Coconut Production

Present Status and Priorities for Research

Alan H. Green, editor
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Alan H. Green, editor

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ABSTRACT

The coconut is primarily a smallholders' crop with a recorded history of cultivation going back for more than 3,000 years and now thriving throughout the humid tropics. Every part of the palm is utilized and it is an important component of intercropping and multi-storey cropping systems. The purpose of this paper is to introduce the coconut crop to non-specialists, discuss the constraints to increased productivity, the current status of research, and the priorities for further research in a number of disciplines.

The basis of every improvement in crop productivity is good quality planting material and this results from long-term breeding programs aimed at genetic improvement followed by efficient propagation. The development of precocious, high-yielding hybrids, and seedgarden techniques to mass-produce them, has greatly increased the yield potential of current planting material. Nevertheless, as a result of the long breeding cycle, very few generations have been achieved, and coconut breeding is still in its infancy. The current state of genetic conservation and breeding techniques and results are described. The constraints mentioned above in part explain the long-sustained attempts to obtain vegetative propagation. The status of this research is discussed in a paper which described both embryo and tissue culture.

Agronomic research, like breeding, is very time-consuming, and even the responses of mature palms take several years to fully measure. The same problem constrains the transfer of technology to smallholders, who can rarely afford the delayed returns to better inputs, even though very significant yield increases can be achieved which are economically viable. Nevertheless, a number of inexpensive techniques are available which can improve yield or value through modified practices. Much of the current knowledge of agronomy refers to research on traditional tall palms. Insufficient is known of the different needs of hybrids, and this aspect requires accelerated research.

Many diseases plague the coconut palm. Some are relatively trivial but several are lethal. Of the latter, the casual organisms of some of the most important remain to be unequivocally demonstrated. In most cases the utilization of natural or genetically engineered resistance is the only probable solution.

The coconut palm suffers less from pests and biological control of rhinoceros beetle, the most serious in many areas, is well developed. However, some significant problems remain to be overcome, particularly pests which attack the inflorescence and immature nuts.

The ultimate fate of the senile palm is to be removed to make way for its more productive successor. The development of techniques to fully utilize the vast timber potential of this renewable resource provides the potential of both a significant income for the coconut farmer and an alternative to the utilization of tropical rain forest species. The milling and utilization of coconut wood is described in the final chapter.
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The World Bank has forecast that coconut oil prices will continue to be low over the coming decade, as will those of other vegetable oils. Furthermore, the possibility of a decline in the exportable surplus of the Philippines, which exports 75% of the coconut oil in world trade, has cast doubt on the future availability of supplies. This risk may inhibit investment in industrial processes based on coconut oil feedstock. There is an urgent need to increase both the efficiency of coconut production - to improve farm incomes, and the output - to promote confidence in the availability of future supplies. Increasing populations and reduced poverty in developing countries will increase in future dietary consumption of vegetable oils and, in many countries, popular preference is for coconut oil. These considerations, together with the importance of coconut as smallholders' crop, and in some locations the only feasible crop, emphasizes the need to optimize cultural practices by the generation and dissemination of improved technology.

Eighteen members of the scientific staff of a major coconut research institute and fifteen individual scientists have contributed to this paper. Its objectives are to review the more important biological factors which influence coconut production and to identify means by which the necessary improvements may be realized in the world's major coconut producing areas. There has been no attempt to provide a fully comprehensive review of every aspect of coconut production, and processing of the crop has been excluded from consideration. Rather, the contributions have provided an important insight into the recent objectives and achievements of research and described many of the best current cultural techniques. In this way it is hoped that those involved in coconut development will benefit from a greater awareness and understanding of the technical constraints and the means by which they can be most successfully overcome.

The Bank is most grateful to all those who have contributed papers and to the many who have provided review and advise. Brief biographical notes on those who have collaborated in the production of this work are presented in the appendix. Special mention must be made of A.H. Green, who was largely responsible for the concept of the paper, solicitation of the contributors, and for much of the editing and organization of the text.
I. INTRODUCTION

1.1 The coconut palm has been called the "Tree of Life" because it is the source of many raw materials essential to traditional life-styles in the Pacific region. Coconut leaves are used for roofing and mats; the trunk provides wood for furniture; the coconut meat is used as food, as feed, in the production of soap and cooking oil; the husks are used to produce ropes and mattresses; the shell is used to produce charcoal; and even the roots are used in dyes and traditional medicines.

1.2 Worldwide, coconut oil is popular as a cooking oil and also has a number of industrial uses in products ranging from laundry detergents to non-dairy creamers. Thus demand for coconut oil is a composite of demand for two very distinct types of final goods, and in each market coconut oil faces severe competition from vegetable oils less expensively produced. The vast majority of coconut oil is used directly as a cooking oil and in certain parts of the world has a strong taste preference over other cooking oils. However, the rapid expansion of soybeans in South America and palm oil in Malaysia and Indonesia has resulted in the availability of cheaper alternatives. While coconut oil still commands a premium over soybean, rapeseed and palm oils, the trend of prices within the oilseed complex as a whole has been downwards over the past forty years, and coconut oil prices have followed, as illustrated in Figure 1.1. Additionally, in a world where total consumption of vegetable

Figure 1.1

COCONUT OIL PRICES 1950 - 1990
CONSTANT 1985 DOLLARS PER METRIC TON

--- Actuals ---- Trend
oils has grown rapidly, the consumption of coconut oil has stagnated. From 1980 to 1987, world consumption of major vegetable oils grew by 5.17% annually and the consumption of animal-source fats and oils grew at a 1.1% pace. The world’s annual consumption of coconut oil in 1980 was 2.77 million tons when coconut oil cost $674/ton (in nominal dollars). In 1987, despite a price of $442/ton only 2.96 million tons was consumed, yielding an annual growth of less than 1%.

1.3 The coconut industry remains vitally important in the Philippines, Indonesia, Papua New Guinea, Sri Lanka, and parts of India and Malaysia. In the Philippines, the world’s largest producer of copra and coconut oil, it has been estimated that one-third of the population, 18 million people, depend directly or indirectly on the coconut industry for their livelihood, and the vast majority of producers worldwide are smallholders. In Kerala, for example, where 90% of holdings are less than 1 hectare, the average holding is one-fifth of a hectare. But, despite their great importance to so many, little investment has occurred in the coconut sectors. From 1980-1986, the 12 members of the Asian and Pacific Coconut Community (APCC) reported only 776,000 hectares of new area, 65% of which was in Indonesia.

1.4 In North America and the European Economic Community the industrial uses of coconut oil account for approximately one-half of final demand. While the uses are varied, the bulk of industrial-use coconut oil goes into the production of soaps and detergents. In this market, coconut oil faces competition from palm kernel oil, the other important “lauric oil.” Lauric alcohols, a basic component for detergents, can be constructed from palm kernel oil as well as from coconut oil, although currently the process is more expensive if palm kernel oil is used. While coconut plantings have been limited, the acreage devoted to oil palms, which produce both palm oil and palm kernel oil, has grown rapidly over the past decade. Production of palm kernel oil is expected to grow at 5-6% annually through the remainder of the century. Coconut now provides about 75% of the lauric oils, but over the next 12 years, that share is expected to drop to two-thirds.

1.5 Looking at the prospects for coconut oil and the relationship between costs of the various oils, coconut oil is likely to continue declining in importance, unless substantial productivity gains can be found. A study commissioned by the World Bank estimates the cost of producing a ton of coconut oil in the Philippines at US$320-400. The cost of jointly producing palm oil and palm kernel oil in Indonesia is estimated at US$200-220/ton. Given the evolving cost structure in the market for edible oils in general, and lauric oil in particular, coconut oil will continue to face strong competition in the foreseeable future.

1.6 Fortunately, improved planting material, much higher yielding than the traditional varieties, is already available. In favorable environments and under good management, the best of the new dwarf x tall hybrids can yield more than five tons of copra per hectare; tall x tall hybrids probably over four tons. At such yields, coconut would rank second only to the oil palm in terms of oil production per hectare, and much exceed the present potential of any of the annual crops. This paper argues that if the coconut industry is to realize its potential, there will have to be much stronger support from governments in the producing countries. They must mobilize the necessary
scientific and financial support and adopt fiscal policies which allow the
grower an equitable share in the value of his crop. Such commitment will only
materialize if new investment in coconut is judged economically sound in the
context of national agricultural strategies and food policy objectives. This
paper aims to help convince the decision makers that coconut is, indeed, a
crop for the twenty-first century, which should be judged on its potential and
not on its present performance.

1.7 The following paragraphs give an outline of the principal areas where
further research is required. In succeeding chapters, these subjects are
treated in greater detail by scientists directly involved in the ongoing
research programs.

i. New varieties are required which will perform well in less favored
environments and greater effort should be made to broaden the genetic
base of existing collections. Genetic engineering may eventually
have a part to play, but foreseeable improvement will depend mostly
on conventional breeding. Genetic improvement and planting material
production and the subjects of the first paper in Chapter III.

ii. The improved hybrids are available in only limited quantities and
propagation by conventional means is slow and expensive. Micro-
propagation (tissue culture) techniques should be developed in order
to clone elite palms selected within the best hybrid populations,
thereby eliminating these constraints. Vegetative propagation of
coconuts, the status of research and the priorities for future
research are the topics covered in the second paper of Chapter III.

iii. The nutritional requirements of the high yielding varieties need to
be better defined and linked to research on the economics of
manuring, especially under smallholder conditions. Two papers in
Chapter IV deal with nutrition and manuring, particularly of hybrids
and young palms.

iv. Although the coconut is, by its stature and habit of growth,
inherently well adapted for use in multicrop farming systems the
interactions between crops require further study if the best possible
use is to be made of the land. The advantages and disadvantages of
coconuts on smallholdings and commercial estates, also their value on
coral atolls, are considered in the first three papers of Chapter IV
and the design of experiments with particular reference to inter-
cropping in the final paper of this chapter.

v. The coconut is susceptible to many pests and diseases that restrict
or even preclude, its cultivation. Some causal organisms have yet to
be identified; others have been long known but effective controls
have yet to be developed. The emphasis should be on integrated and
environmentally acceptable techniques. Coconut diseases are
discussed in the four papers making up Chapter V, and pests in
Chapter VI.

vi. Traditional copra production is labor intensive, unpopular and
increasingly expensive. There is a need for mechanization so that
the much heavier crops to be expected in future can be economically
harvested and processed. This is more particularly a problem of large-scale estates, discussed in the third paper of Chapter IV, but solutions could well apply also to groups of smallholders.

vii. New non-food uses of coconut oil need to be developed if the maximum profit is to be derived from the crop and better use must be made of coconut by-products, including timber. The uses and techniques for handling coconut wood are the subject of Chapter VII.

1.8 We believe that these agronomic and technical problems can be solved. However, before higher yields and lower production costs can be realized by growers the results of research have to be incorporated into farming practice. Since the coconut will still be grown primarily by small, and often poorly educated, farmers, this transfer of technology will make great demands on the information and extension services, which may require as much outside assistance as the research institutions.

1.9 With few exceptions, the national coconut research programs are seriously understaffed and underfunded. In the short to medium term, therefore, a great deal of support will be needed from the international donor community. The long term aim must be to develop and strengthen the national services to the point where they can serve the local industry effectively without external aid. But, in this drive towards self-sufficiency, it will be important not to lose sight of the need for, and benefits to be derived from, a collaborative approach to research. A strong case can be made for additional regional networks, like those being promoted by the FAO for Asia and the Pacific region. Even so, many small countries, often those most heavily dependent on the coconut for their foreign exchange earnings, will never be able to afford an effective research program. For them international support will be vital.

1.10 The need for research has been increasingly recognized both nationally and internationally. For example, the International Board for Plant Genetic Resources (IBPGR) has funded collecting expeditions to expand the genetic base of ongoing national breeding programs. We believe that such sponsored collections, and the varieties eventually bred from them, should be made freely available to all producers through an international program. In 1985, the Technical Advisory Committee (TAC), reviewing the priorities and future strategies of the Consultative Group on International Agricultural Research (CGIAR), recommended that coconut be included in an expanded overall program, and that US$2.0 million a year (1.7% of the budget) be allocated to the crop. Ways of implementing this proposal are now being finalized. The World Bank's Special Program for African Agricultural Research (SPAAR) also envisages additional support for research on perennial crops, including coconut. In 1986, the European Economic Community gave evidence of its concern when DG XII -- the division responsible for promoting science and technology in support of development -- commissioned a study to evaluate proposals for co-ordinating and strengthening the ongoing coconut (and oil palm) research funded by the European community under bilateral aid programs. As a result, the Bureau for the Development of Research on Tropical Perennial Oil Crops (BuroTrop) has been established in order to co-ordinate the interventions of donor countries and reinforce the activities of the research and development centers of producer countries.
1.11 With a large proportion, in some countries the majority, of existing coconut stocks over-aged and unproductive it is vital that steps be taken without delay to rehabilitate the industry. It is to be hoped that the international community will rally to the aid of the producing countries. Millions of small farmers and some of the poorest countries will be the principal beneficiaries.
II. THE COCONUT PALM AND ITS CULTIVATION

Historical Background

2.1 The coconut is one of the most widely distributed of crop plants and has a long history of cultivation in Asia, Africa, Latin America and throughout the Pacific region. Its center of origin is, however, unknown; small coconut-like fossils, between one and 15 million years old, have been found in New Zealand (Cocos zeylandica). Although even older fossils, dating back 15-40 million years, have been collected from the deserts of Rajasthan, Indian scientists do not believe that the coconut originated in the sub-continent. Current opinion seems to favor Melanesia or Southeast Asia but the evidence remains inconclusive. Also unclear is how the coconut reached some of the places where it flourishes today: both dispersal by ocean currents and transportation by early navigators certainly played their part but the specifics remain legendary. Nevertheless, the coconut has a recorded history of cultivation going back well over 2,000 years in Sri Lanka and more than 3,000 years along the Malabar Coast of India, now the modern state of "Kerala" ("the land of the coconut"). The history is a fascinating one and is further discussed by Hugh Harries in Appendix A.

2.2 The coconut is known by a variety of names which reflect its usefulness to man; e.g., Tree of Life, Tree of Abundance, Tree of Heaven, etc. The immature nut provides a pleasant beverage, the raw kernel is an important article of food; pared, shredded and dried it provides the desiccated coconut of commerce. The oil is used for cooking, for illumination and lubrication, and in the manufacture of margarines, bakery fats, soaps, detergents and toiletries. Coconut-cake, the residue after extracting oil from copra, is valuable as cattle and poultry feed. Tapping the inflorescence produces sap which can be used to provide sugar, vinegar, sweet or fermented toddy and, when distilled, arrack. The timber can be used for building and furniture construction; the plaited leaves for roofing; fiber from the husk for the manufacture of ropes and matting; the shell for charcoal or the manufacture of artifacts (pots, buttons, bowls, etc.).

2.3 Copra, the dried kernel of the coconut, was first used in the western world in the mid-19th century to provide oil for soap-making. By the end of the century the oil was also being used for making margarine. In the early 1900s, growers responded to the greatly increased demand by undertaking extensive new plantings. In 1912, Sir William Hesketh Lever wrote: "I know of no field of Tropical Agriculture that is so promising at the present moment as coconut planting, and I do not think in the whole world there is promise of so lucrative an investment of time and money as in this industry". This typified the mood at a time when coconuts were to become known as the "Consols of the East". Between 1910 and 1923, world exports increased from 385,000 tons (oil equivalent) to over 800,000 tons; an annual growth rate of 5%. Ten years later (1935), exports topped one million tons; but it took over 40 years to progress from one million to 1.5 million tons (annual growth rate, less than 1%). In the early 1960s, soybeans replaced coconut as the major source of vegetable oil in world trade. The earlier optimism was replaced by disillusion and the United Nations report on the Coconut Industry of Asia (1969) considered that "the danger of substitution of products or of the source of
supply has very much darkened the future of the coconut economy of Asia. World Bank forecasts (Report No. 814/88—Price Prospects for Major Primary Commodities) predict that world production of coconut oil will increase from 3.2 million tons in 1987 to only 3.5 million tons by 2000 (Table 2.1); and exports, estimated at 1.7 million tons for 1987, are not expected to increase substantially (1.83 million tons in 1990 and 1.85 million tons in 2000). In sharp contrast, soybean exports (oil equivalent) are expected to increase from 7.9 million to 12.2 million tons and palm oil exports from 6.5 million to 11.7 million tons over the same thirteen year period.

Table 2.1: WORLD BANK FORECASTS OF COPRA PRODUCTION BY MAIN COUNTRIES AND ECONOMIC REGIONS ('000 tons oil equivalent)

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>'000 tons</td>
<td>'000 tons</td>
<td>Percent 1987</td>
</tr>
<tr>
<td>ASIA</td>
<td>2,772</td>
<td>2,942</td>
<td>86.6</td>
</tr>
<tr>
<td>Philippines</td>
<td>1,565</td>
<td>1,500</td>
<td>48.9</td>
</tr>
<tr>
<td>Indonesia</td>
<td>714</td>
<td>840</td>
<td>22.3</td>
</tr>
<tr>
<td>India</td>
<td>248</td>
<td>263</td>
<td>7.7</td>
</tr>
<tr>
<td>Malaysia</td>
<td>124</td>
<td>134</td>
<td>3.9</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>86</td>
<td>170</td>
<td>2.7</td>
</tr>
<tr>
<td>AFRICA</td>
<td>120</td>
<td>155</td>
<td>3.7</td>
</tr>
<tr>
<td>AMERICA</td>
<td>91</td>
<td>135</td>
<td>2.8</td>
</tr>
<tr>
<td>OCEANIA</td>
<td>190</td>
<td>223</td>
<td>5.9</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>102</td>
<td>120</td>
<td>3.2</td>
</tr>
<tr>
<td>WORLD</td>
<td>3,200</td>
<td>3,485</td>
<td>100.0</td>
</tr>
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2.4 Today, about 85% of world coconut production comes from Asian countries, and this figure is expected to remain more or less constant until the end of the century.

Botany

2.5 The palms (family Palmae) are among the most ancient of woody plants. There are some 2,600 species, 600 of which are included in the subfamily Cocoideae to which both the coconut (Cocos nucifera) and the oil palm (Elaeis guineensis) belong. The genus Cocos at one time had over 60 species of palms assigned to it; today it is generally considered to be monotypic with C. nucifera, the sole species.

2.6 The common tall variety (var. typica) accounts for the great majority of the world's coconut population. It has a single unbranched stem with a
radiating crown of long pinnate leaves; growing to a height of 30 meters or more, it can, under favorable circumstances, live for more than 100 years. However, the economic life is generally considered to be around 60. Flowering usually begins when the palm is 5-6 years old and continues throughout life. The inflorescence, which does not emerge until three years after initiation of the spadix, is normally branched and bears both male and female flowers. After flowering, development and ripening of the fruit (botanically a fibrous drupe and not a true nut) takes a further year.

2.7 In 1949, Narayana and John recognized three principal tall varieties—typica; spicata, with an unbranched inflorescence, and androgena, with predominantly male flowers. Dwarf coconuts were divided into two varieties—nana, relatively delicate and bearing in three years, and javanica, more robust and bearing in four years. Both talls and dwarfs were further divided into forms according to geographic origin. In more recent classifications spicata and androgena are no longer given varietal status. The dwarf javanica was also dropped and incorporated in nana. Fremond, Ziller and de Nuce de Lamothe (1966) based their classification on flowering behavior, distinguishing between the allogamous, or cross-pollinating, talls and the autogamous, or self-pollinating, dwarfs. Although controversy still exists, the method proposed by Fremond and his coworkers is the basis on which accessions to most breeding programs are now classified. The International Board for Plant Genetic Resources (IBPGR) accommodates this system in its recommended minimal list of descriptors for the documentation of coconut germplasm while also allowing the further distinction proposed by Harries based on fruit composition:

(a) "niu vai", coconuts with roundish fruits and thin husk likely to have developed under cultivation as a result of selection for desirable yield characteristics; and

(b) "niu kafa", triangular shaped nuts with thick husk and large cavity, better suited to natural dispersal, and thought to have evolved without the intervention of man.

2.8 Recent breeding programs have tended to concentrate on the production of dwarf x tall hybrid varieties: often more productive than either of the parents, and effectively combining precocity with high yield at maturity. Some of these hybrids also have advantages in terms of disease resistance. However, tall x tall hybrids, which outyield the pure tall varieties and bear larger nuts than the dwarf x tall hybrids may be preferred where the principal market is for fresh nuts for domestic consumption. Further progress can be expected by more rigorous selection within the parent populations prior to hybridization. Although some problems have still to be resolved, refinement of tissue culture techniques should, within a few years, make possible the mass propagation of clones derived from outstanding individual palms.

Environmental Requirements
Climate

2.9 The coconut is essentially a crop of the lowland humid tropics, 90% of production coming from within the zone 20°N and 20°S latitude. It has been grown successfully at an elevation of over 1,000 m near to the equator, but is rarely planted in quantity at altitudes above 300 m. In Jamaica, at 18°N, the
crop is said to be unprofitable if planted above 120 m. Ideally the average temperature should be in the range 27–32°C with a diurnal variation of not more than 7°C. Annual rainfall requirements may range between 1,000 mm and 2,500 mm depending on seasonal distribution, the water retaining capacity of the soil, the depth of the water table and the availability of additional sources of water, e.g., by lateral percolation. Ample sunshine is required, preferably in excess of 2,000 hours, though total solar radiation is more important than hours of bright sunshine. At relative humidities below 60% stomatal closure may restrict transpiration; while humidity close to saturation predisposes the palm to a number of diseases.

Soils

2.10 The coconut tolerates a very wide range of soil conditions, from the almost pure coral found on atolls, to peats and acid swamps. In some circumstances it may be the sole economic crop at the farmer's disposal. Although the highest yields are probably obtained on fertile alluvial and volcanic soils the coconut may not then be the most profitable crop that can be grown. Under these conditions it is frequently found as one component of a multicrop system. The traditional tall varieties are better suited by their stature and habit of growth to multicrop systems than the dwarf varieties and some of the dwarf hybrids.

2.11 The myth that the coconut will only thrive within sound of the sea has been disproved by the many plantations that have been established successfully inland, sometimes as much as 500 km from the sea. However, coastal conditions do have their advantages. Soils just inland of the beaches are often well-drained and well-aerated, and rainfall is supplemented by abundant supplies of moving freshwater, often enriched by nutrients during its lateral movement from higher ground further inland. Humidity is usually high and diurnal temperature fluctuations small. The other supposition, that because the coconut thrives near the sea it must require salt for satisfactory growth, was disputed for many years. For example, Jean Adam (Encyclopedie d'Agriculture Tropicale, 1942) maintained that, despite the prevalence of the practice in many coconut growing areas, applications of salt, or seawater, could in no way be justified. This view persisted generally until the 1970s. However, good responses to chlorine have since been obtained in many fertilizer trials and, although the special role the element plays in coconut physiology is not yet fully understood, its importance can no longer be ignored.

Cultivation

2.12 Despite the coconut's long history of cultivation, standards remain for the most part rather low. Because it survives with a minimum of attention it has not always been recognized that the coconut responds well to good husbandry; it has even been described as a 'lazy man's crop' and farmgate prices have frequently been set so low that farmers have been unable to afford the inputs that would have enabled them to increase yields. Thus, in many countries, a low input, low output system has come to be accepted as the norm and coconut growers remain all too often amongst the poorest of the poor. Although coconuts are frequently grown in association with other crops, or with livestock, the overall productivity of such systems has also been limited by inadequate inputs.
2.13 The whole subject of multiple cropping with coconut needs to be re-evaluated both in the context of the yield potential of the new hybrid varieties grown in plantation monoculture and ongoing agroforestry research into methods of measuring interactions between woody perennials and herbaceous plants when grown in association (see, for example, Plant Research and Agroforestry published by the International Council for Research in Agroforestry in 1983). Optimum solutions will, nevertheless, be difficult to define, even for specific locations, because of conflicting goals. The most productive system in terms of biological yield over the short to medium term may be neither financially profitable nor indefinitely sustainable. Their proven sustainability is indeed the principal virtue of the traditional systems as found, for example, in the Indonesian kampung or West Indian creole gardens.

Harvesting

2.14 Harvesting methods are largely determined by the end use but are also influenced by social conditions and the characteristics of the variety. The simplest system involves leaving the nuts to fall when they are fully ripe and collecting them from the ground. The plantation must, however, be kept well weeded to prevent the loss of nuts and this represents an additional cost. The method is unsuitable for the production of top quality coir (the fiber from fully ripe nuts is too brittle and the dark color also detracts from the value); it is too risky in areas where predial larceny is rife, and is impracticable with varieties whose nuts germinate on the palm if not picked.

2.15 The normal practice is, therefore, to pick the nuts from the palm; tender, immature, nuts for drinking purposes, slightly unripe nuts where the fiber is required for the manufacture of coir, and ripe nuts where the principal objective is copra production. In some countries harvesters still climb the palms to gather the crop; but this is hard work and increasingly bunches are cut from the ground using long poles, usually bamboo, with a sickle shaped knife attached. Monkeys (generally Macacus nemestrina) are trained to climb the palms and pick the ripe nuts in parts of Malaysia, Thailand and Indonesia.

Processing

2.16 The kernel of the ripe nut when removed and dried provides the copra of commerce. The simplest process involves splitting the whole nut and leaving the kernel exposed to the sun to dry. More usually the husk is removed before the shell is split and smoke or hot air kilns are used to accelerate drying.

2.17 Copra from the traditional tall varieties may be expected to contain between 68% and 72% of oil, from dwarf varieties the range is lower, 63% to 68%. Although there are no agreed international quality standards it is generally accepted that good copra should contain not more than 6% moisture, have less than 1% free fatty acid and be uncontaminated by dirt or other extraneous matter; however, high oil content attracts no premium.

2.18 The traditional method of extracting oil from coconut for household purposes does not involve drying. Fresh coconut is grated, mixed with hot water and pressed to extract the coconut "milk" (an emulsion of oil and
water). The oil is then obtained by separation and boiling but the process is inefficient and only 60% of the oil is recovered. Much research has been carried out in attempts to improve the efficiency of this basic process for extracting both oil and protein suitable for direct human consumption from fresh kernels. The Tropical Development and Research Institute (TDRI) in the U.K. has devised a continuous closed-loop circuit which permits recovery of 96% of the oil. Good results have also been claimed for the Solvol Process developed in Kerala and two processes developed to the pilot plant stage in the Philippines. However, the economic viability of these processes has yet to be demonstrated in a large industrial plant and the vast majority of coconut oil is still obtained from copra using conventional expellers. As far as the grower is concerned copra is likely to remain his principal source of revenue though in some areas, where markets exist, by-products (principally coir and coconut shell) offer opportunities for generating additional on-farm income.

REFERENCE

III. SELECTION, BREEDING AND PLANTING MATERIAL PRODUCTION

Summary and Recommendations

3.1 The emphasis of coconut breeding programs has very much been on the improvement of yield. For many years it was thought that this could be achieved by mass selection, based on phenotypic characters, within locally available varieties. For a number of reasons, discussed elsewhere in this chapter, this method proved largely ineffectual and the first major progress came with the decision to work instead with hybrids, often produced by crossing varieties of widely different geographic origins.

3.2 The switch to hybrids has enormously increased the yield potential of the crop. While traditional tall varieties rarely produce more than two tons of copra per hectare, the hybrids now available can, under good conditions, produce more than five tons. Where one of the parents is a dwarf the hybrids are also significantly more precocious, coming into bearing at least two years earlier than tall palms.

3.3 However, with a breeding cycle requiring up to 16 years, progress has been relatively slow; and even when proven material is available the low multiplication rate means that several more years must elapse before it can be made available in sufficient quantities to have any impact on production.

3.4 Both breeding and planting material production are greatly handicapped by lack of a simple means of propagating palms vegetatively. Other constraints facing current programs include:

- lack of commitment on the part of governments to provide on a continuing basis the resources required to sustain a long-term breeding program;

- reluctance to collaborate with other countries, or where the will exists, a lack of facilities for so doing;

- a still inadequate understanding of the genetics of the crop;

- a limited range of genetic variability within the collections;

- inadequate information about what is available in other countries; and

- the danger of introducing disease if exotic varieties are imported.

Research Priorities

3.5 While the ranking of priorities will differ from country to country according to the stage of development of the ongoing program, the following requirements are fairly general:

- undertake new prospections to enlarge the genetic base of the collections;
- ensure the preservation of existing gene stocks by collecting material representative of the vast areas of old palms likely to disappear as major replanting programs are initiated around the world;

- improve facilities for the international exchange of breeding material with due precautions against the attendant risks, through quarantine arrangements, etc.;

- initiate studies to improve understanding of interactions between genotype and environment (e.g. drought tolerance), and the genetic factors determining resistance to major pests and diseases. Select positively for these factors in addition to yield;

- improve existing hybrids by selecting elite individuals within each of the parent populations, and broaden the range of hybrids under progeny testing.

3.6 Although neither feasible nor necessary in every individual program, in the global context a major effort should be devoted to perfecting means of propagating the coconut vegetatively. Vegetative propagation would provide greater homogeneity and higher yield in commercial plantings; it would facilitate the multiplication of disease resistant material and would enable greater use to be made of elite individuals within breeding programs. It would also have a role to play in the preservation of gene banks (e.g. by ultra low temperature storage of embryogenic or calloid material) as an alternative to living palm collections.

3.7 At the present time the manpower and financial resources committed to research on the crop are inadequate to permit the realization of these objectives. Ongoing programs which are making a valid contribution should be ensured the resources they need to pursue their research effectively; and international support, through the International Board for Plant Genetic Resources, should be enhanced and extended. Producers should collaborate more closely through regional networks; and there should be at least one breeding center, possibly more, internationally administered and funded, which would ensure the availability of the best possible planting material to small countries which lack the resources to implement effective breeding programs of their own.
A. Genetic Improvement and Planting Material Production

J. Meunier, J. P. Le Saint, M. de Nuce de Lamothe, F. Rognon and A. Sangare

3.8 Virtually no coconut research was carried out until the beginning of the 20th century and well-structured programs have been developed only since the second World War. Yet the position now achieved is most encouraging. Although, initially, yields of two tons of copra per hectare seemed unattainable there are now varieties capable, under good conditions, of producing more than five tons. Some of these have been tested under a range of environmental conditions and for their tolerance to diseases. Methods of large scale seed production have been developed and in some countries large-scale development programs have been launched and are progressing successfully. Nevertheless, numerous constraints remain which limit the role of the coconut in particular regions.

Principal Constraints

3.9 The principal constraints, not necessarily in order of importance are listed below:

Human: Some institutions are reluctant to commit themselves to a breeding program which, with a perennial crop such as the coconut, is both costly and time-consuming. There are also those who are strongly prejudiced against hybrids and have campaigned, without scientific justification, against their use. In one country it has even been claimed that the use of high yielding hybrids could lead to "genetic suicide" and the utter collapse of the industry. However, as a result of research in many countries (amongst which one may cite India, Indonesia, Malaysia and the Philippines) the superiority of the hybrids is coming increasingly to be recognized, thus confirming the results obtained by the IRHO in Cote d'Ivoire.

Scientific: Lack of a clearly defined program has hampered many schemes. More needs to be known about the biology and physiology of the crop, the genetic variability of ecotypes, the heritability of specific characters, factors permitting early identification of yield potential, and the mechanisms which determine resistance or tolerance to diseases.

Geographical: Paradoxically, the greatest research effort has probably been made in Cote d'Ivoire where coconut cultivation is a secondary activity. In contrast, some of the major producers still do not have research facilities commensurate with the size and importance of the industry. Although Brazil is now organizing coconut research, this is still in its early stages and there is at present no major research center for coconut on the American continent. For Oceania and the Pacific, Vanuatu has facilities for both research and training but exchange of planting material is currently restricted due to the presence of disease.
Biological: The size of the nut and the absence of dormancy complicate the exchange of material and the design of trials; while the long generation time and the time required to assess performance delay genetic progress. Subsequently, low multiplication capacity necessitates large and expensive seed gardens in order to produce improved seed in commercial quantities.

Economic: Collection of planting material from the wild, genetic and comparative trials are demanding in terms of manpower, time and land resources. These problems are particularly onerous in the case of large perennial plants such as the coconut.

Environmental: The two most serious environmental constraints are:

(i) drought, which regularly afflicts extensive areas in, for example, East and West Africa, India, Mexico and Brazil; and

(ii) diseases, which may hamper or even preclude coconut cultivation on a local, national or sometimes regional level.

Research Priorities

3.10 We believe that, long term, the above constraints may be overcome by giving priority to certain areas of research.

1. Design and Implementation of an Effective Improvement Scheme

1.1 The Basis for an Improvement Strategy

3.11 Little is yet known about coconut genetics—serious work is comparatively recent and theoretical studies have been rendered difficult by the palm's bulk, perenniality and low multiplication capacity. Nonetheless, some useful lessons have been learned. The first is that mass selection (choice of parents based on phenotypic characters) has consistently failed as a means of improving yield per hectare. It is now generally accepted that to improve yield it is necessary to select individuals through progeny tests. Heritability calculations have shown that the principal components of yield (number of nuts per tree and weight of copra per nut) are negatively correlated; and even where the heritability of one component is high the heritability estimated for yield is usually low (Liyanage and Sakai, 1961; Meunier et al., 1984). Secondly, intra-population selection has resulted in only very limited progress. The explanation lies in the lack of genetic variability within the local strains and, particularly where the initial parents were few in number, a significant amount of inbreeding. Unfortunately, despite their now well-documented weaknesses, both techniques are still practised.

1.2 IRHO Results

3.12 Launched at the beginning of the 1950s, the IRHO program was at first based on the West African tall (WAT), characterized by high nut numbers but relatively low copra per nut. In Cote d'Ivoire such palms are capable of producing between 2 and 2.5 tons of copra per hectare. However, it was soon realized that, for the reasons outlined above, only limited progress could be
expected and, around 1960, the first attempts were made to exploit heterosis (hybrid vigour) by introducing into the program coconut varieties from different regions, for example, East Africa, Southeast Asia and Polynesia.

3.13 The advantages of the dwarf x tall cross had long been recognized in India and the hybrid vigour observed with respect to growth and flowering characteristics had been documented (Liyanage, 1956). The IRHO therefore accorded a certain priority to d x t hybrids in its own program since, a priori, the two parent materials possessed important complementary characters:

- the dwarf comes into bearing at an early age, but does not increase rapidly in height, it produces many small nuts with poor quality copra;
- the tall takes longer to bear, puts on height rapidly, and usually bears fewer but larger nuts yielding copra that is oil rich and easy to dry.

3.14 The first hybrid produced by the IRHO, the Malayan Yellow dwarf x West African tall (known subsequently as PB (Port Bouet) 121 or the MAWA hybrid) has produced spectacular results:

- precocity far superior to that of the tall variety (bearing at 3-1/2 to 5 years compared with 5-1/2 to 7 for the WAT);
- much higher early yield;
- yield at maturity almost twice that of the better parent (WAT).

3.15 Since then comparable results have been achieved with other hybrids and their performance has been tested in many locations. PB 121 is currently under test in 43 countries throughout the tropics.

3.16 The superiority of the best hybrids over any "local" tall varieties is now so great that encouraging growers, today, to plant local talls would, in our view, be tantamount to delaying progress by 50 years.

3.17 The essentials of the IRHO program (Gascon and Nuce de Lamothe, 1976) are:

- Prospection to increase genetic variability.
- Production and testing of inter-origin hybrids.
- Varietal improvement through progeny testing; followed by recombination and a new cycle of improvement.
- Improvement of the best hybrids using elite individuals, of good combining ability, from each of the parent populations.
- Special schemes such as: broad-based crosses to increase variability with a view to cloning, backcrosses or selfings for transferring disease resistance or to reproduce a particular cross.
Current priorities are to:

(i) increase available genetic variability;
(ii) analyze this variability and assess combining ability; and
(iii) improve breeding techniques.

1.3 Genetic Resources

3.18 Since improvement depends on the exploitation of genetic variability the probability of achieving progress may be expected to increase in proportion to the amount of variability available to the breeder. Since 1960 several centers have made determined efforts to put together comprehensive collections; amongst the largest are:

- Cote d'Ivoire, 60 well-represented ecotypes;
- the Philippines, numerous local ecotypes;
- the Solomons, Pacific ecotypes.

Others, which vary in numbers of origins and individuals, include:

- in Africa - Benin, Madagascar, Mozambique, Nigeria, Tanzania and Togo;
- in Asia - India, Indonesia, Sri Lanka and Thailand; and,
- in the Pacific - Fiji, Papua New Guinea, Samoa and Vanuatu.

3.19 In 1978, the IBPGR accorded a measure of priority to coconut, noting that:

"- there is an urgent need to collect germplasm for breeding;
- there are large replanting schemes causing loss of material;
- even the existing collections are inadequate and more cooperation and exchange of information about them is needed;
- coconut is of high social and economic importance."

