History of Cocoa Research and Improvement in Papua New Guinea

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1900s

It is likely that the earliest introductions of cocoa to Papua New Guinea occurred between 1884 and 1900 into German New Guinea from Samoa, some of these introductions being in the vicinity of Rabaul through the connections of German trading companies to Samoa (Appendix 2). As described in Appendix 2, there is strong evidence that these introductions were mainly Trinitario cocoa that had originated in Ceylon, Cameroon and Java. There is some evidence of a direct introduction from Venezuela that would also most likely have been a Trinitario type (Bridgland LA, 1960, cited below). The fact that the type of cocoa first widely planted in Papua New Guinea was Trinitario has been of great importance for the success of the cocoa improvement program in this country right through to the present day. Even now, the cocoa breeders at CCIL are exploring the diversity of Trinitario cocoa on farms throughout the country for well-adapted types.

Because of its great genetic variability, based on its hybrid (Criollo x Forastero) origin and its high degree of self-incompatibility ensuring out-crossing, Trinitario cocoa has been of fundamental importance in the development of the cocoa industries in Papua New Guinea and Indonesia. In particular, it has allowed selection of superior types of cocoa (e.g. disease resistant and higher yielding types with excellent bean quality), which was not possible with the very uniform West African Amelonado cocoa on which the industry in Ghana and Nigeria was based; this cocoa originated from the introduction of only one or a few pods and was inbreeding and so gave rise to very uniform cocoa population.

1920s and 30s

Cocoa was one of the first crops to be planted when the Government Demonstration Plantation was opened at Keravat in 1928. In 1930 the Demonstration Plantation was renamed the Lowlands Agricultural Experiment Station (LAES). This played a role in the industry's expansion by advising growers on methods of cocoa management and supplying seed from selected trees that appeared to have good traits. Two years later, in 1932, LAES introduced cocoa from Java, and, again, this was undoubtedly Trinitario cocoa (Djati Roengo clones), which was the dominant type in Java at the time, having originally come from Venezuela. The common cocoa in Java in the late 1800s was a Criollo type known as 'Java Red' that may have contributed to the Trinitario cocoa types (the K and KA clones) that were selected and tested at LAES, Keravat and widely planted in Papua New Guinea after the Second World War (see Bridgland LA, 1960, 'Cacao improvement programme, Keravat'. The Papua New Guinea Agricultural Journal 12, 149). Red-podded Trinitario types are common in Papua New Guinea and these may trace their origin back to the type that was introduced from Java in 1932. Also a collection of Criollo cocoa was reported to occur in the Botanic Gardens in Rabaul up until the Second World War and this was probably derived from the cocoa introduced from Java.

In 1938, E.C.D. (Clive) Green, the Superintendent of LAES, published 'Cacao Cultivation and its Application to the Mandated Territory of New Guinea' (New Guinea Agricultural Gazette 4/4). This included recommendations for the layout of plantations and mixed cropping with coconuts (as shade), coffee, bananas or foodcrops. Green appreciated that soil fertility had to be maintained under cocoa and advised that all prunings and organic waste be returned to the soil in a system of shallow trenches dug between rows of cocoa so that over time all the cocoa was manured in this way. He also recommended composting of weeds with the addition of nitrogen-rich animal manure. These recommendations still apply.

Green was well aware of the genetic heterogeneity of the Trinitario cocoa in Papua New Guinea and strongly recommended selection of improved types from the available plantings throughout the country. This approach still contributes to the cocoa breeding program at CCIL.

Most of the research work undertaken before the Pacific War (1941-45) was concerned with seed selection and vegetative propagation. A simple spacing trial was planted in September 1935, but few results had been collected when the war intervened. Even in the 1930s, the cocoa weevil *Pantorhytes* was a problem, as reported by the government entomologist J.L. Froggatt in 1938 ('Weevil pests of cacao'. New Guinea Agricultural Gazelle, 4/3, 6); it has continued to be a major problem in certain areas up to the present time. Spraying and banding trials were initiated, but were discontinued because of unfavourable weather.

By the time of the Japanese invasion of Rabaul during the Pacific war (January 1942), Keravat was supplying seed that produced high yielding trees resulting from three generations of selection, presumably from crosses within Trinitario as recommended by Green. This was clearly excellent cocoa as beans sent to the United Kingdom, America, Germany and Australia achieved the same price as beans from Trinidad and a higher price than those from Ghana. The outbreak of the war halted all work at LAES, which became a major base and centre of food gardens for the Japanese forces. The superintendent, Clive Green, remained at his post right up until the arrival on the station of Japanese troops, escaping into the surrounding rainforest where he survived for several months before surrendering to the Japanese commander at Keravat. He died in the sinking by an American submarine of the 'Montevideo Maru' near the Philippines as it was taking prisoners-of-war from Rabaul to Japan. Most of the experimental cocoa and all the research records were destroyed during the war. The cocoa collection at the Rabaul Botanic Garden also suffered major damage.

The Lucker family was closely involved with the establishment and on-going history of LAES. Hans Lucker was the field overseer and a close friend of Clive Green, and gave him shelter during the Japanese invasion. After the war, his son Paul Lucker worked as an assistant to Leon Bridgland from 1950 to 1960, and another son Dick Lucker was the station mechanic from 1957 to 1972 (see Anon. 'Lowlands Agricultural Experiment Station, Keravat, Papua New Guinea, 1928 – 1978', compiled by David Loh on the 50th anniversary of the station).

1940s

R.E.P. Dwyer (Economic Botanist from 1946, later Chief of Division of Agricultural Extension, and Director of the Department of Agriculture, Stock and Fisheries from 1952 to 1957), in the Preface written for the reissue of Green's booklet after the war, bemoaned the loss of much of the superior planting material selected before the war. D.H. Urquhart, who had been the Director of Agriculture on the Gold Coast (Ghana) and was sent to report on cocoa in the Pacific on behalf of Cadbury Bros, the South Pacific Commission and the Australian Minister for Territories, recommended that the Solomon Islands use seed from Keravat, declaring that the cocoa he had seen at Keravat was "the best I have encountered anywhere to date" (Urquhart DH, 1951, 'Prospects of growing cacao in the British Solomon Islands, with notes on Malaya, Ceylon, and Java' A report, Bournville, Cadbury Bros). Later Urquhart published the definitive book on cocoa at the time ('Cocoa', Longmans, Green and Co., London, 1955).

Cocoa was one of the first crops re-established in Papua New Guinea after the war. By this stage, planting cocoa under coconuts was standard practice in many areas of Papua New Guinea. This was based on trials conducted at LAES and in New Ireland and later became common throughout Southeast Asia. Many outstanding plantations in Papua New Guinea were based on this system and planting cocoa under existing coconuts (and other long-standing trees such as breadfruit, galip and betelnut) later became common in smallholdings.

