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CONTENTS

A REVIEW OF RELATIONSHIPS BETWEEN SHADE TYPES AND COCOA PEST AND DISEASE PROBLEMS IN PAPUA NEW GUINEA

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ABSTRACT

In Papua New Guinea, unlike most other cocoa cultivating countries, the permanent overhead shade is provided mainly by coconuts and/or Leucaena leucocephala *(Lam.) De Wit. Selection of cocoa shade species has been based on agronomic characteristics and there have been few attempts to determine the relationships between cocoa pests and diseases and the shade species.*

This paper outlines the major pests and diseases in Papua New Guinea cocoa plantings and reviews their relationships to the main shade trees used. Evidence is presented to show that many of the present day problems have arisen from the use of leucaena as a shade tree. In contrast, the widespread practice of interplanting cocoa under coconut palms has considerable economic and managerial advantages and the cocoa generally suffers less from insect and disease attack than sole planted cocoa.

It is concluded that recommendations incorporating the planting of high yielding, disease resistant cocoa under high yielding, hybrid coconut palms at least three to four years old, should be formulated and actively promoted in Papua New Guinea.

INTRODUCTION

Cocoa has been grown in Papua New Guinea since the end of the last century and many systems of cultivation have been tried. The crop is generally grown beneath the shade of selectively thinned forest or cultivated shade trees. Young cocoa plants require fairly heavy shade, although this requirement diminishes as the trees age.

In cocoa cultivation, four ways in which shade species are used have been recognised (Green 1938):

1. As a cover crop which protects against soil erosion and reduces weed competition during establishment of seedlings
2. As a temporary or nurse shade before the closure of the cocoa canopy
3. As a windbreak and hedge
4. As a permanent overhead shade.

One of the functions of shade is to buffer against changes in the environment (Murray 1964) and the selection of shade species is based on this and other agronomic or physiological characteristics.

Although there is an extensive literature on these agronomic aspects (eg. Chalmers 1967; Henderson 1954; Murray 1957; Wyrley-Birch 1970) and most authors have reported specific pest and disease problems associated with the shade species, few workers have examined the relationships between shade

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density or species and the pest and disease incidence in cocoa. The microclimatic effects on the cocoa ecosystem caused when the shade canopy is changed and the possibility of the shade species itself being an alternative host may influence the incidence of pests and disease in the cocoa.

This review concentrates on the relationships between cocoa pest and disease problems and the species of shade trees and density of shade used in Papua New Guinea and will only briefly discuss the agronomic suitability of the various forms of shade.

GENERAL RELATIONSHIPS BETWEEN COCOA PESTS AND DISEASES AND SHADE

It has been stated that "cocoa trees prefer the type of shade trees which allow the light to filter through, but still protect them from the sun" (Urquhart 1953). This requirement can be provided either by thinned forest trees or by regularly spaced trees planted for shade. However, all the desirable qualities for a permanent shade tree (Henderson 1954; Murray 1957; Urquhart 1961; Wyrley-Birch 1970) are rarely found in one species, and the requirements vary between cocoa growing regions. Tree species which are favoured for permanent shade are usually legumes (which may improve the nitrogen status of the soil), or trees which bear another crop (e.g. coconuts, areca nuts, other fruit or nuts, rubber, oil palm) or become a valuable source of timber.

Since the light requirement for cocoa increases as the tree matures, the density of the shade should be gradually reduced as trees commence bearing to maintain acceptable yields. Caution must be exercised, however, since the removal of shade is frequently followed by increased insect attack (Anon. 1971; Entwistle 1972; Lim 1978).

General principles for reducing the disease incidence in shaded cocoa were outlined by Dadant (1953), who suggested that "a space of several feet should separate the cocoa tree level from the shade tree level". He found that this prevented the low branches of shade trees from intermingling with the upper branches of the cocoa and allowed air movement through the cocoa canopy and the space between cocoa and shade tree thereby reducing humidity.

MAIN COCOA PEST AND DISEASE PROBLEMS

Over 300 insect species (Szent-Ivany 1961, 1963) and 47 diseases (Shaw 1963) have been recorded from cocoa in Papua New Guinea. Fortunately, in most areas there are only six or seven species of pests which regularly cause crop loss or tree damage, but many others may occasionally form large populations and cause loss of production. Throughout the country the two greatest cocoa problems are *Pantorhytes* spp. (Coleoptera: Curculionidae) and *Phytophthora* pod rot disease. Vascular streak dieback disease was a serious threat to cocoa growing in many areas but has now been largely removed by both natural and controlled selection of resistant clonal material (Anon. 1972).

Studies over the past 30 years have indicated that the severity of attack by many of the main cocoa pests is influenced by the density of shade or type of shade tree used.

RELATIONSHIPS BETWEEN COCOA PESTS AND DISEASES AND SHADE

In Papua New Guinea, some 70% of the country's cocoa is interplanted under coconuts (in some cases leucaena is also present) and about 20% is cocoa under leucaena alone. The remainder is grown unshaded or can be found under a variety of shade trees, the most common of which are thinned primary forest or

Erythrina spp. The relationships between shade and cocoa pests and diseases are discussed below, while the main host associations are listed in *Table 1*, and *Table 2* indicates how the population levels of some of the cocoa insects could be expected to vary among the three main cocoa ecosystems of Papua New Guinea.

Temporary shades

Green (1938) discussed the merits of six species used for temporary shade *Aeschynomene americana* L., *L. leucocephala* (Syn. *L. glauca*), *Crotalaria anagyroides* Kunth, *Cajanus cajan* (L.) Millsp. (Syn. *C. indicus*), *Tephrosia candida* (Roxb.) DC. and *Tephrosia vogelii* Hook. f.. The last four species are all susceptible to pink disease (*Corticium salmonicolor* Berk. and Broome) (Green 1938) and *C. anagyroides* is an alternative host for both *Tiracola plagiata* Walker (Dun 1967) and *Zeuzera coffeae* Nietner (Entwistle 1972). *Flemingia* sp. is now used in some areas, but is an alternative host for *Helopeltis clavifer* Walker, the most damaging cocoa mirid in Papua New Guinea (Smith 1978), and for pink disease.

Unshaded cocoa

Although it is difficult to establish cocoa without using shade, mature trees generally gave higher yields if unshaded, provided fertiliser applications were adequate. In Papua New Guinea, highest yields have been recorded in unshaded cocoa (Charles 1961, 1971) but conditions become much more favourable for some insect pests (Byrne 1971). It was suggested by Byrne (1971) that a compromise could be reached between high yields in unshaded cocoa and lower insect attack to shaded trees by the less drastic thinning of shade around the block edges, since "this could assist in keeping down infestation of pests such as *Pansepta teleturga* Meyrick." This system has been tested in Malaysia, where Lim (1978) reported that shade removal, except around the block boundaries, increased the incidence of mirids, thrips and leaf eating pests. He indicated that success from shade removal would require a continuous closed cocoa canopy and the maintenance of a high standard of pest control.

Pantorhytes populations were greater on unshaded than on shaded cocoa trees (Bourke 1971; Hassan 1971), and Smith (1981a) reported that populations of *H. clavifer* were frequently damaging on unshaded cocoa. In addition, increased damage levels of the insect pests *Platyacus ruralis* Faust, *Rhyparida* spp., *Z. coffeae* and *P. teleturga* were all correlated with inadequate shade levels (*Table 2*) and Dun (1951) suggested that "proper control of shade will go far toward lessening the amount of damage" by the latter pest.

It is possible that unshaded cocoa would suffer less from disease since increased air movement and lowered humidity could create conditions unfavourable to fungal pathogens.

Coconuts

This regime has been described as the ideal shade for cocoa (Henderson 1954) and has been used in Papua New Guinea since early this century (Urquhart and Dwyer 1951). Both Godyn (1974) and Henderson (1954) listed many advantages of interplanted over sole planted cocoa and various authors have reported that yields of both crops are equal, if not better than, those in sole planted areas (Barrant 1978; Denamany *et al.* 1978; Henderson 1954; Ramadason *et al.* 1976; Shepherd *et al.* 1976; Urquhart 1957).

As Dun (1967) remarked, the widespread use of coconuts "was probably fortuitous but has proved highly satisfactory since the conditions provided by this combination were entirely unsuitable for the development of the more important (cocoa flush defoliating) species." Most other cocoa pest problems also occur

Table 1.—**Main cocoa pests and diseases in Papua New Guinea and their relationships to shade species**

Pest species	Order: Family	Shade tree as alternative host	Author and date	
Flush and foliage feeders				
Ectropis sabulosa Warrengren	Lep. : Geometridae	*Leucaena*	Smee	1963
Hyposidra talaca Walker	Lep. : Geometridae	*Leucaena*	Smee	1963
Achaea janata (Linnaeus)	Lep. : Noctuidae	*Albizia* spp., *Hevea*	Smee	1963
Tiracola plagiata Walker	Lep. : Noctuidae	*Leucaena, Crotalaria, Hevea*	Catley	1962
Ceroplastes chiton (Green)	Hom. : Pseudococcidae	*Erythrina, Gliricidia*	Shah	1976
Ferrisiana virgata (Cockerell)	Hom. : Pseudococcidae	*Leucaena, Albizia*	Szent-Ivany & Catley	1960
Planococcos citri (Risso)	Hom. : Pseudococcidae	*Erythrina, Leucaena, Tephrosia, Hevea*	Szent-Ivany	1956
Rhyparida spp.	Col. : Chrysomelidae			
Platyacus ruralis Faust	Col. : Curculionidae			
Pod feeders				
Amblypelta spp.	Heterop. : Coreidae	*Cocos*	Brown	1958
Helopeltis clavifer (Walker)	Heterop. : Miridae	*Pueraria, Flemingia, Eucalyptus*	Smith	1978
Pseudodoniella laensis Miller	Heterop. : Miridae			
Pseudodoniella pacifica China and Carvalho	Heterop. : Miridae			
Pseudodoniella typica China and Carvalho	Heterop. : Miridae			
Vertebrate pests				
Flying fox	Chiroptera : Pteropidae	*Ceiba*		
Parrots	Psittaci : Psittacidae	*Cocos*		
Rats	Rodentia : Muridae	*Cocos*		
Woodborers				
Glenea spp.	Col. : Cerambycidae			
Oxymagis horni Heller	Col. : Cerambycidae			
Neotermes spp.	Isop. : Kalotermitidae	*Leucaena, Gliricidia*	Smee	1963
Pansepta teleturga Meyrick	Lep. : Xyloryctidae	*Casuarina, Ceiba*	Bailey	1978
Pantorhytes spp.	Col. : Curculionidae			
Zeuzera coffeae Nietner	Lep. : Cossidae	*Albizia* spp., *Crotalaria, Eucalyptus, Hevea*	Entwistle	1972
Pod rots				
Botryodiplodia theobroma		*Hevea*	Shaw	1963
Phytophthora palmivora (Butler) Butler		*Cocos, Hevea*	Shaw	1963
		Leucaena leaflets	Newhook & Jackson	1977

Table 1. Cont. —

Pest species	Order : Family	Shade tree as alternative host	Author and date
Stem cankers and diseases			
Corticium salmonicolor Berkley & Broome		*Cajanus, Cassia, Casuarina, Tephrosia, Erythrina, Flemingia, Leucaena, Hevea*	Shaw 1963; Zaiger 1968
Phytophthora palmivora (Butler) Butler		as above	
Seedling blight			
Phytophthora palmivora (Butler) Butler		as above	
Rhizoctonia sp.			
Vascular streak dieback			
Oncobasidium theobromae Talbot & Keane			
Root rots			
Phellinus (*Fomes*) *noxius* (Corner) G.H. Cunningham		*Leucaena*	Thrower 1965
Rigidoporus (*Fomes*) *lignosus*		*Albizia, Cassia, Cocos, Hevea*	Shaw 1963

Table 2. — **Expected effect of shade species on population levels of some cocoa insect pests**

Pest species	Coconut shade	Leucaena shade	Unshaded cocoa	Author	Date
Leaf defoliating caterpillars	Almost complete absence of pests	Very damaging levels of all four species	Except for *Achaea*, levels greatly reduced.	Dun Anon.	1967 1966
Rhyparida spp.	Almost absent	Almost absent	Damaging levels	Anon.	1965
Platyacus ruralis	Almost absent	Almost absent	Damaging levels	Dun	1951
Helopeltis clavifer	Populations generally small; causing no economic loss	Generally high and damaging populations	Highest population levels are found	Smith	1972
Neotermes spp.		Attack to cocoa frequently ascribed to presence of leucaena stumps		Anon.	1963
Pansepta teleturga			Damaging levels	Bailey	1978
Pantorhytes spp.	Generally small populations causing no economic loss	Populations frequently high and damaging to cocoa	Populations frequently very high and damaging	Hassan	1971
Zeuzera coffeae			Levels may increase as shade cover is reduced	Anon.	1965

with low incidence under coconut shade. In particular, populations of *Pantorhytes* (Hassan 1971) and *H. clavifer* (Smith 1981a) are generally small and rarely cause economic damage to cocoa. Room and Smith (1975) have demonstrated that a negative association exists between *Pantorhytes szentivanyi* Marshall and coconut shade.

Two species of nettle caterpillars which feed primarily on coconut fronds have occasionally caused localised (although severe) defoliation to cocoa on the mainland of Papua New Guinea, but these outbreaks have been shortlived and usually of only one generation. Only the vertebrate pests listed in *Table 1* as associated with coconuts have caused significant damage since they can feed on both pods and coconuts. However, the extent of damage has been no more severe than in sole planted cocoa. *Amblypelta theobromae* Brown (Heteroptera: Coreidae) the only coreid to cause significant damage to cocoa has not been recorded from coconuts; while those *Amblypelta* species which do promote coconut nutfall (Brown 1958) rarely attack cocoa pods.

Phytophthora palmivora (Butler) Butler has not been recorded from coconuts in this country since 1940 (Shaw pers. comm.) although the disease was originally described from coconuts and other palms in India (Thorold 1975).

Leucaena

Agronomically, this species appeared to be an ideal cocoa shade in Indonesia and Papua New Guinea, although it was generally unsuited to countries which have long dry seasons, since leucaena then seeds profusely and becomes very dense and difficult to eradicate (Chok 1970; Urquhart 1961). Prior to 1960 there appeared to be few disadvantages of using leucaena in Papua New Guinea, but since then it has become evident that many cocoa pests and diseases are associated directly or indirectly with this shade species.

Table 1 records a substantial list of pests and diseases associated with leucaena, including three defoliating caterpillars, *Neotermes* spp., root rot (*Phellinus noxius* (Corner) G.H. Cunn.) and *P. palmivora*. Dun (1967) reported that "as a result of the association of caterpillars and leucaena shade trees, there is a tendency to remove the latter to varying degrees up to complete removal" to prevent flush foliage damage. In addition, populations of both *Pantorhytes* (Bourke 1971) and *H. clavifer* (Smith 1981a) are at higher and more damaging levels under this shade than under the taller shade given by coconuts, rubber or thinned forest. A significant association between leucaena and *H. clavifer* has been shown (Room and Smith 1975).

Although cocoa swollen-shoot-virus disease has not been recorded in Papua New Guinea, two potential mealy bug vectors (*Planococcus citri* (Risso) and *Ferrisiana virgata* (Cockerell)) are present as minor pests of the crop. The latter has been recorded "in dense populations" from leucaena (Szent-Ivany and Catley 1960), while in Indonesia, Kalshoven and van der Vecht (1950) reported that leucaena was "a favourite host, and that crops grown with (it) are liable to suffer infestations" (from mealy bugs).

Thinned forest

Very few insect pests have been encountered in cocoa grown under thinned forest, but the root rots *Phellinus noxius* and *Rigidoporus lignosus* (Klotzsch) Imaz. spreading from forest trees and decaying stumps have frequently killed cocoa trees. Dun (1967) found that flush defoliating caterpillars were generally absent from the cocoa and populations of *H. clavifer* were very low compared to those under leucaena shade. In other countries however, cocoa pest attacks may be initiated from forest trees which remain after partial clearing (Conway 1971; Dadant 1953; Entwistle 1972;

Urquhart 1953). Growers with small landholdings frequently practice partial clearing since the cost of clearing is then considerably reduced, but the shade density cannot be manipulated accurately and damage to cocoa trees from falling branches is frequently encountered. Competition for moisture or nutrients may also be important and yields are frequently very low.

