, the flavour characteristics of Australian (Queensland) produced beans from fermentations was not commercially acceptable.

The problem which emerged was that, at best, the beans generally had only 'weak' cocoa flavour development. This limitation is not something that can be corrected during the secondary processing phase (roasting). The physical parameters of the Australian beans were comparable (and in some cases superior) to beans from Ghana and the best beans from Indonesia. Therefore, the flavour weakness was predominantly attributed to the biochemistry of the fermentations rather than the Australian growing environment or the germplasm utilised (although these can have an imprecise influence).

This gave rise to the following:

i. conduct of a more rigorous program of 'commercial-scale' fermentations based on typical methodology employed overseas with particular attention to the 'turning' schedules (aeration), monitoring of fermentation temperature and ensuring good drying practice

ii. establishment of a University of New South Wales PhD scholarship funded by Cadbury Schweppes entitled 'Fermentation of Australian Cultivated Cocoa Beans' and conducted in co-operation with the NACDA program at South Johnstone

iii. in association with ii) above, conduct of a number of experimental fermentations using alternative techniques and regimes in reference to 'standard' methodology.

Whilst the PhD project was conducted on a commercial-in-confidence basis, the researchers (Professor Grahame Fleets and Hugh Dirks) did assist the NACDA project in regards to performance and feedback of various fermentation trials. These were conducted with the aim of establishing a repeatable method for fermenting Australian cocoa beans to produce a good quality product.

6.2 Methodology

6.2.1 Introduction

Development of good cocoa flavour is dependent on the fermentation process. Good quality cocoa beans which are not fermented do not have the flavour development necessary for manufacturing good quality chocolate. Beans which are poorly fermented often develop off-flavours or have high acidity.

Ghana cocoa is widely regarded as the world's best quality 'bulk' cocoa. It has a reputation for good and very consistent flavour attributed to a diverse, diligent grower base and a national quality assurance and marketing system. It provides a 'standard' against which other cocoas can be benchmarked. Conversely, much cocoa from Indonesia and SE Asia is of low and variable quality due to poor or non-existent fermentation practices. Some good quality Asian cocoa is produced from particular estates or regions where fermentation and drying are well managed.

Although fermentation is a complex process, the traditional techniques are simple and only basic hardware is required. The most primitive method is to wrap a 'heap' of cocoa beans in banana leaves. A slightly more sophisticated technique is to use specially constructed baskets or trays. However the most common technique used in larger plantations is to use slatted hardwood boxes which allow aeration and drainage of liquid 'sweatings'. In all cases, the fermenting beans are periodically 'turned' which aerates the mass of beans. Fermentation is generally conducted over 5–7 days and then the beans are sun dried.

Commercial-scale fermentations require at least 50kg of wet bean. This is because fermentation relies on the heat developed from exothermic processes. Heat loss from small batches can be excessive resulting in incomplete fermentation. To adequately ferment small batches, an external heat source and/or good insulation is required. The upper limit of batch size for fermentations is generally around 800–1,000 kg of wet bean at which point the physical mass of beans prevents uniform aeration.

6.2.2 Micro-fermentations

Initially, the yields from trials in the NACDA project were insufficient to provide enough wet bean for commercial-scale stand-alone fermentations. This was also the case with pods which were gathered from 'wild' cocoa trees growing in the region during the very early stages of the program.

For these beans, specialised techniques for small-scale fermentations were employed. A methodology provided by Neil Hollywood (DPI&F) was used and is detailed as follows:

Microfermentation method

The standard procedure we employ is to bring pods to the laboratory to break them. We aim for 1kg of wet beans as this volume fits neatly into the wire frame we've constructed to fit inside an anaerobic jar and is also a convenient amount for assessment tests.

The 1 kg is then inoculated with 10g of pulp from day 1 of a Tavilo commercial fermentation. In a situation where you don't have a fermentary at hand, I would recommend putting them spread out in a place where fruit flies are present. Take note whether the flies land on the cocoa. If so, then after a couple of hours, it could be considered inoculated. We have tried using freeze dried ampoules of isolates, taking into account levels of different species usually present but odours of the fermentation and flavour of the resultant cocoa were very uncharacteristic. Once you have inoculated cocoa and conducted a fermentation, some of the pulp could possibly be frozen to inoculate the next batch.

We have found that, as per some of the old literature, that if an anaerobic phase doesn't occur in the first 24 hr, as per what happens in a commercial fermentation, the flavour is different enough for a taste panel to pick it up significantly in triangle tests although it is not that different. I do not use a gas pack in the anaerobic jar as the microbial activity is sufficient to reduce oxygen levels.

After the first 24 hours, the beans are transferred to a flat bottomed Buchner funnel on an Erlenmyer flask, to allow drainage of the sweatings and the whole lot placed in an incubator. Plastic wrap, secured with a rubber band, is then placed over the top of the Buchner funnel, to prevent excess moisture loss. From then on, the beans remain in the Buchner funnel, are turned once daily with a spatula and the incubator's temperature is adjusted as per the following table:

Time	**Fermentation Apparatus**	**Temperature**
D0-D1	Wire frame in Anaerobic Jar	30^{o}C
D1-D2	Buchner funnel on Erlenmyer flask	35^{o}C
D2-D3	Buchner funnel on Erlenmyer flask	40^{o}C
D3-D4	Buchner funnel on Erlenmyer flask	46^{o}C
D4-D5	Buchner funnel on Erlenmyer flask	47^{o}C
D5-D6	Buchner funnel on Erlenmyer flask	47^{o}C

Standardisation of the drying regime is also important as can be seen from the differences between sun and artificially dried cocoa. Now that we have solar dryers that are intermediate in rates between sun and artificial drying, we use them as a standard drying procedure.
Prior to the solar dryers, we used sun drying for three days followed by a form of fairly rapid artificial drying as a standardised drying procedure.
Notes:

i. Pod fragments should be no problem for fermentation and can be removed after drying.
ii. Placental material no problem for fermentation but will result in poor aeration if beans stick together.
iii. Placental material can be a problem in drying when beans stick together in clumps.

As larger quantities of beans became available, a few fermentations were conducted in 'eskies' (Figure 6.1) which provided some insulation. Additionally, these fermentations were sometimes conducted in an artificially warmed room. This method is not optimal since typical eskies do not allow free drainage of the sweatings.

Figure 6.1 Fermentation conducted in an esky with about 25 kg of wet bean.

6.2.3 Fermentation boxes

Once sufficient quantities of beans became available for stand-alone fermentations, hardwood fermentation boxes were constructed and used in the NACDA project.

Initially a 'small box' with about 90 kg wet bean capacity was used. Later, larger 300 kg capacity boxes of similar construction were also used. Both sizes of box incorporated a slatted timber floor and a tray underneath to catch and funnel the 'sweatings'. On advice from Neil Hollywood, the timber sides of the original boxes were modified so that a 5 mm gap was created between boards to allow better aeration.

A new 90 kg box with its first fermentation is shown in Figures 6.2a. Figure 6.2b shows the same box after several uses and with the spaced sideboards as described above. A temperature probe connected to a 'TinyTalk' datalogger is shown inserted into the mass of fermenting beans. In most cases these electronic data loggers were used to monitor temperatures during the fermentation process. This provided an indication whether fermentation was proceeding properly and helped determine the endpoint. The larger 300kg box with a central divider is shown in Figure 6.3a and b.

At the completion of box fermentations, only basic hygiene was generally practiced. This was simply to ensure that all beans were removed to eliminate mould and spoilage. Traditionally, well used and 'seasoned' boxes are considered a source of innoculum for the next fermentation and so they are not washed or disinfected.

a.

b.

Figure 6.2. a. New 90 kg fermentation box (left); b. used 90 kg box with temperature probe and spaced side boards (right).

a. b.

Figure 6.3 a. 300 kg fermentation box ; b. internal floor of 300 kg fermentation box (right).

Fermentation barrels

During 2004 a novel apparatus for fermenting cocoa was trialled and subsequently adopted. This was simply a commercial plastic composting barrel mounted vertically on a supporting axle and frame. The barrel is shown in Figure 6.4 – it has a removable end cap for loading and unloading and a stainless steel axle passing through the middle. One end of the barrel was modified by drilling 10 mm holes to allow aeration and drainage of 'sweatings'. The fermenting cocoa was held in the end with the holes and filled to just below the level of the axle (which was about 100 kg of wet bean). To 'turn' the fermenting bean, the barrel was manually revolved several times as well as tapped to dislodge any beans adhering to the inside. The idea of the barrel was from the point-of-view of saving time and labour since the turning and unloading could be accomplished very efficiently.

Initial fermentations using the barrels produced foul flavours and it was suspected that the plastic barrel itself may have been responsible. However, these off-flavours were later attributed to problems with the fermentation and not the barrel. Subsequently, good fermentations were achieved using the barrel technique.

Figure 6.4 Composting barrel used for cocoa fermentations at South Johnstone.

6.2.4 Fermentation methodology

The general method adopted for fermenting beans from the NACDA trials is given below. It should be noted that there were frequent departures from this method. This was due to progressive development of the technique and apparatus; experiments conducted in conjunction with the Cadbury – University of New South Wales PhD program; and logistical constraints such as personnel availability and weather.

1. Pods stored for at least one week prior to pod splitting and bean extraction.
2. Fermentations were started on the same day as pod opening as soon as enough beans were collected. Usually, a temperature log was also commenced.
3. Exposed beans (in boxes only) were covered with wetted Hessian bags or banana leaves to provide insulation and reduce moisture loss.
4. First turn after 24 hrs.
5. Second turn on second day (after 48 hrs).
6. Third and subsequent turns every two days thereafter.
7. Fermentation was stopped after 5–7 days when:
    - the vinegar smell had disappeared or was very weak
    - most beans were plump and swollen (a bean at this stage has a brown-purple exudate after being pierced)
    - the temperature of fermenting beans had declined to around 37oC.
8. Drying by hot air at 40–45^{o}C over 2–3 days; or in sun over 5–7 days; with daily turning in either case.

In conjunction with the PhD fermentation project, many variations/alternatives to this technique were performed but these are not recorded in detail here. Such experiments included short and long fermentations; using various inoculums; manipulating pH; fermentations using banana leaves; daily turning and comparing sun versus hot air drying.

However, one consistent problem was identified in conducting fermentations at South Johnstone during cooler winter months. Winter ambient temperatures at South Johnstone are significantly less than typical cocoa growing regions in the world. Commencing fermentations with the pods (and wet bean) at low ambient temperatures of about 20^{o}C seemed to inhibit the fermentation process. Instead of reaching typical temperatures of up to 50^{o}C considered indicative of good fermentation, temperatures in the fermenting mass only reached 35–40^{o}C at best.

To overcome this, fermentations vessels were placed in a warmed and insulated room throughout the fermentation process to reduce heat loss and maintain temperature. On a few occasions, pods were sometimes stored in the same warmed room (or in direct sunlight) immediately prior to pod splitting to raise their initial temperature. This was particularly important if pod splitting was performed in the morning after a particularly cold night when ambient temperatures had dropped to well below 20^{o}C.

Smilja Lambert (Mars Confectionery) communicated the following in relation to fermentations at South Johnstone after a visit in 2004.

Comments on Queensland fermentations – Smilja Lambert (pers comm.)

1 – With pod storage (7–10 days, even up to 14 days, especially if you do not have too much of *Phytophthora*) you will manage to improve significantly the fermentation temperature and efficiency.

2 – Assure good drainage for sweatings to drain away as soon as possible, but not so much ventilation that would cause too much heat loss.

3 – If you have more than 100kg of wet beans the fermentation mass is large enough that there should not be a problem to ferment (not too much of heat loss compared to the fermenting volume). Larger quantities are even better, however you will have better results if not making fermentation deeper than 50–60 cm.

4 – Yeasts will transform sugar in ethanol in an anaerobic process during the first 1–2 day of fermentation (small temperature increase will be observed, but it is not this reaction that will provide the main heat for the good fermentation).

5 – Transformation of ethanol to acetic acid is the exothermic reaction that will increase strongly the temperature of fermentation and this reaction is provided by *Acetobacter* which are aerobic bacteria. Therefore you need aeration and this is the reason why the temperature will always increase after the turning.

6 – First turn is almost obligatory after 48 hours of fermentation (to get aeration for *Acetobacter* to start proliferating and producing acetic acid). Normally one more turn after additional 48 hours would be enough. Daily turns might make your cocoa very sour, but this will also depend on the volume of mucilage that your cocoa beans have. The more voluminous is the mucilage, the more acetic acid will be produced from turns every day. The best is to try.

7 – To maintain/conserve the heat of the fermenting cocoa, cover/insulate your fermentation box well, but do not use plastic sheet for this (there should be some ventilation for *Acetobacter* to grow well and produce acetic acid).

8 – High temperature and low pH (due to acetic acid produced) will inhibit the growth of putrefaction microbes.

9 – When the temperature starts to decrease after 5–6 days (and pH normally starts to increase) then stop the fermentation and slowly dry the beans.

10 – The best for the production of quality cocoa is sun drying with naturally lower temperature during the night (the main browning reactions occur during the drying process), this way reducing

astringency and bitterness. Additionally, by slow drying the acetic acid can evaporate from the cocoa bean, reducing the exaggerated sour note.

11 – The cocoa flavour development takes a bit of time, so it is the best if you send your samples for the sensory evaluation not earlier than two months after the fermentation.

6.2.5 Drying methodology

As outlined in point 10 of the proceeding, drying can have an important influence on cocoa flavour. Generally, cocoa from fermentations at South Johnstone was sun dried as this offered the most assured means of achieving good flavour development (to allow complete flavour development and liberation of acetic acid). Under ideal conditions, sun drying at South Johnstone took 5–7 days. Several drying trays were constructed for this purpose (Figure 6.5) with cocoa placed in a thin layer of no more than 3–4 beans deep and stirred at least daily. Also, a moveable polycarbonate roof was also constructed to provide rain protection during the frequent showery weather.

At South Johnstone, the ability to sun dry was often limited by prevailing wet weather. The only alternative available on-site was to use a sample dehydrating oven. Cocoa was placed on removable trays which were stacked in the oven (as shown in Figure 6.6). This unit had low air circulation characteristics and reasonably controlled drying could only be achieved with careful management. To avoid mould development the depth of beans in trays was limited to about 25mm. Stirring was carried out twice daily (morning and afternoon) and trays were rearranged within the oven each day to ensure even drying.

Figure 6.5 Sun-drying cocoa on trays at South Johnstone.

Figure 6.6 Oven drying cocoa in trays at South Johnstone.

6.3 Results and discussion

6.3.1 Introduction

Cocoa samples from NACDA trials and fermentations were forwarded to Cadbury's grinding facility in Singapore ('MacRobertsons'). MacRobertsons personnel objectively assessed the Australian samples against standard quality criteria. They were also compared to reference samples of cocoa from Ghana and Indonesia.

An extract from MacRobertsons concurrent specification for Non-Ghana cocoa beans is given in Table 6.1. Definitions from the same specification documents are provided in Table 6.2. In both cases these are closely related to Cocoa Standards published by the International Cocoa Organisation.

6.3.2 Results from micro-fermentations

Details and analyses of micro-fermentations performed on beans harvested from local sources prior to the availability of cocoa from the NACDA trials is given in Tables 6.3 and 6.4.

This data provided some early assurance that the physical parameters of Queensland grown cocoa beans were generally of commercial standard, particularly since these beans were sourced from unmanaged trees descended from seed lines imported into Australia at least 20 years earlier.

In particular the fat levels were good (average 54.5%) and the bean size of most samples was well below the minimum standard (average 91). The beans had a slightly higher than desirable shell content (average 14.2%) which was attributed to the 'old' genetic material. More significantly however, there was only weak cocoa flavour development at best despite bean colour indicating that the beans were well fermented. Nonetheless, these pilot fermentations were conducted with no prior experience of the procedure and it was expected that 'proper' fermentations could be achieved once larger quantities of bean were available from the growing trials.

Table 6.1 Physical and chemical specifications for cocoa beans (Source: MacRobertsons).

Properties/ Analyses		Specification
Cut Test:	Fully Brown	55% minimum
	Part Brown / Part Purple	10% minimum
	Fully Purple	5% maximum
	Mouldy	3% maximum
	Slaty	3% maximum
Moisture Content		7.5% maximum
Bean Count		100–110 per maximum
Defects:	Double Beans	2.5% maximum
	Clusters	Absent
	Foreign Matter	Absent
	Waste *(includes flat beans, mucilage, bean fragments, shell and fines)*	1.5% maximum
	Insect Damaged / Insect Infested / Germinated	2.5% maximum
	Live Insects	Zero tolerance
Flavour / Odour		Free of from any objectionable foreign or off-flavour or odour
Pesticides:	Organochlorine	<0.02 mg/kg
	Organophosphorus	<0.05 mg/kg
	Synthetic Pyrethroids	<0.05 mg/kg
	Lindane	<0.001 mg/kg
GMO Free		Not to be grown from genetically modified organisms

Table 6.2 Cocoa bean definitions (Source: MacRobertsons).

Cocoa Bean	Fermented and dried seed of the cocoa tree (*Theobroma cacao*).
Broken Bean	A cocoa bean of which a fragment is missing, the missing part being equivalent to less than half the bean.
Doubles	Two cocoa beans fused together during the fermentation process that can be split apart with finger pressure.
Fragment	A piece of cocoa bean equal to or less than half the original bean.
Flat Bean	A cocoa bean of which the cotyledons are too thin to be cut to give a surface of the cotyledon.
Cluster	More than two beans joined together which usually cannot be split apart by finger pressure.
Foreign Matter	Any substance other than cocoa beans, fragments and pieces of shell.
Germinated Bean	A cocoa bean, the shell of which has been pierced, slit or broken by the growth of the seed germ.
Insect Damaged Bean	A cocoa bean the internal parts of which are found to contain insect at any stage of development or to show signs of damage caused thereby, which are visible to the naked eye.
Mouldy Bean	A cocoa bean on the internal part of which mould is visible to the naked eye.
Smoky Bean	A cocoa bean which has a smoky smell or taste which shows signs of contamination by smoke.
Thoroughly Dry Cocoa	Cocoa which has been thoroughly dried throughout. The moisture content must not exceed 7.5%.
Waste	Debris remaining after removal of whole, double and broken cocoa beans, clusters and foreign matter. This shall include cocoa bean fragments, pieces of shell, broken nibs, dust and flat beans.
Slaty Bean	A cocoa bean whose internal surface exposed by a cut is uniformly slaty grey indicating that the bean has not been fermented.

6.3.3 Analyses from commercial-scale fermentations

The overall aim of the fermentation work was to demonstrate the commercial acceptability of Australian grown cocoa using traditional techniques. This was achieved as borne out by parameters in Tables 6.5 to 6.8. It should be noted however, that Tables 6.5 to 6.8 include data from experimental fermentations conducted in association with the Cadbury – University of New South Wales PhD project and some of these fermentations produced variable and/or inferior outcomes. Therefore the data in Tables 6.5 to 6.8 should not be regarded as a definitive guide to the quality of cocoa grown in the NACDA trials (Queensland).

Nonetheless, some general conclusions from the fermentation work and the 'physical' data in Tables 6.5 to 6.8 are summarised follows:

- Commercial-scale fermentations were successfully conducted using Australian grown cocoa beans which resulted in acceptable flavour characteristics. Generally however, there was difficulty in routinely achieving thorough fermentations. This is evidenced by only moderate levels of fully-brown beans and weak to mild cocoa flavour characteristics indicating that fermentations were not always proceeding as completely as possible. It is assumed that improved cocoa flavour development can be achieved with Australian grown beans, based on more proven method/s of fermentation and drying. In conjunction with this, there is similar scope in refining levels of related attributes such as moisture content and the nib pH.
- The physical characteristics of Australian grown beans meet International Cocoa Standards for commercial acceptability. For Queensland produced beans sourced from the NACDA trials:
    - the overall average bean count was 91, which is good
    - the overall average nib fat was 54.7%, which is comparable with commercially produced cocoa
    - the overall average shell content was 13.4%, which is also comparable with commercially produced cocoa.
- Meeting standards such as tolerable levels of defects and chemical residues will depend on implementing good production management practices and appropriate secondary processing technology. These should be independent of the inherent quality of Australian grown cocoa.

Based on the above, it is concluded that it would be entirely possible to commercially produce good quality Australian-grown cocoa for sale into the world market. Further investigation of fermentation and drying practice will be required, potentially based on application of findings from the Cadbury – University of New South Wales PhD project. It is presumed that appropriate technology for processing of the dried and fermented bean prior to shipping can readily be constructed since it is not complex. Alternatively, such equipment it could be adapted from other industries or sourced from overseas. Notwithstanding this, it will also be dependent on successful commercialisation of the mechanised pod splitting and bean separation technology (described in Section 5).

Table 6.3 Details of micro-fermentations conducted with locally sourced, unmanaged cocoa.

Fermentation ID	Date Harvested	Pod Source	No. Days Ferment	No. Pods	Pod Weight (kg)	Wet Bean Weight (kg)	Wet Bean (%)	Drying	Moisture Content (%db)	Dry Bean Weight (kg)	Pod Index	Dry Bean (%)	Recovery (%)
1	Apr 2000	Conti – Tully	7	25	13.3	3.2	23.8	hot air @ 45C		1.37	18.2	10.3	43.5
2a	May 2000	Conti – Tully	5.5	48	19.5	4.7	24.2	hot air @ 50C		2.04	23.5	10.5	43.2
2b	May 2000	Daniells – East Palmerston	5.5	26	10.0	2.9	28.5	hot air @ 50C		1.12	23.2	11.2	39.2
3a	Jun 2000	Scomazzon – Mossman	5.5	35	13.8	4.0	29.0	3 days in sun		1.84	19.0	13.4	46.0
3b	Jun 2000	Pollock – Mossman	5.5	53	14.9	5.4	36.6	3 days in sun		2.08	25.5	14.0	38.3
4	Nov 2000	Conti – Tully	unknown	31	9.6	2.3	23.5	1 day in sun; 2.5 days hot air @45C		0.72	43.1	7.5	31.7
5	Dec 2000	Conti – Tully	6.5	130	44.4	10.0	22.5	1 day in sun; 1 day hot air @55C	1.5	3.95	32.9	8.9	39.6
6	Apr 2001	Conservatorium – Innisfail	6.5	29	8.8	2.5	28.3	8 hrs in sun; 32 hrs hot air @ 45C		1.20	24.2	13.6	48.0
7	May 2001	Pollock – Mossman	unknown	32	11.3	2.5	22.0	3.5 days in sun	6.4	1.09	29.4	9.6	43.8
8	May 2001	Conti – Tully	6.5	40	16.4	4.2	25.7	hot air @ 45C	5.5	1.70	23.5	10.3	40.3
9	Jul 2001	Conti – Tully	5.5	16	6.0	1.3	21.8	10 days in shade; 1 day hot air 47C	6.6	0.57	28.1	9.5	43.8
10	Nov 2001	Conti – Tully	6.5	40	14.7	3.3	22.4	1 day in sun; 2.5 days hot air dry @ 40C	4.1	1.36	29.4	9.3	41.3
11	Nov 2001	Conti – Tully	7.5	87	22.2	5.7	25.7	5 days in sun	5.6	2.70	32.2	12.2	47.4
12	Nov 2001	Kebby – Coquette Point	6.5	48	28.9	5.5	18.9	5 days in sun	6.6	1.87	25.7	6.5	34.3
13	Dec 2001	Conti – Tully	6.5	62	15.36	4.25	27.7	5.5 days in sun	5.0	2.10	29.5	13.7	49.4
Averages					0.35		25.4				27.2	10.7	42.0

Table 6.4 Analyses by MacRobertsons of micro-fermentations conducted with locally sourced, unmanaged cocoa.

2000–01		Colour (%)			Moisture Content (%db)							
Fermentation ID	Pod Source	Fully Brown	Part Brown Part Purple	Fully Purple	Whole Bean	Nib	Bean Count (No. per 100g)	Fat on Dry Nib (%db)	pH	Shell Content (%)	Flavour	Appearance
1	Conti – Tully	76	24	-	7.8	6.2	85	55.7	4.5	17.4	acidic	rough
2a	Conti – Tully	78	22	-	5.2	4.0	80	55.4	5.6	17.4	no cocoa flavour	pale, look washed
2b	Daniells – East Palmerston	78	22	-	5.8	3.9	88	53.8	5.6	19.7	no cocoa flavour	pale, look washed
3a	Scomazzon – Mossman	91	9	-	7.1	5.7	74	50.5	4.8	13.9	very weak cocoa flavour	ok
3b	Pollock – Mossman	98	2	-	5.9	5.3	115	53.8	4.9	13.6	very weak cocoa flavour	ok
4	Conti – Tully	98	2	-	4.8	3.8	122	56.0	6.1	15.0	weak cocoa flavour	rough
5	Conti – Tully	98	2	-	4.8	3.6	77	55.3	5.2	11.8	weak cocoa flavour	ok
6	Conservatorium – Innisfail	100	0	-	4.9	4.1	106	53.7	5.6	11.5	weak cocoa flavour	ok
7	Pollock – Mossman	96	4	-	6.4	4.6	96	53.0	5.1	12.1	weak cocoa flavour	ok
8	Conti – Tully	98	2	-	5.5	5.1	94	55.0	4.6	16.4	very acidic	dark coloured, rough
9	Conti – Tully	84	16	-	6.6	4.9	92	54.5	5.2	16.5	weak cocoa flavour	ok
10	Conti – Tully	92	8	-	4.1	3.7	88	54.5	6.2	10.3	weak cocoa flavour	ok
11	Conti – Tully	96	4	-	5.6	4.6	83	56.1	6.2	11.3	weak cocoa flavour	ok
12	Kebby – Coquette Point	82	18	-	6.6	5.2	92	53.9	5.5	15.1	weak cocoa flavour	ok
13	Conti – Tully	98	2	-	5.0	4.5	77	55.6	5.9	10.9	weak cocoa flavour	ok
Averages		91	9	-	5.7	4.6	91	54.5	5.4	14.2		

Table 6.5 Analyses by MacRobertsons of 2002 fermentations from NACDA trials (referenced to Ghana and Indonesia cocoa).

2002					Colour				Moisture Content (%db)							
Fermentation ID	Date	Origin	Method	Drying	Fully Brown	Part Brown Part Purple	Fully Purple	Defects	Whole Bean	Nib	Bean Size (No.per 100g)	Nib Fat (% db)	pH	Shell Content (%)	Flavour/ Aroma	Appear-ance
12645	1-Jul-02	Ghana			92	8	-	-	6.4	5.7	87	55.3	5.8	11.7	Acceptable	ok
12930	7-Nov-02	Indonesia			96	4	-	-	6.0	5.3	90	55.5	5.4	15.9	Acceptable	ok
11	15-Jul	SJ	incubator		90	10	-	-	4.8	4.0	118	52.7	5.2	16.8	weak cocoa	ok
7	14-Aug	Mossman	incubator		40	60	-	-	4.4	3.8	96	56.4	5.1	15.2	weak cocoa	ok
8	14-Aug	Mossman	esky		24	76	-	-	6.2	4.2	96	55.9	4.7	16.6	weak cocoa	ok
9	18-Aug	Mossman	incubator		30	70	-	-	5.7	4.6	96	56.6	5.1	13.9	off-flavour	ok
10*	16-Sep	SJ	incubator		58	42	-	-	5.1	4.2	117	53.0	6.0	11.4	weak cocoa	ok
6*	19-Sep	Mossman	box		58	42	-	-	4.9	3.9	88	54.7	5.7	10.4	weak cocoa	ok
4	2-Oct	Mossman	box		24	76	-	-	4.6	3.9	86	53.1	5.7	10.4	weak cocoa	ok
5	4-Oct	Mossman	box		44	56	-	-	4.8	4.2	90	54.1	5.6	10.9	weak cocoa	ok
1*#	25-Oct	Mossman	box	sun	62	38	-	-	5.4	4.6	86	55.2	5.6	11.3	weak cocoa	ok
2*#	25-Oct	Mossman	box		72	28	-	-	5.1	4.2	84	54.9	6.0	11.4	weak cocoa	ok
3*	28-Oct	SJ	box	dryer	68	32	-	-	5.5	5.0	91	55.3	5.2	11.5	weak cocoa	ok
9	4-Nov	SJ + H3 (Mossman)	box	dryer	40	60	-	-	5.6	4.6	86	52.9	4.8	16.5	slightly smoky	ok
1	20-Nov	Mossman	box	dryer	48	52	-	-	5.3	4.5	97	54.8	5.4	11.8	ok	ok
2*	30-Nov	Mossman	box	dryer	44	56	-	-	5.2	4.4	103	53.9	5.3	10.5	ok	ok
11*	5-Dec	Mossman + SJ	box	dryer	48	52	-	-	5.7	4.7	85	56.2	5.2	12.1	ok	ok
13	1-Dec	Mossman + SJ	box	dryer	42	58	-	-	5.1	4.7	83	53.5	5.3	14.6	foul	ok
2002 Averages					50	50			5.2	4.3	94	54.6	5.4	12.8		

* flavour profiling conducted – refer to Table 6.9
# fermentation temperature log illustrated – refer to Figure 6.5

Table 6.6 Analyses by MacRobertsons of 2003 fermentations from NACDA trials (referenced to Ghana and Indonesia cocoa).

2003 Fermentation ID	Date	Origin	Method	Drying	Colour: Fully Brown	Colour: Part Brown Part Purple	Colour: Fully Purple	Defects	Moisture Content (%db): Whole Bean	Moisture Content (%db): Nib	Bean Size (No. per 100g)	Nib Fat (%db)	pH	Shell Content (%)	Flavour/ Aroma	Appearance
12645	1-Jul-02	Ghana			92	8	-	-	6.4	5.7	87	55.3	5.8	11.7	acceptable	ok
12930	7-Nov-02	Indonesia			96	4	-	-	6.0	5.3	90	55.5	5.4	15.9	acceptable	ok
12	14-Jan	Mossman + SJ	box	dryer	86	14			5.6	5.0	85	54.2	5.3	13.0	foul	ok
3	12-Feb	Mossman	box	dryer	84	16	-	-	4.5	3.7	90	52.3	5.4	14.3	ok	ok
4*	17-Feb	Mossman	box	dryer	82	18	-	-	5.9	4.6	90	52.0	5.2	15.6	ok	ok
5	3-Mar	Mossman	box	dryer	88	12	-	-	5.4	4.4	87	52.8	5.2	15.9	weak cocoa	ok
6	6-Mar	Mossman	box	dryer	88	12	-	-	5.0	4.0	89	52.3	5.1	15.8	foul	slightly mouldy
7#	17-Mar	Mossman	box	sun + dryer	82	18	-	-	5.6	4.6	86	52.9	4.8	16.5	slightly smoky	ok
8	7-Apr	Mossman	box	sun + dryer	86	14	-	-	5.8	5.1	90	51.0	5.1	16.0	foul	ok
1	29-Nov	Mossman + SJ	control	control	68	32	-	-	4.9	4.6	85	55.3	5.4	12.2	no cocoa flavour	ok
2	29-Nov	Mossman + SJ	box – sour dough	sour dough	54	46	-	-	5.6	4.8	83	53.7	5.1	12.1	no cocoa flavour	ok
5	29-Nov	Mossman + SJ	box – fungus	fungus	44	56	-	-	5.0	4.5	86	53.8	5.3	11.5	ok	ok
3	1-Dec	Mossman + SJ	box	dryer	64	36	-	-	5.3	4.4	85	54.6	5.7	11.1	off flavour	mouldy
4	1-Dec	Mossman + SJ	heap – banana	dryer	28	72	-	-	4.9	4.2	97	53.2	5.8	11.6	ok	ok
6	1-Dec	Mossman + SJ	box	dryer	60	40	-	-	4.6	4.3	90	54.6	5.8	11.4	off flavour	ok
2003 Averages					70	30			5.2	4.5	88	53.3	5.3	13.6		

* flavour profiling conducted – refer to Table 6.9
# fermentation temperature log illustrated – refer to Figure 6.8

Table 6.7 Analyses by MacRobertsons of 2004 fermentations from NACDA trials (referenced to Ghana and Indonesia cocoa).

2004					Colour				Moisture Content (%db)							
Fermentation ID	**Date**	**Origin**	**Method**	**Drying**	**Fully Brown**	**Part Brown Part Purple**	**Fully Purple**	**Defects**	**Whole Bean**	**Nib**	**Bean Size (No. per 100g)**	**Nib Fat (%db)**	**pH**	**Shell Content (%)**	**Flavour/ Aroma**	**Appearance**
12645	1-Jul-02	Ghana			92	8	-	-	6.4	5.7	87	55.3	5.8	11.7	acceptable	ok
12930	7-Nov-02	Indonesia			96	4	-	-	6.0	5.3	90	55.5	5.4	15.9	acceptable	ok
7	4-May	Mossman + SJ	box no turn		80	20	-	-	5.9	5.4	99	52.2	5.9	13.9	no cocoa	ok
8	4-May	Mossman + SJ	box turned		54	46	-	-	5.9	5.1	97	50.6	5.7	13.1	no cocoa	ok
12	28-May	Mossman + SJ	heap banana	dryer	34	66	-	-	5.1	4.3	99	54.9	5.5	13.7	ok	ok
13	28-May	Mossman + SJ	box	dryer	48	52	-	-	4.6	4.0	96	55.7	5.1	13.2	ok	ok
11	29-May	Mossman + SJ	barrel	sun	72	28	-	-	6.0	5.4	99	54	5	13.4	ok	ok
9	21-Jun	Mossman + SJ	box	dryer	38	62	-	-	3.9	3.7	96	56.9	4.9	14.9	ok	ok
10	21-Jun	Mossman + SJ	barrel	dryer	48	52	-	-	4.0	3.3	91	57.4	4.8	14.8	ok	ok
14	28-Jun	Mossman + SJ	barrel	dryer	52	48	-	-	5.8	5.1	94	55.2	4.9	13.3	ok	ok
1	12-Jul	Mossman + SJ	barrel	dryer	20	80	-	-	5.2	4.1	85	55.6	5.0	15.2	no cocoa	ok
2	12-Jul	Mossman + SJ	box	dryer	40	2	-	58	4.7	3.8	87	56.6	5.0	13.1	no cocoa	ok, white spots
15	2-Aug	Mossman + SJ	large box	dryer	82	18	-	-	4.2	3.6	88	56.4	4.9	14.9	ok	ok
16	2-Aug	Mossman + SJ	box	sun + dryer	88	12	-	-	5.0	4.4	80	55.5	5.0	15.6	ok	ok
19	2-Aug	Mossman + SJ	barrel	sun + dryer	100	0	-	-	4.0	3.5	103	56.5	5.4	13.1	ok	slightly mouldy
17	6-Aug	Mossman + SJ	box	sun + dryer	98	2	-	-	6.6	5.5	94	56.2	5.2	13.8	off flavour	ok
18	6-Aug	Mossman + SJ	barrel	sun	90	2	-	8	6.3	5.2	94	53.7	5.5	14.2	ok	ok
20	6-Aug	Mossman + SJ	barrel	sun	96	4	-	-	6.5	5.5	88	56.6	5.3	12.9	off flavour	ok
3	30-Aug	Mossman + SJ	box inoculate	sun + dryer	88	12	-	-	5.1	4.2	106	53.6	4.9	15.4	no cocoa	ok
4	30-Aug	Mossman + SJ	box	sun + dryer	84	16	-	-	4.4	3.6	98	54.6	4.8	15.2	ok	ok
5	30-Aug	Mossman + SJ	barrel	sun + dryer	42	58	-	-	4.8	3.8	81	56.5	4.9	14.3	slightly musty	slightly mouldy
6	26-Oct	Mossman + SJ	barrel inoculate	sun	28	72	-	-	8.2	6.3	86	54.9	5.1	13.9	underfermented	Mouldy
7	26-Oct	Mossman + SJ	barrel warmed	sun	46	54	-	-	7.0	5.7	84	55	5.1	14.7	underfermented	Mouldy
8	26-Oct	Mossman + SJ	barrel ambient	sun	53	47	-	-	6.4	5.8	96	54.8	5.1	13.6	ok	ok

Table 6.7 Continued Analyses by MacRobertsons of 2004 fermentations from NACDA trials (referenced to Ghana and Indonesia cocoa).

2004 Fermentation ID	Date	Origin	Method	Drying	Colour: Fully Brown	Colour: Part Brown Part Purple	Colour: Fully Purple	Defects	Moisture Content (%db): Whole Bean	Moisture Content (%db): Nib	Bean Size (No. per 100g)	Nib Fat (%db)	pH	Shell Content (%)	Flavour/ Aroma	Appearance
12645	1-Jul-02	Ghana			92	8	-	-	6.4	5.7	87	55.3	5.8	11.7	acceptable	ok
12930	7-Nov-02	Indonesia			96	4	-	-	6.0	5.3	90	55.5	5.4	15.9	acceptable	ok
9	15-Nov	Mossman + SJ	box control	dryer	12	88	-	-	4.9	4.7	92	53.7	4.8	12.4	ok	ok
10	15-Nov	Mossman + SJ	'25' ovendried	dryer	18	82	-	-	5.2	4.6	93	55.2	4.9	12.9	ok	ok
11	15-Nov	Mossman + SJ	'50' ovendried	dryer	12	88	-	-	5.5	4.6	90	55.8	4.8	13.5	ok	ok
12#	15-Nov	Mossman + SJ	control	sun + dryer	14	86	-	-	6.3	5.6	94	54.7	4.9	13.0	ok	ok
13	15-Nov	Mossman + SJ	'25' sun + oven	sun + dryer	10	90	-	-	6.1	5.3	98	54.0	4.9	12.2	ok	ok
14	15-Nov	Mossman + SJ	'50' sun + oven	sun + dryer	40	60	-	-	5.9	5.5	104	54.4	5.0	12.2	ok	ok
15	22-Nov	Mossman + SJ	control	sun	48	52	-	-	6.8	5.9	119	55.0	5.4	13.5	no cocoa	ok
16	22-Nov	Mossman + SJ	yeast	sun	44	56	-	-	7.3	5.8	115	53.4	5.3	13.2	no cocoa	ok
17	22-Nov	Mossman + SJ	yeast	dryer	60	40	-	-	6.7	5.8	128	54.8	5.4	12.7	no cocoa	ok
18#	22-Nov	Mossman + SJ	control	dryer	58	42	-	-	6.0	4.8	134	54.8	5.4	12.8	no cocoa	ok
19	22-Nov	Mossman + SJ	'50' sun dried	sun	78	22	-	-	6.5	5.8	110	55.2	5.2	13.2	ok	ok
20	22-Nov	Mossman + SJ	'50' oven dried	dryer	80	20	-	-	5.9	5.1	124	55.6	5.3	12.7	no cocoa	ok
2004 Averages					63	37			5.7	4.8	98	55.0	5.1	13.7		

fermentation temperature log illustrated – refer to Figures 6.8 to 6.9

Table 6.8 Analyses by MacRobertsons of 2005 and 2006 fermentations from NACDA trials (referenced to Ghana and Indonesia cocoa).