This IBPGR support has contributed to the creation of new collections, in the Andaman Islands, and additional prospections to complete existing collections, in the Philippines, Indonesia and Pacific territories.

3.20 Although significant progress has been made in the past 15 years much remains to be done:

- additional prospections in unexplored, or inadequately explored, areas (Philippines, the Pacific and, especially, Indonesia);
safeguarding of existing collections;
- proper evaluation of the collected material (frequently lacking at present);
- improvement of techniques to facilitate the exchange of material;
- creation of "vitro-collections" (in vitro culture);
- establishment of computerized data banks;
- development of biochemical techniques to assess variability.

3.21 In the interest of efficiency it has been suggested (Nuce de Lamothe and Le Saint, 1985) that the main centers be associated in a "network" thereby facilitating collaboration between breeders, the rapid dissemination of information, the standardization of techniques and the more effective use of resources.

1.4 Testing of Inter-Origin Hybrids

3.22 Every prospection increases the amount of material to be tested and, since each progeny requires half a hectare and occupies the land for about 15 years, it becomes physically impossible, at any one center, to test all possible combinations between origins in the collection. Nevertheless the probability of detecting superior hybrids remains a function of the number of combinations tested. It is, therefore, desirable that the different programs should complement one another. In general each center would give priority to working with its indigenous populations but would agree to share with other centers responsibility for testing hybrids between local and exotic varieties. The best hybrids would be exchanged and comparative trials carried out in a range of environments.

3.23 This type of collaboration should be feasible under a networking arrangement and, indeed, virtually exists between IRHO and its partners around the world. The autonomy and freedom of action of the individual center would be in no way impaired by participation in the network.

1.5 Improvement of the Best Hybrids

3.24 Inter-origin hybrids, based on parent populations at least one of which is heterogeneous, are themselves heterogeneous. Initial results indicated that, by selecting within each parent population those individuals which show the best combining ability with the other origin, yield increases of 15% to 30% might be achieved. Over the past few years the IRHO has concentrated on the improvement of its best hybrids in this way, and 339 progenies derived from 12 hybrid combinations are currently under evaluation.

1.6 Breeding Techniques

3.25 Increasingly effective tools are being developed to assist breeders in their choices: certain of these techniques clearly have an important role
to play in coconut breeding especially where they offer the possibility of reducing costs; e.g. by reducing the area or time required to realize a program.

- The analysis of genetic variability: electrophoresis of isozymes (Benoit and Ghesquiere, 1984) does not reveal sufficient polymorphism to be useful and research in this field needs to be strengthened.

- Early identification of high-yielding material: currently a measurement of heterosis is used at mitochondria level to select oil palm crosses in the nursery (Kouame, 1978). In the absence of any clear correlation between morphological characters of young coconut palms and yield at maturity attempts should be made to develop this type of test for yield and other characters.

- The creation of data banks: until now, the number of centers and the range of material used in breeding programs has been quite limited; the number of selection generations is low and the breeding history well recorded even though dispersed in numerous documents. However, as programs expand the amount of data to be recorded and collated will increase very fast. It is important that data banks be created to facilitate storage and retrieval of this information which should be made available to all breeding centers.

2. In Vitro Culture Methods
   2.1 Cloning

3.26 Priority should be given to the development of a reliable in vitro technique for vegetative propagation. In the coconut, as with the oil palm, there is considerable variability within progenies and cloning of the best individuals would give significantly better results. The technique would have particular advantages in the coconut because of:

- The low multiplication rate using conventional techniques, especially with tall x tall hybrids or where it is desired to exploit individual combining ability;

- The high cost of seed gardens; and

- Difficulty of transportation and storage of seed nuts.

3.27 In 1982, IRHO and ORSTOM in France, with the cooperation of Cote d'Ivoire, embarked upon a program of research into somatic embryogenesis. Other institutions working in this field include Wye College and Unilever in the United Kingdom; and the Central Plantation Crops Research Institute (CPCRI), St. Aloysius College and the National Chemical Laboratory in India. Although plantlets have been obtained it is proving more difficult than with the oil palm to evolve a reliable process.

3.28 More research is also required into ways of producing exceptional individuals for cloning (ortets) and for ensuring the genetic conformity and stability of the ramets (individuals within the clone) produced.
2.2 **Embryo Culture**

3.29 A method for the *in vitro* culture of zygotic embryos has been perfected. The IBPGR and the IRHO participate in the funding of research to apply this technique under field conditions to facilitate the work of prospecting expeditions (collection, storage and transportation of new acquisitions) and also to facilitate exchanges between distant breeding stations.

2.3 **In Vitro Culture Technologies**

3.30 The production of haploids through andro- and gynogenesis greatly speeds up the creation of new varieties, and, in the case of a perennial such as the coconut, is the only way of obtaining pure lines. Multiplication of pollen grains was achieved by the IRHO in collaboration with the University of Paris-Sud (Montfort, 1984); although the work was halted before plantlet regeneration could be achieved it is hoped that the program can be resumed in the near future.

3.31 Genetic engineering, which includes the study and modification of the genetic complex, is a promising approach since, once it is known how a character is controlled at the molecular level, it can be exploited either in a traditional improvement program or by direct transfer. The modification of hereditary nuclear or cytoplasmic information is simplified through the use of protoplasts. Research on oil palm protoplast culture and plant regeneration from protoplasts is currently being undertaken by IRHO, in France, Unilever in the United Kingdom and PORIM in Malaysia. This type of research could also be valuable in the coconut particularly for the creation of disease resistant material.

3.32 The cryopreservation (ultra low temperature storage) of embryogenic structures has been developed for the oil palm (IRHO-CNRS collaboration). The creation of gene banks preserved *in vitro* as embryoids or callus in liquid nitrogen seems to offer the only alternative to living collections which are both expensive to maintain and constantly at the mercy of environmental hazards.

3. **Adaptation to the Environment**

3.33 Calling for a multidisciplinary approach, the concept of performance testing is fundamental to coconut improvement. Of particular importance are breeding for:

(a) drought tolerance, linked with physiology and agronomy; and

(b) resistance to diseases, linked with phytopathology.

3.34 In most cases, with no physiological or inoculation tests available, the only way to identify these characteristics is to place the planting material under stress. By carrying out performance trials at many locations, under a networking arrangement, the most interesting hybrids could be assessed for their resistance to drought or various diseases in a wide range of environments. Such performance trials would allow the diffusion of varieties.
with a high degree of safety as well as having an important demonstration effect.

3.1 Drought

3.35 Drought is a serious problem in several countries (Benin, Nigeria, East Africa, India, Mexico, Brazil, etc.). They could form the basis of a collaborative network. To date, little research has been done on drought tolerance in the coconut but some fundamental studies undertaken in Benin on the physiology of drought tolerance in the oil palm may be relevant.

3.2 Diseases

3.36 Numerous studies are being carried out on the etiology, epidemiology and varietal reaction to diseases such as lethal yellowing, cadang-cadang, foliar decay and hartrot. The IRHO already has a comprehensive program covering the diseases of West Africa. For diseases representing a serious threat over large areas regional networks should be encouraged, for example:

- South America for diseases caused by flagellate protozoa;
- The Caribbean, Mexico and West Africa for mycoplasmas.

4. Research Institutes

3.37 Breeding programs are being carried out at many centers, but the resources and effort are unequally distributed through the coconut growing areas.

4.1 Asia

3.38 Although the overall facilities are considerable there are certain weaknesses, amongst which may be cited a lack of coordination.

3.39 India was the first country to establish a coconut research station (Kasaragod, 1916). Selection and breeding started seriously in the early 1930s. In Sri Lanka the Coconut Research Institute dates from 1929. In the Philippines work on coconut improvement was started as long ago as 1908 at the College of Agriculture but there was no national coconut research institution until 1973 when the Philippines Coconut Authority received technical support and funding under the FAO/UNDP Coconut Research and Development project.

3.40 In Indonesia interest in coconut improvement goes back to the early 1900s; however, the first coconut research station was not established until 1930 (Menado, Sulawesi). Since 1973 the Agency for Agricultural Research and Development (A.A.R.D.) has, with assistance from FAO and the World Bank, given fresh impetus to the program. There is also now a research center funded by the plantation industry. There are also programs in Thailand (at Sawi, with ODA cooperation), in Malaysia (Malaysian Agricultural Research and Development Institute with IBPGR support) and in Vietnam (with assistance from FAO and IRHO).
4.2 Africa

Despite the minor importance of coconut in the country's economy, research carried out by the IRHO at the Marc Delorme Station in the Cote d'Ivoire is recognized as having made a major contribution to coconut improvement. Financial difficulties could jeopardize the future of this important program unless some external support can be mobilized. In Tanzania the National Coconut Development Program is supported by research carried out with the assistance of GTZ and IRHO. Elsewhere in Africa research is rather restricted at the present time.

4.3 The Pacific

The IRHO station at Saraouto in Vanuato has an important breeding program as well as being a training center for the region. Better cooperation is sought with other Pacific centers such as the Solomons, Fiji, Papua New Guinea, Samoa and Tonga—some of whose programs require strengthening or reactivation.

4.4 Latin America

In Jamaica the Coconut Industry Board built up a major germ plasm collection in its search for resistance to lethal yellowing, but the program has had to be reduced since ODA support ceased in 1981. In Brazil the recently established National Coconut Research Center at Aracuaja is as yet handicapped by its isolation and lack of resources. Thus, the Caribbean, Central and much of South America are without major genetic improvement and seed production facilities. Since major genetic programs are beyond the means of most individual countries in the region the creation of an association network would seem to be in their common interest.
ADDENDUM

3.44 Attempts at improving local tall varieties of coconuts having, in the main, failed; emphasis is now placed on the production of hybrids. As explained in the above paper, the superiority of the hybrids lies in their greater precocity (particularly if d x t) and higher yield at maturity. The following tables 1/ provide more quantitative comparisons based on statistically designed trials in different environments.

Table 3.1: EARLY YIELD OF HYBRID AND TALL VARIETIES
(Cumulative production: tons of copra per ha)

<table>
<thead>
<tr>
<th>Country</th>
<th>Cote d'Ivoire</th>
<th>Indonesia</th>
<th>Malaysia</th>
<th>Philippines</th>
<th>Thailand</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of trials</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Tall varieties</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>D x T hybrids</td>
<td>6.6</td>
<td>5.9</td>
<td>2.7</td>
<td>4.6</td>
<td>3.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

3.45 Tall varieties tested include those from Bali, Malaysia, Rennell, Tagnanan, Thailand, Vanuatu and West Africa. In the d x t hybrids, dwarfs were from Cameroon, Malaysia and Nias and talls from Rennell, Tenga and West Africa. Over this considerable range of origins and environments the early production of the hybrids was, on average, 10 x greater than that of the tall varieties. The additional income at this early age is a big advantage and planters, including smallholders, increasingly indicate their preference for the hybrids.

Table 3.2: PRODUCTIVITY OF HYBRID AND TALL VARIETIES
(Mean yield: tons of copra per ha per year)

<table>
<thead>
<tr>
<th>Country</th>
<th>Cote d'Ivoire</th>
<th>Indonesia</th>
<th>Malaysia</th>
<th>Philippines</th>
<th>Thailand</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of trials</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Age of palms</td>
<td>9-14</td>
<td>6-9</td>
<td>9-13</td>
<td>7-8</td>
<td>7-8</td>
<td>-</td>
</tr>
<tr>
<td>Years recorded</td>
<td>4/5</td>
<td>2/3</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Tall varieties</td>
<td>1.8</td>
<td>0.6</td>
<td>2.6</td>
<td>1.3</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>T x T Hybrids</td>
<td>3.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.1</td>
<td>3.3</td>
</tr>
<tr>
<td>D x T Hybrids</td>
<td>4.0</td>
<td>3.2</td>
<td>3.7</td>
<td>2.3</td>
<td>2.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

1/ Derived, by courtesy of the IRHO, from a paper published in Oleagineux in December, 1986.
On average the hybrids have yielded more than twice as much as the tall varieties. However, in some of the Asian trials the tall palms are still not fully mature and more data will be required before reliable comparisons can be made for all situations; differences between countries should also be interpreted with caution because of age differences in the palms.

3.46 One of the criticisms most frequently levelled at the hybrids is that, because they require a high level of inputs to realize their full potential, they should be expected to yield less well than the traditional tall varieties under smallholder conditions where standards of husbandry are normally lower. In fact this does not happen, the hybrids maintain their superiority over the traditional varieties even when maintenance is neglected and no fertilizers are applied. The following figures are taken from a trial carried out in South Sulawesi:

Table 3.3: CUMULATIVE YIELD: TONS OF COPRA PER HA OVER SEVEN YEARS

<table>
<thead>
<tr>
<th>Variety</th>
<th>Fertilizers &amp; good maintenance</th>
<th>No fertilizers &amp; no maintenance</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khina I hybrid</td>
<td>5.83</td>
<td>2.85</td>
<td>4.34</td>
</tr>
<tr>
<td>Local tall</td>
<td>0.09</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean</td>
<td>2.96</td>
<td>1.5</td>
<td>2.23</td>
</tr>
</tbody>
</table>

Note: Khina I = Nias Yellow Dwarf x Tenga Tall.

3.47 In Kerala a hybrid between the Chowgat Dwarf Orange (CDO) and the West Coast Tall (WCT) was compared with the West Coast Tall. Table 3.4 and Figure 3.1 illustrate convincingly the superiority of the hybrid, whether or not fertilizers are applied:

Table 3.4: YIELD OF CDO x WCT HYBRID AS PERCENTAGE OF WCT YIELD

<table>
<thead>
<tr>
<th>Kilograms of NPK fertilizer per palm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
</tr>
<tr>
<td>2.5</td>
</tr>
<tr>
<td>3.0</td>
</tr>
</tbody>
</table>
Figure 3.1

YIELD OF HYBRID & TALL VARIETIES
(with and without NPK fertilizers)

FIGURE 3.1
YIELD OF HYBRID & TALL VARIETIES
WITH & WITHOUT NPK FERTILIZERS

HUTS PER PALM

KILOGRAMS OF NPK FERTILIZER PER PALM

- 25 -
REFERENCES


B. Coconut Propagation

Jennet Blake

Perspectives

3.48 Once the benefits of hybrid planting material were established, seed gardens were set up to produce hybrid seednuts under controlled conditions and in commercial quantities.

3.49 Up to the present time, the most generally successful hybrids have been produced using the Malayan dwarf as the female parent and crossing it with a local tall variety, thus combining the larger nuts and better copra quality of the tall parent with the greater precocity, higher nut numbers and reduced height of the dwarf parent. A particular advantage of the Malayan dwarf is that it carries some resistance to disease, e.g. to lethal yellowing in Jamaica.

3.50 Although some varieties used in breeding may initially have been selected for disease resistance the main thrust of breeding programs has been increased yield. With so many serious diseases of coconut around the world, it is important to incorporate some measure of breeding for resistance, but this may be difficult until more is known of the aetiology of the diseases. Current work on cadang-cadang in the Philippines will be very useful in this respect.

3.51 The advantages of vegetative propagation by tissue culture (micropropagation) have been apparent for some time but, for the coconut, the technique is only at the development stage. Clonal plantlets for field testing should be available in the next few years, but it will be the beginning of the next century before the technique has a significant impact on production.

3.52 Micropropagation of clonal stock will aid breeding programs and could also be used in the selection and multiplication of disease-resistant varieties. Cost factors will determine whether clonal plants will be produced for direct field planting in commercial plantations.

Seednut Production

3.53 In order to improve and select stock for field planting it is essential to have some control over pollination. Currently, two methods are in use. The method of "directed natural pollination" allows open pollination to occur in a mixed planting of the two chosen parents after complete emasculation of the female parent. Since the stocks of both parents are raised from seed, and are therefore heterozygous, the hybrids produced will themselves be very variable, though generally an improvement on the parents.

3.54 Once methods of collecting, storing and transporting pollen were developed, it became possible to separate male and female plantings spatially and use the method of "assisted pollination". Complete emasculation of the female parent is again required but the pollen used can be taken from known,
preferably progeny-tested, male parents thus providing a higher quality hybrid. Illegitimate seedlings can often be recognized in the nursery by their off-color. This method is the most successful in producing quality hybrids but is labor-intensive and therefore expensive.

**Embryo Culture**

3.55 There is a strong demand in the Philippines for Macapuno nuts; these are filled with jelly endosperm and are esteemed as a delicacy. Normally only a few of the nuts on a palm are of the Macapuno type and, since these do not germinate normally, the character is difficult to reproduce. Other countries have similar nuts but, for the reason given, supplies are everywhere very restricted and demand remains unsatisfied. In the Philippines, de Guzman removed embryos from Makapuno nuts and grew them successfully into plants under in vitro conditions. Tissue culture of embryos ensured transmission of the Makapuno characteristic to the extent that the plants produced a much higher proportion of Makapuno-type nuts. However, even after some years experience there are still problems at the transfer stage and perhaps as many as half may be lost between the culture vessel and establishment in the field. A more reliable method of embryo culture could have great potential. Ultimately it should be possible to use the calloid method (see below) for propagating this type of coconut.

3.56 In view of the limited supply and high cost of hybrid seednuts it might be of interest to excise the embryos and proliferate them by a method of secondary embryogenesis. As far as is known this has not been attempted but should be considered as a possible way of increasing the amount of good planting material.

**Vegetative Propagation**

3.57 For the past fifteen years, many workers around the world have been trying to develop a method of clonal propagation for coconut, and a small measure of success has recently been achieved.

3.58 At Wye College inflorescence tissue of Malayan dwarf has been used to produce a type of callus which has been termed "calloid" as it is only partly dedifferentiated (much less dedifferentiated than the callus from which oil palm is regenerated). The calloid is produced on a high 2,4-D medium, the level of 2,4-D is later reduced to obtain embryoids. The most difficult phase is the development of embryoids into plantlets. However, this should not prove too great a stumbling block; some clonal plantlets have already been obtained at Wye, and Unilever have established one plant in the Solomon Islands. Workers at IRHO in France appear to have obtained somatic embryos from leaf tissue but have not as yet been able to obtain plantlets. With further work on the coconut system, it should be possible to proliferate embryoids in a manner analogous to that of the oil palm.

3.59 Attempts have been made in India to obtain direct embryogenesis on leaf tissue, and this has been successful using seedling leaf, but little detailed information is available. Such a method using mature tissue would be very useful as it avoids a callus phase in which somatic mutations may occur.
Reversion of flower meristems to produce vegetative shoots is an attractive possibility since mutations are least likely to occur in a system which maintains organized meristems throughout the culture period. Although flower meristems have continued to lay down bracts in culture, a complete reversion to vegetative growth has not been reliably obtained. However, flower reversion has recently been achieved with date palm inflorescence material, which suggests that it should also be possible with coconut.

Priorities for Research

There are no intrinsic difficulties in culturing coconut embryos, but the success rate of establishing plants needs to be increased. Although some information is available from de Guzman's work, it would be helpful to have the publication of full details of a protocol for culturing and establishing embryos. This is an area of considerable importance since embryo culture has a role to play in:

(a) the transport and preservation of germplasm;

(b) the multiplication of Macapuno-type nuts; and possibly

(c) the multiplication of hybrid embryos to boost the output of assisted pollination programs.

A reliable method of clonal propagation of coconut would be a great asset in breeding programs, but it would be essential to demonstrate that the plantlets produced were genetically identical to the parent. Reversion of flower meristems or direct embryogenesis should be the most reliable systems, though it is possible that the callus method may prove to be equally stable genetically. This can only be determined by field trials of plants produced from tissue culture in which comparison is made both between individuals within the clone and with the parent palm.

Variation obtained or induced during the callus or calloid phase, could be used as a source of somaclonal variation, producing plants which could be selected for such traits as disease or drought resistance. Although this area cannot be exploited at present, it should be borne in mind when planning research programs.

The techniques of tissue culture can be used in any part of the world which has adequate laboratory facilities. Well-trained personnel are a pre-requisite, but the facilities required are not elaborate. Any investment in coconut tissue culture must be on a reasonably long-term basis; but, given the commitment, tissue culture methods of embryogenesis and vegetative propagation can certainly be developed and would be invaluable in breeding programs, in the transfer of germplasm and in the production of commercial planting material.
IV. AGRONOMY

Summary and Recommendations

4.1 Although most agronomic research on coconut has, for reasons of convenience, been carried out on experiment stations under conditions more akin to those found on industrial estates than on smallholdings it is now generally accepted that, in a smallholder dominated sector, the usefulness of the results depends largely on the extent to which they remain applicable when the constraints under which small farmers operate are taken fully into account.

4.2 Smallholder aspects take precedence in the papers by D.H. Romney and K. Trewren; D. Friend and A. Leng look at the future of coconut as an estate crop; the IRHO workers concentrate on the nutritional requirements of the newer hybrid varieties and R.W. Smith focuses on young palms, while Janet Riley discusses experimental designs suitable for agronomic trials with monocrop coconuts and in intercropping situations.

Rehabilitation

4.3 Although the future of both estates and smallholdings must lie with the improved hybrid varieties, these have yet to be adequately tested in all environments and, even where tested, may not yet be available on a large scale for distribution to farmers. There remains, therefore, considerable interest in the rehabilitation of existing plantings through a combination of better maintenance, fertilizers, redensification of depleted stands, pest and disease control and, probably, intercropping. Many of these agronomic aspects have been well researched, and technically sound solutions are available to resolve most problems. There may, however, be socioeconomic constraints which limit their application. For example, a lack of markets for intercrops, or a shortage of labor which restricts their production; inequitable farmgate prices which make the use of fertilizers uneconomic, or a lack of credit facilities for the purchase of such inputs; a general lack of logistic support, or poor extension services which leave the farmer unaware of the technical solution to his problem. Land tenure systems, and the small uneconomic units which result from excessive fragmentation of holdings cause great difficulties in many countries.

Replanting

4.4 If replanting is to take place at anything like the rate generally considered necessary, substantial investments will be required in setting up and operating hybrid seed gardens and ensuring the availability of high quality planting material. Governments will have to ensure an economic environment conducive to development and change; and project staffs will have to be capable of convincing farmers of the need for a joint effort if success is to be achieved. Coconut smallholdings tend often to be self-perpetuating; with a high population density and a spread of ages within the stand of fifty years or more, the yield remains very stable and it is difficult for the farmer to decide the point at which it becomes
financially worthwhile to sacrifice his existing palms and replace them with material of higher yield potential. Demonstration plots undoubtedly have an important role to play; these should compare hybrid and traditional varieties, with and without fertilizers, and with improved husbandry contrasted with the traditional system.

4.5 For industrial estates, with large areas of uniformly-aged palms showing declining yields, the decision is perhaps easier but even here there are trade-offs to consider. Although clear felling prior to replanting results in the most rapid development of the young palms and ensures their earliest possible entry into production it may still pay to retain a proportion of the old stand for two or three years, the revenue they generate offsetting the delay in getting crop from the young palms. Although agronomic trials can be set up to investigate the technical impact of delayed felling, the decision in individual cases will depend as much on financial considerations; cash flow problems, the cost of capital, and judgments relating to future price prospects.

4.6 There is little evidence of pest and disease problems presenting a major hazard in replanting coconuts after coconuts but there is increasing concern about the long term impact of unsatisfactory agronomic practices during the lifetime of the first generation of palms. Incorrect manuring creates nutrient imbalances, organic matter may be seriously depleted and soil structure degraded. More research is needed on means of rehabilitating such soils.

Nurseries

4.7 The choice has to be made between conventional (open field) and polybag nurseries. With the traditional varieties experiments have shown the polybag system to be superior; there is as yet less evidence in the case of the more precocious hybrid material. As with replanting techniques, cost considerations may be the determining factor; with cost and logistic difficulties ruling out polybag material where a nursery has to serve a widely-scattered farming community. In the long term the advent of clonal material is likely to require a greater degree of automation in nursery practices.

Planting Density

4.8 Recommended planting densities for tall varieties range from as low as 100 palms per hectare (10 m square spacing) to as high as 210 palms per hectare (7.5 m triangular spacing); dwarfs may be planted as close as 6.5 m, over 270 palms per hectare if triangularly spaced. There is no one "correct" figure as the optimum will depend on varietal characteristics, soil and climatic factors and the farming system adopted. Much more information is needed on the impact of spacing on the partition of assimilates between vegetative dry matter and crop production (harvest index) and the interaction of coconuts at various spacings with other crops in a multicrop system.
Maintenance of Immature Areas

4.9 Under traditional systems of minimal attention, the development of young coconuts is severely retarded by both nutritional deficiencies and competition from weeds. Where labor is available and markets exist, intercropping offers a solution to both these problems. On estates, monocrop coconut still predominates but there is a tendency to move toward chemical or mechanical maintenance as manual labor becomes more expensive. The long term effects of these practices require further investigation.

Nutrition

4.10 Foliar analysis is a useful and generally reliable technique for the diagnosis of nutrient deficiencies, but it has to be recognized that it does not and cannot, even when coupled with properly designed fertilizer trials, provide an infallible recipe for the determination of the quantities of fertilizer which should be applied.

4.11 In view of the very large quantities of potassium removed in the crop the importance of this element in coconut nutrition is readily understood. Since, however, much of the potash is in the husk, the amount of fertilizer actually required will depend on whether or not husking takes place in the field, and the fertilizer value of husks, fallen fronds, etc. should be taken into account in assessing the value of these by-products in alternative uses. The fact that potassium is most often applied as muriate of potash has tended to mask the importance of chlorine in coconut nutrition; there can no longer be any doubt that both K+ and Cl- are required, though the physiological role of chlorine is imperfectly understood. There is some evidence that it may be related to the control of stomatal movement.

4.12 The special nutritional problems of atoll soils are discussed by K. Tewren. Iron deficiency occurs just about everywhere and there are difficulties with the uptake of other minor elements, among them copper, manganese and zinc, but responses to these are less consistently obtained.

Design of Experiments

4.13 The size, heterogeneity and cropping behavior of the coconut palm make it a difficult subject for experimentation. The problems are discussed by Janet Riley and attention is drawn to the usefulness of "nearest neighbor" and fan-type systematic designs for carrying out intercropping and spacing trials.

Research Priorities

4.14 Of all the research disciplines, agronomy comes closest to the real world of the farmer and although much basic and applied research remains to be done the greatest short-term advance is likely to come from adaptive trials, demonstration, and good extension services in order to get
existing knowledge incorporated into farming practice. There will have to be close collaboration between agronomists, extension workers and agroeconomists if this objective is to be realized.

4.15 In view of the increasing interest in both short term and permanent intercropping more basic research is required into the relationships between species in multicrop systems: the management of trees, the effect of population density on both the coconut component and a range of intercrops whether these be annual or perennial species. Changes in harvest index need to be known for each crop in relation to planting density and canopy structure. Also important are fundamental studies on rhizosphere activity and the effects of inter-specific competition for moisture and nutrients on root activity.

4.16 Although foliar analysis has proved a useful diagnostic tool, it would be advantageous to develop other measures more directly related to the physiological activity of the palm. It would also be useful to know more about the effects of varying the placement, and the timing and frequency of fertilizer applications. Given the degree of heterogeneity of current planting material it is unlikely that the small differences to be expected will be shown as either practically or statistically significant until it is possible to carry out trials on clonal palms.
A. Rehabilitation and Replanting Schemes for Smallholders
D.H. Romney

General Considerations

4.17 Surveys, as a means of identifying farmers' needs, can be both expensive and misleading; with the surveyor often receiving those answers which the smallholder believes he wants. Again, although smallholders may not need aid they will seldom refuse it. It is, therefore, important to be sure that any proposed investment in coconut replanting or rehabilitation is intrinsically sound before a project is launched. Otherwise, farmers may be saddled with obligations they cannot meet and the aid agency may find that it has spent more on consultant services and administration than on goods and services provided to the grower.

4.18 Before embarking on any rehabilitation or replanting scheme certain basic criteria should be met:

- Ecological conditions should be well-suited to coconut cultivation;
- The planned production increase should meet a national need, for domestic consumption, import substitution, or to increase exports;
- Prices for fresh nuts or copra should be attractive; offering the possibility of high net profit per hectare on expensive land, or high returns per man-day where labor is the principal constraint. The scheme should not depend for its viability on sale of by-products since these have relatively low value and often unreliable markets;
- There should be clear evidence of farmer interest (e.g., growers already paying high prices for planting material).

4.19 It is preferable that coconut should already form part of a stable mixed cropping system in the country; and the proposed production increase should not bring the coconut into competition with another successful permanent crop for which investment and expertise are already available.

4.20 If there are doubts about appropriate management techniques, choice of varieties, fertilizer requirements, or how to control pests and diseases; these problems should be resolved before the scheme is commenced. It is also important in designing the scheme to identify the main constraints faced by farmers already using their own resources to rehabilitate or replant their holdings, so that they may be removed.

4.21 The following are important to the success of any scheme:

- Price: The farmer should be ensured an equitable price for his produce and should receive prompt payment. If quality is a problem this may be the time to introduce grading and differential prices.
- Communications: It may be necessary to establish a farmers' organization through which project staff can communicate with growers, and
ensure that their needs, as they perceive them, are considered. Demonstration plots should be set up to show the beneficial effect on coconut growth and yield of the practices advocated under the scheme (weed control, intercropping, combating major pests and diseases, regulation of stand density, fertilizer application, etc.).

- **Advisory Services:** The farmer should be regarded as a customer and should be visited regularly. Advice given should be recorded and followed up to assess its effectiveness.

- **Logistic Support:** Good quality seedlings, fertilizers, herbicides and other inputs should be made readily accessible in the small quantities usually appropriate to the farmers' needs.

- **Incentives to Farmers:** The farmer should be encouraged to adopt a high standard of husbandry; for example, seedlings should not be issued until the land has been properly prepared for planting and fertilizers should be withheld if a field is overgrown with weeds. The need for credit will vary from project to project but, where credit is given, farmers should be made aware of their eventual debt service obligations from the outset. As an added inducement a rebate may be given if the farmer succeeds in bringing his plants into bearing by the target date.

- **Land Tenure:** To qualify for assistance a farmer should have the right to use land suitable for coconuts. For reasons of equity, the area allowed per farmer may have to be restricted in the early stages of a project if funds or planting material are limiting.

**Rehabilitation**

4.22 Rehabilitation, here defined as measures to improve the productivity of existing bearing trees, may be expected to provide a quicker return on investment than the planting of a new grove. However, farmers attitudes and misconceptions may militate against success:

- They may have been visited by third-rate advisory staff in the past and be unconvinced of the merits of the new proposal;

- They may believe that planting a new "wonder variety" will not only increase yields but also reduce the need for inputs (if not, what is all the fuss about?);

- They may expect the new scheme to provide free or cheap goods, or to make available scarce resources.

Hence, a rehabilitation scheme must:

(i) Demonstrate the effectiveness of the recommended techniques;

(ii) Convince farmers that effort on their part is required to achieve success; and encourage them in their endeavors through
such activities as providing good tools at cost, ensuring availability of inputs such as fertilizers and pesticides, and making more expensive items, such as knapsack sprayers, available on loan.

4.23 Only areas carrying palms capable of responding should be accepted into the program. Where drainage is impeded this should be the first factor attended to. Stand density must be adequate; filling gaps in a bearing stand with new seedlings is not effective, as competition from the older trees will prevent the seedlings developing into productive palms. Where stands are very low, fields should be cleared and replanted.

4.24 Where rats are a problem controlling them, using the well-tested and relatively safe coumarin-type poisons, gives a very quick return for a modest outlay. The next most important operation is weed control; usually the elimination of shrubs and clumps of tall grasses. However shrubs containing nests of Oecophylla ants should be retained if the area is infested with pests, such as Amblypetla or Pseudotheraptus, which these ants help to control. Subsequently, clean weeded circles up to 4 m radius should be maintained around each palm. Where farmers are prepared to intercrop their coconuts, this should be encouraged to generate extra income and help to control weeds.

4.25 Where there are identified nutritional deficiencies, fertilizer application is the next stage; but until there is evidence that economic responses will be achieved investment should be kept low. Phytosanitary measures to control major pests (Oryctes or Rhyncophorus) should also be part of the package.

Replanting

4.26 A replanting scheme is an opportunity to introduce improved varieties and improved management practices to farmers, insisting on the latter as a condition for receiving the new material. Planting material production is best done by a coconut agency rather than by the farmers. The aim should be to make available, at the appropriate planting season, high quality seedlings of varieties which are of proven suitability to local growing conditions and market requirements. First-cross hybrids have shown their value (precocity, high yield per hectare, small stature, disease resistance) in many parts of the world and a replanting scheme should enable smallholders to participate in such benefits--but not be subjected to the risks of variety testing. Nevertheless, it is essential to have proper selection procedures so that candidates lacking the necessary minimal resources do not enter the scheme.

Nurseries

4.27 The areas selected should be disease free and water for irrigation should be available when required, particularly important in the case of polybag nurseries. Growing conditions throughout the nursery should be uniformly good to facilitate selection of potentially superior seedlings; substandard material should be destroyed, never retained in the hope that it will improve later. The site should be readily accessible to vehicles at all seasons and strategically located in relation to the group of farmers it is to serve.
Clearing Before Replanting

4.28 Replanting areas of tall coconuts with tall coconuts was shown in Sri Lanka, Malaysia and Solomon Islands to be most economically done by progressive thinning of the old stand. When replanting with dwarf x tall hybrids in Tanzania, competition from mature talls has resulted in substantial reduction in growth and delayed onset of bearing of the young trees. However, because farmers are naturally reluctant to fell bearing trees and complete clearing exposes the young plants to greater risk of *Oryctes* damage, it is recommended that:

(a) After lining, all non-productive palms and those within 2 m of any planting peg are felled or poisoned;

(b) Two years after planting the best 25 bearing trees per hectare are selected and all others destroyed;

(c) Four years after planting the best 12 trees per ha are selected for permanent retention and the remainder destroyed.

4.29 Yield distribution data from India, Indonesia and Tanzania indicate that the 25 trees retained after Year 2 will produce about 30% of the original yield, and the final 12 about 17%.

Planting Density

4.30 On industrial estates planting density is a compromise between the costs of planting material, maintenance and harvesting, and the need for high yield in the early years and sustained production at maturity. Smallholders generally prefer wider spacings which maximize yield per tree and allow intercropping to offset establishment costs. While the recommended spacing should be that which best suits the variety and the growing conditions, perhaps 8 m as a standard, smallholders should be allowed to widen the spacing to 10 m if they intend to intercrop; when corridor cropping, distances of, perhaps, 6 m x 12 m should be encouraged.

Field Operations

4.31 Since maintenance on smallholdings is usually manual it is unnecessary to remove the stumps of the old palms. Rotting coconut trunks are the preferred breeding sites of *Oryctes* but it seldom infests the stumps. The breeding cycle, from egg to adult, takes about three months so all felled trunks should be regularly inspected at two-month intervals and all beetle larvae destroyed, starting six months after felling and continuing as necessary for up to two years.

4.32 For young palms weed control is vital; yet replanting plans often lay more emphasis on fertilizers than herbicides. Clean weeding circles around the palms is less costly and creates less risk of erosion than weeding the whole field. However the circles are rarely large enough to eliminate competition for water and nutrients, or even physical competition in the case of
Imperata cylindrica or Cynodon dactylon. Research in Tanzania with dwarf x tall hybrids has shown significant differences in growth and onset of bearing according to circle size, with or without fertilizers. Minimum circle sizes required at different ages have been found to be:

<table>
<thead>
<tr>
<th>Age of tree (Months from field planting)</th>
<th>Size of weeded circle Radius (m)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-12</td>
<td>1.5</td>
<td>7</td>
</tr>
<tr>
<td>12-18</td>
<td>2.0</td>
<td>12</td>
</tr>
<tr>
<td>18-24</td>
<td>2.5</td>
<td>20</td>
</tr>
<tr>
<td>24-36</td>
<td>3.0</td>
<td>28</td>
</tr>
<tr>
<td>36-48</td>
<td>4.0</td>
<td>50</td>
</tr>
</tbody>
</table>

4.33 During the fourth year, with 4 m circles and a stand of 150 trees per ha, 0.75 ha has to be weeded for each hectare of plantation. The amount of labor required is considerable and it is as yet too soon to say whether the additional crop eventually realized as a result of the improved growth of the young palms will suffice to offset the costs. Weeding is particularly important at the end of the rains in order to conserve moisture for use by the coconuts. In some situations, herbicides can be cheaper and more effective than manual weeding (depending on relative costs of labor and chemicals and the type of weeds to be controlled). The low toxicity to coconuts and rapid detoxification in the soil of glyphosate make this one of the products ideal for smallholders. The addition of ammonium sulphate to the spray mixture greatly enhances the effectiveness of glyphosate. However, for herbicides to be economic and safe farmers must be educated in their use, must be provided with suitable equipment, such as the right type of spray nozzles and, although the hazards are small, must be made aware of the dangers. Phenoxyacetic acid based herbicides (2,4-D and 2,4,5-T) can kill coconuts even at concentrations below those required to kill broadleaved weeds. Other products, such as bromocil, are dangerous as they are absorbed by coconut roots.