Gliricidia sp.

Apart from *Neotermes* spp., no important pest and disease associations with this shade species have yet been encountered in Papua New Guinea, but several have been recorded elsewhere (Brown *et al.* 1967; Conway 1971; Entwistle 1972, Shah 1976). This species required a considerable amount of management to maintain suitable shade density and was susceptible to wind damage. It was however highly attractive to *Anoplolepis longipes* (Jerdon), (Hymenoptera:Formicidae) which are recommended in some situations for the control of *Pantorhytes* in cocoa (Baker 1972; Room and Smith 1975; Smith 1981b).

Other shade species used

Various other species including *Albizia* spp., *Casuarina equisetifolia* L., *Ceiba pentandra* (L.) J. Gaertner (kapok), *Erythrina* spp., *Eucalyptus deglupta* Blume and *Hevea brasiliensis* (Willd. ex Adr. de Juss.) Muell.-Arg. (rubber) have been tested as a source of permanent shade for cocoa in Papua New Guinea, but each has one or more agronomic disadvantages and is associated with at least one of the major cocoa insect pests or diseases found there. For instance, *C. equisetifolia* is a host of *P. szentivanyi* (Smith 1981b); *E. deglupta* is a host of *H. clavifer* (Smith 1978) and *H. brasiliensis* is a host for two defoliating caterpillars and no less than seven diseases of cocoa (Shaw 1963).

IMPLICATIONS FOR COCOA GROWING IN PAPUA NEW GUINEA

Although economic chemical control of all the pests and diseases mentioned in *Table 1* (with the exceptions of *Pantorhytes* spp. and *P. palmivora*) is possible, it is desirable that input of pesticides to the cocoa ecosystem be kept to a minimum. If populations and inoculum levels of cocoa pests and diseases could be reduced and maintained at a low level by a combination of cultural, and biological controls and limited pesticide useage, then the resultant damage to the cocoa could be below the level at which production loss occurs.

An integrated approach to pest management in Paua New Guinea, which incorporates the selection of shade species and shade densities, the spot treatment of borer channels with penetrant insecticides and the introduction of antagonistic ant colonies was recommended by Smith (1981c) and is being carried out on some plantations on the Gazelle Peninsula.

The information presented in *Table 1* indicates that many of the major pest and disease problems of cocoa in Papua New Guinea have been caused by the use of leucaena as a source of permanent shade and Room and Smith (1975) recommended that this practice be stopped.

The practice of interplanting cocoa beneath coconuts appears ideal for Papua New Guinea and should be actively promoted since general pest and disease problems are fewer in these situations, and the management and economic advantages are significant. Papua New Guinea is currently embarking on a replanting scheme using locally produced, very high yielding hybrid coconuts and selected budded or hybrid cocoa. Research efforts to determine spacing and fertiliser requirements for hybrid palms and the optimum time for interplanting with cocoa should begin as soon

as possible.

Current recommendations suggest that growers who are prepared to use fertilisers and are capable of dealing with likely pest problems should remove all shade once the canopy closes, while growers who are not likely to use fertilizer should retain overhead shade of medium densities, eg. leucaena at about 200/hectare. Given the cocoa pest problems associated with leucaena shade, the findings that *Pantorhytes* spp., *P. teleturga* and *H. clavifer* are all most damaging in unshaded cocoa and that the first two pests are so difficult to control, it is suggested that these recommendations be changed and that the replacement system of interplanting cocoa under hybrid coconut palms be intensively investigated.

CONCLUSIONS

Cocoa culture in Papua New Guinea during the past 30 years has been beset with pest and disease problems which were largely unknown, or at least only minor, prior to World War II, when almost all cocoa was planted beneath coconuts. It is believed that many of the present day problems are due to the widespread use of leucaena as a shade tree. Leucaena is a host for many major cocoa insect pests, and being a low growing tree, its canopy is frequently contiguous with that of the cocoa growing beneath it. This allows easy access of pests to the cocoa and reduces the air movement directly above, within and below the cocoa canopy, thus favouring the build up of diseases.

Unshaded cocoa, although known to give maximum yields if fertilised adequately, is very susceptible to attack by several pests which are extremely difficult to control, and should not be recommended except under very intensive management. Although many other species of trees have been tested as cocoa shades, none have been as suitable as coconuts, under which a low pest and disease incidence is generally found.

It is suggested that recommendations to grow cocoa in unshaded or leucaena shaded conditions, should be changed and that new recommendations incorporating cocoa interplanted under coconuts be promoted. Where cocoa is to be planted under older coconuts with large gaps in the canopy, gliricidia should be used, at least as a temporary shade. When more information on optimum spacing and fertiliser requirements for the newly developed, high yielding coconut hybrids is available, recommendations for the establishment of high yielding, disease resistant cocoa under palms three to four years old should be formulated. This latter dual cropping system would appear to be the ideal combination from both the agronomic and the pest and disease management aspect.

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SWEET POTATO (*IPOMOEA BATATAS*) PRODUCTION AND RESEARCH IN PAPUA NEW GUINEA

R. Michael Bourke*

ABSTRACT

Sweet potato production and research work in Papua New Guinea is reviewed. The estimated annual production is worth over K200 million. It is the staple food in most of the highlands and parts of the lowlands. In the central highlands, it provides between 65% and 90% of people's energy intake. Aspects reviewed are the significance and distribution of the crop, the timing and effect of its introduction, the crop's ecological place and role in various cropping systems, cultivars grown, cultural techniques used, systems of harvest, crop yield, major pest and disease problems, and future prospects.

Some 180 agronomic field trials have been carried out. Research work reviewed includes cultivar, inorganic fertilizer, method of cultivation, plant density, effect of weeds and weedicide, time to maturity, method of harvesting, tuber protein content analyses, storage and other agronomic studies. Also reviewed are the possible manufacture of a dried sweet potato product, littleleaf disease studies and work on sweet potato as a stockfeed. The status of current research is mentioned. Available data on the importance of sweet potato in people's diets and agriculture, number of cultivars used by different groups and yields under subsistence conditions are presented.

INTRODUCTION

This review is intended primarily to bring together data on sweet potato production and research in Papua New Guinea from published and unpublished sources. The reference list becomes, in effect, a bibliography of sweet potato in the country. In such a wide ranging paper the review of research work is of necessity only a summary. An adequate review, for example, of all organic and inorganic fertilizer trials would constitute a paper in itself. This review does however draw the attention of researchers to previous work. The cropping systems in which sweet potato are grown are defined and mapped. This updates and expands on earlier work of Brookfield (1962) and Kimber (1972a).

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SWEET POTATO CULTIVATION

Significance and distribution

Sweet potato (*Ipomoea batatas* (L.) Lam.) is by far the most important food crop in Papua New Guinea. The only production estimates are now 20 years old. Walters (1963) estimated annual production to be 1,223,000 tonnes from an approximate area of 72,000 hectares. Given the expansion of crop area since then, present production is probably worth over K200 million per year, if tubers are valued at a conservative 15 toea per kilogramme. No other single crop, including the export crops, contributes as much to the national economy. As well as being a major subsistence crop, sweet potato is an important cash crop and is the main crop grown at institutions, such as schools.

The principal products for human consumption are the tubers which are

baked in a fire, boiled or steamed in a stone oven. Small tubers are used raw as pig feed and large herds of pigs are maintained on sweet potato tubers, particularly in the highlands. The vines and leaves are occasionally eaten by people as a green vegetable, but their main use is as pig feed.

Areas where sweet potato is the staple food or a significant co-staple are shown in *Figure 1*. It is cultivated extensively in the highlands at elevations between 1200 m and 2700 m where it is generally the staple food.

Production is generally increasing in the lowlands (0-600 m) and intermediate altitude zone (600-1200 m), together with that of *Xanthosoma* and cassava, at the expense of the traditional staples, particularly *Colocasia* taro. This change is occurring because of the loss of fertile forest land which is necessary for taro cultivation; the ease of cultivation of sweet potato; pest and disease problems of taro; and the loss of traditional values associated with other staples. On Bougainville and New Ireland for example, sweet potato has displaced the traditional staple taro to a large degree.

Available information on the contribution of sweet potato to villagers' diets and the proportion it constitutes of all food planted is summarized in *Table 1*. The dependence of people in the central highlands on sweet potato is striking. Here it provides an estimated 53% to 94% of people's energy intake, 19% to 73% of their protein intake, 56% to over 90% of their total food intake (by weight) and occupies 57% to 91% of total garden land planted to food crops. Venkatachalam (1962), Oomen and Malcolm (1958), Lambert (1975) and Harvey and Heywood (1983) all conducted dietary surveys in Yobakogl village in the Sinasina area of Chimbu Province. The most recent survey (Harvey and Heywood 1983) however shows that the contribution of sweet potato to the people's diet has declined considerably and it has been displaced by rice, flour and other imported goods. This trend is likely to be occurring elsewhere in the highlands. On the highland fringes and in the lowlands, sweet potato is of lesser significance because of the presence of other staple foods.

Introduction to Papua New Guinea

It is generally accepted that sweet potato was introduced to Papua New Guinea some time in the past 400 years following European exploration in the New World. Yen (1974) has proposed that it came to Papua New Guinea from the West Indies via Africa, India and the East Indies (Indonesia). Various authors have estimated that sweet potato has been in the highlands for 200 to 300 years. Some examples are Upper Kaugel Valley, minimum of 170 years (Bowers 1968); Kainantu area, 200 to 300 years (Watson 1965); Wahgi Valley, 250 years (Golson 1981); Tari Basin, 250 years (B.J. Allen, pers. comm.).

The effect of the comparatively recent introduction of sweet potato into the highlands has been controversial. Watson (1965, 1977) has suggested that a subsistence revolution occurred following its introduction. It is hypothesized that this revolution included radical changes in gardening patterns, an increase in the importance of pigs, a human population explosion, a change in the relationship between the sexes amongst the highlanders, changes in social structure and an increase in warfare. Other workers have rejected this hypothesis. Brookfield and White (1968) suggest instead that the introduction of the sweet potato was not of major relevance to the development of agriculture in the highlands, although its introduction has had some effects, such as an expansion of cultivation into areas of higher altitude, the clearing of montane forest and the resultant more extensive planting of casuarina trees to provide wood in deforested areas.

Golson (1982) agrees with Watson that the introduced sweet potato was superior

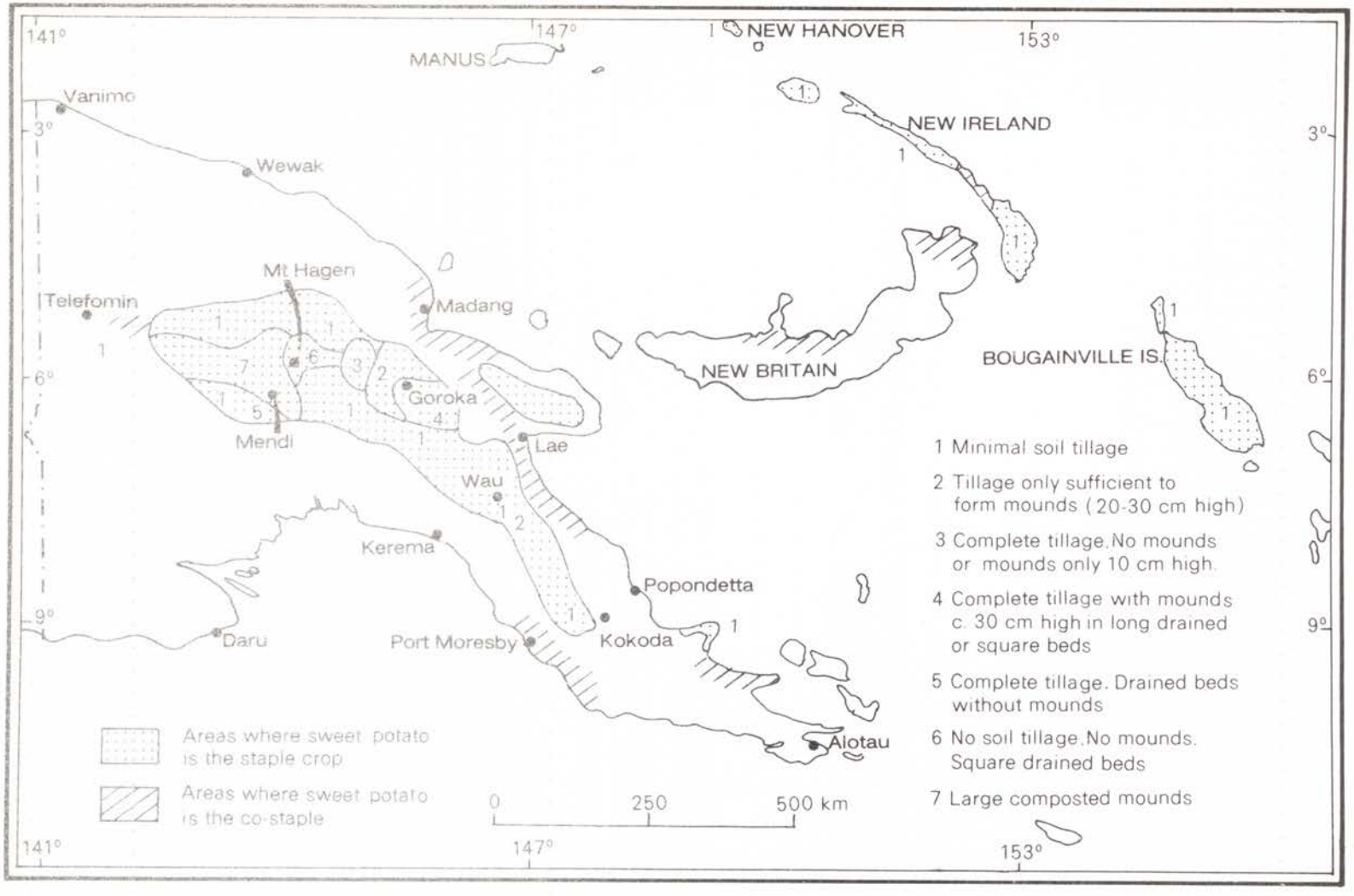

Figure 1. —**Sweet potato growing areas and tillage/plantings systems in Papua New Guinea**

Table 1. —**Importance of sweet potato in the diet of various groups of people in New Guinea**

Location *	*Contributions of sweet potato (%)*				*Source*
	Energy intake	Protein intake	Total food intake (by weight)	Area of food crops planted	
Gumine, Chimbu (2,3)	94	53	83	– (1)	Bailey & Whiteman (1963)
Sinasina, Chimbu (2)	92	–	89	–	Oomen & Malcolm (1958)
Baiyer R., W.H.P. (2)	89	73	86	–	Oomen & Corden (1970)
Kundiawa area, Chimbu (2,3)	87	48	80	–	Baily & Whiteman (1963)
Sinasina, Chimbu (2)	84	69	–	–	Lambert (1975)
Okapa, E.H.P. (2)	80	60	–	–	Jeffries (1978)
Okapa, E.H.P. (2)	78	41	–	–	Reid & Gajdusek (1969)
Upper Chimbu Valley (2)	77	41	70	–	Hipsley & Kirk (1965)
Sinasina, Chimbu (2)	76	56	77	–	Venkatachalam (1962) (4)
Lai Valley, Enga (2)	73	33	63	63-67	Waddell (1972)
Siane, Chimbu (3)	65	–	56	–	Salisbury (1962)
Lufa, E.H.P. (2)	64	37	–	–	Norgan *et al.* (1974)
Sinasina, Chimbu (2)	53	34	61	–	Harvey & Heywood (1983)
Nembi Plateau, S.H.P. (2,6)	47	19	–	–	Baines (1983)
Simbai, Madang Prov.	30	10-17	19	–	Rappaport (1968)
Simbai, Madang Prov.	25	–	16	–	Clarke (1971)
Upper Kaugel Valley, W.H.P. (2)	–	–	>90	–	Bowers (1968)
Sirunki Plateau, Enga (2)	–	–	90	–	Sinnett (1975)
Patep, South of Lae	–	–	38	–	Langley (1950)
Kaiapit, Markham V.	–	–	25	–	Langley (1950)
Trobriand Islands	–	–	14	–	Langley (1950)
Rigo, Central Prov.	4	2	4	–	Hipsley & Kirk (1965)
Middle Sepik E.S.P.	–	–	0.3	–	Oomen & Malcolm (1958)
Sirunki Plateau, Enga (2)	–	–	–	91	Allen (1982)
Wissel Lakes, Irian Jaya (2) (7)	–	–	–	>90	Pospisil (1963)
Nembi Plateau S.H.P. (2)	–	–	–	89	Bourke (in press)
Lai Valley, Enga (2)	–	–	–	87	Allen (1982)
Nagovisi, Bougainville	–	–	–	c.85-90	Mitchell (1976)
Tsak Valley, Enga (2)	–	–	–	83	Allen (1982)
Aiyura V., E.H.P. (2)	–	–	–	57(5)	R.M. Bourke (unpubl. data)

Notes: * Abbreviations used. E.H.P. — Eastern Highlands Province, E.S.P. — East Sepik Province, S.H.P. — Southern Highlands Province, W.H.P. = Western Highlands Province.