2005–06					Colour				Moisture Content (%db)							
Fermentation ID	Date	Origin	Method	Drying	Fully Brown	Part Brown Part Purple	Fully Purple	Defects	Whol-e Bean	Nib	Bean Size (No. per 100g)	Nib Fat (%db)	pH	Shell Content (%)	Flavour/ Aroma	Appearance
12645	1-Jul	Ghana			92	8	-	-	6.4	5.7	87	55.3	5.8	11.7	acceptable	ok
12930	7-Nov	Indonesia			96	4	-	-	6.0	5.3	90	55.5	5.4	15.9	acceptable	ok
1	17-Jul	Mossman + SJ	box	dryer	24	76	-	-	7.3	5.5	97	56.1	5.0	16.3	slight smoky	ok
2	17-Jul	Mossman + SJ	box washed	dryer	30	70	-	-	5.2	4.1	99	56.2	4.8	10.6	ok	ok
3	17-Jul	Mossman + SJ	washed	sun + dryer	40	60	-	-	6.7	5.6	96	55.1	5.0	11.0	ok	ok
4	17-Jul	Mossman + SJ	large box	dryer	54	46	-	-	4.8	3.9	94	56.2	4.8	13.7	ok	ok
5	17-Jul	Mossman + SJ	large box	sun + dryer	48	52	-	-	5.3	4.6	87	56.2	4.9	13.2	ok	ok
6	17-Jul	Mossman + SJ	box	sun + dryer	28	72	-	-	7.4	4.9	87	56.3	4.8	16.4	slight smoky	ok
7	17-Jul	Mossman + SJ	box	dryer	40	60	-	-	6.8	4.6	94	55.8	4.7	15.9	slight smoky	ok
8	17-Jul	Mossman + SJ	barrel	dryer	38	62	-	-	6.8	4.9	87	55.3	4.8	15.0	ok	ok
9	17-Jul	Mossman + SJ	barrel	dryer	44	56	-	-	6.2	4.8	82	55.3	4.8	15.1	slight smoky	ok
10	25-Jul	Mossman + SJ	short		54	46	-	-	6.8	5.6	91	56.5	5.1	12.7	ok	ok
11	25-Jul	Mossman + SJ	long		54	46	-	-	7.5	5.4	92	56.5	4.9	14.6	ok	ok
2005 Averages					41	59			6.4	4.9	91	56.0	4.9	14.0		
1	22-Aug	Mossman + SJ	barrel	sun + dryer	62	38	-	-	4.4	3.6	89	55.0	6.2	12.4	weak cocoa	ok
2	22-Aug	Mossman + SJ	box inoculate	sun + dryer	62	38	-	-	4.3	3.6	80	55.0	6.3	11.3	weak cocoa	ok
3	22-Aug	Mossman + SJ	barrel	sun + dryer	42	58	-	-	4.8	4.2	88	54.3	5.9	14.1	weak cocoa	ok
4	22-Aug	Mossman + SJ	box	sun + dryer	44	56	-	-	5.1	4.3	81	54.5	5.8	12.9	weak cocoa	ok
2006 Averages					53	48			4.7	3.9	85	54.7	6.1	12.7		

6.3.4 Temperature logs of commercial-scale fermentations

As previously discussed, temperature data logging was routinely conducted for most fermentations. The temperature of the fermenting bean mass was recorded via temperature probe and electronic data logger for the entire fermentation. These records are potentially useful to indicate the 'degree' of fermentation achieved and in real-time served as a guide to the endpoint of fermentations.

In the following, some selected temperature log examples from fermentations conducted in the NACDA project are presented and discussed. Most of these can be cross-referenced with the data in Tables 6.5 to 6.7.

Initial 'box' fermentations

Figure 6.7 shows the temperature log for one of the early box fermentations. It was conducted in October 2002 when enough beans were becoming available from the NACDA trials in Queensland to perform the first 'stand alone' fermentations. This particular fermentation was done with 104 kg of wet bean. The dried beans only developed 'weak cocoa flavour' (as per table 6.5). There were two turns, the first at about 50 hrs and the second at 96 hrs. It took over 2 days for the temperature of fermentation to reach 40°C and the peak temperature reached just after the second turn was only 42°C. The temperature went into sustained decline on day 6 so the fermentation was stopped.

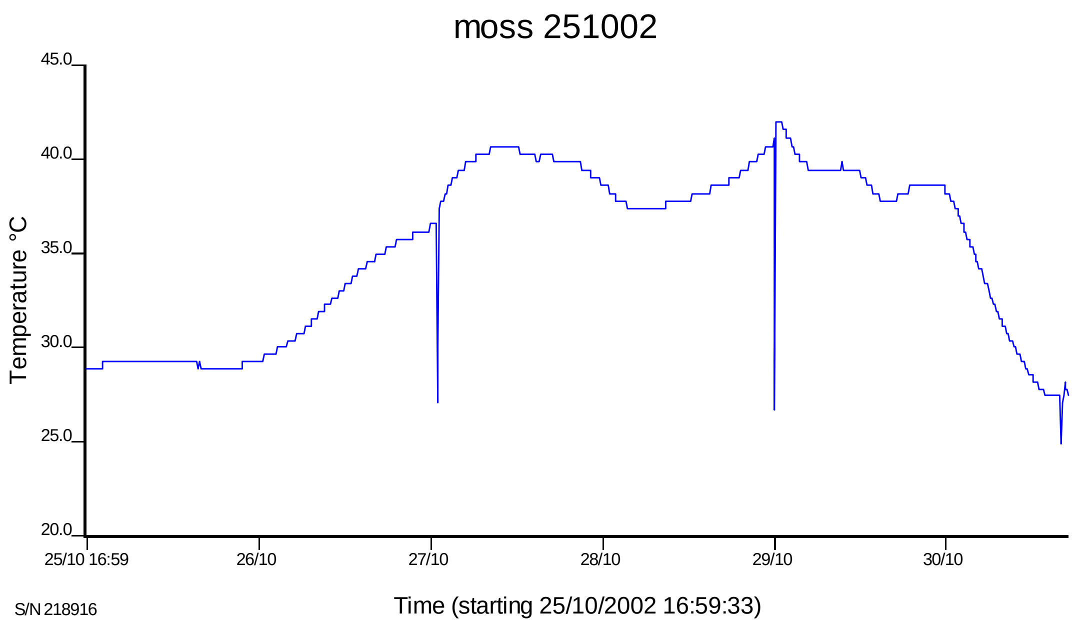


Figure 6.7 Initial fermentation using 'box'.

Problems with winter fermentations

Figure 6.8 illustrates how low ambient temperatures at South Johnstone during winter months delayed the on-set of fermentations. This fermentation was conducted in June 2003. As can be seen from the log, the ambient temperature was 22.5°C at the start of the fermentation. The temperature remained almost constant until the first turn at about 40 hrs which produced a modest temperature increase to about 31°C over the next 24 hrs at which time there was a second turn. After the second turn there was a good temperature increase to about 46°C on day 4 but this was not sustained and for unknown reasons the temperature declined before peaking at almost 50°C on day 6. This pattern is not representative of a classic fermentation proceeding. No flavour data is available for this fermentation.

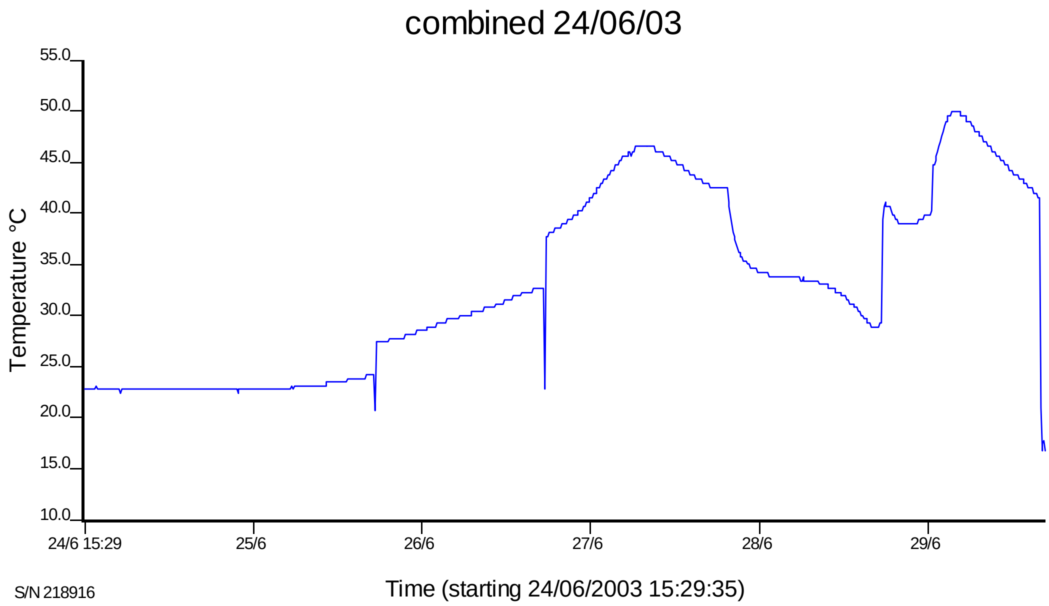


Figure 6.8 Winter fermentation with poor temperature profile.

Summer fermentation

Figure 6.9 shows the temperature log from a box fermentation conducted in March 2003 when ambient temperatures were higher. The fermentation started at 27°C and there was a steady increase to 29°C after two days at which point the first turn was carried out. This was followed by an increase to 40°C over two days and the second turn. The third turn was conducted after five days by which point the temperature had increased to 50°C.

Although this fermentation showed a steady temperature increase and temperatures over 45°C were sustained for three days, it still took over four days to reach 45°C. The temperature was not in significant decline when the fermentation was stopped after seven days but it was probably prudent to stop the fermentation at this point anyway, since beans from this fermentation developed a ‘slightly smoky’ flavour. This is attributed to the length of fermentation having increased risk of purification bacteria developing with attendant off-flavours. Despite warmer ambient conditions, this fermentation took too long to get under way. In hindsight, it may also have not been necessary to conduct the third and/or fourth turns.

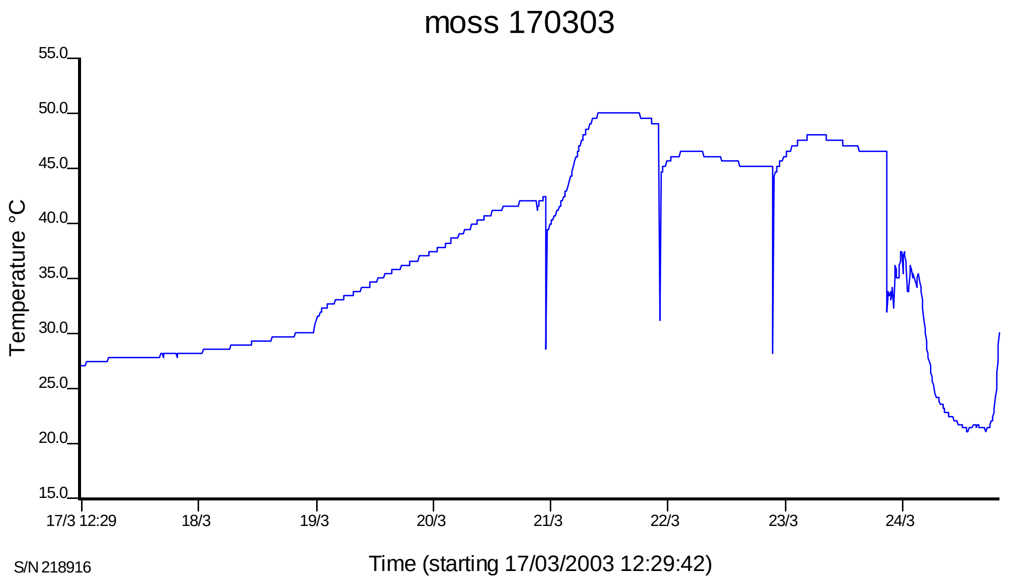


Figure 6.9 ‘Slow’ box fermentation during summer.

Barrel fermentations

Figure 6.10 shows a fermentation which resulted in 'ok' cocoa flavour (as per Table 6.7). The temperature profile is not dissimilar to the previous example (Figure 6.9) however the increase to 45^{o}C is more rapid (about 2.5 days) and the fermentation was stopped just short of five days (the extra data reflects ambient conditions recorded by the logger after removal from the fermentation but before downloading). This fermentation was conducted using the plastic barrel apparatus with the whole apparatus held inside an artificially warmed room. The first two turns were conducted at daily intervals (rather than after two days as per the previous example). The results of this fermentation gave only 14% fully brown beans (86% part brown/part purple) indicating that the fermentation could probably have been left longer.

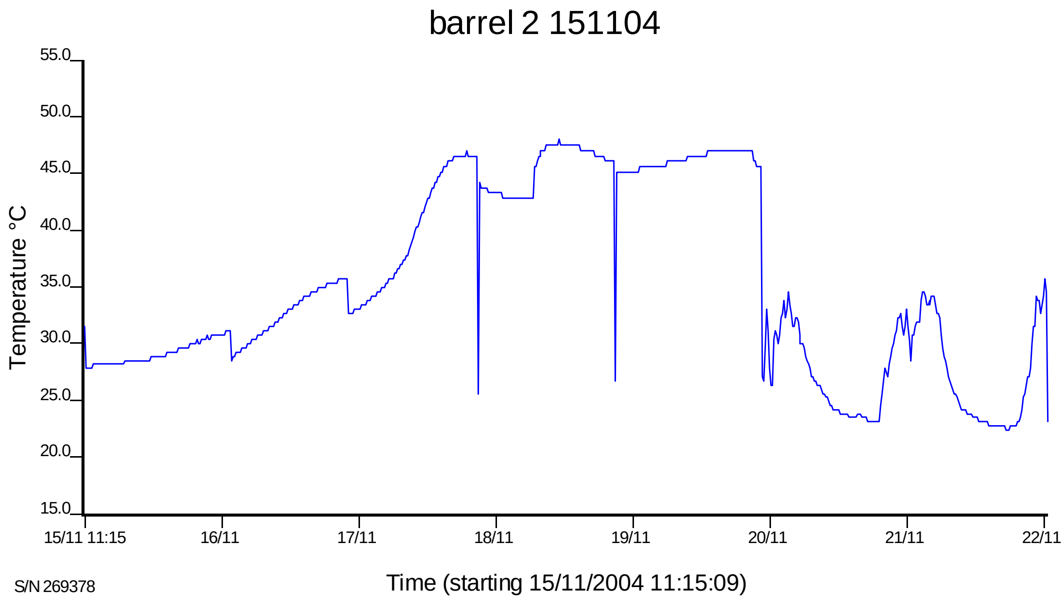


Figure 6.10 Barrel fermentation in warmed room.

Figure 6.11 shows the temperature log of a barrel fermentation also conducted inside a warmed room as per the previous example (Figure 6.10). There was an even more rapid increase in temperature (reaching 45°C within two days) and sustained temperatures above 45°C for three days (note that as previously data after 27/11 reflects ambient conditions recorded by the logger after removal from the fermentation but before being downloaded). However, this fermentation resulted in beans with 'no cocoa flavour' (as per Table 6.7) despite 58% being fully brown. This illustrates that temperature alone is not necessarily a complete guide to the success of fermentation. Possibly, the absence of appropriate micro flora or the fermentation being stopped prematurely resulted in the lack of flavour development.

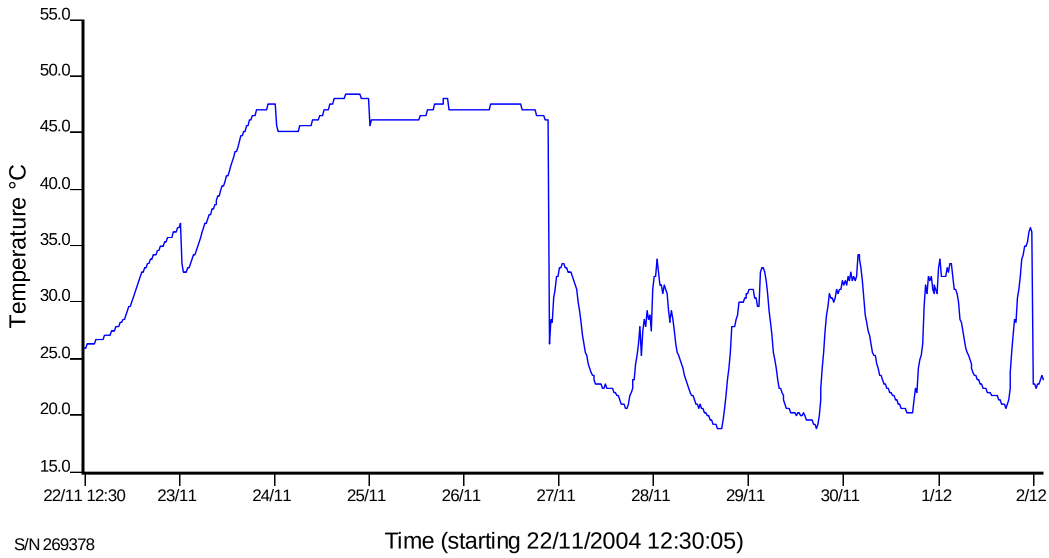


Figure 6.11 Barrel fermentation in warmed room.

6.3.5 Results of flavour profiling

The foregoing analyses of fermentations by MacRobertsons only provided a general remark about the chocolate flavour characteristic of samples i.e. 'no cocoa flavour', 'weak cocoa flavour', 'ok', or in the case of the Indonesian and Ghana samples, 'acceptable'. It was confirmed with MacRobertsons that an assessment of 'ok' indicated that the beans were acceptable, having no taints and with at least some cocoa flavour.

Considering that the 'cocoa flavour' characteristic of Queensland samples was apparently lacking (in general), it was asked if this characteristic could be assessed in more detail and feedback given.

MacRobertsons subsequently selected a number of samples with reasonable chocolate flavour for further flavour profiling. This involved manufacturing chocolate 'tasters' for a panel of trained assessors. The samples which were selected are indicated in Tables 6.5 and 6.6. The results of the flavour profiling are given in Table 6.9 together with the results for a sample of Ghana cocoa. These results are not discussed as they were forwarded by MacRobertsons without an explanation of the rating scale or any accompanying commentary or conclusions. However, it was noted by MacRobertsons that their panellists '*are trained to detect off-flavours and are not into flavour profiling*'. Therefore the data in Table 6.9 should not be regarded as definitive.

Table 6.9 Flavour profiling of selected NACDA fermentations by MacRobertsons (referenced to Ghana beans).

Fermentation ID & Date	Origin	Flavour Results					Overall CFS*
		Cocoa	Acidity	Brown Fruit	Bitterness	Undesirables	
Standard	Ghana	4.6	1.0	0.2	1.0	0.0	5.5
#10 16-Sep-02	S Johnstone	3.0	0.7	0.0	0.8	2.0 – musty	3.2
#6 19-Sep-02	Mossman	3.3	0.5	0.3	0.5	0.0	4.0
#1 25-Oct-02	Mossman	3.3	0.8	0.0	1.0	0.0	4.0
#2 25-Oct-02	Mossman	3.7	0.8	0.0	0.8	0.3 – smoky	3.8
#3 28-Oct-02	S Johnstone	3.2	0.7	0.0	1.2	0.3 – smoky	3.5
#2 30-Nov-02	Mossman	4.3	1.0	0.3	1.0	0.0	5.0
#11 5-Dec-02	Combined	4.3	0.8	0.3	0.8	0.0	5.0
#4 17-Feb-03	Mossman	4.3	0.6	0.6	0.6	0.6	5.0

*Chocolate Flavour Score

6.3.6 Bulk cocoa shipment

In 2003 1,600 kg of dried and fermented beans from NACDA trials in Queensland was shipped to MacRobertsons in Singapore (via Cadbury Melbourne). It was blended with other cocoas and used in MacRobertsons normal manufacturing operations. This product was only comprised of beans which had tested 'ok' or 'acceptable' in previous sampling. All other product which was of inferior quality due to poor cocoa flavour development, off-flavours or contamination was discarded. Figure 6.12 shows the packaged product at South Johnstone ready for shipment. In Figure 6.12 the product is shown sealed in plastic bags which is not recommended, however in this instance the product had been previously stored in a cold room so 'sweating' and condensation within the sealed bags had not been a problem.

Whilst there was no need for further quality testing of the material, it was requested that the size and degree of flatness of beans in this bulk shipment be assessed. This was because there was some concern that the beans from NACDA trials were smaller and flatter than was commercially desirable.

The results of these tests are presented in Table 6.10. There are four samples which reflect the composition (origin) of lots in the total shipment i.e. Mossman, South Johnstone or a 'Combined'. The results were acceptable and allayed concerns about the level of flat beans. The bean count for the South Johnstone lot (111) was just higher than commercially desirable (<110).

Figure 6.12 NACDA dried and fermented beans ready for bulk shipment to MacRobertsons, Singapore.

Table 6.10 Size and flatness of NACDA beans in bulk shipment to MacRobertsons, Singapore (2003).

Lot	Bean Count (No. per 100g)	Flat Beans (%)
Combined #2	93	1.1
Combined #1	91	0.9
South Johnstone	111	1.2
Mossman	92	0.6

6.3.7 Results from fat analyses

In December 2002, three samples of fermented and dried beans from the NACDA trials were forwarded to Cadbury's Claremont Analytical Laboratories in Tasmania for analyses and testing of fats. The following tests were conducted on the cocoa butter:

1. Fatty acid composition by gas liquid chromatography of the fatty acid methyl esters (FAME).
2. Tryglyceride profile.
3. Solid fat content (melting profile).

The results of these tests are reproduced in full in Appendix A5. The results are based only on three samples of beans and should be regarded as preliminary and not necessarily representative of any general run of Australian produced cocoa.

Fatty acid composition

Table 6.11 shows results of the FAME analysis for the three Queensland grown samples, compared to 'typical data' for West African Cocoa butter (Talbot 1999). The results are consistent with cocoa butter being a relatively simple fat (typically being comprised of palmitic, stearic and oleic acids).

Table 6.11 FAME analysis of selected Queensland cocoa samples by Cadbury Claremont Analytical Laboratories (compared to 'typical' West African cocoa butter).

Carbon No.		Fatty Acid Composition (%)			
	FAME* Name	West Africa	Mossman (sun-dried)	Mossman (hot air-dried)	South Johnstone (hot air-dried)
C4:0	Butyric acid	no data	not detected	not detected	not detected
C6:0	Caproic acid	no data	not detected	not detected	not detected
C8:0	Caprylic acid	no data	not detected	not detected	not detected
C10:0	Capric acid	no data	not detected	not detected	not detected
C12:0	Lauric acid	no data	not detected	not detected	not detected
C14:0	Myristic acid	0.1	not detected	not detected	not detected
C16:0	Palmitic acid	26.0	25.4	25.3	25.7
C16:1	Palmitoleic acid	0.3	no data	no data	no data
C18:0	Stearic acid	34.4	36.6	36.4	35.3
C18:1	Oleic acid	34.8	33.5	33.9	34.3
C18:2	Linoleic acid	3.0	3.1	3.1	3.2
C18:3	Linolenic acid	0.2	0.2	0.2	0.2
C20:0	Arachidic acid	1.0	1.0	1.0	1.0
C20:1	Eicosenoic acid	no data	not detected	not detected	not detected
C22:0	Behenic acid	0.2	0.2	0.2	0.2
C24:0	Lignoceric acid	no data	not detected	not detected	not detected

Tryglyceride profile

The trygliceride composition of the Queensland samples is presented in Table 6.12. No discussion of these results is provided.

Table 6.12 Trygliceride composition of selected Queensland cocoa samples by Cadbury Claremont Analytical Laboratories.

Carbon No.	Triglyceride Profile (%)		
	Mossman (sun-dried)	Mossman (hot air-dried)	South Johnstone (hot air-dried)
C26	0.0	0.0	0.0
C28	0.2	0.2	0.2
C30	not detected	not detected	not detected
C32	not detected	not detected	not detected
C34	0.1	0.1	0.1
C36	0.7	0.7	0.7
C38	0.8	0.8	0.8
C40	0.1	not detected	not detected
C42	not detected	0.0	0.0
C44	0.3	0.3	0.3
C46	0.2	0.2	0.1
C48	0.6	0.7	0.6
C50	19.7	19.8	20.4
C52	45.8	45.8	45.9
C54	30.2	30.1	29.7
C56	1.3	1.3	1.2

Solid fat content

The solid fat content of the three Queensland samples is presented as average values in Table 6.13 together with typical data for other cocoas (Talbot 1999). The Queensland data is also shown graphically in Figure 6.13.

Table 6.13 Average solid fat content of Queensland cocoa samples by Cadbury Claremont Analytical Laboratories referenced to typical data for Brazil, Ghana and Malaysia cocoa (sourced from Talbot 1999).

Temperature (^{o}C)	Solid Fat Content(%)			
	Brazil	Ghana	Malaysia	Queensland (average 3 samples)
0	no data	no data	no data	90.3
10	no data	no data	no data	87.3
20	66.3	76.2	81.2	81.3
25	60.1	70.4	76.2	76.1
27.5	no data	no data	no data	71.0
30	36.9	45.1	54.8	60.1
32.5	6.6	13.3	19.7	26.4
35	2.0	0.0	0.0	4.9
40	no data	no data	no data	1.7
60	no data	no data	no data	0.0

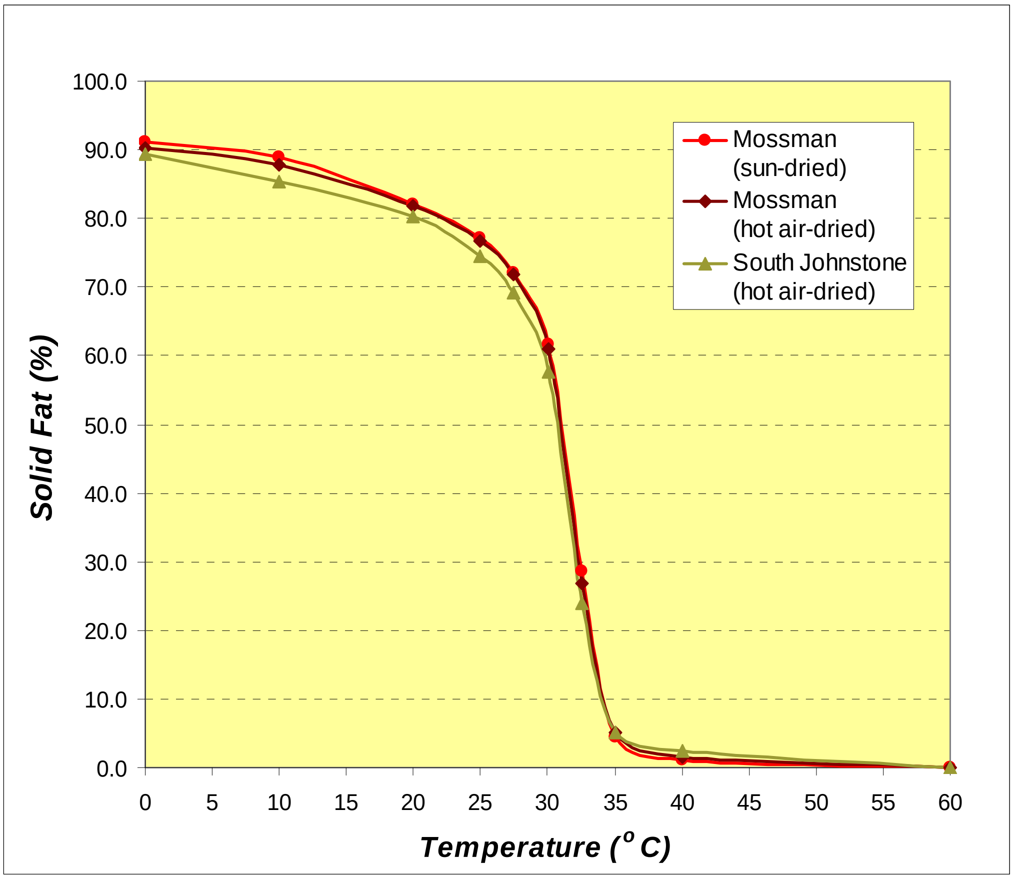


Figure 6.13 Solid fat content (melting profile) of three selected Queensland cocoa samples.

The solid fat content determines the melting behaviour of the cocoa butter which is important to the behaviour in chocolate. The quantity of fat and its melting characteristics, especially hardness, depend on the variety of cocoa, the post-harvest processing and the environmental conditions. In particular, the average daily temperature during the last few months of pod development affects the hardness of the cocoa butter; lower temperatures give butters that are softer or have a lower melting point (Fowler 1999).

The data in Table 6.13 shows the Queensland samples to have a cocoa fat level of 76.1% at 25°C indicating it to be quite a hard butter at room temperature (comparable to Malaysia). Generally, Malaysian cocoa butter is harder than West African (Ghana) butter which in turn is harder than Brazilian butter and this is borne out by the data in Table 6.13.

In Figure 6.13 the South Johnstone sample has lower solid fat content for temperatures up to about 32°C than both of the Mossman grown samples. This indicates a slightly softer butter. Given similarities in genetics and post-harvest processing for these samples the difference could mainly be attributed to environment. South Johnstone is a cooler growing environment than Mossman, so this is in agreement with the observation that lower temperatures give butters that are softer or have a lower melting point (Fowler 1999).

This high butter hardness of the Queensland cocoa may well be regarded as a desirable attribute depending on the specification of butter required. However, the data also shows a significant level of solid fat content above 37°C (human body temperature) for the Queensland grown cocoa. This may result in the manufactured chocolate having a waxy mouth feel. Alternatively, these values may be attributed to polymorphism of the fat crystals in the samples for solid fat analyses. If so then this could be reduced by better tempering of the sample prior to analysis.

6.4 Summary

Commercial-scale fermentations were successfully conducted using Australian grown cocoa beans (sourced from NACDA trials in Queensland) which resulted in acceptable flavour characteristics.

However, it was more difficult to achieve consistent and thorough fermentations than had been anticipated at the outset. This is attributed to inexperience with the method and techniques for fermentation rather than any deficiency in the beans themselves. The cocoa flavour characteristics were often variable with ‘weak’ or ‘no’ cocoa flavour sometimes being attributed. Further experimentation and experience with fermentation techniques and drying conditions is required to develop a proven method/s which works under local conditions. This may need to adapt to seasonal changes in weather (ambient temperature) and bean characteristics (in particular mucilage content).

The primary physical characteristics of beans (bean size, fat content, shell content) met International Cocoa Standards for commercial acceptability and were comparable with cocoa from Ghana and Indonesia. Meeting standards for other attributes such as tolerable levels of defects and chemical residues will be depend on the application of good production management practices and appropriate secondary processing technology which should be readily attainable. Neither of these is seen as being dependent on the inherent quality of Australian grown cocoa.

It is concluded that it would be entirely possible to commercially produce good quality Australian-grown cocoa for sale into the world market. This will require further development of fermentation practice and sourcing appropriate technology for processing of the dried and fermented bean prior to shipping. Notwithstanding, it will also depend on successful commercialisation of the mechanised pod splitting and bean separation technology to produce an acceptable sample of wet bean.

7. Farming systems

7.1 Density trial

7.1.1 Background and philosophy

Elsewhere in the world, cocoa is generally grown in a block planting arrangement or intercropped with other species. It is often grown as a virgin planting in newly cleared land with remnant rainforest trees being retained to provide shade and wind protection. There is usually no requirement for access by machinery and topography often prohibits access anyway. Even in situations where cocoa is planted in regular rows at nominal spacings, it is not pruned or managed with the intention of machinery access. Some road access and headlands may be provided to allow movement of pods/beans from the plantation.

In Australia, defined planting layouts are required for efficient layout of irrigation and to allow machinery access for management and harvesting.

7.1.2 Hybrid Yield Evaluation Trial (HYET) layout and trial design

Based on the preceding, the HYETs at all sites comprised single row and double row planting layouts using a consistent planting density close to 1,200 trees/ha for both the double and single rows. This was considered the best-bet for Australian cocoa plantings based on information from overseas studies.

The primary purpose of the single row layout was to try and emulate a ‘traditional’ planting. With this layout the issue of machinery access was secondary and the row spacing adopted (3.3 m) was not thought sufficient at the outset to allow machinery access. Because of this, at the CPHRF site, a wider ‘access’ was provided every fourth row (between blocks) which allowed pesticide applications, etc. At the Mossman HYET a similar wider access row was provided by virtue of the neighbouring twin-row planting (6.5 m centres) and single-row guard rows (at 4 m centres).

The purpose of the double row planting was to provide a yield comparison with the single rows but based on a layout for mechanisation. At the time of trial development it was thought that the double row layout would be more suitable for mechanisation than a wider-spaced single row layout. The principle advantages offered by the double row layout were perceived as follows:

- more efficient utilisation of irrigation (infrastructure and application efficiency)
- easier implementation of intercropping (with bananas and papaya)
- easier to implement and manage shade species (along centreline of double row)
- less root-zone compaction by vehicles
- halves the number of vehicle passes for pesticide, herbicide, pruning and harvesting operations.

Details of these layouts and the block/trial design are given elsewhere (Appendix A2).

7.1.3 Farming Systems Trial (FST) layout and trial design

The FST planted at South Johnstone was set-up to evaluate alternative planting densities to the HYETs. The yield performance at higher and lower densities would provide data to determine if a different planting density was justified (notwithstanding the different costs of establishment).

The density trials were conducted on both the double and single row layouts. The overall double row layout was the same as for the HYETs to provide a basis for comparison. For the single rows however, the row spacing was increased to 4 m compared to 3.3 m in the HYETs. This was to allow better access for machinery. The planting density was therefore altered by selecting different in-row tree spacings. The overall block layout is given in Appendix A3.

Double rows

There were four double rows at 6.5 m centres with 2.5 m between the plant row centres. An offset planting arrangement was used for the planting rows within each double row. Due to the flatness of the site and high rainfall intensities at South Johnstone, each double row was hilled prior to planting to a height of about 0.2m with a bed width of about 3.0 m. This left about 0.4 m between the edge of the bed and the plant rows. There was a 3.5 m inter-row space between beds with slight 'V' profile to assist drainage.

There were four densities in 16 blocks (four blocks per row) with 20 trees per block. Each density treatment was planted with two hybrids i.e. 2 replicates × 2 hybrids (PNG1 and PNG5) × 4 densities = 16 blocks as per Table 7.1.

Table 7.1 Double row density trial treatments.

Density (trees/ha)	In-Row Tree Spacing (m)	Block Treatments
A – 2,051	1.5	2 × PNG1 and 2 × PNG5
B – 1,538	2.0	2 × PNG1 and 2 × PNG5
C – 1,026	3.0	2 × PNG1 and 2 × PNG5
D – 810	3.8	2 × PNG1 and 2 × PNG5

Single rows

There were four single rows at 4 m centres with 11 trees per block. Due to the flatness of the site and high rainfall intensities at South Johnstone, each single row was hilled prior to planting to a height of about 0.2 m with a bed width of about 1.0 m. This left about 0.4 m between the edge of the bed and the plant. There was a 3 m inter-row space between beds with slight 'V' profile to assist drainage.

There were four densities in 16 blocks (four blocks per row). Each density treatment was planted with two hybrids. Limited numbers of seedling plants meant that only PNG5 was common to both the double and single row density treatments i.e. 2 replicates × 2 hybrids (PNG 4 and PNG5) × 4 densities = 16 blocks as per Table 7.2.

Table 7.2 Single row density trial treatments.

Density (trees/ha)	In-Row Tree Spacing (m)	Block Treatments
A – 2,083	1.2	2 × PNG4 and 2 × PNG5
B – 1,471	1.7	2 × PNG4 and 2 × PNG5
C – 1,042	2.4	2 × PNG4 and 2 × PNG5
D – 806	3.1	2 × PNG4 and 2 × PNG5

The basis of the trial layout was to improve the flow of machinery and picking labour. As such the trial design does not allow for a true statistical analysis. Data from the plots is presented as means with associated standard error of the means (SE). This allows the means of treatments, whether in double or single row treatments to be compared. The density trials at South Johnstone about three months after planting are shown in Figure 7.1.

Figure 7.1 South Johnstone density trial three months after cocoa planting: left – single rows; right – double rows.

7.1.4   Trial establishment and management

Trees were planted and managed as per trees in the Mossman and South Johnstone HYETs. Planting was carried out in July/August 2000 and seedlings protected with individual shade and wind screens (Figure 7.1). Super phosphate was applied pre-planting at the rate of 30 kg/ha. At planting a Monsoon fertiliser tablet (10 g) was included with each seedling. Fertiliser management was as discussed in Section 4A.5.

Insect control was utilised as required particularly for the control of swarming beetles (*Rhyparida* spp.). In the first 18 months of growth up to 12 applications of insecticide were applied.

7.1.5   Results and dscussion

Early growth measurements

Early growth measurements were conducted on the treatment combinations in the double row blocks. Measurements included jorquette height, final tree height in May 2002 approximately 22 months post planting and height change over 14 months from March 2001 to May 2002. Tree diameter changes were also measured. The data was analysed as a completely randomised block with each variety replicated two times.

Height

There was no significant hybrid or density effect on height of plants, change in height over time or the final jorquette height (Tables 7.3 and 7.4).

Table 7.3 Mean tree jorquette height, tree height and tree height changes at four plant density treatments grown in a double row arrangement at South Johnstone.

Planting Density Trees/ha	Mean Jorquette Height (cm) @14/1/02	Initial Height (cm) @7/03/01	Height (cm) @6/10/01	Height (cm) @14/01/02	Height Change (cm 7/3/01 – 24/5/02	Final Height (cm) @24/5/02
A – 2051	143	105	163	208	180	242
B – 1538	126	90	141	188	167	221
C – 1026	132	88	144	190	182	231
D – 810	130	93	142	184	158	209
	n.s.	n.s	n.s.	n.s.	n.s.	n.s.

Table 7.4 Mean tree jorquette height, tree height and tree height changes for two hybrids.

Hybrid	Mean Jorquette Height (cm) @14/1/02	Initial Height (cm) @7/03/01	Height (cm) @26/10/01	Height (cm) @14/01/02	Height Change (cm) 7/3/01 – 24/5/02	Final Height (cm) @24/5/02
PNG1	132	97	154	199	176	233
PNG5	134	91	140	186	167	219
	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

The analysis of tree diameters measured on the 21/11/01, 14/3/02 and 24/5/02 did not show any significant density or hybrid effect (Tables 7.5 and 7.6).

Table 7.5 Mean tree diameter at four plant density treatments grown in a double row arrangement at South Johnstone.

Planting Density Trees/ha	Diameter (mm) @21/11/01	Diameter (mm) @14/3/02	Diameter (mm) @24/5/02
A – 2051	24.5	36.0	44.0
B – 1538	23.8	35.7	42.8
C – 1026	24.8	35.1	41.8
D – 810	23.1	34.9	42.7
	n.s.	n.s	n.s.

Table 7.6 Mean tree diameter for two hybrids on three occasions.

Hybrid	Diameter (mm) @21/11/01	Diameter (mm) @14/3/02	Diameter (mm) @24/5/02
PNG1	24.5	36.4	44.6
PNG5	23.6	34.4	41.1
	n.s.	n.s.	n.s.

Early tree height, diameter and growth as measured by change in height were unaffected by density and variety. This result is not unexpected because even at the highest density trees in the early development stages are acting as individuals and not competing for resources such as light, water and nutrients.

Pod yields

Commercial levels of crop were harvested from May–June 2002. Recorded cropping occurred from July 2002 and whole pod yields are presented on a financial year or seasonal basis. In the double row treatments, annual production rose sharply from 2002/03 to a mean yield for all treatment of 16,406 kg/ha and 17,520 kg/ha in 2003/04 and 2004/05 respectively (Figure 7.2). In the single row treatments the mean pod yield peaked at 31,568 kg/ha in the 2004/05 season. The sharp yield decline in the 2005/06 season is due to the lack of recordings for the later half of the season as the orchard was severely damaged by Cyclone Larry in March 2006. Yield data for the 2005/06 season is based entirely on pods collected from July to December in 2005. Hence the true pod production value may be assumed to be at least double that shown in Figure 4.2, i.e. approximately 15,000 kg/ha.

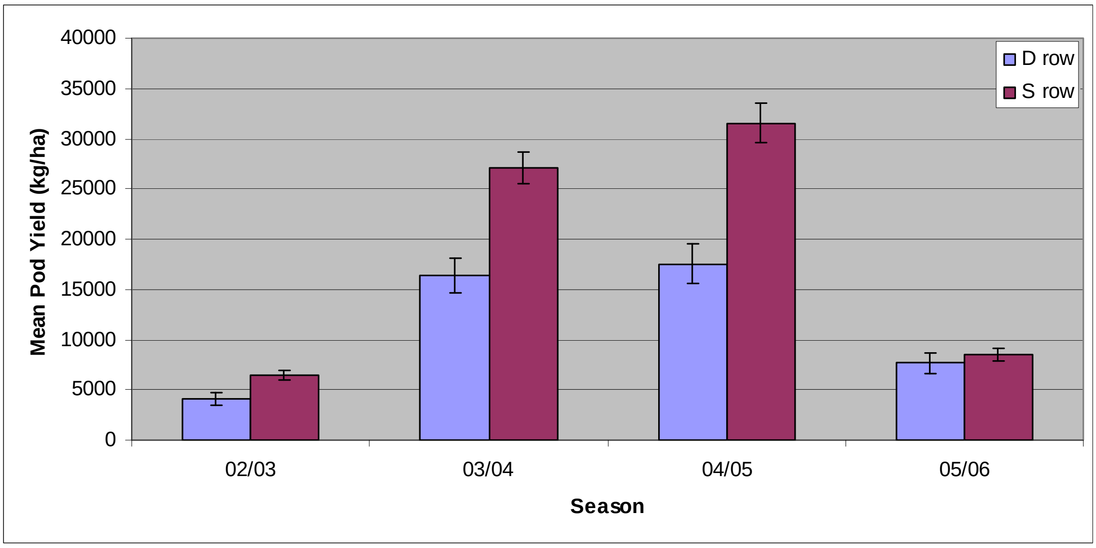


Figure 7.2 Mean seasonal whole pod yields across four densities and two hybrids for cocoa grown either in a double (D) or single (S) row layout. The standard error (SE) of the means is displayed by the error bars.