After the war (1946), F.C. (Frank) Henderson was appointed government Economic Botanist and Agronomist-in-Charge at LAES, and began selecting promising trees from the remains of the pre-war cocoa at Keravat and the Rabaul Botanic Gardens. In an article 'Cacao as a crop for the owner-manager in Papua and New Guinea' (1954, The Papua and New Guinea Agricultural Journal 9/2), he considered that the deep, well-drained pumice soils of New Britain and adjacent islands were excellent for cocoa. Henderson's original parent trees were selected on the basis of vigour, pest and disease resistance, apparent yielding ability, and pod and bean characteristics. Leon Bridgland, Henderson's successor as the Agronomist-in-Charge at LAES (from 1952), made the point that "indeed, anything that survived the War must have possessed remarkable vigour" (Bridgland LA, 1960, cited above). Henderson's selections from Keravat were designated as K (Keravat) clones (e.g. K5, K20, K82). In an attempt to recover the high yielding types that had been selected and distributed to plantations before the war, material was sourced from trees thought to be from the mother trees on a plantation near Lae and on Asalingi Plantation in the Bainings region in East New Britain. The Asalingi selections were designated KA (Keravat Asalingi) clones and included the famous KA2-101. These clones were all Trinitario cocoa, the dominant if not the only type surviving in Papua New Guinea after the war. Many of the clones selected immediately after the war are still used as the Trinitario parents in the current breeding program. Pure Criollo types are generally regarded as being less robust than Trinitario, and have not survived in most countries to which they were introduced, including Papua New Guinea, Java (Indonesia) and Ceylon (Sri Lanka). Their use is not mentioned in literature published after the war in Papua New Guinea. Pods from the selected trees were used to plant up a number of progeny trials on LAES. These blocks provided a valuable source of genetic material for later selection and breeding work. One of the blocks (Block 405) is still producing well and remains a source of breeding material, although only 40 percent of the original trees are still standing, the remainder being replacements of various ages.

Henderson noted that Phytophthora Pod Rot (Black Pod) was the most serious disease, and *Pantorhytes* weevils and *Glenea* longicorn beetles were the most serious pests. All remain problems to this day. It is evident that the rapid adaptation of indigenous insect pests to the introduced cocoa caused serious problems, as shown by the fact that the entomologists B.A. O'Connor (1946-47) followed in 1947 by G.S. (Gordon) Dun were the earliest scientists appointed along with Henderson after the war, with Dun continuing to work at Keravat for 20 years until 1967.

1950s

From 1946 to 1952 the cocoa research programme expanded rapidly under the leadership of Henderson at LAES. In the mid to late 1950s and through into the 1960s, A.E. (Arthur) Charles, Peter Byrne and Leon Bridgland carried on the work on cocoa improvement which was summarised in 1960 in the above-mentioned paper by Bridgland. This work included clonal selections and early studies of hybrid seed development. Progeny trials of K and KA clones were initiated. As discussed above, Papua New Guinea Trinitario cocoa was very heterogenous. It included a high degree of self-incompatibility that ensured out-crossing. This, along with the several likely sources of introduction of cocoa to Papua New Guinea (from Cameroon, Ceylon and Java via Samoa, and directly from Java and possibly Venezuela) ensured that a wide variety of types occurred, including green- and red-podded types (see Appendix 3, Figure A3.9). The first crossing programme in 1958 looked at the possibility of obtaining improved material by crossing extreme Trinitario types, the selection of parents being based on pod and bean characteristics. This was, however, only partly successful. Vegetative propagation by rooted cuttings was tested and developed in the nursery by R.J. (Reg) Harris and I.L. (Ian) Edward (Edward IL, 1960, 'Clonal cacao at Keravat - Part I'. The Papua and New Guinea Agricultural Journal 13; 1961, 'Clonal cacao at Keravat - Part II'. The Papua and New Guinea Agricultural Journal 14, 16). Arthur Charles summarised the studies on shade and spacing in a paper published in 1961 ('Spacing and Shade Trials with Cacao', 1961, The Papua and New Guinea Agricultural Journal 14, 1).

From the early 1950s and through into the 1960s Leon Bridgland, with Ken Newton, R.J. Friend and later with John O'Donohue, conducted trials on the most appropriate methods of fermenting and drying cocoa under the particular climate in the main cocoa growing areas of Papua New Guinea. This work resulted in recommendations to growers on commercial and efficient methods of processing cocoa for export (Bridgland LA, 1959, 'Cacao processing – history and principles'. The Papua and New Guinea Agricultural Journal 12, 49; Bridgland LA, 1959, 'Processing methods for cacao growers in Papua and New Guinea'. The Papua and New Guinea Agricultural Journal 12, 87).

The pioneering agronomists at LAES, Frank Henderson, Leon Bridgland, John Richardson, Peter Byrne, Ken Newton, Ron Carne and John O'Donohue (from 1959), continued through the 1950s a wide ranging series of studies of all aspects of cocoa growing, including genotype development, propagation, spacing, shade, and pest and disease control.

Through the 1950s Gordon Dun continued important studies of the insect pests of cocoa, including stem borers (*Pantorhytes, Glenea*), mirids and flush defoliating caterpillars. Mirids (Cocoa Capsids) caused heavy losses of pods at all stages of development, especially during wet periods. J.L. Gressitt studied longicorn beetles and *Pantorhytes* weevil on cocoa through the 1950s and into the 1960s. From 1954 J.J.H. (Joe) Szent-Ivany worked as an entomologist with Gordon Dun and they did much to document and describe the full range of insect pest species attacking cocoa (see Appendix 7).

Dorothy Shaw was appointed to establish the first plant pathology section at the headquarters of the Department of Agriculture, Stock and Fisheries in Port Moresby (Konedobu) in 1955 and in a long career until 1976 documented the diseases of cocoa (among many other crops), identified diseases, and advised on their research and control. The first plant pathologists appointed at LAES were R.J. Friend (1955-57) and Peter Thrower (1956-57) who began research on the biology and control of Phytophthora Pod Rot (commonly known as Black Pod, caused by *Phytophthora palmivora*), which was the most serious disease, regularly destroying a significant proportion of the pods especially during wet weather.

A chemistry section was initiated at LAES in 1954 with the appointment of Don Murty and Stan Baseden, early studies being directed at the serious decline in coconuts on New Ireland, which was shown to be caused by potassium deficiency in the coralline soils.

1960s

Entomological work was continued strongly through the 1960s by Gordon Dun, Joe Szent-Ivany, Lance Smee and Ted Fenner, and through into the 1970s by Erol Hassan, Dermott O'Sullivan, Remigius Berena, and Peter Bailey who especially studied the ecology and management of the *Pantorhytes* weevil, *Pansepta* bag moth, and *Glenea* longicorn beetles among many other insect problems. *Pantoryhtes* was identified as the major insect pest of cocoa in many provinces. Control methods, included biological control using Crazy Ants, were developed. The research on the biological control of cocoa pests using ants was summarised in 1973 by P.M. Room ('Control by ants of pest situations in tropical tree crops; a strategy for research and development'. The Papua New Guinea Agricultural Journal 24,98). Early studies of the Giant African Snail, accidentally introduced by the Japanese during the war and a pest of cocoa nurseries and young cocoa plantings, resulted in the adaptation of a *Gonaxis* snail for biological control (Dun GS, 1967, 'The giant snail'. The Papua and New Guinea Agricultural Journal, 18, 123).

Studies on Black Pod and other diseases were taken up by Peter Hicks from 1962 to 1978. The virologist, Rip van Velsen, working at LAES from 1958 to 1966, mainly on diseases of food crops, was unable to detect any significant virus diseases of cocoa but studied a virus disease of larvae of a defoliating insect pest of cocoa.