1 – = no data.

2 Locations in the central highlands of New Guinea.

3 Adult men only. Figures for other groups in the population are similar.

4 Venkatachalam's data were recalculated by Lambert (1975).

5 This figure is derived from measurements of crop area planted by 10 women over a 3 year period (1980-1982).

6 Pregnant women only.

7 Irian Jaya (West New Guinea) is a province of Indonesia.

to other pig feed, but also notes that it could be grown productively over a wider range of soils and altitudes. He maintains that agricultural production for pig keeping would have been less localized than prior to its introduction and thus it may have reduced inequality between men.

Ecological place and farming systems

Sweet potato is cultivated in a wide range of environments. It is grown from sea level to the altitudinal limit of agriculture in Papua New Guinea. This limit is in fact determined by where sweet potato will grow. It is usually at about 2700 m, but occurs as high as 2850 m in parts of Enga and Chimbu Provinces. The crop attains its greatest importance above 1200 m. Above 2300 m regular frost damage occurs.

It is the staple crop in areas where the mean annual rainfall ranges from 1500 mm (for example Mumeng) to about 5000 mm, (for example Pangia or Boku) and is grown on soil types ranging from sandy loams to heavy clays and peats. In the highlands where the crop is most important, the soils are generally loams or clays. It is grown on slopes ranging from flat land to 40°. The wide range of ecological conditions under which the crop is grown reflects both its adaptability and its wide genetic base within the country.

The farming systems in which sweet potato is grown are equally diverse. The crop is grown in systems using both grass and forest fallow. Grass fallow systems are more important, especially in the highlands. A number of cultivation systems can be distinguished and these are described below. Locations where the different systems are used are shown in *Figure 1*.

The cultivation techniques are as follows:

1. Minimal tillage. The soil is disturbed only enough to plant vines. This method is common in forest areas, especially in the lowlands, the fringes of the highlands and on forested land in the highlands as it is opened up for the first time.

2. Soil tilled sufficiently only to form mounds 20 to 30 cm high. The entire soil surface is not tilled. This method is practised in forested areas on slopes in the Eastern Highlands and parts of Chimbu Province. It is also used on light textured soils, such as sandy loams on river terraces, in both the lowlands and highlands (*Plate I*).

3. Complete soil tillage, but no mounds or mounds only 10 cm high. This is done in grassland areas on very steep slopes in the Chimbu Province. Horizontal soil retention fences made from branches are often used in this system.

4. Complete tillage with mounds about 30 cm high formed in long drained beds (Eastern Highlands) or in square beds (parts of Chimbu) and sometimes without beds (parts of Eastern Highlands). The entire soil surface is tilled prior to mounding. This system is mostly used in grassland soils but it is also practiced in forest soils. A peanut (*Arachis hypogaea* L.) or winged bean (*Psophocarpus tetragonolobus* (Linnaeus) A.P. de Candolle) rotation is commonly employed to maintain soil fertility.

5. Complete tillage with long drained, rectangular or square beds without mounds. This system is used in grassland soils in the Southern Highlands south of the composting zone (system 7).

6. No soil tillage. Deep drains 30 to 50 cm deep are dug to form beds 4 to 5 metres square. The spoil from the drains is thrown on top of the beds and sweet potato is planted into this loose soil. This system is used in the Wahgi, Baiyer and Nebilyer Valleys of the Western Highlands. A peanut and winged bean rotation is often used in this system.

7. Very large mounds 1.5 to 5 metres in diameter. Compost is formed within the mounds by placing grass and other organic material inside (Waddell 1972). This system is generally practised in grasslands in Enga, Southern Highlands and the western part of the Western Highlands Province. It is also used in forested areas on the fringe of the area where compost is used. D'Souza and Bourke (1982) give a more detailed map of where this system is practised (*Plates II and III*).

8. Mechanical soil tillage. Mounds or ridges are formed by hand or by tractor drawn implements. This system is practised by some commercial and institutional farmers on flat or gently sloping land in grassland areas in the lowlands and highlands.

The duration of the cropping and the fallow phases varies considerably in the cultivation systems described above. There is a tendency for intensity to increase from system 1 to 7 above. At one extreme a single crop of sweet potato is followed by a long forest fallow of up to 40 years duration. The other extreme occurs in the Tari Basin where sweet potato has been cultivated continuously for over 200 years with fallows of only 2-3 months between crops (Wood 1982).

Cultivars and cultural techniques

There are very many cultivars in Papua New Guinea. Yen (1974) suggests that more cultivars could be collected in Papua New Guinea than from any other area in the world. There are probably some 5000 cultivars grown. About 900 cultivars (including some duplicates) are maintained on research stations. Survey information on cultivars held by various groups of villagers is summarized in *Table 2*. The recorded number of cultivars held by any one group ranges from 6 to 71, with a mean of 33, although some of the lower figures are almost certainly underestimates. In the lowlands the number of cultivars held by any group of people is generally smaller than in the highlands (*Plate IV*).

The process which gives rise to new cultivars of a normally vegetative crop is spontaneous germination of true seeds, some of which produce cultivars which are retained and may eventually replace existing ones or may be grown along side existing ones. This process, cultural isolation of growers and growers' taste preferences explain the large numer of cultivars (Yen 1974; Powell *et al.* 1975). Cultivars introduced since European contact are rapidly replacing traditional ones and many traditional cultivars are now being lost (*Table 2*). Most cultivars are introduced from elsewhere in Papua New Guinea.

The crop is normally propagated by stem cuttings. These are almost always taken from the apical portion of the vine and cuttings from mature plants are preferred (Kimber 1972a). Surveys of crop densities have been conducted in five areas over a wide range of altitudes (*Table 3*). The range in crop density encountered within a limited area is very large. This is consistent with experimental work, described in a later section, which has shown that plant population does not have a major influence on crop yield. Vine and root pruning are both practised by some people. Cultivation of sweet potato in the highlands is mainly the responsibility of women. Men clear new areas, and do the heaviest work such as removing the basal parts of cane grass and fencing whilst the women prepare the soil and plant, weed and harvest the crop.

Systems of harvest and crop yield

The most common harvesting system is progressive removal of large tubers as they are needed. In the highlands, up to four harvests may be made from individual plants over a period of a year or more. On Bougainville (Mitchell, 1976) and in other lowland areas, a single harvest is taken and all tubers are

Plate I— **A sweet potato garden near Panguna, Bougainville. The crop is planted in small mounds following a secondary forest fallow (system 2)**

Plate II— **Mounded sweet potato gardens (system 7) dominate the landscape in the Lai Valley near Wapenamanda in Enga**

Plate III— **A woman and her daughters heap soil to form a composted mound near lake Kopiago in the far west of the composting zone. Grass used for the compost is in the right foreground**

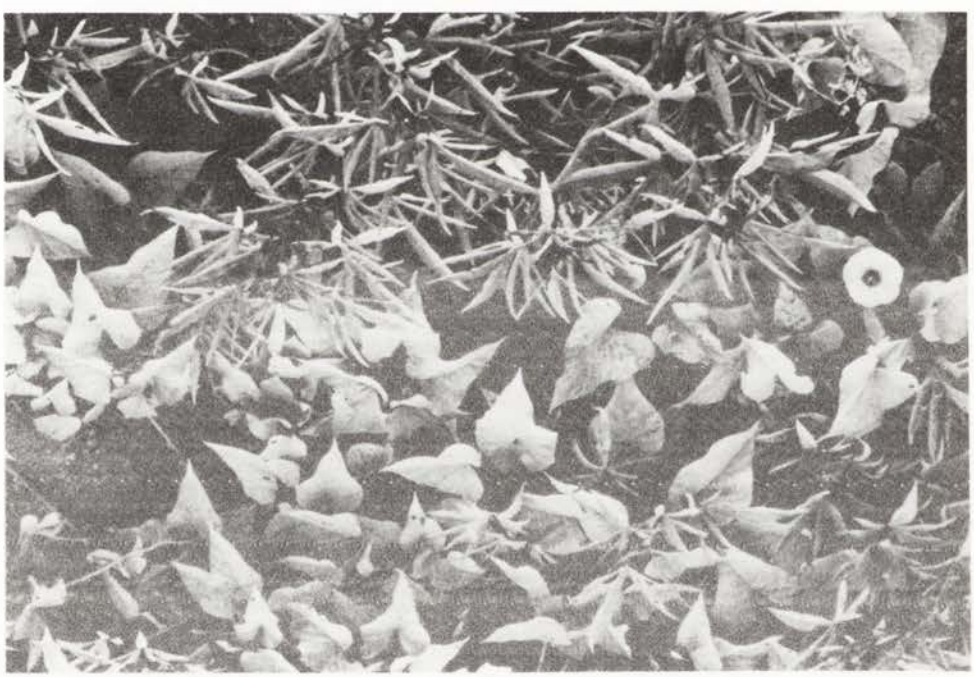

Plate IV— **A mixture of cultivars is used in a subsistence garden. It is estimated that there are of the order of 500 separate cultivars used in Papua New Guinea. Sweet potato growers maintain 33 cultivars on average**

Table 2. — **Number of sweet potato cultivars grown by various groups in New Guinea**

Location and approximate altitude(6)	Cultivars now grown			Traditional cultivars now lost	Source
	Total number	Traditional cultivars	Post-contact introductions		
Upper Chimbu Valley, Chimbu Prov.* (c.2200 m)	71	45	26	—(1)	Sterly (1978)
Baliem Valley, Irian Jaya* (1650 m) (2)	70+	—	—	—	Heider (1970)
Sinasina area, Chimbu Prov.* (1800-2500 m)	67(3)	28	32	36	Hide *et al.* (1979)
Tari Basin* (1600 m)	53	—	—	—	Powell (1982)
Upper Mendi Valley, SHP* (2000 m)	49	30	19	—	Simpson (1978)
Simbai area, Madang Prov.* (1500-2300 m)	48(4)	43	5	—	Bulmer (1982)
Upper Mendi Valley, SHP* (2100 m)	42	—	Most cvs	22	Harrison (unpublished, 1976)
Mt. Hagen area, WHP* (1600-1900 m)	40-50	—	—	30-40	Powell *et al.* (1975)
Lai Valley, Enga* (1800 m)	35	—	—	—	Waddell (1972)
Upper Lai Valley, Enga* (2100 m)	31	25	6	—	Meggitt (1958)
Chimbu Province* (1500-2700 m)	30+	—	—	—	Brookfield and Brown (1963)
Simbai area, Madang Prov.* (1500-2300 m)	29(5)	21	8	22	Bulmer (1982)
Upper Chimbu Valley, Chimbu Prov.* (1900 m)	29	—	—	—	Komba (1978)
Kainantu area, EHP* (1550-1800 m)	27	20	7	—	Watson (1967)
Nembi Plateau, S.H.P.* (1650 m)	25	11	14	25	Bourke (in press)
Obura area, EHP (1600-2300 m)	25	—	—	—	Hays (1981)
Simbai River, Madang Prov. (1300-1600 m)	24	—	—	—	Rappaport (1968)
Sirunki Plateau, Enga* (1900-2700 m)	24	—	—	—	Sinnett (1975)
Kagua area, SHP* (1600 m)	17	11	6	—	Abaya (1978)
Lamari River, EHP (1000-1700 m)	16	—	—	—	Boyd (1975)
Simbai River area, Madang Prov. (700-1100 m)	15+	—	—	—	Clarke (1971)
Sirunki Plateau, Enga* (2600 m)	13	11	2	—	Walker (1966)
Pangia area, SHP* (1500-1600 m)	10	—	—	16	Paia (n.d.)
Markham Valley (300 m)	7	—	—	—	Langley (1950)
Snake River, Morobe Prov.* (1100 m)	6	—	—	—	Langley (1950)

Notes: * Sweet potato is the main staple food.
1. — = no data.
2. Irian Jaya (West New Guinea) is a province of Indonesia.
3. Includes 7 cultivars of unknown origin.
4. Situation in 1963-64.
5. Situation in 1980.
6. Abbreviations used: see *Table 1*, footnote.

Table 3. — **Crop densities of sweet potato observed in village gardens**

Location	Approximate altitude (m)	Sample size	Mean density (plants/ha)	Range of densities (plants/ha)	Source
Sirunki-Laiagam area, Enga Prov.	2350-2600	62	43,000	18,000-86,000	C. Tumana (pers. comm.)
Kerowagi-Kundiawa area, Chimbu Prov.	1650-1750	32	46,000	30,000-91,000	C. Tumana (pers. comm.)
Gazelle Peninsula, East New Britain	0- 400	30	49,000	15,000-172,000	R.M. Bourke (unpubl. data)
Kainantu area, E. Highlands Prov.	1550-1900	30	62,000	42,000-95,000	C. Tumana (pers. comm.)
Nembi Plateau, S. Highlands Prov.	1650-1700	27	76,000	38,000-110,000	E. D'Souza (pers. comm.)
			85,200	$\bar{x}$ = 70,000	

removed at the same time, regardless of size. Tubers are occasionally stored in holes in the ground filled with sand (Kimber 1972a) and are also stored in dwellings for a few days before consumption (Siki 1979).

The available information on subsistence yields is summarized in *Table 4.* (Some figures in the literature are excluded as they are estimates only.) Reported subsistence yields range from 2 to 50 t/ha, with most values in the range 5 to 25 t/ha. Experimental yields have ranged from crop failure to 71.2 t/ha (Enyi 1977) with most between 10 and 40 t/ha. In the lowlands experimental yields of 10-20 t/ha are the rule, whilst in the highlands yields are often in the range 20-40 t/ha. Time to maturity is 5-6 months in the lowlands, 6-8 months in the highlands and 7-12 months (and longer) at high altitudes.

Pest and disease problems

Rats cause much damage to tubers. To reduce damage by rats, villagers often turn the vines to expose the soil to the sun and thus make the soil harder. Also women and children hunt and eat the rats.

Domestic and wild pigs can do much damage at times so that in most parts of Papua New Guinea individual gardens or groups of gardens are fenced in to keep pigs out.

The sweet potato weevil (*Cylas formicarius* (Fabricius)) can be a major problem, but is serious only in areas with a marked dry season, such as around Port Moresby, or in very dry years. The recommended control measure is crop rotation and use of uninfested planting material (Kimber 1972b; Smee 1965; Sutherland 1982a).

Hawkmoth (*Agrius convolvuli* (Linnaeus)) has been recorded as attacking sweet potato leaves, mainly in the lowlands. The damage is generally not severe, but it can defoliate a crop (Froggatt 1936, 1939). This pest is controlled by the introduced cane toad (*Bufo marinus* (Linnaeus)) (Anon. 1941).

The sweet potato leafminer (*Bedellia somnulentella* (Zeller)) has reduced yields in the highlands in some years (Kimber 1972b) and also in the Markham Valley (E.S.C. Smith, pers. comm.).

Other occasional insect pests are the vine borer (*Omphisia anastomosalis* Guenée), the large tortoise beetle (*Aspidomorpha* spp.), the small tortoise beetle (*Cassida* spp.), the horned weevil (*Apirocalus ebrius* Faust), black flea beetle (*Arsipoda tehimberensis* Jacoby), the sweet potato mirid (*Halticus tibialis* Reuter), and a sweet potato plant hopper (Sutherland 1982b).