Density had a strong impact on crop yield with the highest mean yields recorded at the highest planting density in both the single and double row layouts. In the single row trial block the mean yields are all within the variation of yields as shown by the SE suggesting that the mean yields for the four densities are not different. Whereas in the double row layout, density appears to have had a strong impact on yield with plants in the highest density outperforming the two mid-density treatments which in turn out performed the trees at the lowest density (Figure 7.3).

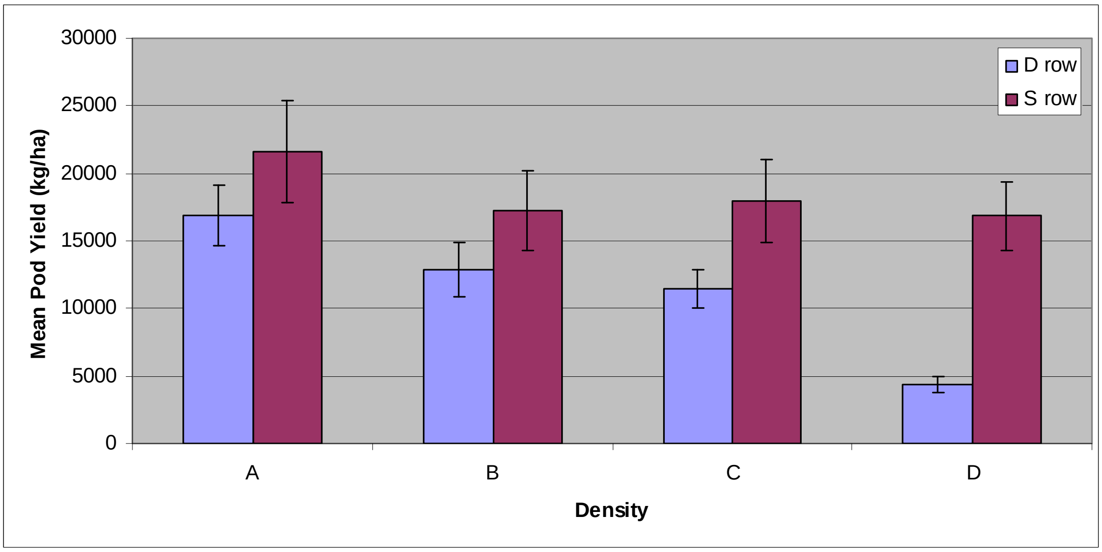


Figure 7.3 Mean whole pod yields at four densities across all seasons and two hybrids for cocoa grown either in a double or single row layout. The standard error (SE) of the means is displayed by the error bars.

Double Row

Within the double row trial plot the interactions between plant density, hybrid and season is shown in Figure 7.4. In the full production seasons of 2003/04 and 2004/05 yield declined with density and was generally higher for the hybrid PNG1. Mean maximum whole pod yields were in the vicinity of 25,000 kg/ha at the highest density which is roughly equivalent to a dry bean production of 2.5 t/ha.

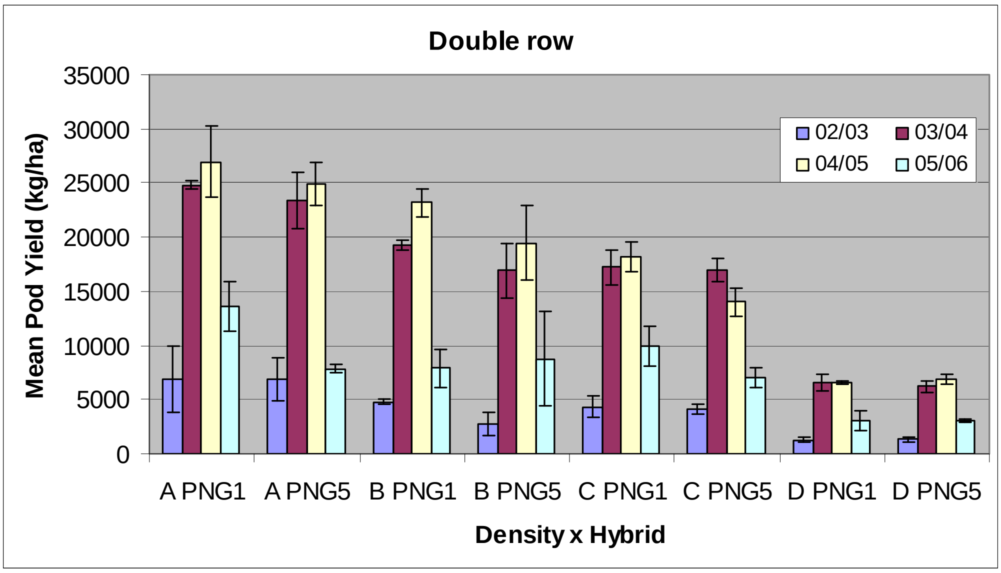


Figure 7.4 Mean whole pod yields for two cocoa hybrids (PNG1 and PNG5) grown at four densities (A, B, C and D) in a double row arrangement.

Single row

Within the single row trial plot the interactions between plant density, hybrid and season is shown in Figure 7.5. In the full production seasons of 2003/04 and 2004/05 yield declined marginally with density was similar for the two hybrids used. Mean maximum whole pod yields were in the vicinity of 35,000 kg/ha at the highest density which is equivalent to a dry bean production of 3.5 t/ha.

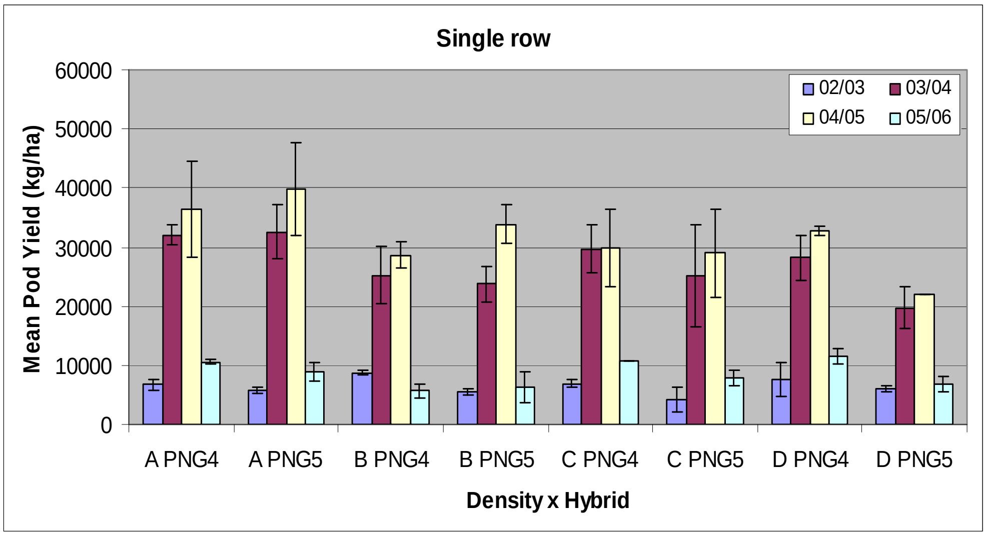


Figure 7.5 Mean whole pod yields for two cocoa hybrids (PNG4 and PNG5) grown at four densities (A, B, C and D) in a single row arrangement.

In this comparison of row arrangements and plant densities single rows out preformed double rows and the highest yields were achieved at the highest densities in both row arrangements. Density had less of an impact in the single row arrangement with mean yields at the three lowest densities only being marginally lower then that achieved at the highest density. Whereas in the double row arrangement yields declined with decreasing density.

The large yield differences between the single row and double row blocks is unusual given data collected at the HYET site in Mossman. The markedly lower yields achieved in the double row blocks as compared to the single row blocks may be explained by their location in orchard. The double row blocks were situated at the south-eastern end of the block which was exposed to the predominant trade winds. A lack of effective wind breaks meant that trees in the double rows partially acted as wind breaks. This may also explain why in the double row arrangement yield was strongly associated with increasing density. In higher density plantings trees tend to shelter each other more effectively than at lower densities.

7.2 Trellising and pruning study

7.2.1 Background

Pruning management strategies with the aim of manipulating tree structure and/or reducing the long-term pruning requirement will be important in Australia. The cocoa hybrids selected have a vigorous growth habit which requires regular pruning to maintain a manageable canopy. This is particularly the case for a ‘mechanised’ production system where machine access is required and to maximise the efficiency of ground-based harvesting.

The pruning of the HYET trials was to adopt best practice management based on general cocoa literature and recommendations by both Tony Lass and Nick Richards. The pruning management of the HYET trials is discussed elsewhere (Section A4.2.3). Some alternative pruning treatments were applied to the four single rows of the density trial at South Johnstone and trellises were installed on two of the four rows. This was carried out see if there was any advantage from tree structure manipulation with regard to the overall pruning requirement and pod presentation for harvest. These strategies were not implemented as a replicated formal trial with only subjective observations being made. Also, the individual pruning strategies adopted were only implemented for a couple of years as they took too much time to maintain and no benefits were perceived in the short-term.

7.2.2 Methodology

The pruning strategies adopted had the aim of developing trees with a ‘Y’ shape. This was based on a jorquette height in the range of 1–1.2m with a ‘V’ shape formed by the lateral fan branches above the jorquette. Within the ‘V’ pruning was carried out to achieve open and closed centre options. Overlaying this was additional pruning of the ‘hand’ branches (above the jorquette) to develop a bi-lateral (one lateral per side) or quad-lateral (two laterals per side) structure.

Figure 7.6 shows idealised illustrations of these pruning styles based on a mature tree. These pruning styles were implemented on both the ‘free-standing’ rows and the ‘trellised rows’.

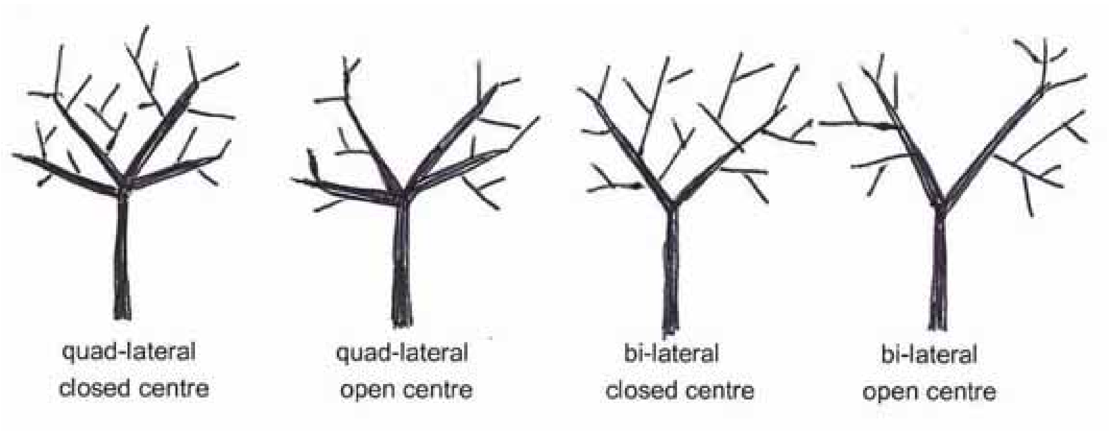


Figure 7.6 Proposed tree structures from various pruning styles.

The trellis structure was also modelled on a vase (‘Y’) shape and is illustrated in Figure 7.7. There was a 75^{o} angle between the ‘arms’ which were 1.8 m long, spreading to a 2.1 m span at 2.4 m above ground level. The junction of the arms was 1m above ground level. Four tensioned wires were run through each arm along the length of the row.

The main laterals (above the jorquette) were progressively secured to the wires with the aim of developing and maintaining a uniform tree structure. Pruning was carried out as per the styles in Figure 7.6 except that all branching below the wires were removed when pruning was conducted.

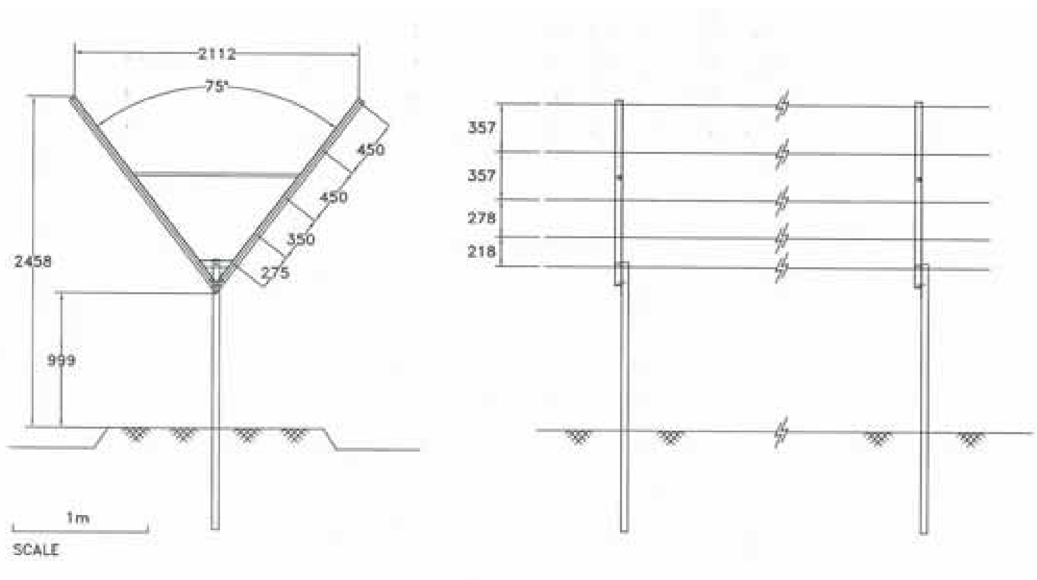


Figure 7.7 Geometry of ‘Y’ trellis used with cocoa at South Johnstone.

7.2.3 Results and discussion

The trellis structure and wire were erected post-planting and pre-jorquette production. Trellising of the cocoa seedlings commenced post-jorquette formation. A major difficulty experienced with the process was the lack of uniformity in jorquette height. Of particular problem were seedlings which jorquetted above and below the lower support wires (Figure 7.8a and b.).

a.

b.

Figure 7.8 Hybrid seedling variability showing jorquetting a. above; and b. below the lower trellis wire.

Trees jorquetting below the lower trellis wire could be managed by guiding the branches up and onto the trellis. Trees which jorquetted substantially higher then the lower trellis wire were re-pruned to force a new chupon to develop and re-jorquette. It quickly became apparent that there was considerable work required to train trees to the trellis and manage growth as originally planned.

Maintaining an open centre (Figure 7.9a) was difficult as access was restricted due to the presence of the trellis wires. Harvesting was also complicated by the trellis wires. However, at times the pods were well presented for harvest, as shown in Figure 7.9b, as per the initial concept of the trellising option. Trellised trees allowed a clean harvest face to be seen by pickers. Figure 7.10a and b show how production on the main trunk and main lateral branches above the jorquette is easily visible.

a.

b.

Figure 7.9 a. A view of the open centred trellis arrangement during early establishment. b. The trellis structure allowed ready access (at times) for hand harvesting of pods from the main trunk and trellised lateral branches.

a. **b.**

Figure 7.10 Early pod production on trellised trees occurring on the main trunk (a. and b.) with early production occurring on trellised lateral branches (b.).

The trellis wires managed to control the profile of mature trees without causing bark damage (Figure 7.11). Shoot growth would continue to grow 'out' of the structure and required regular pruning if the clean face was to be maintained.

Figure 7.11 Mature trellised cocoa trees.

The trellis structure did not help maintain tree integrity during the cyclone. The structures were made from steel and were well anchored and did not fail, however wires were stretched or broke and trees were blown over. The wall of trees which the trellis presented was vulnerable to damage because trees could not flex as individuals (Figure 7.12).

Figure 7.12 Tree damage in trellised cocoa following Cyclone Larry in March 2006.

7.3 Harvesting productivity and mechanisation

7.3.1 Background

At a given location, cocoa pods ripen for harvest more-or-less throughout the year with cyclical peaks and troughs in production. Traditionally, pods are manually cut from trees with hand held or pole mounted knives. Cocoa pods are firmly attached to the trunk or branch. Pods should not be pulled from trees since this action can tear the bark which damages potential flowering sites and increases the risk of disease. Once cut from the tree, pods can be handled quite roughly since they are relatively tough and external damage or 'bruising' is of no concern.

Harvesting of cocoa trees presents major difficulties for mechanisation due to:

- non-synchronised ripening
- pods do not 'drop' from trees when ripe but remain firmly attached
- pods are variable size
- pods are frequently difficult to access because of the leaf canopy, branch structure and proximity of neighbouring pods
- ripe pods are often right next to immature or maturing pods
- variability in tree habit and height.

Due to these factors, there was no expectation that cocoa harvesting in Australia could be fully mechanised (as with coffee for example).

However, cocoa is comparable with ordinary tree fruit crops in terms of harvested quantities and should be capable of economic handling under Australian labour cost regimes. Additionally, significant efficiency gains were envisaged through use of appropriate trailed or self-propelled catching frames and/or gantries and bulk/vehicular transport and handling of harvested pods. Development of such equipment was restricted to conceptual proposals.

Nonetheless, measurements of harvesting productivity were made from regular trial harvesting at Mossman and South Johnstone (with some one-off measurements also made at CPHRF).

7.3.2 Materials and methods for harvest productivity measurement

Pod removal

Pods were cut manually from trees using ordinary secateurs (or a hooked knife) as shown in Figure 7.13a. This was possible for pods within arms reach and is the quickest method. It only becomes awkward if the peduncle (or stalk) of the pod is difficult to access with the secateurs blades. This occurs when it is shielded by neighbouring branches or pods.

Using this method the pod usually can be grasped with one hand while being cut with the other. So rather than let fall to the ground, the cut pod can be immediately thrown or placed into a collection vessel.

As trees matured, production moved higher in the canopy and a greater proportion of pods were out of arm's reach. For these pods a commercially sourced extendable picking pole was used with an interchangeable chiselled blade at one end, as shown in Figure 7.14a. The pole was adjustable in length from 1,400 to2,200 mm. The blade is positioned against the peduncle (between the pod and the branch) as shown in Figure 7.13b. By applying a sharp tap to the end of the pole (via hand or a slide hammer) the pod can be dislodged and falls to the ground. Harvesting with poles requires retrieving the cut pods from the ground where they are sometimes obscured in the leaf litter or end up some distance away from the base of the tree.

Figure 7.14a, b also shows a custom built picking aid copied from a commercial version. It was used initially for harvesting cocoa from private unmanaged trees prior to the NACDA trials producing pods. However it was not used with the NACDA trials as it was prone to inflicting excessive bark damage because of the size of the cutting head. The cutting hook, when used to cut the peduncle in a downward movement usually ended up pulling pods from the tree causing extensive bark damage.

a.

b.

Figure 7.13 a. Harvesting low-hanging pods using secateurs. b. Harvesting pods higher in the canopy using an extendable picking pole with blade.

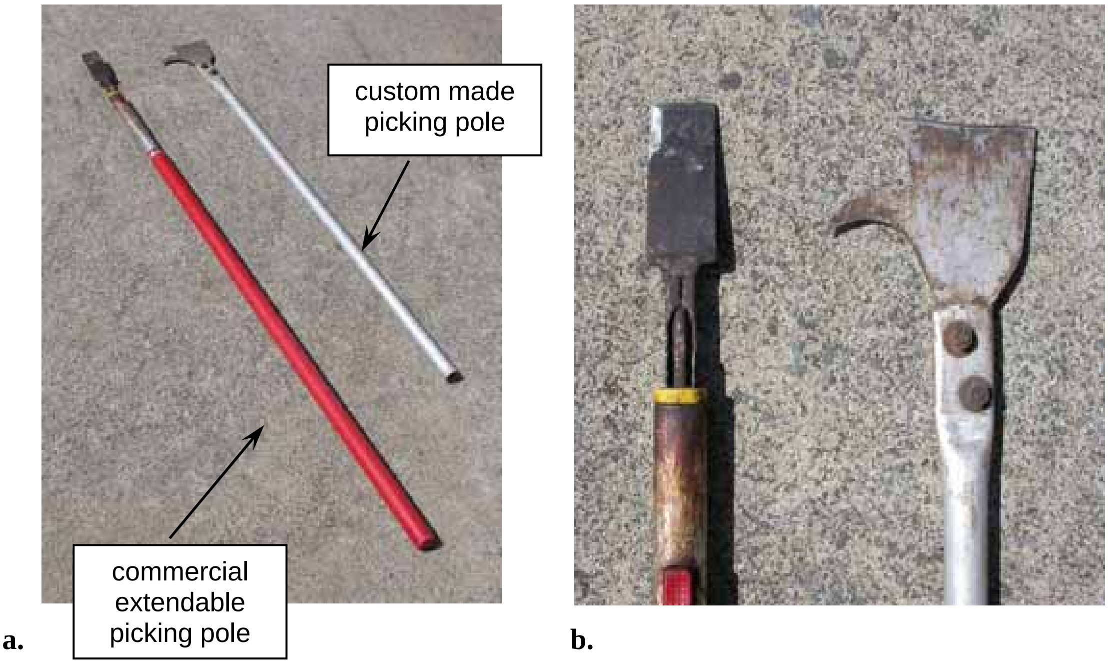


Figure 7.14 a. Picking poles used for harvesting high cocoa pods (custom made pole proved unsuitable). b. Close up of cutting heads.

Pod harvesting and collection

Data collection for trials required that pods harvested from ‘blocks’ within the plantings at South Johnstone and Mossman had to be segregated for subsequent weighing and sub-sampling. Normal practice was to harvest individual blocks discretely and collect pods into labelled fertiliser bags which were carried to the edges of the planting for collection.

To mimic commercial harvesting operations it would have been preferable to harvest pods ‘continuously’ from the entire planting and collect them via a travelling, in-field bulk bin. Since this was not possible due to the constraints of trial data collection described above, a compromise was developed.

For the outer guard rows (which were not divided into trial blocks), pods could be harvested continuously and thrown or dropped into regular ‘piles’ in the inter-row. This was an approximation of harvesting with an in-field bulk bin (which was not constructed) whereby pods would be harvested in the same fashion but placed or thrown into the collection bin and/or catching frame.

A similar process was also followed for harvesting pods from the individual trial blocks excepting that that pods were placed at the base of each tree instead of being collected into regular piles within the inter-row. This enabled pods to be kept separate for individual blocks and for individual sample trees (in some cases).

Because of the need to collect pods at the base of each tree, this more contrived approach may be perceived as being less of an approximation of commercial harvesting practice compared to the method of throwing pods into inter-row ‘piles’. In practice this was not the case however, as with many pods it was compensated for by the ability to simply drop pods directly to the ground at the base of the tree – particularly when harvesting using secateurs.

Productivity trials

Based on the above two approaches productivity trials were conducted from 2003 to 2005 at Mossman and South Johnstone. By this time the cocoa was yielding at commercial levels and there was routine harvesting occurring. Over this period the canopy continued to mature such that there was an increasing proportion of the crop being produced higher in the canopy. This effect is not accounted for in the data analysis.

There was some earlier data collection in November 2002 from a small numbers of trees at South Johnstone but this is not considered representative and is presented separately.

The gross time from the start to the completion of harvesting events was recorded and the number of harvesting crew. The weather conditions were noted and also at the completion of each harvesting event, an estimate was made of the proportion of pods occurring above or below head height.

Typically there was a crew of 2–4 operators. With a crew of more than two, the harvesting was generally conducted with at least one operator being dedicated to harvest higher pods using a picking pole. This left the remaining operators to harvest lower pods using secateurs and retrieve the pods felled by the picking pole operator. However, this was not a fixed procedure, as it was most efficient for some overlap of duties at times depending on the cropping pattern.

In a separate operation at the completion of harvesting the number of pods harvested was counted as they were collected into the marked fertiliser bags (this was not included in the measurement of harvest time).

Gross times only for harvesting using the above methods were recorded – there was no discrete data collection based on time taken for individual trees or individual pods. Nor was any time-and-motion type of analysis conducted.

In some cases gross measurements were made separately for harvesting pods from trellised and un-trellised rows and for harvesting pods using the picking poles (pods higher in the canopy) versus harvesting pods using secateurs (pods within arms reach).

7.3.3 Results of harvest productivity trials

Harvest productivity based on harvesting a small number of trees at South Johnstone by one person in November 2002 using secateurs is given in Table 7.7. This data is not considered to be representative of commercial conditions since the harvesting was for only a short time on a small number of trees. The trees were relatively small (so that pods were easily accessible) and the operator did not become tired.

The harvest productivities ranged from 5,100 to 10,600 pods/person/day. This is very high and is equivalent to about 200 to 425 kg dry bean/day. This excludes time required to remove pods from the field (by bulk transport) and there is no allowance for fatigue.

Data from productivity trials conducted at Mossman and South Johnstone from 2003 to 2005 is presented in Table 7.8. No attempt is made to determine any differences which could arise from the planting layout (double versus single rows). The data is treated as one set excluding the last harvest event where ‘high’ pods were harvested separately to the ‘low’ pods.

From Table 7.8 the overall average time per pod for harvesting was 8.9 sec (±0.6 sec). Based on an 8 hr working day with no allowance for fatigue or field efficiency losses, this corresponds to a harvest productivity of about 3,250 pods/person/day.

Table 7.7 Small block harvest productivities measured at South Johnstone, November 2002 (single person).

November 2002: Pods harvested into tray of ATV by one person, single row planting

No. of Trees						
Total	**Actually Harvested**	**No. of Pods**	**Gross Time (sec)**	**Average Time (sec/pod)**	**Productivity (pods/day)***	**Comment**
1	1	35	95	2.7	10,600	good height
1	1	30	83	2.8	10,400	good height
31	8	60	332	5.5	5,200	complete row
32	14	60	338	5.6	5,100	complete row, low trees
3	2	11	44	4.0	7,200	

* assumes an 8-hr working day

Table 7.8 Compiled harvest productivity measurements (August 2003 to November 2005).

Date	Weather	Planting Layout	No. Operators	Pods (% ≤ head height)	Method	No. Trees	Total No. Pods Harvested	Avg. No. Pods per Tree	Total Gross Time (sec)	Average Time per Tree (sec)	Average Time per Pod (sec)	Productivity (pods/person/day)
Mossman 27-Aug-03	overcast & mild	double rows	2	90	inter-row	144	113	0.8	1440	10	12.7	2260
		single rows	2	90	under trees	160	328	2.1	2430	15	7.4	3887
		double rows	2	90	under trees	270	502	1.9	3720	14	7.4	3886
South J. 8-Aug-03	overcast, mild &windy	single rows	1	80	under trees	90	329	3.7	2040	23	6.2	4645
		single rows	1	80	under trees	90	248	2.8	1638	18	6.6	4360
South J. 25-Sep-03	fine & warm	double rows	3	80	under trees	180	712	4.0	7020	39	9.9	2921
		single rows	1	75	under trees	45	247	5.5	1650	37	6.7	4311
		single rows	2	75	under trees	90	280	3.1	3120	35	11.1	2585
		single rows	1	90	inter-row	121	96	0.8	810	7	8.4	3413
Mossman 8-Oct-03	warm & humid	single rows	2	80	under trees	144	204	1.4	2280	16	11.2	2577
		single rows	2	80	under trees	160	237	1.5	1680	11	7.1	4063
		single rows	2	80	under trees	160	199	1.2	2400	15	12.1	2388
		double rows	2	80	under trees	128	308	2.4	2760	22	9.0	3214
		double rows	2	80	under trees	256	415	1.6	4680	18	11.3	2554
South J. 9-Oct-03	fine & warm	double rows	3	75	under trees	180	412	2.3	4500	25	10.9	2637
		double rows	3	80	under trees	340	620	1.8	7560	22	12.2	2362
South J. 10-Oct-03	fine & warm	single rows	2	75	under trees	180	553	3.1	8400	47	15.2	1896
South J. 28-Oct-03	very hot & humid	double rows	3	80	under trees	330	1008	3.1	12240	37	12.1	2372
		single rows	3	80	under trees	90	246	2.7	3960	44	16.1	1789
		single rows	3	80	under trees	90	192	2.1	3420	38	17.8	1617
		double rows	2	80	under trees	180	426	2.4	6000	33	14.1	2045
Mossman 29-Oct-03	hot & humid	double rows	2	65	under trees	384	1885	4.9	14160	37	7.5	3834
		double rows	2	65	inter-row	144	856	5.9	8880	62	10.4	2776
		single rows	2	65	under trees	320	1396	4.4	9720	30	7.0	4136
Mossman 19-Nov-03	fine & warm	single rows	2	70	under trees	144	693	4.8	3480	24	5.0	5735
		single rows	2	70	under trees	144	827	5.7	4380	30	5.3	5438
		double rows	2	70	under trees	135	826	6.1	3960	29	4.8	6007
		double rows	2	70	under trees	135	804	6.0	3600	27	4.5	6432

Date	Weather	Planting Layout	No. Operators	Pods (% ≤ head height)	Method	No. Trees	Total No. Pods Harvested	Avg. No. Pods per Tree	Total Gross Time (sec)	Average Time per Tree (sec)	Average Time per Pod (sec)	Productivity (pods/person/day)
		double rows	2	70	under trees	135	426	3.2	2280	17	5.4	5381
Mossman 15-Dec-03	very warm & humid	single rows	2	85	inter-row	144	758	5.3	4740	33	6.3	4606
		single rows	2	85	under trees	160	639	4.0	4320	27	6.8	4260
		single rows	2	85	under trees	160	1167	7.3	7200	45	6.2	4668
		double rows	2	85	under trees	144	811	5.6	4800	33	5.9	4866
		double rows	2	85	under trees	144	700	4.9	4800	33	6.9	4200
		double rows	2	85	under trees	144	482	3.3	3360	23	7.0	4131
South J. 2-Nov-04	very warm & humid	single rows	2	60	ATV tray	40	616	15.4	4080	102	6.6	4348
		single rows	2	60	ATV tray	28	602	21.5	3120	111	5.2	5557
		single rows	2	60	ATV tray	50	812	16.2	4920	98	6.1	4753
Mossman 10/11-Aug-05	fine & mild	double + single rows	2	50	inter-row	896	5058	5.6	66960	75	13.2	2175
									Average	**35**	**8.9**	
									Median	**30**	**7.4**	
									Standard Error	**4**	**0.6**	
Mossman 13/14-Sep-05	fine & warm	double + single rows	2	100	inter-row	896	3535	3.9	37200	42	10.5	2737
		double + single rows	2	0	inter-row	896	2111	2.4	48840	55	23.1	1245

It was supposed that the average harvest time per pod would be highest when there were few ripe pods on trees and lowest when there was a high ‘pod load’. This is because a greater proportion of the workers time would be spent productively harvesting pods, rather than non-productively (such as walking between trees and looking for ripe pods). If so, harvesting productivity could potentially be increased by deliberately synchronising or concentrating the harvest.

Figure 7.15 shows the overall average number of ripe pods harvested from trees for each harvest trial and the corresponding average harvest time (sec/pod). Based on this data there is only a weak relationship between the ripe ‘pod load’ and the average time taken to harvest pods. This suggests that comparatively little time is ‘wasted’ walking and looking for ripe pods when not actually harvesting.

This is borne out by the data in Figure 7.15 which graphs the average number of ripe pods harvested from trees for each harvest trial and the corresponding average harvest time per tree based on the total number of trees harvested. There is a reasonably linear relationship between the time taken to harvest a tree (or planting) and the number of pods to be harvested, i.e. the higher the number of pods per tree, the longer it will take to harvest (Figure 7.16). The slope of the linear trend line is about 5secs/pod with an intercept of 11 sec/tree representing a ‘field factor’. Theoretically, this ‘productivity equation’ could be used to estimate the harvest requirement based on the number of trees and the ‘pod load’.

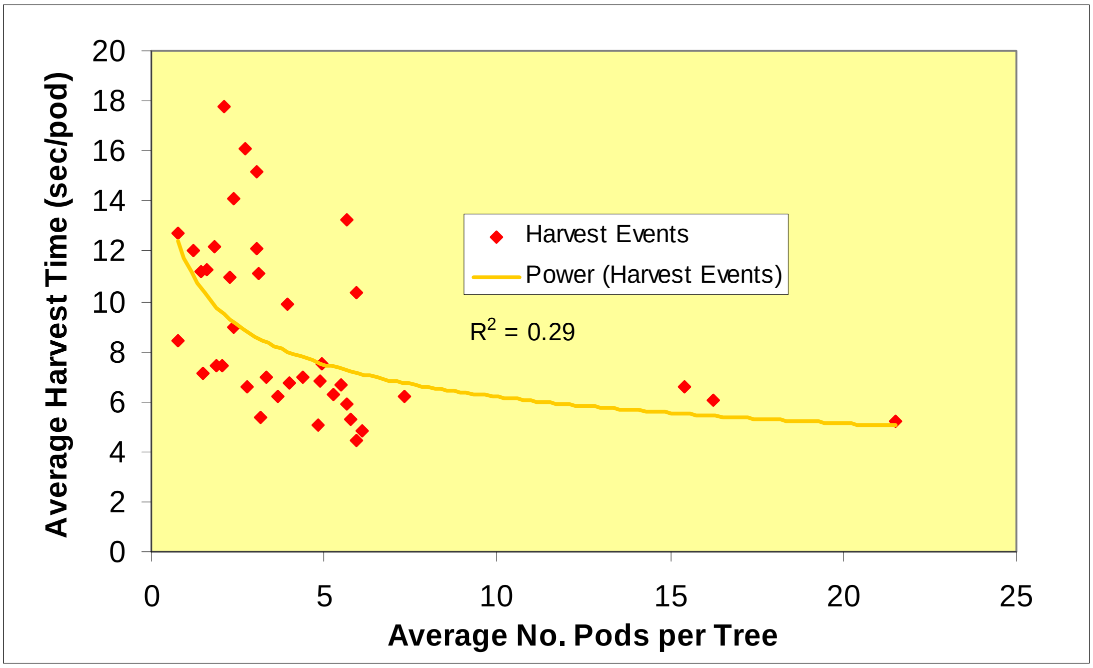


Figure 7.15 Harvesting efficiency based on the average number of ripe pods harvested per tree.

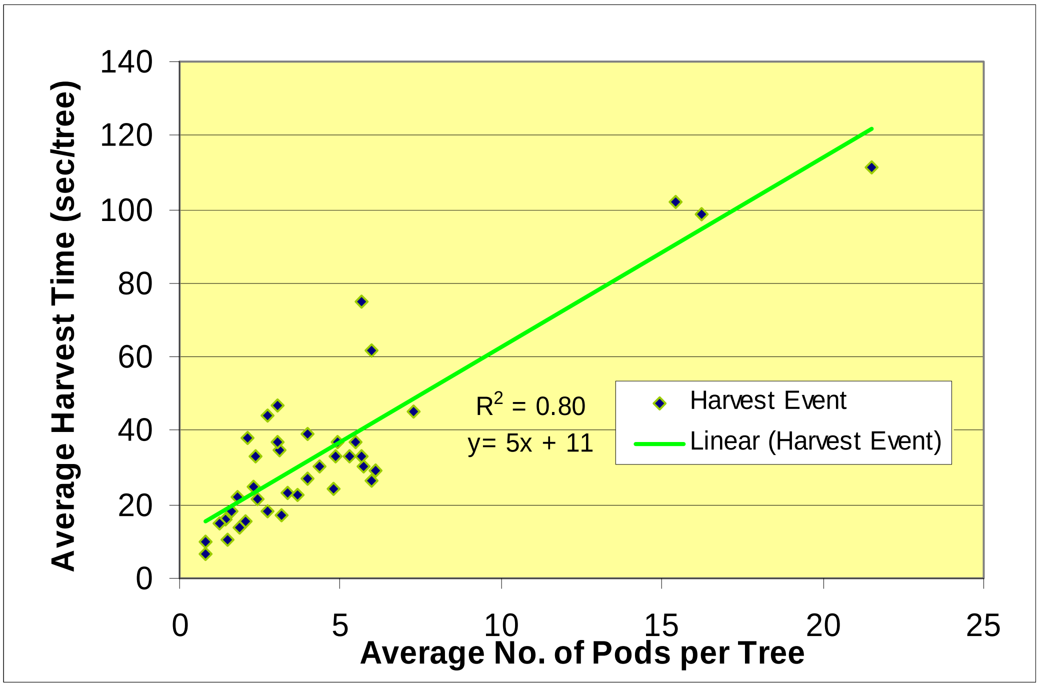


Figure 7.16 Harvesting time relative to the average number of ripe pods harvested per tree.

For example:

5 hectares @ 1,200trees/hectare; with an average ripe pod load of 5pods/tree.

Using the above 'productivity equation':

y = 5x + 11

y (sec/tree) = 5 (sec/pod) × 5 (pods/tree) + 11 (sec/tree)

= 36 (sec/tree)

Therefore:

Harvest requirement = 5 (ha) × 1,200 (trees/ha) × 36 (sec/tree)

= 216,000 (sec)

= 60 (hrs)

= 7.5 (person days) @ 8 hrs/day

In practice it would not usually be known what the average 'ripe pod load' per tree will be prior to harvesting although an estimate could be made. Also, the parameters of the 'productivity equation' will change, depending on the individual plantation and personnel.

Note that the relationship between the average time taken to harvest a pod and the overall daily productivity is not linear. This is illustrated in Figure 7.17 which graphs a range of productivities for the corresponding average time taken to harvest a pod. From the graph, increasing the productivity from 2,000 to 3,000 pods/person/day requires a reduction in the average harvest time per pod by about 5 secs. To increase the productivity another 1,000 pods/person/day (from 3,000 to 4,000) only requires a 2 sec reduction in the average harvest time per pod.

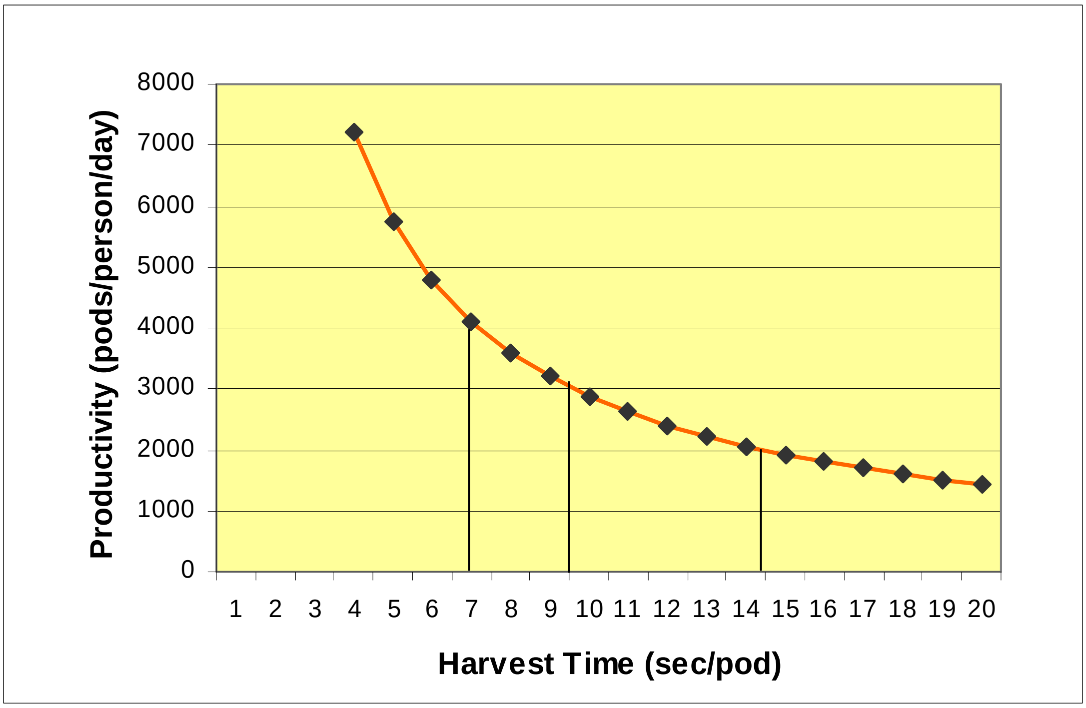


Figure 7.17 Productivity relative to harvesting time.

Harvesting productivities measured at the Darwin HYET on a single day are shown in Table 7.9. The average productivity achieved was 2,229 pods/person/day with no allowance factor for fatigue or field efficiency. Whilst this is based on only a small number of observations, it is considerably less than the picking rates achieved in Queensland. This is possibly attributed to the dense canopy which was typical of the trees in the Darwin trials. This made it more difficult to locate and access pods during harvesting.