The chemistry section continued at LAES with the appointment of Colin Levy (1962-65) and Austin Puddy (1966-68), and later Ron Polhill (1970-71) and Jon Vilkki (1971-73), who conducted leaf and soil nutrient analyses linked to fertiliser trials with many crops, including cocoa.

Influenced by the cocoa genotype development activities of the Cocoa Research Unit at the University of Trinidad and the availability of new cocoa collections from the Upper Amazon, in 1962 the agronomists John O'Donohue and Ken Newton introduced from Trinidad seed of Upper Amazonian material, comprising progeny of several crosses of clones from within the Nanay, Parinari, Scavina and IAC groups (e.g. Na32 x Pa35, Na33 x Na 34, Sca6 x Sca9). The seed was planted out on LAES and selected trees became the Amazonian parents (KEE clones) of the 'hybrid' cocoa seedlings released in the 1980s. Open pollinated seed from ICS (Imperial College Selections) clones from Trinidad and seed of West African Amelonado from Malaysia was also introduced. In 1962-64, progenies of the Upper Amazonian types introduced from Trinidad were evaluated and useful types were selected, producing clones designated KEE (e.g. KEE2, KEE5, KEE12, KEE22, KEE42, KEE43, KEE52), several of which are parents of the current Hybrid Clones. A new crossing programme was begun in which seven Amazonian parents and seven Trinitario parents were hand crossed in 21 combinations to provide seed for progeny testing.

The breeding programme proceeded smoothly until the outbreak of a destructive epidemic of a dieback disease in many parts of the country. The disease killed many trees on plantations in East New Britain, Talasea in West New Britain, and in the Madang, Lae and Morobe areas on the mainland and threatened the existence of the expanding cocoa industry. The disease was first recorded on LAES in clone K1-102 in clone Testing Series III in early 1961. Dorothy Shaw, and the former LAES agronomists Leon Bridgland, Ian Edward and John Richardson, who were then working in the private plantation industry, first described the unique symptoms of the disease in detail and concluded that it was different from dieback conditions caused by insects or exposure that had long been known to be a problem in cocoa (e.g. in West Africa).

The dieback disease caused havoc in the cocoa research program at Keravat. It was so damaging that most trials were terminated and the proposed hybrid breeding programme was postponed. The disease killed many trees on the research station and many trees were stumped in an attempt to control it and rehabilitate the cocoa. Several years were spent on research into this disease and, as a result, much agronomic and breeding work was not resumed until 1969. Farmers propagated cocoa from the survivors of the epidemic and in doing so undoubtedly selected for a degree of resistance to the disease (often called 'tolerance' in Papua New Guinea). The agronomist John O'Donohue, working with John Thompson, assessed the disease incidence in particular clones and determined that there was a wide range of reaction to the disease, ranging from the highly susceptible response of K1-102 (which was eventually driven to extinction by the disease) to a highly resistant response in several clones, most notably KA2-101. These differences were clearly evident in the clone testing trials that had been set up prior to the epidemic. Planting of this partially resistant material enabled the industry to recover and continue expanding. O'Donohue also conducted field trials in which he raised cocoa seedlings under plastic shelters in plantings with high levels of infection and showed that these protected the plants from infection, providing evidence that the disease was caused by a wind-borne pathogen (for a summary of these studies see Department of Agriculture, Stock and Fisheries, Annual Report 1967-69, Port Moresby, 1972, pp.34-40). The agronomists and some growers had also observed that steep gradients of disease incidence occurred in young cocoa blocks planted adjacent to old infected cocoa, again providing evidence that the disease was caused by a wind-borne pathogen.

1970s

The Planters Association of New Guinea (later the Cocoa Growers Association) raised funds for the recently established University of Papua New Guinea (UPNG) to undertake research into the cause of the disease. Don Drover, of the Chemistry Department, found no evidence of a nutritional cause, and subsequently (1969-1972) a post-graduate student, Philip Keane, was employed to work at LAES with the support of the Agronomist-in-Charge, Peter Byrne, and supervision by Ken Lamb of UPNG and Noel Flentje of the University of Adelaide, to study possible microbial causes (initially a virus cause was considered, following the history of Cocoa Swollen Shoot Virus in West Africa). Eventually Keane found strong evidence that the cause was an indigenous wind-borne basidiomycete fungus, a new species that was named *Oncobasidium theobromae,* that grew only in the xylem vessels of infected branches (Appendix 8). In order to distinguish the disease from the common dieback caused by exposure or insect damage, it was called 'Vascular Streak Dieback' or VSD. The disease was later found to be a serious problem in cocoa in Malaysia, Indonesia and elsewhere in South East Asia, but does not occur naturally in New Ireland, Bougainville, the Solomon Islands or further east in the Pacific. It is thought that this distribution of the disease in cocoa reflects the distribution of the fungus in its original indigenous host, which is still unknown. These studies were later supported financially by Cadbury-Fry-Pascall Pty. Ltd., The New Guinea Biological Foundations and the Reserve Bank of Australia.

Chris Prior continued studies on the biology and control of VSD from 1973 until 1984 at LAES. He also studied the nature of resistance to the disease, and developed a method of growing the fungus on cocoa tissue culture. He also developed methods for screening cocoa for resistance, and developed and applied a strict quarantine protocol for transferring planting material from Keravat to VSD-free areas such as Bougainville and New Ireland. Later Jason Dennis, while enrolled as a Ph.D. student in LaTrobe University (1988–1991) with supervision from Philip Keane and supported by the Biscuit, Cake, Chocolate and Confectionary Alliance (UK) and the Cocoa Board of PNG, continued studies at Keravat on the epidemiology and management of the disease and showed its close association with wet weather and over-shading.

With the knowledge that there was strong partial resistance to VSD in certain cocoa genotypes and that the disease could be controlled by cultural means including raising plants in a covered nursery, preventing over-shading, and regularly pruning out infections in the field, the agronomy and breeding studies were recommenced in 1972 under the leadership of the long-serving agronomists Peter Byrne and John O'Donohue, supported by Anthea Putter, who arrived from South Africa in 1971, and new graduates from UPNG, Ted Sitapai who took up his position in 1975 and Tore Ovasuru in 1976. The assessment of clonal trials was continued. Hand-crossing of Amazonian and Trinitario clones was carried out in 1972 and the progenies were field-planted in November 1973. The progenies of the Amazonian x Trinitario crosses were tested from 1975 to 1980 for yield and quality characteristics as well as for resistance to VSD and Black Pod (which had long been a serious disease).

A study of vegetative propagation techniques, started in the 1930s using cuttings, was continued through the 1960s and 70s. Much effort was put into developing methods of mass propagation of clones using cuttings, and special gardens of selected clones were planted to provide large numbers of cuttings for striking in the LAES nursery, under the direction of Jelta Hofman (1962-67), Bernie Kamp (1966-69), Hans Allaries (1970-74) and Henri Bruyn (1969-1972) who had prior experience of cocoa in Indonesia. This work was continued by Rod Saunders (1973-74) and Mirivari Areori (1974-78). The change from striking rooted cuttings to bud grafting of seedling rootstocks as a more effective method of clonal propagation gave rise in 1976 to a program of bud grafting to produce commercial quantities of clonal planting material, and the transition from the distribution of cuttings was completed by late 1977. At that time LAES distributed selected Trinitario clones (the self-compatible KA2-101, KA5-201 and K82, and the self-incompatible KA2-106, K24-106, K21, K20 and K13 clones).