Sweet potato littleleaf is a condition caused by a mycoplasma-like organism

Table 4.—**Sweet potato yields recorded in subsistence gardens in New Guinea**

Location and approximate altitude*	Yield (t/ha)	Source	Notes
Snake River area, Morobe Prov. (1100 m)	37.7-50.3	Conroy and Bridgland (1950)	
Tsak Valley, Enga Prov. (1500-1900 m)	33.2-37.0	Anon. (1967b)	Average over all soil types and slope classes
Tsak Valley, Enga Prov. (1900-2300 m)	31.3-34.9	Anon. (1967b)	
Oksapmin area, W. Sepik Prov. (1800 m)	31.1	Cape (1981)	
Tsak Valley, Enga Prov. (>2300 m)	27.6-30.7	Anon. (1967b)	Average over all soil types and slope classes
Chimbu Prov. (1900-2300 m)	24.0-26.6	Anon. (1967a)	
Kaugel Valley, WHP (2200 m)	23.5	Bowers (1968)	River terraces
Chimbu Prov. (<1900 m)	22.5-24.9	Anon. (1967a)	Average over all soil types and slope classes
Enga Prov. (1500-1900 m)	22.4-25.0	Anon. (1967b)	
Lai Valley, Enga Prov. (1800 m)	20.9	Waddell (1972)	Small mounds
Enga Prov. (1900-2300 m)	21.2-23.6	Anon. (1967b)	Average over all soil types and slope classes
Enga Prov. (>2300 m)	18.6-20.7	Anon. (1967b)	
Mt. Hagen (1600 m)	18.4	Clarke (1977)	Good soil. After 8 year fallow
Lai Valley, Enga Prov. (1800 m)	17.4	Waddell (1972)	Large mounds
Upper Lai Valley, Enga Prov. (2100 m)	15.7	Meggitt (1958)	First crop on best soil
Chimbu Prov. (>2300 m)	15.0-16.6	Anon. (1967a)	Average over all soil types and slope classes
Upper Wage Valley, Enga Prov. (2650 m)	c.14.0	Wohlt (1978)	Per year
Kamu Valley, Irian Jaya (c.1500 m)	16.9	Pospisil (1963)	Complex cultivation
Kamu Valley, Irian Jaya (c.1500 m)	13.8	Pospisil (1963)	Shifting cultivation
Koplago-Kelabo, S.H.P. (1400-1700 m)	13.6	Modjeska (1977)	
Tari Basin, SHP Prov. (1600 m)	13.1-13.3	Wood (1982)	Peaty soils
S.W. Bougainville Island (100 m)	12.2/8.5	Mitchell (1976)	First and fifth crops respectively. 21-22 weeks
Tari Basin, SHP (1600 m)	11.2-11.3	Wood (1982)	Alluvial soils
Mount Hagen (1600 m)	9.3	Clarke (1977)	Poor soil. In cultivation for 10-15 years
Nembi Plateau S.H.P. (1400-1700 m)	7.1	Crittenden (1982)	
Simbai River, Madang Prov. (1300-1600 m)	6.5	Rappaport (1968)	Over 120 weeks in mixed garden. Total garden production 15.5 t/ha
Nembi Plateau, SHP (1650 m)	6.3	Bourke (in press)	Soil fertility reduced by many years of cropping
Tari area, SHP (1600-1800 m)	5.4-8.5	Wood (1982)	Volcanic ash soils
Manus Island (100 m)	c.2.0	Rooney (1982)	Following taro blight epidemic, people changed briefly to a sweet potato staple

Note: * See *Table 1*, footnote for abbreviations.

(Pearson 1981, 1982) and transmitted by *Halticus tibialis* and by vegetative propagation (Van Velsen 1967). It is a serious problem in village gardens in Central Province and has also caused severe yield loss in experimental plots at Keravat in the past, although the condition is no longer present there.

Leafscab, caused by the fungus *Elsinoe batatas* Jenkins and Viegas, is common on sweet potato vines and leaves. This condition is worse in the highlands than in the lowlands and cultivars vary widely in resistance to it. Goodbody (1982) reported that scab caused a 50% yield loss in a fungicide trial in the highlands.

Leafspot (*Cercospora timorensis* Cooke) has been recorded many times from sweet potato in Papua New Guinea (Shaw 1963), but the economic significance is unknown.

In the Upper Mendi area of the Southern Highlands, sweet potato yields were severely reduced in 1980 by a condition associated with nematode damage and the fungus *Fusarium oxysporum* Schlechtenbal ex Fries (M. Anders, pers. comm.).

Constraints and future prospects

The constraints on crop production vary with the location and the type of farmer. In Central Province, littleleaf disease and sweet potato weevil can be major problems. Weevil can be a constraint in other dryer areas or in dry years. Inadequate soil moisture restricts planting in the dryer months in parts of the Eastern Highlands, Central Province and the Markham Valley, giving rise to some seasonality of production. Excessive soil moisture can also be a serious problem, especially on heavier soils in the highlands and in wetter years, leading to reduced crop yield or even crop failure.

Commercial production is mainly constrained by non-agricultural factors. Access to tractors in working order and for a reasonable price is a major constraint for some commercial farmers, especially in the Eastern Highlands. Transportation of produce and marketing problems are other major constraints.

Continuing expansion of production is likely in both the subsistence and commercial sectors. Courses for farmers in commercial sweet potato production have been run at Aiyura in the highlands and at Laloki near Port Moresby to encourage commercial production (Bourke 1982b; King 1982). Use of irrigation in the dry Port Moresby area has the potential to facilitate expansion of production to meet the high demand there. It is likely that sweet potato will continue to replace the traditional staples in the lowlands and intermediate altitude areas, as has already happened in some areas in recent decades.

RESEARCH WORK

Research on sweet potato in PNG has concentrated on crop agronomy, farming systems, use of the tubers for stockfeed, the littleleaf condition and production of a dried sweet potato product. Up to the end of 1982, some 180 agronomic field trials have been undertaken, mostly by staff of the Department of Primary Industry. A listing of 136 agronomic trials done on the crop between 1928 and 1978 is given by Bourke (1982a). The research work is briefly reviewed below.

Agronomic trials

Cultivar trials. Over 50 cultivar trials have been conducted at 11 locations. In these, yield, taste, resistance to leafscab and weevil, and protein content have been evaluated. Cultivars have been released mainly on the basis of high and stable yields and acceptable taste. Current releases are listed in *Table 5*. Introductions from Peru, the United States of America (USA) and the International Institute of Tropical Agriculture (IITA) in

Table 5. — **Recommended D.P.I. cultivars for various environments in Papua New Guinea (after Akus 1982, King 1982, Kurika 1982)**

Highlands	Dry Papuan lowlands	Humid lowlands
Markham 1	Keravat 40	K 9
Merikan	Doura 1	K13
Naveto	Laloki 2	
Serenta	Unu 1	
	NG 7571	

Nigeria have been evaluated. Peruvian cultivars imported from New Zealand in an attempt to obtain frost resistant material performed poorly and were not frost resistant. Cultivars from the USA have not yielded particularly well and the soft orange coloured tuber is not acceptable to Papua New Guineans' taste. Some of the IITA cultivars have yielded more than local material at Aiyura (1600 m), Laloki (80 m), and Tambul 2300 m) (Akus submitted for publication; King 1982). Evaluation of these cultivars is continuing.

Fertilizer trials. Over 50 trials on inorganic and organic fertilizer have been carried out, most of them in the highlands. Much of the highlands work on inorganic fertilizers is unpublished and results have not been very consistent. In some of the unpublished highland trials, increased yield responses to nitrogen, phosphate or potassium were recorded. In other trials, yields were depressed by fertilizer. Inconsistent responses may reflect different soil types or the effects of using different cultivars.

Results of published fertilizer trials in the highlands follow. In a trial in the Bismarck Mountains, Clarke and Street (1967) observed an increased yield response to a combined N, P and K fertilizer. In a trial at Aiyura that included various levels of a NPK mix and urea, treatment effects were somewhat inconsistent and barely significant. NPK appeared to be beneficial while urea had a nil or negative effect (Anon. 1972 p. 68). In another series of four trials at Aiyura, treatments were a NPK mix (sometimes in combination with Mg or a minor mix), sulphur, lime and control. In no case did fertilizer plots yield significantly better than unfertilized and any effect of fertilizer appeared to be a yield depression (Anon. 1972 pp. 69-70). In two trials at Aiyura and one near Goroka, Kimber (1982a) found increased yield responses to nitrogen and potassium but not to phosphate.

In a trial on the Nembi Plateau in the Southern Highlands, D'Souza and Bourke (in preparation) examined the effect of N,P,K,B and a minor mix. Potash gave a large increase in yield, whilst phosphate gave a small but significant increase and boron depressed yields.

Seventeen field and six pot trials have been undertaken on a young volcanic soil on New Britain in the lowlands (Bourke 1977b, 1978a). In most of these trials, nitrogen gave large yield increases, especially in grassland sites. Potassium increased yield in a depleted forest soil but not at other sites. In most trials, nitrogen increased tuber yield, but in others it depressed yield. The inconsistency in response to nitrogen was possibly because of the use of different cultivars.

Thirteen experiments on organic fertilizers have been performed in the highlands and lowlands. Organic fertilizers tested were: pig manure, chicken manure, coffee pulp, compost placed in the mound and azolla (*Azolla pinnata* R. Brown) (D'Souza and Bourke 1982, 1983, in preparation; Kimber 1982c; Leng 1982; Siki 1980; Thiagalingam and Bourke 1982; Velayutham *et al*. 1982; A.W. Wood, pers. comm.). In 12 of the 13 trials (the exception being one using chicken manure) organic fertilizer increased tuber yield. In one trial where no response was recorded, yield levels were already very high (Velayutham *et al* 1982). The consistent yield responses to organic fertilizers and the inconsistent responses to inorganic fertilizers suggest that yield responses are more likely with organic fertilizer than with inorganic fertilizer.

Method of cultivation. Seven experiments have compared plantings in ridges, mounds or flat land. In a trial on a sandy loam at Keravat (20 m) on New Britain, large hills and ridges gave a yield of 37.7 t/ha compared with 11.3 t/ha using the local method of small ridges (Anon. 1941). At Aiyura (1600 m) Kimber (1970, 1971, 1976a) compared flatland plantings with mounds and ridges of various sizes in 5 trials on mostly heavy soils. Flatland planting was very much inferior in most trials and mounds gave higher yields than ridges for corresponding size. On the other hand, C.J. Rose (pers. comm.) found no significant yield difference between large and small mounds and ridges on a light soil at Piwa (1600 m) in the Tari Basin.

Plant density. In seven trials at Aiyura plant densities ranging from 11,000 plants to 110,000 plants/ha were compared. There was very little difference in yield of marketable tubers (over 100 g weight) between treatments, but the yield of stockfeed tubers (under 100 g) increased with increasing density (A.J. Kimber, pers. comm.).

Effect of weeds and herbicide. Four herbicide trials and one trial examining the effect of weeds on yield have been carried out at Aiyura (Anon. 1973). It was found that yield was increased as the weed-free period after planting extends from 0 to 8 weeks. Paraquat ("Gramoxone" I.C.I.) at 0.14 litres a.i./500 litres water/ha applied at two and four weeks after planting gave good weed control.

Time to maturity. At Keravat in the lowlands, Jamieson (1968) examined various crop characteristics on one soil type with varied pre-crop histories using successive row by row harvesting of plots. He found that maxima in crop yield, number of tubers and flowers occurred earlier in more depleted soil; and that maximum flowering was a useful indicator of time of achievement of maximum yield.

Method of harvesting. Three comparisons have been made of single harvesting of all tubers versus progressive harvesting of large tubers. The latter technique is the universal practice in the highlands. Anon (1965) reported on a trial at Aiyura conducted for three and a half years. The single harvest technique gave higher yields than progressive harvesting. A.J. Kimber (pers. comm.) compared the two techniques for two cultivars over three plantings at Aiyura. He found that the average daily yield was greater with the single harvest method for the first planting. Kimber did not consider results from the second and third planting because yields were very much reduced. If they are considered however, the cumulative and daily yields from the two techniques are similar.

The third trial was done by Rose (1979) at Tari. A single planting was used with different growing periods for the two techniques. Rose reported that progressive harvest gave a greater total yield. However average daily yields (bulking rate) were not significantly different for

the two techniques. The two techniques gave a different tuber size distribution, with the progressive harvesting giving a lower bulking rate for marketable tubers (over 100 g) and a higher bulking rate for smaller tubers (under 100 g).

The results of these three experiments could be interpreted in different ways. The present author's interpretation would be that the two techniques give similar bulking rates of total tuber yield, that is, if both were practiced over a long time period, the total yield achieved would be similar.

Tuber protein content. Because of the importance of sweet potato in highlanders' diets, tuber protein content can have a major effect on protein intake. The protein content of tubers from 11 Department of Primary Industry cultivar trials has been analysed. In addition, six reports of tuber protein content have been reviewed by Heywood and Nakikus (1982). Both published and unpublished analyses indicate that tuber protein content varies markedly between cultivars. For example, the range was 0.6-2.9% protein (fresh weight basis) in the series of analyses reviewed by Heywood and Nakikus (1982). Where the same cultivars have been analysed from different experiments, the ranking of the various cultivars was not very consistent from analysis to analysis. It is not clear whether this is because of variation in tuber protein content between plantings or because of problems in the techniques used. In one series of experiments, the protein content of three cultivars was increased by N or NPK fertilizer (Kimber 1976b).

Storage trials. Trials using various techniques of storing tubers have been carried out at Kandep (2350 m) and Kuk (1600 m) by Aldous (1976) and at Keravat (20 m) by Bourke (unpublished data). Aldous covered piles of tubers with dry grass to form mounds. Bourke covered tubers with dry grass and then a layer of soil to form clamps. It was found that it was possible to store tubers successfully for up to 50 days at Kandep, 40 days at Kuk and 30 days at Keravat. It is likely that the difference in storage times at the three locations is related to differences in air temperature.

Other agronomic studies. Sweet potato has been the main indicator crop used in various DPI farming systems trials. These include trials on soil exhaustion, crop rotation, intercropping and type of fallow (Bourke 1977a; D'Souza, Bourke and Akus, submitted for publication; Kesavan 1982; Kimber 1974; Kimber 1982b; Newton and Jamieson 1968). Growth analysis studies have been done by Bourke (1978b, 1984) and Enyi (1977). Uniformity studies have resulted in a recommended plot size of 16 m by 2.5 m for trial work (A.J. Kimber, pers. comm.), although in practice smaller plots are usually used. Mechanical cultivation of sweet potato has been evaluated in the Western Highlands by Fooks and Groedl (1982). The influence of some environmental factors and earthworm populations on sweet potato yields have been studied by Rose and Wood (1980).

Other reseach work

"Kaukau rice". Experiments on producing a dried sweet potato product known as "kaukau rice" were done in 1977. Siki (1979) and Thomas (1982) describe the process. No further production was carried out because of an inadequate supply of tubers, low sales due to high cost, poor consumer acceptance and poor marketing (Thomas 1982).

Littleleaf disease. Some work has been done to identify the causal organism of the littleleaf condition and on methods of transmission (Van Velsen 1967). This and other work is reviewed by Pearson (1982).

Stockfeed. Sweet photo tuber and foliage have been evaluated as pig and

poultry feed. Malynicz (1971) found that raw sweet potato and a 53% crude protein concentrate gave satisfactory returns for growing pigs. Supplementation of standard rations with sweet potato foliage was not found to improve pig performance (Malynicz and Nad 1973). Rose and White (1980) examined the apparent digestibility of raw sweet potato by village pigs. Live weight gains of pigs foraging in old sweet potato gardens and on fallow land have been compared by Rose (1981). A tethering system of pigs grazing a sweet potato crop has been found to be successful (Rose 1976).

Watt (1973) summarizes the results of other research on feeding sweet potato to pigs. This includes the fact that cooking sweet potato increased live weight gain when compared with raw sweet potato and that pigs grazing sweet potato require a protein supplement of 500 g concentrate per pig per day for optimal growth.

Turner *et al.* (1976) examined various diets based on sweet potato and a protein supplement as poultry feed. They concluded that unless concentrate prices are low and sweet potato is considered a free food, it is more economic to use a fully prepared ration.