Table 7.9 Harvest productivity data from Darwin HYET trial block – October 2003.

Rep.	Row layout	Operators	No. Trees Harvested	Total No. of Pods Harvested	Average No. Pods per Tree	Gross Time (sec)	Average Time per Tree (sec)	Average Time per Pod (sec)	Productivity (pods/person/day)*
1	single	3	37	152	4.1	3240	88	21.3	1351
2	single	3	55	277	5.0	3600	65	13.0	2216
3	single	2	49	283	5.8	3000	61	10.6	2717
1	double	3	76	408	5.4	6300	83	15.4	1865
2	double	3	105	638	6.1	6840	65	10.7	2686
3	double	2	90	381	4.2	4320	48	11.3	2540
						Averages	**68**	**13.7**	**2229**

*assumes an 8-hr working day

Harvesting costs

Harvesting costs for a range of harvesting productivities are given in Table 7.10. The data in Table 7.10 is based on an assumed labour cost of $20/hr. Costs are presented on a $/t basis for dry bean (assuming a pod index of 26 and 29) and for pods (assuming and average pod weight of 350 g and 250 g). For a ‘typical’ harvest productivity of 3,250 pods/person/day the harvesting costs would be $1,288/t dry bean (PI = 26) and $141/t pod (350g pods).

Table 7.10 Harvest costs based on labour at $20/hr for a range of harvest productivities and pod characteristics.

Harvest Productivity (pods/person/day)	Unit Harvesting Costs			
	$/t dry bean		$/t pod	
	PI= 26	PI= 29	350g avg.	250g avg.
2000	2080	2320	229	320
2500	1664	1856	183	256
3000	1387	1547	152	213
3500	1189	1326	131	183
4000	1040	1160	114	160
5000	832	928	91	128

7.3.4 Pod bulk handling parameters

Cocoa is comparable with other tree fruit crops in terms of harvested quantities. However, the unit value of a cocoa pod on the basis of its equivalent quantity in dried and fermented bean (as per Table 7.11) is typically less than for crops like mangoes or avocados. Therefore cocoa needs to be harvested and transported with maximum efficiency to enable economic handling under Australian labour cost regimes.

Table 7.11 Values for individual cocoa pods based on the pod index at a range of prices for dry bean.

Price (AU$/t dry bean)	Value of an Individual Cocoa Pod (cents)		
	Pod Index		
	30	25	20
2,000	6.7	8	10
3,000	10	12	15
4,000	13.3	16	20

Pod volumes

Table 7.12 details measurements of density characteristics for pods from the Queensland based NACDA trials. The average volumetric density for pods was about 1,300 pods/m^3 with a corresponding weight of about 400kg.

Based on a standard commercial plastic bulk bin with a capacity of 1m^3, Table 7.13 shows the number of bins required per day for a range of picking rates. This demonstrates the need for efficient handling of bulk bins on and off the harvest aid and via transport to pod processing. The dry bean equivalent value of pods in each bin would range from $87 to a maximum of $260.

Table 7.12 Density characteristics of Queensland cocoa pods.

Date	Number Pods	Weight (kg)	Volume (m^3)	Average Pod Weight (g)	Volumetric Density (pods/m^3)	Bulk Density (kg/m^3)
unknown	40	-	0.033	-	1212	-
unknown	190	-	0.142	-	1338	-
Aug-03	1040	331	0.782	318	1330	423
Aug-03	1200	387	-	323	-	-
Aug-03	940	304	0.754	323	1247	403
Aug-03	1080	355	-	329	-	-
Nov-03	2101	765	1.569	364	1339	488
Nov-04	616	144	0.443	234	1391	325
Nov-04	602	124	0.456	206	1320	272
Nov-04	812	137	0.519	169	1565	264
Aug-05	800	350	0.768	438	1042	456
Aug-05	786	290	0.768	369	1023	378
Aug-05	964	348	0.768	361	1255	453
Aug-05	1110	374	0.768	337	1445	487
Averages				**314**	**1292**	**395**

Table 7.13 Daily requirement of bulk bins for harvesting.

No. of Bulk Bins per Day				
Picking Rate	**Number of People in Harvest Crew**			
(pods/person/day)	**1**	**2**	**3**	**4**
2,000	1.5	3.1	4.6	6.2
3,000	2.3	4.6	6.9	9.2
4,000	3.1	6.2	9.2	12.3
5,000	3.8	7.7	11.5	15.4

7.4 Concepts for mechanised harvest aids

Significant efficiency gains are envisaged through use of appropriate harvest aids and associated bulk handling vessels. These would likely be trailed or self-propelled catching frames and/or gantries which direct harvested pods to the bulk storage bins. The storage vessels themselves would need to be compatible with an on-farm transport system and also integrate with the on-farm or remote pod processing plant.

Some recommended principles and ideas for cocoa harvest aids are as follows:

- lightweight with agricultural 'balloon' tyres to minimise ground-pressure and allow use in wet conditions
- maximum width of 2.8 m to allow ease of movement around the machine
- as low profile as possible to reduce the 'height' for throwing harvested pods into the catching frame/s and avoid damage to hanging branches
- capable of carrying multiple (at least two) bulk storage bins
- capable of in-field un-loading and replacement of bulk storage bins without need for other machinery
- 3-wheel design for maximum manoeuvrability on headlands
- low power consumption (e.g. small motor powering hydraulic pump-drive)
- catching frame or conveyor configuration as long as practicable to allow maximum access from along the row when harvesting and reduce number of machine 'movements'
- remote low-speed forward-reverse and steering control to avoid need for dedicated driver or loss of productivity by harvest crew repeatedly mounting and dismounting machine
- 'creep' function to allow slow continuous progress along rows
- potential use of an elevating platform/s to assist access to higher pods in the canopy.

Alternative approaches for 'mechanisation' of cocoa harvesting include mechanised pick-up of pods from the ground after manual harvesting from trees and in-field processing of pods to wet bean via a mobile pod splitting unit which moves along with the harvest crew. Both of these concepts were dismissed because of perceived limitations and disadvantages.

A machine for recovery of harvested pods from the ground could well be developed based on similar machines used for nut harvesting. Such a machine would offer the advantage of allowing the harvest crew to work in the orchard without regard to co-ordinating a collection vehicle. The collection vehicle would need to be relatively sophisticated being self-propelled and furnished with machinery for separating pods from extraneous material and conveying them to on-board storage.

However, this would have the attendant disadvantages of increased weight, size, power requirement and cost. It also introduces elements of double handling. Since pods are manually harvested then they may as well be delivered *directly* to a bulk storage container rather than via an intermediate ground collection vehicle. Also the ground collection vehicle would need to periodically off-load to bulk storage containers which is another handling operation. An alternate option would be for it to offload to a larger bulk transport vehicle or directly to the pod processing factory both of which introduce a degree of operational inflexibility.

An in-field mobile pod processing plant could be designed but would represent poor utilisation of capital as its capacity would be well in excess of the highest rates of harvesting. It would also impose operational constraints since it commits to pod splitting and subsequent fermentation at each harvest event.

Although not constructed in the project three concepts for harvest aids were proposed. These range from a basic catching frame to a more sophisticated self-propelled machine which embodies most of the recommended design criteria (previously outlined). These are illustrated in Figures 7.18 to 7.20 with an accompanying discussion. All of the figures illustrate a single-row cocoa planting at 4 m centres (vertical and horizontal scales are indicated in metres). The harvest aids are based around a bulk bin with capacity of about 1m^3 (1.1 m x 1.1 m x 0.8 m) which is a standard commercial (Nally 780 V10 MegaBin®).

Figure 7.18 shows a simple harvest aid design based on a catching frame constructed over a bulk bin. In this example the bin is carried via a 3-point-linkage attachment to an orchard style tractor however it could just as easily be towed by an appropriate all-terrain type vehicle. This simple design could be utilised for early harvests of new plantings or for long-term in small plantings as it is low cost and could use existing farm vehicles for mounting/towing. However, this approach would require regular stop-start vehicle movements which would reduce harvesting efficiency.

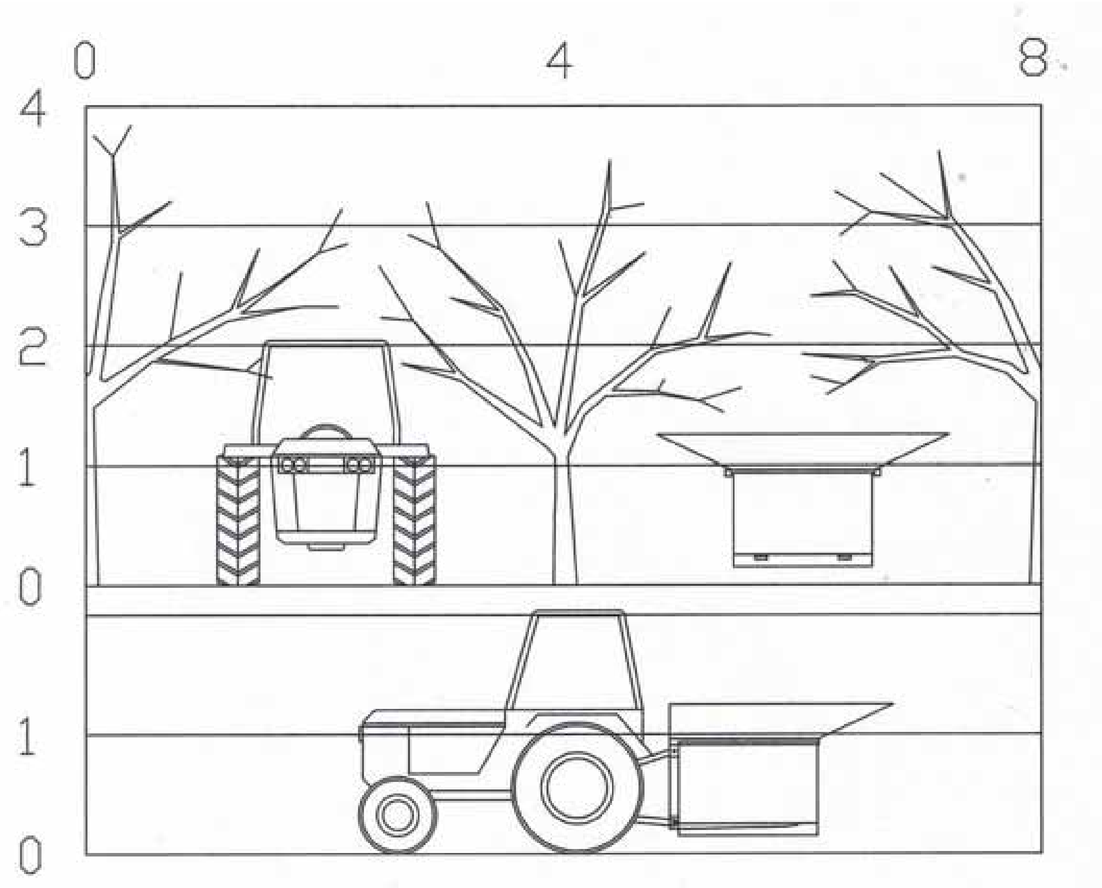


Figure 7.18 Basic harvest aid device for cocoa.

Figure 7.19 shows a more sophisticated design of harvest aid which has two rear catching bins mounted low on each side each with a conveyor for elevating pods into the bulk bin. The unit is trailer mounted but could also be self-propelled. Three bulk bins are stored on unit and there is clearance so that full bins can be removed from the rear of the machine. The unit is trailer mounted but could be alternatively implemented as a self-propelled design which may allow extra bin storage and/or longer catching bins/conveyors. The principle advantages of this design are the ability to carry extra storage bins and lower lip height of the catching bins. This would reduce down-time for bin changeover and make it easier to ‘throw’ pods into the catching bins.

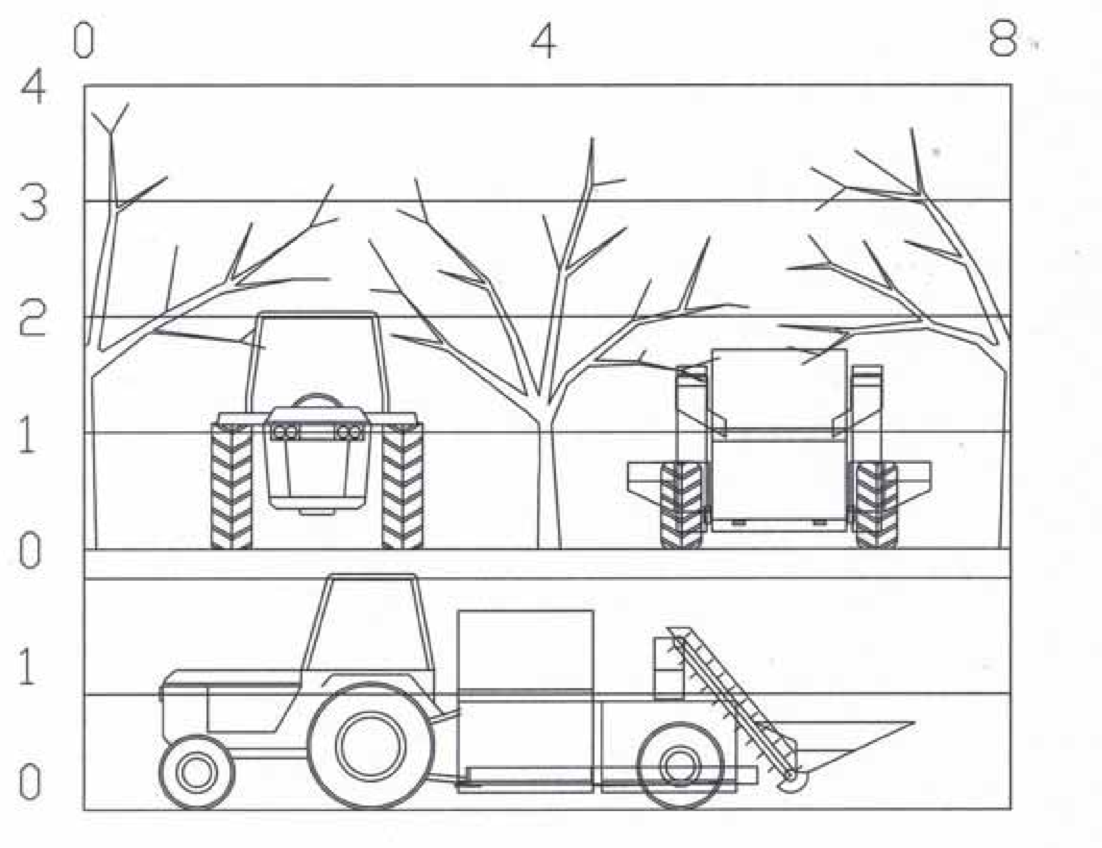


Figure 7.19 Cocoa harvest aid.

Figure 7.20 shows a 3-wheeled, self-propelled design similar to the previous unit in concept except two bulk bins are filled simultaneously. Additional bulk bins could also be stored at the front of the machine. A further enhancement would be to extend the effective reach of the rear catching bins via an inclined chute or flat belt conveyor to allow maximum 'coverage' along the row. This machine also has hydraulically raiseable platforms on each side to assist with reaching pods higher in the canopy. Whether the extra expense of this feature would be justified in practice by increased efficiency of harvesting higher pods can only be speculated. This machine could be remote controlled by one of the harvesting crew (or platform operators). It would have a high degree of manoeuvrability by virtue of the single front steering wheel.

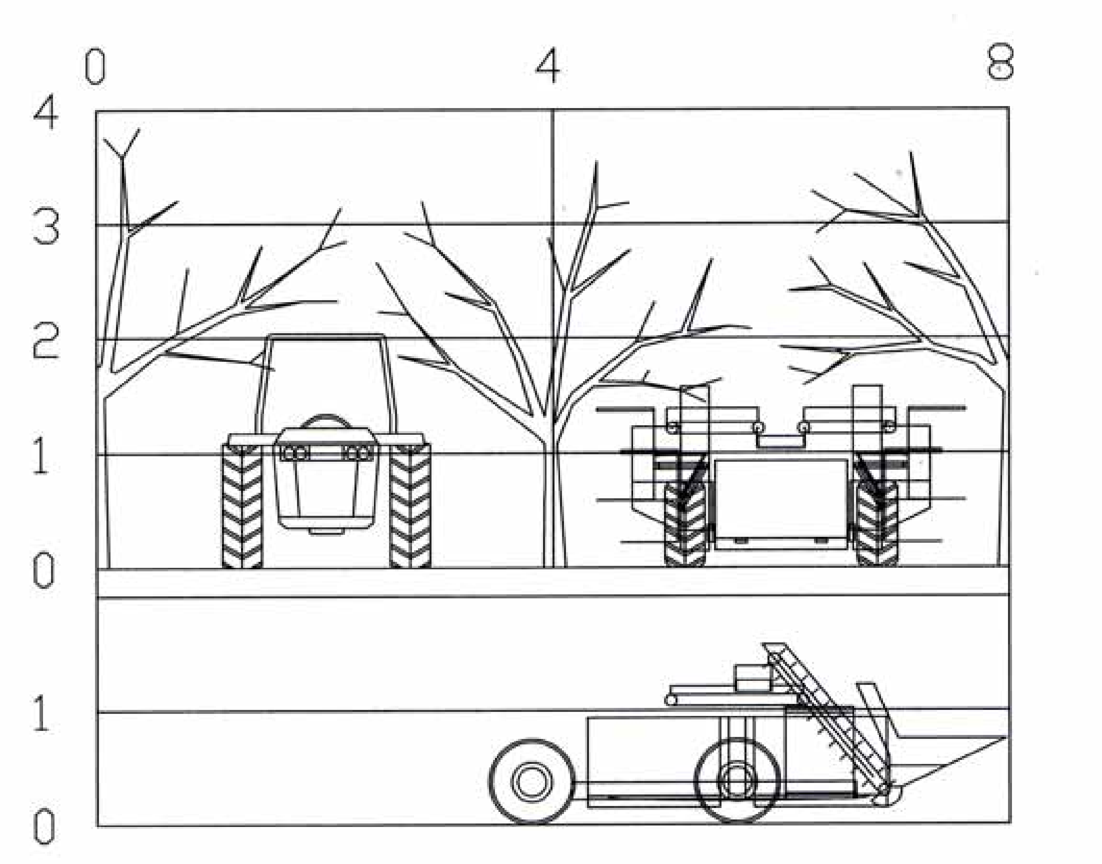


Figure 7.20 Self-propelled cocoa harvest aid. Note the orchard tractor is inserted for reference only.

7.5 Summary

The farming systems trial covered a range of factors influencing the productivity of cocoa orchards in Australia.

Tree density effects were examined with four densities ranging from 800 to 2100 tree/ha in both single row and double row configurations. In this comparison of row arrangements and plant densities single rows out preformed double rows and the highest yields were achieved at the highest densities in both row arrangements. Density had less of an impact in the single row arrangement with mean yields at the three lowest densities only being marginally lower then that achieved at the highest density. Whereas in the double row arrangement yields declined with decreasing density.

Trellising and pruning combinations were not formally tested. The observation-based trials indicated that the labour requirements of trellised trees were high and did not result in any significant advantage over non-trellised trees. The trellised trees were damaged just as severely as non-trellised trees during Cyclone Larry.

Harvest productivity measurements indicated that commercial harvest productivities are likely to be about 3,000 pods/person/day for an 8 hour working day. There was not a strong relationship between crop load and harvest productivity. Cocoa is comparable with other tree fruit crops in terms of harvested quantities. However, the unit value of a cocoa pod on the basis of its equivalent quantity in dried and fermented bean is typically less than for crops like mangoes or avocados. Therefore cocoa needs to be harvested and transported with maximum efficiency to enable economic handling under Australian labour cost regimes.

Cocoa has to be manually removed from the tree using cutting implements. Pods once removed do not require careful handling. A mechanised cocoa harvest aid is based on the concept of a towed or self-propelled device. This device would facilitate the efficient collection and field handling (transport) of pods to a bulk storage container. Three concept proposals are outlined. Mechanised pod recovery from the ground (similar to macadamia harvesters) is not recommended due to compromised operational flexibility. Whereas in-field mobile pod splitting is not recommended since its capacity would be well in excess of the highest rates of harvesting achievable.

8. Clonal introductions

8.1 Introduction

The Cocoa Study Tour to Malaysia confirmed the superior performance of clonal cocoa over hybrid material in terms of higher yield potential (up to 30%) and reduced vigour (Lemin et al. 1998). A clonal introduction, propagation and distribution program was carried out as part of the project to expedite the availability of clonal material should further research and development work be required.

The introduction of vegetative material brings with it the risk of exotic pests or diseases. AQIS currently require that imported cocoa vegetative material be fumigated with methyl bromide and grown in closed quarantine at a government post-entry quarantine facility for a minimum of nine months with disease testing. Budwood of selected clones was imported, fumigated and then grafted onto seedling stock (already prepared) and maintained in quarantine for nine months. Approved disease free material was released to NT Coastal Plains Research Station and the Queensland Department of Primary Industry and Fisheries Centre for Wet Tropics Agriculture.

Cocoa budwood was imported from the International Cocoa Quarantine Centre based in Reading, UK. The centre currently has 350 clones available for exchange and a further 100 undergoing quarantine. Material at the centre undergoes strict quarantine procedures including virus indexing over a two-year period, weekly observations by staff, and six-monthly inspections by independent pathologists and virologists plus annual inspection by the UK Ministry of Agriculture, Fisheries and Food.

8.2 Materials and methods

Cocoa germplasm was imported from the University of Reading's clonal repository centre. Material imported included AMAZ 15-15, EET 399, ICS1, IMC 67, NA 33, PA300, P4A, P4B, SCA6, SCA11, SCA19. The material for importation was selected following consultation with Tony Lass (Cadbury UK) and David Lim (BAL Plantation, Malaysia). The 11 clones were considered to have a good mix of quality, yield and disease resistant characteristics. Details on the origin, compatibility and cocoa type and disease resistance are available in Table 8.1.

Budwood entered Australia (AQIS Permit 199909569) via the quarantine screen house in Darwin, NT, from 1999 to 2001. The buds were grafted onto local seedling stock and viable buds which developed into shoots were maintained in quarantine for nine months prior to release.

Released material was further propagated at the Coastal Plains Research Station (CPRS), NT. An initial evaluation block was established at CPRS with four replicate plants per clone (Figure 8.1). This block was utilised to supply budwood to the Centre for Wet Tropics Agriculture (CWTA) at South Johnstone where a clonal collection was established but not evaluated.

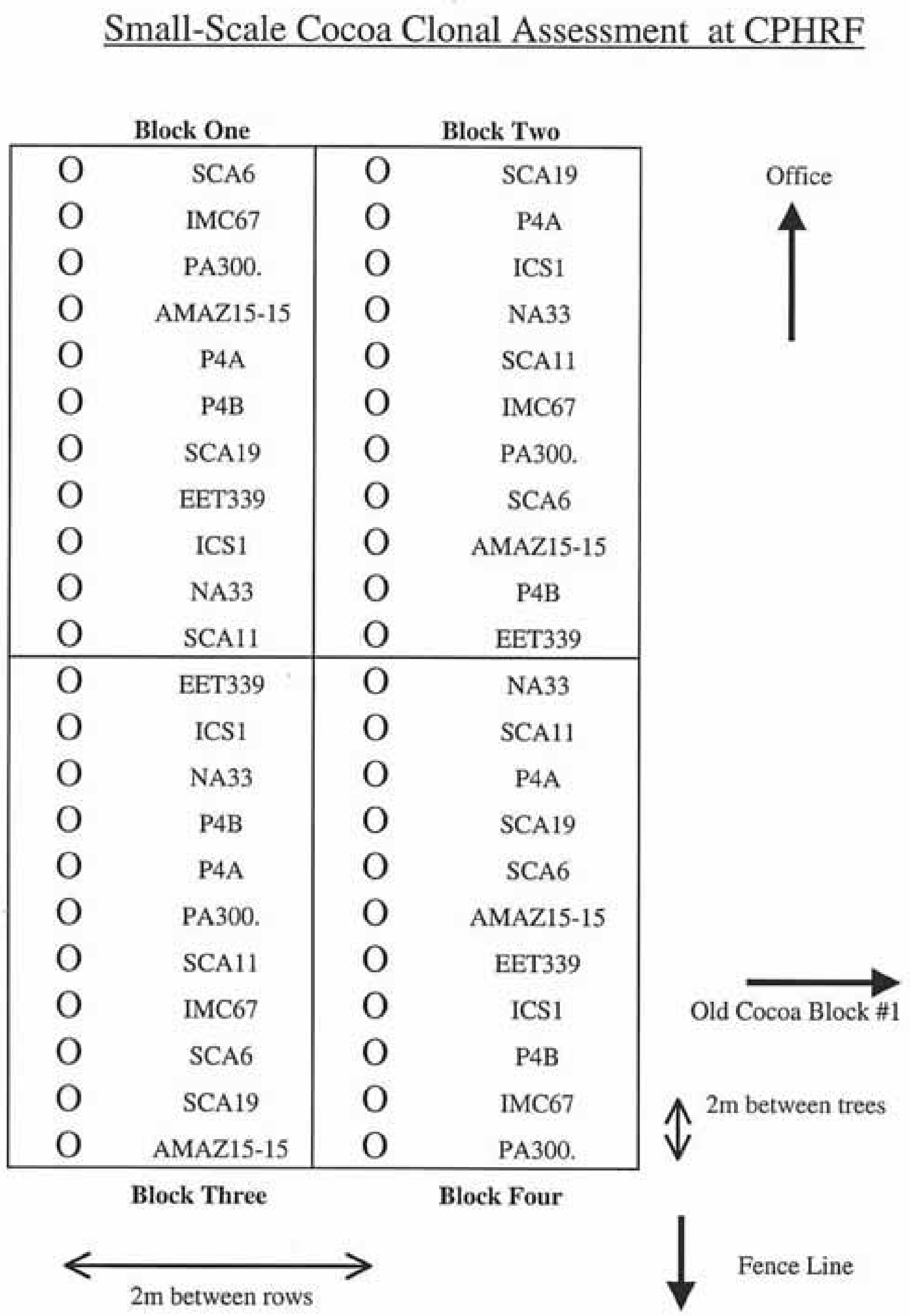


Figure 8.1 Layout of introduction block for clones at Coastal Plans Horticulture Research Farm (CPHRF).

Table 8.1 Cocoa clones imported into Australia and details of their origin, type, reproductive self compatibility and disease resistance. This information has been gleaned from the CocoaGen DB and ICGD web-based data bases.

Cocoa Clones	Origin (CocoaGen DB)	Type (CocaGen DB)	Reproductive self compatibility (CocoaGen DB)	Phytophthora[1] Resistant (ICGD)	Witches Broom[2] Resistant (ICGD)	Ceratocystis wilt[3] Resistant (ICGD)	VSD[4] Resistant (ICGD)
AMAZ 15-15	Peru		Self incompatible				
EET 399	Ecuador		Self incompatible	x			x
ICS1	Trinidad	Trinitario	Self incompatible	x	x	x	
IMC 67	Peru	Forastero	Self incompatible	x	x	x	x
NA 33	Peru	Forastero	Partial compatibility	x	x	x	x
P4A	Peru	Forastero					
P4B	Peru	Forastero		x	x		
PA300	Peru						x
SCA6	Peru	Forastero	Self incompatible	x	x	x	
SCA11	Peru	Forastero	Self incompatible	x	x		
SCA19	Peru	Forastero	Self incompatible				

1 – Phytophthora spp.; 2 – Crinipellis perniciosa; 3 – Ceratocystis fimbriata; 4 – Oncobasidium theobromae.
Note: None of the clones are listed as resistant to Canker (Phytophthora spp.), Mosaic Virus, Moniliophthora Pod Rot and Pinks Disease (Corticum salmonicolor).

8.3 Propagation – budding

Clonal stock can be produced in several different ways including marcotting, cuttings, grafting, budding and by tissue culture.

Cuttings, grafting and budding are all used commercially with micro-budding being a relative popular technique pioneered in Malaysia (Yow and Lim 1994). Micro-budding has a number of advantages which include:

- method of propagation which can efficiently utilise limited budwood
- plagiotropic buds (fan branch wood) can be inserted on young seedling stock (3–6 weeks of age) below the cotyledons thus eliminating chupon (water-shoot) production
- the method produces uniform planting material.

The pictorial series in Figures 8.3a to l show in detail the techniques utilised for propagating the introduced elite clonal material.

8.4 Discussion

It was acknowledged at the start of the project that evaluation of the clonal material was not within the scope of the initial evaluation project. The aim was to introduce the material for utilisation if the initial hybrid evaluation leads to further research and preliminary industry development.

Evaluation of clonal material under northern Australian growing environments will be necessary to fully evaluate cocoa yield potential, bean quality, and growth habit. The material has been subsequently propagated in 2008 and planted out in randomised complete blocks with four replicates on two farms.

Clonal material is usually propagated from fan branch (plagiotropic wood) buds above the jorquette. These buds continue to develop as plagiotropic wood and branch low to the ground (Figure 8.3a). The structure of trees produced from fan branch buds is different from seedling trees which have a long single trunk (orthtropic wood) which then jorquettes into fan branch wood (Figure 8.2b).

a.

b.

Figure 8.2 Tree shape of a. seedling tree with a single trunk (orthotropic wood) to 1.5 m height and a branching (plagiotropic wood) structure above; and b. budded tree using buds from fan branches. Note the low and multi-branched characteristic of the plagiotropic budded tree.

The shape of seedling trees has considerable benefits for high density plantings in the context of mechanised field operations such as spraying for weeds, pests and diseases and tree pruning. Initial picking operations are also made easier by the ready access to pods along the single upright trunk and the overhead branches.

The merits or otherwise of seedling versus plagiotropic tree structure has been discussed by various authors. The most recent deliberations by Miller and Guiltinan (2005) suggest that the production of orthotropic-based material has merits for research and commercial purposes. Despite the perceived advantages of the 'seedling' structure, data collected by Trinidad and Malaysian research agencies shows that the yield potential for clones is similar if grafted onto seedling stock as plagiotropic or orthotropicic buds. Hence the production and productivity of material based on the importation of clonal material should not be limited by its plagiotropic origins.

8.5 Summary

Eleven cocoa clones were successfully introduced into Australia from the Reading University cocoa clonal repository centre.

The clones consist chiefly of Forastero material with one clone being of Trinitario origin. The eleven clones were considered to have a good mix of quality, yield and disease resistant characteristics.

The material has not been formally evaluated but the collection has been maintained by DPI&F at CWTA, South Johnstone and by DRDPIF&R at CPHRF.

a. Cocoa seedling suitable for budding

b. Cocoa budwood (fan branch)

c. Budd prepared for removal

d. Seedling stem prepared for the bud

e. Bud placed on stem

f. Leaf petiole removed

g. Taping bud using laboratory Parafilm

h. Taped bud using laboratory Parafilm

i. **Budded seedling. Note bud placement below the cotyledons.**

j. **Budded seedlings with part removal of leaves**

k. **Bud break**

l. **Established budded shoot**

Figure 8.3. Seedling and budwood selection and sequence of budding operations for micro budded cocoa.

9. Economic modelling

9.1 Background

A principle aim of the NACDA project was to investigate the economics of cocoa production in northern Australia. To this end an economic model of production was progressively developed and this was later utilised by Invetech who were commissioned to review the NACDA research program in late 2004.

The chronological summary of economic modelling related to the NACDA program was as follows:

1. 1998 – Development of a gross margin model of estimated costs and returns of cocoa production by Huyn Ngo of NT DPI&F. This model was used in the lead-up to submission of the original research proposal as an indicator of the viability or otherwise of cocoa production in northern Australia.
2. 1999 – Commissioning of an independent economic assessment of investment in cocoa production in northern Australia. This was requested by the RIRDC Research Manager to investigate the likely economics of establishing a new cocoa industry in Australia and to determine the investment opportunity it represented. The modelling was conducted by Agtrans Research and Consulting and paid for by Cadbury Schweppes.
3. 2003–04 – Progressive development of a more sophisticated NACDA cocoa economic model by Craig Lemin using the original Agtrans model as a template. This was carried out to provide a more robust assessment of cocoa production and allow a comparison between growing sites and alternate production models.
4. 2004–05 – Commissioning of a Commercialisation Plan for an Australian cocoa industry. This was requested by RIRDC contingent to progressing to Stage 3 of the NACDA research program. The study proposed was structured as Stage 1 – ‘Business Case’ and a Stage 2 – ‘Business Model Development’. The study was conducted by Invetech Pty. Ltd. commissioned by RIRDC with a funding contribution by DPI&F. Economic modelling conducted within the study utilised the NACDA cocoa economic model.

The background, assumptions, results and findings from these models and studies is detailed in the following.

9.2 Estimate of cocoa costs and returns – Ngo model

9.2.1 Introduction

A preliminary model of cocoa production in northern Australia was developed by Huyn Ngo (NTDPI&F) in March 1998 in consultation with Yan Diczbalis. The preliminary findings were presented at the inaugural Cocoa Workshop at Berrimah in March 1998. The model was refined in the lead-up to a subsequent Working Group meeting at Darwin in August 1998.

The model was based on a gross margin analysis of the per hectare variable production costs of cocoa at maturity (seven years and onwards). Whilst a relatively simple model, it provided a quick estimate of cocoa production costs and returns and identified the major costs factors.

9.2.2 Assumptions

The main assumptions used in the costing were as follows:

- use of hybrid seed for planting material

- 1,200 trees/ha planting density
- irrigation applied for 30 weeks/year (NT)
- mechanical aids used in harvesting and processing
- wet to dry bean conversion factor of 2.5:1
- exchange rate of AU$1 = US$0.62 or £0.37
- labour costs of AU$11 /hr.

The detailed production assumptions used are given in Table 9.1 which is based on a mature yield of 3 t/ha dry bean.

9.2.3 Results

The gross margins from the Ngo model for NT cocoa production over a range of yields for at the prevailing July 1998 price of £1,040 /t are given in Table 9.2

From the Ngo model, gross margins for NT cocoa production were also calculated over a range of prices at various yields. At July 1998 CS had communicated cocoa prices were projected to steadily increase over five years as per Table 9.3. At an upside price of £3,200 /t, the model indicated that the yield to recover the variable production costs was less than 2 t/ha.

9.2.4 Conclusions

Based on the prevailing cocoa price of £1,040 /t at July 1998 (or US$1,743 /t and AU$2,811 /t), it was estimated that a yield of 4.2 t/ha dry bean would be required just to recover the variable production costs. Alternatively the cost of production had to be further reduced (which was seen as more achievable).

At projected future cocoa prices of up to £3,200 /t, a extremely optimistic scenario, the yield required to recover the variable production costs was 2 t/ha dry bean. Alternatively if a yield of 3 t/ha dry bean could be achieved, then there was a substantial gross margin available to cover fixed production costs and provide a return on investment.

Table 9.1 Cocoa production costs (assuming mature yield of 3 t/ha dry bean).

Item	Total Variable Cost ($/ha)	Proportion of Total Variable Costs (%)
Establishment Cocoa establishment @ 1200 trees/ha, $3 per established seedling Shade establishment @ 570 trees/ha, $4 per tree thinned to zero by year 4	-	-
Fertilisers Based on a modification of Table 7.3 (Wood and Lass 1985) Up to 3 kg nitrophoska/tree/year (after year 7) Foliar sprays for micronutrients Yearly liming @ 0.5 t/ha/year	2,020	20
Weed control 1 spray/year (after year 5) 1 slashing/year	153	1.5
Pest and disease control Potential pests included mealybug, scales, flatids, amblypelta, helopeltis, monolepta 3 x dry season sprays 2 x wet season sprays Also yearly trunk injections of phos-jet for blackpod control (after year 4)	933	9
Pruning Required for chupon pruning, 5-hand pruning, internal canopy pruning and height control Based on data from Wood and Lass (1985) 19 man-days/ha/year	1813	18
Irrigation Water use based on average climatic data for Darwin i.e. 30weeks/yr @ about 500 L/tree/yr Year 1 2 3 4 5 crop factor 0.8 0.8 0.8 0.8 0.8 efficiency % 85 85 85 85 85 canopy % 3 10 25 60 90 total ML/ha/y 0.4 1.4 3.4 8.1 12.2 peak L/tree/wk 17 56 140 336 504	501	5
Harvesting and bean processing Traditional at 80 kg wet bean/person/day Assumed 'mechanised' 160 kg/person/day	4136	42
Fermentation and drying Labour estimates only @ 2 man-days/ha/year (equivalent to $58 /t dry bean)	176	2
Sundries	**243**	**2.5**

Table 9.2 NT cocoa production gross margins at £1,040/t (Ngo model).

Yield (t/ha dry bean)	2.0	2.5	3.0	3.5	4.0	4.5
Income ($/ha)	5,623	7,028	8,434	9,840	11,245	12,651
Total Variable Costs (AU$/ha)	8,503	9,239	9,975	10,714	11,737	12,189
Gross margin ($/ha)	-2,881	-2,210	-1,541	-875	-492	461

Table 9.3 Projected cocoa prices at July 1988.

	Projected Cocoa Prices* at July 1998	
Year	Low (£/t)	High (£/t)
1997–98	1,150	1,190
1998–99	1,180	1,500
1999–00	1,235	2,000
2000–01	1,360	2,500
2001–02	1,450	3,200

*Dr Barry Kitchen, Cadbury Schweppes Australia.

9.3 Economic assessment of investment in cocoa production – Agtrans Research model

9.3.1 Introduction

An independent economic assessment of investment in cocoa production was commissioned for the original project proposal to RIRDC. This was required because of the budget amount requested. The work was paid for by CS and conducted by Agtrans Research (Brisbane). Agtrans consulted closely with the project Steering Committee (Diczbalis, Lemin and Richards) in the development of production and cost assumptions.

There were several aspects to the assessment as follows:

1. Base case economic analysis of a 50 ha plantation using best-bet assumptions for production and prices.
2. Secondary analysis based on likely outcomes from the research program i.e. confirmation of higher yields and reduction in a number of specific production costs.
3. Analysis of the returns to investment in cocoa R&D (in the context of funds budgeted in the project proposal).
4. Analyses to determine sensitivity of investment criteria to changes in key variables.

These analyses are presented in the following with the exception of the returns to R&D investment analysis.

9.3.2 Assumptions and methodology

The analysis is based around a model 50 ha cocoa planting in northern Australia (Queensland). A 10% price premium for Australian produced cocoa was assumed over the world price. This is based on a supposition that Australian growers could achieve superior quality and offer supply security. Two price regimes were used based on an historical average and a forecast scenario. The capital cost of land is included in the economic analysis. Returns to investment are based on a 7% discount rate and the analysis was conducted over a 30-year timeframe.

Base case assumptions

The base assumptions for the AgTrans economic analysis are given in Table 9.4.

Secondary analyses

Assumptions regarding the likely impact of cocoa R&D in Australia were also modelled to provide an indication of the influence of these improvements on the returns to investment in cocoa production. The key assumptions influenced by R&D are detailed in Table 9.5. Both the historical and standard price regimes were modelled with these assumptions.

Table 9.4 Base assumptions for the AgTrans economic analysis of a 50 ha cocoa plantation in northern Queensland.

Assumptions	Value (AU$)	Source
General		
Planting density (trees/ha)	918	Cocoa steering committee
Maximum yield (t/ha dry bean)	3	Cocoa steering committee
Time to maximum yield (years)	7	Cocoa steering committee
Historical price regime (£/t dry bean)	1,000	Average world price 1989–96
Forecast price regime (£/t dry bean)	1,000 in 2000 increasing to 2,000 in 2010	Cocoa steering committee
Price premium for Australian cocoa (%)	10	Assumed
Exchange rate (£:AU$)	0.37	Prevailing
Capital Costs		
Land ($/ha)	12,500	Cocoa steering committee
Land preparation ($/ha)	500	Cocoa steering committee
Mounding ($/ha)	750	Cocoa steering committee
Irrigation establishment ($/ha)	5,600	Cocoa steering committee
Planting material ($/ha)	5,000	Cocoa steering committee
Shade establishment ($/ha)	1,500	Cocoa steering committee
Plant and equipment ($)	187,500	Cocoa steering committee
Fermentary and drying ($)	52,500	Cocoa steering committee
Variable Costs		
Weed control ($/ha)	93	Cocoa steering committee
Pest and disease control ($/ha)	875	Cocoa steering committee
Fertiliser ($/ha)	2,525	Cocoa steering committee
Pruning ($/ha)	2,509	Cocoa steering committee
Slashing ($/ha)	76	Cocoa steering committee
Irrigation ($/ha)	36	Cocoa steering committee
Irrigation rate (ML/ha/year)	10	Cocoa steering committee
Harvesting ($/t dry bean)	1,100	Cocoa steering committee
Pod splitting ($/t dry bean)	440	Cocoa steering committee
Bean extraction ($/t dry bean)	660	Cocoa steering committee
Bean processing ($/t dry bean)	15	Cocoa steering committee
Sundries and contingencies ($)	293	Assumed @ 2.5% of variable costs/year
Fixed Costs		
Professional services ($/year)	3,000	Assumed
Permanent labour ($/year)*	20,000	Cocoa steering committee

* One labour unit assumed @ $40,000 /year. It is assumed that 0.5 units are required for managing a 50ha planting.