To further increase the genetic diversity of cocoa available for breeding, selections from Puerto Rico and Ghana were introduced in the early 1970s. Introductions of material from cocoa collections at Kew Gardens, the University of Reading, and USDA Miami commenced in 1975 and continued for some time.

Through the 1970s, E.S.C. (Stuart) Smith published a series of papers on a wide range of insect pests of cocoa, including mirids, *Pantorhytes* and longicorns, and on integrated pest management and the effect of shade on cocoa pests. He and Chris Prior published a particularly significant paper on the link between Phytophthora Bark Canker and stem boring insects (Prior C and Smith ESC, 1981, 'Association of Phytophthora bark canker and insect damage in cocoa in Papua New Guinea'. Annals of Applied Biology 97, 27). In 1981 Smith completed an M.Sc. through UPNG on the biology, ecology and control of the mirid *Helopeltis clavifer* and developed a practical census and control method for this important pest (see Appendix 7).

1980s

In the early 1980s at LAES the spray technology specialist, Peter Jollands, developed improved spraying techniques for cocoa, especially for weed and Black Pod control. The work begun by Dorothy Shaw, Peter Thrower and Peter Hicks in the 1950s and 60s on the epidemiology and control of *Phytophthora palmivora* was continued strongly through the 1980s by Alastair McGregor, Philippa Jollands and Ted Sitapai. Phillipa Jollands recruited Yak Namaliu and Josephine Saul-Maora to the pathology section of LAES in early 1984, and they remain as senior members of that section to the present time. Philippa Jollands also studied root diseases of cocoa. As well as developing spraying methods and researching methods of cultural control, they screened cocoa clones and progenies for resistance to the disease, and developed effective methods of screening to support the breeding program, including methods of inoculation of attached and detached pods (Appendix 8). From 1986, Mark Holderness led the research on Black Pod and, with Yak Nalamiu and Josephine Saul-Maora, conducted research into the use of trunk injection with phosphonate to control Black Pod and Stem Canker, with William Waine, Erica Simogun and Sotutu Tamasan as technical assistants. Ted Sitapai studied the resistance of cocoa to Phytophthora Pod Rot and Canker and completed a Masters degree on this topic in 1989 at the University of the West Indies in Trinidad. He returned to continue research at Keravat, eventually becoming the Agronomist-in-Charge of LAES.

Through this period, Stuart Smith (until 1982), followed by Marcus Arura and John Moxon (assisted mainly by Fidelis Hela and Kiteni Kurika) in the LAES entomology section, continued the studies of the many serious insect pests of cocoa and coconuts and collaborated with the pathologists on the control of stem cankers associated with insect damage. The biological control of *Pantorhytes* weevils, longicorns, mirids and other cocoa pests by Crazy Ants (*Anoplolepis*) and Kurukum Ants (*Oecophylla*) was studied by Moxon assisted by Hela and K. Kusunan. Many new insecticide formulations were evaluated in field trials against a wide variety of cocoa pests. Smith demonstrated that there was considerable biological control of insect pests by natural enemies, and that coconut shade benefited biological control of insect pests in cocoa. Resistance of cocoa to several insect pests was confirmed in a series of trials by Moxon, and early screening techniques for resistance using cocoa seedlings were developed. Descriptions of the most important insect pests and recommendations for their biological, cultural and chemical control had been developed by the LAES entomologists over the years and these were updated and summarised by Moxon in a series of papers in Harvest Vol. 9 in 1983 and later in a series of well-illustrated LAES Information Bulletins (Nos. 42-55) in 1992 (Appendix 7). This whole issue of Harvest (Vol. 9, nos. 3 and 4, pp. 111-204) consisted of a series of papers on all aspects of cocoa production by David Kidd, Arthur Charles, Ted Sitapai, John Perkins, Stuart Smith, John Moxon, JE VanS Greve, Alastair McGregor and Chris Prior. John Moxon was the Officer-in-Charge of LAES from 1986 to 1993.

Following a decision by the PNG Government that research and development for the main agricultural commodities should be funded by the respective industries, in 1981 the Cocoa Board of PNG established the Cocoa Industry Company Limited to be funded by a levy on exported cocoa and Tavilo Plantation near LAES was purchased to provide land for cocoa research. Until about 1993, cocoa research continued to be conducted at LAES Keravat, alongside the on-going research on other crops that was eventually taken over by the National Agricultural Research Institute (NARI). Some LAES (NARI) scientists such as Gade Ling and Tio Nevenimo continued to conduct research on cocoa in mixed cropping systems. The Cocoa Industry Company's activities were funded by an increase in the levy on exported cocoa. In 1986, the Cocoa and Coconut Research Institute (CCRI) was formed from the Cocoa Industry Company (with the Cocoa Board and Copra Marketing Board as equal shareholders) and assumed responsibility for cocoa and coconut research under the direction of a board composed of cocoa and coconut industry leaders. The first Institute Director was Dr Peter Turner who gave outstanding scientific leadership to the institute until 1990, based on his long experience in cocoa research and development in West Africa and Malaysia. Kervera Plantation, adjacent to Tavilo, was purchased to provide land for coconut research, however, the damage done by Rhinoceros Beetle (*Scapanes australis*) and the Black Palm Weevil (*Rhynchophorus bilineatus*) on plantings of young palms limited coconut research and Kervera was also used for expanding cocoa research. In 1989 CCRI established the Duncan Research Station at Mabiri in Central Bougainville especially for the introduction of new hybrid planting material and establishment of a seed garden to serve the important cocoa industry in that province. However, during the decade-long civil crisis in Bougainville during the 1990s the station became inoperable and cocoa production in Bougainville declined sharply. In late 1992 two plantations, Murnas and Kaile, were purchased to establish the Stewart Research Station for coconut research in Madang Province where *Scapanes* and *Rhynchphorus* were less destructive. Some cocoa research, especially on resistance to VSD, which was common there, was conducted also.

In the pathology section at LAES and later CCRI, Chris Prior in collaboration with Stuart Smith studied the biological control of insects such as *Pantorhytes* with fungal pathogens of the insects. This was the basis of his later highly-acclaimed work, after leaving Keravat, on biological control of plague locusts in Africa by spraying mineral oil suspensions of spores of a pathogenic fungus.

An epidemic of a psyllid that defoliated the shade tree *Leucaena leucocephala* resulted in much damage to cocoa due to the lack of shade. A Mexican variety of *Leuceana* showed good tolerance to the psyllid. The entomology section led by John Moxon was responsible for introducing a biocontrol agent to control the psyllid and restore shade. Also, there was evidence of biocontrol of the psyllid by fungal pathogens under humid locations. This episode gave a boost to the general replacement of *Leucaena leucocephala* by *Gliricidia sepium* as shade for cocoa in most regions of Papua New Guinea.

Until the 1980s, most of the cocoa being grown on farms was Trinitario seedlings derived from open-pollinated pods produced on farms (i.e. farmers propagating from their own trees) or distributed from LAES, along with limited distribution of thirteen clones selected for yield and resistance to VSD. Since the early 1970s, these had been propagated by cuttings at LAES. Clones propagated from cuttings were difficult to grow, often having lop-sided growth and shallow root systems causing instability of the mature trees. A method was therefore developed by John O'Donohue, Ted Sitapai and the LAES nurseryman John Hewitt to produce clones by bud or patch grafting onto seedling rootstocks. These clones were much more robust, being developed on seedlings with a normal deep taproot. Distribution of the elite Trinitarion clones by budding and grafting started in the late 1970s and continued in the early 1980s. In the late 1980s Leon Bridgland, working in collaboration with CCRI, made a large collection on Bougainville of Trinitario trees field selected for yield and resistance to Black Pod. These were established as a clone collection at Kurwina Plantation and are believed to remain there.