**Intercropping**

4.34 The improvements in coconut growth and yield by the contribution of intercropping to weed control, in addition to the profits gained from the intercrops, have been shown in many countries.

4.35 In a smallholder situation, intercropping when replanting or rehabilitating coconuts is likely to be better for both the coconuts and the farmers than the too frequent alternative of weeds and bush. However, for optimum results, certain precautions need to be observed. In dry areas, where competition for moisture is the limiting factor, farmers should grow only intercrops which complete their development during the rainy period and mature by the dry season. Examples are maize, upland rice, peas, beans, groundnuts, sweet potatoes and pumpkin. If perennial crops are grown, such as citrus as
nesting hosts for Oecophylla, the coconuts should be spaced more widely. Where rainfall and nutrients are adequate, competition for light may be the limiting factor, and it is important that intercrops such as banana or cassava should not be planted too close to the young coconuts. The suitability of pigeon peas as a coconut intercrop is questionable in areas where Pseudotheraptus or Amblypelta are present--because the pigeon peas harbor the ant Anoplolepis longipes which is antagonistic to Oecophylla.

4.36 For bearing coconuts, bananas are a shade tolerant intercrop with reduced leaf-spot under the shade. Sunflowers and upland rice are believed to enjoy partial shade. Cocoa and coffee can be profitable intercrops with mature coconut provided their own special requirements are met. Pasture under coconuts competes for both moisture and nutrients and young coconuts are liable to damage unless protected against grazing cattle. The profitability of a coconut/cattle enterprise will depend on local circumstances.

Coconut Manuring

4.37 Rehabilitation and replanting schemes require the timely application of appropriate fertilizers; it is, however, important to know what nutrients are needed and the magnitude of the responses to be expected. Even where trial data are available, it has to be remembered that responses will vary from year to year and from farm to farm. It is prudent, therefore, to recommend rates which tend towards the lower limit of what is expected to be profitable (law of diminishing returns). Where trials data are unavailable low rates are again indicated, composition being guided by general principles. Deficiency of a nutrient in other crops does not necessarily indicate that the coconut will respond, but it is a guide. Except after clearing heavy forest immature coconuts always respond to nitrogen; with phosphate, on the other hand, deficiencies are rare and the quantities required by coconuts are low. Requirements of potash fertilizer can be greatly reduced by ensuring that the husk is left in the field. The approximate quantities of nutrients removed are:

<table>
<thead>
<tr>
<th></th>
<th>Grams per 40 nuts harvested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Coconut husk left in the field</td>
<td>100</td>
</tr>
<tr>
<td>Husk removed from the field</td>
<td>120</td>
</tr>
</tbody>
</table>

These proportions provide some preliminary guide to fertilizer mixtures and rates. In low rainfall areas, growth and yield are reduced and fertilizer requirements are less. While foliar analysis can be a guide to deficiencies the published critical levels should be interpreted with caution as they do not apply in all environments. Elements other than N, P and K may be deficient in certain areas; e.g., boron (clear symptoms of deficiency in dry areas on soils of high pH); chlorine (where leaf levels are below about 0.2%
on leaf dry matter); magnesium (deficiency likely to be induced where high levels of potash are applied); and sulphur (leaf and copra symptoms). However, it is not justified to take special steps to add these elements to a fertilizer mixture unless the need for them is clear, and remember that chlorine will already be present if muriate of potash is used as a source of K, as will sulphur if the nitrogen fertilizer is sulphate of ammonia.

4.38 As a general policy smallholders should be provided with an NPK fertilizer formulated to take account of known deficiencies. In coconut manuring there are many instances of positive interactions between the major nutrients and, for this reason, even if only one element is clearly deficient, it is unwise to apply single fertilizers. Since transport, handling, bags and application are important components of the overall cost of fertilizing, a concentrated fertilizer is preferable. However, certain precautions need to be observed, e.g., where N is in the form of urea up to 20 percent can be lost due to volatilization if it is applied in hot weather interspersed with light showers. While burying the fertilizer reduces such losses, and is often also recommended with phosphates, the additional labour required may discourage the smallholder from fertilizing his palms. Although various trials have failed to demonstrate any clear advantage from applying fertilizer more frequently than once a year, biannual applications are to be recommended as they do reduce the risk of root burning or excessive leaching losses, particularly in coarse textured soils. It has been generally recognized that even with bearing trees, the best uptake of fertilizer occurs within a radius of 2 m from the trunk. On sandy soils, however, studies of root-tip distribution suggest that fertilizer should be spread 3 - 3.5 m from the base of the palm.

Pests and Diseases

4.39 It is important to ascertain for any area whether its coconut pests and diseases are (a) minor, (b) major but controllable, or (c) potentially so severe as to preclude profitable coconut development.

4.40 As examples of the third category mention may be made of mites (Aceria guerreronis) which can make coconut cultivation uneconomic in dry areas; and hart-rot (Phytomonas staheli) at present limited to Latin America but of major importance there and with no known cure. Also in this category are a number of diseases, believed to be caused by mycoplasma-like organisms, for example Cape St. Paul wilt, Kribi disease, Kaincope, and Awka disease (all in West Africa) and Lethal disease (in Tanzania); at present there is no cure and there are no known resistant varieties.

4.41 Although rarely preclusive the following can be difficult and costly to control:

--- Lethal yellowing requires the planting of resistant varieties, such as Maypan hybrids or, in some areas, Malayan dwarf.

--- Premature nut-fall (caused by Pseudotheraptus wayi and Amblyphelta cocophaga) can often be kept in check by providing nesting sites for Oecophylla ants through the interplanting of citrus, sour-sop, or clove, etc.
Palm weevils (Rhyncophorus palmarum) may be particularly dangerous in association with red ring disease (Rhadinaphelenchus cocophilus) for which the weevil is the principal vector, but good sanitation and simple trapping may provide sufficient control.

Rhinoceros beetles (Oryctes spp.) remain a widespread problem and some of the newer control measures (olfactory traps, introduction of Baculovirus oryctes) have had only limited success; in many areas manual methods of collection and destruction of the beetles remain the only effective way to protect young palms.

Wild pigs can destroy substantial numbers of coconut plants up to one year after planting. Traps and hunting are only partial solutions, but a perimeter trench 75 cm deep with spoil heaped on the inner side is virtually pig-proof if regularly maintained.

Research Priorities

4.42 Although sometimes needing judicious interpretation the results of research on coconut agronomy, plant improvement and plant protection are generally applicable to smallholders. Subjects of special relevance to the smallholder situation on which further information is required include:

**Intercropping.** Although intercropping is advisable in principle for weed control, for limitation of pests and diseases and for profit, more needs to be known about the effect of different environments. In addition to crops typical of the area, improved and exotic intercrops should be tested.

**Project Design.** Too little is known about the impact of project design on the success of past rehabilitation and replanting schemes.

4.43 The records should be analyzed, and additional surveys conducted as required, to determine:

- the effects of incentives/penalties on the level of success of different components of the scheme;
- the effect of environmental factors and management practices on the percentage of plants surviving after transfer to the field, the percentage reaching bearing, and the eventual yield;
- the extent to which losses are offset by the planting of replacements;
- the acceptance of improved techniques by different classes of farmers.
4.44 In many countries there is a need to make the results of research more rapidly and more readily available to farmers. The results of research must be promptly evaluated and then interpreted for the benefit of advisory staff. The relevance of the research program should be under constant review; initiating new research to fill gaps in existing knowledge and modifying, or if necessary terminating, trials that are no longer useful.
Coconut Production on Coral Atolls
K. Trewren

Coconuts in the Economy

4.45 Although in terms of world trade their contribution is insignificant the coral atolls deserve special attention because of the importance of the coconut in the lives of the local people; to many it is indeed the "Tree of Life". The coconut is invariably the most important, and on some atolls it is virtually the only, staple crop. The giant swamp taro (Cyrtosperma chamissonis) is grown as a staple root crop in Micronesia and Eastern Polynesia and breadfruit (Artocarpus altilis) is also important on most atolls. Minor food crops include sweet potatoes, bananas and pawpaws.

4.46 In addition to fresh kernel, for manufacture into copra or for domestic consumption, the coconut also provides coconut cream and coconut milk - prepared from the grated kernel; oil - extracted by boiling the grated kernel in water; and toddy - sap collected by tapping the inflorescence - which, when boiled, yields molasses which may be used as a sugar substitute, or to make sweets, or when diluted, as a drink. The water from under-ripe nuts is also used for drinking. The coconut apple (haustorium of the germinating nut) may be eaten raw or boiled, and the heart of the palm provides the so-called millionaires' salad. The palm also provides both timber and thatch for house construction. The coconut is, not surprisingly, an important symbol of wealth in many atoll communities and the ownership of a large number of trees greatly enhances the social status of the individual or family.

Soils

4.47 The structure of all atolls is based on aragonite coral with secondary calcite overlying a core of volcanic origin. The soil cover is formed largely from calcareous sand, mostly calcium and magnesium carbonates derived from the shells of marine algae and foraminifera. On the lagoon side of atolls the parent material may be almost exclusively composed of such sand, i.e. it is virtually non-coralline. In marked contrast the outer windward ramparts will comprise boulder-sized coral and coralline algal rubble thrown up from the reef by periodic storms. Between the two the soils contain varying quantities of loose angular stones of coralline origin. Some of the poorer "soils" consist almost entirely of this material; such coconuts as there are will be chlorotic and unproductive and the vegetation is usually dominated by Scaevola sericea and Messerschmidia argentea.

4.48 A calcareous crust or pavement generally occurs just above the water table but may outcrop at the surface in places. Bivalve shells may also be present.

4.49 The top 15 cm of the sands, containing some organic matter, is dark greyish to black in colour and alkaline in reaction (pH 7.6-8.0). Below this is found a very coarse white and pink gravelly sand, almost entirely calcium and magnesium carbonate, with a pH which may be as high as 9. This subsoil layer contains no coconut feeder roots, though thick structural roots may descend to depths greater than 1 meter. Feeding roots are generally concentrated within 7 cm or so of the surface, though a second layer, about 1 cm thick, may occur immediately above the calcareous crust.
4.50 The soils are highly permeable and have low moisture retaining capacity. Reserves of nitrogen and potassium are extremely low, and because of the high calcium carbonate content, phosphorus tends to be fixed as tricalcium phosphate and other insoluble compounds. The topsoils may contain up to 5 percent by volume of clay sized particles but these are formed by the action of carbonic acid from the humus on algal shells and coralline fragments; there is no colloidal mineral matter. The organic matter therefore plays an important role in the formation of aggregates, the retention of moisture, and the fixation of the exchangeable mineral elements. The reduction of pH which is brought about by the organic matter also increases the availability of phosphorus and some trace elements, notably iron. In scattered localities deposits of reddish-brown, humus rich, phosphatic soils are to be found. These are derived from a mixture of guano and coralline sands; the total P content may exceed 100,000 ppm with available P around 200 ppm.

4.51 Total quantities of iron, manganese, zinc and copper are generally very low, and the problem is exacerbated by the fixation of these elements due to the high pH. The levels of available calcium and magnesium are very high whilst sodium is adequate to high. Sulphur may be marginal, and boron levels appear to fluctuate widely both from year to year and from area to area.

4.52 A curious feature of a few atolls is the presence of true peat bogs, derived from the reed Scirpus riparius around the fringes of freshwater lakes. A typical example is the bog of Teraina (Washington Island) in the Northern Line Islands, Kiribati.

Climate and Yield

4.53 Because the soils have such poor moisture retention capacity, there is a close relationship between long term average rainfall and yield. For example:

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Rainfall (mm)</th>
<th>Mean Yield /a (kg per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuvalu (9 islands)</td>
<td>3,036</td>
<td>1,200</td>
</tr>
<tr>
<td>Gilbert Islands (16 islands)</td>
<td>1,661</td>
<td>500 /b</td>
</tr>
<tr>
<td>Christmas Island (Kiritimati)</td>
<td>795</td>
<td>140 /c</td>
</tr>
</tbody>
</table>

/a Yield is expressed as copra equivalent.
/b In the Gilberts there is also a close correlation between copra production and the rainfall of the preceding year.
/c Christmas Island was uninhabited and devoid of coconuts when first discovered by European explorers. Many of the coconuts planted subsequently have died out; the figure of 140 kg represents the average yield of the surviving blocks.
4.54 Even though, on Tuvalu, the rainfall is well distributed and moisture is not a limiting factor the production of over a ton of copra per hectare, coming as it does from naturally regenerating coconut woodland that receives no fertilizer, is surprisingly high. Nevertheless it is clear that the atolls are much more vulnerable to the vagaries of climate than are the islands of volcanic origin whose soils have a much better moisture retaining capacity. This is especially unfortunate for the atoll people; with their limited range of crops, they are largely dependent on the coconut tree and marine products for their survival.

Constraints

4.55 The potential for increased production is severely limited. Important among the constraints are:

i. The nature of the soils;

ii. The geographic isolation, scattered distribution and small size of the islands;

iii. The fragmented distribution of the parcels of land which constitute a true atoll (this makes communication difficult, impedes the harvesting and transportation of the crop and complicates the distribution of fertilizers and other requisites).

iv. Low rainfall, and vulnerability to cyclone damage

v. The presence of saline groundwater

vi. Land tenure systems which result in a family's land resources being divided into numerous individually tiny smallholdings widely scattered over an island.

vii. The high population density characteristic of many islands (this puts pressure on food supplies and there is reluctance to replant even senile palms as long as they continue to produce a few nuts).

viii. The widely fluctuating price of copra discourages the investment of money or labour in the crop.

4.56 The geographical isolation and scattered distribution of the islands is well illustrated by the case of Tuvalu. There are just nine islands, dispersed in a chain 580 km long over 1.3 million sq. km of ocean. The total land area is only 26 sq. km., the largest island is 509 ha, the smallest 41, and they are 3,000 km from the nearest land mass, Australia. Transportation costs are enormous; for example, freight charges may double the cost of imported fertilizers. The Tuamotu Archipelago comprises no fewer than 76 atolls and just one volcanic island. The Republic of Kiribati consists of 33 islands in the central Pacific, stretching 3,200 km from east to west and
1,600 km from north to south. Most atolls consist of a narrow ribbon of land, often not more than 100 meters wide, encircling a large lagoon. The ribbon is fragmented by passages which allow tidal movement between ocean and lagoon. Tabiteuea Island in Kiribati consists of over fifty separate islets and Kwajalein atoll in the Marshall Islands has a lagoon area of 2,850 sq km.

Research Findings

4.57 Nutrient Requirements. The first fertilizer trials on coral atolls were laid down in 1959 on Rangiroa Island in French Polynesia. The work soon demonstrated the need for iron in particular and that once the iron deficiency had been corrected, responses could be expected to manganese and nitrogen. Various methods of applying iron and manganese were tested, including placing the chemical directly in a hole drilled in the trunk, either in solution or in solid form and applications to the soil, either broadcast or placed in a single hole at the base of the trunk. Trunk injections brought about dramatic improvement within six months but also caused severe foliar necrosis and flower abscission. The treatment eventually recommended was soil application of 400 g of ferrous sulphate and 150 g of manganese sulphate in a hole at the base of the trunk. In a trial comparing sources of nitrogen it was found that ammonium nitrate and calcium cyanamide markedly increased leaf N levels; ammonium sulphate had a slight effect while "Azorgan" and urea had no effect at all. It was also noted in other experiments that levels of potassium, zinc and copper were very low but no responses were obtained to their application. Unfortunately the Rangiroa program was terminated abruptly in 1973.

4.58 Work carried out in Tuvalu from 1978 onwards has fully confirmed the importance of iron. Applications to severely chlorotic, stunted palms have rapidly and dramatically improved the appearance of the palms, raised leaf Fe levels and, subsequently, increased yield. In one experiment, comparing different methods of applying iron, trunk injections of ferrous sulphate not only corrected the deficiency but also significantly changed the foliar levels of nitrogen, phosphorus, sulphur, calcium, magnesium, sodium and manganese. Not all of these effects showed up quickly. While levels of iron and sodium changed within 4 months of the iron being injected; nitrogen, phosphorus, sulphur and manganese took 16 months and the change in calcium level did not achieve statistical significance until 28 months after the treatment was applied (samples were collected for analysis at four months and annually thereafter).
Table 4.1: THE EFFECTS OF TRUNK INJECTIONS OF FERROUS SULPHATE ON FOLIAR LEVELS OF IRON, NITROGEN, PHOSPHORUS, SULPHUR, CALCIUM, SODIUM AND MANGANSE (Elements X or ppm in leaf dry matter) /a

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fe ppm</th>
<th>N X</th>
<th>P X</th>
<th>S X</th>
<th>Mg X</th>
<th>Ca X</th>
<th>Na X</th>
<th>Mn ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated (control)</td>
<td>9.8</td>
<td>1.14</td>
<td>0.13</td>
<td>0.14</td>
<td>0.65</td>
<td>0.76</td>
<td>0.75</td>
<td>19.0</td>
</tr>
<tr>
<td>FeSO4 injected</td>
<td>87.7</td>
<td>1.65</td>
<td>0.18</td>
<td>0.18</td>
<td>0.50</td>
<td>0.55</td>
<td>0.53</td>
<td>8.1</td>
</tr>
<tr>
<td><strong>Response /b</strong></td>
<td><strong>+77.9</strong></td>
<td><strong>+0.51</strong></td>
<td><strong>+0.05</strong></td>
<td><strong>+0.04</strong></td>
<td><strong>-0.15</strong></td>
<td><strong>-0.21</strong></td>
<td><strong>-0.22</strong></td>
<td><strong>-10.9</strong></td>
</tr>
<tr>
<td>As % of Control</td>
<td><strong>+795</strong></td>
<td><strong>+45</strong></td>
<td><strong>+38</strong></td>
<td><strong>+29</strong></td>
<td><strong>-23</strong></td>
<td><strong>-28</strong></td>
<td><strong>-29</strong></td>
<td><strong>-57</strong></td>
</tr>
</tbody>
</table>

/a Leaf 14 where available, otherwise 4th from lowest frond.  
/b Mean of three treatments (10, 20, and 30 grams per palm).

4.59 The 45 percent increase in leaf nitrogen level in response to iron injections (without application of nitrogenous fertilizer) is important since it indicates that nitrogen deficiency on these atoll soils may be less serious than had previously been assumed. This result has since been confirmed in three other trials on Tuvalu. Since slow release nitrogenous fertilizers are extremely expensive to import these findings have important implications for the economics of coconut manuring on the atolls.

4.60 The increases in phosphorus and sulphur are encouraging though levels on the untreated plots are not indicative of any deficiency and neither element is normally a limiting factor on atoll soils. The reduction in calcium, magnesium and sodium can only be beneficial since these elements are too high in the untreated palms.

4.61 Iron-manganese antagonism has been demonstrated in a number of trials in Tuvalu and French Polynesia. This is a subject which requires further investigation since levels of both elements are normally very low, iron less than 30 ppm, and manganese less than 20 ppm. There is, however, some evidence that the local coconut varieties have become adapted to these very low manganese levels; 13 leaf samples taken from areas of apparently healthy palms in Kiribati averaged only 9.3 ppm manganese, with individual samples as low as 3 ppm. Despite the earlier Rangiroa results, three field trials and one nursery trial in Tuvalu have all failed to show responses to applications of manganese.

4.62 In Tuvalu potassium deficiency appears to be more widespread than that of nitrogen. In one nitrogen x potassium factorial trial, muriate of potash significantly increased yield but the nitrogen (applied as IBDU -
isobutylidene diurea - 32% N) had no effect. In another potash trial, placement of the fertilizer was also shown to be important, application 50 cm from the trunk giving yields 4.6 times higher than when the fertilizer was applied at a distance of 2 meters.

4.63 In atoll research, leaf analysis has always been preferred to soil analysis, largely because of the importance of the trace elements which tend to be fixed in the soil as insoluble compounds. Recently, however, the ISFEI extract method \(^1\) has been used in Tuvalu to determine levels of available phosphorus, potassium, copper, manganese, zinc and iron in soils. The results have been encouraging.

**Choice of Varieties**

4.64 Surveys of the local coconut populations have been carried out in both French Polynesia and Tuvalu to identify the best material for use in future breeding trials. In Tuvalu, the populations proved to be very heterogeneous, due perhaps to earlier introductions by man or to chance arrivals brought in on ocean currents. Whole fruit weights ranged from 479 to 3,308 grams; but of the fruit which weighed 3,308 grams 2,200 grams was husk (dry weight).

4.65 In Rangiroa, introductions made in 1964-65 included:

- Tall varieties -- from Vanuatu, and Rennell Island
- Dwarf varieties -- from Fiji (red and yellow), Tahiti (green) and Cook Islands (green)

Planted in a block along with selected Rangiroa tall and Rangiroa dwarf red palms the introduced varieties, particularly the talls, showed poor adaptation to the coralline environment.

4.66 The following hybrids have also been bred at Rangiroa:

- Rangiroa tall x Rangiroa tall
- Rangiroa tall x Rennell Island tall
- Rangiroa tall x Rangiroa red dwarf
- Rangiroa tall x green dwarf from Port-Bouet (or Equatorial Guinea)
- Rangiroa tall x yellow dwarf from Port-Bouet (or Ghana)
- Rangiroa tall x Cook Islands green dwarf
- Rennell Island tall x Rangiroa red dwarf
- Rangiroa red dwarf x green dwarf from Port-Bouet
- Rangiroa red dwarf x yellow dwarf from Port-Bouet

4.67 After 13 years of yield recording it was concluded that Rangiroa tall x green dwarf from Port-Bouet was the best variety, showing good adaptability to the environment, early bearing (first harvest at 3 years), high copra per

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\(^1\) Developed in the International Soil Fertility Evaluation and Improvement program of North Carolina State University.
nut (313 g) and a yield of almost 3,000 kg of copra per hectare at maturity. Three seed gardens have been set up on Raiatea in the Society Islands to produce this hybrid.

4.68 Most atoll countries have scattered plantings of various introduced varieties. Malayan red dwarf, Malayan yellow dwarf and Fiji dwarf are popular in village areas as toddy trees, but do poorly on less fertile soils. The Rennell Island tall is also liked in villages for its large nuts and can do well under high rainfall conditions on a “fertile” soil; under more normal coralline conditions it becomes chlorotic and unproductive. On Tarawa (Kiribati) 22 ha of Rennell Island tall x Malayan red dwarf hybrids, planted on reclaimed lagoon mud, have responded well to fertilizers and a half-hectare plot of Rennell Island x local tall hybrids appear fairly healthy despite being planted in poor coralline soil.

Establishment

4.69 On Kiritimati (Christmas Island), under conditions of low and irregular rainfall, it has been found that coconuts can be successfully established by digging planting holes down to the water lens (up to 2.5 m deep), refilling to 30 cm above the lens with topsoil and planting 3 to 6 months old seedlings. As the trees grow the pits gradually refill with windblown sand and eventually the boles are completely buried. Water and nutrients being obtained largely from the lens, the system can be considered a form of hydroponics. A successful variation of this technique is to open large pits with a bulldozer and plant a twin row of 6 to 10 palms, 2 meters apart, in each pit.

Spacing

4.70 Trials have been laid down in Kiribati to determine the spacing required under a range of rainfall conditions. Where rainfall is not a limiting factor the optimum density appears to be around 150 palms per hectare; but where precipitation is low (795 mm) even 120 palms may be too many (both figures refer to traditional management without fertilizers).

Maintenance

4.71 Leguminous cover crops are generally considered advantageous but only two species, *Canavalia sericea* and *Vigna marina*, have been found to survive under atoll conditions. Unfortunately, *Canavalia* (a climber) is invasive and costly to control while *Vigna* is difficult to establish more than 30 m from the sea. Trials have shown that good maintenance is important as untended bush growth competes seriously with the palms for available nutrients. Control of rats (*Rattus exulans* and *R. rattus*) is widely practised using baits of warfarin or, more recently, bromadioline. However, information is lacking on the economics of rat control in the atoll environment.

Research Priorities for the Future

4.72 Agronomy

i. Nutritional work to date has concentrated on the problems of the poorest soils; there is a need to investigate the economics of manuring on average to good soils.
ii. Injection of ferrous sulphate can cause necrosis at the site of injection and of the fronds, while soil applications require such large doses as to be uneconomic. There is a need to develop a more effective way of correcting iron deficiency and several new trials have been started in Kiribati to investigate this problem.

iii. Digging planting holes is the most laborious task in a replant operation; trials are needed to determine the optimum size of planting hole under a broader range of soil and climatic conditions.

4.73 Breeding

i. Genetic resources must be conserved and representative collections established. Especially important are heterogeneous populations such as those in Tuvalu.

ii. More variety testing needs to be done to determine adaptability to specific environments. Trials should include dwarf x tall hybrids using a local variety as the tall parent. At present the risk of introducing disease severely limits the possibilities for testing exotic material.

Pest and Disease Control

4.74 Due to the delicate ecological balance of an atoll and, in particular, the need to avoid pollution of the water lens, biological control is much to be preferred; pesticides should be used with extreme caution, if at all.

i. Serious pests, for which fully effective control measures have yet to be developed, include:

the coconut flat moth (Agonoxena argaula)

the stick insect (Graeffea crouani)

the coconut scale insect (Aspidiotus destructor) together with other species of scale insect and mealybugs, and the coconut borer (Homoeasoma spp.)

ii. Diseases. Leaf rot caused by Drechslera spp. (= Helminthosporium spp.) is particularly serious on nursery seedl-
ings and young palms growing under high rainfall conditions. Susceptibility to attack seems to be increased by applications of nitrogen and reduced by potassium but better control is needed.

Other Research

4.75 More work needs to be done on the marketing of coconut products such as palm hearts (millionaires' salad), toddy and toddy by-products, in order to reduce the atolls' dependence on copra.
C. Coconut as an Estate Crop
D. Friend and A. Leng

Economics

4.76 The coconut is predominantly a smallholder crop and large estates are comparatively rare. Nevertheless, they do exist, and the question to be asked is: Does the coconut have a future as a large scale plantation crop?

4.77 Twenty years ago the answer may well have been an emphatic no. However, recent advances in coconut breeding, in particular the development of hybrid varieties such as the MAWA (Malayan yellow dwarf x West African tall) and the MAREN (Malayan red dwarf x Rennell Island tall) have changed the picture, making the answer less clear. Copra yields in excess of 4 tons a hectare may now be expected, compared to the previous level of one to three tons. The potential for clonal propagation and even higher yields is just around the corner.

4.78 High yield alone may not be enough; great advances have also been made in the production of other vegetable oils, against which the coconut directly competes. The coconut does, however, have several advantages over most other oil producing crops and these may assure its future as an industrial crop.

4.79 Methods of maintenance, harvesting and processing are still relatively primitive and opportunities exist for cost reduction through improved technology.

4.80 The coconut is, moreover, well adapted to intercropping. In the immature years there is ample land and light available for a range of short term intercrops, income from which could offset some of the replanting, or new planting costs. At maturity, adjustments in planting density could permit a wide range of crops being grown in the interline. Thus there are opportunities for both large and small growers to improve their income per hectare and to spread risk.

4.81 There are also opportunities in many countries for exploiting a greater range of coconut products and by-products; in addition to the well established markets for copra, desiccated coconut and coconut oil, increasing use is being made of coconut cream and experimentation is in progress for the production of a whole range of new coconut based foodstuffs.

4.82 From the point of view of the large estate the role of the agronomist can no longer be restricted to investigating the problems of monocrop coconuts. He must also concern himself with farming systems and must be prepared to work in close cooperation with agricultural engineers, marketing experts and economists.

Farming Systems

4.83 The grower has basically three choices:

(a) Monocrop coconut - with no other revenue earning activity
(b) Mixed farming - with monocrop coconut as one component of a system including other crops or livestock.

(c) Intercropping - coconuts intercropped (during immaturity, at maturity or both) with other crops, including such options as production of pasture or fodder for livestock.

4.84 The choice should be based on a sound knowledge of the ecology; the market, and the general economic environment. The problem of selection is a complex one, and not every estate will make the right decisions, but at the regional or national level planners should be able to achieve a mix which makes efficient use of the resources available.

4.85 The agronomist, in collaboration with specialists in other disciplines, has a role to play both at the national and at the estate level. At the national level he should evaluate, and select the best amongst what is often a wide range of more or less suitable crops for the region. At the estate level, the choice is further refined to take account of a range of location specific factors (soil, climate, labour availability) which can affect the quality and profitability of the crop for the individual grower.

**Monocrop Coconuts**

4.86 This should be the yardstick against which other systems are evaluated. The difficulty is that most of the information available relates to populations of largely unimproved tall varieties. In most countries the potential of the best of the currently available hybrids when grown in monoculture has yet to be demonstrated and, until this is known, there is no sound basis for assessing the relative profitability of alternative systems. Clonal material, which may be expected to outperform the best of the available hybrid varieties, could also change the situation when successfully introduced on an estate scale.

4.87 **Land preparation.** Wherever possible the preparation of land for planting, or replanting, should allow for the mechanization of field operations. This may not at present seem urgent in some countries but coconuts are a long term crop and pressures, both economic and social, may necessitate mechanization before palms planted today reach the end of their economic life.

4.88 **In certain conditions complete clearing for the plough, or subsequent tractor access, may be deleterious to the soil.** The likely long term effect of such operations on crop development and soil stability should be assessed and weighed against the advantages.

4.89 **The nursery.** In large scale nurseries, it should be possible to achieve a greater degree of automation than is practised at present, e.g. by autobagging, remote controlled irrigation, and application of fertilizers and pesticides through the irrigation system. While the capital costs would be high, less labour would be required and the quality and uniformity of the planting material should be enhanced. When clonal material becomes available the automated system, operated on a sufficiently large scale, should certainly prove beneficial.
4.90 **Cover crops.** Cover cropping, usually with creeping legumes, is now standard practice on most estates producing tree crops as a monoculture, whether coconut, oil palm, or rubber. The mixtures chosen aim at providing a rapid cover in the immature stages and include species which persist under the denser shade of the mature trees. Agronomic problems are usually localized and related to establishment difficulties or pest infestation. New cover crop species should be tested as they become available.

4.91 **Planting density.** Conventional spacing experiments require large areas of land and are expensive to run; because of this, many of the early trials tested too few densities, covering too narrow a range, and used plots that were too small to avoid edge effects. Even if well enough designed, trials have often failed to give useful results because the objectives have been unclear. How is "optimum" density to be defined? For a company it may be the one that maximizes return on investment, in which case detailed costings must be kept and judgements made about the relative value of present and future crop. Where food security is an issue a government's prime objective may be to maximize yield per unit area of land; but a small farmer may equally look to maximize returns per unit of labour. The scientist will be interested in maximizing harvest index, or meeting some other criterion of biological efficiency.

4.92 Given that the objectives can be clearly defined, and that resources are available for collecting and analysing all the necessary data, the use of systematic fan-type designs allows the testing of a wider range and greater number of densities on relatively small areas.

4.93 However defined, the optimum density determined in a trial will be specific to the trial location and the particular varieties under test; but if trials can be organized to compare widely different types (e.g. a vigorous, large growing tall, some intermediate hybrids and a small dwarf) over a range of environments it may be possible to predict near optimum spacings for hybrids and cultivars as yet untested in formal density trials.

4.94 **Fertilizer use.** World Bank forecasts have indicated that between 1985 and the year 2000 the price of urea, in constant dollar terms, will increase by 25%, phosphate by up to 22%, depending on type and origin, and potash by around 5%. Copra prices, over the same period, are forecast to decrease by 20%.

4.95 The new hybrid varieties respond to substantial inputs of fertilizer applied during development and early maturity, and already fertilizers may represent 50% of an estate's direct production costs. Everything possible must, therefore, be done to ensure that fertilizers are used as efficiently as possible and that the requirements are limited by nutrient recycling.

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4.96 While foliar analysis is useful for detecting nutrient deficiencies or imbalances the results are subject to so many variables (accuracy of sampling, diurnal variations in leaf levels, seasonal factors, varietal differences) that it is rarely possible to use foliar analysis as a quantitative guide to fertilizer requirements and most large companies carry out their own trials, as a basis for determining fertilizer needs on the major soil types represented on their estates. Changes in nutrient status of individual fields are monitored by routine foliar analysis.

4.97 Even if fertilizer needs can be assessed with reasonable accuracy by experimentation, actual fertilizer policy will be affected by a host of extraneous factors. Prices and price prospects greatly influence the decisions taken. Financial constraints occur from time to time and one of the first "economies" advocated is usually to "cut out the fertilizer this year." Too little is known about the long term impact on production levels of these interruptions to a regular supply of nutrients; further research may prove them to be more harmful than is generally supposed. Development of computer programs to handle the large numbers of variables involved should result eventually in more effective decision making.

4.98 Application costs are usually small relative to the cost of the fertilizer. For mature palms on level terrain mechanical application presents no difficulty as suitable machines are readily available. In the immature phase, it is generally accepted that fertilizers should be applied in the drip circle, where feeder roots are most concentrated, and to achieve this it is usual to apply the fertilizer by hand. However, the efficiency of hand application frequently leaves a great deal to be desired, so the development of an interrupted band applicator, or a side placement distributor operating on two rows at once would be an advantage.

4.99 More attention should also be paid to the timing and frequency of fertilizer application. On most estates, fertilizers are applied once or twice a year without regard to differences in soil type or the solubility of the fertilizer. This is probably not the most cost effective system, but it remains extremely difficult to achieve sufficient accuracy in fertilizer trials to demonstrate differences due to fractionation of doses as statistically significant.

4.100 The most sophisticated method of applying fertilizer in the right place and at the right time is through an irrigation system and "fertigation," as it is called, is in widespread use in orchard crops. The capital cost of such an installation is high, but it may have its place in future on coconut estates using high yielding clonal material. It may also prove profitable in an intercropping system where the underplanted crop is of high value; experiments are already in progress on cocoa and coffee.

4.101 Weed control. Where cover crops are present the main tasks in immature areas are to maintain the purity of the cover by selective weeding and to circle weed the young palms. General inter-line weeding becomes necessary where there are no cover crops. The objectives are (i) to protect the young
palms from competition by weeds for moisture and nutrients and (ii) to maintain access for man and machine in the interline; both at minimum cost and without any deleterious effect on the palms.

4.102 A wide variety of herbicides is available, the different chemicals varying greatly in their degree of specificity in action. The principal objective of herbicide trials work is to identify the most cost effective solution for dealing with a particular spectrum of weeds, taking into account the cost of competing chemicals, and their relative persistence. Also important is their safety in use in terms of possible crop damage, environmental effects and toxicity to man.

4.103 Where labour is scarce and/or expensive more sophisticated methods of application should be investigated. For example the knapsack sprayer may be replaced by the controlled droplet applicator, resulting in productivity increases of 80 to 100 per cent. Tractor mounted sprayers are of such precision today that herbicides can be applied in almost any situation without adversely affecting the crop. Monitoring equipment ensures that the correct quantity of chemical is applied. For weed control, therefore, a survey of what is already available, and careful selection for the prevailing conditions is much more likely to be cost effective than extensive new field trials on the estate(s) concerned. Central research organizations and commercial suppliers are much better equipped to do the basic agronomic work on new products and processes.

4.104 Pest and disease control. As with weed control, the basic research is usually carried out by specialists. It must, however, be recognized that unsuitable agronomic practices can predispose plants to attack by pathogens and insect pests. Leaf spots, for example, in the nursery and in the field usually result from attack by a range of relatively weak parasites; outbreaks being triggered by adverse growing conditions such as moisture stress or nutritional deficiencies. Pest outbreaks may result from changes in the balance between the pest species and its natural predators, for example where a predator's weed host is destroyed by herbicides. The experimenter should always take into account and where possible assess these side effects arising from agronomic treatments. To this end, a comprehensive coconut pest and disease manual, well illustrated and easy to use by the non-specialist, would be a boon to the industry.

4.105 Harvesting and processing. In some countries the coconut is harvested from the palm, bunches of varying degrees of ripeness being cut by a sickle shaped knife attached to a long pole. Elsewhere fallen ripe nuts are collected from the ground beneath the palms. Both methods are labour intensive and would benefit from mechanization. Although a device has been marketed for the harvesting of dates from the palm, nothing effective has yet been developed for the coconut. When it is, due regard will still have to be paid to harvesting interval to ensure optimum quality in the end product whether it be the ripe kernel for copra or oil, or the less mature husk for coir manufacture.

4.106 Some crops are already picked from the ground by machine and delivered to a suitable receptacle, for example passion fruit and macadamia nuts. Given suitable ground conditions there must be an adaptation somewhere
that could be made to pick up coconuts. Relying on natural nut-fall is limited to certain cultivars and restricts the range of quality by-products that can be produced, e.g. coir. Attention should also be given to controlling fruit fall by chemical means.