Table 9.5 Key assumptions for the AgTrans economic analysis based on likelihood of R&D success.

R&D Area	Base Assumption (without R&D)	Likely Improvement (with R&D)	Probability of R&D Success (%)
A. Yield increase (t/ha dry bean)	3	4	100*
B. Harvesting efficiency improvements ($/t dry bean @ 3 t/ha dry bean)	1,100	550	75
C. Mechanisation of pod splitting and bean processing to reduce costs ($/t dry bean @ 3t/ha dry bean)	1,100	275	75
D. Pruning cost reduction ($/ha)	3,344	2,230	75

This is based on a 50% probability of achieving yield increase through optimised management of the hybrid yield trials and a 50% probability of achieving a yield increase through the use of imported clonal material.

Sensitivity analyses

The key variables and ranges considered for the sensitivity analyses are given in Table 9.6. The ranges of values specified were considered to be the most reasonable ranges.

Table 9.6 Ranges of key variables for sensitivity analyses using the AgTrans economic analysis.

R&D Area	Base Assumption (without R&D)	Likely Improvement (with R&D)	Ranges of Values for Sensitivity Analyses (%)
Discount rate (%)	7	7	5–10
Maximum price in 2010 (£/t dry bean)	2,000	2,000	1,000–3,000
A. Yield increase (t/ha dry bean)	3	4	3.3–4.5
B. Harvesting efficiency improvement ($/t dry bean @ 3 t/ha dry bean)	1,100	550	275–660
C. Mechanisation of pod splitting and bean processing to reduce costs ($/t dry bean @ 3 t/ha dry bean)	1,100	275	110–275
D. Pruning cost reduction ($/ha)	3,344	2,230	836–2,230

9.3.3 Results

Base case scenario

The results of analyses to determine returns from the base case assumptions are presented in Table 9.7. Using these assumptions, investment in cocoa would not be viable for either the historical or forecast price regime at the 7% discount rate. For a break-even nett present value (NPV), a price increase of £134 /year to a maximum of £2,340 in 2010 is required.

Table 9.7 Investment criteria returns for a 50 ha cocoa plantation in northern Queensland using AgTrans base case model.

Investment Criteria	Historical Price Assumption	Forecast Price Assumption
Nett Present Value ($M)	-4.06	-1.02
Benefit/Cost Ratio	0.44:1	0.86:1
Internal Rate of Return (%)	negative	0.6

Secondary assumptions scenario

The results of analyses to determine the assumed R&D impacts are presented in Table 9.8. Considered separately, none of the individual R&D impacts produced a positive NPV except for the increased yield scenario using the forecast price regime. For the historical price regime, mechanisation of pod splitting and bean processing produces the largest change in NPV. For the forecast price regime, yield increase produces the largest change in NPV since the rising price enhances the benefits of increased yields.

Table 9.8 Investment criteria returns for a 50 ha cocoa plantation in northern Queensland using AgTrans model with assumed benefits from R&D.

Investment Criteria	Historical Price Assumption	Standard Price Assumption
Yield increase		
Nett Present Value ($M)	-3.86	0.19
Benefit/Cost Ratio	0.52:1	1.02:1
Internal Rate of Return (%)	negative	7.9%
Harvesting efficiency improvement		
Nett Present Value ($M)	-3.61	-0.57
Benefit/Cost Ratio	0.48:1	0.92:1
Internal Rate of Return (%)	negative	3.8
Mechanisation of pod splitting and bean processing to reduce costs		
Nett Present Value ($M)	-3.39	-0.35
Benefit/Cost Ratio	0.48:1	0.95:1
Internal Rate of Return (%)	negative	5.1
Pruning cost reduction		
Nett Present Value ($M)	-3.57	-0.53
Benefit/Cost Ratio	0.47:1	0.92:1
Internal Rate of Return (%)	negative	3.9

The results of an analysis based on assumed benefits from all the R&D areas are presented in Table 9.9. Under the historical price regime the NPV is still negative but for the forecast price regime the NPV is $2.18M and the investment criteria are favourable. The break-even price for post year 2010 was calculated to be £1,443 at the 7% discount rate.

Table 9.9 Investment criteria returns for a 50 ha cocoa plantation in northern Queensland using AgTrans model with assumed benefits from all R&D combined.

Investment Criteria	Historical Price Assumption	Forecast Price Assumption
Nett Present Value ($M)	-1.87	2.18
Benefit/Cost Ratio	0.69:1	1.36:1
Internal Rate of Return (%)	negative	16.1

Sensitivity analyses

The results from sensitivity analyses of the key R&D areas are given in Table 9.10. The 'expected' case of combined benefits as per Table 9.9 is an NPV of $2.18M. Price is the most important variable. Of the production variables, yield was the most important. Yield and harvesting were considered with both upside and downside risk relative to the 'expected' case whereas the other variables were considered only with upside potential (i.e. lower costs) resulting in lower range NPVs equal to the 'expected' case scenario.

Table 9.10 Ranges of key variables for sensitivity analyses using the AgTrans economic analysis.

Variable	Lower Range NPV ($M)	Upper Range NPV ($M)
Price	-1.86	7.06
Discount rate	0.98	3.62
Yield	1.08	2.97
Pruning	2.18	2.83
Harvesting	2.04	2.48
Processing	2.18	2.38

9.3.4 Summary and conclusions

AgTrans acknowledged that the modelling to determine the investment returns from cocoa production in northern Australia was largely based on unconfirmed information provided by the Cocoa Steering Committee. There was considerable uncertainty associated with the key variables such as yield, price and major production costs.

Using the base case model for an assumed 50 ha cocoa plantation, the investment returns were negative for the historical and forecast price regimes. However, assuming the combined impact of 'expected' benefits from R&D into cocoa production resulted in favourable investment criteria under the forecast price regime. The 'expected' NPV was estimated to be $1.28M, with an internal rate of return (IRR) of 16.1%.

The principle driving variable was the future cocoa price. Cocoa prices averaged £1,000 over the previous 10-year period. The break-even price regime required prices to increase linearly from £1,000 in 2000 to £1,433 in 2010 and remain at that level.

9.4 NACDA economic model of cocoa production

9.4.1 Introduction

During Phase 2 of the NACDA program, it was decided to further develop an economic model of cocoa production in Australia based on the knowledge and experience arising from the research and development program. The working Agtrans model was made available to NACDA in 2004 with the idea of using it as a basis for refinement.

However, on examining the Agtrans model in detail it was found that some aspects of it were quite simplistic including:

- the chosen planting density had no impact on the model
- the model was based on a 50 ha planting area only
- modelling of pruning, harvesting and pod processing was on the basis of a crude estimate of 'hours/tonne' with no scope for the influence of pod index or 'contracted' processing.

Nonetheless, it was decided to use the Agtrans model as a template for a more sophisticated model of cocoa production. The calculation of investment parameters such as the NPV, benefit cost ratio (BCR) and IRR were retained as well as the basic layout and workings of the model.

The model was expanded to allow entry of alternate management options such as the land cost, capital equipment, planting density, shade density/species, irrigation set-up and contracted pod processing. Also, inputs such as nutrition, pruning, and labour for harvesting were matched to the crop development and location.

The original model was structured on the basis of growers producing dry beans for market with the income being based on the prevailing AU$ /t price of dry beans.

Later the model was also adapted to allow the calculation of total costs to the grower and/or processor for production of whole pods, wet bean and dry bean depending on the marketing arrangement.

9.4.2 Assumptions and methodology

The NACDA economic model was expanded to allow entry of alternate management options such as the land cost, capital equipment, planting density, shade density/species, irrigation set-up and contracted pod processing. Also, inputs such as nutrition, pruning, and labour for harvesting were dependent on the stage of crop development and location.

Determination of the production cost structure was based on:

1. Capital costs of establishment and equipment.
2. Area dependent variable production costs (weed control, pruning, disease management etc.).
3. Area dependent variable production costs (harvesting and pod processing).
4. Fixed costs.

The income was determined from assumed prices and yield. A yield profile (% of full yield) was used as the crop matured.

Output from the model was the total costs, total returns and nett cash flow. From these parameters, the NPV, BCR and IRR were also calculated. A gross margin output could be determined by setting the fixed costs to $0. Because labour estimates/costs were made for all the various production aspects, a detailed breakdown of labour requirements (man-days/year) could also be extracted.

The base assumption variables for the NACDA economic model are given in Table 9.11.

Table 9.11 Base assumptions for the NACDA economic model.

Assumptions	Value (AU$)	Impact/Comment
Environment	wet or dry	irrigation water usage
Land ($/ha)	owned or purchased	depends on situation
Area of producing cocoa (ha)	5, 25 or 50	depends on model farm
Planting layout	single or double rows	irrigation establishment
Planting density (trees/ha)	typically 1,200	establishment costs
Planting material	hybrid seed or clonal	establishment costs
Irrigation system	sprinkler or drip	establishment/maintenance costs
Field mortality (%)	5	establishment costs
Fertiliser application	solid or soluble	establishment and maintenance costs
Windbreaks	yes (spacing) or no	establishment costs and land area
Pod/bean processing	on-farm or contracted	processing costs
Yield profile (% of full yield)	Yr1=0, Yr2=5, Yr3=30, Yr4=60, Yr5=90, Yr6=100	production costs and income
Full yield (t/ha dry bean)	typically 3	production costs and income
Pod index (no. pods/kg dry bean)	25	harvest and processing costs
Bean ratio (wet unfermented bean weight to pod weight)	0.25	harvest and processing costs
Recovery ratio – dry bean fermented bean weight to wet unfermented bean weight	0.4	harvest and processing costs
Processing losses (% bean)	5	yield
Price (US$/t dry bean)	variable	income
Exchange rate	variable	income
Labour ($/hr)	owner supplied or employed 20	production costs

The specific assumptions associated with production in the NACDA economic model are detailed in the following.

Capital equipment for growing

Table 9.12 lists the capital equipment estimates used in the NACDA model for field operations. In some production scenarios it was assumed that much of this equipment was already available based on assumed farming operations being conducted in conjunction with cocoa production (or prior to).

Nursery and planting

The model allowed for either on-farm nursery (sufficient for a 5ha planting) or purchase of planting material from a commercial nursery. Planting material could be either seedlings (hybrids) or vegetatively propagated (clones).

The on-farm nursery option assumed a capital cost for the nursery of $5,350 including labour for erection. The estimated costs for on-farm raised material was $2.40 for hybrid seedlings $6.10 for clones (including labour). The cost of material from a commercial nursery was estimated at $4 and $10 respectively.

Planting costs were estimated at $920 /ha assuming a 2-person operation with the owner assisting, rising to $1,720 /ha with all labour employed.

Table 9.12 Base assumptions for the NACDA economic model.

Estimated Capital Equipment Requirements	$
Field Maintenance	
4WD utility	30,000
quadbike (1 per 50 ha)	12,000
general tractor (60 hp, 1 per 100 ha)	60,000
orchard tractor (40 hp, 1 per 50 ha)	45,000
second hand orchard tractor (40 hp, 1 per 25 ha)	25,000
small slasher (1 per 50 ha)	4,000
spray boom (1 per 50 ha)	3,000
mister (1 per 50 ha)	10,000
fertiliser spreader (1 per 100 ha)	6,000
pneumatic secateurs (1 set per 15 ha)	2,500
mechanical pruner (1 per 100 ha)	15,000
secateurs & tensiometers etc.sundries (per 5 ha)	500
Harvesting	
secateurs & poles etc. (per 10 ha)	500
harvest aid (1 per 10 ha)	25,000
field bins (6 per harvest aid per day)	250
field bin trailer (1 per 50 ha)	3,500
Workshop & Machinery Sheds	
5 to 10 ha	0
25 ha	25,000
100 ha	50,000

Land preparation

Costs are dependent on the previous use of the site. For a site coming out of sugarcane production (in Queensland say) a cost of $250 /ha is estimated to spray out the cane, rip planting lines and apply lime.

Windbreak establishment and maintenance

There is a choice between various windbreak species including trees, bamboo and Bana grass which are assumed to be planted six months prior to the cocoa field planting. The windbreak spacing can also be nominated. Establishment and maintenance costs are dependent on species.

Shade establishment and thinning

Shade is assumed at densities depending on the planting layout (double or single rows) and the site location (wet or dry tropics). Shade densities range from about 350–500 trees/ha. Either Gliricidia or a tree species can be selected. Shade is assumed to be established 6 months prior to the cocoa field planting and thinned to a permanent shade level at two years. Thinning is to 10% of the original planting in the wet tropics and 10% in the dry tropics.

Establishment and maintenance costs for shade are calculated. Income from harvest of permanent shade trees as commercial timber species can be factored in.

Irrigation

Estimated costs for irrigation establishment are given in Table 9.13 (including labour).

Table 9.13 Estimated capital costs for establishment of irrigation in cocoa.

Plating layout and irrigation type	Irrigation Establishment Costs ($/ha)
Double row – sprinkler	2,450
Double row – drip	4,375
Single row – sprinkler	3,425
Single row – drip	3,625

Irrigation water usage is dependent on site and increases as the canopy closes. Assumed maximum yearly requirements were 12 ML/ha for a dry tropics site and 4 ML/ha for a wet tropics site. No direct cost for water was budgeted. Pumping costs were estimated at $15/ML.

Fertiliser

Fertiliser costs assumed for a mature planting are given in Table 9.14 together with the number of applications. Costs for application are related to the planting layout and fertiliser type. A lime application @1,000 kg/ha was assumed every two years.

Table 9.14 Estimated fertiliser costs for a mature cocoa planting (2006).

Fertiliser Type and Site	Fertiliser Costs ($/ha)	No. of Applications per Year
Solid – wet tropics	900	8
Solid – dry tropics	1,500	4
Soluable – wet tropics	1,320	24
Soluable – dry tropics	1,760	24

Weed control and slashing

Herbicide applications are dependent on the site and maturity of the cocoa (canopy). Estimated costs for herbicide (excluding application costs) are given in Table 9.15 for the trial sites in Queensland and NT. Costs for application are related to the planting layout. Slashing frequency was 10 times/year initially, reducing to 3 times/year at year 4 and on.

Table 9.15 Estimated herbicide costs for cocoa by site location.

Site	Herbicide Costs ($/ha)						
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 on
Mossman	265	425	425	310	230	115	115
South Johnstone	265	370	370	300	150	115	115
NT	75	625	625	380	270	270	135

Pest control

Chemical applications for pest control at the Mossman and South Johnstone sites are given in Table 9.16. Frequency and timing of pesticides will be variable depending on pest pressure and management skill. No estimates were made for NT sites. Costs for application are related to the planting layout.

Table 9.16 Estimated pesticide costs for cocoa by site location.

Site	Pesticide Costs ($/ha)		
	Year 1	Year 2	Year 3 on
Mossman	390	265	330
South Johnstone	370	370	330
NT	n/a	n/a	n/a

Disease control

A twice yearly application of fungicide (potassium phosphonate) by foliar spray for phytophthora control was budgeted. The total cost excluding labour for application was estimated at $300/ha/year.

Canopy management (pruning)

Assumptions for the various pruning activities are given in Table 9.17. It was also assumed that from year 5 and on, some method of mechanical pruning (hedging or trimming) could be implemented. Estimates of the time required for mechanical pruning were 2.05 hr/ha for double row plantings and 2.5 hrs/ha for single row plantings.

Table 9.17 Estimated pruning requirements for cocoa by year from planting.

Activity	Year			
Chupon Removal	**1**	**2**	**3**	**4 & on**
frequency	1	2	2	0
sec/tree	4	6	6	0
sec/tree/year	4	12	12	0
hr/ha/year	1.3	4.0	4.0	0.0
Structural	**2**	**3**	**4**	**5 & on**
frequency	1	2	2	1
min/tree	1.0	2.0	1.5	1.0
min/tree/year	1.0	4.0	3.0	1.0
hr/ha/year	20.0	80.0	60.0	20.0
Height	**4**		**5 & on**	
frequency	2		1	
min/tree	0.5		0.5	
min/tree/year	1.0		0.5	
hr/ha/year	20.0		10.0	

Harvesting

A harvest rate of 10 sec/pod and 7.5 sec/pod was assumed for the dry and wet tropics respectively. The assumed field efficiency was 90%. The unit harvesting costs ($/ha dry bean) depend on the pod index and yield.

A labour requirement of about 3 hrs/t dry bean was budgeted for pick-up, transport and handling of pods on-farm.

Pod and bean processing (pod splitting and fermentary)

The scenario for pod splitting and bean extraction was based on a contract rate arrangement ($/t dry bean). A mobile pod splitter and bean extraction plant bought to the farm would batch process pods accumulated from the previous week or so of harvesting. A processing capacity of about 370 kg/hr dry bean (2.7 hr/t dry bean) was calculated and used to determine a contract rate which included labour costs, depreciation and 5% return on investment. A contract pod processing cost of $131 /t dry bean was calculated but this is highly dependent on the assumed annual throughput (utilisation) of the plant. There is also a significant level of uncertainty about the implementation, cost and performance of the pod splitting and bean extraction technology.

A labour allowance of 0.5 hrs was budgeted for composting and disposal of waste pod material from pod splitting.

The scenario for bean processing was based on a central fermentary which received wet bean ex contract pod splitting and processed it through to dried, fermented bean for shipment to market. The costs for the central fermentary were based on the facility handling production from 100 ha of mature cocoa (400 t/yr dry bean). Costs for fermentation, drying (mechanical), grading, packing and quality assurance were budgeted. Based on the processing capacity of 400 t/year dry bean, a processing cost of $244 /t dry bean was calculated which included labour and administration costs, depreciation and 5% return on investment. There is a high level of uncertainty with this cost due to significant conjecture regarding the actual set-up and related and capital costs.

Tables 9.18a tof list the capital equipment estimates used in the NACDA model for various pod and bean processing scenarios. Each estimate is made up of a detailed breakdown of the equipment required and for buildings and land where appropriate. The totals for mobile pod splitting and central fermentary scenarios were used in the calculation of the contract processing rates described above.

Table 9.18a Estimated capital equipment requirements for farm utilising contracted pod splitting and fermentary.

On-farm Contract Splitting or Off-farm Central Fermentary	$	Basis
forks for tractor	5,000	each
shaded area for bin storage	0	available
mulch spreader (1 per 100 ha)	20,000	each
Total	**25,000**	

Table 9.18b Estimated capital equipment requirements for a mobile pod splitter.

Mobile Pod Splitter	$ Each	Number	$ Total
truck	50,000	1	50,000
dog trailer	15,000	1	15,000
power source	5,000	1	5,000
hydraulics	6,000	1	6,000
feed hopper with live floor	4,500	1	4,500
pre-feed roller conveyor	2,500	1	2,500
pod splitter feed conveyor	3,500	2	7,000
pod splitter	20,000	2	40,000
bean separator inc. pod waste elevator/conveyor, wet bean conveyor	17,500	1	17,500
pod chopper	3,500	1	3,500
storage for fermentation bins	2,500	1	2,500
Total			**153,500**

Table 9.18c Estimated capital equipment requirements for 10 ha farm with on-site pod splitting plant and fermentary (e.g. stand-alone plantation in isolated location).

On-farm Pod Splitting and Fermentary (up to 10 ha)	$ Each	Number	$ Total
forks for tractor	5,000	1	5,000
pallet jack	1,000	1	1,000
shed	30,000	1	30,000
elevating feed hopper with live floor	7,500	1	7,500
pre-feed roller conveyor	2,500	1	2,500
pod splitter feed conveyor	3,500	1	3,500
pod splitter	20,000	1	20,000
bean separator	15,000	1	15,000
pod waste elevator/conveyor	2,500	1	2,500
pod chopper	3,500	1	3,500
wet bean conveyor	2,500	1	2,500
fermentation bins	500	18	9,000
fermentation monitoring equipment	500	3	1,500
mechanical dryer	25,000	1	25,000
elevating conveyor	5,000	1	5,000
dry bean hopper	3,500	1	3,500
dry bean grader	5,000	1	5,000
bagging hopper & bag sewer	5,000	1	5,000
Total			**147,000**

Table 9.18d Estimated capital equipment requirements for 25 ha farm with on-site pod splitting plant and fermentary (e.g. stand-alone plantation).

On-farm Pod Splitting and Fermentary (up to 25 ha)	$ Each	Number	$ Total
forklift	20,000	1	20,000
pallet jack	1,000	1	1,000
shed & office	50,000	1	50,000
elevating feed hopper with live floor	7,500	1	7,500
pre-feed roller conveyor	2,500	1	2,500
pod splitter feed conveyor	3,500	1	3,500
pod splitter	20,000	2	40,000
bean separator	15,000	1	15,000
pod waste elevator/conveyor	2,500	1	2,500
pod chopper	3,500	1	3,500
wet bean conveyor	2,500	1	2,500
fermentation bins	500	30	15,000
fermentation monitoring equipment	500	6	3,000
mechanical dryer	25,000	2	50,000
elevating conveyor	5,000	1	5,000
dry bean silo	5,000	1	5,000
dry bean grader	7,500	1	7,500
cleaned dry bean hopper	3,500	1	3,500
container loading	3,500	1	3,500
Total			**240,500**

Table 9.18e Estimated capital equipment requirements for 100 ha farm with on-site pod-splitting plant and fermentary (e.g. stand-alone plantation).

On-farm Pod Splitting and Fermentary (up to 100 ha)	$ Each	Number	$ Total
forklift	20,000	1	20,000
pallet jack	1,000	2	2,000
shed & office	75,000	1	75,000
elevating feed hopper with live floor	10,000	1	10,000
pre-feed roller conveyor	2,500	1	2,500
pod splitter feed conveyor	3,500	2	7,000
pod splitter	20,000	2	40,000
bean separator	20,000	1	20,000
pod waste elevator/conveyor	2,500	1	2,500
pod chopper	3,500	1	3,500
wet bean conveyor	2,500	1	2,500
fermentation bins	500	114	57,000
fermentation monitoring equipment	500	20	10,000
mechanical dryer	35,000	4	140,000
conveyor ex dryer	3,500	1	3,500
Elevator	10,000	1	10,000
dry bean silo	7,500	2	15,000
conveyor ex silo	3,500	1	3,500
dry bean grader	10,000	1	10,000
Cleaned dry bean hopper	5,000	2	10,000
container loading	3,500	1	3,500
Total			**447,500**

Table 9.18f Estimated capital equipment requirements for central fermentary with attendant mobile pod splitting plant capable of processing production from 100ha.

Central Fermentary and Mobile Pod Splitter (up to 100 ha)	$ Each	Number	$ Total
land	75,000	1	75,000
shed & office	75,000	1	75,000
forklift	20,000	1	20,000
pallet jack	1,000	2	2,000
mobile pod splitter	153,500	1	153,500
wet bean processing	67,000	1	67,000
dry bean processing	195,500	1	195,500
quality assurance and monitoring equipment	5,000	1	5,000
Total			**593,000**

FORM costs

Assumed operating costs (FORM = fuels, oils, repairs and maintenance) for farm machinery used in conjunction with cocoa production are listed in Table 9.19.

Table 9.19 FORM costs for farm machinery assumed in NACDA economic model.

Machinery Item	Rate	Unit
4WD utility	10.00	$/hr
quadbike	4.00	$/hr
60 hp general tractor	25.00	$/hr
40 hp orchard tractor	15.00	$/hr
small slasher	5.00	$/hr
spray boom	2.50	$/hr
mister	5.00	$/hr
pneumatic secateurs	3.00	$/hr
mechanical pruner	5.00	$/hr
chainsaw	3.00	$/hr
harvest aid (15 hp motor)	4.00	$/hr
pod splitter & bean separator (mobile)	15.00	$/hr
pod splitter & bean separator (in fermentary)	7.50	$/hr
pod spreader trailer	2.50	$/hr
forklift	7.50	$/hr
dryer	75.00	$/t dry bean
grading	4.00	$/hr
bagging	4.00	$/hr
bulk loading	4.00	$/hr

9.4.3 Results

The results of a gross margin analysis for a 5 ha cocoa planting at 1,200 trees/ha utilising hybrid seedling material are presented in Tables 9.20a and b. The gross margins for a range of prices and yields are tabulated. On the basis of the small size of the planting, it is assumed that all labour for growing and harvesting is provided 'free' by the grower/owner.

The gross margins in Table 9.20a is based on the production of dried and fermented bean with the pod splitting and bean processing being contracted out. The gross margins in Table 9.20b are based on the production of pods with the grower selling whole pod to a central processor. In both Tables the black area indicates the most likely price-yield combinations; the greyed areas indicate possible scenarios whilst the remaining outcomes are considered unlikely.

Table 9.20a Gross margin analysis for a 5 ha farm model based on the production of fermented dried bean.

Price ($/t dry bean)	Yield (t/ha dried bean)						
	1.5	2.0	2.5	3.0	3.5	4.0	4.5
1000	-$2,070	-$1,879	-$1,688	-$1,498	-$1,307	-$1,116	-$925
1500	-$1,358	-$929	-$501	-$73	$356	$784	$1,212
2000	-$645	$21	$687	$1,352	$2,018	$2,684	$3,350
2500	$67	$971	$1,874	$2,777	$3,681	$4,584	$5,487
3000	$780	$1,921	$3,062	$4,202	$5,343	$6,484	$7,625
3500	$1,492	$2,871	$4,249	$5,627	$7,006	$8,384	$9,762
4000	$2,205	$3,821	$5,437	$7,052	$8,668	$10,284	$11,900

* The July 08 commodity cocoa price for dried bean was approximately AU$3000 /tonne. Dried bean for speciality or origin cocoa sells at a price premium to bulk cocoas based on quality attributes and demand.

Table 9.20b Gross margin analysis for a 5 ha farm model based on the production of and sale of pods.

Price ($/t dry pods)	Yield (t/ha pods)						
	15	20	25	30	35	40	45
150	-$1,735	-$1,430	-$1,130	-$825	-$525	-$220	$80
200	-$985	-$430	$120	$675	$1,225	$1,780	$2,330
250	-$235	$570	$1,370	$2,170	$2,980	$3,780	$4,580
300	$515	$1,570	$2,620	$3,675	$4,725	$5,780	$6,830
350	$1,265	$2,570	$3,870	$5,175	$6,475	$7,780	$9,080
400	$2,015	$3,570	$5,120	$6,675	$8,225	$9,780	$11,330
450	$2,765	$4,570	$6,370	$8,175	$9,975	$11,780	$13,580
500	$3,515	$5,570	$7,620	$9,675	$11,725	$13,780	$15,830
550	$4,265	$6,570	$8,870	$11,175	$13,475	$15,780	$18,080
600	$5,015	$7,570	$10,120	$12,675	$15,225	$17,780	$20,330

* The July 08 price offered by an Australian cocoa processor was in the vicinity of $320/tonne delivered to a central fermentary in Mossman. A higher price ($500/t) was being offered for organically grown cocoa.

From Table 9.20a, for a yield of 2.5 t/ha of dried bean and a price of $3,000 /t the indicated gross margin per hectare is $3,062. From Table 9.20b, for a yield of 25 t/ha of pods (approximately equivalent to 2.5 t/ha of dried bean) and a price of $300 /t of pod the indicated gross margin per hectare is $2,620.

9.4.4 Summary

The NACDA model was continually developed over a one-year period culminating in its use by Invetech in late 2004 for modelling various establishment scenarios and investigating sensitivities to price, yield and farm size. These analyses are discussed in Section 9.5.

The model has not been utilised significantly since that time and requires review for the currency of input cost assumptions, likely yields and prices and the various management options. It would also benefit from simplification by reducing detail and/or redevelopment into a more user-friendly format.

The gross margin analyses presented in Section 9.4.3 show reasonably favourable margins over the expected range of prices and yields. For the production of pods (as compared to dried bean) the gross margins at comparable yields are even more favourable. This is important, since there would be less risk to the grower in the production of pods given the considerable uncertainty about the actual costs of bean processing which is a major input cost. This risk would instead be borne by processors.

Therefore, growers would initially be advised to enter the industry on this basis provided that such a processor is in the marketplace willing to buy pods. This model also depends on the long-term viability of the processor.

The alternative is for growers to produce dried and fermented beans themselves (or on a co-operative basis). This has more inherent risk and has lower theoretical margins to pod production. It is also less attractive in comparison to other horticultural crops. However, the principle point of difference is that the cocoa market (world) is very large, is expected to grow and has sophisticated trading instruments to reduce risk. As a fall-back, growers should always be able to sell dried beans no matter what scale of production is attained in Australia.

Significant opportunities at higher margins exist for growers who can establish a good reputation for quality, continuity of supply or both. They could also develop partnerships with value chain participants to extract extra returns through branding and marketing. However, presuming an inherent price premium for Australian produced cocoa at the outset is highly optimistic.

9.5 Commercisalisation plan for the Australian cocoa industry – Invetech

9.5.1 Introduction

RIRDC funding for Phase 3 of the NACDA research program (2005–07) was contingent on an independent review of the research program and this was conducted by Invetech Pty. Ltd. (Dr Brent Jenkins).

This review proposed to develop a ‘Commercialisation Plan for the Australian Cocoa Industry’ and was divided into two phases. Phase 1 (completed) examined the Business Case and was an ‘Assessment of the NACDA Sponsored Research’ (Phase 2 – Business Model, was not conducted).

The key questions posed and addressed by Invetech were as follows:

- Industry Analysis: what issues are facing the Australian cocoa industry and which if any are addressed by domestic cocoa production?
- Technology Profile: what base supports the development of a globally competitive Australian cocoa industry?
- Market Profile: what are the characteristics and issues pertaining to the global cocoa industry, including the size and growth of markets accessible to Australian produced cocoa?
- Cost and Risk Analysis: would cocoa production in Australia be profitable and what are the risks to further industry growth and development?
- Value Proposition: the value chain opportunities and risks; is an industry justified?

To support these analyses Invetech conducted meetings with stakeholders, reviewed market data and interviewed a number of industry participants in Australia.

The Final Report was released in January 2005 and provided a good background and analysis of the business case for an Australian cocoa industry. It concluded that the technical risks associated with cocoa production in Australia were addressed or manageable. However, the high cost structure, non-premium product and exposure to currency movements lead to a marginal value proposition despite the potentially large market opportunity.

Invetech's findings from the modelling of various cocoa production enterprises (conducted in relation to the 'Cost and Risk Analysis') are reported here only.

9.5.2 Methodology and assumptions

The Invetech modelling was based on the NACDA economic model developed by Craig Lemin. As such the inputs and basis of the model are the same. The resulting output format was also the same except Invetech included a depreciation component in the cost structure.

Invetech's modelling was based around three scenarios and three farm sizes as follows:

1. 'New' enterprise ex sugarcane production: 5 ha, 20 ha and 40 ha models.
2. 'Leveraged' enterprise in conjunction with other horticulture: 5 ha, 20 ha and 40 ha models.
3. 'Greenfields' enterprise.

Labour assumptions

The overriding labour assumptions for the farm scenarios were as follows:

- 5 ha – owner/family provides all labour except a person is hired to assist with planting and harvesting (50% of requirements)
- 20 ha – the owner provides labour for establishment and maintenance but additional labour is hired for cocoa planting, harvesting and pruning (with the relative contribution of the owner for planting and harvesting less than in the 5 ha case)
- 40 ha – labour is costed for all operations.

Major assumptions

Three pricing assumptions were modelled (based on an assumed exchange rate of AU$1 = US$0.7):

1. Forecast price (2005–2011) of US$1,200 /t dry bean.
2. Base case price of US$1,884 /t dry bean.
3. 20 year maximum price of US$2,400 /t dry bean.

Three yield assumptions were modelled ranging from 3 to 5 t/ha dry bean.

The major assumptions for establishment and production were as follows:

- land preparation six months prior to cocoa planting
- planting density of 1,200 trees/ha
- single row planting layout with sprinklers and fertigation
- allowance for windbreaks

- allowance for shade (temporary and permanent)
- plant ready hybrid cocoa seedlings purchased ex commercial nursery at $4 each
- 8% field mortality replanted second year
- yield profile Y1=0%, Y2=-5%, Y3=30%, Y4=60%, Y5=90%, Y6=100%
- full yield = 4 t/ha dry bean
- pod index = 26
- processing losses = 5%
- harvest productivity = 7.5 sec/pod at 90% field efficiency (equivalent to 3,456 pods/person/day)
- allowance (costing) for all management operations (irrigation installation, operation and maintenance; shade and windbreak planting, removal and maintenance; cocoa planting; fertiliser application; weed, pest and disease control; pruning; pod harvesting and handling)
- pod and bean processing by central fermentary at contract rates
- $250 /ha income in Y15 from harvest of permanent shade species.

Specific assumptions

For the 'New' enterprise (ex sugarcane production) scenario it was assumed that the land was already owned by the farmer, however there is an allowance for land preparation costs at $250/ha. There are also capital costs for installation of a bore and pump as well as fertigation and irrigation systems. Some capital equipment and infrastructure is assumed to be already owned including a tractor, slasher, spray boom and workshop. However, it was assumed that for the 5 ha farm size, a secondhand orchard tractor was purchased. At larger scales, all equipment purchased is new.

For the 'Leveraged' enterprise (in conjunction with other/existing horticultural operations) the assumptions were the same as for the 'New' enterprise scenario except for the following:

- land preparation costs were reduced to $100 /ha
- irrigation is assumed to be already available (installed) however an allowance of $1,000 /ha and $1,500 /ha is made for conversion costs for the 20 ha and 40 ha farm size models respectively
- at the 5 ha farm size, only cocoa specific capital equipment is assumed to be purchased i.e. pruning and harvesting equipment. At larger scales, all equipment purchased was new.

For the 'Greenfields' enterprise all capital equipment, land preparation and plantation establishment requirements are fully costed.

9.5.3 Results

'New' enterprise scenario (ex sugarcane)

The cost structure for the three farm sizes relative to the three pricing regimes for a 'New' enterprise scenario is shown in Figure 9.1. This is based on a mature planting, yielding at 4 t/ha dry bean.

At the larger farm sizes, harvesting costs rise most significantly due to the reduced relative contribution by the self-employed 'owner' and increased reliance on hired labour. Even at the most favourable cost structure, the economics in relation to the 'Base Case' price regime is marginal and well above the 'Forecast' regime or the 'Current' price (January 2005).

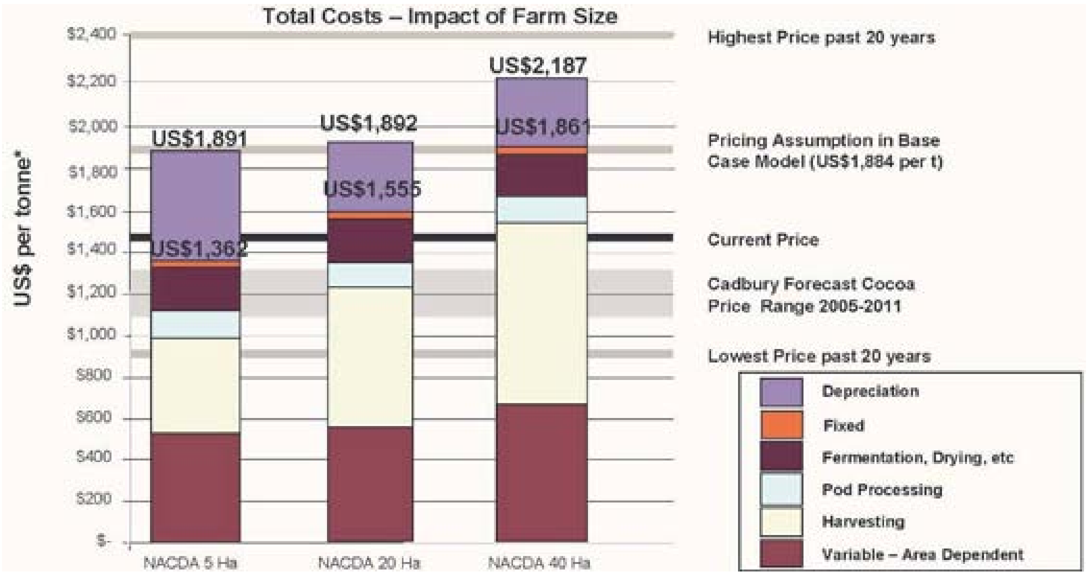


Figure 9.1 Cost structures for 'New' enterprise farm sizes (Source: Jenkins 2005).

Sensitivity analysis of yield and price is shown in Figure 9.2 (based on a 5 ha farm size). Yield has a large impact, however positive margins are only achieved at yields above 4 t/ha dry bean and for the 'Base Case' price regime.

	Margin* US$/tonne (Year 6)	Yield (Tonnes per Ha)		
		2.5	4.0	5.0
Cocoa Price US$/tonne	1,200 (Forecast)	*($1,334)*	*($691)*	*($476)*
	1,885 (Model Assumption)	*($650)*	*($7)*	*$208*
	2,400 (20 yr Maximum)	*($134)*	*$509*	*$723*

** Includes all cash costs and depreciation*

	IRR** %	Yield (Tonnes per Ha)		
		2.5	4.0	5.0
Cocoa Price US$/tonne	1,200 (Forecast)	*Neg*	*Neg*	*Neg*
	1,885 (Model Assumption)	*Neg*	*2.2%*	*5.8%*
	2,400 (20 yr Maximum)	*2.2%*	*9.9%*	*13.4%*

*** Based on cash flows only*

Figure 9.2 Sensitivity analysis: yield and price for 'New' enterprise 5 ha farm size (Source: Jenkins 2005).

Sensitivity analysis of farm area and price is shown in Figure 9.3 (based on a 4 t/ha dry bean yield). The 5 ha and 20 ha farm sizes have similar margins, however the 20 ha farm size had the highest IRR (11.5%) at the '20 Year Maximum' price regime.

	Margin* US$/tonne (Year 6)	Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Cocoa Price US$/tonne	1,200 (Forecast)	($691)	($692)	($987)
	1,885 (Model Assumption)	($7)	($8)	($303)
	2,400 (20 yr Maximum)	$509	$507	$212

* Includes all cash costs and depreciation

	IRR** %	Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Cocoa Price US$/tonne	1,200 (Forecast)	Neg	Neg	Neg
	1,885 (Model Assumption)	2.2%	2.1%	Neg
	2,400 (20 yr Maximum)	9.9%	11.5%	5.0%

** Based on cash flows only

Figure 9.3 Sensitivity analysis: farm area and price for 'New' enterprise at 4 t/ha dry bean yield (Source: Jenkins 2005).

Sensitivity modelling of farm area and yield is shown in Figure 9.4 (based on the 'Base Case' price regime). The 5 ha farm size provides slightly higher margins than the 20 ha farm size and the IRR sensitivity to yield was similar for the 5 ha and 20 ha farm sizes. The 40 ha farm size is not viable at any of the yield assumptions.

	Margin* US$/tonne (Year 6)	Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Yield (Tonnes per Ha)	2.5	($650)	($552)	($905)
	4.0	($7)	($8)	($303)
	5.0	$208	$173	($102)

* Includes all cash costs and depreciation

	IRR** %	Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Yield (Tonnes per Ha)	2.5	Neg	Neg	Neg
	4.0	2.4%	2.1%	Neg
	5.0	5.8%	5.7%	Neg

** Based on cash flows only

Figure 9.4 Sensitivity analysis: farm area and price for 'New' enterprise at 4 t/ha dry bean yield (Source: Jenkins 2005).

'Leveraged' enterprise scenario

The cost structure for the three farm sizes relative to the three pricing regimes for a 'Leveraged' enterprise scenario is shown in Figure 9.5. This is based on a mature planting, yielding at 4 t/ha dry bean.

The reduced capital requirements bring depreciation costs down so that this scenario provides a lower cost structure compared to the 'New' enterprise case. The relative advantage to the 'New' enterprise case is maintained at all farm sizes. The 5 ha and 20 ha farm sizes had costs structures lower than the

‘Forecast’ price regime. However, the cost structures for all farm sizes were above the ‘Current’ (January 2005) price and the ‘Forecast’ price regime.