Hybrid seedlings from crosses of selected parent clones were to be the next development in cocoa planting material. It had been observed in several countries that crosses between widely different cocoa genotypes (e.g. Trinitario x Upper Amazonian) gave very vigorous offspring and this was assumed to be similar to the hybrid vigour or heterosis observed in crosses between inbred lines of maize that had given great increases in maize yields. Around the cocoa-growing world at that time there was great enthusiasm for developing and planting hybrid seedlings based on the fact that the crossing of genetically widely different types such as Amazonian Forastero and Trinitario gave a degree of hybrid vigour, with the result that a proportion of the progeny grew faster and gave higher yields than either parent. The planting of hybrid seed was also favoured by the fact that seeds are much easier to transport, and seedlings are much easier to manage, than clonal plants.

Accordingly, testing of the progeny of crosses between Trinitario (K or KA) and Upper Amazonian (KEE) clones, begun in the 1960s, was pursues with greater vigour. Clones were selected on the basis of yield, cocoa bean quality and disease resistance. In 1982 Ted Sitapai and David Kidd published a seminal paper on 'Hybrid cocoa in Papua New Guinea' (Harvest 8, 6).

Led by Ted Sitapai, David Kidd, Gade Ling and later by Trevor Clarke, seed gardens to produce hybrid seed were established at several locations and hybrid seed (Seed Garden 1 - SG1) production commenced commercially in 1982 under the direction of the Cocoa Industry. This work was taken up by Geok-Yong Tan, who was employed as a specialist cocoa breeder by the Cocoa Board in 1980, building upon the clone testing work carried out by the LAES agronomists through the 1960s and 1970s. As well as continuing progeny testing of the Trinitario x Amazonian crosses, Tan, supported by the statistitian Wai-Koon Tan, conducted several detailed field trials on the inheritance of important traits (including resistance to VSD and Phytophthora Pod Rot) in diallele crosses, and demonstrated that resistance to both diseases was inherited additively. In collaboration with John Moxon, he also demonstrated in breeding trials inheritance of resistance of cocoa to several insect pests.

In the seed gardens, three Amazonian parent clones (KEE2, KEE5, and KEE52) were crossed in all combinations with three Trinitario parent clones (KA2-101, KA5-201, K20 or K24-102) selected mainly for VSD resistance and yield. Unfortunately several of the clones selected as parents for the SG1 hybrids were very susceptible to Phytophthora Pod Rot (e.g. KA2-101, KA5-201) and this disease became more common and destructive in the field plantings of the SG1 hybrid seedlings.

In an attempt to widen the genetic base of material available for breeding, especially for resistance to Black Pod, further introductions of ICS clones and Amelonado material from Malaysia via the Solomon Islands were made in the mid-1980s and these were evaluated.

Improved hybrid seed gardens were established in the period 1982-87, and new hybrid seed (SG2 seed produced in Seed Garden 2) became available to growers in 1988. In these gardens KEE22 and KEE23 were crossed with KA2-106 and KA2-101; KEE43 with KA2-106, KA2-101 and K82; KEE12, KEE42 and KEE47 with K82 and KA2-106. Growers were supplied with a mixture of the progeny of these crosses. These parent clones placed more emphasis on resistance to Black Pod (K82 had been shown to have a consistently lower incidence of Black Pod over many years – see Chapter 7, Figure 7.3), although the inclusion of KA2-101 also ensured some resistance to VSD in the mix. The crosses with KA2-101 were later removed because KA2-101 was too susceptible to Phytophthora Pod Rot; interestingly, K82 has a high level of resistance to Black Pod but is susceptible to VSD.

The SG1 and SG2 hybrid seedlings distributed in Papua New Guinea were faster growing, gave more precocious early yield, and were thought to be higher yielding than the Trinitario cocoa that had been widely planted in Papua New Guinea, although the two were never compared under the same conditions in properly designed field trials. However, there were many problems with these hybrid seedlings when they were used on farms:

- They were not the uniform progeny of homozygous, inbred parent lines as in hybrid maize, but rather the progeny of highly heterozygous parents, and so they had great genetic variability (there was evidence that in field plantings only 10% of the trees produced 90% of the yield, while 60% of the trees produced very little).
- The design of the seed gardens, in which cross-pollination relied on natural pollination, did not ensure that the crosses were as intended, contributing to the genetic variability of the hybrid progeny.
- The progeny did not perform on the plantations as well as they had on the experiment station, perhaps because the test hybrids were obtained by hand pollination while the commercial hybrids were produced in seed gardens.
- The trees were precocious, growing rapidly to give large trees and early yields, but they required much pruning and were especially difficult for smallholders to manage. They were selected on vigour rather than Harvest Index.
- Their precocious early yield tended to decline sharply after 5 or 6 years, compared with the old Trinitario trees that tended to maintain their yield over many years.

These problems led to a critical review of the breeding program in the early 1990s.

The need to use land more efficiently and to promote the growing of cocoa by smallholders and traditional farmers led to much research, beginning in the 1980s under the direction of Gadi Ling, Louis Kurika, Tio Nevenimo and John Moxon at LAES, and supported by David Loh, on combining food crops with cocoa and on diversification of shade trees, including the use of betel nut, fruit trees, bananas and galip nut. This work included alley-cropping of cocoa with food crops or legume hedgerows which increased aeration of the cocoa and reduced incidence of Black Pod. Studies of the most appropriate shade, spacing and fertiliser applications that had started in the late 1950s continued through the 1980s led by the agronomist Tom Laven, especially as different recommendations were required for Trinitario clones and hybrid seedlings. Kana Aburu, following an outstanding record as a student at Vudal Agricultural College and later at UPNG, worked as an agronomist concerned mainly with development of spice and food crops at LAES until his early death in 1982.

In the late 1980s through into the 1990s, research on Karkar Island, Madang Province, led by David Guest from the University of Melbourne and funded by a private research organisation (the Cocoa Black Pod Research Trust established by the Roger and John Middleton families), developed a successful method of trunk injection of cocoa with neutralised phosphorous acid (phosphonate) for control of Black Pod and Phytophthora Stem Canker (summarised in Guest DI, Anderson RD, Foard HJ, Phillips D, Worboys S and Middleton RM, 1994 'Long term control of *Phytophthora* diseases of cocoa using trunk-injected phosphonate'. Plant Pathology 43, 479). Several young researchers supported by the Trust (listed in the above publication, and including James Dean) conducted research on the diseases of cocoa, especially Black Pod and Vascular Streak Dieback, on the island. While working in this program, Ross Anderson discovered infection of avocado by the VSD pathogen that had previously been found only on cocoa, work later confirmed by Jason Dennis at CCRI Tavilo.