4.107 At its most basic the production of copra involves splitting the nut, with or without prior removal of the husk, and exposing the kernel to the sun to dry. Where sun drying is impracticable various systems of smoke or hot air drying have evolved, using firewood, coconut shell, or husk and shell as fuel. While it is difficult to produce good copra with smoke dryers or direct hot air kilns, even the simplest indirect hot air dryers are adequate to meet the requirements of smallholders and are capable of producing top quality copra.

4.108 On estates the system is essentially similar, larger hot air dryers accept either half nuts in the shell or extracted fresh kernel. Although some continuous systems have been tried a batch process is usually used. Hot air is provided either directly by the complete combustion of diesel fuel or wood and nut waste or through heat exchangers using wood and nut waste. Fan assisted air circulation may be used to speed up the drying process.

4.109 Much could certainly be done to reduce the present high labour content of this generally unpopular task and there seems no reason why ultimately fresh kernels should not be extracted from the nut and processed into copra or oil, or put through a wet process by-passing the copra stage, in a factory type operation.

4.110 Coconut by-products. One of the strengths of the coconut palm is the variety of by-products that can be obtained from it. At the estate level, two major by-products are available as a result of copra extraction; fibre for coir production and shell for charcoal. Much remains to be learnt about the effects of agronomic practices (fertilizer regimes, harvesting standards, choice of varieties) on the yield and quality of these by-products.

4.111 New developments. Coconut cream is becoming increasingly popular. Processing by spray drying and the preparation of various protein supplements are being researched and other new coconut-derived food products are being investigated. It remains to be determined whether the quality of these new products will be influenced by varietal or climatic factors.

4.112 "Millionaire's salad", from the heart of the coconut palm, is now appearing on menus throughout the world and is amenable to canning and probably other forms of preservation. Its production could prove lucrative for the monocrop grower. An initial high density planting could be thinned when the young palms reached an age at which they would yield a reasonable crop of "salad". Trials would be required to determine the best initial density and the most appropriate rate of thinning to achieve an acceptable compromise between yield of salad and palm to palm competition affecting the precocity and early yield of the palms retained for eventual nut production.

Mixed Cropping and Intercropping

4.113 Estates often plant more than one crop, and usually these are in separate monocrop blocks. In these circumstances, the treatment of the
coconut component will not differ significantly from what happens on a pure coconut estate. The choice between separate monocrop blocks and some system of intercropping will be determined by the circumstances of the individual estate; particularly the range of soil types, topography, and the special requirements of the individual crops. In some circumstances monocrop blocks on selected sites may show higher returns than intercropping.

4.114 In parts of the world where pressure on land is high, intercropping of coconuts may represent the most efficient use of resources and small farmers have, over the centuries, developed some complex multi-storeyed, coconut based cropping systems. Only in comparatively recent times, however, has intercropping of coconuts been adopted on larger commercial estates.

4.115 In immature areas there is sufficient, though decreasing, light and root room for a range of crops. This "space" exists even if the ultimate aim is to grow monocrop coconuts. To exploit the interline in mature palms, however, needs more careful planning. If it is decided that coconut is to be the main crop, spaced to give maximum yield, then intercrops will be selected that adapt to the shade pattern imposed by the coconuts. If the intercrop is seen as the major revenue earner, the coconut may be no more than a shade tree with a potential return. Generally, the objective will be to maximize returns per hectare and reduce risk, through a combination of crops which together provide an element of protection against fluctuating commodity prices.

4.116 Interplanting in immature palms. Light interception and root zone exploitation by the palms increase exponentially over the first three to four years after planting. In the first year, if nutrients and water are not limiting, the interline can be prepared and treated as for a monocrop. Any field crop which does not overshade or smother the young coconuts can be selected. In subsequent years the plantable area declines; while the palms are less likely to suffer from competition for light they may be more vulnerable to competition for moisture and nutrients.

4.117 While marketability will be the prime consideration in the choice of an intercrop, research is required to:

(i) ensure that the most suitable crop within the marketable range is chosen;

(ii) determine the long term effect of the available intercrops on the precocity and productivity of the palms.

4.118 Permanent intercropping. If markets for short term intercrops are uncertain it may be preferable to use this period to establish a permanent intercrop such as cocoa. When the coconuts are a year or so old a temporary shade tree can be planted in the interline and the cocoa itself planted a year of two later. Where there is a market the temporary shade for the cocoa can itself be a cash crop, for example pigeon pea (Cajanus cajan). In such a case timing is very important; the temporary shade must not compete unduly with the young coconuts and yet must be of sufficient size to protect the young cocoa.
4.119 Other permanent intercrops can be established without shade during the immature phase. Examples would be vanilla, grown on trellisses, or trees such as cloves, allspice and nutmeg.

4.120 Probably, the oldest "intercrop" on estates is pasture for cattle. Considerable research has already been done and suitable grasses, or grass legume mixtures, have been identified for most environments.

4.121 More research is, however, required on the interactions between the coconut, particularly as regards spacing and density, and whatever intercrop is selected. With a multicrop system the design problems are even more difficult than with monocrop coconuts but the systematic fan designs again offer a means of reducing the size of the experiments required for more conventional designs. Paired fan designs, one intercropped the other not, could be used to investigate the competition effect of the intercrop on the coconut at different densities.

4.122 Although triangular spacing has been shown to be the most efficient for monocrop coconuts, a number of alternative arrangements merit investigation where permanent intercropping is envisaged, for example rectangular spacing, single or double hedgerow planting, clump planting, or various combinations of these.

4.123 Fertilizer regimes also require investigation in multi-crop situations. There is a tendency to apply to each crop the fertilizers that it would receive if grown in monoculture. This may not be the most economical solution. More needs to be known about total dry matter production, and the removal of nutrients in crop and crop waste, for each crop in the system when it faces competition for light, moisture and nutrients; not present in the monocrop situation under which most such studies have been carried out. Root distribution studies, coupled with the use of radioactive tracers, could be used to help determine the optimum placement of fertilizers so that each crop derives maximum benefit.

4.124 Much may be learned about the manipulation of trees, population densities, and mixtures of trees and herbaceous crops, by reference to the methods in use in agroforestry for studying interactions at the interface between crops. (See for example Plant Research and Agroforestry published by the International Council for Research in Agroforestry - ICRAF - in 1983).

4.125 Pest and disease control in intercropping may pose special problems. Occasionally there may be a pest which causes economic losses in both crops, such as the nutfall bug (Amblypellia cocophaga) which causes premature nutfall in coconut and tip wilt and pod damage in cocoa. Chemical control of a pest affecting one crop in a mixture may destroy the natural predators of a second pest affecting the other crop. Integrated control methods, with minimal recourse to persistent chemicals, are likely to offer the best solution.

Conclusions

4.126 With the recent development of much higher yielding varieties, and the likely availability of even more productive clonal material in the not too
distant future, the coconut may be expected to survive as a profitable mono-
crop on an estate scale.

4.127 More research is needed, however, so that mechanization can be
applied as rising living standards make labour increasingly expensive. As
fertilizers become relatively more costly, greater efficiency in their use
will also be necessary. The profitability of the crop could be enhanced by
the development of new coconut products and the more efficient use of by-pro-
ducts.

4.128 Coconut is already well established as the basis for a number of
intercropping systems but more needs to be known about interactions between
the different crops in order to maximize returns per hectare.
Response to Fertilizers

4.129 Long term research carried out by the IRHO on the West African tall (WAT) in Cote d'Ivoire since 1952, and by other organizations on local varieties in other countries has given quite consistent results. It has been shown that production can be doubled by appropriate manuring, the annual yield of mature palms increasing from around one metric ton of copra per hectare without fertilizers to two tons a hectare when nutritional deficiencies are corrected (Ochs and Ollagnier, 1977). It is usual to diagnose such deficiencies by leaf analysis and the following critical levels for leaf 14 are widely accepted (Manciot, Ollagnier and Ochs, 1980).

<table>
<thead>
<tr>
<th>Element</th>
<th>Critical Levels as a Percentage of Leaf Dry Matter in Frond 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.00</td>
</tr>
<tr>
<td>P</td>
<td>0.12</td>
</tr>
<tr>
<td>K</td>
<td>0.90</td>
</tr>
<tr>
<td>Mg</td>
<td>0.24</td>
</tr>
</tbody>
</table>

In practice, however, because the coconut is essentially a smallholder crop and growers face many socio-economic constraints, the potential benefits of manuring have never been fully realized.

Fertilizer Requirements of the Hybrid PB 121

4.130 The advent of hybrid varieties has had a big impact on the future prospects of the industry. The first such hybrid, the Port Bouet (PB) 121, a cross between the Malayan yellow dwarf and the West African tall, has proved both more productive and more precocious than tall varieties. First released in 1970 it is now widely planted throughout the world; with many countries using it for new plantings and to replace the very old coconut groves which are their main source of production. Nutritional research has therefore been redirected towards the needs of PB 121 and the other high yielding hybrids which are becoming available to diversify the range of planting materials.

4.131 The first trials with PB 121 were set up in 1970 in Cote d'Ivoire on the Marc Delorme research station and on the commercial estates of Palmindustrie. Subsequently, work was extended to Indonesia, the Philippines and, most recently, Brazil.

4.132 Nutrient uptake by young palms at different ages has been monitored by dissecting and analyzing PB 121 seedlings specially planted for the purpose. From three years onward growth considerably increases and, coupled with the onset of production, results in very high mineral consumption between three and six years when the root system is still not fully developed (Ouvrier, 1984). At maturity the requirements stabilize.

4.133 Nutrient removal in the crop has been measured on an area of 12 year old palms producing more than 6 tons of copra per hectare (Ouvrier and Ochs,
The results, set out in Table 4.2, show that although, because of the exceptional yield, the removal of nutrients is considerable, it is nevertheless about proportional to the lesser crop of tall varieties.

Table 4.2: HYBRID COCONUT PB 121: ANNUAL REMOVAL OF NUTRIENTS (KG) ASSOCIATED WITH A YIELD OF 6,700 KG OF COPRA PER HECTARE (138 bearing palms per hectare)

<table>
<thead>
<tr>
<th>Bunch components</th>
<th>Dry wt.</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Cl</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spikelet</td>
<td>492</td>
<td>3</td>
<td>&lt;1</td>
<td>14</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Stalk</td>
<td>349</td>
<td>1</td>
<td>&lt;1</td>
<td>7</td>
<td>&lt;1</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Husk</td>
<td>7,843</td>
<td>19</td>
<td>1</td>
<td>116</td>
<td>5</td>
<td>4</td>
<td>12</td>
<td>92</td>
<td>1</td>
</tr>
<tr>
<td>Shell</td>
<td>3,849</td>
<td>5</td>
<td>&lt;1</td>
<td>9</td>
<td>1</td>
<td>&lt;1</td>
<td>2</td>
<td>4</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Endosperm</td>
<td>6,375</td>
<td>80</td>
<td>13</td>
<td>47</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18,908</td>
<td>108</td>
<td>15</td>
<td>193</td>
<td>9</td>
<td>15</td>
<td>20</td>
<td>125</td>
<td>9</td>
</tr>
</tbody>
</table>

Potassium and chlorine dominate, which partly explains the importance of these elements in coconut nutrition. The husk accounts for 67 percent of the potassium and 85 percent of the chlorine. This indicates the considerable reduction in fertilizer requirement which can be achieved by leaving the husk in the field where it is quickly broken down, releasing the locked up nutrients to be recycled (Ouvrier and de Taffin, 1985).

4.134 Potassium and magnesium. Cote d'Ivoire plantations are found in coastal zones, on sandy soils very poor in exchangeable cations, particularly potassium and magnesium. Not surprisingly potassium and magnesium fertilizers markedly increase copra production in these situations. Unlike magnesium, potassium affects both the number of nuts and the quantity of copra per nut and there is a positive interaction when both elements are applied.

4.135 The first fertilizer trial on PB 121, Experiment PB CC16, set up in 1970 on a planting of the same year illustrates the effects of the two elements on both yield (Table 4.3) and foliar composition (Table 4.4). Copra production increased more than threefold, from 1.2 tons per hectare per year (8 kg per palm) without fertilizer to almost 4 tons a hectare (26 kg per palm) for the best treatment combination -- 3 kg of KCl + 0.75 kg of Kieserite per palm each year. Together the fertilizers also increased the levels of K and Mg in the leaves though KCl alone reduced leaf magnesium.
### Table 4.3 EXPERIMENT PB CC16 (1970 PLANTING): EFFECT OF POTASSIUM AND MAGNESIUM FERTILIZERS ON PRODUCTION, MEAN OVER 8 YEARS.

<table>
<thead>
<tr>
<th>Kieserite (33% MgO) Kg/palm</th>
<th>Kilograms of copra per palm</th>
<th>Tons of copra per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Muriate of potash (60% K2O) Kg/palm</td>
<td>Muriate of potash (60% K2O) Kg/palm</td>
</tr>
<tr>
<td></td>
<td>0 1.5 3.0 Mean</td>
<td>0 1.5 3.0 Mean</td>
</tr>
<tr>
<td>0</td>
<td>8.0 19.1 12.8 13.3</td>
<td>1.22 2.90 1.95 2.02</td>
</tr>
<tr>
<td>0.75</td>
<td>7.7 22.6 26.2 18.8</td>
<td>1.17 3.43 3.98 2.86</td>
</tr>
<tr>
<td>1.50</td>
<td>8.9 23.1 24.4 18.8</td>
<td>1.35 3.51 3.71 2.86</td>
</tr>
<tr>
<td>Mean</td>
<td>8.2 21.6 21.1 17.0</td>
<td>1.25 3.28 3.21 2.58</td>
</tr>
</tbody>
</table>

Main effects of K and Mg are significant at the 1% level of probability. The linear K x Mg interaction is 5.4 kg/palm (0.80 tons per hectare).

### Table 4.4 EXPERIMENT PB CC16 (1970 PLANTING): LEVELS OF K AND MG IN LEAF DRY MATTER, FROND 14, MEANS OVER 4 YEARS

<table>
<thead>
<tr>
<th>Kieserite (33% MgO) Kg/palm</th>
<th>K percent on dry matter</th>
<th>Mg percent on dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Muriate of potash (60% K2O) Kg/palm</td>
<td>Muriate of potash (60% K2O) Kg/palm</td>
</tr>
<tr>
<td></td>
<td>0 1.5 3.0 Mean</td>
<td>0 1.5 3.0 Mean</td>
</tr>
<tr>
<td>0</td>
<td>0.520 1.436 1.658 1.205</td>
<td>0.139 0.110 0.065 0.105</td>
</tr>
<tr>
<td>0.75</td>
<td>0.459 1.380 1.675 1.172</td>
<td>0.249 0.163 0.170 0.194</td>
</tr>
<tr>
<td>1.50</td>
<td>0.465 1.294 1.605 1.121</td>
<td>0.355 0.236 0.216 0.269</td>
</tr>
<tr>
<td>Mean</td>
<td>0.482 1.370 1.646 1.166</td>
<td>0.248 0.170 0.150 0.189</td>
</tr>
</tbody>
</table>

Main effects of muriate of potash on leaf levels of both K and Mg are significant at the 1% level of probability. The effect of kieserite on leaf Mg is significant at the 5% level.

The response surface calculated from the experimental data indicated a maximum theoretical yield of 26.6 kg of copra per palm per year in response to annual applications of 2.4 kg of KCl + 1.3 kg of kieserite. However, taking into account harvesting and processing costs (US $70 per ton of copra),
the applied cost of the required fertilizer mixture (US $200 per ton) and the ex-plantation price of copra (US $200 per ton) over the experimental period, the economic optimum rates of application were shown to be 2 kg of KCl + 1 kg of kieserite for a yield increase of 18.3 kg copra per palm (2.75 tons per hectare) -- yield with fertilizer 25.8 kg per palm (3.87 tons per hectare), yield without fertilizer 7.5 kg per palm (1.12 tons per hectare). The critical, frond 14, leaf levels were found to be 1.4 per cent of K and 0.2 percent of Mg on leaf dry matter.

4.137 The response represents an annual return of US $2.35 per palm (US $352.50 per hectare) for an outlay of US $0.60 per palm (US $90.00 per hectare), a highly satisfactory benefit:cost ratio of almost 4:1.

4.138 These results were obtained at a time when it was still standard practice to remove the nuts from the field prior to husking. For the past four years husking has been done in the field and it is expected that this will allow the same yields with even less fertilizer (trial in progress).

4.139 Potassium and chlorine: Where potassium is shown to be deficient it is usual to apply muriate of potash (KCl). However, chlorine also plays an important role in coconut nutrition (Ollagnier et al., 1983) and it can at times be difficult to apportion an observed yield response between the two elements. In the preceding experiment, set up a few kilometres from the ocean, the effect of chlorine, if there is one, is extremely difficult to separate from the massive response to potassium. It is suspected, though this has not yet been proven, that the high critical leaf level found for K (1.4 per cent against the normal 0.9 percent) was the result of an additional chlorine effect (leaf chlorine increased from 0.3 to 0.7 percent in response to the KCl applied). Moving only 20 or 30 kilometers further inland, the chlorine effect was clearly demonstrated in Experiment DA CCl at Dabour where leaf chlorine on the control plots was <0.1 percent. Application of sodium chloride alone increased yield from 8 to 12 kg per palm: KCl alone gave 15.5 kg and KCl + NaCl gave 24.2 kg (Table 4.5).
Table 4.5: EXPERIMENT DA CCl: EFFECT OF MURIATE OF POTASH AND SODIUM CHLORIDE ON YIELD AND FOLIAR COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>Muriate of potash</th>
<th>Sodium sulphate</th>
<th>Sodium chloride</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Copra kg/palm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.1</td>
<td>12.2</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>15.5</td>
<td>24.2</td>
<td>19.9</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>11.8</td>
<td>18.2</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td><strong>K\text{I} on leaf d.m.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.388</td>
<td>0.402</td>
<td>0.395</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.380</td>
<td>1.440</td>
<td>1.410</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.884</td>
<td>0.921</td>
<td>0.903</td>
<td></td>
</tr>
<tr>
<td><strong>Cl\text{I} on leaf d.m.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.076</td>
<td>0.549</td>
<td>0.313</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.136</td>
<td>0.661</td>
<td>0.399</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.106</td>
<td>0.605</td>
<td>0.356</td>
<td></td>
</tr>
</tbody>
</table>

4.140 Two experiments in Indonesia, both set up at about the same distance from the sea (Bangun Purba and Bah Lias Estates in North Sumatra) also show a considerable chlorine effect on yield. The soils are much richer in potassium, with leaf K on control plots already higher than the 1.4 percent critical level found in the experiment at Port Bouet. Leaf chlorine, on the other hand, increased from about 0.1 percent on the control plots to 0.3 - 0.4 percent following applications of KCl (Table 4.6).
Table 4.6 EFFECT OF MURIATE OF POTASH IN EXPERIMENTS AT THREE SITES IN INDONESIA

<table>
<thead>
<tr>
<th>Muriate of potash</th>
<th>Ban Purba N. Sumatra</th>
<th>Bah Lias N. Sumatra</th>
<th>Bergen Lampung</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Copra kg/palm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.7</td>
<td>11.4</td>
<td>17.2</td>
<td>12.4</td>
</tr>
<tr>
<td>1</td>
<td>15.7</td>
<td>16.7</td>
<td>27.0</td>
<td>19.8</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>18.7</td>
<td>27.5</td>
<td>(23.1)</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>(12.2)</td>
<td>15.6</td>
<td>23.9</td>
<td>(17.9)</td>
</tr>
<tr>
<td><strong>K\textsuperscript{+} on leaf d.m.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.410</td>
<td>1.500</td>
<td>0.686</td>
<td>1.199</td>
</tr>
<tr>
<td>1</td>
<td>1.530</td>
<td>1.560</td>
<td>0.819</td>
<td>1.303</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>1.600</td>
<td>0.892</td>
<td>(1.246)</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>(1.470)</td>
<td>1.530</td>
<td>0.799</td>
<td>(1.250)</td>
</tr>
<tr>
<td><strong>Cl\textsuperscript{-} on leaf d.m.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.037</td>
<td>0.120</td>
<td>0.046</td>
<td>0.068</td>
</tr>
<tr>
<td>1</td>
<td>0.257</td>
<td>0.430</td>
<td>0.243</td>
<td>0.310</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
<td>0.530</td>
<td>0.412</td>
<td>(0.471)</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>(0.147)</td>
<td>0.360</td>
<td>0.211</td>
<td>(0.259)</td>
</tr>
</tbody>
</table>

4.141 In a third experiment in Indonesia (Bergen Lampung) K and Cl may both have contributed to the response though correlation analysis clearly points to a dominant chlorine effect:

\[
\text{Copra/tree as a function of K (Cl constant)} \quad r = 0.0001 \\
\text{Copra/tree as a function of Cl (K constant)} \quad r = 0.69^{**}
\]

In this experiment, as on many commercial plantations located on clay soils poor in K and rich in exchangeable Ca or Mg, it appears difficult to bring leaf K up to the Ivorian critical levels; posing the question of a possible cation antagonism between K and Ca or Mg. On some heavy red clay soils in Java it has proved impossible to raise leaf K above about 0.7 to 0.8 percent without applying massive and quite uneconomic doses of fertilizer. Clearly much research remains to be done before it will be possible to establish reliable critical levels for potassium in all situations.

4.142 On the other hand, chlorine deficiency is easily determined. It plays a role as soon as one moves away from the coast, even at short distances inland as in Cote d'Ivoire and the Philippines. Fertilizer treatments can therefore concentrate on correcting this deficiency, using the least expensive source of chlorine while also taking into account a possible accompanying
cation effect (Ollagnier and Wahyuni, 1984). The experiment at Bergen, affected by a very severe drought in 1983, showed that chlorine also plays a role in drought resistance. More basic studies on the nature of this effect have been undertaken by the IRHO in Cote d'Ivoire from which it appears that chlorine may be important in controlling stomatal movement.

4.143 **Nitrogen.** In Cote d'Ivoire, experiments have shown that in a well managed plantation, developed from forest, with a legume cover established at planting and where fallen palm fronds remain in the field, nitrogen supply is normally adequate in spite of the soil's low organic matter and nitrogen content. On replantings, and without a legume cover, severe nitrogen deficiencies occur and very heavy applications of nitrogenous fertilizer are required to bring leaf levels up to the critical value. In very highly populated regions of the coast, small farmers have, for decades, been using coconut fronds and husk for building material and domestic fuel. The soil on these old coconut groves, impoverished in organic matter, has lost its capacity to retain moisture and nutrients to the point where it has become almost impossible to establish traditional cover crops such as Pueraria. Replanting, even with high yielding hybrid material would be only marginally economic on account of the large amounts of nitrogen fertilizer required. Research is being oriented towards the use of hardy, shrubby legumes planted with coconut in an attempt to both restore fertility and provide an alternative fuel for domestic needs.

4.144 Experiments on PB 121 in Indonesia have not shown significant yield increases in response to nitrogen fertilizers despite relatively low leaf N levels (1.8 - 2.0 percent). Can it be concluded that hybrid coconuts, at least PB 121, do not under normal conditions need much additional nitrogen despite their apparently high requirements? It should, however, be emphasized that nitrogen fertilizers frequently do have a positive effect on the growth of young palms.

4.145 **Phosphorus.** There have been few, if any, significant responses to phosphate on sandy soils in Cote d'Ivoire whose sole advantage is that they are not particularly low in phosphorus. Yield increases obtained (5 - 6 percent) are quite modest in comparison to responses to potassium fertilizers.

4.146 Two other experiments were set up using PB 121, one in Benin on palms benefitting from irrigation, the other at Bergen Lampung in Indonesia. Soils at both sites are very deficient in phosphorus (total P 100 ppm). Yield increases remain, nevertheless, not more than 3 or 4 kg copra per palm per year in response to applications of 3 kg of rock phosphate. The critical level for leaf P would appear to be around 0.135 percent, higher than the 0.12 percent derived from the earliest experimental results. However, the economics of manuring to achieve this level will depend on cost factors.

4.147 **Fertilizer rationing.** Responses to fertilizer generally follow the law of diminishing returns with the unit response diminishing as the rate is increased. Therefore, fertilizer rationing, i.e. using lower rates than those indicated to achieve maximum yield response, while reducing production also reduces the fertilizer budget and may show a higher return on investment.
This is particularly important for the small farmer who, needing the money for other purposes, frequently cannot afford to apply the fertilizer needed to maximize yield.

4.148 Table 4.7 illustrates the effect of such fertilizer rationing with a practical example based on the data from Experiment PB CC16. The amount of fertilizer (3.7 kg per palm per year) required to achieve maximum yield was reduced in steps of 20 percent and at each level the profit and the benefit:cost ratio were calculated on the basis of costs ruling at the time. As previously indicated the economically optimum rate was found to be 3 kg per palm of a mixture containing 2 parts of KCl and 1 part of kieserite. Halving the fertilizer rate reduced the yield by 24 percent and the net profit from fertilizer by 27 percent but the benefit:cost ratio improved by 35 percent, from 4:1 to 5.4:1. All else being equal, if the price of copra were to fall by 50 percent the economically optimum rate of fertilizer would reduce to 1.5 kg per palm and the critical leaf levels would drop from 1.4 to 1.2 percent for K and from 0.2 to 0.18 percent for Mg.

Table 4.7 EXPERIMENT PB CC16: EFFECT ON PRODUCTION OF RATIONING DOES OF MURIATE OF POTASH AND KIESERITE

<table>
<thead>
<tr>
<th>Fertilizer Mixture Per Palm Per Yr.</th>
<th>Production. Copra/Palm/Year</th>
<th>Financial results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kg</td>
<td>Kg</td>
<td>US$/Palm</td>
</tr>
<tr>
<td>3.7</td>
<td>100</td>
<td>26.6</td>
</tr>
<tr>
<td>3.0</td>
<td>80</td>
<td>25.8</td>
</tr>
<tr>
<td>2.3</td>
<td>60</td>
<td>23.5</td>
</tr>
<tr>
<td>1.5</td>
<td>40</td>
<td>19.7</td>
</tr>
<tr>
<td>0.8</td>
<td>20</td>
<td>14.4</td>
</tr>
<tr>
<td>0.0</td>
<td>0</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Fertilizer mixture comprises muriate of potash and kieserite. Original cost data were in CFA francs, here converted to US$ to facilitate comparison with other data.

4.149 In an experiment such as PB CC16 with treatments tested at only three levels the true effect of low rates of application cannot be determined with sufficient precision. To remedy this situation the protocol of ongoing experiments has been modified and new trials, designed specifically to study the effect of fertilizer rationing, have been set up on smallholdings.

4.150 Substitute fertilizers. As terms of trade are likely to worsen in the years ahead, with imported fertilizers becoming increasingly expensive relative to the price of copra, the economics of manuring must be kept under constant review. Savings can certainly be made if by-products, such as old
fronds and coconut husk, can be left in the field and further economies can be made by selecting the cheapest source of required nutrients (sodium chloride for example). In addition, efforts should be made to make better use of all kinds of organic fertilizer available on or near the plantation. Nitrogen fixation is also important, particularly in the case of impoverished soils where a minimum reconstitution of organic matter is required.

Basic Research

4.151 Preliminary studies have shown that the development of the coconut root system varies considerably according to soil type. However, more needs to be known about the uptake of nutrients, whether available in the soil or applied as fertilizer, if application techniques are to be optimized as regards timing, frequency, and placement. Moreover, the evolution of soils under typical conditions of exploitation should be more intensively studied to determine possible long term harmful effects of certain agronomic practices. Simultaneously, effort should be put into developing methods for the restoration of degraded soils.

Conclusions

4.152 Although a good deal of information has been acquired about coconut nutrition, particularly with respect to the requirements of the new hybrid material, a number of problems remain. Through foliar analysis in association with fertilizer experiments critical leaf levels have been determined for most of the elements, though there is still some uncertainty, notably as regards chlorine. The consequences of fertilizer rationing, whether permanent or temporary, merit close attention in the context of both industrial estate management and the special problems of smallholders.

4.153 Up till now, research has been focused on the requirements of PB 121, the first dwarf x tall hybrid to be extensively planted around the world. With attention now being paid to the requirements of other hybrids it may be possible to identify even more efficient planting material, giving still higher yields under optimum conditions, or showing improved performance under conditions of sub-optimal nutrition.
REFERENCES


Ouvrier M. 1984. Study of the growth and development of young PB-121 (MYD x WAT) hybrid coconuts.


E. The Nutrition of Young Coconut Palms
R. W. Smith

Introduction

4.154 Up to twelve years may elapse between planting a coconut seed and the realization of an economic return. The necessary investment in terms of finance and labor tends to deter many small farmers from either replacing old stands of palms or planting new groves. Over the past 20 to 30 years, research has done much to shorten this period by production of more precocious varieties and the development of improved agronomic treatments. Productivity throughout the life of a coconut palm is influenced by its treatment in the early years. Given a good start in life, allowing it to develop a strong root system and initiate a sturdy trunk, the palm will come into bearing early and will be able to realize its yield potential in future years.

Components of Yield

4.155 Once flowering has commenced, a healthy coconut palm produces an inflorescence in each leaf axil. The early leaves however either do not have inflorescence initials in their axils, or these do not differentiate and develop. Yields initiation thus depends upon two factors:

(a) the rate of leaf production. A fast rate reduces the time taken for the first inflorescence bearing leaf to be produced and;

(b) the initiation of an inflorescence in the axil of as early a leaf as possible.

4.156 Inflorescences always have ample male flowers, producing a surplus of pollen. However, the number of fruit per bunch is dependent upon the number of female flowers and the proportion of these which set. Yield subsequently and continuously depends upon the following factors:

(i) the rate of leaf production, and hence

(ii) the rate of inflorescence production;

(iii) inflorescence abortion; normally this is not a problem, but it can occur under certain edaphic, climatic or other conditions;

(iv) number of female flowers per inflorescence;

(v) percentage setting and retention of young fruit and;

(vi) growth and development to maturity of the fruit.

4.157 Yield in terms of copra production, oil production and the production of by-products such as coir fibre, shell, copra cake and even coconut water depends upon:
(i) fruit size;
(ii) the husk to nut ratio;
(iii) endosperm, shell and water content of the nut;
(iv) water content of the endosperm; and
(v) percentage oil in the endosperm.

There are additional "quality" factors which are more or less important, depending upon local practices, markets and end uses. These include:

(i) Size of nut;
(ii) Fibre quality;
(iii) Huskability (ease with which the husk is removed from the fruit);
(iv) Oil quality (composition);
(v) Water quality (sweetness);
(vi) Protein content of the endosperm;
(vii) Propensity for fruit to germinate on the parent palm;
(viii) Pest and disease resistance; and
(ix) Rate of vertical growth (influenced by internode length and rate of leaf production), which affects tree height and cost of harvesting.

Effect of Nutrition on Early Yield

4.158 Nursery Practice: Coconut seed nuts in the nursery do not normally respond to fertilizer. They usually have ample nutrient reserves in the endosperm, and the young roots emerging from the seed serve only to anchor the seedling and to absorb water. It is therefore important to ensure that seedlings are not left too long before transplanting, resulting in depletion of nutrients, and that roots are not damaged when the seedlings are lifted. The connection between the shoot and the haustorium inside the cavity of the nut is fragile, hence care must be taken to protect it. The use of poly bags has been shown to reduce transplanting shock, but is an added cost and the profitability of their use is doubtful.

4.159 Transplanting: The nutrition of transplanted seedlings is important. In sandy loams, loams or clay loam soils, phosphate is often applied in the planting hole, but clear cut responses are not always achieved. However, in
calcareous, shaly or coralline soils establishment is markedly improved by incorporation of organic matter, phosphate, and trace elements, especially iron and/or manganese.

4.160 **The Pre-bearing Years:** Growth of young coconut palms is retarded by shade and by competition from weeds. The grower should therefore ensure that his palms are not shaded (for example by a catch crop such as bananas or by underplanting in existing over-dense coconut groves), and that weeds are controlled by keeping weed free circles around each palm, either by hand weeding or the use of herbicides. Response to fertilizer, is much reduced in the presence of weeds or shade, although nitrogen will even then prove beneficial on sandy soils or soils which seriously lack organic matter. In the pre-bearing period, nitrogen is particularly important. The quantity required is related to soil conditions and is best determined by experimentation coupled with leaf analysis. In the absence of location specific data a useful guide is 400 g of sulphate of ammonia (21% N) per palm per year of age up to the fifth year, or to aim at foliar levels of N = 1.8%, on D.M. in a mid-canopy leaf. A precise sampling procedure for young palms is not yet available, and the interpretation of results can be difficult. However, foliar symptoms can be a valuable guide to diagnosing deficiencies of N or K: shortage of N results in a pale leaf color, shortage of K in premature yellowing of the mature leaves with terminal necrosis on the pinnae. It should be stressed that the palm responds to the removal of weeds more than to fertilizer application during these early years, and water relations are exceedingly important.

4.161 An adequate supply of nitrogen significantly increases the rate of leaf production and accelerates the onset of flowering. Both trunk diameter and leaf length tend to be increased. Little or nothing is known of the effect of nutrition on development of the root system, and the instances where there has been a positive effect of phosphate, or a N x P interaction, could indicate that phosphate might be beneficial in this regard, particularly on phosphate deficient soils.

4.162 Little research has been done on the role of leguminous cover crops in supplementing the N supply of young palms, though they may be beneficial where the soils are suitable, and the legumes can be supplied with adequate phosphate. Intercropping with annual food crops, such as sweet potato, cassava, maize, sunflower and pumpkins may provide additional revenue and the palms do not suffer provided that the intercrops are not planted too close. Fertilizers applied to the inter-crops reduce competition between them and the palms and can have a direct benefit to palm growth. The surface feeding roots of young palms can easily be damaged by cultivation of the soil in preparing land for inter-crops, and care should be taken to avoid this.

4.163 Young palms, especially the Malayan dwarf and its hybrids can suffer from leaf diseases, such as Pestellotia, Helminthosporium and Dreshleria, especially where the nutrient balance is incorrect: High N : K ratios pre-dispose the trees to infection. There are no reported interactions between other diseases or pests and young palm nutrition.
4.164 The Early Years of Bearing. From the second year, in the case of dwarf palms, to the 4th - 6th year in the case of hybrid or tall palms, the inflorescences normally start to appear and the palms rapidly settle down to regular spathe production. For early high yields, the agronomic objective is to ensure that each inflorescence carries at least a minimum number of female flowers, (10 per inflorescence is a useful indicator) and that the rate of inflorescence production is sustained at a high level. The numbers of female flowers per inflorescence, and the rate of inflorescence production are markedly affected by nitrogen nutrition, and the proportion of female flowers held after pollination is enhanced by potassium nutrition.

4.165 Most growth characteristics of agronomic importance are genetically controlled, including internode length, leaf length, numbers of pinnae per leaf, pinnae width and fruit composition. Leaf length and fruit size can be affected by nutritional status, mainly by N and K, and leaf retention is affected by potassium nutrition, potassium deficiency causing premature senescence of leaves, resulting in fewer leaves per crown. In extreme conditions, this can result in low net assimilation rates and shedding of leaves prior to maturity of the fruit in their axils, and their support (both physical and physiological) can be lost, resulting in premature fruit drop.

Research Priorities

4.166 The following topics require further study:

Basic Information (Strategic Research)

(i) The effects of nutrition on the development of coconut root systems.

(ii) The role of mycorrhiza in coconut nutrition.

(iii) Foliar analysis as a diagnostic tool for assessing fertilizer requirements of young coconut palms.

(iv) The role of leguminous crops in the N nutrition of young palms.

Location Specific Information (Adaptive Research)

(i) Studies on nutrition of young palms in relation to soil conditions, and interactions between the coconut and associated intercrops.

(ii) Establishment systems for new palm groves and for replacement of old palms.

Socio-economic factors are important, as are markets for intercrops.

Conclusions

4.167 The nutrition of young coconut palms is important in establishing vigorous, early bearing and high yielding palms which have the ability to
sustain high productivity throughout their economic life. Weak palms, developing thin trunks due to poor nutrition can never be rehabilitated into high production. Nitrogen is the key, and its status should be maintained by assessing the rate of leaf production, onset of bearing and number of female flowers per inflorescence, supplemented by foliar analysis and observations of foliar symptoms. All these factors can guide the appropriate remedial treatment.
4.168 Reliable statistical methods for the design and analysis of perennial crop data have been available for many years, an excellent description of such techniques being given by Pearce (1976). However, as agronomic research develops, the need for new statistical methods also increases; a description of some of the available methods and of some necessary statistical developments are given here with particular relevance to the coconut.