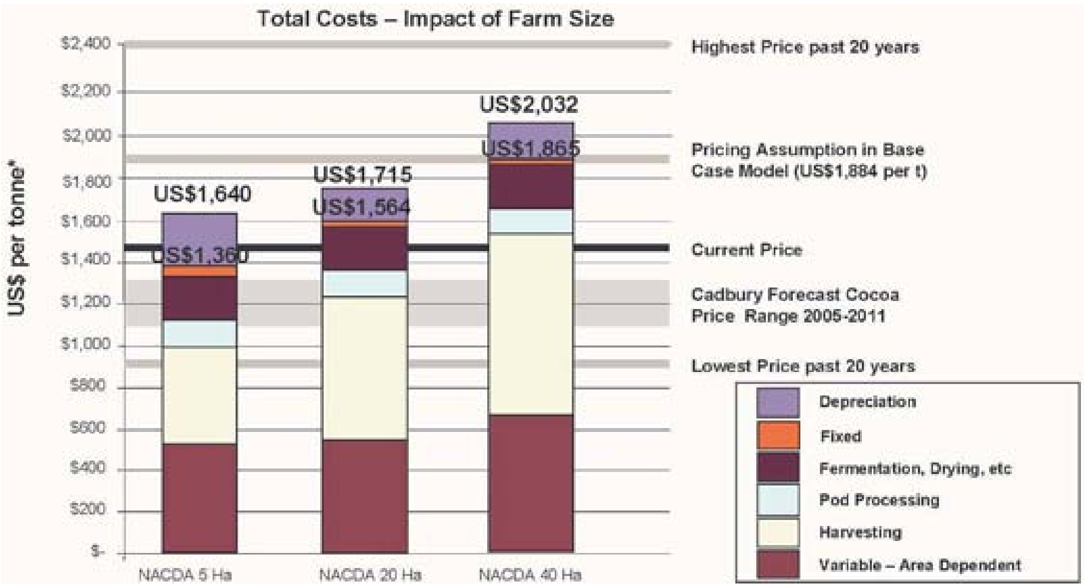


Figure 9.5 Cost structures for ‘Leveraged’ enterprise farm sizes (Source: Jenkins 2005).

Sensitivity analysis of yield and price is shown in Figure 9.6 (based on a 5 ha farm size). Whilst the margins are improved relative to the ‘New’ enterprise, a combination of high yields and high prices is still required to produce favourable returns.

	Margin* US$/tonne (Year 6)	Yield (Tonnes per Ha)		
		2.5	4.0	5.0
Cocoa Price US$/tonne	1,200 (Forecast)	($932)	($440)	($275)
	1,885 (Model Assumption)	($247)	$244	$409
	2,400 (20 yr Maximum)	$267	$760	$924

* Includes all cash costs and depreciation

	IRR** %	Yield (Tonnes per Ha)		
		2.5	4.0	5.0
Cocoa Price US$/tonne	1,200 (Forecast)	Neg	Neg	Neg
	1,885 (Model Assumption)	Neg	8.6%	12.6%
	2,400 (20 yr Maximum)	8.8%	18.3%	22.4%

** Based on cash flows only

Figure 9.6 Sensitivity analysis: yield and price for ‘Leveraged’ enterprise 5 ha farm size (Source: Jenkins 2005).

Sensitivity analysis of farm area and price is shown in Figure 9.7 (based on a 4 t/ha dry bean yield). As for the ‘New’ enterprise scenario, the 5 ha and 20 ha farm sizes have similar margins, however the 20 ha farm size had the highest IRR (20.6%) at the ‘20 Year Maximum’ price regime.

Margin* US$/tonne (Year 6)		Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Cocoa Price US$/tonne	1,200 (Forecast)	($440)	($515)	($832)
	1,885 (Model Assumption)	$244	$168	($148)
	2,400 (20 yr Maximum)	$760	$684	$367

* Includes all cash costs and depreciation

IRR** %		Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Cocoa Price US$/tonne	1,200 (Forecast)	Neg	Neg	Neg
	1,885 (Model Assumption)	8.6%	8.0%	Neg
	2,400 (20 yr Maximum)	18.3%	20.6%	9.8%

** Based on cash flows only

Figure 9.7 Sensitivity analysis: farm area and price for 'Leveraged' enterprise at 4 t/ha dry bean yield (Source: Jenkins 2005).

Sensitivity modelling of farm area and yield is shown in Figure 9.8 (based on the 'Base Case' price regime). As for the 'New' enterprise scenario, the 5 ha farm size provides slightly higher margins than the 20 ha farm size and the IRR sensitivity to yield is similar for the 5 ha and 20 ha farm sizes. The 40 ha model remains an untenable proposition at any of the yield assumptions.

Margin* US$/tonne (Year 6)		Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Yield (Tonnes per Ha)	2.5	($247)	($260)	($638)
	4.0	$244	$168	($148)
	5.0	$409	$311	$16

* Includes all cash costs and depreciation

IRR** %		Farm Area (Hectares)		
		5 Ha	20 Ha	40 Ha
Yield (Tonnes per Ha)	2.5	Neg	Neg	Neg
	4.0	8.6%	8.0%	Neg
	5.0	12.5%	12.5%	0.5%

** Based on cash flows only

Figure 9.8 Sensitivity analysis: farm area and price for 'Leveraged' enterprise at 4 t/ha dry bean yield (Source: Jenkins 2005).

'Greenfields' enterprise scenario

The cost structures of 'Greenfields' versus 'Leveraged' scenarios for the 5 ha farm size are shown in Figure 9.9. This is based on a mature planting, yielding at 4 t/ha dry bean. The higher capital requirements for the 'Greenfields' venture mean that this scenario is not viable and no additional modelling was conducted.

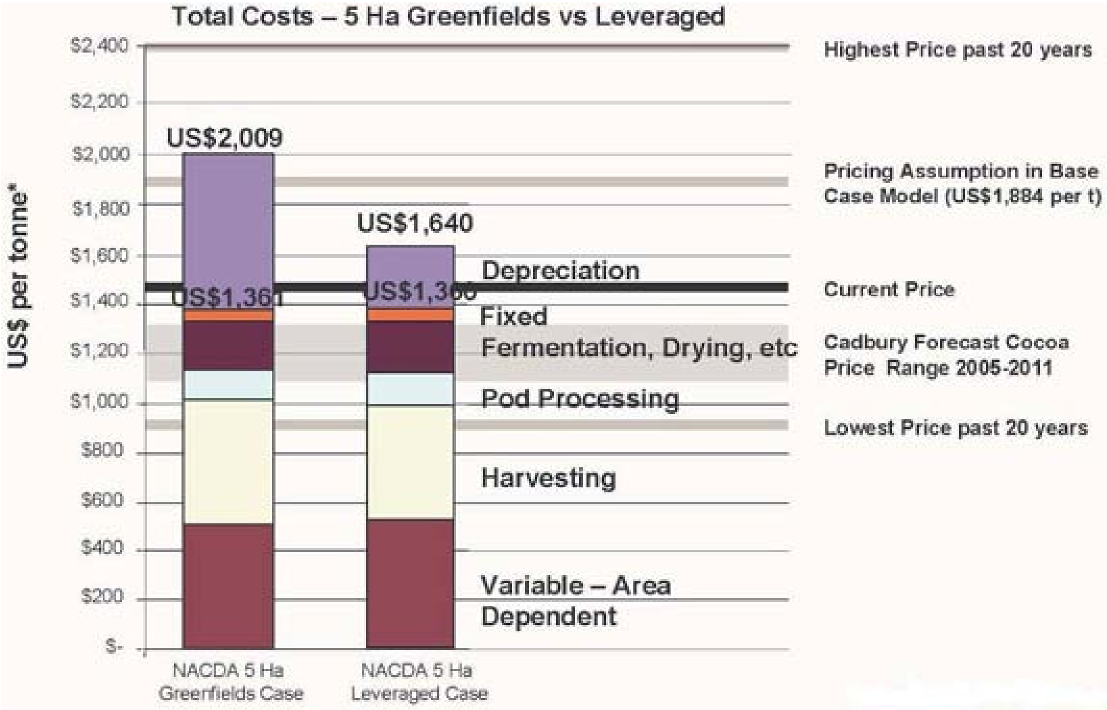


Figure 9.9 Cost structures of 'Greenfields' versus 'Leveraged' enterprises for a 5 ha farm size (Source: Jenkins 2005).

Conclusions

Invetech preliminary assessment of the value proposition for Australian cocoa production was based as follows:

- Growing cocoa in Australia is technically feasible? – Yes
- Quality standards for 'bulk' cocoa can be achieved? – Yes
- Growing cocoa in Australia would be economically attractive? – No
- Profitability is insensitive to major variables such as price and yield? – No
- There is strong demand from potential end users? – Possibly.

A risk analysis identified the technical and commercial risks as per Table 9.21

Table 9.21 Risk analysis of Australia cocoa production.

Risk Factor	Impact	Likelihood
Technical		
Failure to reach anticipated yields of 4t/ha dry bean from demonstrated levels of 3t/ha	High	Unlikely-Medium
Pest and disease susceptibility	Medium	Medium
Failure to commercialise mechanised pod splitting and bean separation technology	High	Low
Commercial		
Lack of commercial investment in growing	High	Medium
Unacceptable returns to growers	High	Medium
Processing costs are uneconomic at small initial scales	Medium	Low
Price premium for Australian bean is not attained	High	Medium

Invetech concluded that the value proposition presented by Australian cocoa production for commodity cocoa markets was marginal. The technical risks were seen as manageable but were dependent on attaining sustainable, acceptable yields (4 t/ha dry bean). The commercial risks were considerable and required entrepreneurial and investment activities outside the scope of the NACDA research program.

Nonetheless, Invetech considered that an integrated business model aimed at premium or value-added chocolate products was realisable. This was being pursued at that time by start-up company Cocoa Australia who were facilitating and supporting industry establishment and standing in the marketplace as a buyer of Australian cocoa for end-use in high value products.

10. Situation post-NACDA

10.1 Trial sites

The final (Queensland) phase of the NACDA project finished at July 2007. The HYET established at Mossman (on the Goodman property near Port Douglas) survives and is being managed by Cocoa Australia. The South Johnstone planting never recovered from the severe effects of Cyclone Larry in March 2006 and was removed in about March 2007. By agreement and due to sub-economic performance, formal monitoring of the Darwin trial work ceased in June 2005. Some strategic harvesting was conducted in March-May 2006 but the trial was then removed in June of the same year. Likewise the planting at FWRI (Kununurra) was only retained until early 2004.

10.2 Industry development

CS has continued its interest in an Australian cocoa industry by supporting an industry development project in northern Queensland in association with DPI&F and RIRDC. This has seen field establishment of about 9 ha of cocoa on four private properties from mid-2007; mainly in the Innisfail district but also at Ingham. It is not currently clear how cocoa produced from these plantings will ultimately be processed and marketed. However, there is some interest by private investors to establish a cocoa processing facility and fermentary. Potentially, this could be conducted in conjunction with a research and development initiative focussed on processing and fermentation and with support from government and industry.

Separately, another commercial entity (Cocoa Australia) has been behind establishment of about 25 ha of cocoa on several private grower properties centred on the Mossman district. Cocoa Australia was founded by ex CS employees in 2004 with a business model based around cocoa processing. Cocoa Australia has linkages with Mossman Mill Company Ltd. (co-operative sugar mill) through development of low GI sugar and ‘Farm by Nature’ (retail chocolates and fruit snacks) through a related company structure. Cocoa Australia has undertaken to purchase and process pods from its grower base and has already established an embryonic processing and fermentation facility based on the prototype equipment developed in the NACDA program under a lease arrangement.

10.3 Recent prices and outlook

Average monthly US$ denominated cocoa prices since the start of the NACDA project in 1999 to date are shown in Figure 10.1 (sourced from the ICCO). The corresponding AU$ prices are also shown by applying the average monthly exchange rate (sourced from the Reserve Bank of Australa). Initially prices were falling but rose to quite high levels in 2002 and 2003 due to a combination of market speculation and supply concerns against a background of sustained demand increase and falling SGRs. This was assisted by a relatively low Australian dollar at that time. Prices above AU$2,500 /t are estimated to be economic for cocoa production in Australia (and especially so above AU$3,000 /t as was the case for the period June 2002 to April 2003). There was a relatively stable period from late 2002 to early 2007 when prices remained around the US$1,500 /t. Prices then entered a significant upward trend driven by demand pressure and peaked at around US$3,000 /t in June 2008. This trend was also linked with a boom in commodities generally and to increased participation of speculators in the cocoa market.

Figure 10.1 also shows the ‘Standard’ price assumption used by the AgTrans modelling prior to the project commencing (refer to Section 9). History has shown this assumption to have been highly optimistic. In contrast however, Figure 10.2 shows the cocoa price outlook published by LMC International in May 2000 to have been quite accurate. The outlook is based on three demand scenarios: low, medium and high. Actual average yearly prices have generally followed the forecast trends and remained within the band between the low and high demand scenarios except over the last two years when prices moved significantly above even the high demand forecast.

Since mid-2008, prices have been in steep decline. The ICCO price in late October 2008 had fallen to around US$2,000 /t. This has primarily been a result of non-commercial speculators exiting the cocoa market as a result of the global financial crisis. However, due to the corresponding steep falls in the value of the Australian dollar, cocoa prices in Australian dollars have remained relatively high (around $3,100 /t).

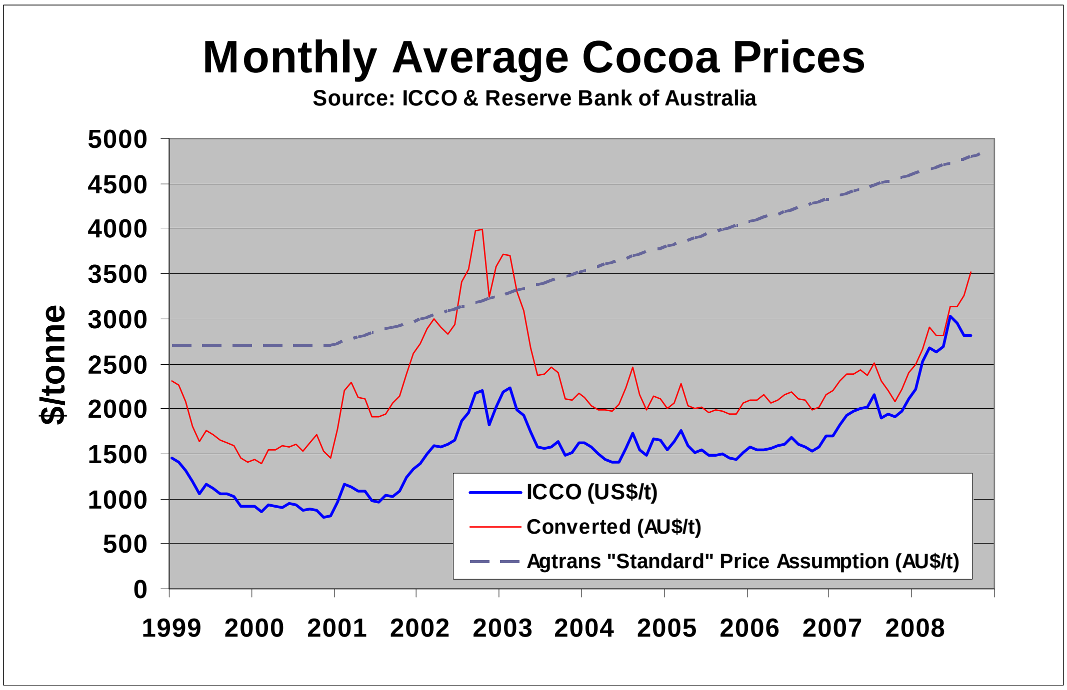


Figure 10.1 History of cocoa prices since commencement of the NACDA project.

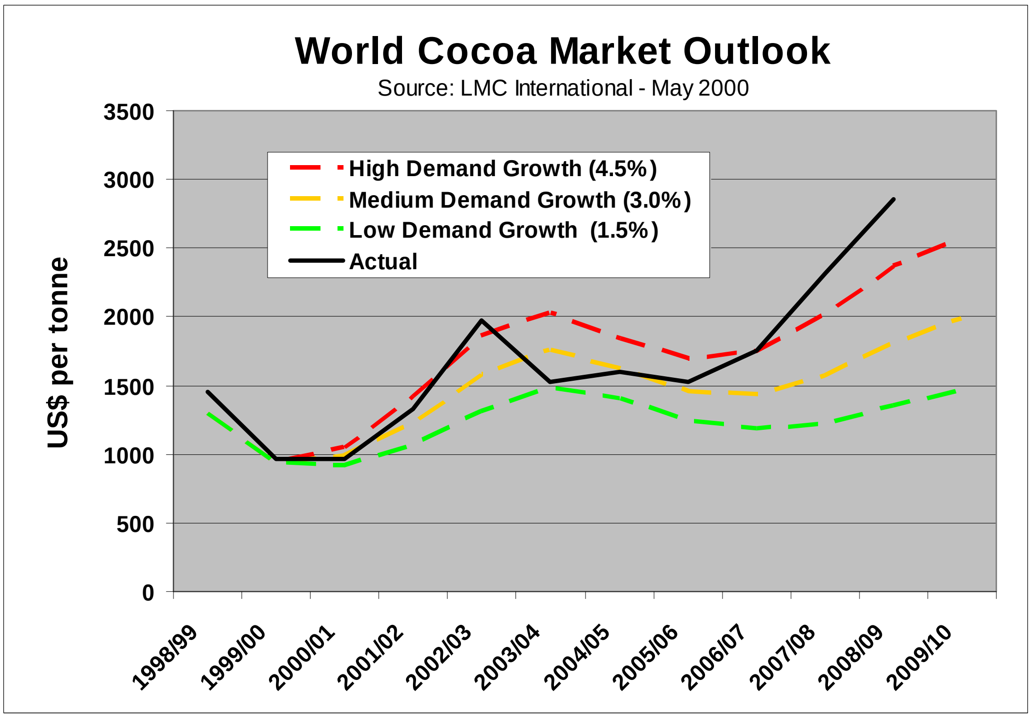


Figure 10.2 Actual cocoa prices versus forecast in May 2000 by LMC International.

World production for the 2006/07 cocoa year was reported to be 3,360,000 t (Source ICCO Quarterly Bulletin of Cocoa Statistics XXXIV No.3) which is 660,000 t higher than in 1999 when the NACDA project was initiated. The ICCO forecast in May 2008, is for production to increase from 3,700,000 t in 2007/08 to 4,500,000 t in 2012/13 which is an estimated average growth rate of 3.7% per annum. For the corresponding period world grindings would increase from 3,700,000 t to 4,300,000 t. This is despite an environment of recent high cocoa prices and a forecast slowing in global economic growth.

Given these projections, the world SGR is expected to increase from 42% for the 2007/08 cocoa year to 50% at the end of 2012/13. As a result, the ICCO expectations for cocoa prices in real terms are for an increase to US$2,300 /t in 2008/09. Prices are then expected to gradually decline to US$2,000 /t in 2012/13, due to the rising SGR.

10.4 Summary

As anticipated by CS at the outset, cocoa prices have trended upwards over the eight years of the NACDA project. Cocoa production and consumption have also increased at about the levels previously forecast.

Recent strong cocoa prices and the May 2008 projections by ICCO for continuing growth in consumption at about 3% per annum lend support to the development of a cocoa industry in northern Australia. Additionally, prices offered for speciality and origin cocoa beans are generally significantly above the bulk cocoa price. This would improve the investment fundamentals of an Australian cocoa industry catering to such markets.

The formation and activities of ‘Cocoa Australia’ and continued support of CS, are encouraging for the current fledgling industry which is focussed on producing a high quality ‘Australian’ chocolate.

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Appendices

A1 Hybrid yield evaluation trial summary of hybrid cocoa monthly and annual whole pod yields and dry bean equivalent for double and single row configurations and trial sites.

A1.1 Hybrid 1

Hybrid 1		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	Darwin	South J	Mossman	Darwin
2002–03	July	17		385	207	
	August	1016		420	2305	
	September	583		790	1947	
	October	2702	109	572	3063	18
	November	1854	9	794	1126	
	December	327		183	363	
	January	1010		624	1265	
	February	1558		0	2450	
	March	415	75	0	736	17
	April	350		0	1188	
	May	172	57	25	379	222
	June	669	237	44	1223	327
	Total Pod Yield (kg/ha)	10673	487	3837	16251	584
	Total Dry Bean Yield (t/ha)	**1.07**	**0.05**	**0.38**	**1.63**	**0.06**
2003–04	July	1226	671	815	1791	299
	August	1957	581	2345	1672	317
	September	1558	592	4484	1980	329
	October	4015	1290	1477	3958	785
	November	2123	2538	1464	2195	1522
	December	1935	1101	2134	2711	800
	January	1386	1511	975	2514	2020
	February	501	699	147	625	579
	March	1561	799	1075	1405	613
	April	696	789	801	347	618
	May	410	1085	2438	734	713
	June	2011	812	3454	1053	443
	Total Pod Yield (kg/ha)	19378	12468	21608	20988	9037
	Total Dry Bean Yield (t/ha)	**1.94**	**1.25**	**2.16**	**2.10**	**0.90**

Hybrid 1		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	**Darwin**	**South J**	**Mossman**	**Darwin**
2004–05	July	2800	987	3306	1814	789
	August	4920	1057	4908	3558	632
	September	3055	1303	1637	3145	1456
	October	7045	986	3601	7256	626
	November	1384	1411	1859	1213	1128
	December	626	2310	477	447	1785
	January	85	2439	131	219	1554
	February	209	2321	16	220	1700
	March	1773	3147	149	1297	2268
	April	1612	2105	364	1484	948
	May	3782	1855	878	3168	1160
	June	2981	1793	2104	2468	1575
	Total Pod Yield (kg/ha)	30273	21714	19429	26288	15621
	Total Dry Bean Yield (t/ha)	**3.03**	**2.17**	**1.94**	**2.63**	**1.56**
2005–06	July	2275		1729	2623	
	August	4007		908	4375	
	September	2619		1796	3309	
	October	3035		2564	3186	
	November	2223		3171	1906	
	December	366	5560	1000	211	2714
	January	56	2224	*	5	1243
	February	0	3336	*	0	1470
	March	0		*	0	
	April	0	969	*	0	655
	May	46	485	*	186	327
	June	154	485	*	709	327
	Total Pod Yield (kg/ha)	14781	13059	11168	16510	6737
	Total Dry Bean Yield (t/ha)	**1.48**	**1.31**	**1.12**	**1.65**	**0.67**

Hybrid 1		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	**Darwin**	**South J**	**Mossman**	**Darwin**
2006–07	July	710			2007	
	August	520			1527	
	September	2469			3148	
	October	4393			4762	
	November	324	No	No	1088	
	December	59	Data	Data	70	
	January	58	Collected	Collected	45	
	February	58			13	
	March	166			125	
	April	1216			696	
	May	2517			1928	
	June	2166			1726	
	Total Pod Yield (kg/ha)	14657	0	0	17135	0
	Total Dry Bean Yield (t/ha)	**1.47**	**0.00**	**0.00**	**1.71**	**0.00**

A1.2 Hybrid 2

Hybrid 2		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	**Darwin**	**South J**	**Mossman**	**Darwin**
2002–03	July	43		710	125	
	August	756		874	1628	
	September	412		1125	1087	
	October	1829	25	1563	2404	4
	November	1831	97	1393	2043	
	December	867		575	360	
	January	1487		747	1886	
	February	2236		0	3017	
	March	695	85	0	951	3
	April	259		46	1532	
	May	71	97	246	310	107
	June	512	159	721	1871	109
	Total Pod Yield (kg/ha)	10997	462	8000	17216	222
	Total Dry Bean Yield (t/ha)	**1.10**	**0.05**	**0.80**	**1.72**	**0.02**
2003–04	July	1593	401	1905	1286	210
	August	2254	362	2948	1751	285
	September	1527	239	3968	1786	183
	October	2816	674	2250	2064	486
	November	1682	1883	1767	1817	1354
	December	2312	1202	2254	2884	750
	January	2246	1909	1894	2272	1644
	February	540	1102	101	888	793
	March	996	1014	401	1716	666
	April	449	527	676	1649	585
	May	229	677	2974	341	892
	June	1136	308	4076	953	325
	Total Pod Yield (kg/ha)	17781	10298	25213	19407	8172
	Total Dry Bean Yield (t/ha)	**1.78**	**1.03**	**2.52**	**1.94**	**0.82**
2004–05	July	1585	684	4380	1574	646
	August	4288	529	5116	3676	396
	September	2437	1129	2250	2412	834
	October	6771	480	2802	7440	357
	November	1748	639	2017	2102	360
	December	1507	1360	1436	1795	1133
	January	89	1299	0	176	1159
	February	153	1370	0	289	977
	March	1375	1884	178	1452	1958

Hybrid 2		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	Darwin	South J	Mossman	Darwin
	April	1688	1027	270	1241	787
	May	3386	795	463	2505	661
	June	2816	988	2056	1546	913
	Total Pod Yield (kg/ha)	27842	12183	20968	26210	10183
	Total Dry Bean Yield (t/ha)	**2.78**	**1.22**	**2.10**	**2.62**	**1.02**
2005–06	July	2334		1119	1697	
	August	3527		377	3361	
	September	2792		1541	3702	
	October	3075		2964	4687	
	November	2693		2346	2785	
	December	301	3055	1299	361	2929
	January	49	1222		106	1251
	February	0	1833		0	1678
	March	0			0	
	April	0	592		0	787
	May	103	296		28	394
	June	103	296		164	394
	Total Pod Yield (kg/ha)	14978	7292	9646	16891	7433
	Total Dry Bean Yield (t/ha)	**1.50**	**0.73**	**0.96**	**1.69**	**0.74**
2006–07	July	593			805	
	August	387			1002	
	September	1601			2134	
	October	3254			2605	
	November	1494	No	No	1012	
	December	287	Data	Data	115	
	January	93	Collected	Collected	24	
	February	35			51	
	March	144			140	
	April	817			723	
	May	1531			1320	
	June	2191			1309	
	Total Pod Yield (kg/ha)	12427	0	0	11242	0
	Total Dry Bean Yield (t/ha)	**1.24**	**0.00**	**0.00**	**1.12**	**0.00**

A1.3 Hybrid 4

Hybrid 4		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	**Darwin**	**South J**	**Mossman**	**Darwin**
2002–03	July	74		589	206	
	August	359		297	1828	
	September	789		967	2414	
	October	2181	20	1166	3278	15
	November	1737	56	962	2439	48
	December	653		148	578	
	January	1736		461	1678	
	February	2874		0	1980	
	March	1445	105	0	718	8
	April	1486		46	967	
	May	115	146	33	348	69
	June	669	318	83	716	213
	Total Pod Yield (kg/ha)	14119	645	4752	17151	354
	Total Dry Bean Yield (t/ha)	**1.41**	**0.06**	**0.48**	**1.72**	**0.04**
2003–04	July	2449	335	430	1433	149
	August	1347	267	1396	3243	320
	September	1459	348	2828	3271	372
	October	2747	406	1531	3316	529
	November	1504	1867	1469	1891	894
	December	2165	1113	1533	2779	687
	January	2472	1920	1911	3783	1801
	February	617	1103	253	720	1255
	March	1912	1425	645	2032	1241
	April	404	734	841	738	875
	May	431	917	3212	708	773
	June	1165	442	4365	1144	642
	Total Pod Yield (kg/ha)	18672	10877	20414	25058	9537
	Total Dry Bean Yield (t/ha)	**1.87**	**1.09**	**2.04**	**2.51**	**0.95**
2004–05	July	1878	706	3141	1886	1166
	August	4772	814	4359	5548	685
	September	2609	1230	2058	3047	1338
	October	7220	518	4597	7832	557
	November	1826	499	2474	2393	824
	December	2016	1660	2114	2646	1478
	January	248	2396	70	209	1340
	February	233	1819	0	139	1315
	March	1391	3176	98	1435	2187

Hybrid 4		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	Darwin	South J	Mossman	Darwin
	April	1478	2352	257	1370	827
	May	2976	1836	480	2393	908
	June	2495	1713	1679	2563	974
	Total Pod Yield (kg/ha)	29141	18716	21326	31461	13599
	Total Dry Bean Yield (t/ha)	**2.91**	**1.87**	**2.13**	**3.15**	**1.36**
2005–06	July	2782		2103	2734	
	August	4203		757	4107	
	September	3545		1502	4138	
	October	3302		2615	3559	
	November	2335		3161	3408	
	December	273	3520	2518	520	3315
	January	67	1408		109	988
	February	0	2112		0	2327
	March	0			0	
	April	0	856		0	1106
	May	114	428		298	553
	June	140	428		192	553
	Total Pod Yield (kg/ha)	16762	8753	12656	19065	8842
	Total Dry Bean Yield (t/ha)	**1.68**	**0.88**	**1.27**	**1.91**	**0.88**
2006–07	July	636			913	
	August	623			759	
	September	2083			3176	
	October	3110			4020	
	November	1475	No	No	1641	
	December	172	Data	Data	134	
	January	48	Collected	Collected	16	
	February	37			100	
	March	266			66	
	April	1453			1339	
	May	1940			2127	
	June	2313			1931	
	Total Pod Yield (kg/ha)	14156	0	0	16222	0
	Total Dry Bean Yield (t/ha)	**1.42**	**0.00**	**0.00**	**1.62**	**0.00**

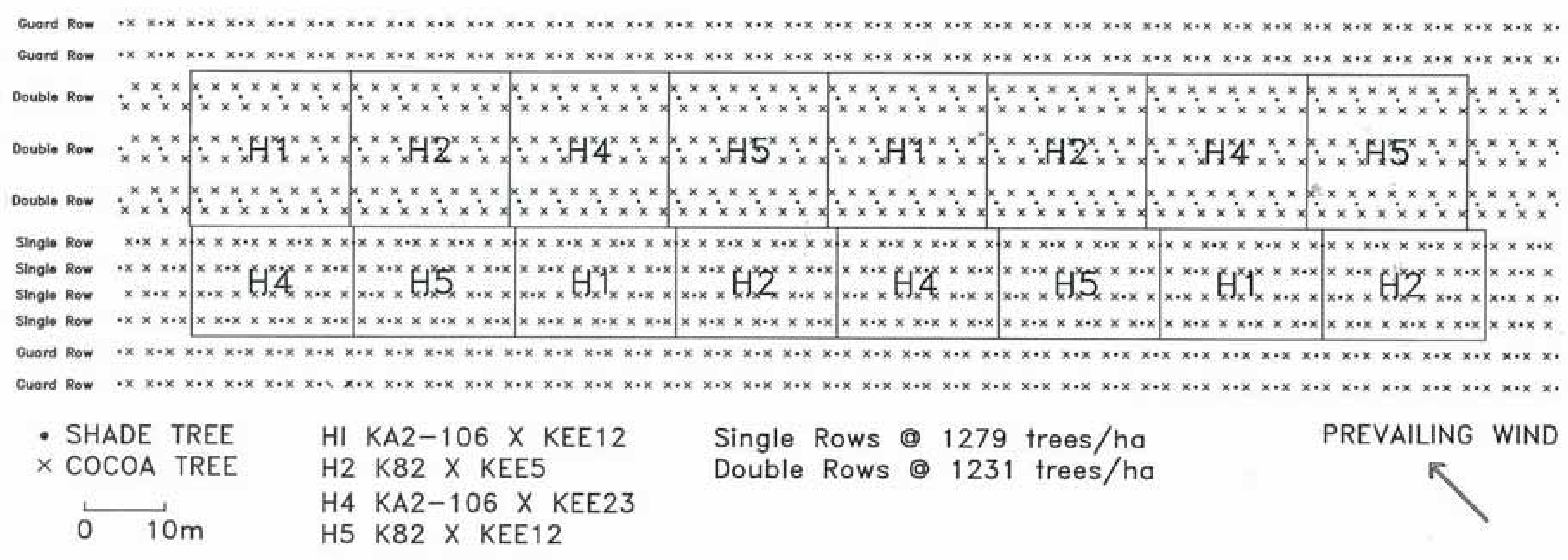
A1.5 Hybrid 5

Hybrid 5		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	Darwin	South J	Mossman	Darwin
2002–03	July	127		424	127	
	August	545		517	1438	
	September	262		553	1221	
	October	1653	38	703	2144	35
	November	1267	49	1050	1196	13
	December	403		237	371	
	January	877		488	1508	
	February	1804		0	2290	
	March	649	89	0	501	
	April	853		109	987	
	May	272	116	424	343	45
	June	844	188	66	1114	233
	Total Pod Yield (kg/ha)	9556	481	4573	13239	326
	Total Dry Bean Yield (t/ha)	**0.96**	**0.05**	**0.46**	**1.32**	**0.03**
2003–04	July	1230	414	1689	1969	287
	August	1350	422	3069	1530	666
	September	483	594	2907	1106	612
	October	1511	779	1404	3236	653
	November	896	1873	1380	1776	1965
	December	1118	955	909	2218	917
	January	1119	1817	731	2492	2240
	February	533	999	50	996	884
	March	1398	1062	708	2210	762
	April	334	701	649	663	681
	May	311	952	2246	492	1322
	June	954	361	4372	1364	744
	Total Pod Yield (kg/ha)	11237	10929	20114	20052	11732
	Total Dry Bean Yield (t/ha)	**1.12**	**1.09**	**2.01**	**2.01**	**1.17**
2004–05	July	1503	640	3980	2417	757
	August	3316	790	3521	6343	666
	September	2507	1226	1267	3077	1190
	October	5925	638	2257	5956	376
	November	1576	777	1630	1045	638
	December	958	1651	739	949	1349
	January	127	1518	95	112	1289
	February	191	1860	14	147	1210
	March	1515	2267	695	1325	1962

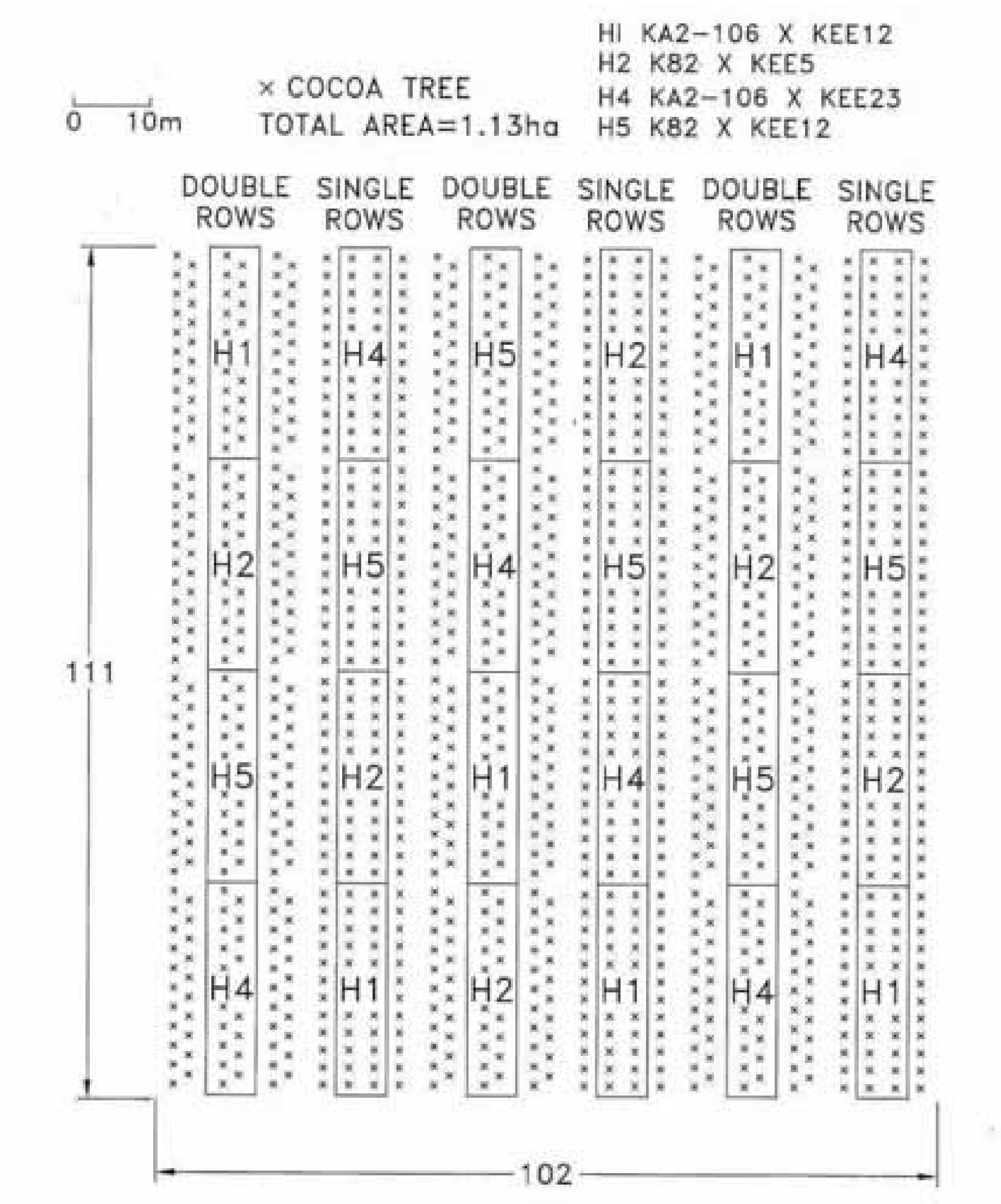
Hybrid 5		Double Rows			Single Rows	
		Pod Yield (kg/ha)			Pod Yield (kg/ha)	
		Mossman	**Darwin**	**South J**	**Mossman**	**Darwin**
	April	1777	1024	1099	953	1072
	May	4055	1241	1225	3146	1040
	June	2513	1060	2133	2419	1454
	Total Pod Yield (kg/ha)	25963	14693	18657	27890	13002
	Total Dry Bean Yield (t/ha)	**2.60**	**1.47**	**1.87**	**2.79**	**1.30**
2005–06	July	2655		1666	3797	
	August	4008		645	5182	
	September	3459		1891	3669	
	October	2853		2933	2578	
	November	2531		3088	1294	
	December	344	3101	1160	204	3077
	January	50	1241		22	1595
	February	0	1861		0	1481
	March	0			0	
	April	0	1108		0	1114
	May	283	554		371	557
	June	349	554		457	557
	Total Pod Yield (kg/ha)	16532	8418	11384	17573	8380
	Total Dry Bean Yield (t/ha)	**1.65**	**0.84**	**1.14**	**1.76**	**0.84**
2006–07	July	1045			1059	
	August	765			1635	
	September	1969			2920	
	October	3169			5515	
	November	1111	No	No	1090	
	December	186	Data	Data	151	
	January	164	Collected	Collected	63	
	February	27			22	
	March	197			262	
	April	1107			1369	
	May	2437			2080	
	June	2281			2056	
	Total Pod Yield (kg/ha)	14459	0	0	18220	0
	Total Dry Bean Yield (t/ha)	**1.45**	**0.00**	**0.00**	**1.82**	**0.00**