The first cocoa extension officer, or National Crop Advisor (Cocoa), based at LAES, was J.D. (Dick) Rotscheid in 1977, followed by David Kidd (1981-82), and Trevor Clarke in 1985-87, and then by Alfred Nongkas who managed the Smallholder Cocoa Rehabilitation and Extension Program (SCREP) with assistance from Luke Blansjarr. Trevor Clarke collated and edited the first Cocoa Technical Manual produced by CCRI and wrote the first handbook for smallholder cocoa farmers, 'Torubat I Wokim Bisnis Long Kakao' (1980) that was developed later by Colin Benton and Jane Belfield as 'Josip I Planim Kakao' (1993), and still later as 'Joseph and Lucy Grow Cocoa' by Martin Powell (2005). David Kidd continued as a senior extension officer and later publications and training officer through to 1996, and was joined by John Duigu in this role in 1994. John Perkins was the Department of Agriculture and Livestock Regional Economist based in Rabaul, with interests in smallholder cocoa processing; he spent 6 months at LAES in 1983 helping to develop small scale post-harvest processing of cocoa. Following publication of LAES Information Bulletin No. 30 (Perkins, J and Kidd, D, 1982, 'Simple ways to improve cocoa processing') and presentation of a paper 'Alternative Policy for Cocoa in Papua New Guinea' by Clarke and Perkins to stakeholders in East New Britain Province in 1983, studies were commenced of small scale fermenting and drying of cocoa, leading to the development of smaller fermentation boxes and the small passive solar/kiln driers that eventually became common among smallholders. Through the late 1980s and into the 1990s Scott Yarbro, followed in 1994 by Eric Omuru and 1999 by Joachim Lummani, studied and advised on the economic aspects of cocoa development in Papua New Guinea.

1990s and 2000s

Following a critical review of the breeding program (Lass RA, Mossu G, Sitapai EC and Keane PJ, 1992, 'Mission to Review the Past and Future Cocoa Breeding Program at CCRI, Papua New Guinea', unpublished report, PNG Cocoa and Coconut Research Institute), Yoel Efron was recruited as cocoa breeder in December 1993. John Moxon was appointed Institute Director of CCRI in June 1993 and remained until 2000. He, along with Uron Salum and Tony Lass, was responsible for appointing Yoel Efron and strongly advocated a breeding program based on development of clones selected from the best performing hybrids ('hybrid clones'). He sourced substantial funds from the European Union to construct a new office/laboratory complex at Tavilo and oversaw construction of the building based on the elevated LAES/Queenslander design surrounded by verandahs. Funds for a 400,000 capacity nursery and staff housing were included. He also secured European Union funding to support the breeding, agronomy and pathology research programs for many years. Following the earlier purchases of Tavilo and Kervera Plantations for cocoa research, three further plantations (Ralauwat, Kulon and Londip) were purchased with a loan from the Copra Marketing Board in order to help fund the research and development activities of the Institute. The loan was repaid within 10 months from the profits from the plantations due to outstanding management led by Ayyamani Jagadish, who developed a highly productive block management system where labourers were given a block of cocoa to manage and were paid a proportion of the cocoa production from their block. From 1993 onwards CCRI pursued a vigorous policy of sending staff for overseas higher degree training, based on research on a topic of industry priority within Papua New Guinea and part-time residence at an overseas university for literature reviewing, specialist laboratory research and thesis writing.

In August 2003, in order to link research and industry development more closely, the PNG Cocoa and Coconut Institute Limited (CCIL) was established by merging the CCRI and the PNG Cocoa and Coconut Extension Agency (CCEA), with the Cocoa Board and the Kokonas Indastri Koporesen (KIK) as equal shareholding boards and the mandate of research and development in cocoa and coconut production, processing and marketing.

Yoel Efron and his colleagues Peter Epaina, Jeffrie Marfu, Mathias Faure and James Butubu, redirected the cocoa breeding program with an emphasis on selecting and propagating clones from the best hybrid progeny (SG1 and SG2) trees and producing trees more suitable for smallholders (see Efron Y, Epaina P and Marfu J 2003 'Breeding strategies to improve cocoa production in Papua New Guinea', Paper for International Workshop on Cocoa Breeding for Improved Production Systems, October 2003, Accra, Ghana). The best progeny from the hybrid crosses were developed as 'Hybrid Clones' that were further tested before the first new types were released in 2003. They also selected less precocious trees suitable for smallholders, and developed methods of juvenile budding on the hypocotyls of 2-week-old seedlings, which speeded up the budding process and distribution of clones.

The substantial cocoa breeding and selection trials were severely disrupted by the catastrophic eruption of Tavurvur volcano in Rabaul on 19 September 1994, which covered the research station with ash and defoliated most of the trees. This disruption led to the establishment of new trials in 1995 with the aims to:

- increase yield potential,
- improve production uniformity and stability (to avoid the tree-to-tree variation observed with SG hybrid seedlings),
- increase resistance levels to major diseases (this was extended to include resistance to Cocoa Pod Borer after its incursion in 2006),
- reduce management costs (by producing smaller trees that required less pruning and facilitated harvesting),
- improve quality characteristics, and
- develop ecologically targeted varieties (suited to different environments in Papua New Guinea).

The Hybrid Clones were tested extensively in Genotype x Environment trials in several locations around Papua New Guinea before being released commercially in 2003. A second series of Hybrid Clones, which included both Small and Big types, was released in 2013 (Appendix 6). The aim was to provide planting material for poly-cross hybrid seedlings or poly-clonal mixtures for planting on farms, to avoid the problem of genetic uniformity and vulnerability while ensuring that all trees were highly productive. The Hybrid Clones have performed outstandingly well in trials in many locations and they are now the recommended planting material (Appendix 6). While the clones needed more pruning to shape them in the early stages, their early yield convinced farmers to try them on their farms.

Much agronomic research was conducted to support the development of the new Hybrid Clones. The agronomists led by Martin Powell, Eremas Tade and David Yinil, and supported by Godfrey Hannett, and later by Chris Fidelis and Peter Bapiwai, developed methods of pruning to ensure the growth of well-structured clonal trees and produced a manual on ‘Formation Pruning of Cocoa Clones’ (Efron Y, Ayyamani J and Tade E, PNG Cocoa and Coconut Research Institute), based on on-station and on-farm studies in collaboration with the breeding section. They tested the new clonal material on station and in many locations where the performance of the clones could be observed under farm conditions and farmers could see for themselves the difference between the clones and the older hybrid seedlings. They also continued trials on spacing, shade, pruning and fertiliser treatments. In 2009 Eremas Tade completed a Ph.D. study on the agronomy, physiology and genetics of a dwarf mutant of cocoa through the University of Queensland. The agronomy and breeding sections developed a successful method of rehabilitation of old, overgrown cocoa by chupon budding using the new Hybrid Clones (Tade E, Hannett G and Efron Y, ‘A Manual for Cocoa Rehabilitation by Chupon Budding’. Cocoa and Coconut Institute of PNG).

The work of the agronomists, in collaboration with the extension workers, John Duigu, Alfred Nongkas, Otto Liran and Anton Varvaliu, and their extension teams in various provinces, in doing multi-location testing of clones on farms, was a departure from the previous tendency to test materials only on the experiment station in East New Britain, and was a model that was later taken up in the work on Integrated Pest and Disease Management (IPDM).

Hybrid seed continued to be distributed, but this was produced only by stringent hand pollination to ensure that the crosses were as intended. Distribution was targeted especially at growers in remote areas with less developed management skills.