4.169 Coconut palms like many other perennial plants, grow to be large and live for many years. This first property implies that two palms, although chosen to be as similar as possible, may develop unexpectedly with different patterns of growth during the several phases of development and the second property results in palms being subject to damage or destruction before the end of an experimental period. Unlike annual crop experiments, perennial crop experiments have a possibility of three sources of error: initial plant-to-plant variation brought over from the nursery, plant-to-plant variation which develops soon after planting and environmental variation caused by position within the field. The first source of error usually disappears very rapidly, the second develops quickly and soon reaches its maximum but the third builds up during the course of the experiment and becomes the main source of error. Details of this division of error can be found in Smith (1938), Pearce (1960) and Freeman (1963). With long-term experiments on coconuts, the most uniform land should be chosen, any irregularities controlled by a suitable choice of design, and defective plants should be excluded.

4.170 Much has been written on the design of experiments and a summary of such work is not given here: some comments upon the relevance of different designs for coconut trials will suffice. The most common design for use with trees is the randomized block design. Besides being relatively easy to analyze, the design is robust to the many disasters which may occur during the life of the experiment. If whole plots, whole blocks or whole treatments have to be omitted from the analysis, reliable estimates of the treatment effects can still be obtained. Also, should the original set of treatments be discontinued and a second set tested on the same trees, a randomized block design permits easy allocation of new treatments to old plots.

4.171 Other designs such as Latin squares, split-plot designs and non-orthogonal designs are useful should practical considerations demand them and economy need to be exercised. However, with coconut palms, which are non-clonal, most of the variation will come from the plants themselves: smaller blocks will involve fewer plants such that greater variation will result. Concentration upon the elimination of environmental variation with complex designs will not necessarily reduce the overall variation in the experiment, unless the trial is short-term and upon well-established palms. Also, in a long-term trial subject to possible accidents, even simple designs can become difficult to analyze while complex designs can become impossible to analyze.
4.172 As coconut palms live for many years, their effect upon the soil can be considerable; when the palms are removed the site must be examined carefully for residual effects before it can be used for another trial. To reduce the chance of interaction with the residual effects, new treatments must be carefully balanced with respect to old treatments, such as by the use of efficient blocking procedures.

4.173 The shape and position of blocks is dictated by the land upon which the experiment is to be sited. In general, it is advisable to keep the blocks small and compact so that the land within each is as homogeneous as possible and palms are planted so that they "neighbor" each other and thus grow in as similar a way as possible. The choice of large blocks formed from palms of similar condition or behavior should possibly be avoided in favor of calibration which will take account of both palm-to-palm and environmental variation, whereas blocking will only take account of the latter variation.

4.174 The choice of number of palms per plot depends very largely upon the area of experimentation and the climate, but Joachim (1935) found that 18 or 20 coconut palms per plot planted at a 25 ft x 25 ft spacing gave optimum results in terms of standard error per plot, which was about 14%. For treatment differences of 15% to be considered significant, he found the required number of replications to be six. The use of adequate numbers of guard rows is essential where treatments may spread from one plot to another, as the root system of the coconut palm is extensive and can encroach on adjacent plots.

4.175 If a young palm dies or becomes diseased during the early stages of a trial, it should be removed and a seedling of similar size and quality should be planted in its stead so that root competition can continue as before. Should several losses be expected during the early stages of growth then all replacements should be made at the same time so that the new palms will be similar and can be allowed for in the analysis in a relatively straightforward way.

Recording the Crop and Analyzing the Data

4.176 Yield varies greatly from palm to palm within an experiment. Therefore data showing responses to treatments, climatic effects and disease incidence should all be recorded on an individual palm basis. Any consistent patterns in behavior can then be accounted for at the analysis stage. Although all palms within one experiment may be of the same age they will not necessarily, even if of the same variety, come into bearing at the same time. There will also be a considerable lag between the first application of a treatment and its measurable effect on yield; as much as 2 years for an effect on numbers of nuts per bunch and about a year for weight of copra per nut. The amount of data collected will depend on the resources available but should ideally include measurements of vegetative dry matter production (frond number, frond weight, annual increment in stem growth), canopy measurements and estimates of light penetration, nutrient removal in crop by-products, number of bunches, female flowers per bunch, number of nuts set, number of nuts reaching maturity, nut composition (husk, shell, fresh kernel, nut-water), harvest index, and incidence of pest and disease attack.
If records are kept for at least one year before experimental treatments are applied, the data can be used as calibrating measurements and their use as independent variates in the analysis of covariance permits adjustment of the treatment means to correct for the effects of initial random palm-to-palm variations. More than one independent variate can be used in the analysis if their inclusion increases precision. Abeywardena (1964) obtained a better analysis of coconut yield by using \( x \), the number of bearing palms per plot, and \( y \) as double covariates. As the coconut palm tends to biennialism in cropping, adjustments of yield by measurements from several years can be advantageous. Iyer (1958) found that the average of the last three pre-experimental years' yield data formed a covariate which helped detect differences between manurial treatments. The choice of the number of pre-experimental years' data will be dictated largely by the treatments involved: if many years pass before a treatment effect is likely to appear then covariates must be found from the pre-experimental years, however long ago they occurred.

Whilst a biennial bearing tendency has been reported in coconut, the extent to which the palms in an experiment bear biennally should be ascertained for the treatments being tested. Once this is known, fluctuations in yields can be accounted for in the analysis. Hoblyn et al., (1936) proposed an index, \( B \), to establish the existence of biennial bearing in fruit trees, and a second index, \( I \), to measure the intensity of the bienniality. Although the first index is considered to be insensitive, the second has been found to be a useful measure and should be examined using analysis of variance upon the calculated values for all of the plots. Abeywardena (1962) examined this approach in relation to coconut yields and found that although a biennial bearing tendency existed, annual fluctuations caused by the effect of the previous year's rainfall on developing bunches were sizeable. Abeywardena suggested, therefore, that Hoblyn's indices should be used on data which have been adjusted for the effects of the weather.

Although an efficient statistical analysis requires the summary of data collected each year, the analysis of all the data collected over the whole period of the experiment can provide valuable extra information. The simplest way is to add together all of the data from one plot over the whole period to give total yield and to analyze the resulting measurements. Similar calculations can be done for separate periods during the length of the trial, although with the biennial cropping tendency in coconut, the periods, to be comparable with each other, should be of equal length and should contain an even number of years. A more detailed analysis including time as a factor can be useful, though time should not be considered to be a split-plot factor. For each plot there are successive observations made at various points in time. Unlike in a true split-plot experiment, these successive observations cannot be randomized at all and they will be correlated, those taken more closely in time being more likely to be closely correlated than those which are widely spaced in time. Rowell and Walters (1976) discussed a more accurate method of analysis of data collected over time. They advocated the calculation of the corresponding error degrees of freedom. For example, if the effects of \( t \) treatments on the rate of change of yield in coconuts is of interest, a linear regression can be fitted to the \( h \) annual measurements for each
plot; an analysis of variance of the $ht$ linear regression coefficients can then be produced. If interest lies in the quadratic component as well, this can also be calculated for each plot and an analysis of variance produced of the $ht$ quadratic-component regression coefficients. If a total of $c-1$ such contrasts are calculated and analyzed, the sum of all $(h-1)$ error sums of squares and the $(h-1)$ block sums of squares are the error sum of squares for the inadvisable split-plot analysis. The total of the $(h-1)$ error sums of squares may be quite different from the total of the $(h-1)$ block sums of squares and the $(h-1)$ error mean squares from the separate analyses may also be quite different, thus invalidating any combined analysis. The partitioning of the analysis for each contrast is therefore necessary so that comparisons between appropriate treatment and error mean squares can be made.

**Intercropping and Agroforestry**

4.180 Mixed tree and food crop systems are important in the tropics and semi-arid tropics since the inclusion of several species provides the farmer with a range of food and cash crops, fuel and shelter. Typical agroforestry farming systems comprise an upper storey of timber trees or palms, a middle storey of fruit bushes and a lower storey of cereals, legumes and root crops. Here, each of the species may be of equal importance. In the taungya system, annual species are grown between rows of trees during their establishment. This protects the soil of the exposed interlines against erosion and provides food for the farmer during these early years. Here the important crop is the tree crop, the growing of the annual species being abandoned once the trees have developed. Other systems may include animals to graze the pasture under the trees, whilst returning nutrients to the soil in the form of manure.

4.181 The coconut palm traditionally has been intercropped in India and the Far East. More complex systems with coconut include spice trees, fruit and coffee bushes. Cocoa has proved particularly successful as an intercrop on an industrial scale. Research priorities involve the identification of profitable combinations of species with coconut palms, the improvement of farming practices for these combinations and the adequate assessment of experimental data from the associated species.

**Design of Intercropping Experiments**

4.182 Because intercropping experiments involve more than one species, the number of factors to be investigated is much larger than in monocropping experiments. A complex design immediately becomes more complex when a second species is included in the trial, and the relative arrangement of the two species also becomes a factor of interest. With the length of life of coconut palms and the possibility of tree loss before the end of the experimental period, the design of an intercropping trial can become very different from the original plan and the subsequent analysis can be far from simple. The most robust design for such trials is the randomized block design, with possible factorial treatment structure and careful use of confounding to reduce block size, if necessary. Additional plots may be needed for monocrop treatments, if a comparison is to be made between the mixed-crop treatments and the coconut grown alone. These plots may be randomized amongst the intercropped plots within each block or they may be placed around the edge of the
blocks, rather like control plots in some monocropping experiments. However, if the purpose of the experiment is to compare intercropping treatments with each other, then monocrop plots are not needed and should be excluded from the design.

4.183 The use of split-plot designs should be avoided except when practical requirements demand their use. With such a design, the treatments applied to the mainplots are estimated with less precision than those applied to the split-plots. The importance of the treatment estimates and information about likely main-plot treatment responses should therefore be determined before a split-plot design on monocrops is chosen. With intercrops, however, estimates of the main-plot treatments and split-plot treatments are usually required with the same precision. Since one species is usually grown on the main plots, the second species planted on the sub-plots with the treatments under examination, and as responses of both species to the treatments are usually required with equal precision, a split-plot design is not appropriate.

4.184 Typical intercropping plots with two species are laid out either with the species in alternate rows or with several rows of the second crop planted between each pair of the first crop. This ratio of first- to second-crop density should be determined with care for mixtures with coconut palms. Since they are large trees with extensive rooting systems, a single row of the second species could not fail to be influenced by the shade of the coconut and by root competition. Several rows of the second crop would be influenced to a different degree according to the distance from the palms, those plants mid-way between two rows of coconut palms being influenced the least. The chosen planting system will obviously reflect the efficiency of traditional planting systems and the need to determine new ones, but, whatever layout is chosen, it should be remembered that the analyses of the resulting data may be quite different.

4.185 Possible arrangements of the two species as indicated in Figure 4.1 have a number of plants of the second species located in the vicinity of one coconut palm. Thus in Figure 4.1(a) each palm in the row is considered to be most influential upon the nine plants in one plot adjacent to it. In Figure 4.1(b) each palm is surrounded by a "ring" of plants and these are assumed to be most influenced by it. In Figure 4.1(c), each palm in a row is assumed to influence the nearest ten plants in the rows of the second crop. Obviously many such arrangements are possible and the definition of neighboring trees must be chosen after consideration of the structure and known pattern of behavior of both species. Such designs are known as "nearest-neighbor" designs.
Figure 4.1: NEAREST NEIGHBOR DESIGNS FOR INTERCROPPING TRIALS

**Figure 4.1(a)**

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block I

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etc.

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block I

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etc.

**Figure 4.1(c)**

**Block I**

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**Block II ... etc**

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</table>
A particular class of designs, systematic designs, involve the gradual increase in spacings between trees across a block. With intercropping experiments, the intra-species spacing of both species are increased gradually across the block, these increases being in the same, or opposite, directions. Alternatively, the inter-species spacing is increased gradually from one end of the block to the other. The advantages of such designs are that guard rows are not needed between plots and the effective harvested area is larger than that achieved in a traditional randomized-plot design. However, with coconut palms such designs should be used with great care. Since the analysis of data from systematic designs involves the fitting of response curves across the increased-spacing treatments, sufficient replication should be achieved to counteract the expected tree-to-tree variability. The choice of second species for such a trial must be made knowing that guard rows will be non-existent and that influence from the coconut palms cannot be avoided. Finally, since such trials will often be done on land which is likely to be non-homogeneous and whose past history may be unknown, the existence of fertility trends may coincide with the change of plant spacing, thus producing inaccurate estimates of the treatments. To avoid this, the experimental area should be fully investigated for likely patterns of variation and replicate blocks should be laid out to run across trends, not along them, with the direction of increase in spacing treatment reversed for some blocks.

Analysis of Intercropping Experiments

Any intercropping experiment involving coconut and a second crop, say cocoa, will produce two sets of data each year for the length of time that the two crops are grown together. If one crop is planted before the other or one crop comes to the end of its useful life before the other, then there will be extra data at the beginning or at the end of the trial; these must be analyzed taking into account the special structure of the trial at these times. It is advisable with intercropping data to do several analyses to extract all possible information about the treatment responses. For each year that data are collected from both species, an analysis of the coconut data from the intercropped plots should be done, as should a separate analysis of the cocoa data from the intercropped plots. If monocrop plots are included in the trial, then an analysis of the coconut monocrop data should be done quite separately from an analysis of the cocoa monocrop data. From these individual-yield analyses the pattern of response of each species to the treatments will be established. The variability of the data for the intercropped and for the monocrop plots can be estimated and minimized by the choice of suitable covariates from previous years' data or by construction of covariates from positional factors.

Once this information is known, an analysis of both coconut and cocoa data from the intercropped plots can be done. The most appropriate way to do this is to consider a bivariate analysis of variance of both sets of data for one year at a time. When two crops are grown together in one plot, the growth of one will be influenced either positively or negatively by the other, and vice versa. This pattern of behavior will be represented by the correlation between the yields of the two species and will possibly be different for different treatments. In a bivariate analysis of variance, not only is the
variation within the coconut data established for each factor, but the covariance between the two sets of data is established for each factor as well. A bivariate analysis of variance table such as the following can be constructed:

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Coconut Sums of Squares</th>
<th>Cocoa Sums of Squares</th>
<th>Coconut/Cocoa Sums of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>treatment A</td>
<td>a - 1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>treatment B</td>
<td>b - 1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>residual</td>
<td>n - a - b + 1</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>total</td>
<td>n - 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The behavior of each species relative to the other can thus be determined for different treatments. Standard multivariate methods can then be used to test for differences between the treatments. A useful further analysis was proposed by Pearce and Gilliver (1978). They formed two new variates by adjusting the coconut and cocoa variates for each other, thus allowing for the correlation between the two. The new variables are uncorrelated and have unit variance. Bivariate analysis of variance of these two new variates provides a division of the variance and covariance according to the block and treatment structure and provides treatment mean values for each variate. These mean values, no longer confused by the correlation, can be plotted against each other, and confidence regions can be drawn to indicate the precision of the estimates.

4.189 Analysis of several years' data from both coconut and cocoa plants on the intercropped plots should be done, as in the monocropping situation, by calculating contrasts of interest for each crop in each plot and then analyzing, by bivariate analysis, the resultant data. Further work on this approach and the inclusion of previous years' data as covariates is currently in progress.

4.190 The analysis of nearest-neighbor designs involves the method of adjustment by neighboring plot values. Thus, yields of coconut palms can be adjusted by a covariate formed from the yields of the neighboring cocoa trees and vice versa. If the second crop is of less importance, it may be enough to adjust the coconut values and to concentrate upon the results of this analysis. If both crops are of equal importance, then adjustment may need to be done on both species until a reliable and accurate analysis is obtained. The calculation of a nearest-neighbor variate can be done by one of several different methods and the location of nearest-neighbor plants within an intercropping trial is not easily determined; further statistical work is needed and is currently underway at Rothamsted.
Trials on Experimental Stations and Farmers Fields

4.191 The gain of information from trials on an experimental station must eventually lead to the testing of treatments on farmers' fields or commercial plantations before final recommendations can be made. Experimental land on research stations is chosen for its suitability to permit accurate experimentation; experimental land on farmers' fields is chosen largely by the willingness of the farmer to have experiments done on his property. Experiments on research stations are likely to be better controlled, management of operations better supervised and damage to the plots prevented, if possible. Experiments on farmers' fields, however, may well be done on less-than-perfect land, trees may have been planted before the site was chosen and little protection may be given to the trial plots from undesirable effects of animals and trespassers. Reliance may need to be placed upon data recorders who are unskilled in the use of measuring equipment and in the methods of data recording and accuracy. Whilst some farmers can be very willing to have experiments done on their fields, their eagerness to impress other farmers with the importance of this task can result in over application of treatments and application to control plots, in order to produce impressive trees. Adequate supervision is, therefore, necessary, although not always possible if the experimental site is some distance away from the research station.

4.192 A difficulty arises with experiments on farmers' fields or commercial plantations when coconuts produced at the sites would normally be sent to market. The farmer wants to gain his usual profits and may wish to pick the nuts before the experimenter thinks suitable. The experimental area, once a field of similarly-producing trees, now consists of plots with yields varying according to the treatment application and compensation may be necessary for the farmer's overall loss.

4.193 However, despite such difficulties, certain advantages are gained by experimenting on commercial fields. Agricultural practices will certainly be those that the experimenter is wishing to examine and improve, and crops spoiled by treatments will soon become apparent from the farmer's disappointment. Commercial plantations permit large plots to be used and, although tree-to-tree variability, apart from clearly diseased trees, may be unknown at the start of the trial, measurements can soon be taken for future use as calibrating variables.
REFERENCES


V. DISEASES

Summary

5.1 The coconut is subject to many diseases, some lethal others merely debilitating—reducing yield but not killing the palm. Some pathogens are virulent, attacking even vigorously growing palms, many are weak parasites capable of causing disease only on palms predisposed to attack by malnutrition, poor drainage or some other cultural neglect.

5.2 J. L. Renard and M. Dollet provide an overview of the present situation in the following paper. S. Eden-Green looks in greater detail at lethal yellowing and related diseases, J.W. Randles deals with cadang-cadang and K.V. Ahamed Bavappa describes the latest developments in research into Kerala root wilt disease.

5.3 There are no reliable global estimates of the economic losses attributable to disease. In Kerala, root wilt disease is estimated to be responsible for the loss of almost one billion nuts a year, worth as copra at world market prices perhaps US$40 million. In the 1950s losses due to cadang-cadang in the Philippines were assessed at around US$16 million a year.

5.4 For the future, the as yet uncontrollable diseases believed to be caused by MLO (mycoplasma-like organisms) pose the greatest threat. Not only are large areas of existing palms at risk, but the threat of disease is acting as a major disincentive to new coconut developments in many parts of the world. Bearing in mind the similarity of many of these diseases, a strong case can be made for a concerted attack on them; perhaps coordinated through a body such as the former International Council on Lethal Yellowing.

A. Phytopathology

J.L. Renard and M. Dollet

Objectives

5.5 Outward signs of coconut diseases are very varied and may include yellowing, browning, and wilting as well as localized or general necrosis of the leaves, nut-fall and bud rot. Less evident are root rots and internal stem necrosis. Leaf diseases caused by parasitic fungi are easiest to detect rapidly (Heminthosporium sp., Drechslera sp., Pestalotiopsis palmarum, Pellicularia filamentosa, Catacauma torrendiella, Coccostroma palmicola, etc.). For all other kinds of decay the pathogen has to be determined by isolation and in vitro culture; the pathogenicity is then demonstrated by artificial inoculation. It was in this way that wet bud rot and nut-fall were associated with Phytophthora palmivora and Phytophthora heveae and stem bleeding disease with Thielaviopsis paradoxa. In other cases these methods have failed to reveal the causal agent and many decay diseases of coconut were long described as being of "unknown origin." Over the past 15 years, considerable progress has been made and the most serious diseases in this group can probably be explained by the presence of certain etiological agents or insect vectors (Table 5.1).
Table 5.1: SOME COCONUT DISEASES
Their Etiology and Possible Control

<table>
<thead>
<tr>
<th>Disease</th>
<th>Causal agent</th>
<th>Vector</th>
<th>Possible control method</th>
<th>Varietal resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lethal yellowing in Jamaica and Florida</td>
<td>Mycoplasma</td>
<td>Myndus crudus</td>
<td>Tetracycline</td>
<td>Maypan, Dwarfs</td>
</tr>
<tr>
<td>LY in Togo, Ghana and Cameroon</td>
<td>Mycoplasma</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Cadang-Cadang</td>
<td>Viroid</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Foliar decay due to Myndus taffini</td>
<td>?</td>
<td>Myndus taffini</td>
<td>Elimination of vector host plant Hibiscus tiliacous</td>
<td>Vanuatu tall and Green dwarf x Vanuatu tall</td>
</tr>
<tr>
<td>Hartrot</td>
<td>Flagellate protozoa</td>
<td>Lincus sp</td>
<td>Insecticide treatment (Endrin)*</td>
<td>?</td>
</tr>
<tr>
<td>Dry bud rot</td>
<td>? (Possibly viral?)</td>
<td>Sogatella cubana</td>
<td>Temik in the nursery</td>
<td>PB 121 more tolerant than dwarf varieties or Rennell tails</td>
</tr>
</tbody>
</table>

* (Endrin is proscribed in many countries, and the acceptability of Temik is disputed - Ed.).
5.6 All these diseases, even those of lesser importance, represent a threat to the extension and modernization of the coconut industry. The aim of future research must be to protect both the capital invested and the future production potential.

**Methodology**

**Disease Identification**

- Some diseases may be identified with reasonable confidence from the external symptoms. In general, however, when dealing with cryptogamic diseases it is necessary to isolate the organism and culture it *in vitro*.

- Hartrot may be reliably diagnosed through the presence of flagellate protozoa which are easily seen under the microscope.

- Mycoplasma like organisms (MLO) may be identified as such under the electron microscope though finer classification is not possible.

- Viruses may be identified by electron microscopy, by indexing on a test plant and by extraction and purification.

- For viroids: nucleic acids are extracted from diseased tissue and the viroid is detected by polyacrylamide gel electrophoresis (PAGE) or molecular hybridization (MHA).

5.7 **Reproduction of the Disease.** This is usually simple when dealing with parasitic fungi but more difficult for other pathogens where it may be necessary first to identify the vector insect.

5.8 **Parasite Biology.** Development of an effective control requires knowledge of the parasite's method of reproduction and the conditions required for its development.

5.9 **Epidemiology.** To understand why disease outbreaks occur it is necessary fully to understand the biology of both the host and the pathogen and to analyze external factors such as soil, climate, topography and husbandry practices which influence their interaction.

5.10 **Chemical control.** Cryptogamic diseases are frequently controllable by chemicals and a wide range of fungicides is available. However, before a fungicide can be recommended it has to be tested against the disease, and the likelihood of a resistant strain of the pathogen developing must be assessed.

5.11 Trials in the nursery and in the field should be set up to define:

- the effectiveness of the different pesticides' active ingredients;

- the method of application: leaf spraying, injection into the stem, or root uptake; and

- the frequency of treatment.
5.12 **Biological Control.** This method is theoretically possible, but is only applied, and only proves effective, in rare cases; the existence of a hyperparasite fungus on *Catacauma* leaf diseases seems to be an interesting example in the case of the coconut (still being studied).

5.13 **Resistant Varieties.** An initial assessment of resistant or tolerant varieties can be made through regular field counts where different types of planting material exist, such as on research stations. If this is insufficient, performance trials should be set up on disease sites (lethal yellowing, hartrot, cadang-cadang, etc.). Once inoculation techniques are mastered it may become possible to test the reaction of planting material at an early stage, such as in the nursery.

5.14 **Integrated Control.** Combines a number of different approaches:

- use of tolerant or resistant planting material;
- attention to cultural and environmental factors (nutrition can have an important influence, as can location and topography);
- choice of an appropriate fungicide correctly applied; and
- where possible, biological control.

**Current Research**

5.15 We summarize below ongoing research in different locations:

5.16 **Cote d'Ivoire.** IRHO pathologists at the Marc Delorme Research Station have studied several problems:

- dry bud rot, a disease induced by an unknown pathogen which seems to be transmitted by two vector insects, *Sogatella kolophon* and *S. yubana*;
- *Phytophthora heveae*, identification of causal agent, development of control method, damage assessment, mortality and nut-fall, varietal performance; and
- *Helminthosporium* leaf spot, resistance breeding.

5.17 **Vanuatu.** Research since 1980 has made possible the screening of varieties and hybrids for resistance to foliar decay transmitted by *Myndus taffini*, using vector insects in cages. Research into field behavior of the vector has led to the identification of an alternative host plant, *Hibiscus tiliaceus*. It is suspected that the causal agent is a virus and attempts to isolate and identify it continue.

5.18 **Brazil.** Recent damage by *Phytophthora palmivora* in the nursery led to joint experiments in association with Cote d'Ivoire and ORSTOM pathologists in Noumea.

5.19 **Brazil.** Research is conducted jointly with EMBRAPA's CNPCo. Work has been carried out to identify the cause of *queima das folhas*, a disease
about which little is known. Recently, in a program involving both CNPCo and private plantation companies, research has also been carried out in an attempt to control lixa, a disease caused by *Catacauma torrendiella*.

5.20 **Guiana.** Research has shown that hartrot is transmitted by a bug, *Lincus sp.* The causal agent is believed to be a flagellate protozoon and basic research, involving *in vitro* culturing and serological tests, is continuing at the IRHO/CIRAD virological laboratory in Montpellier.

5.21 **Indonesia.** *Phytophthora* has recently developed as a problem on coconut in Indonesia. Research, mainly on control methods, has been undertaken by PPK and BALITKA in Sumatra and Sulawesi:

5.22 From 1982 to 1984 stem-bleeding was studied in collaboration with PPK in North Sumatra and in the Lampung province of south Sumatra. It is now known that the disease is linked to environmental factors, for example, an outbreak may be triggered by severe drought; it is also favored by excess nitrogen and by chlorine deficiency. It is concluded that there is no need for further intensive research.

5.23 Some years ago, imported West African tall palms, exhibited symptoms resembling stem-bleeding disease though it is believed that the cause was different. The condition is no longer observed but periodic checks are still made as a precautionary measure.

5.24 **Philippines.** In 1978 there was a recurrence of *Phytophthora* which caused severe nut-fall and killed large numbers of palms. Different systemic fungicides have been tested. As in Indonesia, the West African tall variety is subject to a type of trunk decay.

5.25 **Other diseases.** An account of research on coconut diseases would be incomplete without mention of the work on cadang-cadang in the Philippines, Kerala root wilt disease in India and lethal yellowing in Tanzania. Little or no work is in progress on red ring disease (caused by *Rhadinaphelenchus cocophilus*) in South America and the Caribbean, or on Natuna disease (cause unknown) in Indonesia. Other problems, of minor importance, include blast, *Ganoderma, Curvularia sp.*, and *Pellicularia filamentosa*. *Marasmiellus cocophilus* has caused some concern in the Pacific, where it has resulted in restrictions on the movement of planting material.

Principal Results

5.26 **Phytophthora spp.** This parasite develops inside the host plant before visual symptoms appear. Therefore curative treatments have been ineffective. However, preventive treatment by stem injection of systemic fungicides provides excellent protection. Application via the leaves or leaf axils gives only mediocre results.

5.27 Stem injection of Metalaxyl and Phosethyl A1 offers complete protection against bud-rot. Although Metalaxyl is not effective against *Phytophthora* induced nut-fall Phosethyl A1 reduces loss of crop by at least 80%. However, such stem injection is not widely adopted because it is difficult, costly and may give variable results, perhaps because
different **Phytophthora** species are involved, or resistant strains may have developed.

5.28 **Helminthosporium halodes** (*Dreschlera incurvata*) develops on the spear and sporulates as soon as the first leaf opens. On old leaves, the necrotic lesions resulting from **Helminthosporium** attack may be invaded by **Pestalotiopsis**, with this fungus often considered as the initial parasite; which it may be when it develops following initial damage to the leaves by insects.

5.29 **Helminthosporium** leaf spot is difficult to control; but weekly applications of Chlorothalonil or Mancozeb, among the most effective fungicides, make it possible to reduce the development of the fungus. The best effect is obtained by applying the fungicide to the under surface of the leaves where the parasite penetrates.

5.30 Among the cultivars most sensitive to **Helminthosporium** attack are the Polynesian, Rennell and Vanuatu tall varieties, and the red and yellow dwarfs. The West African tall and the Malaysian yellow dwarf x West African tall hybrid (PB 121) are among the most tolerant.

5.31 "**Queima das folhas**". This disease, characterized by premature drying and falling of the leaves, occurs in the state of Bahia and in Sergipe.

5.32 During the past two years the role of **Botryodiplodia** sp. has been clearly proven in the expression of symptoms. However, this fungus only penetrates through wounds and we suspect the involvement of another fungus, **Coccostroma** palmicola. "**Queima das folhas**" has long been considered a disease affecting palms growing under unfavorable conditions; a view not incompatible with the involvement of two parasitic fungi. There is no known control method.

5.33 **Lixa**: **Catacauma torrendiella**. This leaf disease, occurring exclusively in Brazil, is only of importance on commercial plantations and damage is less in coastal areas than on inland sites. The disease has only been under study for a short time. The parasite is a little known ascomycete (Phyllachoraceae). Its cycle on the plant takes several months with an incubation period of some 3 months. The formation of hard black stromata leads to the premature drying of the leaves. Benlate is effective against the parasite but cost effective methods of application have still to be worked out. The existence of a hyperparasitic fungus has led to a reduction in the incidence of **Catacauma**, offering hope of a natural control method.

5.34 **Diseases transmitted by insects**. Multi-disciplinary research is often needed. Both dry bud rot and foliar decay are transmitted by insects; dry bud rot in Cote d'Ivoire by **Sogatella** spp and foliar decay in Vanuatu by **Myndus taffini**. Although the identity of the causal organism remains unknown in both cases, transmission using vector insects in cage tests allows screening of varieties to test their reaction to the pathogen.

5.35 In Guiana it has been established that the vector of hartrot is the bug **Lincus croupius** which develops in the axils of the lower leaves.
5.36 The close link between vector insects, alternative host plants amongst the weed flora, and transmission of the causal organism has been clearly demonstrated in the case of dry bud rot. The combination of an insecticide (Temik) applied to the soil and regular weeding is an effective way of controlling the disease.

5.37 Priorities for Future Research. During the past two decades much has been learnt about coconut diseases; notably demonstration of the presence of mycoplasmas and viroids and the identification of insect vectors. Numerous aspects require further in-depth investigation to develop effective control measures, for example the role of insect vectors and the search for tolerant varieties, which may be, in the long term, the surest approach. With its large genetic collection at Port Bouet in Cote d'Ivoire the IRHO is in a position to make an important contribution.

5.38 Phytophthora. Diseases associated with various species of Phytophthora have expanded considerably in recent years and further research merits a degree of priority:

- an inventory of disease-related Phytophthora species is required;
- development of selective isolation methods;
- assessment of damage related to individual species;
- methods of transmission;
- preservation of the parasite (possible dormancy of P. heveae oospores);
- epidemiology in different regions;
- varietal sensitivity; and
- chemical control methods for individual species.

5.39 Leaf diseases in Brazil. Faced with the threat of continuing spread of queima das folhas, further research is needed into the role of Botryodiplodia and to define control measures. For Catacauma torrendiella a particular effort should be made to study the biology and propagation of the parasite and the factors which limit infection.

5.40 Lethal yellowing. Given the importance of lethal yellowing type diseases in East and West Africa and Mexico, and notwithstanding the decision to discontinue the work in Jamaica and Florida, it seems highly desirable to promote further research into this problem:

- knowledge of the vectors in each location is likely to provide the key to effective control;
- based on this information and an understanding of the biology of the insect, it may be possible to modify the environment in ways which would reduce the population of the vector. This method together with
the planting of tolerant varieties would be preferable, for environmental reasons, to the use of persistent chemicals;

- comparison of the mycoplasma strain responsible for lethal yellowing in the different countries concerned should facilitate a better coordination of control strategies; and

- finally, the setting up of screening trials involving a large number of varieties and hybrids should be undertaken wherever these diseases exist, in an attempt to identify tolerant planting material.

5.41 For both Phytophthora and lethal yellowing there would be merit in coordinating the research through the establishment of networks. Results in the different regions may well be complementary. Field work will be of first priority with laboratory investigations being undertaken where necessary.

5.42 Hartrot. The priorities would be:

- more research into vectors to identify the species of Lincus involved in each geographical zone, or perhaps the identification of a bug of different genus in Ecuador, Brazil, or elsewhere; and

- identification of tolerant planting material through comparative trials using cage tests or by injection of cultures of the pathogen.

B. Lethal Yellowing and Related Diseases
S. Eden-Green

Distribution
5.43 Lethal yellowing has been known for many years in the northern Caribbean basin; the Greater Antilles, Jamaica, Cayman, Cuba and Hispaniola, and probably in the Bahamas and the Florida Keys. The disease spread to mainland Florida in 1971, where about 30 other palm species have also been affected, to Texas around 1978 (in date palms) and was diagnosed in the north east of the Yucatan peninsula of Mexico in 1982. Mycoplasma-like organisms (MLO) have been consistently associated with the disease and the similarities of symptoms, epidemiology, host range and varietal resistance strongly suggest that the same disease is present throughout this region, where it is referred to as Caribbean LY.

5.44 Similar diseases in Africa have also been associated with MLO, notably Cape St. Paul wilt (Ghana), Kaincope disease (Togo), Kribi disease (Cameroon) and lethal diseases in Tanzania. These diseases are included here under the general heading of LY but differences in varietal susceptibility and epidemiology suggest that they may be caused by different strains of the pathogen.

Extent of Losses
5.45 The rapid and destructive spread of LY in the Caribbean is well documented. In Jamaica alone, at least five million 'Jamaica Tall' palms were destroyed in the 20 years following spread of the disease to the main coconut growing areas in the east of the island. Similar devastation has been seen in
parts of Ghana and Tanzania, but patterns of spread show greater variability in Africa and losses may be more manageable. From losses in international collections of coconut varieties in Jamaica, it has been calculated that some two-thirds of the world's coconut palms are susceptible to LY. This figure takes no account of the observation that some varieties are resistant to Caribbean LY but not to African strains of the disease.

**Symptoms and Diagnosis**

5.46 In palms bearing nuts, the first symptoms of the disease are usually a premature shedding of immature nuts (nutfall), often accompanied or closely followed, by appearance of one or more, blackened, newly-opened inflorescences. This is followed by a progressive discoloration and shedding of foliage, upwards from the oldest fronds. A dry necrosis soon develops in the young newly-expanding spear leaves and progresses downwards to the soft internal tissues above the growing point where a wet, foul-smelling internal rot develops. The growing point itself may remain intact until most of the foliage is affected, but the whole of the top of the crown eventually rots and falls off, 3-6 months after the first symptoms appear. The bright yellow coloration of affected fronds is a varietal characteristic particularly noticeable in the Jamaica Tall; fronds of other varieties may turn bronze or brown. Symptoms in prebearing palms follow a similar pattern but seedlings, up to about 18 months old, are not affected in the field.

5.47 Early symptoms in other palm species are generally similar to those in coconut but the sequence of spear necrosis and the discoloration of leaves may differ; in date palms, for instance, spear necrosis is often a primary symptom and affected leaves are grey and dessicated.

5.48 In common with other plant 'Yellows' diseases, the LY MLO cannot be grown on microbiological culture media and the etiology of the disease has yet to be proven. Diagnosis requires confirmation by electronmicroscopy of the presence of MLO in the phloem of diseased, but not of healthy palms, the best sites for examination being young, actively growing tissues such as root tips, unopened inflorescences and expanding spear leaves. This is usually a job for specialist laboratories remote from coconut growing areas and there is a great need for simple and reliable diagnostic tests to detect the disease in the field.

**Epidemiology and Spread**

5.49 Patterns of spread of LY in the Caribbean region are characteristic of an airborne vector. Primary infection foci may appear several kilometers from the nearest source of disease, followed by a more localized, but random, secondary spread. Broad 'disease fronts' of secondary spread can sometimes be recognized as the disease moves into a new area, but new primary infection foci invariably overtake attempted control by removal of diseased trees. In Africa, patterns and rates of spread are more variable; rapid and extensive spread has been reported in some parts of Ghana but in Togo spread of the disease is said to resemble a slowly spreading ink-stain. Both extremes are seen in Tanzania, but spread is generally much slower than in the Caribbean. These differences could reflect differences in the pathogen, its mode of transmission, or the genetic background of coconut populations grown in these regions.
5.50 There is now good evidence that Caribbean LY is spread by a planthopper, *Myndus* (formerly *Haplaxius*) *crudus* (Cixiidae) but, after testing massive numbers of insects, repeated transmissions have been obtained only in Florida and not in Jamaica. Adults of *M. crudus* are often abundant on coconut foliage but breed in undergrowth on stoloniferous grasses. Epidemiological analyses indicate that spread is from palm-to-palm and does not involve alternative hosts of the disease. Vectors of LY in Africa are unknown but *Myndus* has not been found on palms in East Africa.