A2 Hybrid yield evaluation trial layouts

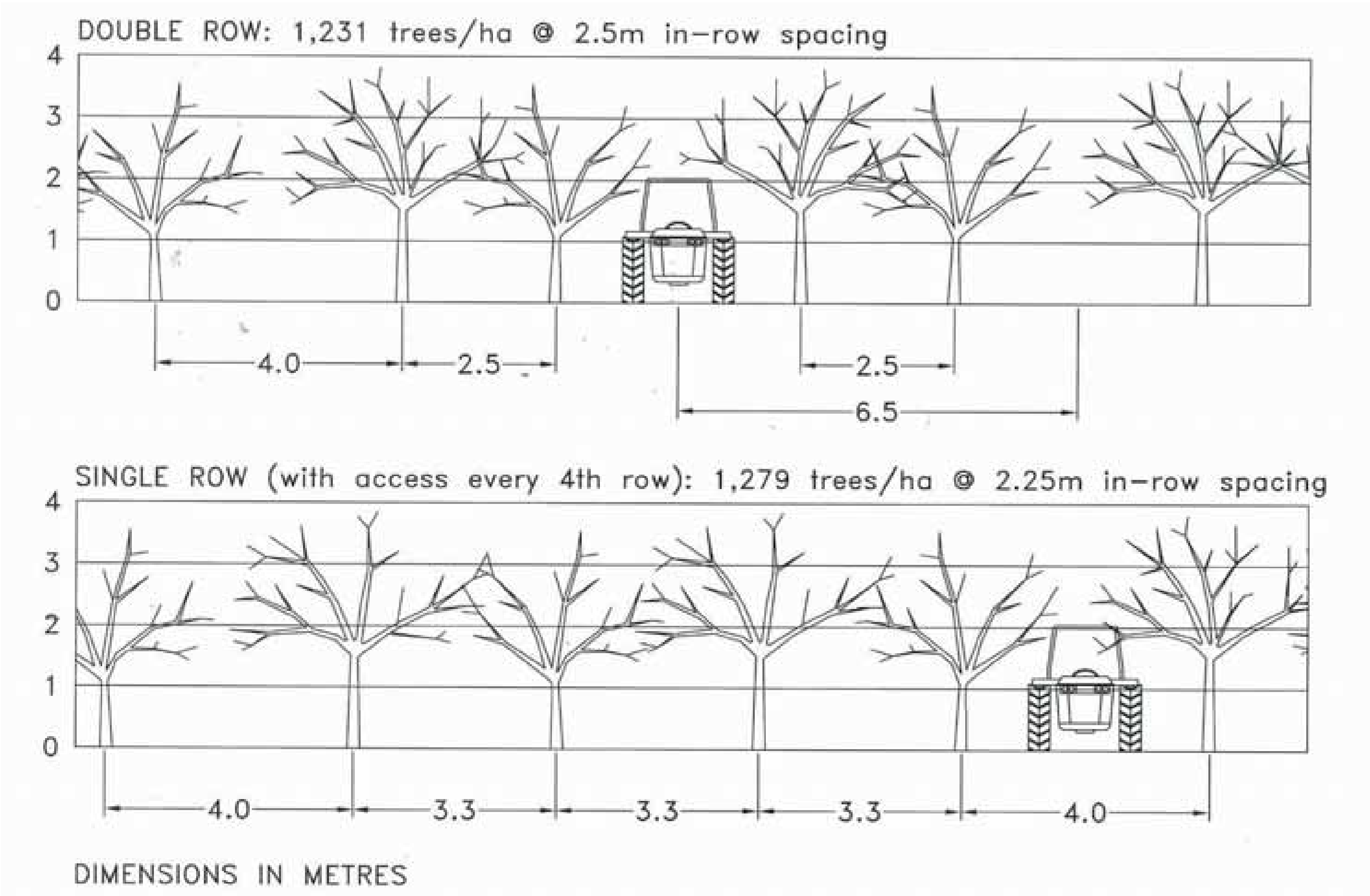
A2.1 Mossman HYET block and planting layout



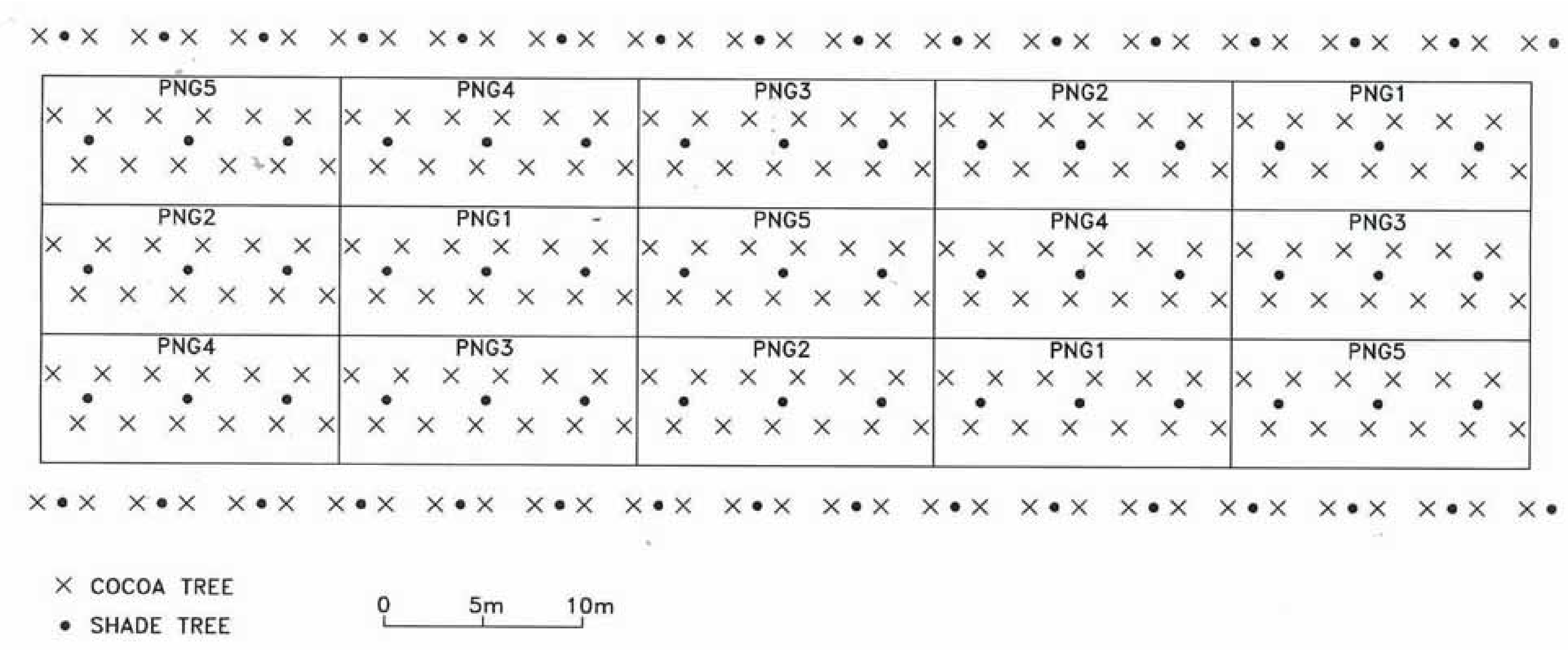
A2.2 CPHRF (Darwin) HYET layout



A2.3 Mossman and CPHRF HYET row cross sections



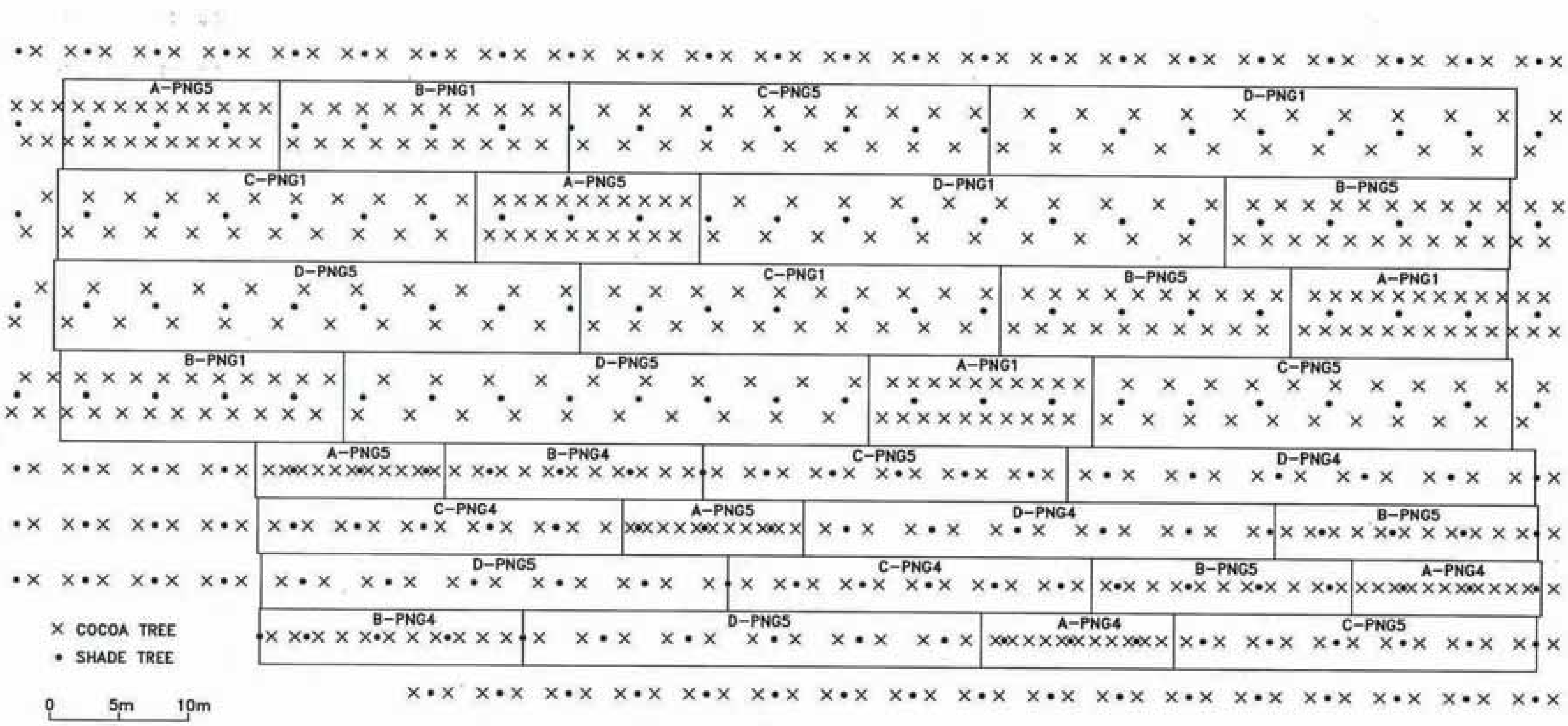
A2.4 South Johnstone 'mini' HYET block and planting layout



A3 Farming Systems Trial block and planting layout

Double rows: A = 2,051, B = 1,538, C = 1,026, D = 810 trees/ha

Single rows: A = 2,083, B = 1,471, C = 1,042, D = 806 trees/ha



A4 Climate data for Port Douglas and South Johnstone

A4.1 Mean Monthly Maximum Temperature

South Johnstone

T max °C

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						22.5	24.3	25.7	27.8	28.5	30.1	29.2	26.9
2001	30.5	29.2	31.0	28.4	27.4	24.8	24.7	25.7	27.7	29.5	31.0	32.8	28.5
2002	32.4	32.6	30.5	28.6	27.2	25.2	24.3	24.9	27.7	29.6	30.0	31.7	28.7
2003	30.8	31.8	29.9	29.2	26.3	25.3	24.2	25.8	28.0	30.0	30.5	31.1	28.5
2004	32.1	31.7	30.0	27.7	26.9	24.9	24.7	26.1	26.7	29.5	30.3	31.1	28.5
2005	30.4	32.5	30.5	28.0	26.4	25.4	24.3	24.0	27.5	30.2	31.2	32.7	28.6
2006	31.4	31.6	29.5	28.9	26.0	24.1	23.8	25.3	26.1	27.3	29.9	29.7	27.8
2007	31.0	29.7	30.3	28.3	27.5	22.7							28.3
Mean	31.2	31.3	30.2	28.4	26.8	24.4	24.3	25.4	27.4	29.2	30.4	31.2	28.3

Port Douglas

T max °C

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						24.4	25.5	26.5	29.2	30.4	30.7	29.5	28.0
2001	31.1	29.5	31.1	29.2	28.3	26.6	26.6	27.3	29.2	30.8	32.3	33.5	29.6
2002	33.0	33.1	31.7	30.0	28.3	26.8	26.1	27.0	29.0	31.0	32.0	32.5	30.0
2003	31.7	32.1	30.6	30.0	27.7	26.6	25.8	27.0	29.1	31.0	32.0	32.5	29.7
2004	32.5	31.4	30.2	28.3	27.8	25.7	25.7	27.0	28.3	30.1	31.2	31.3	29.1
2005	30.6	32.3	30.9	28.9	27.3	26.2	25.5	25.6	28.2	31.1	32.1	33.6	29.3
2006	31.4	32.1	30.1	28.8	27.0	25.6	25.2	26.2	27.6	28.6	31.2	31.1	28.7
2007	32.2	30.1	31.0	28.9	28.3	24.5							29.2
Mean	31.8	31.5	30.8	29.2	27.8	25.8	25.8	26.6	28.6	30.4	31.6	32.0	29.3

A4.2 Mean Monthly Minimum Temperature

South Johnstone

T min °C

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						16.1	13.5	15.4	17.3	21.0	21.9	22.3	18.2
2001	22.3	23.2	22.5	21.5	15.3	19.0	14.2	15.0	18.0	19.8	22.4	23.4	19.7
2002	23.6	24.0	21.4	20.4	18.4	15.8	14.7	15.7	16.4	18.5	20.1	22.6	19.3
2003	21.9	23.5	22.0	20.4	18.3	18.0	17.1	16.5	16.1	20.0	20.4	23.1	19.8
2004	23.6	23.7	22.2	21.5	19.4	15.6	15.5	13.6	17.3	19.4	21.7	22.8	19.7
2005	23.3	23.3	22.6	21.3	17.3	19.0	16.6	16.9	17.6	20.5	21.6	22.5	20.2
2006	23.2	23.1	23.3	22.9	20.5	18.1	16.2	14.6	17.2	18.3	20.4	22.1	20.0
2007	23.6	23.1	22.9	20.0	20.2	16.6							21.1
Mean	23.1	23.4	22.4	21.1	18.5	17.3	15.4	15.4	17.1	19.6	21.2	22.7	19.7

Port Douglas

T min °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						18.5	15.9	17.7	19.7	22.5	23.3	23.3	20.1
2001	23.7	23.8	23.6	22.7	18.3	20.6	17.0	17.6	20.5	21.5	23.9	24.9	21.5
2002	24.8	25.4	23.4	22.0	20.0	19.0	17.7	17.8	18.7	21.3	22.6	24.5	21.4
2003	23.8	24.8	23.8	22.3	20.3	19.9	18.8	19.1	18.9	22.0	22.7	24.7	21.7
2004	24.9	25.0	23.5	22.6	21.6	18.6	18.1	16.5	20.0	21.2	23.2	24.3	21.6
2005	24.5	24.9	24.2	22.7	20.0	20.5	18.8	18.5	19.6	22.6	23.5	24.6	22.0
2006	24.4	24.5	24.2	23.7	21.9	19.9	18.4	17.3	19.3	20.3	22.1	23.8	21.6
2007	24.6	24.0	23.9	21.9	21.9	19.0							22.6
Mean	24.4	24.6	23.8	22.6	20.6	19.5	17.8	17.8	19.5	21.6	23.0	24.3	21.6

A4.3 Mean Monthly Rainfall

South Johnstone

Monthly Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000						136.0	41.6	144.5	25.9	190.6	808.2	424.7	1771
2001	243.7	839.8	312.0	31.1	36.9	223.9	39.5	37.1	69.4	154.0	103.7	113.1	2204
2002	218.1	380.5	321.0	381.5	342.1	18.8	53.8	84.0	27.8	0.6	38.1	101.9	1968
2003	212.6	169.4	260.0	497.0	289.5	152.2	133.0	81.0	13.9	24.7	10.8	490.8	2334
2004	324.2	587.0	936.7	517.5	155.5	97.8	96.7	7.1	79.2	41.2	256.4	352.1	3451
2005	464.4	96.1	572.5	381.3	72.1	168.7	231.9	338.1	14.5	54.9	15.7	139.4	2549
2006	493.5	230.4	1048.5	457.0	220.1	306.9	171.8	12.7	138.8	106.3	16.1	313.8	3515
2007	299.4	1063.2	421.4	145.3	411.9	155.3							2496

Port Douglas

Monthly Rain (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000						28.4	4.8	72.5	8.8	59.5	346.5	495.2	1017
2001	226.9	791.8	129.8	181.7	4.4	70.1	8	9.4	20.4	90.5	109.1	47.1	1689
2002	114.1	256.6	80.5	113.3	80.6	4.6	6.8	28.1	8.1	0	25.1	107	824
2003	165.6	195.3	224.3	235	84.1	41.4	43.6	18.6	5.4	11.3	18.5	234.3	1277
2004	305	663.1	1129.7	161.1	49.6	24.1	35.9	9.1	8.6	25.1	99.8	286.3	2797
2005	500.4	109.4	378.9	182.2	24.8	39	67.5	74.4	4	13.6	29.4	54.3	1477
2006	361.5	246.1	631.9	741.3	48.1	101	45.7	15.3	82.7	68.6	26	99.1	2467
2007	214.3	713.9	198.6	75.2	150.3	67							1419

A4.4 Mean Monthly Evaporation

South Johnstone

Monthly Evaporation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000						95.0	113.2	133.2	169.0	171.0	156.0	146.0	983
2001	175.2	128.4	171.0	141.0	137.8	111.4	121.6	145.2	165.0	188.6	194.6	199.0	1878
2002	193.2	154.6	185.6	151.0	134.2	119.6	121.2	133.2	179.0	217.4	225.2	215.0	2029
2003	179.2	153.4	168.0	151.2	130.8	104.6	133.8	132.4	179.4	201.0	219.6	186.2	1939
2004	178.6	158.0	158.4	136.8	118.4	114.8	115.4	149.4	159.4	198.2	202.2	182.0	1871
2005	166.2	179.2	161.4	146.4	118.4	91.6	124.2	117.8	156.6	190.2	201.8	223.6	1877
2006	166.8	167.8	147.6	110.8	104.0	109.4	109.2	147.2	167.2	197.6	205.6	191.4	1824
2007	173.0	133.2	160.6	150.2	130.2	83.0							830

Port Douglas

Monthly Evaporation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2000						108.8	134.8	145.8	190.6	186.8	167.6	140.4	1074
2001	185	124.4	165.8	143.2	150.8	120.4	144.8	165.2	183.6	201.4	211.8	208.6	2005
2002	197	162.2	199.2	162.4	147	143.2	147.2	159.8	192.4	241	255.8	221.4	2228
2003	199.2	164.4	177.2	159.4	141.4	116.8	149.2	146.6	200.8	217.6	248.4	203.4	2124
2004	189.2	159.6	156.8	138.8	135.6	132.8	139	165.8	199.4	212	220	188.2	2037
2005	167.8	189	178	155.8	135.8	111	142.2	141.6	177.6	214.2	231.4	249.8	2094
2006	166.8	181.2	161	116.2	122.2	126.6	119.4	167.4	186.2	221.4	230.2	209.4	2008
2007	192.8	138.6	169.4	162.4	145.4	99.8							908

A4.5 Mean Daily Radiation

South Johnstone

Mean Radiation (MJ/m^2/day)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						12.2	16.9	18.8	21.5	21.1	19.5	16.5	18.1
2001	21.3	15.2	19.9	16.1	18.5	12.9	17.4	19.6	21.2	24.0	22.9	24.3	19.5
2002	22.8	19.2	20.5	16.8	16.7	15.9	16.0	17.3	22.6	25.1	24.3	23.2	20.0
2003	19.3	19.9	18.6	18.4	15.2	14.5	14.5	17.9	23.0	23.3	24.2	21.4	19.2
2004	21.6	18.4	18.0	15.3	14.6	15.6	15.7	20.6	20.6	24.4	23.2	21.9	19.2
2005	20.0	23.4	17.6	16.8	16.5	13.0	15.1	16.6	21.4	22.7	23.2	24.3	19.2
2006	19.9	21.7	15.6	13.6	12.4	12.5	14.5	19.7	20.4	22.2	23.8	20.6	18.1
2007	19.2	16.6	18.5	17.7	14.4	11.2							16.3

Port Douglas

Mean Daily Radn (MJ/m^2/day)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						13.7	17.2	19.8	22.0	22.1	20.7	17.9	19.0
2001	21.6	16.2	20.5	17.5	18.8	14.7	18.2	19.9	21.9	24.1	23.8	24.6	20.2
2002	23.4	20.5	21.1	17.8	17.6	16.4	16.6	18.1	23.1	25.2	24.9	23.1	20.7
2003	20.8	21.0	19.1	18.8	16.7	15.4	15.6	18.5	22.9	23.6	24.7	22.6	20.0
2004	22.2	18.8	18.1	16.4	16.0	15.8	16.8	20.9	21.2	24.7	23.8	22.6	19.8
2005	19.8	23.5	18.0	17.3	17.2	14.4	15.9	17.9	21.7	23.6	24.6	24.7	19.9
2006	19.4	22.9	17.2	14.3	13.6	14.1	15.7	20.2	21.6	23.5	24.8	22.1	19.1
2007	20.0	17.4	19.8	18.8	15.2	13.0							17.4

A4.6 Mean Relative Humidity at Maximum Temperature

South Johnstone

Mean RH @ Tmax

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						67.4	54.6	58.4	54.9	62.8	64.2	67.1	61.3
2001	63.0	72.4	63.2	66.8	53.7	69.0	57.5	55.4	58.5	57.2	58.0	57.5	60.9
2002	59.8	62.2	61.6	64.5	62.9	56.3	58.3	62.4	52.8	51.9	52.6	57.8	58.6
2003	61.0	63.5	65.7	63.2	66.7	67.2	64.3	61.2	52.2	55.3	53.3	64.5	61.5
2004	62.4	65.7	67.1	68.6	66.2	58.5	62.8	52.7	57.4	56.8	58.6	62.9	61.6
2005	67.6	60.4	66.4	68.0	64.1	69.1	66.7	67.2	60.2	60.4	58.3	57.2	63.8
2006	65.0	64.0	71.7	71.4	69.7	67.3	65.6	55.8	60.8	59.0	58.7	64.5	64.5
2007	66.3	70.7	66.7	64.0	67.8	70.0							67.5

Port Douglas

Mean RH @ Tmax

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2000						60.1	50.2	54.1	48.8	54.4	61.2	65.1	56.3
2001	59.6	70.8	62.0	62.9	48.8	61.5	47.8	48.3	52.1	51.7	53.3	54.3	56.0
2002	56.4	58.5	54.9	57.3	58.1	50.6	50.2	52.4	48.3	46.0	46.1	55.1	52.8
2003	56.3	60.5	60.8	58.9	59.6	61.9	57.1	55.7	47.5	50.9	47.2	58.3	56.2
2004	59.9	66.0	65.7	66.4	61.8	54.5	57.9	47.7	50.6	53.2	54.1	61.1	58.2
2005	67.1	59.9	63.0	63.7	58.6	65.6	60.7	59.4	54.9	55.1	53.9	53.6	59.6
2006	64.9	61.6	69.4	72.4	66.3	63.2	60.5	52.1	55.3	53.9	53.8	59.4	61.1
2007	60.9	69.6	63.9	61.2	64.1	64.7							64.0

A5 Results of fat analyses by Claremont Analytical Laboratories (Cadbury – Tasmania)

A5.1 Samples and Analytical Methods

Request For Analysis Report

Scientific Services
Claremont Analytical Laboratory

No: 2002-163CL DATE 19/12/2002

REQUESTED BY: J. ASTON CC: QAM, ASM, FILE

SAMPLE	LAB NO.	ANALYSIS	RESULT	METHOD	ANALYST
COCOA BEANS					
A) Mossman - Sundried	891600038724	FAME	See attached	A-97-080	CY
		Triglyceride profile	See attached	A-97-079	CY
		SFC	See attached	A-95-051	PJM
B) Mossman - Dryer	891600038725	FAME	See attached	A-97-080	CY
		Triglyceride profile	See attached	A-97-079	CY
		SFC	See attached	A-95-051	PJM
C) South Johnstone - Dryer	891600038726	FAME	See attached	A-97-080	CY
		Triglyceride profile	See attached	A-97-079	CY
		SFC	See attached	A-95-051	PJM

COMMENTS:

Sample request date: 13/11/02. All samples are analysed between the date of request and the report date. All samples are analysed 'as received'. This document should not be reproduced except in full.

Authorisation: Scott Huxley

Title: Analytical Services Manager

Document No: SS018
Date of Issue: Nov '02

A5.2 FAME and Triglyceride Profiles – Mossman (dryer) cocoa

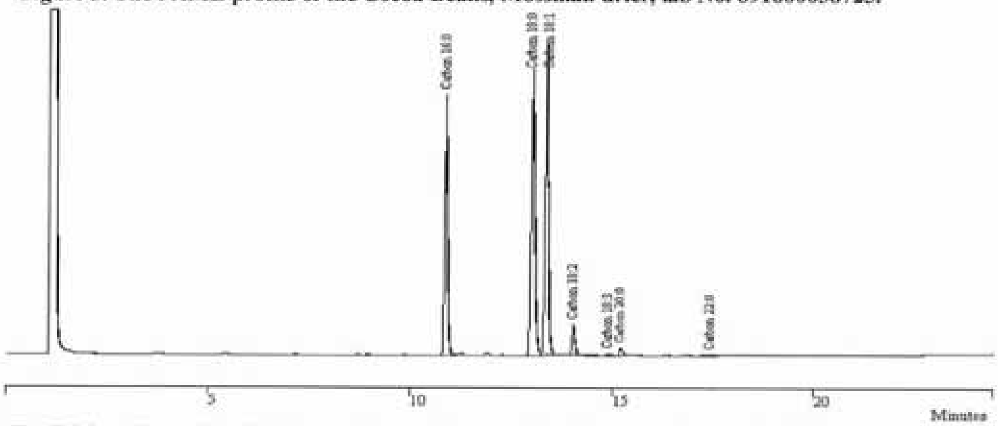
Request For Analysis Report

Technical Department
Claremont Analytical Laboratory

No: 2002-163CL **DATE 19/12/2002**

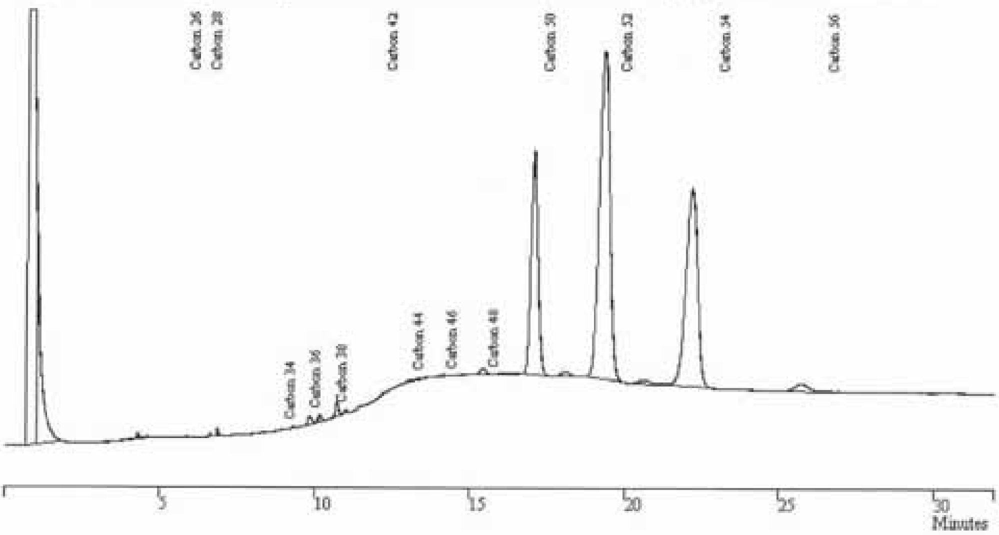
The FAME profile of the Cocoa Beans, Mossman drier, lab number 891600038725 is illustrated in the chromatogram below(figure 3) and summary table 1.

Figure 3. The FAME profile of the Cocoa Beans, Mossman drier, lab No. 891600038725.



The Triglyceride profile of the Cocoa Beans Mossman drier, lab number 891600038725 is illustrated in the chromatogram below(figure 4) and summary table 2.

Figure 4. The Triglyceride profile of the Cocoa Beans, Mossman dryer, lab No. 891600038725.



Authorisation: ____________

A5.3 FAME and Triglyceride Profiles – South Johnstone cocoa

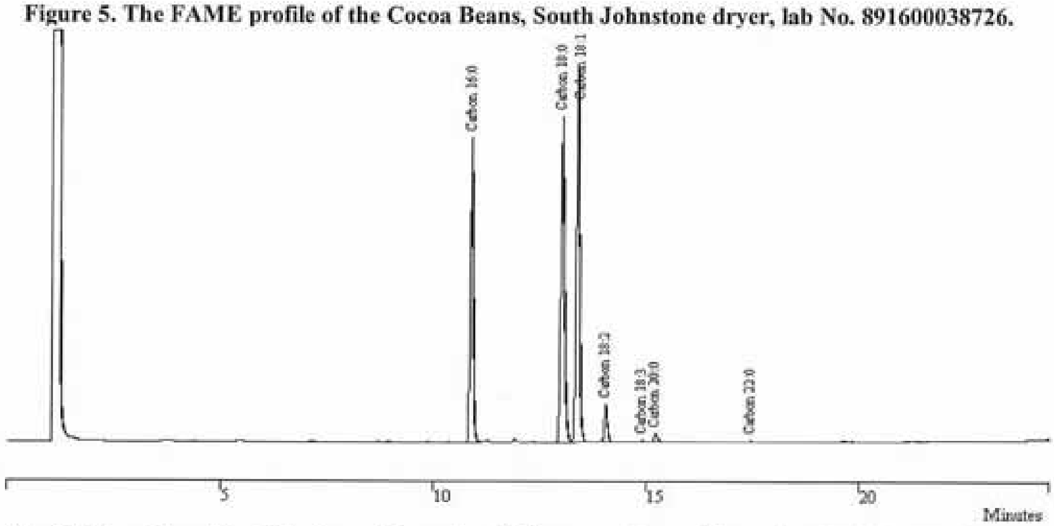
Request For Analysis Report

Scientific Services
Claremont Analytical Laboratory

No: 2002-163CL **DATE 19/12/2002**

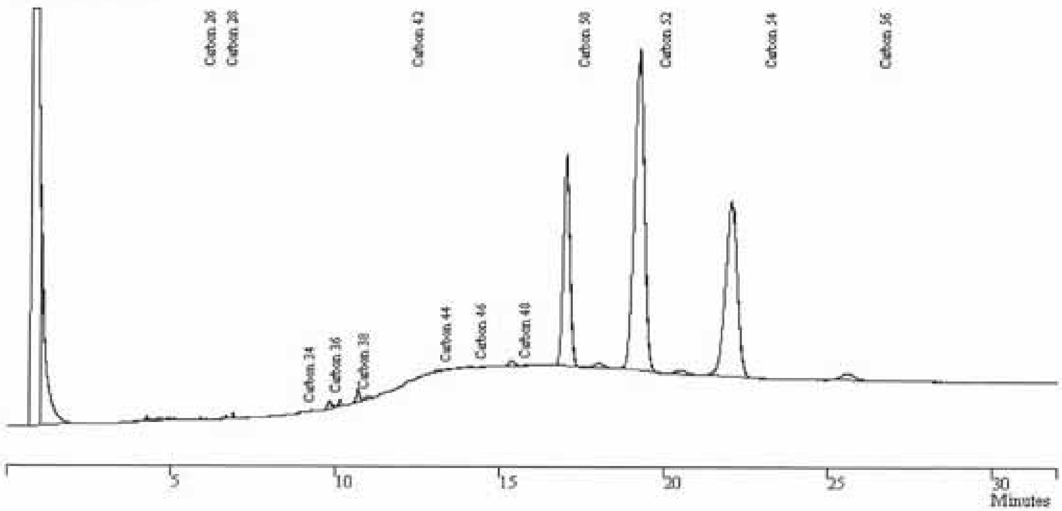
The FAME profile of the Cocoa Beans, South Johnstone - Dryer, lab number 891600038726 is illustrated in the chromatogram below(figure 5) and summary table 1.

Figure 5. The FAME profile of the Cocoa Beans, South Johnstone dryer, lab No. 891600038726.



The Triglyceride profile of the Cocoa Beans, South Johnstone - Dryer, lab number 891600038726 is illustrated in the chromatogram below(figure 6) and summary table 2.

Figure 6. The Triglyceride profile of the Cocoa Beans, South Johnstone dryer, lab No. 891600038726.



Authorisation: ______________

A5.4 FAME and Triglyceride Profiles – Mossman (sundried) cocoa

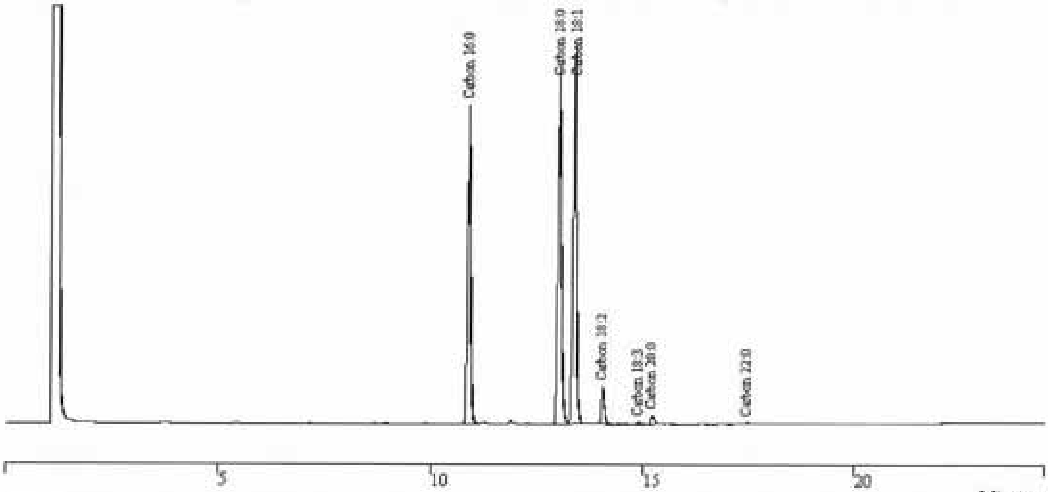
Request For Analysis Report

Scientific Services
Claremont Analytical Laboratory

No: 2002-163CL **DATE 19/12/2002**

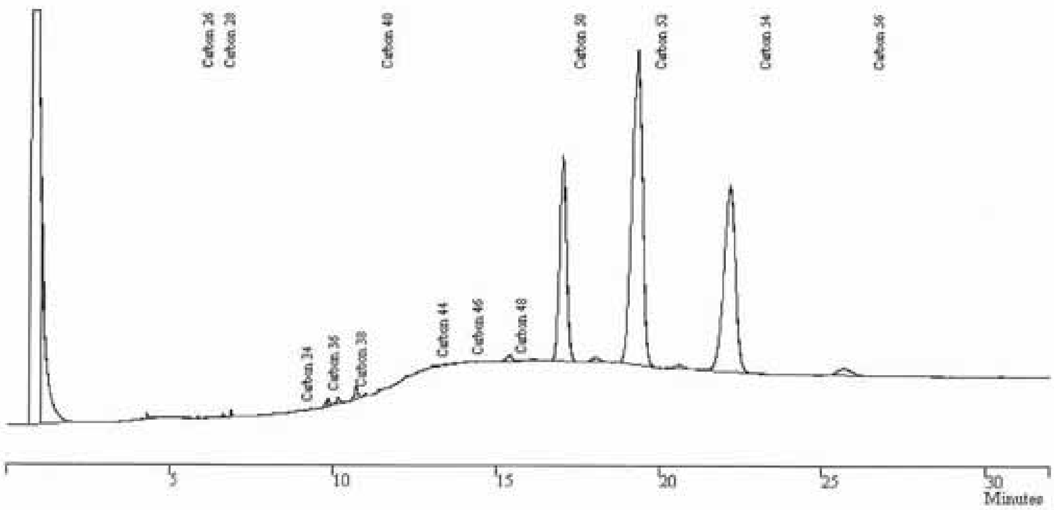
The FAME profile of the Cocoa Beans, Mossman sundried, lab number 891600038724 is illustrated in the chromatogram below(figure 1) and summary table 1.

Figure 1. The FAME profile of the Cocoa Beans, Mossman sundried, lab No. 891600038724.



The Triglyceride profile of the Cocoa Beans Mossman sundried, lab number 891600038724 is illustrated in the chromatogram below(figure 2) and summary table 2.

Figure 2. The Triglyceride profile of the Cocoa Beans, Mossman sundried, lab No. 891600038724.



Authorisation: ____________

A5.5 FAT Melting Profiles Mossman and South Johnstone cocoa

Request For Analysis Report

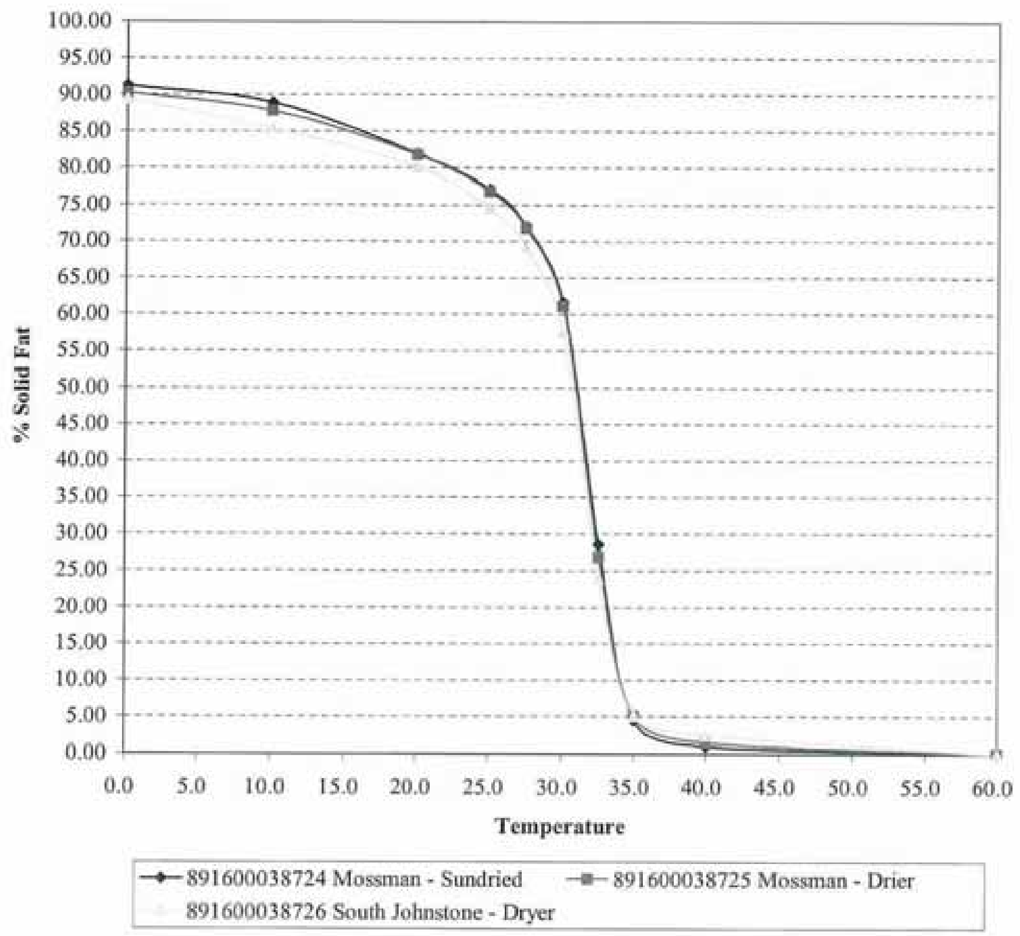
Scientific Services
Claremont Analytical Laboratory

No: 2002-163CL **DATE** **19/12/2002**

SOLID-FAT CONTENT

OUR LAB NO.	SAMPLE DESCRIPTION	TEMPERATURE (CELSIUS) 0.0	10.0	20.0	25.0	27.5	30.0	32.5	35.0	40.0	60.0
891600038724	Mossman - Sundried	91.21	88.88	81.96	77.09	72.01	61.62	28.51	4.51	1.01	0.00
891600038725	Mossman - Drier	90.20	87.76	81.82	76.75	71.73	61.06	26.81	5.09	1.53	0.00
891600038726	South Johnstone - Dryer	89.34	85.37	80.16	74.54	69.24	57.55	23.90	5.07	2.53	0.00

FAT Melting Profile



Authorisation: ____

A6 Trip Report – Cocoa Study Tour, Malaysia-Singapore, 10–15 June 1998

Yan Diczbalis, Senior Horticulturist (NTDPIF), Craig Lemin, Engineer (DPIQ), Nick Richards (AgWA)

Executive summary

Background and purpose of trip

At the request of Cadbury Schweppes Pty. Ltd. (CS), the three state agriculture agencies with research interests in tropical Australia (Agriculture Western Australia (AgWA), Northern Territory Department of Primary Industry and Fisheries (NTDPIF), Queensland Department of Primary Industries (QDPI)) were asked to consider the feasibility of cocoa production in northern Australia. This was in response to concerns by CS about world cocoa supplies. The predicted scenario within the next five years is that world consumption (3,260 t) will exceed supply (2,973 t) and that cocoa stocks will be almost exhausted. This may cause a price rise from £1,190 per tonne currently to about £3,200 per tonne. CS believe that cocoa production may be viable in northern Australia given production problems in Africa, decreasing production from Malaysia and Indonesia and increasing demand for cocoa products (chocolate).