New hybrid crosses continued to be made between various selected parents to produce more hybrid progeny available for further selection as clones. The combining ability of crosses within Upper Amazonian and Trinitario types was also explored.

Further cocoa introductions were made to expand the genetic resources available for breeding in Papua New Guinea – several of the recent introductions from The University of Reading or CIRAD Montpellier have been identified as promising (AMAZ15-15, EET308, IMC85, IMC105, MAN15-2, Pound7, PA107, PA150, SIAL339, T85/599). Many of the introduced clones are being tested as part of an International Clone Trial or Local Clone Trials. New hybrid clones were selected from the progeny of crosses between local (KEE) and introduced clones and preliminary tests gave some outstanding results in 2000-2002 - e.g. AK56-1-4 (pedigree KEE43 x SIAL93) and AK57-1-9 (pedigree KEE43 x Pound5C) gave yields of about 5900 Kg/Ha; while 16-2/3 (C)(pedigree KEE42 x K82) and 73-14/1 (C) (pedigree KEE12 x K24-102) yielded about 4700 Kg/Ha. These results indicate the potential yields that can be obtained from the new generation of Hybrid Clones.

A further aim of the new breeding program was to prospect on farms throughout Papua New Guinea for Trinitario selections that had become well adapted to local conditions of environment, management, and pests and diseases. Since the early 1900s, Trinitario had been propagated from seed taken from open-pollinated pods harvested from the best trees on farms, following the long tradition of food crop propagation in the traditional farming societies of Papua New Guinea. Trinitario cocoa, being mostly cross-pollinated and heterozygous, had given rise to great genetic diversity of cocoa on the farms, and this diversity was ideal for selecting well-adapted types of cocoa. Unfortunately much of this germplasm on farms was lost in the enthusiasm for planting SG hybrids. However, pockets of the old Trinitario material remain because farmers continued to see them as useful trees and these are being collected for future breeding work. Collection of budwood from these trees was begun in 1995 and the selection of trees was guided by advice from farmers on their long experience with particular trees on their farms. Budwood was collected from about 400 trees and clones were established in an observation trial, giving some highly encouraging results, with some of these clones (designated 'Old Trinitarios' or 'OT' clones) giving very high yields.

A problem with the disease resistance of the parents used in the breeding program was that certain clones such as KA2-101 were highly resistant to VSD but very susceptible to Black Pod, while others such as K82 were partly resistant to Black Pod but very susceptible to VSD. In a Ph.D. study by Peter Epaina, while enrolled at the University of Sydney under the supervision of David Guest and Robert Park, the progeny of crosses between these two valuable parent clones were studied to determine the inheritance of their respective resistances and to combine these. Molecular studies on the progeny of the crosses were carried out at the United States Department of Agriculture and demonstrated that resistance to the diseases was controlled by many genes on several chromosomes. There appeared to be no impediment to combining resistance to the two diseases and several progeny appeared to have a degree of resistance to both Black Pod and VSD. These await further field testing and development.

Through the period of development of new cocoa planting material in the late 1980s and 1990s, Neil Hollywood, Barnabas Toreu, Noel Kuman, James Maora, Colin Benton, Jane Belfield, and Leon Bridgeland as a consultant, supported by a long-term AusAID Cocoa Quality Improvement Project, further developed and promoted the improved small-scale fermentation and drying methods suitable for smallholders first developed by John Perkins, David Kidd and Trevor Clarke in the early 1980s. This program was continued by Jane Ravusiro and Kenny Francis in the 2000s. These methods included the use of smaller fermentation boxes to handle smaller batches of cocoa, small combination wood fired and passive solar driers, and ultimately active solar driers that more rapidly dry cocoa than occurs when it is simply exposed to the sun on a drying rack. The work on fermentation and drying methods was supported by the development at CCIL of small-scale chocolate manufacturing methods that were used to test the ultimate taste quality of the cocoa beans from the breeding and processing programs. Staff of CCIL Tavilo and LAES (NARI) Keravat were trained as chocolate tasters to assess the ultimate cocoa quality. On-going research is aimed at avoiding smoke contamination of cocoa beans during drying, a problem that was reported in the very early days of the cocoa industry (Green, cited above) and continues to affect the reputation of Papua New Guinea cocoa on the world market.

Following completion of his Ph.D. studies in 1991, Jason Dennis continued working as a general cocoa pathologist and became the head of the pathology section of CCRI. In 1993 Josephine Saul-Maora completed a

Masters study on the resistance of cocoa to *Phytophthora palmivora,* working at LaTrobe University with supervision from Philip Keane. In the 1994 Julie Flood worked with Josephine Saul-Maora in conducting studies on the control of Black Pod until their work was disrupted by the eruption of Tavurvur volcano. John Konam and Anthon Kamuso joined the pathology section in 1992, becoming long-term research workers through to the present time. In the mid to late 1990s, George Blaha, on secondment from CIRAD, worked with the pathology section to develop and apply a leaf disc method for determining resistance of clones to *Phytophthora palmivora.* Josephine Saul-Maora continued studies on the inoculation of attached and detached pods to determine resistance and developed a rapid field inoculation method using Band Aids to protect the zoospore inoculum. The use of detached pods was later adopted as the standard method for screening new breeding material for resistance to Black Pod. Later John Konam studied the epidemiology of Phytophthora diseases of cocoa for his Ph.D. through the University of Melbourne under the supervision of David Guest, and developed a better understanding of the cultural control of the disease and also found evidence for the involvement of flying insects in spreading *Phytophthora* (1999). With the departure of George Blaha, John Konam became the leader of the pathology section. Studying at the University of Sydney under the supervision of David Guest, Josephine Saul-Maora in 2008 completed a Ph.D. study on the diversity of *Phytophthora palmivora* in Papua New Guinea and showed that only this one species was involved in causing Black Pod and Stem Canker.

Through the 1990s Bob Prior and Samson Laup led the entomology research at CCRI, with support from L. (Lawrence) Ollivier on secondment from CIRAD. They continued the work of documenting and studying the numerous insect pests of cocoa and coconuts and their biological, cultural and chemical control. Paul Gende joined the section in 2000 and has continued entomological studies with Samson Laup through to the present time.

In a project that began in 2004, led by David Guest and Rosalie Daniel from the University of Sydney and supported by the Australian Centre for International Agricultural Research (ACIAR), John Konam and Yak Namaliu, with help from the entomology, breeding, pathology and agronomy sections (including Paul Gende, Yoel Efron, Peter Epaina, Josephine Saul-Maora, John-Thomas Vano, Anthon Kamuso, Ricky Wenani, Philo Asia, David Yinil, Peter Bapiwai, Kula Daslogo and Chris Fidelis) developed methods for Integrated Pest and Disease Management (IPDM) in cocoa (see Konam J, Namaliu Y, Daniel R, Guest DI 2008 'Integrated Pest and Disease Management for Sustainable Cocoa Production'. Australian Centre for International Agricultural Research, Canberra). This project developed and formalised methods for cultural control of Black Pod that had been implemented by Yak Namaliu and his wife Susanna on their family cocoa blocks in East New Britain. These methods involved planting of new types of cocoa with a degree of disease resistance developed by the breeding section, severely cutting back existing overgrown shade and cocoa, growing the trees with light shade and appropriate manuring to promote flowering and pod set, and the frequent removal and burial of diseased pods. While this work was initially directed mainly at management of Phytophthora Pod Rot and Canker, with the arrival of Cocoa Pod Borer it also proved to be very effective at managing this pest – the main cultural control measure for Black Pod of frequently removing from the canopy and composting or burying all infected pods was precisely the measure needed to control Cocoa Pod Borer in infested pods, as had been shown previously in Malaysia.