Economic research. Little economic research has been published on sweet potato. Von Fleckenstein (1976) examined price data for the Goroka market and concluded that sweet potato growers respond to immediate market conditions and to prices as far as they are able.

Recent, current and future research

A number of researchers have completed work that is not available at the time of writing. This includes work by M. Anders and others in the Southern Highlands on cultivar evaluation, the effects of nematode damage, plant density, time of planting, fertilizers and analyses for trypsin inhibitors; work by S. Goodbody and R. Hide in Chimbu on fertilizers, time of planting and cultivar evaluation; work by G. King at Laloki on fertilizers and cultivars; work by S. Sar and J. Sutherland at Laloki and Bubia on insect pest control; work by R.M. Bourke and E. D'Souza in the Southern and Eastern Highlands on crop seasonality. It is likely that much of this work will be published over the next few years.

Ongoing work includes cultivar evaluation and some breeding at Aiyura, Mendi and Laloki; plant nutrition studies at Laloki and in the Southern Highlands; and entomological studies at Bubia.

Given the importance of sweet potato in Papua New Guinea, and the likely continued expansion of production, it is essential that the research work done so far be built upon by further research so as to benefit the nation's growers. A number of research needs are apparent, as follows:

1. Further breeding of new cultivars and evaluation of existing ones is needed.
2. A considerable amount of research work, especially at Aiyura, has not been collated into report form or published. This includes research on cultivars, fertilizers and growth analysis. Analysis and writing up of this work would be valuable.
3. Data on nematode, insect and disease problems are poor, especially on the economic significance of the various pests. Work is needed in this area.
4. Our knowledge of sweet potato in traditional farming systems is still inadequate. For example, we know little of crop and human responses to environmental stress such as excessive soil moisture and further research in this direction would be valuable.

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GROWTH RATES OF PRIANGON CROSSBRED SHEEP AND SOME EFFECTS OF INTERNAL PARASITISM, IN THE LOWLANDS OF PAPUA NEW GUINEA

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ABSTRACT

*Priangon wethers, herded and grazed at low stocking rates, on Para grass (*Brachiaria mutica *(Forsk.) Stapf) pastures with a variety of legumes, in humid (1850 mm annual rainfall) and wet (4000 mm annual rainfall) lowlands, grew at 0.45 kg/week. Final liveweight of fat wethers was about 42 kg with carcasses of 23 kg. Under drier conditions, wethers set-stocked and grazing at high stocking rates on Buffel grass (*Cenchrus ciliaris *L.) with no legumes, grew more slowly and developed chronic hepatic intoxication possibly due to ingestion of dead grass contaminated with fungus. The response to drenching was small ($p < 0.05$) and occurred mainly in smaller younger animals.*

INTRODUCTION

The Priangon, a breed of tropical sheep from Java, has been present in Papua New Guinea (PNG) lowlands since 1880. Temperate breeds including Corriedales and Romney Marsh have been imported on several occasions before 1960 and crossed with Priangons. It is probable that most "Priangons" in PNG have a small amount of these temperate breeds in their genetic makeup. The sheep population has remained small, due partly to high mortalities caused by internal parasitism in set-stocked, but not free ranging, sheep. Holmes and Leche (1977) reported the performance of Priangon type sheep, free ranging in the drier lowlands and set stocked in the wet highlands.

This paper reports further studies on the performance of Priangon type sheep under different management systems and environmental conditions. One system involved set-stocking at a density sufficient to utilize pasture efficiently; sheep were not housed at night. The other system, used at two sites, simulated the situation which may develop in village sheep raising, with sheep housed at night and grazed over a large area at a low stocking rate, in a humid to wet tropical environment. The response to different drenching regimes was also measured.

MATERIALS AND METHODS

The experiment was a factorial design, with three sites and four drenching treatments.

Sites

(a) Erap Beef Cattle Research Centre in the "dry" lowlands at 100 m altitude: Sheep were set-stocked at 5 per hectare on a pure stand of "Nunbank" Buffel grass (*Cenchrus ciliaris* L.) and were not housed at night. Salt blocks were provided. Rainfall during the 12 months of the trial was 980 mm. This was considerably below the expected 1250 mm due to the non occurrence of the mid-year wet season. Consequently, the pasture available was considerably less than intended. The pasture was mature, not growing and of low palatability and quality during June-November 1976.

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(b) Bugandi High School, Lae in the very wet lowlands at 5 m altitude: Sheep were housed at night in a hut with a slatted floor and given free range over about 40 ha of low lying swampy country. Salt blocks were provided. The main pasture species were *Brachiaria mutica* (Forsk.) Stapf. and *Axonopus compressus* (Sw.) Beauv., *Calopogonium* sp., *Mimosa invisa* Martius ex Colla and *M. pudica* L. Rainfall averages 4000 mm/year, with the wettest period from June to August. There was always an abundance of green, growing pasture.

(c) Urimo, Sepik Plains Livestock Station in the humid lowlands at 200 m altitude: Rainfall is about 1850 mm annually, with at least 80 mm in each month. Humidity is usually very high. The sheep were housed at night and grazed 20 ha of *Brachiaria mutica* and *Stylosanthes guyanesis* (Aublet) Swartz in a young forestry plantation. There was always an abundance of green growing pasture. Since the area is known to be phosphorus deficient, a phosphorus supplement was provided.

Animals and treatments

At each site, 10 Priangon wethers of 6-12 months and 10 wethers of 12-18 months of age were divided into three groups of four and one group of eight, each group comprising half young wethers and half older wethers. The groups of four sheep were drenched at four, eight or twelve week intervals respectively while the groups of eight were not drenched. All sheep ran together to ensure a continuous parasitic challenge. The drench used was levamisole hydrochloride ("Nilverm" ICI) at the manufacturer's recommended dose rates.

The trial commenced in June 1976, at Erap and Bugandi and in September 1976 at Urimo, and was completed in June 1977.

Measurements

Every four weeks, all sheep were weighed off pasture and faecal samples were collected for counting of nematode eggs per gram of faeces (e.p.g.) using the McMaster flotation technique. Some samples of faeces from Erap and Urimo were cultured to permit identification of parasites. At Bugandi, sheep were slaughtered as fat animals. At Erap, where growth had been poor after December 1976, autopsy was performed on the eight slowest growing animals and the others were not slaughtered. No slaughter data were available from Urimo.

Data were analysed by standard statistical methods (Snedecor and Cochran 1967). Eggs per gram counts were transformed to square roots to normalise distributions.

RESULTS

Growth rate and parasite burden

At Erap, growth ceased after six months, at the onset of the wet season in December. At Bugandi, growth was rapid for nine months then almost ceased, averaging only 0.10 kg/week subsequently since most wethers were then fully grown. At Urimo, sheep grew continuously throughout the experiment. Growth rates were constant during these periods of rapid growth, despite climatic fluctuations and drenching. Rates were analysed over the period of rapid growth (*Table 1*). The fastest growth was recorded at Urimo ($p<0.01$), and growth was not closely related to differences in e.p.g. between sites. Differences in pasture quality and availability appear to have been more important than differences in parasite burden. At Erap, the legume-free pasture stopped growing during the mid-1976 drought; at Urimo and Bugandi, an abundance of green grass and legumes approached optimal grazing conditions for tropical sheep.

Drenched wethers out-performed untreated animals at all sites ($p<0.05$), although only marginally at Urimo. There was no difference between different frequencies of drenching. At Erap and Bugandi, the smaller younger wethers responded more to drenching ($p<0.05$) than larger animals which showed a non-significant response (*Table 2*).

Egg counts

At Erap, mean e.p.g. rose during the wet season, then declined from February to April and rose again in May at the onset of the mid year wet season. Since many of these wethers were sick and losing weight at this time, only values prior to December were analysed. Among untreated wethers at Bugandi and Urimo there was no regular seasonal pattern in e.p.g. although wide fluctuations occurred within individual animals and months (*Table 1*). The reduction in e.p.g. by drenching was highly significant ($p<0.001$) at all sites with small and inconsistent differences between different frequencies of treatment (*Table 1*). The correlation between e.p.g. and growth rate was not significant within any site or between sites.

Culture of a small number of faecal samples (*Table 3*) showed a significantly higher proportion of larvae of *Haemonchus* sp. ($p<0.05$) and *Cooperia* sp. ($p<0.001$) at Erap and significantly more *Trichostrongylus* sp. larvae ($p<0.001$) at Urimo.

Carcasses and autopsy findings

At slaughter, all wethers from Bugandi bar two undrenched small wethers produced commercially acceptable carcasses with adequate fat cover (*Table 2*). At autopsy, most of the wethers from Erap ranged from thin to emaciated and had gross cirrhosis of the liver. Histopathological examination revealed varying degrees of hepatic necrosis, fibrosis, fatty changes and focal abscessation, a picture indicative of a chronic intoxication with subsequent bacterial invasion.

DISCUSSION

At Urimo, Priangon wethers grew well with or without drenching, while sheep at Erap with the same e.p.g count res-

Table 1. — **Mean growth rates (kg/wk) and nematode eggs per gram (e.p.g.) of faeces of Priangon wethers grazed at three sites in the P.N.G. lowlands**

	Erap		Bugandi		Urimo		
	Not drenched	Drenched	Not drenched	Drenched	Not drenched	Drenched	S.E.M.
Period	2.6.1976 to	14.12.76	2.5.1976 to	8.3.1977	10.9.1976 to	20.6.1977	
Growth Kg/wk	.305	.374	.365	.466	.454	.476	.056
Mean e.p.g.	553	300	118	66	563	240	20
e.p.g. in							
June 1976	28	0	56	5	—	—	
July	422	87	45	5	—	—	
August	488	177	270	40	—	—	
September	400	32	N.S.	345	155	206	
October	48	0	8	5	780	818	
November	1250	803	230	90	410	24	
December	2575	303	100	27	468	364	
January 1977	1490	185	80	20	486	216	
February	570	11	180	42	856	202	
March	997	603	112	33	162	337	
April	728	137	30	173	107	90	
May	3060	1765	252	167	—	—	

N.S. No samples.

Table 2. — **Growth rates and carcass data for small (17.6 kg, 9 months old) and large (24.3 kg, 15 months old) Priangon wethers at Bugandi, either not drenched or drenched with levamisole**

		Growth rate kg/week	Age at slaughter (months)	Live weight (kg)	Carcass weight (kg)	Dressing %
Small wethers	Not drenched	.32[b]	21	31.0[a]	16.2[a]	54.6[a]
	Drenched	.54[a]	21	41.5[b]	22.7[b]	54.5[a]
Large wethers	Not drenched	.41[ab]	27	40.5[b]	22.3[b]	57.0[ab]
	Drenched	.40[ab]	27	42.7[b]	24.2[b]	58.8[b]
S.E.M.		.06		2.8	1.7	1.2

a,b Means in the same column with different superscripts are signficantly different.

Table 3. — **Proportions of parasites cultured from a limited number of faecal samples from two sites**

	Haemonchus %	*Trichostrongylus* %	*Cooperia* %
Erap (March 1977)	58.6[a]	7.0[a]	34.4[a]
Urimo: January 1977	43.0[ab]	57.0[b]	.0[c]
February 1977	3.5[b]	91.1[b]	3.4[bc]
April 1977	21.8[ab]	68.0[b]	10.2[b]

a,b,c Means in the same column with different superscripts are significantly different.

ponded to drenching by increased growth. The parasitic burden at Urimo may have been made up of less pathogenic nematodes than at Erap (*Table 3*). These few samples represent only a small proportion of the year, and no conclusions can be drawn from these data except that more detailed studies are needed of the species of parasites involved in infestation, since such great differences appeared between sites and months. Sheep at Bugandi had the lowest egg counts, yet the younger wethers showed a response to drenching, in reduction in egg numbers and increased growth rates. Under conditions of extensive grazing at low stocking rates, internal parasites were a minor problem for the Priangon.

The disease condition observed at Erap after December 1976 is consistent with a fungal intoxication, which might have some similarities to "facial eczema"; many sheep have been observed with skin lesions typical of that disease. A similar "facial eczema"-like condition has been noticed in sheep from other sites both in the highlands and lowlands and including Bugandi. The severest outbreaks in terms of skin lesions and mortalities have occurred at Erap, in sheep grazing Buffel grass pastures. The close grazing compelled by the shortage of feed resulted in the sheep consuming the dead grass in the base of the sward and this may have been contaminated with toxins of fungal origin especially after the onset of the wet season. The dead under-storey of pastures is often visibly infested by fungal growth. Although Erap is the driest of the three sites, it is still in the humid tropics; even on sunny days humidity is often above 60%, and some rain was recorded

(>1 mm) on at least seven days in the driest months of this trial, providing an environment favourable for fungal growth.

The growth rates recorded at Bugandi and Urimo are similar to those recorded for sheep grazing foothill country near Erap, and in the Eastern Highlands, where feed was not limiting and included a significant amount of legume, and sheep were penned at night (Holmes and Leche, 1977). Thus at four sites with very different environments, ranging from 3 m to 1600 m altitude, 1250 mm to 4000 mm rainfall and completely different pastures, Priangon wethers between six and 27 months old were capable of growing about 0.45 kg/week until reaching live weights of about 42 kg. Only at Erap itself did Priangons fail to achieve this growth rate. Both the occurrence of legumes, even if not palatable, and the presence of green feed at all times contribute to a high protein, high digestible energy diet, which would appear to be essential for sheep. The high rainfall, humidity and temperature were not deleterious to this breed of tropical sheep. A herding system covering large areas makes available a wide range of pasture plants and allows considerable scope for selective grazing. A low stocking rate can be maintained in many areas since much of PNG grasslands are not used for any agricultural purpose or are in fallow.

We conclude that internal parasites are a minor problem of Priangon sheep grazed at low stocking rates and penned at night even in hot, extremely wet environments. The sheep were capable of producing satisfactory growth rates and adequate carcass finish under these conditions. More intensive set-stocking on Buffel grass pastures resulted in poor growth rates and a hepatic intoxication, suspected of being of fungal origin.

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INTAKE, DIGESTIBILITY AND GROWTH BY TROPICAL BREEDS OF CATTLE CONSUMING TROPICAL GRASSES SUPPLEMENTED WITH MILL RUN

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ABSTRACT

*When ten steers were fed a diet of 75% or more mill run plus Hamil grass (*Panicum maximum *Jacq. var. Hamil) chaff, intake was highly variable between and within animals over 6 weeks. Dry matter digestibility ranged from 16% to 58% and two steers developed severe diarrhoea.*

*The effect of supplementing grazing steers with mill run was evaluated in an 18 week feeding experiment in a 4(genotype) × 4(diets) factorial design. The steers were (a) 2 year old 5/8 Brahman × British crossbred, (b) yearling 5/8 Brahman × British crossbred, (c) 2 year old "Javanese Zebu" (JZ), 2 in each group and (d) 2 year old purebred Brahman, 1 per group. Diets were (i) grazing Buffel grass (*Cenchrus ciliaris *L.) (ii) grazing Buffel grass + 4 hours/day fed mill run* ad libitum *in pens (iii) grazing Buffel grass + 20 hours/day fed mill run* ad libitum *in pens (iv) pen fed* ad libitum *30% Hamil grass chaff and 70% mill run. Feed (ii) gave fastest growth rates for all breeds, while treatment (iv) gave slowest growth. Treatment (iii) was better than (i) for crossbreds, but worse for JZ and Brahman. Intakes of supplementary mill run, (ii) and (iii) and of complete diet (iv) were greater by crossbreds than JZ or Brahman. Digestibility of organic matter was 60.6% for diet (iv). Yearling crossbred steers (b) were not slaughtered. In the other groups, at slaughter, fat cover was greatest with diet (ii), least for diet (iv), but "finish" of all carcasses was adequate. Thus all breeds of steers were able to fatten on four hours of supplementary feeding/day, consuming about 1 kg mill run pellets/100 kg liveweight, growing about 1 kg/day and fattening from store condition in 18 weeks. On more intensive feeding, the Brahman and JZ did not consume as much or grow as fast as Brahman crossbreds.*

INTRODUCTION

Mill run, a by-product of flour milling, equivalent to about 25% of grain, has 11.6% digestible crude protein and total digestible nutrients of 81 for cattle (Crampton and Harris, 1969), indicating that it might be a satisfactory major component of cattle feeding rations. Where food-processing systems are well advanced, rations are formulated from many ingredients. In Papua New Guinea (PNG) the sources of the few food-processing by-products available are separated by distances which may preclude the use of compounded rations. Each ingredient must be evaluated as the major component in simple diets, which will accentuate any deleterious characteristics such as the laxative effect of wheat bran in mill run. The first experiment examined the effect on digestion of feeding high levels of mill run in a full feeding situation. The second experiment assessed the usefulness of

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mill run fed at lower levels as a supplement to grazing for fattening steers.