At a meeting convened in Darwin (March 1998), a steering committee was formed to develop a feasibility project plan for presentation to the group. The steering committee comprised:

- Mr Yan Diczbalis, Senior Horticulturalist, NTDPIF
- Mr Craig Lemin, Senior Agricultural Engineer, QDPI
- Mr Nick Richards, Horticultural Development Officer, AgWA

Members of the steering committee undertook a tour of cocoa plantations in Malaysia during June 1998 with funding from CS ($5,000) and RIRDC ($5,000). Initial plans to visit cocoa plantations in the Medan region of Indonesia were abandoned due to civil unrest. Alternatively, contacts in the Tawau region of Sabah (Malaysia) were arranged by Mr Tan Kim Khiang, Operations Manager, MacRobertson Foods Pte. Ltd., Singapore (a subsidiary of CS).

Objectives of trip

1. Investigate cocoa farming systems and production technology on best-practice plantations including:

- significance of clone-based propagation versus hybrid seed planting
- production management practices (propagation, planting, layouts, shade usage, pest and disease management, nutrition, canopy management, irrigation)
- labour requirements and organisation
- mechanisation developments
- harvesting
- post harvest processing (pod splitting and bean extraction, fermentation and drying)
- costs and returns of production
- quality issues.

2. Gain an overview of cocoa (dry) bean processing.

Benefits expected

Information gathered on the trip would be used directly for development of the feasibility project plan to be presented to the working group (August 1998). This plan would directly influence a decision on advancement of a project proposal to investigate cocoa production in northern Australia. If viable, cocoa provides opportunities for new crop development and import replacement.

Itinerary

Date	Day	Location	Activity	Host
10-6	Wed	Kuala Lumpur → Tawau	AM: Malaysian Agricultural Research & Development Institute for meetings with researchers and visit to publications library PM: travel	Dr Abd Shukor Rahman – Director, Horticulture Research Centre, Malaysian Agricultural Research and Development Institute (MARDI) Dr Abd Razak Shaari – Assistant Director, Horticulture Research Centre, MARDI Dr Izham Ahmad – Assistant Director, Horticulture Research Centre, MARDI Dr Chan Ying Kwok – Assistant Director, Horticulture Research Centre, MARDI
11-6	Thur	Tawau	AM: Majulah Koko Plantation (Teck Guan Holdings Sdn. Bhd.) for tour of fermentary, nursery and estate PM: Cacao Paramount Sdn. Bhd. for tour of cocoa processing factory	Mrs Florence Hong – General Manager (Marketing Dept.), Teck Guan Perdana Bhd. Mr Hong Ngit Ming – Deputy Managing Director, Teck Guan Perdana Bhd.
12-6	Fri	Tawau	AM: Quion Hill Research Station for meetings with cocoa researchers PM: Goodstock Plantation (Commerstar Corporation Sdn. Bhd.) for tour of fermentary	Mr Chris Ngor – Director, Commerstar Corporation Sdn. Bhd. Mr Lee Yu Man – Principal Research Officer, Quion Hill Agriculture Research Station (QHRS) Mr Chong Tan Chun – Cocoa Research Officer, QHRS
13-6	Sat	Tawau → Singapore	Travel	
14-6	Sun	Singapore	Cocoa project planning meeting	
15-6	Mon	Singapore → Darwin	AM: MacRobertson Foods Pte. Ltd. for tour of cocoa processing factory PM: travel	Mr Kim Khiang Tan – Operations Manager, MacRobertson Foods Pte. Ltd.

Cocoa Farming Systems and Production Technology (Tawau region of Sabah, Malaysia)

Introduction

- Malaysian cocoa production has been eroded over recent years due to substitution of large areas with oil palm, reduced availability of labour and increased labour costs.
- Oil palm margins are currently very good (net returns of RM$300 /t are possible) and this combined with its low input requirements has encouraged large-scale plantings.
- There was some interest in the potential for planting oil palm in Australia given suitable climate and land availability. Soil pH of 4.5 to 5.5 is acceptable. In Malaysia/Indonesia the area required to justify a mill is about 10,000 ha.
- Malaysian cocoa is inferior in quality to West African sources (Ghana in particular) but has improved significantly over the last decade (attributed to improved fermentation procedures) and is superior to most Indonesian cocoa (usually unfermented).
- The majority of cocoa plantation labourers are Indonesian or Philippine nationals (e.g. 100% on Teck Guan's plantations). Recently, the Malaysian government has levied a tax on foreign workers of about MR$2,500 per year (paid by employers) which has impacted significantly on profitability of cocoa production. Sourcing labour is becoming more of a problem, however the situation is easier than in peninsular Malaysia.
- On average the labour requirement for cocoa is 1 person per 5 acres compared to 1 person per 50 acres for oil palm.
- Currently, the move out of cocoa has probably stabilised due to increased prices and the perceived benefit of remaining diversified. However, the Asian currency crisis has increased pressure on cocoa margins since the costs of imported fertilisers and chemicals have rapidly escalated.
- Recently cocoa production costs have risen from MR$3,200 /t to MR$5,000 /t. The current price is £1,003 /t dry bean.
- Tawau is a highly regarded region for cocoa production since it has good climate and well-drained volcanic soils. Tawau (land below the wind) is outside the typhoon belt. At QHRS annual rainfall of 2,500 mm is evenly distributed throughout the year and minimum temperatures are about 19^{o}C.
- Cocoa was first planted in the Tawau region circa 1957. Production peaked in 1989/90 and has since declined to around 100,000 t (principally due to substitution with oil palm). Because of the even rainfall distribution, irrigation is not necessary. However, prior to our visit, the region had just emerged from an unprecedented 6-month drought that resulted in yield reductions of up to 50%.
- Historically, cocoa production has been dominated by large estates (approximately 90%) however, prolonged depressed prices has seen a shift to more smallholder-based production (now estimated at 50%). It is still common for the large estates to buy dried bean from smallholders for marketing.
- In Malaysia, smallholder plantings range from a few to several hectares, which is more than in other cocoa producing countries. Also, large estate style plantings are only common in Malaysia and Indonesia.
- Most of the industry development work carried out by the Department of Agriculture (DoA) is aimed at smallholder producers. However, DoA has recently cut operational budgets by 50% and this has affected cocoa research and development programs. At QHRS research priorities are shifting away from cocoa to avocado, durian, papaya and pineapple.
- Cupuacu is planted on a Dept. of Agriculture Research Station in Sabah and is undergoing some evaluation.

Yields and propagation

- The original industry moved from seedling production to hybrid seed production with the DoA conducting significant breeding work.
- In the early 1990s the large estates began using clonal material i.e. grafting high yielding budwood onto rootstock.
- Clonal cocoa had a superior yield performance over hybrid cocoa (up 3.5 t/ha dry bean) although the clone-environment interaction needs to be considered when making selections.
- Advantages of clones include:
    - 30% higher yield plateau
    - less variability in tree to tree yields
    - less variability in season to season yields
    - less vigorous growth and reduced pruning requirements
- Cloned trees are earlier establishing and achieve good productivity faster. Typically peak production is reached after 5 years and continues until 8 years. Significant yield declines occur after 12 years.
- Use of hybrid seed is now very limited with most growers (including smallholders) using a mixture of QHRS and commercial clones such as PBC 123, BR 25, BAL 209 and KKM 25.
- Principal clones at Teck Guan:
    - PBC 123 (Prang Bazer Clone)
    - BR 25 (Baron River)
    - TG 1,2 (estate selections)
- QHRS currently has 5 clones recommended for release: QH 326, 968, 1003, 1176 and 1287. All have medium to high levels of Vascular Streak Dieback (VSD) tolerance. Selection is also based on a minimum butter fat content of 53% and a minimum bean size of 1 g.
- For new trees side-grafting is now commonly used on young seedlings (generally less than 3 months of age and sometimes as young as 3 weeks), achieving up to 90% success rates and bearing at 18 months. Older trees are top worked using a side-cleft graft.
- At Teck Guan production is typically 1,500 t from 400 ha i.e. 3.7 t/ha (in the range 4.9 to 2.5 t/ha)
- Researchers at QHRS quoted general industry yield figures as follows:
    - 2.5 t/ha is a good average commercial yield
    - 3.7 t/ha was possible with good management
    - 4.9 t/ha can be achieved under the best conditions
    - 1.2 t/ha is also common
- The yields of smallholder producers are usually lower than those achieved on the estates. In smallholder plantings, yields typically range from 1 to 2 t/ha however yields as low as 0.5 t/ha can occur.
- LonSum Plantation (Medan) supplies material throughout Indonesia. Currently their preferred clones are GC 29, UF 11, UF 191, PA 4,310, BL 703 and IML 49. Selection criteria:
    - yield > 1.5 t/ha
    - bean size > 1 g

- butter fat > 55%
- shell content < 12%
- acceptable growth without excessive vigour
- good tolerance to VSD, Blackpod and hopefully Cocoa Pod Borer (CPB)

Planting arrangement and shading

- On the plantations we visited, cocoa was planted in rows and divided into blocks. Though not necessarily physically distinguishable, blocks were assigned to individual workers. There was no apparent hilling, contour planting or terracing.
- A network of access roads (suitable for tractors or 4WD) linked all areas of the farm to the fermentary.
- Most large commercial estates in Sabah have moved to zero shade for productive trees although some remnant forest trees are common in plantations (these are systematically being felled for burning in dryer furnaces).
- At Teck Guan, cocoa trees are established under shade (predominantly *Gliricidia* spp.) where shade treed densities start at 3.0 x 3.0 m and are progressively reduced so that by year 3 all shade has been removed.
- Shade is still considered necessary for establishing trees and is recommended by the Dept. of Agriculture with progressive thinning after canopy establishment. The final shade density recommended was 40 x 40 m (6.25 trees/ha). QHRS researchers also felt that the shaded plantations were less adversely effected during the recent drought.
- Most of the cocoa was planted on hillsides including in gullies and on road batters/cuttings (only very steep slopes were avoided). This rough terrain and the presence of large logs within plantations would currently hinder any attempts at mechanisation in many areas.
- Plant density trials at QHRS have showed that densities beyond 1,300 plants/ha did not demonstrate yield benefits. Current recommendation is a square planting at 3.05 x 3.05 m (10 x 10 ft) giving 1,076 plants/ha.
- At Teck Guan typical plant spacing is 1.83 m (6 ft) with rows spaced at 3.66 m (12 ft) giving 1,496 plants/ha. There was also some double row plantings with trees in each double row on a triangular layout at 2 x 2 m and with 6 m between double rows (centre to centre) giving 1,667 plants/ha.
- LonSum Plantation (Medan) experimented with high density plantings but experienced no yield advantage at densities ranging from 816 to 1,633 plants/ha. Currently a 3.6 x 3.0 m layout giving 926 plants/ha is used.

Pruning

- The labour required for pruning is potentially a serious impediment to viable cocoa production in Australia.
- QHRS researchers commented that pruning should be a continual process conducted throughout the year with small pieces, particularly uppermost tips of branches requiring regular removal.
- Trees are pruned to prevent cross-over of laterals from tress in neighbouring rows. This prevents complete closure of the canopy and allows light into the under-story.
- Pruning is also carried out to limit tree height to 3 to 3.5 m.
- The growth habit of cocoa is poorly suited to mechanical ‘hedging’ or pruning ‘on the face’ with a mass of branch development resulting from pruning in this way.
- The row spacing and growth habit of trees on plantations visited did not permit vehicular access and all operations within the plantation were carried out manually.

Pests and diseases

- Cocoa Pod Borer (CPB) can be a major problem and has been responsible for the demise of cocoa production in some regions. Currently commercial control is maintained by a schedule of manual spraying requiring 2 applications per month. Synthetic pyrethroid resistance has been experienced (now using a product named ‘505’ but active ingredient not ascertained).
- Control of CPB utilising a predator wasp was not successful due to failure of the wasp larvae to remain sufficiently active in the field. The cost of larvae breeding and release programs proved prohibitive.
- There were no other major pests reported other than sometimes having to control leaf eating insects.
- Disease is generally not a problem in the Tawau region.
- Blackpod (*Phytophthora* spp.) is present but is only of minor significance and this is attributed to growing on hill slopes (well drained soils) and the even rainfall distribution.
- VSD (*Oncobasidium theobomae*) is a fungal disease and generally only common when clones with reduced VSD tolerance are grown in higher rainfall areas.

Harvesting and pod splitting

- After harvesting (throughout the year) pods are usually left in the field in heaps of several hundred pods for 3 to 6 days (12 days is preferred).
- Splitting and bean extraction is carried out manually and workers receive payment based on kg of wet bean. In this way pods are returned directly to the field, which recycles nutrients (but also provides good breeding sites for mosquitoes).
- Typical payment for harvested (wet) bean is MR$0.12 /kg and workers can harvest and extract about 100 kg per day (payments are increased if the terrain is difficult or the yield is low).
- The estate managers were aware of mechanical pod splitting technology but could provide no details.

Fermentation, drying and marketing

- Most fermentation is carried out on a 5 day basis with 1 turn on day 3.
- Shallow wooden boxes are used for fermentation with a capacity of about 400 kg wet bean (1.2 x 1.2 x 0.5 m). Deeper (1 m) boxes are also used (800 kg) however altered conditions for fermentation in these boxes may have implications for quality.
- Temperature during fermentation is not monitored (but felt to be about 45^{o}C).
- Netting bean in boxes facilitates turning using a crane or forklift and is more common when beans are turned daily.
- Covering fermenting beans with hessian bags is recommended but not generally practiced.
- Forced hot air drying to 7.5 to 8.5% moisture content dry basis (mcdb) occurs over 1.5 to 3 days. Under-drying will result in mould development, over-drying causes splitting and breakage of nibs (7.5% mcdb preferred for storage).
- The drying facilities were basic and comprised masonry block beds with a plenum beneath steel perforated flooring. Forced air @ 50^{o}C is delivered to the plenum from wood fired furnaces with no heat exchanger (beans can acquire ‘smoked’ flavours if wood burning is not efficient). The depth of cocoa on the bed was approximately 100 to 200 mm (though this may

vary depending on dryer demand). Air flowrates were low and regular stirring (manual) is necessary to avoid uneven drying and moulds.

- After drying some basic grading equipment was used for separation of small and broken beans and bean clusters (beans stuck together with dried placental material). Inclined rotary trommels or vibrating screens are used.
- Dry bean is bagged into 62 kg jute sacks for shipping and export.
- Before shipment samples are kept for cross reference and various quality assessments are conducted including:
  - beans per 100 g
  - weight of 100 beans
  - proportion impurities by weight
  - number of germinated beans
  - insect infestation
  - maximum 3% beans with internal moulds
  - maximum 25% beans under-fermented (nib colour)
  - ensure minimum 65% beans fully fermented (nib colour)
  - ensure 7.5 to 8.5% mcdb.
- At Teck Guan (average production 1,500 t dry bean per year) the drying capacity was 50 t wet bean (20 t dry) every 3 days utilising 5 beds (capacity of 10 t wet bean each) or 2,400 t dry bean per year. An experimental solar collector was installed (with Canadian technical input) but was not judged successful as the drying air temperature achieved was only 40^{o}C.
- At Goodstock the drying capacity was 800 t wet bean per month (300 t dry) or 3,600 t dry bean per year. Significant quantities of fermented bean were purchased from smallholders for drying and marketing.
- LonSum Plantation (Medan – Nick Richards): Bean is pressed prior to fermentation with the aim of removing excess acidic juices partially responsible for nib acidity. Drying is in 2 stages – initially for 8 h @ 60^{o}C in a circular dryer with mechanical stirring and finally in a rotary dryer for 8 to 12 h @ 60 to 70^{o}C (both kerosene fired). Cadbury-Sime process was implemented (*viz* pod storage after harvest; 5-day fermentation with infrequent turning; longer, 2 stage drying with the final stage using forced ambient air) and whilst bean quality and flavour was improved no price benefit was received for the extra cost and management inputs.

Labour

- Labour accounts for about 65% of cocoa production costs.
- Although large estates have dominated production in Sabah, cocoa is not as suited to plantation style management practices as other traditional plantation crops (e.g. coffee, tea and oil palm).
- On the estates we visited, labour was organised on the basis of assigning particular blocks to individuals or groups of individuals. Whilst cultural management decisions are carried out at the farm level, the various work tasks are carried out on each block by the individual stakeholders.
- Workers are paid on the basis of bean harvested (per kg) and this provides incentive for them to manage their blocks for maximum yield.

- At the time of our visit, workers were being paid about 12 sens/kg wet bean (6 cents) with most workers capable of harvesting 100 kg per day. Payments are increased where the terrain is difficult or the yield is seasonally low.
- A typical labour requirement of 1 person per 5 ha provides the basis for block sizes (reduced to 4 ha in steep locations).
- The Teck Guan estates totalled about 8,100 ha at several sites (typically 400 ha each). Commerstar Corporation had only 400 ha total in 2 estates (considered small) but also owned estates in peninsular Malaysia.

Cocoa (dry bean) processing

A simplified flowchart for cocoa bean processing is given below.

Currently there is excess cocoa processing capacity in the Asian region and cocoa processing appears to be a non-profitable or marginal operation. A key factor in cocoa processing is the cocoa bean to cocoa butter ratio (= 2.3: 1) and this has implications for the relative prices of cocoa beans, powder and butter. Currently, cocoa powder is trading below cost in terms of equivalent raw beans and therefore cocoa butter prices must be greater than 2.3 times the cost of raw beans for processing operations to even begin to be profitable.

Cacao Paramount Sdn. Bhd. (Teck Guan Holdings Sdn. Bhd., Tawau) processes about 20,000 t bean per year. Production is 39% cocoa butter and 42% cocoa powder (balance cocoa liquor). Construction for factory expansion is currently on hold due to low profitability of the operation.

MacRobertson Foods Pte. Ltd. (wholly owned subsidiary of CS, Singapore) processes about 16,000 t bean per annum mainly for distribution to CS chocolate factories in Australia (principally), China and South Africa. This operation appeared to be very efficiently run with highly developed product monitoring procedures. It is also being run at full capacity (24 hour, 7 day per week operation).

Simplified process at MacRobertson Foods Pty. Ltd.:

RECEIVAL
(Cocoa Beans)

SAMPLING AND QUALITY ANALYSIS

CLEANING
(removal of foreign matter)

PRE DRYING
(shell separation)

WINNOWING
(shell removal)

STORAGE
(Nibs)

STERILISATION
(steam treatment)

AKILISATION PROCESS
(raw or 'dutched' (alkalised) depending on product requirements)

DRYING/ROASTING
(heated @ 50^{o}C)

GRINDING

STORAGE
(Cocoa Liquor)

BUTTER PRESS

PACKAGING
(1 t block)

Cocoa Powder
(naturalised/alkalised)

GRINDING
(removes cocoa flavour)

PACKAGING
(25 kg bags)

Cocoa Butter

DEODORIZING

PACKAGING
(1 t blocks)

SHIPPING

Photographs

Mature cocoa (no shade), Majulah Koko Plantation, Tawau district, Sabah.

Almost mature cocoa pods on tree (main crop already harvested).

Harvested cocoa pods waiting splitting and bean extraction.

Split cocoa pod showing cocoa beans and mucilage.

Cocoa beans in fermentation boxes (800 kg approx).

Cocoa bean (cotyledon) in early stage of fermentation.

Cocoa beans being dried after fermentation.

Cocoa butter press, Teck Guan Perdana Bhd, Tawau, Sabah.

Publications obtained

- Mechanised Agriculture. Proceedings National Conference on Mechanised Agriculture, 25–7 May 1993. MARDI.
  Contains articles on mechanised cocoa pod breaking and cocoa seed separation.
- Biological Control in Malaysia: Insects and other pests. MARDI.
  Contains several references to biological control of pests in cocoa.
- Teknologi KOKO-KELAPA (Technology of Cocoa and Coconut).
  a. Vol 1, 1985
  b. Vol 4, 1988
  c. Vol 7, 1991
  d. Vol 8, 1992
  e. Vol 9, 1993
  f. Vol 10,11, 1994/95
     Contains a range of articles relevant to cocoa production.
- Teknologi Makanan. MARDI.
  Contains an article on cocoa fermentation.
- Rehabilitation of Mature Cocoa (Side-cleft grafting method). DoA, Sabah, Malaysia.
- Cocoa – Food of the God. Teck Guan Perdana Bhd.
  A history of chocolate and a description of cocoa growing on Teck Guan plantations.
- MacRobertson Premium Quality Cocoa Products – Product Specifications
  Brief description of the MacRobertson cocoa processing plant and product specifications.

A7 Trip Report – Cadbury Schweppes Asia Pacific Cocoa Meeting, Singapore-Indonesia, 23–24 February 2006

Craig Lemin, Engineer (DPIQ).

Participants

Alan Cook	Group Cocoa, UK
Annette Debono	S&T, Australia
Chandran Gopal	Supply Chain, AsiaPac
Tony Lass	Ethical Sourcing Consultant, UK
Graeme Leith	S&T, NZ
Craig Lemin	DPI&F, Australia
KP Magudapathy	Cocoa, India
Kevin McKie	PBS, AsiaPac
Ian Mitchell	S&T, Australia
Ellen Ong	S&T, AsiaPac
Dave Peters	S&T, Group, UK
David Preece	Group Cocoa, UK
Esther Quah	PA to KK Tan, AsiaPac
KK Tan	Group Cocoa, AsiaPac

Agenda

Day 1, Thursday, 23rd February 2006
Session 1
08.00 Cocoa Industry in Perspective

- Introductions followed by Overview of Global Cocoa Industry (20mins, D Preece)
- Commercial Overview (60mins, A Cook)
- What are the problems faced by the Global Cocoa Industry (20mins, D Preece)
- Bean 2 Bar (30mins, D Peters)
- Ethical Sourcing (20mins, T Lass)

10.30 Break (30mins)

Session 2
11.00 CS Current Activities

- India: Cocoa Requirements/Processing (30mins, KP Magudapathy)
- MacRobertson – Cocoa Quality/Processing/Projected volume increase +5yr (60mins, E Ong/C Gopal)

12.30 Lunch (60mins)

Session 3
13.30 Large Scale Cocoa Production

- Large Scale Cocoa Production Review (30mins, T Lass)
- India: Cocoa Production (30mins, KP Magudapathy)
- Australia: Cocoa Production (30mins, C Lemin & I, Mitchell)
- Discussion and conclusions (30mins, All)

15.30 Break (30mins)

Session 4
16.00 Cocoa Strategy for AsiaPac

- Options for flavour modification of poor quality beans (20mins, D Peters)
- SE Asia production trends/Current Strategy and Issues (40mins, KK Tan & A Cook)
- Discussion and conclusions (30mins, All)

Session 5
17.30 Gap Analysis

- Gap Analysis (60mins, All)

18.30 Meeting Conclusions and Wrap-up

- Conclusions and outcomes from meeting (30mins, D, Preece)

Evening: Group Dinner

Day 2, Friday, 24th February 2006

- All Day Field Trip to Cocoa Plantation, Sumatra (All)

Field Trip Notes

Bahiling Cocoa Estate, Tebing Tingii via Medan, Sumatra

- Estate owned by Asian Agri who also has palm oil (150,000 ha, 26 plantations, 16 mills) and rubber (7,000 ha, 2 factories).
- The cocoa estate (850 ha, 1 fermentary) is a relatively minor operation.
- 2005 yield was 600 t (i.e. average of 0.7 t/ha).
- Provided quality specifications are met, all production is sold to Cadbury (MacRobertsons, Singapore).
- Plan is to remove 200 ha next year and convert to oil palm – therefore they are currently reducing maintenance on some areas. Ultimately all the cocoa may go but this was not confirmed.
- Cocoa pod borer causing significant yield losses – predominantly use non-chemical control i.e. hanging ant nests – ants swarming over pods discourage moths laying eggs; also try to remove all pods when completing harvesting (even if immature).
- Planting density was 1,000 trees/ha (in one area I stepped out a spacing of 4 x 2.5 m but someone else claimed it was 3.3 x 3.3 m).
- Gliricidia used as shade (I stepped out a spacing of 16 x 10 = 63 trees/ha). Claim that it was initially planted 360 trees/ha then thinned to 20–30% of original density (72 to 108 trees/ha).
- Cropping cycle: Jan-Mar light cropping
Mar-Apr small peak
May-Oct trough
Nov-Dec main crop
- Pruning: chupon/adventitious growth @ once/month
canopy @ 3x/year
- Mixture of hybrids and clonal material – some good areas yielding 2 t/ha are all clones ex Golden Hope.
- Harvesting during the peak crop requires 1 man/1.5 ha/day (excluding pod opening).
- Presumably harvesting is done every 2 to 3 weeks though not confirmed.
- Weed control requires 2 man/ha/day (which seems a bit high) – not sure of the frequency.
- Fertiliser is applied at the rate of 300N, 500P, 200K g/tree/year.
- The basic wage is 25,000 Rupiah/day (prevailing exchange rate ~ AUS$1 = R7,050).
- A working day is 8 hrs which includes a half hour lunch break.
- Pods are opened the day of harvesting or the day after.
- Wet bean is hydraulically pressed in perforated stainless steel vessels (they said this was done overnight but in peak times I think it would be less because of capacity constraints i.e. there was only one press and each vessel held approximately 200 to 300 kg wet bean).
- Idea of pressing is to try and reduce acidity but they acknowledged it didn't really work. Why did they continue to do it? It was suggested that it is because it reduced the moisture content and so reduced the drying requirement? I would think that the moisture content at the end point of fermentation would be similar regardless if the beans were pressed or not?
- Pressed beans are fermented in batches in slatted wooden compartments (approximate dimensions were 2 x 2 x 0.6 m = 2.4 m^3

- Nets are used to line the compartments and are lifted by overhead gantry. It was said that the beans are turned daily by transferring beans from one compartment to another. Fermentation was for 5 to 7 days depending on who was telling you. This implies either 4 or 6 turns if in fact they are transferred daily.
- The whole fermentary was bunded with runoff drained to a holding tank. There was no particular treatment to the collected liquid – it was simply pumped out every 3 to 4 weeks (depending on throughput) and sprayed back into the field.
- Drying was mechanical (appeared to be gas-fired). Initially for 8 hrs in an 11 t rotary dryer with constant mechanical stirring with inlet air temperature of 60 to 70^{o}C (this seems hot and may have been the thermostat setting in the plenum after the burner?). Secondary drum dryer of 8 t capacity then used (100 ^{o}C).
- After drying the beans were transferred directly to bulk bins which ran on rails and were in turn emptied into a floor hopper feeding an inclined conveyor.
- Material was conveyed to a grading trommel with 5 outlets:

  1st stage was slatted bars to separate 'residues' (presumably sticks/husk etc.)

  2nd stage was perforated drum (~ 20 mm diameter) to separate 'doubles'

  3rd stage was perforated drum (~ 12 mm diameter) to separate 'Grade A'

  4th stage was perforated drum (~8 mm diameter) to separate 'Grade B'

  material passing through the 4th stage drum was additional 'residues'

- Beans were then bagged (~60 kg hessian) for storage in a separate building for dispatch (presumably there was some tested and quality checking also).
- Double beans and clusters were put out on a cement sun-drying area for further drying (weather dependent as this region experiences year-round rainfall).
- Don't know if the doubles/clusters were subsequently separated (either mechanically or by hand).

Pt. Agrikom Indonusa Abadi, Medan, Sumatra

- Brief visit to a warehouse in Medan – owner buys smallholder produced cocoa and resells after drying and grading. Also trades in other commodities (rubber, palm oil and coffee).
- Saw basic flat bed dryers where cocoa that is not properly dried is finished off (gas fired).
- Otherwise beans are just graded and bagged – there was a large flat-bed sieve type grader being used and a recently purchased densometric grader (not yet commissioned).
- Otherwise there were just lots of stacks of cocoa in bags.
- Sometimes the stacks are fumigated and some of the Cadbury people were interested in the maximum size of stack it was possible to fumigate (by covering with plastic).
- We looked at some of the beans in an open bag which the owner described as 'FAQ'. Appeared to be a mixture of bean sizes (despite being graded) and a range of colour in beans including some rather dark looking beans.
- The aroma of the sample was quite ordinary and not strong.

A8 Trip Report – Barry Callebaut (cocoa manufacturers), Louviers, France, 14 January 2005

Yan Diczbalis, Senior Horticulturist, Department of Primary Industries & Fisheries, Centre for Wet Tropics Agriculture.

Background

In December 2004 an opportunity arose to request a visit to the cocoa manufacturing facilities of Barry Callebaut in France. This opportunity was realised on 14 January while on leave in Europe.

Barry Callebaut, one of the three largest manufacturers of Cocoa products in the world with 26 processing facilities, is an amalgamation of the French company Cacao Barry and the Belgian company Callebaut. The company's main cocoa bean processing facility is located on the outskirts of Louviers, approximately 150 km north-west of Paris.

The visit was facilitated by Mr Philippe Troplin, Manager Semi-finished Product Research and Development following a visit to north Queensland in December 2004. Mr Troplin was interested in cocoa developments in north Queensland.

Barry Callebaut company profile

Barry Callebaut (BC) and their parent companies have been producing cocoa and chocolate products for more than 150 years. They are a fully integrated company involved in every step from the sourcing of cocoa beans to the shelf. They serve the entire food industry, including industrial food manufacturers, professional users and retailers. Barry Callebaut has strong traditional roots in Europe and was formed in 1996 when Belgian chocolate producer *Callebaut* and *Cacao Barry* of France joined forces. The company is headquartered in Switzerland and listed on the SWX Swiss Exchange.

They are the world's leading manufacturer of high-quality cocoa and chocolate products. The company has a global network with about 30 state-of-the-art production sites and some 9,000 employees in 22 countries in Europe, Africa, North and Latin America and Asia/Pacific.

The company processes 13% of the world's cocoa bean crop from countries such as Ivory Coast, Cameroon, Brazil and Ghana. BC have more than 1,650 cocoa and chocolate recipes. Their expertise, together with their focus on innovation and R&D, enables them to cater to many different customer needs and to respond to the varying consumer preferences throughout the world.

Products and applications (from Barry Callebaut's web site, www.barry-callebaut.com)

BC's main business is the production of base materials for the manufacture of chocolate. Chocolate is the result of mixing ingredients such as cocoa liquor, cocoa butter, milk powder and sugar in specific proportions. They produce a range of products in three broad categories;

1. Standard products

Barry Callebaut offers a huge standard range of chocolate couvertures for the chocolate, ice cream, biscuit, dairy or other food industries.

2. Tailor-made products

The R&D team of Barry Callebaut can develop customised recipes, adapted to personal requirements regarding taste, raw materials, technical specifications and composition.

3. Special chocolate products

- Origin chocolate
  Barry Callebaut offers unique origin chocolates that are created with cocoa beans from specific regions. Each origin chocolate has a unique flavor, characterised by the cocoa from that particular region. It has a character of its own, which may differ from crop to crop. In a way it is somewhat similar to the differences one finds in vintage wine of different years. Like wine, the amount of origin chocolate that is produced will differ between years, depending on the cocoa harvest and on the available cocoa supply on the world market. Current origin chocolate available for couverture use are Cuban, Tanzanian, PNG, Madagascar, Java, and Saint Dominican.

- Bake-stable chocolate
  Barry Callebaut offers chocolate and compounds, in various shapes and sizes, which through their heat resistance are especially suitable for dough preparations and baking. They are also ideally suited to use in the finishing and decorating of confectionery, pastry and ice cream creations.

- Chocolate powder
  Barry Callebaut's chocolate powder assortment combines the properties of real chocolate, cocoa liquor and cocoa butter with the advantages of a powder ingredient: easy dosing and melting, increased mix-ability, improved productivity. Applications include desserts, drinks, fillings, ice cream, etc. In addition to the chocolate powders that are used as an ingredient, a ready-to-use mix for chocolate mousse is also available.

- Flavoured chocolate
  Barry Callebaut offers a choice of flavoured chocolate, with an outstanding coffee, cappuccino or caramel taste. They are suitable for incorporating in fillings for pralines or pastries, ganaches, bavarois, etc.

- Fairtrade chocolate
  Barry Callebaut has been certified by the Fairtrade Labelling Organizations (FLO) to produce a range of Fairtrade cocoa and chocolate products. These products are manufactured with raw materials that have been purchased from Fairtrade manufacturers who have been recognised by the FLO. Barry Callebaut's Fairtrade cocoa and chocolate products are manufactured according to the same recipes and in the same way as traditional cocoa and chocolate products. Moreover, Barry Callebaut guarantees a particularly delicious flavor, excellent and consistent quality and perfect processability for all these products.

- Ambao chocolate
  The Ambao label was developed by the Belgian government in order to promote chocolate without added vegetable fats other than cocoa butter. It also includes additional quality criteria to ensure high quality chocolate. More than 200 standard recipes are certified Ambao. Customer specific Ambao recipes can be tailor-made.

- 100% taste, 100% well-being
  More and more consumers want to enjoy something delicious which is also good for them. That is why Barry Callebaut has created a brand new and unique range of chocolate and chocolate products that meet both criteria.

Day tour agenda

8.30 am – Picked up from Hostel in Paris by taxi and driven to the factory at Louviers.

10.15 am – Met at factory by Mr Philippe Toplin (Product & Development, Responsible R&D Semi-Product) introduction to colleagues Mr Guy Raybaud (R&D Semi Finished & Chocolate products) and Ms Frederique Renauld (Inbound Logistics).

10.30 am – Present a PowerPoint presentation on North Australian Cocoa Development Association activities. The presentation covered why the project was initiated, how it was undertaken, current progress and where to next.

11.45 am – Tour of laboratory and cocoa mass testing and taste facilities.

12.45 am – Lunch in factory canteen.

2.00 pm – Factory tour. Tour of bean receivable, cocoa mass, cocoa powder and cocoa butter manufacturing areas. Tour of separate origin dry bean processing and storage facilities.

3.45 pm – Wrap up and thank you.

4.00 pm – Depart for Paris by taxi.

5.30 pm – Arrive in Paris.

Laboratory and factory statistics

- Employs 265 people
- Operates 24 hours/day 363 days per year with two days (Christmas and New Year) of closure
- Full laboratory facilities to examine the quality of dry cocoa beans including testing for
    - cocoa mass colour, flavour and quality
    - cocoa butter melting temperature and rate of crystallisation
    - examine make up of competitor products and produce chocolates to specific recipes
    - taste panel facilities
    - pathology facilities
    - test cocoa batch manufacturing capability (from several kilograms to one or two tonne lots.
- Processes 92,000 t of dry bean per annum, highest processing capacity reached weas 96,000 t of dry bean/annum.
- Raw products received for processing include:
    - whole dry bean (bulk tipper trucks containing 20 to 30 t) from bulk storage facilities in Amsterdam and Rouen
    - de-shelled bean (saves 11–12% on transport costs) bulk bags (1 to 2 t) from West African processing facilities
    - bulk cocoa mass and cocoa butter (1 t blocks) from West African processing facilities to be further processed sand purified
    - origin bean
- Products produced include:
    - cocoa mass
    - cocoa butter
    - cocoa powder
    - origin cocoa mass and butter
    - organic cocoa mass and butter
    - Considerable room for expansion of processing capacity.

Issues raised via discussions with Barry Callebaut Staff

- BC is extremely interested in adding to their lines of origin chocolate. They have expressed specific interest in any potential production from Australia.
- BC believes that ‘origin’ and ‘organic’ range of chocolate products has the biggest growth potential.
- They are prepared to deal with dry bean quantities as low as 100 to 200 t per annum.

- BC currently pay from £100 to £700 pound sterling above the current world price (£900) for origin cocoa beans. Specific examples given were;
    - Madagascar – £100–250 premium per t
    - Java – £600–700 premium per t
- BC has a specific interest in cocoa material based on Trinitario and Criollo genetic material, particularly bean which has ‘light breaking qualities’. Criollo beans represent approximately 5% of the world’s production while Trinitario beans, a hybrid between Criollo and Forastero types, represent 10 to 15% of production. The bulk of cocoa is produced from Forastero types.
- Minimum cocoa bean requirements for BC are:
    - Shell content 10 to 11%. Higher shell percentages impact strongly on yield of cocoa mass and hence the economics of production
    - Fat content of 54.5% preferred
    - Looking for cocoa beans that are acidic with fruity aromatic notes and free of bitterness.
    - Low or no heavy metals, in particular cadmium. Volcanic soils can be high in cadmium.
    - Prefer ‘sun dried’ beans which are free of fuel oil and smoke flavours
    - Cocoa bean should ideally be bagged in well aerated jute or sisal bags. Avoid bagging material made of hydrocarbons, e.g. plastics, as plastics can effect the flavour of beans and plastic debris are extremely difficult to deal with during processing.
- BC suggest that ‘tracability’ and quality assurance (QA) should be a key component of the development of a new industry in Australia. This is required to meet the factories stringent HACCP system.
- BC is keen to purchase 1.0 t or more of current Australian production. They are interested in comparing the quality of material grown in north Queensland (separate sites) and the NT
- In the interim BC have requested that we send them 1 to 2 kg samples of dried bean for initial quality grading and characterisation of cocoa butter
- BC are also interested in obtaining from northern Australia:
    - sequential sampling of beans at 24 hour stages during fermentation from zero to seven days. They suspect that we may be over fermenting beans even after removal at 5 days
    - a 1.0 kg sample of ‘wet bean’ preferably frozen and send by courier in an insulated container.

Proposed actions

1. DPI&F horticulture staff involved with the cocoa project should maintain contact with Barry Callebaut.

2. We discuss the ‘pros and cons’ of meeting BC’s request for trial product. I suggest that it’s in our interest to get feedback on the quality of our current genetic material as soon as possible.

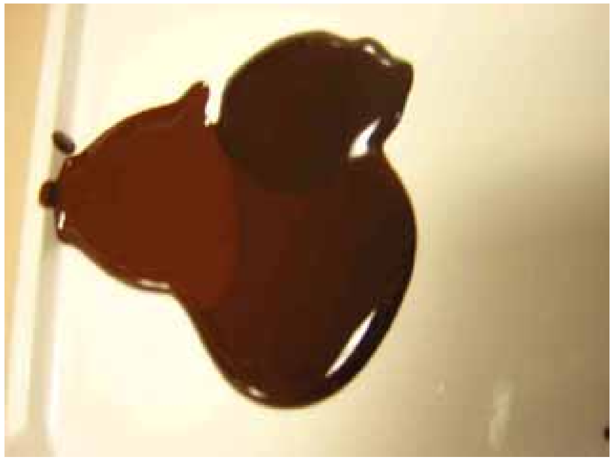
3. We consider inviting a representative of BC to the public meeting scheduled for March/April 2006 to discuss future project support.

Phototour – Barry Callebaut, Louviers, France

1. Administration building

2. Laboratory

3. Laboratory



4. Taste testing cocoa liquor

5. Various liquors

6. Colour difference between origin liquors

7. Tasting evaluation facilities

8. Bulk dry cocoa bean delivery

9. Origin dry cocoa bean delivery (jute bags)

10. Metal removal

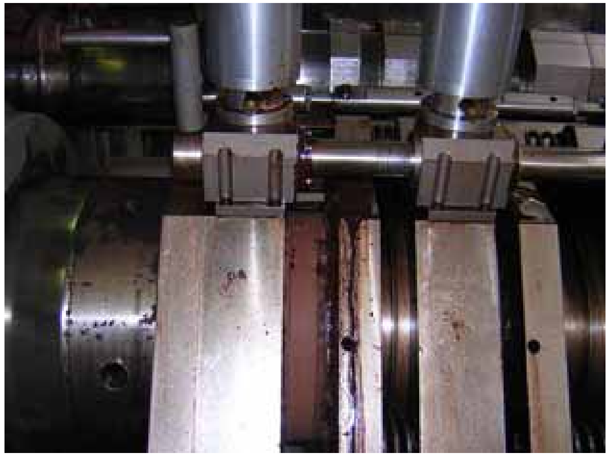
11. Bean density separator to remove non-metallic debris

12. Roasting oven

13. Cocoa mass press to produce butter and powder

14. Screen size 75um

15. Press plate with holes to allow butter removal



16. Press opening to release cocoa powder

17. Cocoa butter purification plant

18. Cocoa butter storage

19. Bulk transport of cocoa butter and cocoa mass

20. Bulk transport of cocoa powder

21. Storage area for origin products

22. View of factory

Producing Cocoa in Northern Australia

RIRDC Publication No. 09/092

By Yan Diczbalis, Craig Lemin, Nick Richards and Chris Wicks

This report documents the implementation and outcomes of an eight-year study which investigated the feasibility of cocoa production in northern Australia.

The study was in response to an approach in 1998 by Cadbury who were subsequently a major supporter of the project.

The study included cocoa growing trials in three northern Australian growing regions, investigations of mechanisation opportunities and a clonal introduction program.

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