Cocoa Pod Borer *Conopomorpha cramerella* (Appendix 7) was first detected in Papua New Guinea at LAES Keravat in March 2006. Gade Ling brought a pod with unusual symptoms, collected by labourers from block 205, to John Moxon (then Officer-in-Charge of LAES) who had seen Cocoa Pod Borer on a study tour to Sabah in 1982 and was immediately alarmed. John Bokosu, in the LAES entomology section, reared moths from the pod and the presence of *Conopomorpha cramerella* was confirmed. Later occurrence of the pest was confirmed at Poro, West Sepik Province (June 2006) and at Bogia, Madang Province (April 2008). The insect had probably spread into West Sepik from the adjacent Indonesian province of Papua, and then been spread within Papua New Guinea by the transport of infested pods. In the previous three decades it had spread inexorably from North Sulawesi to Sabah and then Peninsular Malaysia, and from North Sulawesi to South and Southeast Sulawesi, then through Maluku into West Papua and Papua. The Indonesian entomologist Endang Sulistyowati, who had long experience with the pest in Sulawesi, visited CCIL to offer advice. From 2006 to January 2007, a vigorous eradication campaign, involving heavy pruning of all trees and removal of all pods within the exclusion zone, was conducted around the epicentre of the outbreak in East New Britain. This zone included all the cocoa research trials at CCIL Tavilo, and, as with the VSD epidemic in the 1960s, this severely disrupted the on-going research program. Despite the massive effort put into the attempted eradication, the Pod Borer was found on the outskirts of the eradication zone in late February 2007. Since then, the pest has spread rapidly in and beyond the province and is now found in all the main cocoa growing areas of Papua New Guinea. The response has switched to implementation of management of the pest following recommendations arising from experience in Malaysia and Indonesia that have long lived with the problem (Chapter 7) and the development of IPDM for cocoa in the above-mentioned ACIAR project. Intensive studies of the biology and ecology of the insect under the direction of Samson Laup (until 2015) and Paul Gende have continued. Experience in Malaysia and Indonesia has shown that the pest can be managed to allow cocoa production to recover to the highest yields obtained before the incursion. This has been demonstrated commercially by Graham McNally and Otto Koimba at NGIP-Agmark's Tokiala Plantation in East New Britain Province and also in research at CCIL, including that done under further ACIAR projects on Integrated Pest and Disease Management. Resistance to the insect was screened for by the breeding section in the existing Genotype x Environment trials in East New Britain and Madang, and selections for partial resistance (or tolerance) were made and incorporated into a later Hybrid Clone release (see Marfu J, Butubu J, Epaina P, Varvaliu A, Francis K and Ravusiro J, 2013, 'Provisional Release of Second Series Hybrid Cocoa Clone Varieties, Tolerant to Cocoa Pod Borer'. PNG Ccocoa Coconut Institute Ltd.).

The aim of reducing the height of trees to make them more manageable, especially since the arrival of Cocoa Pod Borer, has led to studies by the agronomy section, involving David Yinil, Eremas Tade, Chris Fidelis and Peter Bapiwai, to develop and promote improved pruning methods. David Yinil and Chris Fidelis were involved in an ACIAR project led by Paul Nelson on the nutrition of cocoa (Nelson PN, Webb MJ, Bethelsen S, Curry G, Yinil D and Fidelis C, 2011, 'Nutritional status of cocoa in Papua New Guinea', ACIAR, Canberra).

Following a review of the agro-ecological zones in Papua New Guinea suitable for cocoa (Hanson LW, Bourke RM and Yinil DS, 1998, 'Cocoa and Coconut Growing Environments in Papua New Guinea. A Guide for Research and Extension Activities'. Australian Agency for International Development, Canberra) the agronomy section began test plantings of cocoa at higher altitude (1200 metres above sea level) in Karamui Valley, Simbu Province, and showed the potential for cocoa planting to be extended into higher altitude environments. While the trees tended to grow more slowly and remained smaller, their yield of pods was found to be as high as in the lowlands. The interesting physiology of this situation remains to be studied. This result opens up the prospect that certain highland valleys may be able to support commercial cocoa production.

There is optimism that the new generation of Hybrid Clones, representing the culmination of a long and well planned and executed breeding program initiated in 1994 and building on the earlier work of the pioneering agronomists at LAES and the plant breeder Geok-Yong Tan, and the new methods of growing cocoa as a smaller tree with more intensive management, especially weekly removal and burial of *Phytophthora* and Cocoa Pod Borer infested pods, offer great hope for a sharp increase in cocoa production on farms in Papua New Guinea.

The major challenge, as always, is to have these research outputs taken up widely on farms, following the aims set out in the Strategic Plan (Appendix 2). Through the 2000s, Joachim Lummani, Eric Omuru, George Curry and Gina Koczberski , supported by ACIAR, have undertaken socio-economic studies of cocoa farming, including methods of improving uptake of new methods by farmers, the effect of, and response to, the incursion of Cocoa Pod Borer on farms, and development of new extension methods. They have concluded that collaboration with private enterprise is an effective way of helping farmers to adopt new methods, and have been able to demonstrate that the new methods of growing cocoa do not necessarily involve more labour. The initial parts of this work have been summarised in the book Curry GN, Koczberski G, Omuru E and Nailina RS, 2007, 'Farming or Foraging? Household Labour and Livelihood Strategies Amongst Smallholder Cocoa Growers in Papua New Guinea', Black Swan Press.

While most of the cocoa research in recent decades has been conducted at the CCIL Tavilo, some cocoa research, especially on cocoa farming systems, continued under NARI at LAES Keravat for about 15 years after the establishment of the Tavilo complex. It is sad to record that the old timber office/laboratory complex at LAES, initially constructed in 1946, was completely destroyed by fire in April 2011. This destroyed the library that housed many of the research reports and original documents accumulated over the long history of the station and, in the entomology section, an extensive and valuable insect reference collection, including the pests of cocoa that had been accumulated since 1946. A new complex has been built and named after the long-serving cocoa agronomist and administrator, David Loh, who first took up appointment at LAES in 1970 and served there until becoming the administrator of the Cocoa Growers' Association in Kokopo in 1986.

The future

The economic benefits of cocoa research conducted from 1965 to 1980 were analysed in an ACIAR-supported study (Antony G, Kauzin G, Loh D, Anderson J, 1988, 'Returns to Cocoa Research 1965 to 1980 in Papua New Guinea'. Australian Centre for International Agricultural Research – ISNAR). It was estimated that the national benefit from the research was 8.3 times the cost of the research and that the effective earnings on funds expended was an enormous 22 percent. The history of cocoa research in Papua New Guinea is one of steady, largely continuous progress from the 1920s to the present day, contributed to by the collaborative and accumulative efforts of a large number of highly dedicated people over that time, and leading to the development of new methods of growing cocoa and new high yielding cocoa varieties that can form the basis of an expanding and productive cocoa industry in this country. The continuation of this research effort is crucial for the future development of a productive cocoa industry that is able to continue to support rural development and give valuable export earnings in Papua New Guinea.