**Containment and Control of Spread**

5.51 Given the capacity for long distance jump spread and the lengthy incubation period of the disease, phytosanitary measures to contain LY are unlikely to succeed. Symptomless palms may serve as a source of inoculum before they can be identified and removed. Removal of diseased palms from new infection foci in Jamaica and in Florida failed to reduce spread but this might be a more logical control measure in areas newly affected by slower-spreading forms of disease. Movement of seed and seedlings from diseased areas should be prohibited, although there is no evidence that the disease can be seedborne.

5.52 In Florida, intensive experimental insecticide treatments aimed at controlling *M. crudus* on palms reduced the rate of spread of the disease but did not prevent it. Given the scale of the problem and the high degree of vector control likely to be required, practical and environmentally-acceptable control treatments will be hard to find. In theory, control of *M. crudus* might be achieved by elimination or substitution of its graminaceous breeding hosts but this will rarely be practicable.

**Chemotherapy**

5.53 The early or pre-symptomatic stages of LY are susceptible to treatment with tetracycline antibiotics and this has been used as an important diagnostic characteristic. In Florida, large-scale treatment programs have been used since the early 1970s as a temporary control measure, pending the establishment of resistant varieties. Continuous treatments are required, two or three times a year, and it is unlikely that the combination of high commercial value and accessibility of the palms that facilitated these programs will be found elsewhere; however, antibiotic therapy might play a role in limiting new, isolated outbreaks of the disease remote from known sources of reinfection. Commercial formulations of oxytetracycline are available and the usual treatments are 1 to 3 grams of active ingredient every four months, applied by trunk injection using either gravity feed or pressure injection apparatus.

**Resistance**

5.54 The high resistance of the Malayan dwarf variety to Caribbean LY was recognized over 40 years ago. This variety, together with its F1 hybrids, has been the basis of coconut rehabilitation throughout that region and recent reports that increasing numbers of palms have been affected by LY in Jamaica give cause for concern. The Malayan dwarf is not resistant to LY in West Africa and preliminary results of variety trials in East Africa also suggest
different varietal responses to the disease. Varieties must thus be screened for resistance in each of the regions where LY occurs and the selection of suitable F1 hybrids and long-term breeding programs must be adapted to local conditions.

5.55 Lack of a controlled experimental inoculation technique is a major constraint on the screening and selection of resistant planting material at present. Fortuitously, extensive collections of world coconut varieties have been exposed to natural infection in Jamaica and the susceptibility of much of the world coconut crop to Caribbean LY can be predicted from this data. Amongst tall varieties, those with long, angular thick-husked fruit (Niu kafa type) are generally more susceptible to the disease than those of the Niu vai type, which have more spherical and relatively thin-husked fruit. It has been proposed that the latter types, and some of the resistant dwarf varieties, represent selection under cultivation in continental southeast Asia, and that this resistance indicates that strains of LY are endemic to that region.

Other Diseases

5.56 In southeast Asia, sporadic and localized outbreaks of diseases with similar symptoms to LY (Malaysia wilt; Natuna wilt) have been described from time to time but a probable pathogen has not been identified. Intensive studies on Vanuatu wilt in the New Hebrides have indicated that MLO are not involved and that disease is thought to be caused by a virus. A disease termed coconut stem necrosis caused considerable losses among nursery seedlings and in young plantings of Malayan dwarf palms and hybrids in Indonesia and peninsular Malaysia and was reportedly associated with MLO. Symptoms of this condition differ from those of LY and it may be related to "blast" disease of young palms in West Africa, which is also thought to have a mycoplasmal etiology. Local varieties apparently are not affected so control should not be a problem. Recent reports have suggested that Kerala wilt, or 'root (wilt) disease', in southern India may also be caused by MLO but the slow decline symptoms of that disease are quite different from those of LY. The possibility that leaf scorch decline in Sri Lanka might also be associated with MLO needs to be investigated.

5.57 Tests for the presence of MLO in samples of diseased coconuts from South America led instead to the discovery of a phloem-inhabiting flagellate protozoon, Phytomonas stahelli. This organism is now thought to be the cause of diseases of coconut in Suriname (hart rot), Trinidad (Cedros wilt) and in Costa Rica, and is also the probable cause of a destructive disease of oil palm ('Marchitez sorpresiva'), also present in Suriname and in parts of Colombia and Ecuador. As no resistance has yet been found in any tall or dwarf coconut varieties this disease may pose an even greater threat than LY, particularly in Central and South America. In oil palm, control has been reported following applications of certain insecticides—apparently a direct effect on the pathogen rather than on its suspected Hemipteran vectors.

Future Research

5.58 Following the discovery of the association of MLO with LY, close cooperation developed between teams carrying out basic research on the disease in Florida and in Jamaica. With participation from other interested groups,
this resulted in the formation of an informal International Council on Lethal
Yellowing (ICLY), which did much to promote research on the disease in the
1970s. Ultimately, work in the Caribbean region was limited by the general
lack of progress in handling and controlling plant MLO diseases, and the
emphasis has since shifted to more applied programs in Africa and elsewhere.

5.59 The immediate needs for research in countries at risk from LY will be
for an applied agricultural program to collect, evaluate and develop coconut
palm germplasm for resistance to local strains of the disease. An
international exchange of germplasm would also help to establish the genetic
vulnerability of coconuts on a global scale, and might reveal strain
relationships between diseases in different regions. Confirmation of an
association with MLO, by electron-microscopy and response to tetracycline
antibiotics, would form part of such an applied program, as would the
identification of insect vectors and studies on their biology, distribution
and control.

5.60 There is, however, also a continuing need for a strategic program of
basic research on the disease: to isolate or purify the MLO and hence prove
the pathogenicity and co-identity of LY-like diseases of coconut and other
palms in various countries; to develop controlled inoculation techniques for
screening for resistance to the disease; and to investigate new techniques,
such as monoclonal antibodies and DNA probes, that may provide ways of
detecting the pathogen in plant and insect tissues. Much of this work is
technologically demanding and sponsors of future research on the disease
should support and encourage close collaborative links with specialist
laboratories.

Conclusions

5.61 The discovery of the probable mycoplasmal etiology of LY has provided
a unifying link between several of the previously "unknown" diseases of
coconut. It also emphasizes the global threat posed by LY, already
established on two continents, and the need for continued research. As the
Jamaican experience has shown, the disease can spread rapidly and
destructively amongst susceptible palms but with foresight and skillful
management a rapid transition to resistant varieties is possible. Countries
as yet unaffected by the disease should take steps to test the vulnerability
of their more common varieties, to collect possible sources of resistance and
to incorporate it into national breeding programs. Regional research
programs, in countries already affected by the disease, will have a global
application and deserve international encouragement and support.

C. Cadang-Cadang Disease
J. W. Randles

Nature of the Disease
5.62 Cadang-cadang is a premature decline disease of coconut palms in the
Philippines, which is generally lethal. The synonym, "yellow mottle decline",
is not in common use. "Tinangaja" is the name of a similar disease with
essentially the same etiology in Guam. The name 'cadang-cadang' is derived
from the Bicolano term 'gadan-gadan' which means dead or dying.
5.63 The disease is caused by viroid, a circular single-stranded RNA with a total length about one-tenth that of the nucleic acid of the smallest viruses. It can be transmitted mechanically under experimental conditions. Its natural mode of transmission is not known, although it spreads slowly in affected plantations. No direct control measures are known.

5.64 The disease is recognized in the central Philippines, including southern Luzon, Samar, Masbate and a number of smaller islands within a zone about 600 km x 300 km. Tinangaja disease which closely resembles cadang-cadang in symptoms and etiology occurs on Guam, in the Marianas Islands. The distribution of cadang-cadang is apparently unaffected by water barriers as rivers appear not to interfere with spread, and it occurs on islands.

5.65 Disease incidence is negligible before plantations are about 10 years old, and after this incidence increases with age. Linear regressions of incidence on age have been observed and 50 to 60% of a plantation may have become affected in plantations about 50 years old.

5.66 It is not known whether spread is from palm to palm or from some other reservoir species. Patterns of spread show that the disease has a scattered random distribution, that the rate of spread is slow (approximately 1% p.a. on average), and that if a vector is responsible, it is rare, inefficient or sluggish. The area within which cadang-cadang occurs has increased very slowly in the last 26 years, and surveys indicate that the boundaries of distribution spread at about 500 meters p.a. New infections can be found several hundred meters ahead of a boundary.

5.67 Epidemics of the disease have occurred at different times in different places. An epidemic which was observed in Albay province in 1951-57 is now declining, whereas in the neighboring Camarines Sur province an area which had an incidence of about 3% in 1956 now has a 50-70% incidence. Distribution of diseased palms tends to be scattered or "random", but clustering of diseased palms occurs infrequently in small areas. Over large areas, centers of high and low incidence are seen. Incidence is positively correlated with age, negatively correlated with altitude, and the beetle species Oryctes rhinoceros, Plesispa reichei, and Hemipeplus sp. were more abundant in areas with high incidence, but these data have not provided information on the factors affecting incidence and spread of the disease. Patterns of disease increase vary between 'simple' interest and 'compound' interest patterns in different sites, with the result that the source of infection in plantations cannot be inferred.

5.68 Cadang-cadang was first mentioned probably around 1914, and later observations showed heavy losses in some areas. For example, incidence on San Miguel Island increased from 25% to 90% between 1931 and 1946, and less than 100 palms survived to the 1970s. Roadside surveys in the Bicol region gave incidence as 1.8 million palms in 1951, 4.6 m in 1952, 5.5 m in 1953 and 7.9
in 1957, when yield losses of US$16 m were estimated. Disease incidence ranged from 9 to 61% in different provinces, and more than 12 m palms were estimated to have been killed in this area by cadang-cadang between 1926 and 1971. In 1978 and 1980, respectively, 391,000 and 209,000 new cases of disease were estimated to have occurred, suggesting that annual rates of increase may have declined since 1960. It is estimated that up to 30 m palms may have been killed by cadang-cadang since it was first recognized.

**Symptoms**

5.69 Infected palms progress through a well-defined series of changes culminating in death. Recognition of these changes is important for field diagnosis. Diseased palms are classed as being at the early (E), mid (M) or late (L) stage. At E, the causal viroid is first detected in the youngest fronds; slowly developing nuts become more rounded than normal with some scarification round the equator of the nut; yellow spotting occurs on leaves; new inflorescences become stunted. At the end of E, leaf spots have enlarged, few nuts are produced, and newly emerging inflorescences are stunted and sterile. At M, spathe, inflorescence, and nut production decline then cease, and leaf spots become more numerous. At L, fronds decline in size and number, the pinnae become brittle, the leaf spots coalesce to give a general yellow or bronze appearance, crown size becomes smaller and the palm eventually dies.

5.70 This progression of symptoms is remarkably constant in the Philippines, with some variation in intensity. Tinangaja disease shows different nut symptoms, in that they are narrow, and lack a kernel, but are produced for a longer period in the disease development cycle than for cadang-cadang.

5.71 E lasts 2-4 years, M lasts for an average of about 2 years, while L, to final death of the palm, averages about 5 years. The mean duration of the disease to death is 9 years, but varies from 7.5 years for 22 year-old palms to 16 years for 44 year-old palms.

5.72 It is rare for palms to show the disease before they commence bearing.

**Diagnosis**

5.73 Although early studies suggested that the production of yellow spots is diagnostic of infection, in practice this is not a reliable indicator of early infection. Later stages are identified by the presence of symptoms on nuts, but this criterion also becomes irrelevant at the late stage when nut production has ceased. Identification of the causal viroid in the extracts of palms is the most reliable indicator of infection. The tests used involve extraction of leaflet tissue from fronds three to about seven by blending in cold 0.1 M sodium sulphite which acts as a reducing agent and maintains pH at above 7. The filtered extract is treated with 5% polyethylene glycol 6000, and insoluble material is collected by low speed centrifuging. This is then subjected to a nucleic acid extraction procedure based on either protease digestion or phenol-sodium dodecyl sulphate-chloroform extraction. The nucleic acids in the extract are recovered by precipitation with ethanol, and the viroid is detected either by polyacrylamide gel electrophoresis (PAGE) or molecular hybridization (MHA).
PAGE: 5% polyacrylamide gels are loaded with the dissolved nucleic acid extract and subjected to electrophoresis for about 2 hours. The viroid band is detected by staining with either toluidine blue, ethidium bromide, or silver nitrate.

MHA: purified viroid is used as a template to synthesize a complementary DNA probe. This is done either by reverse transcription of a viroid template, or by cloning DNA by recombinant DNA techniques. The probe is generally radioactive but can also be labelled non-radioactively, and the presence of viroid is shown by allowing the DNA to hybridize with any viroid present in a test solution under standard conditions. If the viroid is present in a given extract, 'hybrids' form which can be detected by the use of a specific enzyme, or exposure of "dot-bilos" to X-ray film. This assay is about 10 times more sensitive than the most sensitive PAGE assay system.

Host Range
5.74 Cadang-cadang viroid has been inoculated to, and recovered from, the following palms: Areca catechu (betel nut), Corypha elata (buri), Adonidia merrillii (manila), Elaeis guineensis (oil palm), Chrysalidocarpus lutescens (palmera) and Oreodox regia (royal palm). Oil palm and buri palm have been shown to be naturally infected in the field. Attempts to inoculate dicotyledonous hosts have been unsuccessful.

The Pathogen
5.75 Cadang-cadang is caused by a viroid. Viroids are naked, circular, single-stranded, ribonucleic acid molecules of low molecular weight. They consist of between 246 and about 380 nucleotides, and about 10 different viroids are known which cause diseases in crops such as tomatoes, citrus, hops, potatoes, chrysanthemum, and coconut palm. They are smaller and less stable than viruses, and no field vectors are known. They are remarkable because they are the smallest known pathogens, and because they can induce disease with so little genetic information. The coconut cadang-cadang viroid is the smallest of the known viroids (246 nucleotides is the minimum infectious size) and therefore the smallest of all known pathogens.

5.76 Cadang-cadang viroid is unusual in that a dimeric molecule is normally isolated in relatively large amounts from palms with the monomeric molecule, and this also is circular. Moreover, increases in the size of the viroid have been observed as the disease progresses, but this occurs through reiteration of part of the molecule, without changing the basic nucleotide sequence.

5.77 It is thought that viroids may cause disease by interfering with the regulation of nucleic acid or protein synthesis, as they resemble "introns" which are associated with the production of messenger RNA in normal plants.

5.78 Cadang-cadang viroid is infectious by pricking and high pressure injection inoculation, but numerous attempts to demonstrate insect transmission have been unsuccessful. Seed transmission is rare, and would not explain natural spread. Nevertheless, floral parts of palms contain
detectable viroid, and as pollen is distributed from palm to palm, the possibility of pollen transmission is being investigated.

Strategies for Control

5.79 As therapeutic control measures are not applicable to viruses or viroids, strategies for control must be directed towards cultural methods. The only measure available at present is replanting. This recommendation is based on the observation that the rate of spread in new plantings appears not to be markedly increased by the proximity of infected palms. While having an economic cost in lost production and cost of planting, this practice has allowed production to continue in the cadang-cadang area. Attempts at control by eradication of infected palms have been unsuccessful. Application of eradication methodology necessarily depends on the observation of symptom development before infected palms can be removed, and it is possible that spread could occur before an infected palm shows symptoms. Future developments in the detection of viroids in asymptomatic plants should allow tests to be repeated and eradication re-examined as a control measure.

5.80 Other possible measures such as resistance, vector control, and mild strain protection are not appropriate at present.

Future Research

5.81 Areas requiring further investigation are: the epidemiology and spread of cadang-cadang; the identification and selection of resistant varieties; the possibility of using mild strain protection; the early and rapid diagnosis of infection in coconuts and other hosts; and the improvement of inoculation procedures. The achievement of some of these goals could be expected to assist in the development of control measures for coconut cadang-cadang disease.

Similar Diseases of Unknown Etiology

5.82 Foliar decay of coconut palms in Vanuatu differs from cadang-cadang in its symptoms and rate and pattern of disease spread in the field. Symptoms show 6-11 months after inoculation of young seedlings of susceptible varieties, and the most susceptible usually die within two years. This disease is transmitted by the plant hopper cixiid bug, Myndus taaffini and is probably caused by a virus. No cadang-cadang viroid has been found associated with foliar decay. Coconut palms infected with either Kerala Wilt or Tatipaka disease in India do not contain cadang-cadang viroid.
Further Reading


D. Coconut Root (Wilt) Disease
K.V. Ahamed Bavappa

Introduction

5.83 The root (wilt) disease of coconut is reported to have made its appearance a century ago, after the great floods of 1882, in three different areas each about 50 km apart in central Kerala. Even though research was initiated in 1948, the program only gained impetus after 1970, following the establishment of the Central Plantation Crops Research Institute.

5.84 The disease is currently found in eight districts and has affected about 32% of the palm population. However, incidence and severity vary considerably between districts, the highest incidence being in Kottayam (75%) and the lowest in Trivandrum (1.5%).

5.85 The annual loss in crop has been estimated at 968 million nuts. Affected palms bear fewer leaves, and the copra weight and oil content of surviving nuts are reduced. A survey conducted in 1984-85 revealed diseased palms in isolated pockets in the northern parts of Kerala, far from the main disease areas, and also in adjoining districts of Tamil Nadu. The results of the survey are summarized in Table 5.2.
Table 5.2: AREA AND LOSS OF PRODUCTION DUE TO ROOT (WILT) DISEASE IN KERALA

<table>
<thead>
<tr>
<th></th>
<th>1976</th>
<th>1984</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Areas ('000 ha)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total area under coconut</td>
<td>693</td>
<td>674</td>
</tr>
<tr>
<td>Disease affected area</td>
<td>412</td>
<td>410</td>
</tr>
</tbody>
</table>

| **Numbers of palms (million)** |      |      |
| Total number of bearing palms | 60.8 | 59.2 |
| Total number of non-bearing palms | n.a. | 32.4 |
| Bearing palms diseased       | 18.5 | 24.2 |
| Non-bearing palms diseased   | n.a. | 5.4  |

| **Percentage of diseased palms** |      |      |
| Bearing                        | 30.5 | 40.9 |
| Non-bearing                    | n.a. | 16.7 |

**Annual loss of crop: millions of nuts**

| 340 | 968 |


Symptoms

5.86 Symptoms include yellowing and conspicuous bending of the middle and outer whorls of leaves and the characteristic ribbing of the pinnae termed flacidity. Foliar yellowing and marginal necrosis, absent in young diseased palms, are invariably associated with adult palms. Softening and whitening of pinnae of the spear leaf with necrotic spots followed by rotting have also been noticed. Other frequent symptoms include shedding of buttons and immature nuts, and reduction in the number and size of leaves. An indexing method has been worked out by George and Radha (1973) for quantitatively scoring the intensity of the disease.

5.87 The disease, which affects palms of all ages, does not kill the palm outright but reduces its vigor and yield. The extensive root damage which has been reported in diseased palms is now thought to be secondary.

Present Status of Research

5.88 Etiology. The spread of the disease suggests the involvement of a pathogen. Though fungi, bacteria and nematodes have been found associated with the disease, the evidence is currently in favor of a phloem restricted submicroscopic mycoplasma-like organism (MLO). Electron microscopy has revealed the presence of typical MLOs in the sieve tubes of all disease affected palms examined from diverse locations; none have been found in healthy palms.
5.89 **Light Microscopy.** Suitable staining techniques for the detection of MLO have been standardized. Fluorescent microscopy using fluorochromes like DAPI and HOECHST 33258 gives an increase in fluorescence in the sieve tubes of diseased palms. Dienes' stain gave a distinct blue coloration to phloem tissues of diseased palms. These techniques are useful since identification of MLOs by electron microscopy is laborious and time consuming.

5.90 **Transmission.** Mycoplasmas are reported to be transmissible through grafting, by insect vectors and by bridging plants such as dodder.

(a) **Insects.** Systematic cataloguing of insects visiting disease affected palms resulted in the identification of one leaf hopper (*Sophonia greeni*) one plant hopper (*Proutista moesta*) together with the lace bug *Stephanitis typica*, an insect constantly associated with coconut palms in the contiguous root (wilt) affected tract. Both the lace bug and the leaf hopper feed and breed on coconut leaflets. Although immature forms of the plant hopper were not observed on coconut foliage, hoppers are conventional phloem feeders and other mycoplasmal plant diseases are known to be transmitted by such insects. The lace bug, by virtue of its long stylet, is capable of reaching inner tissues of the leaf and is thus a potential suspect in transmission. Electron microscopic examination of lace bugs collected on diseased palms revealed structures resembling MLOs in the salivary glands and brain tissues. Such bodies are absent in lace bugs collected from disease free areas. Transmission studies using the lace bug continue.

(b) **Dodder.** An accession of dodder (*Cassytha filiformis L.*) colonizing coconuts collected from Lakshadweep was maintained under controlled conditions. Transmission of MLOs from a young diseased coconut to periwinkle (*Catharanthus roseus*), a universally accepted mycoplasmal indicator host plant, was accomplished through dodder established on the diseased palm. Electron microscopic studies showed that MLO were present in both the dodder and the periwinkle. Healthy periwinkle plants and the control plants did not show such bodies. Dodder was subsequently bridged from a set of primary infected periwinkle plants to a secondary set of healthy periwinkle plants. However, transmission to healthy coconut palms has not yet been achieved and Kock's postulates remain unproven.

5.91 **Antibiotic Therapy.** MLOs are sensitive to oxytetracycline hydrochloride, a broad spectrum antibiotic, and remission of symptoms is normally observed in treated plants. In order to facilitate large scale trials with coconut, a pneumatic pressure injector was used to introduce the antibiotic with minimal injury to the palm. Uptake, translation and persistence were assessed by bioassay using the bacterium *Bacillus cereus* as test organism. Trials showed that the bole region, below ground level, was the best site for administering the antibiotic.

5.92 **Diagnostic Studies.** The implementation of any phytosanitary programs to contain or control the disease requires a reliable diagnostic technique. To this end a serodiagnostic test has been developed. Physiological studies revealed that stomatal regulation is significantly impaired in diseased palms.
resulting in greater loss of moisture; a linear relationship was observed between the disease index and the rate of transpiration. Comparisons have been made between the serodiagnostic and physiological tests and visual symptoms, and it has been found that in about 75% of the cases tested the infection could be detected before the onset of clear visual symptoms.

5.93 **Eradication Trials.** In an attempt to contain the disease within the contiguous infected tract, a program of eradication of diseased palms followed by surveillance was started in 1971 in over 200 coconut gardens in Shencottah (Tamil Nadu) and in areas north of the Karuvannur river in Trichur district. Up to 1984 recurrence of the disease was observed in only one village and there the initial disease intensity had been high. The observations suggest that in isolated and mildly affected areas the disease might be eliminated by the systematic eradication of infected palms, though it is recognized that such measures did not succeed against lethal yellowing in Jamaica.

5.94 **Management Experiments.** Since root (wilt) disease is debilitating but not lethal its depredations can be reduced by good management. In general, apparently healthy palms and those in the early stages of the disease respond to balanced fertilizer application, addition of organic matter, green manuring, weed control and treatment against leaf rot.

5.95 **Intercropping.** In one trial fodder crops were grown between the palms in a diseased plantation. These were fed to cattle and the cattle manure and other organic wastes returned to the plantation. As a result nut yield increased by 26% over a period of five years (1971-75). The follow up experiment during the next five years confirmed the beneficial effect of such a mixed farming system and laboratory analysis confirmed the improvement in soil conditions—higher levels of soil organic matter, increases in exchangeable bases and enhanced microbial activity. Intercropping with tapioca (*Manihot utilissima*), elephant foot yam (*Colocasia spp.*) and yam (*Dioscoria spp.*) for a period of three years also increased nut yield in disease affected coconut gardens, though by a smaller amount. Under rainfed conditions intercropping with cocoa, using single and double hedgerow systems, increased the yield of coconut by 27 and 35% respectively without any deterioration in the disease situation. Under irrigated conditions with both cocoa and coconuts properly fertilized, the yield of coconut increased from 18 to 46 nuts per palm per year.

5.96 **Basin Management.** In a trial comparing eight leguminous cover crops the highest yield of green material was obtained from *Pueraria phaseoloides*. It also had a beneficial effect on soil microbial activity in the coconut basins.

5.97 **Variety and Fertilizer Effects in a Replanted Area.** In a freshly replanted plot where all palms received a complete NPK fertilizer (500 g N; 300 g P205 and 1,000 g K20) applications of 500 g MgO per palm per year as magnesium sulphate improved the early growth and subsequent yield of both tall (west coast tall) and hybrid (Chowgat orange dwarf x west coast tall) varieties but, with or without the magnesium application, the hybrids substantially outyielded the local tall variety (Table 5.3).
Table 5.3: RESPONSE OF HYBRID AND TALL VARIETIES TO MAGNESIUM SULPHATE,
IN THE PRESENCE OF A COMPLETE NPK FERTILIZER
(cumulative number of nuts/palm over 12 years from planting)

<table>
<thead>
<tr>
<th>Magnesium sulphate (g/palm)</th>
<th>West coast tall</th>
<th>CDO x WCT hybrid</th>
<th>Mean over varieties</th>
<th>Difference between varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>220</td>
<td>311</td>
<td>266</td>
<td>91</td>
</tr>
<tr>
<td>500</td>
<td>464</td>
<td>659</td>
<td>562</td>
<td>195</td>
</tr>
<tr>
<td>Mean Response</td>
<td>244</td>
<td>342</td>
<td>385</td>
<td>414</td>
</tr>
</tbody>
</table>

5.98 Experiments on Cultivators' Fields. Under rainfed conditions palms responded to regular applications of fertilizers and organic manures with yield increasing from 25 to 38 nuts per palm within a period of two years, though the response was slight on palms already in an advanced stage of disease (Table 5.4).

5.99 On-farm trials have shown that irrigation with 250 liters of water per palm per week from January to May, with normal application of fertilizers and plant protection measures, leads to an improvement in the condition of the palms with increases in nut production ranging from 64 to 200%. Again, however, palms in an advanced stage of the disease did not respond.

5.100 Plant Protection. Regular spraying with fungicides helped to reduce significantly the incidence of leaf rot disease which is normally found superimposed on root (wilt) affected palms causing considerable loss in yield. When sequential sprayings with 1% Bordeaux mixture, 0.3% Dithane M-45, and 0.5% Fytolan were carried out between December 1982 and January 1984 on 1,610 leaf rot affected palms, the incidence was reduced to 220 palms.

5.101 Varietal Reaction to the Disease. In two separate blocks of the Central Plantation Crops Research Institute's substation at Kayangulam, WCT and CDO x WCT hybrids were planted after total removal of all the old palms. After twelve years the disease incidence was lower by 41% and the nut yield higher by 62% than in the local tall variety. A varietal screening program to evaluate yield potential and resistance/tolerance to the disease has been in progress since 1972 at the Institute's farm and in cultivators' fields with 45 cultivars and 62 hybrid combinations.
Table 5.4: RESPONSE TO IMPROVED MANAGEMENT OF COCONUTS IN CULTIVATORS' FIELDS

<table>
<thead>
<tr>
<th>Status of palms</th>
<th>Disease index (%)</th>
<th>No. of palms observed</th>
<th>Yield in nuts per palm at start of experiment</th>
<th>Estimated for 1984</th>
<th>Yield response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparently healthy</td>
<td>0-10</td>
<td>114</td>
<td>90</td>
<td>29.1</td>
<td>49.3</td>
</tr>
<tr>
<td>Early stage of disease</td>
<td>11-50</td>
<td>66</td>
<td>82</td>
<td>18.9</td>
<td>30.2</td>
</tr>
<tr>
<td>Disease advanced</td>
<td>&gt; 50</td>
<td>9</td>
<td>12</td>
<td>8.5</td>
<td>9.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>189</td>
<td>184</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Weighted mean</td>
<td></td>
<td>-</td>
<td>-</td>
<td>24.6</td>
<td>38.2</td>
</tr>
</tbody>
</table>

Although the response has been attributed to improved management there remains the possibility that there could have been some change over time due to climatic or other uncontrolled factors.

Strategy for Containing and Managing the Disease

5.102 Mildly Affected Areas. The incidence of the disease in Trivandrum and Trichur districts is only 1.5 and 2.6% respectively. In several other districts of Kerala, and in the neighboring state of Tamil Nadu, it occurs only sporadically. It might be possible to eradicate the disease from these areas through removal of diseased palms followed by active surveillance. It might thus be possible to salvage an area of 130,000 ha of coconut plantation in Trichur and Trivandrum districts by the removal of about 608,000 diseased palms. Similarly, in Tamil Nadu the removal of a few thousand root (wilt) affected palms might enable the whole state to be kept free of the disease. The method would be to treat all diseased palms with 0.01% endosulfan, to reduce the vector population, one month before felling and removing them. Felling would take place in September and October in order to leave a six months gap before replanting with CDO x WCT, or the reciprocal, hybrids or high yielding talls. Seedlings would be sprayed alternately with 0.01% endosulfan and 0.01% monocrotophos at six monthly intervals (March-April and September-October) for three years and would also receive adequate manuring and, where possible, irrigation.

5.103 Highly Diseased Contiguous Areas. The development of young palms affected before or at flowering, is severely retarded and, if they produce at
all, they will yield very few nuts. All such palms should, therefore, be removed using the same method as recommended above for the mildly affected areas. Older palms in an advanced stage of disease would also be removed. The total number of palms requiring to be destroyed is estimated at about 13 million. Replacement would, where possible, be made with hybrids; the objective being to maintain a stand of 175 palms per hectare.

Future Research

5.104 On the evidence available it now seems likely that the disease is caused by a mycoplasma-like organism. Successful culturing of the causative organism will be essential for screening germ plasm for resistance/tolerance and work in this direction has been initiated. If the MLO can be brought into culture (and this has yet to be achieved with any of the MLO-type diseases under study around the world), tissue culture techniques could be used for the in vitro screening of material to identify resistant lines. Apparently resistant/tolerant palms found in heavily infested areas would also be screened for possible use in future breeding programs.

REFERENCE

VI. PESTS

Summary

6.1 The coconut is host to hundreds of different species of insect, some beneficial, some harmful. Probably not more than 1 per cent cause sufficient economic damage to merit pest status; for these, however, considerable research is still required to develop environmentally safe and economically affordable control measures. No attempt is made in the present chapter to deal exhaustively with the subject. The IRHO contribution provides an overview covering the major economic pests while C.J. Lomer and N.W. Hussey deal in greater depth with the problems caused by rhinoceros beetles and coconut mites. The note on red ring disease relies heavily on a report the author wrote in 1964 following a visit to Trinidad and Tobago Coconut Research Ltd and the bibliography prepared by C.G. Dean in 1979. As far as can be ascertained no significant progress has been made since that time.

6.2 The increasing availability of high yielding hybrid coconut varieties calls for a re-examination of the cost effectiveness of pest control. The loss of ten per cent of the average crop, representing perhaps 60 or 70 kg of copra per hectare, is something the grower usually has to live with; because any attempt of control, even if the only input required is the farmer's labour, would be unprofitable. To accept a proportional loss of crop with the hybrids might mean the sacrifice of 300 to 400 kg of copra per hectare and a substantial expenditure at control procedures becomes possible.

6.3 In the past, old problems have been exacerbated and some new problems created by the injudicious use of broad spectrum insecticides which have destroyed the natural balance between pest species and their parasites and predators. There are still products being recommended for use against coconut pests which are being withdrawn from the market in industrial countries because they are no longer considered environmentally acceptable. Fortunately, there is increasing awareness of the dangers and it is noteworthy that in the scenarios set out in the FAO's "Agriculture: Toward 2000" the assumed rate of increase in developing countries' use of pesticides is much smaller than the increases postulated for other inputs such as fertilizers, improved seed, commercial energy and mechanization.

6.4 The modern tendency is towards pest management rather than an all out effort at eradication and this trend can be expected to continue with increasingly sophisticated methods of biological control. As the factors associated with resistance or tolerance become better understood it is also likely that breeders will be able to develop cultivars or hybrids that are much less susceptible to pest attack.

A. Entomology

D. Mariau, R. Desmier de Chenon, J.F. Julia and J.P. Morin

Overview

6.5 Forty years ago, Lepesme recorded some 760 species of insects living on coconut; today the list is considerably longer. Though insects are the
most serious pests, a few mite species and some mammals (rats, wild pigs, elephants) can also cause serious depredations.

6.6 Insect pests may affect (i) the leaves, resulting in production losses of up to 50 per cent or more; (ii) a particular part of the stem or bud, in which case a single individual can cause the death of the palm; (iii) the roots; or (iv) the flowers and fruits. Other insects, not in themselves harmful, are vectors of diseases which may often prove fatal. Some insect pests are of wide geographic distribution, for example the scale insect Aspidiotus, others such as the Tettigoniid "hoppers" (Sexava spp.) found in the Celebes and some Pacific Islands have a limited distribution.

6.7 The entomologist has to find solutions which permit the realization of the ever-increasing production potential of the crop while at the same time maintaining the often delicate balance which exists between harmful species and their natural enemies.

Methodology

6.8 Inventory. An inventory must first be made of the different pests found in the region; research priority is given to those whose economic impact is highest.

6.9 Preliminary studies. Appropriate and selective control measures cannot be developed without preliminary studies of the insect's own biology (life cycle, fertility, population dynamics) and that of its natural enemies (entomophagous and entomopathogenic parasites, and predators). These studies are aimed at finding where the pest is most vulnerable to attack, the weak point on which the eventual control method will be based. The studies also include observations to define damage thresholds at which intervention becomes necessary.

6.10 Biological control. Where natural enemies are inadequate to maintain control new parasites or predators may be introduced; as was the case in certain islands of the Pacific where ladybirds were introduced to control the scale insect Aspidiotus. Epizootic diseases can sometimes be detected within a population; although these will occur naturally only under particular environmental conditions, once these conditions are understood it may be possible to trigger the disease artificially. Behavioral studies have shown that some insects are attracted to light, others to specific olfactory substances. Studies of this type have led to the development of effective biological control measures for a number of coconut pests.

6.11 Chemical control. In many situations chemical control, involving a considerable range of insecticides, is still required. First an effective insecticide, or preferably several, has to be identified. Where several are found they can be used successively to reduce the danger of the pest developing resistance. Preference will be given to chemicals showing the lowest level of toxicity to man and to the crop plant. Trials are then carried out to test rates and frequencies of application so that a cost effective treatment regime can be determined. Finally, before a product is recommended for general use, large scale trials are conducted. Various
methods of application may be employed, from aerial spraying to systemic
control, through injection or root uptake. The solution that is best for an
industrial estate may not be appropriate under smallholder conditions, so
extension personnel will also be involved in the final choice.

6.12 Monitoring. An appropriate routine monitoring system, designed with
due regard to the age of the plantation and the particular pest under
observation, allows intervention as soon as the pre-determined economic damage
threshold is reached.

6.13 Insects as disease vectors. Knowledge of the vector insects (derived
from cage studies) can lead to improved control methods and enable sensitivity
tests to be carried out on a range of coconut varieties.

Research in Progress

6.14 Cote d'Ivoire. A great deal of research has been carried out both at
the IRHO's Marc Delorme Station and elsewhere in the country. Among the more
important pests investigated are the rhinoceros beetles (Oryctes and Augosoma
species), coreid bugs (Pseudotheraptus spp.), scale insects (Aspidiotus),
mites (Eriophyes), leaf eating caterpillars and various disease vectors.
Beneficial insects such as the Oecophylla ant and ladybirds (Coccinellidae)
have also been studied. The collaboration of commercial plantations, notably
Palmindustrie, has permitted the setting up of monitoring systems and the
training of observers. At the present time constrained resources are limiting
the research program.

6.15 Vanuatu. Research at the Saraoutou station has been concentrated on
FDMT, foliar decay transmitted by the plant hopper Myndus taffini. Even if it
proves impossible to control the vector, now that it is known it becomes
possible to test exotic varieties, particularly the hybrids introduced for the
replanting program, for their susceptibility to the disease.

6.16 Brazil. At the end of 1981, an IRHO entomologist began working in
the State of Sergipe in collaboration with the national research organization
EMBRAPA. Pest inventories have been followed by work on the biology and
control of several coleoptera, the leaf beetle Mecistomella and the weevils
Rhinostomus barbirostris and Rhyncophorus palmarum.

6.17 Guiana. For more than two years an entomologist has been on site
studying in particular, the insect vector(s) of Hartrot, a disease caused by a
flagellate protozoon.

6.18 India and Sri Lanka. Despite its many parasites, the leaf eating
caterpillar Nephantis serinopa, is probably the most serious pest. In Sri
Lanka, introduction of the hispid miner Promecotheca led to research on
control via insect parasites. The introduction of Pleurotropis parvulus was a
success. Indonesia. Research has included work on the scarab beetle,
Exopholis, whose larvae attack coconut roots, and on Latoia pallida. Also
important has been the work of training field entomologists for the national
coconut rehabilitation program.
Principal Results

6.19 **Oryctes.** Though chemical control is possible on a small scale, the most effective method is preventive, by discouraging the development of larvae in rotting wood. In plantations developed after forest *Oryctes* attack can be kept within bounds, without recourse to burning, if the felled timber can be concealed beneath a vigorous cover crop within a year of felling the forest; in Cote d'Ivoire this method is effective even though the forest contains substantial numbers of wild oil palms, a particularly favorable host for *Oryctes*. When replanting on poor soils, cover crop development is not sufficiently vigorous and it becomes necessary to burn any old coconut stems that cannot be used for other purposes. A control method using olfactory traps has been developed but is only effective under a limited range of conditions.