MATERIALS AND METHODS

The experiments were conducted at the Beef Cattle Research Centre, Erap, altitude 90 m, in the Markham Valley, Morobe Province, P.N.G. Climate is humid equatorial; mean annual rainfall is 1260 mm with two peak periods; temperatures range from 17°C to 36°C with little seasonal variation. Soils are recently deposited alluvial silt and sandy loams supporting vigorous stands of Buffel grass (*Cenchrus ciliaris* L.).

Feeds

Mill run was pelleted with 1.0% added calcium as crushed limestone, 1.0% salt and a trace element premix (*Table 1*).

Hamil grass was cut by hand, after seed ripening in Experiment 1 and during active growth in Experiment 2. It was dried with a warm forced air drier and chaffed into 1-5 cm lengths.

A well established stand (10 ha) of Nunbank Buffel grass was used for grazing.

Experiment 1

Animals

Ten 5/8 Brahman × British steers, 10-12 months old, weighing 161 ± 12 kg were penned individually and introduced to a diet of 1/3 chaff and 2/3 mill run, over a two-week period. They were then allotted at random to one of five diets, containing 75%, 80%, 85%, 90% and 95% mill run pellets with chaff making up the rest of the diet.

Procedure

Rations were fed at 0800 h after the previous day's refusals had been removed, weighed and sampled for analysis. Quantities offered were adjusted daily to maintain refusals at about 10% of intake. After a preliminary period of 14 days daily intake was measured for 14 days.

In week 4 feed offered was reduced to 95% of that consumed; a gelatin capsule containing one g chromium sesquioxide ("chromic oxide") was administered with a balling gun to each steer at 0700 h and 1600 h. After 5 days, samples were collected from all faeces voided in the pens, during the next five days, to estimate faecal output.

Feed, feed residue and faecal samples were dried at 105°C for 24 hours and analysed for:

(i) ash, by combustion in a muffle furnace at 600°C for 4 hours.
(ii) energy by adiabatic calorimeter.
(iii) chromic oxide by the method of Christian and Coup (1954).
(iv) nitrogen by macro-Kjeldahl method.
(v) acid detergent fibre (ADF) by the method of Van Soest (1963).

Experiment 2

Animals

Five groups of seven steers were assembled, each containing: (a) two 5/8 Brahman crossbreds (age 16-24 months), (b) two "yearling" 5/8 Brahman crossbreds (age 10-20 months), (c) two Javanese Zebu (JZ) (Holmes 1977) (age 20-24 months), (d) one 2 year old purebred (15/16 or higher) Brahman; they were assigned by stratified random allocation on a body weight basis within breeds. One group was slaughtered at the start of the experiment, the others were allotted to one of four feeding regimes.

Procedure

After an introductory period of 14 days, the experiment continued for 18 weeks, from 24/10/78 to 20/2/79. Feeding

regimes used were:

(i) Grazing Buffel grass.
(ii) Twenty hours/day grazing Buffel grass; 4 hours/day (0800 h to 1200 h) in individual pens, fed mill run pellets *ad libitum*.
(iii) Four hours/day (0800 h to 1200 h) grazing Buffel grass, 20 hours/day in individual pens, fed mill run pellets *ad libitum*.
(iv) Full hand feeding; individually penned, continuously fed 70% mill run pellets and 30% Hamil grass chaff, *ad libitum*.

Shade, water and salt were available at all times. Groups (i), (ii) and (iii) grazed the same paddocks to eliminate differences in quality of feed available. The area of pasture was 10 ha, but no conventional stocking rate can be calculated. They were weighed fortnightly after an overnight fast, without water. Feed offered in the pens was adjusted to maintain refusals at about 10%.

After 116 days of the experiment, the daily intake by the steers on full feeding (Group (iv)) was reduced to 85% of that consumed previously and digestibility was measured as described in experiment 1.

Slaughter

After 18 weeks, all large crossbred (a), JZ (c) and Brahman steers (d) were slaughtered in a commercial abattoir. Carcass weight and backfat thickness were recorded.

Statistical Analysis

Data were analysed as a 4 (diets) × 3 (genotypes) factorial, with two animals per group (Sokal and Rohlf, 1969). The purebred Brahmans could not be included in statistical analyses due to lack of computation facilities. Differences among means were tested by Duncan's Multiple Range Test.

RESULTS

Experiment 1

Although the chaff used was low in nitrogen and high in fibre, all rations contained nitrogen adequate for rapid growth and none contained in excess of 20% ADF (*Table 1*).

During the first two weeks of feeding the experimental rations, animals appeared to adapt to the feed with little digestive upset. Intake of Dry Matter (DM) increased during weeks 3 and 4 (*Table 2*) as shown by the positive regressions of intake on time. There was no relation between roughage level and intake due to extreme variation between animals. Mean intakes differed widely between animals on the same diet, and for individual animals, day to day variation in intake was often large, as shown by the standard errors of the regression coefficients. Faeces became more fluid, and two animals (No. 616 and 801) developed severe diarrhoea for several days. The data shows the association between observed diarrhoea and low and erratic intake.

During the digestibility trial, diarrhoea was not observed while feed was offered at 95% of previous *ad libitum* intake. Digestibilities (*Table 2*) showed that considerable digestive disturbances were still occurring in three animals, including No. 616 and 801, which recorded digestibilities below 35%. The validity of these estimates is doubtful due to the occurrence of diarrhoea.

Experiment 2

The Hamil grass chaff, harvested at an early stage of growth, contained more nitrogen and less ADF (*Table 1*) than that used in Experiment 1.

Steers fed mill run adapted with some digestive upsets. Occasionally, loose faeces were voided by three steers on

Table 1. — **Composition of mill run, pelleted with added calcium carbonate, and Hamil grass chaff, expressed on dry matter basis**

	Mill run	Hamil grass chaff	
		Experiment 1	Experiment 2
Ash (mg/g)	83	117	123
N (mg/g)	29.2	5.4	11.2
Energy (MJ/g)	18.19	16.35	16.47
Acid detergent fibre (mg/g)	110	462	420

Table 2. — **Intake of dry matter (D.M.) by steers fed diets of mill run pellets with low levels of roughage (Hamil grass chaff) during a two week period**

	Level of roughage fed									
	5%		10%		15%		20%		25%	
Steer number	616	755	615	693	801	875	681	919	763	898
Daily intake kg of D.M.	3.53	4.12	3.72	5.68	2.89	5.30	5.25	4.41	3.59	4.76
Change of intake g/day	22	118	198	83	70	98	50	29	28	80
S.E. of regression g/day	74	18	39	29	76	46	40	37	28	24
Intake g D.M./$kg^{0.75}$	77.4	91.2	79.0	116.5	64.5	112.9	108.7	108.9	83.0	111
Organic matter digestibility %	24.2	50.8	50.3	55.2	19.0	52.2	53.0	59.1	33.0	52.1

Table 3. — **Intake of mill run pellets (feeds (ii) and (iii)) and pellets plus Hamil grass chaff (feed (iv)) by steers of different breeds and ages (two animals/group except for purebred Brahman, 1/group)**

Treatment	Steer type	Mean L.W. kg	D.M. Intake kg/day	Intake g/kg 0.75 L.W.
Four hours pen feeding	Brahman	389	3.73	43.1
	J.Z.	310	3.15	42.6[a]
	20 month old crossbred	325	3.88	50.7[a]
	Yearling crossbred	254	2.80	44.0[a]
20 hours pen feeding	Brahman	383	3.43	62.9
	J.Z.	277	4.69	69.6[b]
	20 month old crossbred	313	5.88	79.0[b]
	Yearling crossbred	241	4.75	77.6[b]
Full feeding	Brahman	399	7.21	80.8
	J.Z.	261	6.22	95.4[c]
	20 month old crossbred	317	8.23	109.5[d]
	Yearling crossbred	250	7.58	120.8[d]

Means with different superscripts are significantly different ($p < 0.05$, L.S.D. = 12.8).

treatment (iii) and four steers on treatment (iv). Depressions in intake and growth rate occurred during two periods of extremely hot, windless weather. Mean dry matter intakes of supplement (treatment (ii) and (iii) and total ration (treatment (iv)) differed greatly ($p<0.001$) (*Table 3*). Intake differed between genotypes, especially with "full feeding", JZ consuming less feed than the crossbred animals ($p<0.025$); purebred Brahman steers ate even less than JZ but these animals were excluded from statistical analysis. Within crossbred groups, yearlings ate less than 20 month steers on diet (ii) and more on diet (iv) ($p<0.025$). Digestibilities of the ration fed in treatment (iv) were DM 55.1% ± 2.8, OM 60.6% ± 1.6, ADF 28.5% ± 4.8, and N 78.0% (mean ± S.E.M.), with no consistent breed differences. Steers which had developed diarrhoea previously had reduced digestibilities ($p<0.1$).

Growth rates (*Table 4*) were greatest on treatment (ii) for all types of steer ($p<0.001$) and were greatest for two year old crossbreds on all treatments ($p<0.001$). The highly significant interaction ($p<0.01$) is attributed to the relatively poor performance of JZ on treatment (iii) and (iv) and the relatively faster growth of yearling crossbreds on treatment (iv). Brahman and JZ grew faster when grazing without supplement than when intensively fed in treatments (iii) and (iv), while 5/8 Brahman crossbreds grew faster when intensively fed than when grazing.

At the end of the feeding period (*Table 5*), Brahman steers were heaviest; JZ steers from the two more intensive feeding treatments were significantly lighter ($p<0.025$) than on treatments (i) and (ii) and differences between diets were significant ($p<0.05$). Carcass weights of JZ and Brahman crossbreds did not differ on treatments (i) and (ii) but JZ had significantly smaller carcasses in the more intensive treatments (iii) and (iv). Data from the original slaughter group and other unpublished data from this station were used to predict initial carcass weights of the slaughtered animals. Estimated growth of carcass (*Table 5*) followed the same pattern as liveweight growth with crossbreds growing faster than JZ ($p<0.001$) and treatment (ii) supporting the fastest gains ($p<0.001$). However the superiority of the Brahman crossbreds was less marked than with liveweight gains due to the higher dressing percentage of the JZ ($p<0.005$).

JZ appeared fatter but the differences were not significant, partly due to inexpert skinning of the carcass. Two JZ steers had very yellow fat but the differences between breeds were not statistically significant.

DISCUSSION

The laxative effect of the bran in mill run caused frank diarrhoea and reduced digestibility in all full fed treatments and some steers with only four hours of grazing per day. This must preclude the use of mill run at high levels for fattening cattle. The estimates of digestibility must be considered as inaccurate, due to diarrhoea.

The efficiency of utilization of digestible energy (DE) for growth of all steers receiving diet (iv) was close to predictions from NRC (1970) and the poorer growth of JZ steers was due to low voluntary intake, not inefficient utilization of the ration. This lower intake may be related partly to the rather nervous temperament of JZ when confined. However, Vercoe and Frisch (1977) have shown for Brahman, water buffalo and Banteng that intake is lower than for British and European breeds of cattle. It appears that JZ conform to the performance of some other large tropical domestic ruminants. Nevertheless, JZ steers could be fattened as easily as other breeds with a supplementary feeding system.

The most efficient use of mill run by

Table 4. — **Mean growth rate (kg/day) of steers on four feed treatments (values for Brahmans not used in statistical analysis)**

Treatments	Brahman	JZ	Large Brahman crossbreds	Small Brahman crossbreds
(i) Grazing	0.86	0.61^{ef}	0.83^{bcd}	0.67^{def}
(ii) 4 hours feeding	1.06	0.97^{abc}	1.07^{a}	0.90^{bc}
(iii) 20 hours feeding	0.70	0.48^{fg}	1.04^{ab}	0.83^{bcd}
(iv) Full feeding	0.63	0.39^{g}	0.77^{cde}	0.79^{cde}

Values with common superscripts are not significantly different ($p < 0.05$, LSD = 0.218).

Table 5. — **Liveweight at slaughter and carcass data from steers of three breeds slaughtered after 18 weeks on four different nutritional regimes**

Feed treatment	Breed	Liveweight at slaught. (kg)	Cold carcass wt kg	Carcass gain kg/d	Dressing %	Back fat mm
Grazing	Brahman	456	254	—	55.7	14
	J.Z.	345^{ab}	192^{ab}	$.33^{cd}$	55.6^{abc}	6
	Brahman X	358^{ab}	194^{ab}	$.46^{abc}$	54.2^{bc}	4
4 hours	Brahman	455	267	—	58.7	12
feeding	J.Z.	386^{a}	215^{a}	$.59^{a}$	57.4^{ab}	9
	Brahman X	391^{a}	215^{a}	$.60^{a}$	54.9^{bc}	8
20 hours	Brahman	432	247	—	57.2	7
feeding	J.Z.	308^{bc}	181^{ab}	$.35^{cd}$	58.7^{a}	6
	Brahman X	378^{a}	201^{ab}	$.53^{ab}$	53.2^{c}	2
Full	Brahman	438	234	—	53.4	5
feeding	J.Z.	286^{c}	159^{c}	$.23^{d}$	55.4^{abc}	2
	Brahman X	366^{ab}	192^{ab}	$.40^{bc}$	53.6^{c}	4
Least significant difference		59	31	.14	3.4	8.3

Values with common superscripts are not significantly different.

cattle was as a supplement to grazing with diet (ii), mill run provided about half of the animals' energy requirements (NRC 1970), while it was the main dietary ingredient, with limited grazing to provide roughage, in diet (iii). Total hand feeding was unsuccessful. When mill run was used as a supplement, sustained growth resulted in store steers fattening in 18 weeks, despite a short period of reduced performance due to extreme climatic conditions. The carcasses produced by supplementation with mill run were highly commended by the local meat trade. In PNG it is difficult to fatten cattle on pasture at young ages; there is no lot feeding and most steers with adequate fatness are at least 2½-3 years old. In some areas, fat cattle cannot be produced.

Experiment 2 demonstrates the response of steers on good grazing to supplementation with mill run. At other seasons, cooler weather might permit greater intake of mill run, and cattle on poorer quality grazing might respond more effectively to supplementation. A particularly important case for further study occurs in Central Province, which has the added advantage of a large market for beef and close access to a flour mill (under construction) as a source of mill run. Here, under conditions of

variable pasture quality and availability due to a marked wet and dry season each year, an animal which is almost ready for slaughter at the end of the wet season may be little closer to market condition in 6-7 months. Two or three months of supplementation as the pasture deteriorates might enable marketing many months earlier, with an increase in quality, price and turnover. Trials under practical cattle production conditions, perhaps involving the use of self-feeders, are needed in this province.

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ASSESSMENT OF DAMAGE AND CONTROL OF *HELOPELTIS CLAVIFER* (HETEROPTERA: MIRIDAE) ON TEA IN PAPUA NEW GUINEA

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ABSTRACT

The mirid Helopeltis clavifer *(Walker) (Heteroptera: Miridae) caused severe damage to tea in plucking at the Garaina Experimental Tea Plantation during 1977-78. The damage caused and probable reasons for the outbreak are discussed. Spraying with endosulfan gave good control.*

A simple, rapid method of estimation of damage levels was developed and is outlined. The results of regular surveys using this method can be used to monitor damage levels, detect areas requiring spray applications and determine the efficacy of the control measures used. The method could possibly be adapted for use on other pests in Papua New Guinea.

INTRODUCTION

Planting of tea at the Garaina Experimental Tea Plantation in the Morobe Province commenced in 1949 with the intention of assessing the problems and the economics of production of tea growing in Papua New Guinea. During the 1950's and early 1960's the plantation's main function was to produce seed from tea seed bearers for the establishment of the highlands tea industry. The background and progress of the plantation is described in detail in various DASF Annual Reports (e.g. DASF 1961, 1965) and by Graham *et al.* (1963). During the two years until March 1976 the tea factory was undergoing repairs, and field-work on the plantation was reduced to maintenance only. In this period most of the tea bushes were neglected and from March to July 1976 the overgrown tea bushes were pruned back and all *Albizia* sp. shade trees lopped and poisoned. After a second pruning the tea was tipped in to form the plucking table. Regular fertiliser applications were begun and from 1976-1978 the plantation was used to demonstrate the viability of the tea estate and factory at Garaina.

Helopeltis clavifer (Walker) (Heteropera: Miridae) was first reported damaging tea in the Garaina nursery during 1964 and was controlled with insecticides (DASF 1966). By 1967 the insect was attacking seed bearing tea bushes and the problem intensified. Heavy feeding damage caused dieback of shoots and the proliferation of secondary laterals which were also attacked and often killed. The fruit and the enclosed cotyledons of the developing seed were sometimes distorted after being attacked (DASF 1969).

In 1977, *H. clavifer* caused significant damage to tea in plucking at Garaina and this paper describes the damage and methods used to control the pest and outlines a simple method by which *H. clavifer* damage in tea blocks can be regularly

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monitored. The method can be used to indicate if and when insecticidal control measures against the pest should be implemented and the efficacy of these chemical treatments.

METHODS

During a visit in April 1977 to investigate the pest outbreak at the plantation, the damage caused to tea in plucking was examined, and it was suggested that several cultural methods be used in an attempt to contain the infestation without the use of chemicals. It was recommended that the stands of tea seed bearers remaining on the plantation be removed since it appeared that these had provided a permanent, sheltered environment for small *H. clavifer* populations for many years and their removal would prevent pockets of infestation remaining adjacent to the tea fields. The plucking round of thirteen days was to be maintained in order to remove eggs, which are laid in the soft flush and other tissue susceptible to the insects. Pickers were instructed to remove damaged flush tissue and to kill insects sighted during the plucking rounds. Additionally the fertilizing schedule was to be adhered to as far as possible since some researchers had claimed that *Helopeltis* attack was correlated with plant nutrition (Pearson 1958).

A second visit to the plantation was made three months later. It was apparent that the infestation was spreading and that chemical control measures were necessary. Previously, when *H. clavifer* damage was confined to nursery plants and seed bearers, sprays of dieldrin or gamma-HCH (lindane) had been applied (A.F. Hutton, pers. comm.). At that time the major objection to the use of chemicals was the possibility of interference with the insects pollinating the seed bearers.

However in the control programme reported here the main consideration was the possible disruption of other potential pests of tea. For instance both mite and tea tortrix populations have shown upsurges after application of chemicals (usually organo-chlorine insecticides) to control other pests of tea in Sri Lanka (Ceylon) (Baptist 1956; Cranham 1961, 1966). Several species of mites and tortricids have been recorded on tea in Papua New Guinea, and certainly the tortricids are under good control by a range of parasites in the Waghi Valley. Tortricid species occur in low numbers at Garaina and it was assumed that here too they were under good biological control.

After considering several available insecticides, it was decided to assess endosulfan since it is recommended on tea elsewhere, is less likely to kill parasites of other pests, has a relatively short waiting period and imparts no tainting (Fisher and Pierza 1966; Laycock and Templer 1973; Mulder 1971; Sana *et al.* 1975).

Endosulfan at the rate of 440 g a.i. in 60 L water/ha was applied to about 2.5 ha of tea in plucking during July 1977 using a Stihl misting machine, with a diffuser baffle on the nozzle. The spray operator walked down every second inter-row space, spraying two rows at a time and directed the spray at right angles to the line of walk and with the wind. A four hectare block could easily be sprayed by two men in one day.

It was intended that, where necessary, insecticide application was to be made immediately after plucking and that a second spray would be applied directly after the next plucking round. The second spray would kill any nymphs which had hatched from eggs present at the first spray before they became adult. This schedule would also allow the usual 13-14 day plucking interval and a 12-13 day waiting period.

Since it was difficult to gather data on the optimal timing for, and the effectiveness of, the insecticide applications using

visual counts of *H. clavifer*, a damage assessment survey system was developed. This method was used to determine a damage score for each of several transects which covered a representative proportion of each tea block. In the four hectare Garaina blocks, four transects each of 200 m were taken so that the block was uniformly inspected. The recorders walked along the inter-row space recording a positive score each time fresh *H. clavifer* damage was noted on either side of the transect walk. After scoring, one pace was taken before a further score could be made. This pace represented the planting distance of one metre, and if each tea bush were infested a score of about 200 would have been made along the 200 m transect mentioned above. It was necessary to differentiate between damage up to a few days old on flush leaves, which represented fresh *H. clavifer* feeding, and older damage to fully expanded leaves. Only the former was counted as a positive score.

Table 1 shows the levels of infestation and damage counts which were considered applicable over a 200 m transect after preliminary sampling at Garaina. Any block which had a transect score of between 15 and 25 had attained a "warning level" and careful surveys at weekly intervals were necessary. Scores which exceeded 25 (i.e 12.5% of the total possible score) represented a high level of infestation (spray level) in that transect. Any block which had one transect score of 25 or more was to be investigated more thoroughly and, if necessary, all or part of the block sprayed with endosulfan at the earliest opportunity after plucking had finished in that block. Areas adjacent to blocks attaining a "heavily infested" score of 25 were to be carefully surveyed at weekly intervals to monitor *H. clavifer* damage levels.

For practical purposes regularly spaced and permanently marked transects were used in each tea block. The recorders were therefore able to become familiar with their route and could carry out their work without supervision. These fixed sample sites also allowed trends in damage levels to be assessed for far less effort than would have been required using random samples.

Both the damage scoring method and spray application technique were taught to general labourers at Garaina. They were capable of handling these activities with reasonable accuracy. Supervisors checked on damage levels and made the decision whether or not to monitor damage levels more frequently or to implement chemical control measures. During August and September 1977 about 66 ha of tea at Garaina was sprayed with endosulfan and from February to March 1978 a further 32 ha received insecticide applications in response to the monitoring system.

RESULTS

Damage symptoms on tea in plucking

Both the adults and nymphs of *H. clavifer* attack recently expanded flush leaves and the unfurled buds. In the immediate feeding area a series of light green "water soaked" feeding spots are formed. These are generally circular but on recently expanded leaves they sometimes have an angular appearance. The feeding lesions gradually change colour to a light, then dark, brown as all the cells within the lesion die. Frequently areas of necrotic tissue coalesce. Later the lesions become black and occasionally the whole leaf shrivels and dries out from the tip or edges. Attacked leaves curl and are usually grossly distorted. At Garaina it was noted that feeding was concentrated on leaves and that flush stems were rarely attacked. Thus there was less proliferation of side shoots than would normally occur when shoots or growing points are damaged.

The greatest amount of damage observed at Garaina occurred in the first

Table 1. — **Levels of infestation and damage counts considered applicable over a 200 m transect**

Damage count	Infestation level	Percentage of total possible count	Action needed
0	Nil	0	Nil
1-5	Very light	0.5-2.5	Nil
6-10	Light	3.0-5.0	Nil
11-15	Light-medium	5.5-7.5	Nil
16-25	Medium-heavy	8.0-12.5	Close monitoring
>25	Heavy	>12.5	Possible spraying

block to be pruned. The new shoots were so badly damaged that this block was more than a month late in coming into production. This outbreak was almost certainly initiated from a persistant but low intensity *H. clavifer* infestation on the tea seed bearers nearby. In this block 70-80% of the plucking tips were damaged but over the "in plucking" area of the whole plantation the loss of green leaf was small. However, fears that populations of this pest might increase and cause greater production loss necessitated a close examination of the problem.

At the first inspection nymphs were found on 15-20% of all freshly damaged tips examined but these proved to be first and second instar stages only. Further investigation showed that few adults were found during the day and that older nymphs (third, fourth and fifth instars) were generally located on larger twigs or towards the centre of the tea bush. Adults were found much more frequently during the early morning, during cloudy periods or in the late afternoon and it was suspected that the adults and larger, more robust nymphs retired to the more sheltered, humid centres of the bushes during the day to escape desiccation by the wind and sun.

The outbreak and its possible causes

A light infestation of *H. clavifer* had been present on tea seed bearers at Garaina for many years but damage to recently pruned tea was first noted during early December 1976 in areas adjacent to unpruned blocks by J.R. Pippet. The infestation had moved to a contiguous block of tea "in plucking" by February 1977 and then rapidly expanded over much of the area "in plucking" on the plantation. At Garaina the six months of October to March are normally very wet (average of 283 mm of rain per month) and the latter three months receive an average of only 4.0 hours of sunshine per day compared with 5.2 hours in the October to December period (McAlpine *et al.* 1975).

The rapid expansion of the *H. clavifer* outbreak occurred during February 1977 when 400 mm of rain (41% more than usual) fell. In addition this period almost certainly received less sunshine than usual. An abundance of flush tissue for food was available to the expanding pest population since a large area of tea in plucking condition had recently been prepared and shade tree removal, fertilising and weed control had created conditions ideal for flush growth in the plucking table.

Control measures and assessment technique

The cultural methods recommended did not contain the infestation and insecticide applications were commenced in July 1977. Investigations in August/

September 1977 indicated that excellent control was achieved since damage levels in sprayed areas were substantially reduced, while in unsprayed areas *H. clavifer* damage either remained at a stable level or increased. Similarly, satisfactory levels of control were achieved after subsequent sprays in 1978, by which time the monitoring system was in progress (see *Figure 1*).

The survey method as outlined was simple, rapid, and appeared to give a reliable estimate of *H. clavifer* damage levels in the tea blocks. At Garaina one labourer trained in the method could survey more than 34 ha of tea in plucking in one morning (five hours). This involved about 6.5 km of transects through the tea blocks.

In some transects the surveys detected localised areas of heavy pest infestation which otherwise were unlikely to have been noticed. Although the overall transect score or the total block score was below the spray level, the recorder noted that most of the counts were in a short portion of the transect. These small pockets of heavier damage were then delimitated and spot sprayed where necessary.

As an example of the counting system a summary of *H. clavifer* damage counts made at Garaina during the eleven month period February to December 1978 is shown in *Table 2*. In addition three individual cases showing reductions in damage levels subsequent to chemical control are presented in *Figure 1*. The plots in *Figure 1*A represent damage scores in one transect line while that in *Figure 1*B are average counts for four transects in one four hectare block. Notes made on block 8D which was brought into plucking after pruning and tipping-in during 1978 recorded that a high level of damage was observed on 19 September 1978. This block was then plucked for the first time over the following three days (19-21 September) and two endosulfan sprays applied on 22 September and 4 October 1978. By 23 October the block was back into regular plucking and on 11 December the tea bushes were flushing well and had a good colour. The spray treatment in this block had been very effective.

DISCUSSION

Damage at Garaina to tea in plucking was very similar to that described for other *Helopeltis* species in tea growing countries of Asia and Africa (Lever 1949; Benjamin 1968) and the level was high compared to the number of insects involved — a usual feature of *Helopeltis* attack (Carter 1962). It is likely that the damage is caused by the insect injecting a toxic saliva into the plant before sucking the cell contents from the young tissue. This occurs when the insect feeds on other host plants (Smith 1978).

Although the factors responsible for the outbreak of *H. clavifer* in Garaina tea blocks were not clearly identified, it was probable that a combination of meteorological and biotic factors were involved.

The fertilizing regime apparently had no effect on the pest incidence and the association discussed by some authors may merely reflect the inability of the plant to put on new growth faster than it is damaged, rather than a greater susceptibility to pest attack (Carter 1962).

Most investigators of infestations on tea considered that humidity was a major determinant influencing *Helopeltis* distribution in the field (Lever 1949; Carter 1962). Conditions of dull, overcast and damp weather appeared to be conducive to *Helopeltis* outbreaks while infestations declined during windy weather, bright sunshine, drier periods or continual heavy rain. The initial outbreak of *H. clavifer* at Garaina was probably influenced by suitable weather conditions combined with removal of shade trees (less than twelve months previously) and the huge increase in available food supply when the blocks

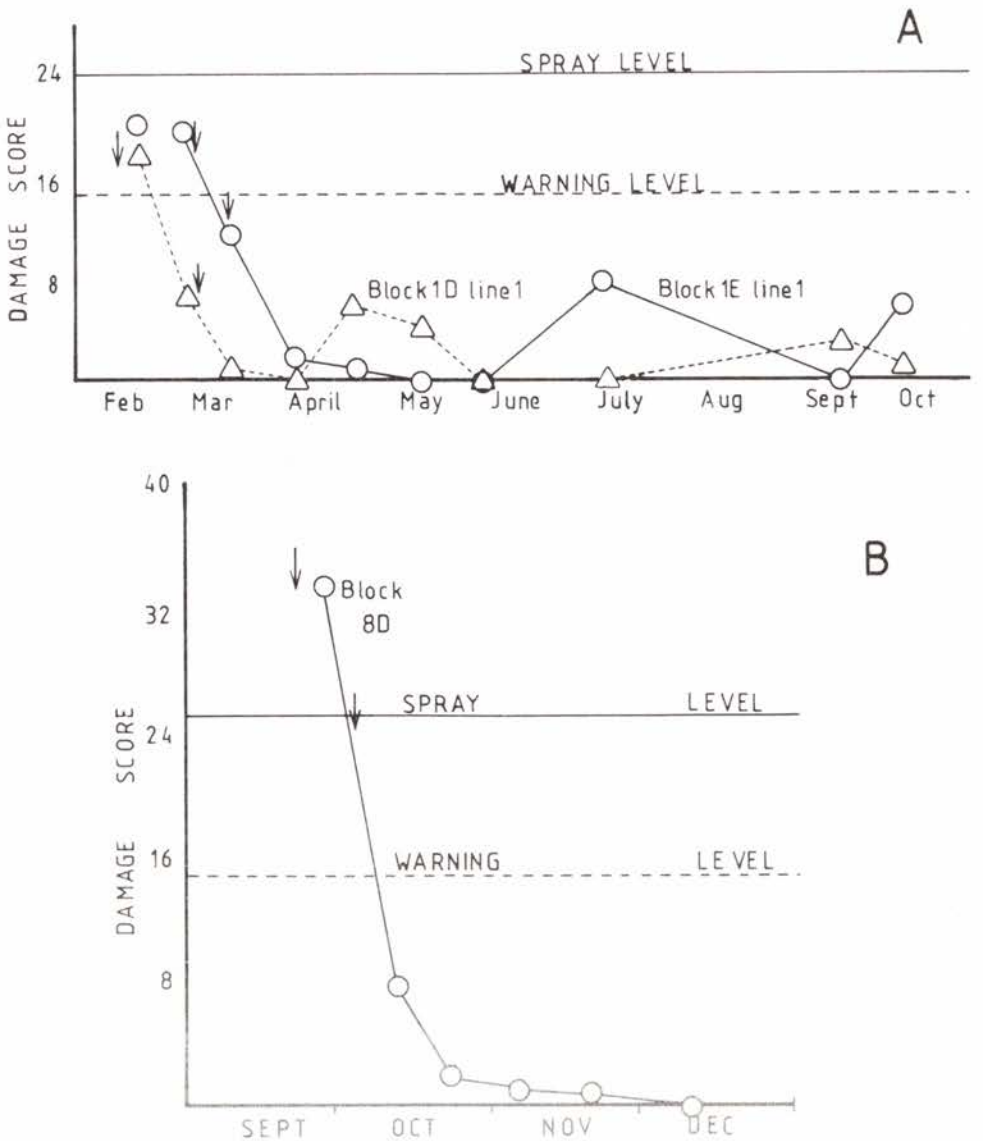

Figure 1.—Assessment counts of recent *H. clavifer* damage in tea blocks at Garaina (1978). Arrows represent an endosulfan spray application.
A. Scores recorded in one transect of Blocks 1D and 1E over a 9 month period.
B. Average scores over four transects in Block 8D

Table 2.—**Summary of *H. clavifer* damage counts made at Garaina from February to December 1978**

Sub-block	No. of rows counted	Total Length of row counted (m)	Approx. area covered (ha)	warning level*	spary level	Damage counts per sub-block on each date										
						22/2	8/3	23/3	10/4	28/4	18/5	5/6	21/6 22	12/7 13	21/9	10/10
7	5	1684	7	127-211	211	9	—	8	5	16	17	13	1	2	4	0
6	6	975	5	73-122	122	14	—	13	8	19	33	22	22	25	14	4
1F	4	800	4	60-100	100	13	19	5	6	5	4	1	1	6	9	7
1C	4	800	4	60-100	100	1	9	3	6	6	2	11	2	0	2	3
1E	4	800	4	60-100	100	27	28	17	8	1	1	8	1	11	30	18
1D	1	200	2	15-25	25	18	7	1	0	6	4	0	0	0	3	1
2H	1	200	2	15-25	25	0	1	0	0	0	2	0	0	1	6	2
1B	4	800	4	60-100	100	0	1	3	5	4	3	4	2	0	3	3
1A	2	275	2	21-35	35	13	10	1	0	1	0	0	2	0	2	1

						28/9	13/10	23/10	6/11	21/11	11/12
8C	4	800	4	60-100	100	—	—	—	46	156	50
8D	4	800	4	60-100	100	135	32	9	5	4	0

* In the text the warning level and spray level were specified for a row length of 200 m. In this table they have been adjusted for different total lengths of row counted.

were converted to plucking condition.