6.20 **Oryctes rhinoceros** is a major pest in a number of Pacific archipelagos. The introduction of *Baculovirus oryctes*, discovered in Malaysia in 1963, has brought about an improvement in several areas, among them Wallis and Samoa.

6.21 **Augosoma.** From the same family as *Oryctes*, and with a similar biology, *Augosoma* can also be a very serious, even fatal, pest. Primary attacks by *Augosoma* are frequently followed by weevil damage (*Rhyncophorus*). Even although 30 or 40 individuals may attack a single palm in the course of one night *Augosoma* movement is relatively restricted in both space and time so that manual collection, albeit on a daily basis, is often a practical proposition. Light traps, using ultra-violet light, give good results under certain conditions and can attract insects over an area of up to about 50 hectares.

6.22 **Pseudotheraptus devastans** is a bug which injects a toxin as it feeds on flowers and fruits. If attacked when young the nuts will shed and a relatively small population of bugs, a few hundred per hectare, can cause almost complete loss of crop. Similar damage is caused by *Pseudotheraptus wayi* in Tanzania and by another coreid bug, *Amblypelta cocophaga*, in the Solomon islands.

6.23 While chemical control is possible treatment has to be repeated at frequent intervals and may be uneconomic. The ant, *Oecophylla*, is an active predator of *Pseudotheraptus* larvae and as such can afford effective control; its presence in the plantation is therefore frequently encouraged despite its aggressiveness towards man (e.g. by planting citrus trees which are favourite nesting sites). Where *Oecophylla* is absent, or rare, nests can be moved into an area and successfully established provided they contain a fertile queen. However, the effectiveness of *Oecophylla* largely depends on the prevalence or otherwise of competing ant species such as *Pheidole* or *Iridomyrmex* and although the *Oecophylla* can be assisted, for example by providing bridges between palms which enable it to avoid ground nesting competitors, the natural balance between competing species seems to be the dominant factor.

6.24 Normally the scale insect (*Aspidiotus*) is kept well under control by ladybirds but major outbreaks can occur and are most likely after severe dry spells when the pest/predator balance is disturbed.
6.25 Since Oecophylla attacks ladybirds and their larvae as well as destroying nutfall bugs; maintaining the correct balance between ladybird and ant populations becomes an important part of pest management. Where Pseudotheraptus is the more important pest, the ants are encouraged; where scale insects are the principal danger the ants are destroyed to encourage a buildup of the ladybird population. This is a good example of the complexity which can exist in the relationships between pest and predator populations.

6.26 Leaf-eating Caterpillars. In terms of the number of species these are the most serious coconut pests. However, control is relatively simple because of the wide range of chemical and biological methods available. More original and very specific methods relating to entomopathogenic organisms are being studied jointly by INRA (French national institute for agronomic research) and ORSTOM (French office for scientific and technical research overseas). Different denso and picorna type viruses have been identified on Sibine in Colombia and other Latin American countries, on Latoia in Cote d'Ivoire and on Darna in Indonesia. These viruses are highly specific and particularly active.

6.27 Limacodidae like Setora and Parasa are not the only family of Lepidoptera affecting coconut. Brassolis sophorae (Brassolidae) in South America and the Caribbean and Agonoxena in the Pacific are serious pests at present only controllable by chemical means. Nephantis serinopa (Chrytophasiidae) is important in Southern India and Sri Lanka; Hidari irava (Hesperiidae) in Indonesia.

6.28 Eriophyes querreronis. These mites destroy the developing tissues of the young nut leading to a more or less drastic reduction in the size of kernel. Under Ivorian conditions losses in the West African tall variety may reach 10 to 15 per cent, or even up to 40 per cent if there is also a serious water deficit. Chemical pesticides are effective but treatment is only cost effective in the case of high value material, e.g. in seed gardens. Trials carried out in collaboration with the U.K. Glasshouse Crops Research Institute using a pathogenic fungus found among mite populations especially in Cote d'Ivoire gave negative results. Severity of attack varies considerably both within and between varieties, offering a possibility of control through choice of planting material. For the moment PB 121 (a hybrid between the Malayan yellow dwarf and the West African tall) appears much more tolerant than the West African tall, with losses restricted to 6 to 10 per cent of copra.

6.29 Vector insects. A number of coconut diseases are transmitted by insects. For example nursery bud rot, occurring in Asia, Africa and South America, is known to be transmitted in Cote d'Ivoire by the Delphacid plant hopper Sogatella. It is now known that foliar decay in Vanuatu is transmitted by Myndus taffini (Cixiidae), whose larvae feed off hibiscus roots, a very common plant in the islands of the group. In Guiana the vector of Hartrot has been identified as Lincus croupius and other Lincus spp. have been associated with the flagellate disease found in different areas of Brazil and Suriname.
Future Research

Particular emphasis should be given to the following themes:

6.30 Entomopathogenic organisms. Research into biological control methods should be intensified using entomopathogenic organisms to control leaf eating caterpillars, which are important on oil palm as well as coconut. Some of the types of densovirus and picornavirus already discovered have quite remarkable qualities including effectiveness at very low rates (distribution of 10 - 20 grams of diseased caterpillars per hectare ground and suspended in water) and the ability of the virus itself to survive even when stored under makeshift conditions. More prospection is required in order to collect the largest possible number of strains and there should be more epidemiological studies in the field. As a second stage the collected material should be submitted to structural, histopathological, biochemical and serological studies and tested on pests of economic importance over a range of crops. Finally, in order to comply with World Health Organization (WHO) recommendations it will be necessary to demonstrate that these viruses are not harmful to man.

6.31 Eriophyes querreronis. The coconut mite Eriophyes causes significant damage in West Africa on the local tall variety. Losses in other areas vary considerably but, as yet, the principal producing countries remain unaffected. However, vigilance is required due to the mobility of the pest. Tolerance varies considerably within and between varieties so selection and breeding of material that is relatively insensitive to mite damage offers possibilities for the future.

6.32 Rhyncophorus. The weevil is a serious pest because it can both kill the palm direct and is considered to be the principal vector of red ring disease which is rife throughout South America. Olfactory traps are used to control the pest but the technique could be developed further by identifying the attractant molecules and producing them synthetically. Complementary field studies would also be required. Support for this research has been sought from different international organizations but there has, till now, been little response.

6.33 Vectors of Lethal Yellowing Type Diseases. Research on lethal yellowing in Jamaica and Florida led to the identification of the vector, Myndus crudus. Similar research should be undertaken in Africa to identify the vectors of the several diseases believed to be of mycoplasmal origin. Even if the vector insects cannot be eradicated their identification would facilitate the screening of coconut varieties for resistance to the diseases.

6.34 Networks are already established for co-ordinating research into entomopathogenic organisms and Rhyncophorus. The setting up of similar arrangements for the study of MLO type diseases should be given consideration.

Conclusion

6.35 The fact that the coconut is essentially a smallholder crop poses special problems both with regard to the dissemination of information about coconut pests and the implementation of effective control measures. Close
collaboration is required between research laboratories, field stations and
the extension services. The control methods evolved must be biologically
effective, easy to apply, economically viable, and environmentally safe. The
safety aspect is particularly important in the case of coconut, which is so
often planted in areas of high population density.

B. Rhinoceros Beetle Biology and Control

C.J. Lomer

Nature of Damage

6.36 Rhinoceros beetles are the main pest of young coconut palms in most
producing countries. Different species attack the seedlings in different
ways, but the most common is for the beetle to burrow down into the growing
point from the leaf axils. The beetle creates a tunnel down the centre of the
palm by ripping out fragments of soft tissue, extracting the sap and expelling
the remains from the top of the burrow. This feeding burrow may be occupied
for up to a week; the nature of the damage caused depends on the point of
entry, the length of the tunnel and the health of the palm. The tunnel
entrance cuts across one or more fronds; when unfolded, these show the
characteristic V-shaped cuts which are the sign of beetle damage. As it takes
several months for these affected points to emerge, the extent of beetle
infestation may go unnoticed for this length of time.

6.37 The prolongation of the burrow is generally along a petiole, and does
little direct harm, although the risk of wind damage is increased. However,
if the tunnel starts low and continues to the meristematic tissue, the palm
can be killed. This is particularly likely to happen if the palm is
undersized and growing slowly. In a well-tended palm, the rate of elongation
of the developing fronds is such that the beetle cannot burrow fast enough to
reach the meristem.

Species Distribution

6.38 All Rhinoceros beetles utilize dead palm logs, standing and felled,
as breeding sites. *Oryctes rhinoceros* is the most damaging of the rhinoceros
beetles, due mainly to its high fecundity. Originally from S.E. Asia
(Thailand, Malaysia, Philippines, Indonesia, China and Korea), and India (Sri
Lanka, Maldives) *O. rhinoceros* has spread throughout the Indian and Pacific
Ocean Islands and is now found in Mauritius, Reunion, Diego Garcia, Cocos
Islands, New Ireland and the Gazelle Peninsula of New Britain (Papua New
Guinea), Fiji, Tonga, Wallis, American & Western Samoa and the Palau Islands.
In Africa (East and West, Madagascar and Seychelles) *Oryctes monoceros* fills
the same ecological niche. However, it has a lower fecundity than
*O. rhinoceros*, and severe outbreaks are less common. Several other *Oryctes*
attack palms in Africa and Madagascar, and also find their breeding places in
rotting vegetation other than palm trunks. All the *Oryctes* species attack
palms as described above.

6.39 The New World equivalent is *Strategus*, species of which are pests of
palms in Costa Rica, Puerto Rico and most other central American countries.
They breed largely in coconut logs, but attack seedling palms from underneath by burrowing through the soil.

6.40 Scapanes australis is the other important beetle pest of palms; two sub-species are found in the Papua New Guinea mainland, and separate ones in New Britain/New Ireland and Bougainville/Solomon Islands. These beetles breed in dispersed sites under rotting logs and attack palms from the side.

Economic Effects

6.41 The economic effects of rhinoceros beetle attack on seedlings and mature palms are best considered separately. In mature palms, artificial defoliation experiments have shown that a 40% loss in leaf area leads to a 70% reduction in nuts produced. This corresponds to a very heavy level of beetle damage. In terms of the number of beetle attacks, an attack every 2-3 months would damage 50% of the emerging fronds, resulting in a yield reduction of about 30%.

6.42 In a seedling plantation, a minimum estimate can be taken as the cost of replanting those palms so severely damaged as to require replacement. Less severe attacks and attacks on larger seedlings, lead to retardation in growth and delays in the onset of bearing, which are difficult to quantify, but which can have severe economic consequences by postponing the economic break-even point.

Control

6.43 Agronomy/Cultural Control. The central core of any control operation must be the maintenance of good agronomic practices. In relation to rhinoceros beetles, this involves three areas; seedling establishment, crop hygiene and cover cropping.

6.44 A well established, fast-growing seedling is far more able to withstand attacks and the use of Malayan yellow dwarf X West African tall hybrid palms, good ground preparation and fertilizer application are of particular importance.

6.45 The removal of all suitable breeding sites within the plantation is important; without this practice, O. rhinoceros, O. monoceros or Strategus can build up massive infestations. This is particularly likely to be a problem if an old coconut, oil palm or rubber plantation is being replaced. In cases where virgin forest is being cleared, particularly if a small patch is involved, species breeding in the forest, such as Scapanes australis and Oryctes boas are more likely to be a problem. Agronomic practices offer little defence against beetles invading from neighbouring badly-maintained properties. It is often difficult to be convinced of the economic necessity for removing logs when old plantations are cleared; if a use can be found for the logs, there is a greater incentive to remove them. Utilization of coconut stems is the subject of another chapter in this review.

6.46 To some extent, removal of felled stems is not so important if a good cover crop able to grow over them is established. Standing palms must, of
course, be felled. *Pueraria phaseoloides* (*javanica*) has been found to be particularly useful in this respect; the seed and *Rhizobium* inoculum are available commercially. The specific *Rhizobium* nitrogen fixing bacterium is not normally found in many tropical soils and inoculation of seeds is necessary. The beneficial effect of the cover crop is believed to be due to the physical barrier it provides to the flight of beetles trying to reach fallen logs. In addition a leguminous cover crop suppresses weeds and provides additional nitrogen to the growing palms, leading to economies in fertilizer use. Possible disadvantages are that in areas with adequate year round rainfall the cover crop can engulf the young palms if not properly controlled; where there is a significant dry season, the cover crop can compete with the young palms for available moisture. Fungi and chemicals, discussed below, provide alternative means of treating stumps which cannot be removed.

6.47 Biological Control by Predators and Parasites. Considerable effort has been put into finding specific predators and parasites of *Oryctes* and introducing them to various countries. The overall impression has been that spectacular population reductions have seldom been observed, but very little quantitative work has been done, and some of the successfully established predators and parasites must contribute to the environmental pressure on pest populations. Similarly, a range of generalized predators feed on *Oryctes*, particularly the larvae, ranging from centipedes and carabid beetles to pigs, rats and monkeys. These probably have a greater effect on the species with dispersed breeding sites, while those breeding in the centre of palm logs are relatively secure.

6.48 Biological Control by Pathogens. Two pathogens of *Oryctes* have been found to be effective, and both offer some scope for further improvement in control; these are the virus *Baculovirus oryctes* and the fungus *Metarhizium anisopliae*. Several other fungi, bacteria and microsporidia have been described as infecting *Oryctes*, but no serious proposals for their use as biological control agents have been made.

6.49 The virus was discovered in Malaysia in 1963, and was rapidly exploited to control *O. rhinoceros* in Fiji, Mauritius, Tonga, Wallis and Samoa. It has been found naturally infecting most *O. rhinoceros* populations throughout the beetle’s original range and seems to be the key mortality factor which the beetle escaped when it spread to new areas. The introduction of virus to these new devastating infestations provides a classic example of successful biological control. The virus has been the subject of a considerable mass of research, which has led to several improvements in the way it can be used and to a greater understanding of its biology. As yet, only *O. rhinoceros*, and *O. monoceros* in the Seychelles, have been controlled by the virus.

6.50 The virus was first described as a Rhabdionvirus, but later serological work showed it to be related to the Baculoviruses. Its nucleic acid content is also characteristic of this family of viruses, which are unique to invertebrates and have been recommended by the WHO as being particularly suitable for pest control. Several viruses of lepidoptera and of saw-flies are currently in use, particularly in forestry. All baculoviruses
except *B. oryctes* possess a protein coating which protects the virus particle. This enables them to persist in the environment, and means that they can be stored and applied as sprays. *Baculovirus oryctes* on the other hand, is very unstable, and is best considered as a contagious disease, spread by direct contact between adults. Though larvae are easily infected by this virus the fact that only 4-10% of larvae in the field are killed is a measure of the lack of transmission to this stage. The main transmission cycle is in the adult population where, particularly at low population densities, sexual contact during mating plays a major role. At higher densities transmission can also result from chance encounters during feeding and oviposition.

6.51 The early releases of virus used macerated larvae to contaminate breeding sites. As beetle population levels were high at the time, this successfully introduced the virus. More recent introductions use release of laboratory infected adult beetles; this is quicker and more effective. The adult beetles are infected prior to release by dropping a virus suspension (a macerated gut from an infected beetle), in 10% sucrose solution onto the beetle’s mouthparts. One gut in one cc can be diluted 1:1000, and used to infect 100,000 beetles. A large box, filled with sawdust, is suspended above the ground to avoid rat predation, and the beetles fly from this over the following few days. Quite small numbers of beetles can be used, although best results have been obtained with a ratio of about 1:10 infected: wild beetles. For an average field infestation of 50 beetles/ha, 5 beetles/ha would be released. The optimum spacing for the boxes would be one per 5 ha (25 beetles/box). This would lead to virus establishment within three months, reduction of the adult population over the following six months, and further reductions in the following generation because of the reduced oviposition. Reduction in the visible damage to palms is evident after six months.

6.52 Further enhancement of control can result from subsequent introductions even where virus already exists. In particular, if beetle populations build up quickly, naturally occurring virus is unable to keep up and hence introductions are highly desirable. The techniques are relatively simple, and the main cost is that of rearing beetles. This is generally done by collecting large third-instar larvae in the field and keeping them in individual tins, in a mixture of manure and sawdust, until the adults emerge.

6.53 Recent work on the genetics of the virus has shown that most of the naturally occurring isolates are very similar, although some variation does exist. These have been analysed by restriction endonucleases, which provide a biological ‘fingerprint’ for each variant. However, the biological significance of variation remains to be explored.

6.54 A separate line of research has given a detailed picture of the structure of the virus genome. This may open up the possibility of genetically engineering improved viruses but as yet this is some way off. Both this work and that on virus variants have relied on the use of a continuous cell-line derived from the Black Beetle, *Heteronychus arator*, which permits virus replication without the need to maintain insect stocks. It also enables inoculum to be stored at ambient temperatures for several weeks, whereas gut macerates must be kept frozen. The cell culture inoculum cannot be diluted before use.
6.55 Miscellaneous Control Methods. Chemical control by mixing lindane with sawdust and placing in the leaf axils is sometimes recommended, as is treatment of dead logs with dieldrin. The use of such chlorinated hydrocarbon insecticides is, however, generally deemed to be environmentally unacceptable. In both cases, treatment needs to be repeated often, and use of fungal spores might provide a cheaper alternative.

6.56 Wire hooking, in which the operator simply spears the beetle in its hole in the palm with a piece of wire, killing the beetle but not necessarily removing it, can be surprisingly effective if labour is cheap. The frass is visible in leaf axils at a considerable distance, and workers need only traverse alternate rows, twice a week, to cut short most attacks.

6.57 Most research projects make use of an attractant chemical, ethyl chrysanthemumate, in traps. However, the cost of the chemical, traps and labour removes any possibility of this being an economically viable control method, at least until a more effective chemical is discovered. The chemical attracts breeding beetles, not feeding ones, so these traps offer little protection to the nearby palms.

Future Research

6.58 Future research on the virus should cover the following three main areas.

(a) Assessment of Biological Significance of Variants. This needs to involve both laboratory LD 50 studies and, ideally, field trials on isolated islands. The problem so far has been that the techniques of genetic analysis are not available in tropical countries, while insect stocks are not available in temperate areas. As a range of characterized virus strains is now available, and in a form which will permit transport by mail, it should be possible to complete such studies. The ideal strain should interfere with the beetle's feeding and reproduction, while allowing it to fly and produce virus for as long as possible.

(b) Search for New Variants. Virus from Vietnam, Thailand, and Burma remains to be characterized, and possibly some more Indonesian islands might also provide new material. However, in general, most of the viruses from Oryctes rhinoceros have been described. No viruses have been found in Strategus from Costa Rica, Scapanes australis from Solomons and Papua New Guinea, nor Oryctes monoceros from Cote d'Ivoire, Madagascar, Kenya and Tanzania. The search should therefore move next to other non-pest species of dynastids, probably in S.E. Asia. Madagascar might also be a possible source in view of the wide range of Oryctes species found there. The rapid destruction of forest areas means that this work should be carried out with some urgency. The problem is that viruses of the Oryctes type are not easily detected and material would need to be sent alive to a laboratory with electron microscope facilities. The alternative would be to filter extracts in situ and infect Black Beetle cells. However, this raises the problem of maintaining a cell culture, and would limit the search to those viruses able to replicate in available cell lines.
(c) **Economics of Virus Release.** There can be no question about the economic viability of introducing virus where none existed previously. Where more quantitative information is required is on the re-release of extra virus, possibly of a superior strain to that already in use. This would involve consideration of the personnel available and would probably be largely a political decision or personal choice.

6.59 **The Fungus, *Metarhizium Anisopliae.*** Research on *Metarhizium*, a green Muscardine fungus, has been moving gently for about sixty years. The fungus does effectively kill *Oryctes*, and many other insects, but epizootics only occur during very moist conditions. The fungus has been found in almost all tropical countries but without apparently contributing to beetle control. The problem seems to be the lack of an effective dispersal mechanism; less than 1% of adult *Oryctes* are found infected with fungus, compared with around 35% carrying virus. This should not necessarily be seen as too great a problem; fungal spores are durable and can be produced commercially, as has been demonstrated for control of spittle bugs (Cercopidae) in Brazil ('Hetaquino'), and for Colorado beetle in USSR ('Boverin'). Unfortunately, research on *Metarhizium* for *Oryctes* control has often been neglected in favour of the virus. In both applied and basic areas, there are distinct gaps in our knowledge.

6.60 Some work on strain variation has been carried out, and a new virulent variant isolated from *O. monoceros* in Tanzania. Spore size, spore colour and nutritional deficiencies have been used as genetic markers, but we lack a definitive means for identification of strains comparable to the use of restriction endonuclease analysis of viruses. This is because of the far greater complexity of the fungal genome, but should nevertheless be considered a top priority for research. Isoenzyme analysis and pyrolysis-gas chromatography have been used with some success, but other methods, such as electrophoresis of polypeptides; restriction endonuclease analysis of mitochondrial DNA, or immuno-electrophoresis with monoclonal or polyclonal antibodies would bear investigation.

6.61 Results so far have shown that increased virulence is associated with the long-spored strains. Nutrition-deficient (autotrophic) mutants (uv-induced) have reduced virulence. Hybrids between different strains have reduced pathogenicity. There is some degree of host specificity, but a strain more virulent towards one species is often also virulent towards a closely-related insect. Virulence can sometimes be improved by selection in the laboratory, but it is necessary to distinguish between genetic selection and enzyme induction. Virulence can be lost by repeated passage on artificial media.

6.62 Other research has looked at toxin and enzyme production and we now have some ideas on the mode of action of fungi. Chitinases are produced which enable fungal hyphae to penetrate the host integument; thus there is no need for spores to be ingested. The host immune response involves melanization; this often results in black spots which can sometimes be seen on *Oryctes* larvae. The larvae are killed within twenty days, and fungal spores are produced on the outside of the cadaver.
In Samoa, *Metarhizium* has been used against *O. rhinoceros* by growing spores on oats or grated coconut followed by distribution to larval breeding sites, where the fungus may remain viable for two years. In Papua New Guinea, fungal spores grown on rice and distributed to palm frond axils increased the incidence of *Metarhizium* in *Scapanes australis* adults, and also infected the palm weevil, *Rhyncophorus bilineatus*. These results seem very encouraging, and treatment of larval sites can be considered a useful component of integrated control.

**Recent research**

**Tanzania.** A GTZ project, working primarily on agronomy of palms, has carried out extensive research on the baculovirus for control of *Oryctes monoceros*, and a field release has been made. Research on *Metarhizium*, which involved the discovery of a virulent strain, has since been dropped, but the strain is available from the Commonwealth Mycological Institute, Perry Lane, Kew, Surrey TW9 3AF.

**Ivory Coast.** The long established oil palm and coconut research stations employ several entomologists, and research on *O. monoceros*, *O. boas* and *Augosoma centaurus* is carried out, concentrating on cultural methods.

**Maldives.** A FAO field project organized by Dr. B. Zelazny is carrying out field releases of different *Baculovirus* strains in *O. rhinoceros*.

**Sri Lanka.** Laboratory-based research on *Baculovirus oryctes* in *Oryctes rhinoceros* at Lunuwila.

**Indonesia.** Field trials on virus re-release at the Bogor Research Institute for Industrial Crops in Java.

**Samoa.** There is continued monitoring of virus and fungus releases against *O. rhinoceros*.

**Papua New Guinea.** Research at Lae and Konedobu, on economic effects of damage and use of fungus.

**Solomons.** Research on *Scapanes australis*

**New Zealand.** Research on molecular biology of *Baculovirus oryctes*, and genetic engineering. Black beetle cells and characterized *Baculovirus oryctes* strains are available from Dr. A. Crawford.

**U.K.** Research at the Institute of Virology, Oxford on strain variation in *Baculovirus oryctes*. Recent work on Strategus has shown that this insect is susceptible to the virus. Characterized strains available from the author, or from the European Cell Culture Collection, PHLS, Porton Down.

**France.** Institut National de la Recherche Agronomique, La Miniere; research on *Metarhizium anisopliae*. 
Priorities for Further Research

6.75 **Fungus, Metarhizium anisopliae.** The applied work on means of disseminating viable spores needs to be supported by more basic studies on the identification of strains and assessment of their virulence.

6.76 **Virus, Baculovirus oryctes.** Much work is already in hand; there needs to be continued collaboration between laboratories with virus-handling facilities and those in a position to carry out field trials. Completely new viruses need to be found to control *Scapanes, Oryctes monoceros* and *O. boas.*

6.77 The selection of virus strains for re-release should be given some consideration; the virus should interfere rapidly with the beetle's feeding and reproduction, while allowing it to fly and produce virus for as long as possible. The economics of virus re-release need to be examined.

6.78 **Attractants.** A more effective chemical or pheromone would be useful, either to trap beetles or to lure them away from palms. To trap feeding beetles, use might be made of the beetle's visual response, which involves a preference for the silhouettes of taller trees. However, a considerable effort has already been put into this area with little result.

6.79 **Antifeedants.** There is considerable interest in these chemicals, which can be either synthetic or natural plant products. If a sufficiently persistent one could be found, or if a plant which repelled beetles could be grown around seedlings, this could be very useful in protecting young palms.

6.80 **Neutralization of Larval Breeding Sites.** Research on coconut wood utilization needs to be continued, and results obtained so far need to be put into practice. Where there are stubborn stumps, the best means of treatment needs to be found at the local level. The choices are burning; treatment with dieldrin; treatment with *Metarhizium* spores; or concealment by cover crop.

Summary

6.81 Complete protection of palms against rhinoceros beetle attack is not possible, but the effects of attacks are less if palms are growing well. Every effort needs to be made to destroy larval breeding sites; by physically removing the dead logs, by growing a leguminous cover crop and by treatment of stubborn stumps with fungal spores or chemicals. *Oryctes rhinoceros* is susceptible to the virus *Baculovirus oryctes;* severe infestations can be reduced by releasing virus. *Strategus* is also susceptible and virus could be used to control it. The fungus *Metarhizium anisopila* has persistent spores which can be used to treat larval breeding sites.
C. Coconut Mite – Eriophyes Guerreronis

N. W. Hussey

Distribution

6.82 This pest can be identified in the field only by the dark, deeply fissured, suberized patches on the surface of the developing nut. This condition, first reported from the Atlantic coast of Colombia in 1949, was found on the Pacific coast of Mexico in 1963 when the mite associated with it was formally named. Since that time it has been reported from Venezuela, Brazil, Nicaragua, Haiti, Jamaica, Cuba, St. Lucia, St. Vincent, Grenada, Dominica and the Bahamas. During the same period serious outbreaks developed on the African seaboard affecting Nigeria, Togo, Benin and the Cote d’Ivoire as well as the Sao Tome and Principe Islands.

6.83 The apparent concentration around the Atlantic coasts prompted a postal survey through the Indian and Pacific Oceans which revealed similar, but less severe, damage from New Guinea, Solomon Islands, Tahiti, Philippines, Thailand, Tonga, Indonesia, Fiji, New Hebrides, Cook Islands, New Caledonia and Sri Lanka. At the four sites underlined mites were found and subsequently identified as Colomerus novahebridensis. It is assumed that this mite, occupying the same ecological niche on the coconut but causing less damage, is widespread in the Pacific Islands and S.E. Asia.

6.84 Yet another mite causing severe superficial damage to nuts in Sri Lanka has been identified as Dolichotetranychus sp. a Tenuipalpid.

Life-History

6.85 Since the mite is so small (0.1 mm), invades the newly-fertilized flower, and lives below the floral bracts little is known of its developmental biology. However, the life-history is believed to be typical of an eriophyd with the 4-legged females each laying about 20 eggs which hatch within one week, the nymphs maturing about 2 weeks later. So long as the feeding damage is not too severe, several successive generations may develop below the same bract. The superficial cells of the young nut are killed causing the tissues to turn brown and, by the time the nutlets exceed 5 cm in length, yellowish-white marks appear on the green coat of the developing husk beyond the bract.

6.86 Laboratory experiments by R. Griffiths at the Ministry of Lands and Food Production, Trinidad have revealed that when the mites leave the shelter of the bract at night hundreds may be blown from the inflorescences even by winds of <6 m.p.h.. Such migrating mites are also readily washed from the nuts by rain. In the field on St. Lucia, the Commonwealth Institute of Biological Control (CIBC) have shown that movement between palms is responsible for as much of the primary infestation as migration to young inflorescences by crawling from infested nuts below. This ready transport by wind no doubt accounts for the dispersion up the island chains of the Caribbean.
Damage

6.87 There have been many claims that the coconut mite is responsible for a substantial fall of young nuts but extensive studies in West Africa, since confirmed elsewhere, do not support this allegation. However, there is evidence that the number of nutlets may be reduced. Normally the superficial damage causes uneven growth of the husk which reduces kernel size. In severe cases damage may constrict nut growth making fibres so compressed that dehusking takes twice the normal time.

6.88 Most estimates of yield loss have been based on direct comparisons between the copra yield from collections of clean and obviously infested nuts. On St. Lucia, detailed observations in 1984 confirmed experience elsewhere revealing losses at different sites on the island ranging from 11-28%. If the most seriously damaged nuts - never utilized by farmers - are included then the range of loss is 15-50%. This range reflects the local differences in agronomic practice. However, should a successful control be developed then the greatest benefit from mite control would occur on the most productive sites.

6.89 In Brazil the mite has been reported to attack the seedling leaves developing from newly planted nuts in nursery beds.

Control

6.90 Varietal Susceptibility. Observations in different parts of the world suggest that the Malayan Tall, Panama Tall, Tahitian Tall, Red Cameroun Dwarf and Hybrid PB 121 are less susceptible to damage than are other varieties.

6.91 Chemical Control. A wide range of pesticides have been applied, either by spraying or stem injection, to control this pest. Repeated (every 30 days) sprays of quinomethionate, cyhexatin and monocrotophos have protected flowers from mite attack and reduced the proportion of infested nuts 8-12 months later. However, such treatment is feasible only on short palms, and repeated applications would rarely be economic. It is of interest that monthly treatments with salt water are reported to have halved the damage in West Africa. Much interest has therefore centred on stem injection. In the Cote d'Ivoire injection of 15 ml monocrotophos into dwarf palms provided protection against mites for 2 months but the technique was not pursued as it was regarded as excessively traumatic for repeated use. On the other hand, claims have been made that 70 year old palms were protected for 3-4 years when 100 ml of vamidothion was injected after all edible nuts were removed. Mite mortality was said to be complete within 14 days. CIBC attempted to confirm this experience on ten sites in St. Lucia with the following results:

(a) the holes, 2.5 cm in diameter and 15 cm deep, could be drilled within one minute on young palms but took up to ten minutes on older palms, thereby making the practice totally uneconomic;

(b) holes of these dimensions held only 50 ml of pesticide whilst the absorption of pesticide was so slow that plugs could not be inserted
for 2 hours. The total dose plus plugging therefore required three operations;

(c) holes readily fill with water in rain and must be swabbed out before inserting pesticide; and

(d) there was no evidence of mite mortality or a reduction in the proportion of infested nuts up to 7 months after treatment. Indeed the differences in yield at different sites exceeded losses due to the mite.

6.92 If control were to persist for many months there is concern about the residue problem. The residues of vamidothion were said to be < 1 ppm after 6 weeks when the usual acceptable level of vamidothion is put at 0.6 ppm. Hence, if mite control did persist for long periods minute quantities of pesticide would have to be lethal. The original work claimed that crystal violet inserted in holes 2.5 x 15 cm was distributed to all inflorescences affecting the calyx and most of the pericarp. On the other hand work in Sri Lanka with 5 ml monocrotophos injected to protect fronds against caterpillars did so for 15 weeks without detectable residues in the kernel 20 days after treatment.

6.93 On present evidence, therefore, chemical treatment, even if feasible, is unlikely to be economic.

6.94 Biological Control. The only potential predators found below infested bracts have been a species of Lupotarsonemus from Sri Lanka but even they are regarded as more likely to be saprophagous.

6.95 The fungus Hirsutella has been found on Eriophyes guerreronis both in Jamaica and Cote d'Ivoire and on Colomerus novahebridensis from New Guinea and New Hebrides. Attempts to use this fungus as a microbial insecticide in Mexico and St. Lucia have not been successful, though the authorities in the former did claim positive results for some months after the application.

Future Research

6.96 Since it appears impractical to bring established infestations under control, the effect of improvements in the agronomy of older plantations should be studied. Well nourished palms obviously suffer smaller reductions in harvested copra even when infested. Most effort should be directed to the rehabilitation of older coconut plantations with emphasis on the following aspects:

(a) choice of cultivar (detailed surveys of infestations on different cultivars together with inoculation experiments);

(b) hygiene of seed coconuts (disinfection procedures to be developed to avoid damage to seedlings);

(c) studies on aerial dispersal of mites to define logical area of separation of new plantations from existing infestations;
(d) protection of young palms by spraying (further work on formulation of polybutenes and acaricides); and

(e) optimal plant fertilizer program to minimize losses.

6.97 Since the two eriophyiid mites occupy the same ecological niche on the plant while their geographical distributions have yet to overlap, experiments on "competitive exclusion" could be attempted on an isolated island. The less damaging species may prove to be the more aggressive.

6.98 Systematic search for more pathogenic strains of *Hirsutella* better adapted to spread by the pest would also be worthwhile.

**D. Red Ring Disease**

A. H. Green

**History and Distribution**

6.99 The disease was first reported in Trinidad by Hart (1905) who described the typical red ring symptoms but was unable correctly to identify the causal organism. Stockdale (1907) concluded that the disease, known at the time as coconut root disease, was probably caused by a fungus, *Botryodiplodia* sp.; a view which prevailed for more than a decade. Nowell (1918), studying the disease in Grenada, was the first to associate it with a nematode and to recognize the probable importance of weevils in its transmission. He also suggested the name red ring disease instead of root disease. Cobb (1919) working with material supplied by Nowell, provided the first full taxonomic description of the nematode and named it *Aphelenchus cocophilus*. After further studies by a number of researchers, Goodey (1960) eventually assigned it to a new genus as the type and only species *Rhadinaphelenchus cocophilus*.

6.100 Early work was done in Trinidad and Grenada but the disease is now known to occur in the Caribbean as far north as St. Vincent and is to be found in all the countries of central America. In South America it extends down the Pacific coast to northern Peru and, on the Atlantic coast as far south as the state of Sao Paulo in Brazil. It may eventually spread further, both north and south, since its principal transmitter the palm weevil (*Rhyncophorus palmarum*) is to be found as far north as Guadeloupe and southwards into Argentina. Despite sporadic reports to the contrary, it now seems reasonably established that the disease does not occur in Africa, South East Asia or the Pacific Islands.

**Life-history and Symptoms**

6.101 The adult nematode is about 1 mm long and very slender; there are four larval stages and the generation time, egg to egg, is 9 - 10 days. All stages have been recovered from the roots, stems and petiolar tissues of coconut palms. A number of other palms also act as hosts, the oil palm, *Elaeis Guineensis*, being perhaps the most important species at risk in terms of potential economic losses.
6.102 Visual symptoms of attack in the coconut palm vary somewhat from variety to variety, resulting in some conflicting descriptions in the literature. It has been suggested that the palm is most vulnerable to attack between four and seven years of age. Although the disease is always fatal, the time taken for the palm to succumb may vary from as little as 7 or 8 months to several years. The oldest fronds are usually the first to show symptoms, but these are rarely definitive and by the time a clear diagnosis can be made the palm is already doomed. The leaflets show a browning starting at the tips and extending inwards; where the oldest leaves are the first affected these symptoms may be indistinguishable from the onset of normal senescence. Later, infected palms may be identifiable by the richness of the yellow, orange or brown coloration which develops; some authorities, however, maintain that even this is not truly diagnostic. Quite often secondary fungal or bacterial rots intervene before the youngest spear leaves are visibly affected. Internally the most characteristic symptom is the red ring to be seen in a cross section of the stem which gives the disease its name. The red discoloration, which tends towards orange or brown in some varieties, is usually about 2 - 4 cm wide and starts 3 - 5 cm from the periphery. The ring may extend several feet upward from the base of the stem, or it may start higher up and extend downwards, in advanced cases it may even extend into the bases of the lower petioles.

Transmission

6.103 A number of insect species have been implicated in the transmission of the red ring nematode from palm to palm. Incontrovertible evidence is available only in the case of palm weevils. In Trinidad, and many other countries, the most important species is the black palm weevil Rhyncophorus palmarum; but in Brazil and El Salvador the principal vector is the bearded palm weevil, Rhinostomus barbirostris.

6.104 Weevil larvae, pupae and adults all carry the red ring nematodes internally and externally, but ability of the nematodes to survive within the body of the adult weevil seems to be restricted to about 8 - 10 days. Griffith (1976) has suggested that not all weevils are capable of transmitting the disease because of a genetically determined enzyme system which prevents the survival of the nematodes in non-vector weevils. The principal vectors are, in his view, weevils smaller than 30 mm; however this finding conflicts with some of the other evidence.

6.105 Fenwick, Maharaj and Mohammed (Trinidad and Tobago Coconut Research Ltd.) did quite a lot of work in the 1960s indicating that soil transmission of the disease could take place via infected roots or even via chips of infected coconut wood scattered in the process of cutting down diseased palms prior to burning. Certainly nematodes can survive long enough, and move far enough, in the soil to infect both healthy and damaged coconut roots.

Crop losses

6.106 Since the disease is most devastating amongst young palms it is difficult to calculate the loss of potential crop which results from nematode infestation. The problem of estimation is made more difficult by the associa-
tion of the disease with weevil attacks, which can themselves be fatal even when nematodes are not involved. As many as 80 per cent of palms in some young plantings monitored in Tobago have been destroyed by the disease.

Control

6.107 Biological control of the nematode itself has so far proved unattainable. Attempts at controlling the palm weevil vectors have been equally unsuccessful, though the bacterium Micrococcus agilis has been shown capable of infecting Rhyncophorus palmarum. Although the virus Baculovirus oryctes has been used successfully in Malaysia and in the Pacific to control the rhinoceros beetle (Oryctes rhinoceros) no virus has yet been found capable of controlling either Rhyncophorus palmarum or Rhonostomus barbirostris.

6.108 Chemical control of the disease has been attempted using systemic nematicides as a soil treatment, by injection, and by placement in leaf axils. Blair (1983) has claimed complete protection of palms in trial plots by placing a granular nematicide formulation in leaf axils but the cost of this method would be prohibitive under practical plantation conditions. Chemical control of the weevils with systemic insecticides has also been attempted but this, too, has proved uneconomic and is also environmentally undesirable, especially under smallholder conditions.

6.109 Physical control by good plantation hygiene, removal and destruction of infested material, and trapping of weevils has achieved some measure of success. These were the methods advocated by Nowell some sixty years ago. That fully effective control seems no nearer today than it was in the 1920s is a measure of the intractability of the problem and perhaps a reflection of the inadequacy of the research effort that has been made. The disease remains a serious threat to both coconut and oil palm development in the neotropics.

Future research

6.110 On economic grounds it may be expected that the greatest efforts at red ring control will in future be made in attempts to protect oil palm developments in South America rather than the traditional coconut areas of the Caribbean where the disease was first investigated.

6.111 More needs to be known about the non-vector weevils postulated by Griffith and the enzyme system which is apparently capable of destroying the nematodes. Following the successes with Baculovirus oryctes and Metarhizium anisopliae in controlling rhinoceros beetles, viral and fungal control of the weevils merits further investigation. Tests with pheromones and other attractant chemicals should also be continued as a means of achieving more efficient trapping. As to the nematode itself, more needs to be known about its behaviour in the palm, in the soil, at the soil: root interface, and in association with different stages in the life cycle of the vector weevils.

6.112 There have been some indications of varietal differences in the susceptibility of coconuts to nematode attack and the possibility of breeding for resistance should not be neglected; the likelihood of being able to produce clonal coconuts on a commercial scale in the not too distant future will add considerably to the chances of success.
REFERENCES


VII. THE UTILIZATION OF COCONUT TIMBER

7.1 Although the decision was taken to exclude coconut processing, and the manufacture and utilization of coconut by-products, from the present report the following contribution from A.G. Astell has been included because of the massive coconut replanting programs that are currently envisaged by all the major producing countries. A reliable market for the stems of old palms could, by generating some cash up front, do much to persuade growers of the value of these programs. Otherwise, replanting may appear to offer merely a period of several years during which growers' income is seriously reduced and their indebtedness substantially increased. The profitable utilization of old palm stems could also enhance the economic rate of return to governments from their investment in replanting and, at the same time, contribute to the preservation of other timber resources within the country.

A. The Utilization of Coconut Palm Stems for Wood Products

A. G. Astell

Introduction

7.2 The rapid decrease in the area of natural forest world wide receives considerable publicity, and is a cause for grave concern among environmentalists, though the concern is possibly greatest in countries where the deforestation is not taking place. Manufacturers of wood products using tropical hardwoods are anxious about the supply of material they will need in future to maintain their operations. Furthermore, those responsible for the administration and utilization of natural forests in countries where the areas are rapidly diminishing should be having serious thoughts concerning the future of the forests and of themselves. A balance has to be struck between competing needs, the need to conserve forest resources and the need for the foreign exchange generated by their continued exploitation. The coconut could have an important role to play in reconciling these needs, with advantage accruing to forestry departments, owners of old coconut plantations, sawmilling organizations and wood product manufacturers.

7.3 The use of coconut palm stems as building material is not new. For generations islanders who have no suitable alternative material available have used it successfully despite the fact that their methods of sawing, grading and seasoning lacked the benefit of modern technology. Buildings constructed from coconut wood have stood the test of time and indicate the value of coconut not only for local construction purposes but also, with improved technology, for a wider range of applications.

7.4 During the past ten years considerable research has been undertaken in order to enhance the quality of coconut timber and establish a market for it in world trade.
Volume of Coconut Timber Available

7.5 The following statistics, taken from the Coconut Stem Utilization Seminar held in Tonga in 1976, indicate the potential supply of coconut timber in Fiji over the next 50 years:

- Total area of palms available for felling (aged ≥ 75 years) 66,000 ha.
- Average stand 125 stems per ha yielding 1.25 m$^3$ per stem = 156 m$^3$ per ha.
- Annual cut 1,320 ha x 156 m$^3$ = 206,000 m$^3$.

This annual yield, sustainable over 50 years, is 27 per cent greater than the total volume of all forest timber logged in Fiji in 1975.

7.6 The limited data available in 1976 for the whole of the South Pacific region indicated an annual log volume of 1.1 million m$^3$, also sustainable for 50 years. For the Philippines it was estimated by the Philippines Coconut Authority in 1979 that implementation of the national replanting program in the 1980s would require the felling of 6 million palms a year, yielding 6 million m$^3$ of coconut logs: a figure equivalent to the permitted logging volume from the natural forests.

7.7 Although global figures are not available it is clear from the examples given that the coconut offers a timber resource far too large to be ignored in any program aimed at the preservation of natural forests.

Conversion of Coconut Stems into Sawn Timber

7.8 The technical problems can be resolved by the use of modern technology; with the use of hard tipped tooth saws making the sawing of the high density material in the bottom section of the stem comparatively simple. However, in order to obtain the maximum volume of high density boards it is important to adopt the correct sawing pattern (Figure 7.1). Various government organizations, in association with the FAO, have set up training establishments to demonstrate the most efficient methods, and these are becoming more widely adopted.

The Uses of Coconut Timber

7.9 The bottom portion of the stem of an old coconut palm has three distinct sections of different density. The outermost 50 mm is high density, the next 50 mm medium density and the remaining centre section is of low density, (Figure 7.2). These dimensions will, of course, vary according to the age and girth of the palm and the conditions under which it has been grown.

7.10 The wood is now becoming more widely known and has great potential due to its ready acceptance of adhesives and the uniform grain and colour within each density band. The denser the wood the darker the colour, and the least dense innermost section is much paler than the rest. The high density
boards make attractive and durable flooring. The high and medium density materials have been used for furniture, panelling and turned wood products as well as for the structural sections of buildings. Their use as cross arms for electric power and telephone poles is being investigated. All three classes have been used in the construction of local housing with the low density material being used as cladding for ceilings and walls.
Figure 7.1:
SAWING PATTERNS FOR COCONUT LOGS TO OBTAIN MAXIMUM HIGH DENSITY MATERIAL

SYSTEM A: AFTER 1ST AND 2ND CUTS THE LOG IS TURNED THROUGH 180°
AND DOGGED FLUSH AGAINST HEAD BLOCKS. SUBSEQUENT
TURNS ARE 90° AFTER FOLLOWING CUTS.

SYSTEM B: AFTER 1ST AND 2ND CUTS THE LOG IS TURNED THROUGH 90°.
THIS PRACTICE IS PREPARED AFTER SUBSEQUENT CUTS.

N.B. BARK LINE OF LOG MUST ALWAYS BE SET PARALLEL TO SAW LINE.
Figure 7.2:

THE DENSITY STRUCTURE OF THE COCONUT STEM

[Diagram showing the density structure of the coconut stem with layers indicating high, medium, and low density areas.]
Constraints to Utilization

7.11 The following are the principal constraints to the wider utilization of coconut timber:

(a) insufficient interest and lack of motivation in forestry departments in the main coconut producing regions where the largest areas of senile palms are available for felling;

(b) insufficient interest generated within the sawmilling industries and among wood product manufacturers in these regions;

(c) inability at this stage, due to insufficient evidence, to convince overseas buyers of the durability and suitability of coconut timber products for use under climatic conditions different from those in which they originate.

7.12 To eliminate these constraints it will be necessary to:

(a) convince forestry departments, sawmilling industries and wood product manufacturers that greater use of the coconut would contribute to an important extent in safeguarding and maintaining regular supplies of traditional timber species from the natural forests;

(b) promote the use of sawn coconut wood in a wider range of commercial products where manufacturing and marketing skills are already available;

(c) develop methods to improve the consistency of grading of the different densities to ensure that the product meets the purchaser's requirements. Stress grading would assist in this respect;

(d) develop improved methods of seasoning and preservation to enhance acceptability;

(e) since age materially influences the quality of the timber, establish a universally acceptable method for determining the age of coconut palm stems thereby protecting the interests of both seller and buyer;

(f) determine, by further research, the minimum age of palm required to yield a high enough proportion of the more valuable high density timber to make the sawing operation profitable.

Conclusion

7.13 Coconut palms represent a major renewable source of decorative hardwood and structural lumber which can be available on a sustained basis for as long as coconut cultivation continues. The use of this resource has positive environmental implication in its own right, but it can and surely must significantly substitute for natural forest hardwoods, thus playing a vital role in reducing the destruction of the tropical rainforests.
Coconut cultivation should now be perceived as an enterprise producing timber as a perennial oil seed. It may be premature to consider breeding for timber production, but this aspect should certainly be taken into account in trials of tall x tall hybrids and suitable stem measurements should be included in the recording routine. Conversion of senile stems to timber offers the opportunity to offset significantly the capital cost of replanting in many countries and, simultaneously removes the risk of rhinoceros beetle infestation.
Introduction

1. The coconut, like the calabash and the bottle-gourd is used as a convenient container wherever modern man has not yet brought the ubiquitous benefits of plastic. Unlike the calabash or the gourd, the coconut comes already filled with a drinkable liquid. This liquid is pure, it is palatable and it is portable. Unlike a plastic container, the coconut fruit is non-returnable, absolutely disposable and totally recyclable. These qualities are found in the immature coconut and they are well known wherever the palm grows. But, for the last one hundred years, the fresh young coconut fruit has been taken for granted by agricultural scientists who have, instead, carefully studied the mature, hard-shelled, hairy, brown coconut of commerce. The water in this ripe nut is insipid and it is the high oil content of the dried endosperm, at around 70%, that interests the economic botanist. As far as the botany of the crop is concerned, the research worker has assumed the commercial plantation coconut to be representative of all coconuts. It has even been classified as Cocos nucifera var typica (Narayana & John, 1949; Liyange, 1958). This is misleading because the commercial coconut is not typical. It is nothing more than a random sample taken into cultivation, out of material that has achieved pan-tropical distribution for totally non-agricultural reasons (Harries, 1978).

2. The concept that the coconut occurs as a wild species that survives without human intervention will only be accepted when two conditions are fulfilled. Firstly, applied scientists undertaking germplasm collections must not restrict themselves to the coconut palms that are conveniently lined up in plantation rows. Secondly, pure scientists collecting taxonomical specimens must no longer reject every Cocos nucifera as merely an escape from cultivation.

Center of Origin

3. The origin of the coconut has often been debated and there have been proposals for both New World and Old World origins for the genus Cocos. The taxonomic argument based on similarities between cocosoid palms native to Central and South America (Martius, 1823-1850) was taken to extreme lengths at a time when the commercial importance of coconut encouraged the idea of introducing it to southern California (Cook, 1901; 1910). When the American palms were assigned to genera other than Cocos the coconut became monotypic with closest associations to Jubaeopsis caffra in southern Africa (Beccari, 1917).

4. Proponents for an Old World origin, have suggested Indian, Indo-Malesian and Melanesian centers for the specific type Cocos nucifera. An origin in the western Indian Ocean, although seemingly supported by the link with Jubaeopsis caffra and the presence of an Eocene fossil, Cocos sahnii in the Indian desert, has not been generally accepted (Chiovenda, 1921). An Indo-Malesian origin was proposed in the region to the north west of New
Guinea, mainly for geological and biological reasons related to Wallace's line (Mayuranathan, 1938). Prior to the time that this suggestion was made a fossilized coconut fruit had been found at Aitape on the north New Guinea coast in association with a human skull but the fact was not published until later (Hossfeld, 1948). The material was estimated by radiocarbon dating to be 4,555 years old. Unfortunately, the whereabouts of the fossil coconut is not now known and it may well have been destroyed in the dating process. Very recently remains of coconuts, dated at about 3,500 before present, have been found associated with human settlements and Lapita pottery in the St. Matthias group of islands in Papua New Guinea (Kirch, 1987, personal communication). A precise New Guinea origin cannot be based on such comparatively recent remains, but most modern text books generally favor somewhere in Melanesia (Child, 1974; Fremond et al, 1966; Ohler, 1984; Purseglove, 1972; Williams, 1975).

5. The antiquity of the coconut in the Indo-Pacific region is born out by the part it plays in the life of the people; as shown by the names it receives, the implements with which it is processed (Werth, 1933) and the uses to which it is put (Chiovenda, 1921-1923). But these all represent factors of domestication and diversity rather than of origin. Similarly, the Miocene fossil, Cocos zeylandica in North Island, New Zealand (Berry, 1926; Couper, 1952) could represent fruit which had floated from elsewhere and not necessarily have grown in situ. The best argument so far put forward in support of a Melanesian origin is that of Lepesme (1947), who drew attention to the high proportion of insects in the Melanesian region which have coconut as a primary host. He also supported the thesis that one animal, the coconut crab (Birgus latro), has a close biological association with the coconut. More recently it has been suggested that this land-living crab could not have achieved a widespread inter-island distribution with only a 30 day aquatic larval stage unless the post-larval glaucothoe stage was spent in the moist husk of a free floating coconut (Harries, 1983). Evidence for wild type coconuts actually growing in the region has been found in Vanuatu where fossil shell and roots dated at 5,420 years before present apparently pre-date human settlement (Spriggs 1984). Taking all the foregoing factors into account, and using data from present day coconut populations in Vanuatu that have a large number of thick husked but comparatively small fruit it is possible to suggest an origin in the region of the Lord Howe Rise-Norfolk Island Ridge at a time when that fragment of Gondwanaland was submerging, some 15 million years ago (Harries, 1978).

Dispersal

6. Natural dispersal by floating was readily accepted by earlier taxonomists but later workers assumed that coconuts were always closely associated with human activities and therefore were distributed by cultivation. Any references to wild coconuts, in the sense that they were indigenous and never cultivated, have been disregarded. For example, an excursion flora for Java (Koorders, 1911) recorded that in 1889 such a form was easily recognized where it occurred on a remote coast by its very small fruit with extraordinarily thick and firm husk yet when a botanical reconnaissance was made of the area in 1957, coconuts were not even mentioned (Jacobs, 1958). Similarly, reports of coconut growing spontaneously at several points on the Queensland coast of Australia (MacGillivray, 1852;
Mueller, 1867; Thozet, 1869; Benthan, 1878) were ignored until recently when a self-sown coconut was found on a Great Barrier Reef island (Buckley and Harries, 1984). Even in the Philippines, where coconuts have reached their most important commercial development and might be thought to have eliminated all progenitors, wild types can still be found (Gruezo & Harries, 1984) close to the place where they were first described at the time of the 17th century European settlements (Alzina, 1668).

7. Some of the antagonism against coconuts floating and establishing naturally, arose from arguments about the Kon Tiki expedition because it was not even realized that the type of coconut in question was not the wild type. Only when it is understood that wild coconuts have particular characteristics and preferred localities is it possible to suggest what plant characteristics to look for and just where to look for them (Table 1).

8. In the absence of man and predatory animals such as pigs (the coconut crab might be considered a symbiont since its presence would aid natural selection for a thick husk and slow germination), coconut palms must have been restricted to the strip of beach just above the high water mark. Under exceptional circumstances Ernst (quoted by Beccari, 1917) found strand plants, including coconuts, 300-500 metres inland after Krakatoa erupted in 1883 and fifty years later Hill and van Leeuwen (1933) reported forty-one germinating coconuts on the beach of the newly emerged Anak Krakatoa IV. Coral fringed islands, and particularly atolls, are preferred habitats and to get from one to the next the coconut must float. Thick-husked, long, angular fruit float better, the embryo is better protected, (and so are any passengers, such as Birgus latro). Slow germination will allow longer distances to be traversed and germination data support this. Even after 200 days from reaping, germination is not complete (Whitehead, 1965).

9. However, a successful species such as the coconut keeps its options open and the germination rate is much quicker when the same type is generously supplied with fresh water. It is possible to show from the results of two experiments where coconuts were floated in the open sea, that such immersion can delay germination (Edmondson, 1941). It has been argued that dormancy is induced and that germination is controlled, to a large extent by the osmotic potentials in the husk (Harries, 1981a) For the wild coconut under atoll conditions, the fruit that falls to the ground germinates slowly depending on how much rainfall there is and on the amount of shade. In this situation a seedling can be present to replace any mother palm that is destroyed by lightning, old age or pests, any time for the best part of a year after the fruit matures. The fruit that falls into the relatively calm waters of the lagoon does not get saturated with salt water. Instead, the embryo is in an aerated, humid and non-saline environment produced by continual absorption, diffusion and evaporation of water through the husk under the hot tropical sun. It germinates quickly, as Edmondson's floating experiment on a sea water reservoir demonstrated. The end result is, that by the time the seednut washes ashore at another part of the same atoll, where adult palms, seedlings and seed might have been destroyed and washed away by a windstorm or tsunami, it can already be growing and can thus maintain a population of coconuts with a common genotype against competition from other plant species.
10. On a coral island, the only other place that a coconut can fall is into the open sea where, due to normal wave action, it will absorb considerable amounts of sea water into the husk, thereby inducing dormancy (Harries, 1981a). If currents and winds are favorable, this fruit might drift, along with any passenger crabs it may carry, to another coastline, perhaps one where coconuts (and the crab) do not already occur. Just how far this might be is a matter of opinion and computer simulation studies on long distance dispersal (Ward & Allen, 1980) and plans for a free-floating experiment between mid-Pacific atolls and the coast of Central America must use the proper, wild type coconut and take into account the possibility of sea-water induced dormancy.

11. It may never be known whether the coconut originated in the Indian Ocean or the Pacific Ocean or somewhere in between but wherever it started from, given enough time the truly wild coconut could, and probably did, spread from island to island as far as the Seychelles Islands to the west and the Line Islands to the east. It is also probable that the coasts of Africa, Asia, Australia and America did receive, and still do receive, coconuts that have floated from oceanic islands. These islands, which on a geological time scale are constantly changing their size and position, have acted, and still act, as a natural conservatory for coconut genetic resources, at least for the wild type.

Domestication

12. Once the coconut came into contact with man there would be selection pressure for other characteristics that were unimportant to the wild type, or indeed downright disadvantageous to it. These characteristics represent the results of domestication, not agricultural cultivation which did not happen till very much later. Unconscious selection pressure through many generations (both human and coconut) improved one characteristic, the water content, and other changes depended on this. The first human contact with a coconut must have been on the sea-shore and it is possible to argue that the sea-shore is an optimal habitat for both man and the coconut. The coconut is a source of drinking water that can be obtained without digging and without tools. The immature fruit is simply banged on a rock to split it. Originally, man may just have been another predator, picking up and eating coconuts that floated ashore, even as Australian aboriginal children do today (Hynes & Chase, 1982). Mature palms might be considered tabu and would certainly not willingly or easily have been cut down until good steel axes became available. If the Vanuatu fossil shows that coconuts grew there for at least 2,000 years before the presence Melanesian people reached these islands then, in the same way, it may have been the presence of the coconut palm, purely and simply as a source of water, that assisted the aboriginal migrations from Asia to Australasia at an earlier time. An even more radical idea is that man and the coconut may have been interdependent, in much the same way that the robber crab and the coconut may have been, and at a very early, possibly aquatic stage in human evolution (Harries, 1979).

13. The contrasts between the characteristics of the wild and domestic coconuts (Table 1) reflect the contrasts between the environments in which the first evolved and the second was domesticated. For the wild type, the curved stem allows palms to lean out over the water, gaining space and light,
effectively increasing the leaf and fruiting functions despite the limited rooting area on a narrow beach. In contrast, the domestic type develops a sturdy bole and erect stem to withstand hurricanes and compete with other tree crops. The wild type is susceptible to certain (MLO) diseases because it was isolated from infection whereas the domestic type shows tolerance brought about by repeated exposure to infection (Harries, 1978).

14. At some stage, the domestic type would have been taken a little way inland around coastal and river settlements on the continental mainland and the larger islands of southeast Asia. The two types would remain geographically isolated from one another and the domesticated coconut would be preferentially planted in new settlements; for instance, those made by Polynesians on isolated Pacific Islands. At about the same time it was probably carried to India (Mayuranathan, 1938). In Africa, coconut dissemination did not follow the route that bananas took -- overland from east to west across the continent -- but were carried by sea to a specific region and within a specific 50 year period. The Portuguese took the predominantly wild type from the western Indian Ocean into the Atlantic Ocean, around the Cape of Good Hope to the Cape Verde region between 1499 and 1549 and from there is went to the Caribbean and to Brazil. Nor were coconuts carried across the Central American isthmus by the Spaniards as is often supposed. The Spaniards took the predominately domestic type from the Philippines after 1650 and disseminated them along the coast of Central and South America. The type of coconut found on the Caribbean coast of America is totally and unmistakably different from the one on the Pacific coast. It was realization of this fact that gave the original clue to the recognition of wild and domestic types. Not until there was extensive river travel during the Californian gold rush, around 1850, and again after 1915 when the Panama Canal was opened, did the two types come into contact there (Richardson et al, 1978).

15. Elsewhere the contrasting wild and domesticated types have undergone introgressive hybridization whenever they have been brought into proximity because there seem to be no barriers to cross-fertilization.\footnote{Dwarf coconut types (with the exception of the Niu leka, or Fiji Dwarf type), are fundamentally domestics since they cannot survive without human involvement. They show predominately domestic characteristics and, in particular, very bright fruit colors.} The introgressed populations which developed show characteristics of both types or some intermediate condition. They are so common and yet so variable - both within populations and between populations - that calling any of them \textit{typica} is meaningless. Yet, once industrial demand for vegetable oil accelerated in the 19th and 20th centuries, all the forms - the introgressed, the domestic and even the wild - have been taken into cultivation.

16. A convenient way to distinguish wild, domesticated and introgressed populations is by fruit component analysis. The wild, or Niu kafa type, is found to have a higher proportion of husk and a slightly lower fruit weight than the domestic or Niu vai type. The proportions of water, shell and endosperm also differ in characteristic ways. The great advantage of fruit component analysis is that it avoids the subjective descriptions upon which previous classifications were based. It has already been used to generate
data from many 10-nut samples taken in the field during germplasm collecting expeditions, from larger samples on agricultural research stations and even from 10 thousand-nut samples on commercial estates (Harries, 1981b). However, many more data need to be accumulated and correlated with other studies, such as germination rates and so on, before coconut varieties can be considered to be well and truly documented.

17. Finally, even the shapes of the nut are diagnostic and make it easy to distinguish the wild and domestic types. This observation has been applied to interpretation of archaeological coconut remains from Brunei in Borneo (Harries, 1981c).

Conclusion

Wild, domestic and cultivated coconuts are quite distinct in all biogeographical features except one - they can interpollinate - and the resulting introgressed populations have made classification difficult in the past. The conditions under which coconut evolved can be quite precisely specified as can the purpose for which it was first domesticated. The isolated conditions still exist today and the coconut palm can be found growing in its original habitat where it will continue to thrive, with or without human intervention. But the importance of the domestic form was displaced by the production of copra and this in its turn, has been superseded by other sources of vegetable oil. The coconut can be considered as perhaps the most successful member of the world's oldest and most durable ecosystem. It is also the most widespread and well known tropical tree crop. The coral reef ecosystem is constantly changing its form and as a result the precise location of a centre of origin for the coconut will probably never be known. The agro-industrial specifications for the cultivated form of the coconut are not inflexible and the type that has the highest oil content, which does not deteriorate by early germination and which has many small fruit suitable for mechanical processing - the wild type - may yet again come into its own as a renewable energy resource wherever and whenever nuclear or fossil fuels are not available.

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<td>Flowering pattern</td>
<td>Cross-pollination is not absolute</td>
<td>Cross-pollinated but often selfed</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Fruit</td>
<td>Long, angular, thick husk</td>
<td>Spherical, thin husk</td>
<td></td>
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<tr>
<td>Nut with husk removed</td>
<td>Ovoid or spindle shaped, thick shell, little water, thick endosperm, high oil content</td>
<td>Spherical to obovate, thinner shell, much water thinner endosperm lower oil content</td>
<td>All combi-</td>
</tr>
<tr>
<td>Germination</td>
<td>Slow</td>
<td>Fast</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Growth rate</td>
<td>Slower</td>
<td>Quicker</td>
<td>Intermediate</td>
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<tr>
<td>Response to MLO diseases</td>
<td>Susceptible</td>
<td>Tolerant</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Response to windstorm</td>
<td>Susceptible</td>
<td>Tolerant</td>
<td>Intermediate</td>
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\a Wild and domestic types are also cultivated.
REFERENCES

Alzina, F. I. 1668 On the palms which are called Cocos and their great usefulness. Trans L. B. Uichanco (1931) Philippine Agriculturalist 20: 435-446.


Oleagineux 36, 63-72.

Harries, H. C. (1981c) The antiquity of the coconut in Western Borneo. 
J. Sarawak Mus. XXXIX (50).

Harries, H. C. (1983) The coconut palm, the robber crab and Charles Darwin: 
April Fool or a curious case of instinct? Principes 27, 131-137.

Hill, A. W. & van Leeuwen, W. D. (1933) Germinating coconuts on a new 

Hossfeld, P. S. (1948) The stratigraphy of the Aitape skull and its 

influence upon plant communities in Cape York Peninsula. Archaeology in 
Oceania 17, 38-50.

Jacob, M. (1958) Botanical reconnaissance of Nura Barung and Blambangan, 
south east Java. Blumea, Suppl. IV; Vol 2.X.


Liyanage, D.V. (1948) Varieties and forms of the coconut palm grown in 
Ceylon. Ceylon coconut Q. 9, 1-10.

MacGillivray, J. (1852) Narrative of the voyage of HMS Rattlesnake. London, 
T. & W. Boone.


Narayana, G. V. & John C. M. (1949) Varieties and forms of the coconut. 
Madras Agric. J. 36, 349-366. (Reprinted as John, C. M. & Narayana, G. V. 
1949 Indian Coconut J. 2, 209-226. Narayana is also cited as 
Venkatanarayana, G.).

Paper No 57.


NOTES ON THE CONTRIBUTORS

A. H. Green

Institut de Recherches pour les Huiles et Oleagineux

1. IRHO is the vegetable oils and oilseed crops research department of the French Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD). IRHO has a mandate to study and develop oil palm, coconut and annual oil crops from cultivation to processing. IRHO, with headquarters in Paris and extensive laboratory facilities in Montpellier, operates in 25 countries throughout Africa, Asia, South America and the Pacific.

2. IRHO was established shortly after the Second World War and became active in coconut research in 1950. Since that time it has become a leader in several areas of research and a major influence in the development of the crop.

3. The following staff of the institute have contributed to this paper:

   M. de Nuce de Lamothe - Director
   X. Bonnequ
   R. Desmier de Chenon
   M. Dollet
   J.F. Julia
   D. Mariau
   J. Meunier
   J.P. Morin
   R. Ochs
   J. Olivin
   M. Ouvrier
   M. Pommier
   J.L. Renard
   F. Rognon
   J.P. Le Saint
   A. Sangare
   G. de Taffin
   N. Zakra

A.G. Astell

4. Worked in West Africa from 1947 until 1970 for African Timber and Plywood Co. (Unilever). An experienced sawmill manager, he has special expertise in the manufacture and maintenance of saws. Since 1970 has been engaged in an advisory capacity in a number of FAO projects involving training and research in sawmilling operations and has been directly concerned with coconut wood utilization in Fiji, Philippines, Jamaica and Thailand.
K.V.A. Bavappa, B.Sc., M.Sc., Ph.D.

5. After graduating from the University of Madras, worked from 1951-56 as a research associate on rice breeding and nutrition. Was engaged for 14 years on all aspects of arecanut research before being appointed Director of the Central Plantation Crops Research Institute at Kasaragod in 1970, a post which he held until 1976. After fulfilling a number of international assignments, including work in Sri Lanka, Thailand, Indonesia, Fiji and Tanzania, re-assumed the Directorship of CPCRI at Kasaragod in 1982. Has participated widely in international conferences and symposia including the meetings of the FAO Technical Working Party on Coconut Production, Protection and Processing. A member of the Scientific Panel for Horticulture and Plantations Crops, ICAR, New Delhi; also a member of the Academic Councils of two other universities. Has more than 160 publications to his credit.

J. Blake, B.Sc., M.S., Ph.D.

6. Received an external degree from London University after studying horticulture at Studley College. Spent a year at Cornell University, USA., gaining an M.S. in floriculture. Received a Ph.D. in horticulture from Reading University in 1955. After a variety of post-doctoral posts, started tissue culture project on coconut propagation with ODA funding at Wye College in 1970. Currently holds post of Senior Research Fellow in the Unit for Advanced Propagation Systems at Wye and is involved with tissue culture propagation of tropical and temperate species. The first clonal coconut plantlet was produced in 1983.

S.J. Eden-Green, B.Sc., Ph.D.

7. Studied biology at the University of East Anglia, followed by research on plant bacteriology at East Malling Research Station, U.K., leading to a Ph.D. from Imperial College, London, in 1972. Appointed to Rothamsted Experimental Station and seconded to ODA lethal yellowing project in Jamaica as plant pathologist/entomologist 1973-81, project leader from 1977. Seconded to ODA Sumatra disease of cloves project in Indonesia in 1982. Broad interest in plant diseases caused by bacteria, mycoplasmas and related agents, and their insect vectors.


8. After studying at the University of Reading and the University of the West Indies joined the Department of Agriculture, Solomon Islands, where he worked as tree crop agronomist from 1965 to 1980. Joined Lever Solomons Ltd as research officer (coconuts) in 1980, transferred to plantation management in 1982, and become General Manager of Pamol Plantations Sabah (another Unilever company) in 1983. Returned to the Solomons in 1986 and is now Managing Director of Lever Solomons Ltd.


9. Read agriculture at Reading University and then spent four years with ICI as field trials officer at Jealott's Hill. Joined Unilever in 1948 as oil palm agronomist to Huileries du Congo Belge. Later moved to Nigeria and
Cameroon to work on oil palm, rubber and bananas, and then to the Solomon Islands to set up what was to become the Joint Coconut Research Scheme. Transferred to London in 1962, and was appointed Research Adviser to Unilever Plantations Group in 1965. Left Unilever in 1977 to join the World Bank, first as agriculturist in the Western Africa region and subsequently as Tree Crops Adviser in the Agriculture and Rural Development Department. Retired in 1984 and has since worked for the Bank and the FAO as a consultant.

H C. Harries, B.Sc., M.Sc.

10. Graduated from London University and worked for five years on disease resistance in tomatoes before moving to Jamaica to work on coconuts. During ten years there produced new hybrid coconuts, MLO-disease resistant, high yielding and wind tolerant; also devised novel techniques for pollen collection and handling. Continued work on hybrid coconuts over four years in Thailand, initiating a breeding program and researching intercrops and cultural practices. Transferred to Papua New Guinea to lead a team in long-term breeding trials and selection of oil palm, work on tissue culture of oil palm and commercial seed production of oil palm, coconut and robusta coffee. Writing the third edition of the Longman Tropical Agriculture series textbook "Coconuts."

N.W. Hussey, B.Sc., Ph.D., OBE

11. After six years war service with the RAF graduated in forestry from the University College of North Wales, Bangor. Lecturer in Forest Zoology at University of Edinburgh from 1949 to 1956. Joined Glasshouse Crops Research Institute as entomologist, later becoming Head of Crop Protection Division and Deputy Director. Retired in 1986 and has since worked as a private consultant, acting in this capacity as the CABI representative in the Caribbean.

A.S. Leng, B.Sc.

12. Studied at Durham Agricultural College and then took an honours degree in botany at King's College, London, followed by a post graduate diploma in plant breeding at Cambridge. Worked as a research assistant at Stirling University, then as assistant plant breeder at Sinclair McGill, Ayrshire. Following a period from 1977 to 1980 as regional trials officer for the National Institute of Agricultural Botany based at Wye College, moved to the Lowlands Agricultural Experimental Station, Papua New Guinea, as food crops agronomist from 1981 to 1984 and is currently research officer to Lever Solomons Ltd. in the Solomon Islands.

C.J. Lomer, M.A., M.Sc., Ph.D.

13. Following a first degree in zoology at Cambridge, studied applied entomology at Imperial College. Worked on control of rhinoceros beetle, Oryctes moncineros, in the Seychelles for three years, followed by two years studying Baculovirus oryctes at the National Environment Research Council Institute of Virology in Oxford. Received external Ph.D. from London University in 1986. Currently working for the ODA on biology and control of the vector insect of Sumatra disease of cloves in Indonesia.
J.W. Randles, B.Ag.Sc., M.Ag.Sc., Ph.D.

14. After graduating from Adelaide University in 1961, worked as Research Officer, Horticulture and Plant Pathology, in the South Australian Department of Agriculture from 1961 to 1966. Joined the Plant Pathology Department of the Waite Agricultural Research Institute, University of Adelaide in 1969 as Lecturer, subsequently becoming Senior Lecturer and then Reader in Virology. In 1981 was awarded a Fellowship of the Alexander von Humboldt Foundation, at the University of Dusseldorf, F.R.G. Between 1973 and 1984 was a part time consultant to FAO-UNDP working on cadang-cadang disease in the Philippines and from 1984 to 1987 has been project leader, Australian Centre for International Agricultural Research, on studies of cadang-cadang and foliar decay diseases of coconut in the Pacific region.

J. Riley, M.Sc.

15. Studied mathematics and statistics at London University and biometry at Reading. She is now the Overseas Development Administration's Biometric Liaison Officer and is head of the ODA Biometrics Unit at Rothamsted Experimental Station. Has travelled to many developing countries to advise on the design and analysis of agricultural experiments and on computer programs suitable for agricultural research. In connection with this overseas work has developed new statistical methods of design and analysis for intercropping experiments.

D.H. Romney, B.Sc., M.R.I.C.

16. Graduated from Reading University in 1951 and joined the Colonial Research Service. Carried out Land Use Survey of British Honduras, 1952-54, continuing to work there as agricultural chemist and later as agronomist, including work on coconuts, until 1960. Joined the Coconut Industry Board, Jamaica, as agronomist and crop physiologist (1960-62) becoming Director of Research in 1962, a post which he held until 1981. Has been with the National Coconut Development Programme in Tanzania (GTZ/IDA) since 1981.

R.W. Smith, B.Sc.

17. Studied botany at Bangor and had further training at East Malling Research Station, England before taking post as Agronomist at West African Cocoa Research Institute (now C.R.I.G.), in Ghana for five years. Agronomist/Crop Physiologist for 10 years with Research Department of the Coconut Industry Board, Jamaica. For the past 15 years has been Agricultural Research Advisor, and later Senior Agricultural Administrator - Research with the U.K. Ministry of Overseas Development (ODA). In the latter post has been involved in coconut research in many coconut growing countries. He has recently been appointed Chairman of the Executive Committee of BuroTrop.

K. Trewren, B.Sc.

18. Studied botany at the University of Wales, Bangor. Worked as agronomist in Lesotho, 1966-68, then spent 10 years in Zambia working on tree crops, specializing in coffee and tea. In 1978 moved to Tuvalu to become coconut agronomist and team leader of a 3-man unit looking into problems specific to atolls. From 1981 to 1986 was tree crop agronomist for Kiribati and Tuvalu. Has now moved to the Solomon Islands.
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