Good control of damaging *H. clavifer* populations was achieved using endosulfan applied through a motorised knapsack mistblower and the timing of sprays could be accurately determined through regular damage surveys. These surveys could also be used to determine the efficacy of chemical control methods. If conducted on a regular (e.g. weekly) basis, pest populations could be monitored and accurate forecasting of damage to tea and planning of control methods to reduce the damage level could be made.

By a slight modification of the recording technique reported here a direct calculation of the percentage infestation of tea bushes could be made. At Garaina this would involve recording one positive score for fresh damage noticed on one side of the transect walk and a score of two if damage occurred on both sides. Then, as before, one pace should be taken before further scoring could take place. Using this method 400 tea bushes would be inspected along the 200 m transect and a score of about 400 would result if all the tea bushes were infested. In this case the damage score divided by four would indicate the approximate percentage infestation of bushes along that transect.

It is felt that this method, with suitable modifications, could be used as a rapid survey technique for monitoring insect damage in tea blocks and, perhaps, in other crops in this or other countries.*

* The authors have recently noted a paper by Rattan working in Malawi who also deals with the possibility of using scouting methods for *Helopeltis:* Rattan, P.S. (1982). A preliminary report on experiments for the control of *Helopeltis shoutedeni* (Mosquito bug). *Quarterly Newsletter of the Tea Research Foundation of Central Africa* No. 65: 15-21.

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SOME FOOD MARKET INFLUENCES OF A LARGE-SCALE SMALL-HOLDER DEVELOPMENT IN THE WEST NEW BRITAIN AREA OF PAPUA NEW GUINEA

C. Benjamin*

ABSTRACT

The influx of over 10,000 settlers into the area around Kimbe in West New Britain through the development of a large-scale agricultural project has had profound influences on both the amount and variety of foods sold in local markets. The paper summarizes the results of a market survey carried out during 1977. The survey showed that some traditional foods for the area, i.e. coconuts, betel nut and seafoods were traded for root crops and vegetables produced by settlers, thus the diet of local villagers was supplemented from food grown by settlers. Settlers supplied 75% of food by weight delivered to one market.

The balance between the two groups is an important factor in the establishment of this and similar schemes. Food gardens in settler blocks are thus of considerable practical significance for personal subsistence and trade and for limiting increases in living costs.

INTRODUCTION

In 1968 the first plantings began for a large-scale development of oil palm (*Elaeis guineensis* Jacq.) in the region of Kimbe in West New Britain. This comprised a nucleus estate and seven major subdivisions of smallholder development, the latter being known as the West Nakanai Oil Palm Scheme. As the scheme increased in size so did the number of smallholders: the current estimate of total settler population of the area is over 10,000 people. The region has traditional agriculture but this was insufficient to meet the demands of such a large population expansion. In addition, particular requirements of individual ethnic groups had to be met. Smallholders were drawn from all over P.N.G. The major groups are Chimbu, Sepik, Tolai and Morobe with smaller numbers of smallholders from West New Britain, Papua, Irian Jaya, New Ireland and North Solomons. Each smallholder block contains 2-3 ha of primary forest at the back of the block available to subsistence gardening with the intention that this will eventually be planted to palms and the gardens will be rotated to the front of the block where mature palms are presently established. However, the obvious importance of food gardens now casts some doubt as to whether the full oil palm acreage should ever be planted (Benjamin 1977a).

On arrival in the settlements, establishment of subsistence gardens was a priority activity. It soon became apparent that both energy and crop preferences varied between the various ethnic groups (Benjamin 1976b). Once personal needs were satisfied, entrepreneurial opportunities began to be explored with the development of a flourishing trade in foodstuffs as the final outcome.

This paper examines the extent of this trade and its significance. Included is the trade activity of the small but important Dagi Coconut Settlement in the region of

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Kimbe and a group of squatter vegetable growers on land at Gigo close to the main market.

The local villagers and original landowners influencing the markets studied come from three area groups i.e. Nakanai, Bakovi and Kombe (*Figure 1*). Their produce is grown on village land and fished from traditional coastal fishing areas.

The survey was initiated to obtain quantitative knowledge of the settler impact on traditional food markets and of the interaction between indigenous and immigrant populations in relation to foodstuff production and trade.

METHODS

The four markets selected for the survey were Kimbe, Mosa, Kavugara and Talasea (*Figure 1*). These markets were situated in areas adjacent to the settlements and villages where the people met and marketed their produce.

The markets of Kimbe, Mosa and Talasea were surveyed over a period of two weeks each during February and March 1977. Kavugara was surveyed in June 1977. All results calculated are presented in terms of a market fortnight. Recordings of types of food were made over the two week period for each market. The 2 week survey period was selected because there is an increased seller attendance on or immediately following pay days.

Each fourth to eighth seller who entered each market was selected giving a sampling intensity of 13%-26% (*Table 1*). All produce delivered was weighed and recorded under the following categories: sweet potato (*Ipomoea batatas* (L.) Lam.), taro (*Colocasia esculenta* (L.) Schott), bananas (*Musa* spp.), Chinese taro (*Xanthosoma saggittifolium* (L.) Schott), peanuts (*Arachis hypogaea* L.), green leafed vegetables such as *Amaranthus* sp., coconuts (*Cocos nucifera* L.), fruit and nuts, betel nut (*Areca catechu* L.) and maize (*Zea mays* L.). Cassava (*Manihot esculenta* Crantz) and yams (*Dioscorea* spp.) were also recorded grouped under the heading of "carbohydrate foods". Meat, fish and shellfish were another classification. Spring onions (*Allium ascalonicum L.*), tomatoes (*Lycopersicon esculentum* Mill.) and capsicum (*Capsicum grossum* Sendt.) were grouped as "other vegetables". Miscellaneous items were such articles as baskets, string bags, carvings and other non-food items.

As the selected sellers left the market their original produce was again weighed and the amounts delivered, sold and unsold determined. Percentages of food sold and unsold could then be calculated. Village, settlement and ethnic origin were recorded.

Sample prices of food items were taken and estimates of the value of food items delivered and sold over a market fortnight were obtained. The data were then used to determine food patterns and social influences on the markets.

Kimbe Market results were representative of the trends for the four surveyed. These results will be discussed in greater detail than those from Mosa, Kavugara and Talasea.

RESULTS

Four major aspects were determined from the data, i.e. those of proportional representation in market usage, food types in relation to ethnic groups and amounts and value of products sold and unsold.

Relative representation and contributions of settlers and villagers

The proportional settler contributions to the four markets are shown in *Table 2*

Table 1.—**Seller attendance and representation during the sample fortnight period at each market**

	Kimbe	Mosa	Kavugara	Talasea
Total sellers	1148	621	725	470
Villagers (%)	47	15	56	77
Settlers and other sources (%)	53	85	44	23
Sample size %	13	13	26	18

Table 2.—**Weight of produce delivered (tonnes) per market fortnight**

Source	Kimbe Market	Mosa Market	Kavugara Market	Talasea Market
Villages				
Talasea (Bakovi)	8.9	0.6	4.4	2.3
Hoskins (Nakanai)	2.7	3.0	0	0
Kombe	1.4	0	0	0
Settlers				
West Nakanai Oil Palm Scheme	17.3	14.9	4.7*	2.7*
Dagi Coconut Settlement	3.3	0	0	0
Squatter settlement				
Gigo	13.9	0	0	0
Plantation employees				
Mosa Plantation	0	1.0	0	0
Other sources	2.3	1.0	0	0.3
Total	49.8	20.5	9.1	5.3

* Kavugara Oil Palm Settlement only.

and from these data their relative importance can be readily seen. Settlers from the oil palm and coconut schemes together with the Gigo squatter settlement comprised 53% of the total number of sellers (*Table 1*) attending the Kimbe Market but contributed 69% or 34.5 tonnes of produce in a market fortnight (*Table 2*).

Squatters from the Gigo area, living in close proximity to the Kimbe Market, had reduced transport costs for their produce. Much of the food (13.9 tonnes) was carried manually for sale (*Table 2*).

All oil palm subdivisions contributed food to the Kimbe Market. Oil palm settlers alone delivered 35% or 17.3 tonnes, of the produce (*Table 2*).

Mosa Market is built on the site of the nucleus estate and caters largely for the plantation and mill workers, many of whom have migrated from other areas of Papua New Guinea. The nearby population comes predominantly from the settlement schemes but villagers regularly attend (*Table 1*) comprising 15% of the sellers and delivering 18% (3.6 tonnes) of produce, mainly coconuts and betel nut. On the other hand, settlers, Mosa employees and others comprised 85% of the sellers and delivered 82% of the produce (16.9 tonnes), principally root crops and vegetables (*Table 2*) with oil palm settlers alone providing 73% or 14.9 tonnes.

Kavugara Market, situated at the community centre of the Kavugara oil palm subdivision, operated four mornings

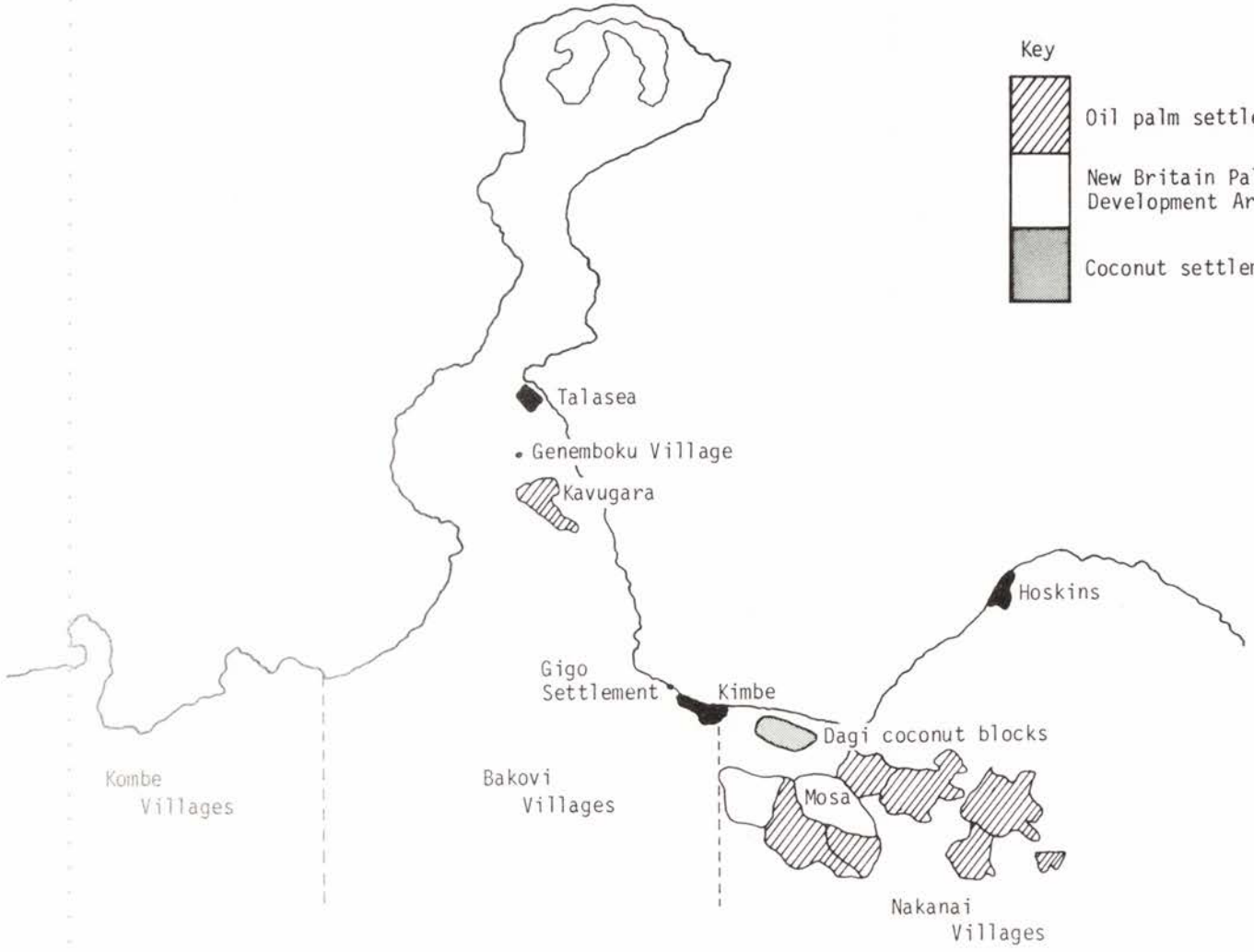

Figure 1.—**Surveyed market sites and areas of seller origin**

over the survey period and saw an active barter system between the Bakovi Village people and the settlers. The villagers, 56% of the sellers (*Table 1*) delivered 48% (4.4 tonnes) of produce during the period (*Table 2*) and settlers (44% of the sellers) delivered 52% or 4.7 tonnes (*Table 2*). The main village involved in this market was Genemboku (*Figure 1*) situated close to the settlement. People here have come to depend on the settlers for supplementing supplies of their traditional crop of taro. Chinese taro was also exchanged between settlers and villagers for betel nut and coconuts. Demand by sellers for coconuts and betel nut from the local villagers was very strong. Some money exchange for food at this market also took place.

Talasea Market had a large proportion of sellers originating from local villages ie. 77% (*Table 1*) but these people only contributed 43% (2.3 tonnes) of the produce delivered (*Table 2*) mainly being coconuts and betel nut. Although only 23% of the attending sellers were settlers from Kavugara their contribution of saleable food was high at 51% or 2.7 tonnes (*Table 2*), again being root crop staples particularly taro and Chinese taro and vegetables.

Food delivered by ethnic groups

It can be seen that the villagers were the major suppliers of coconuts, betel nut, meat, shellfish and fish (*Table 3*). The Nakanai, Bakovi and Kombe villagers who are all coastal people, contributed all of the 0.6 tonnes of fish and shellfish delivered to Kimbe Market. Only a small quantity of root crops were delivered by the villagers, these being sweet potato, taro and tapioca. The Bakovis delivered more fruit and nuts than any other group (0.4 tonnes).

The settlers (Chimbu, Sepik, Tolai and Morobe people) were the major suppliers of root crops, green leafed vegetables, such as *Amaranthus* sp., pumpkin tops (*Cucurbita* sp.), aibika (*Abelmoschus manihot* (L.) Medikus), karakap (*Solanum nigrum* L.), fruit and nuts, and other vegetables such as beans and spring onions. Settlers and villagers alike contributed quantities of yam and cassava or "other carbohydrate foods".

The Sepiks supplied sweet potato, Chinese taro and green leafed vegetables. Chimbu settlers sold largely sweet potato, peanuts, greens and vegetables. The Morobe people delivered great quantities of taro, mostly being grown on the squatter settlements at the back of Kimbe Township. The amount of taro contributed was important for exchange with betel nut and coconuts from villagers, the taro being a traditional crop of the villagers. The amount of food delivered by this group was 15.4 tonnes, or 30% of the total. Many Morobeans came from the Gigo squatter settlement and Morobeans represented 13% of the total sellers therefore their impact on the market was very strong. They delivered individually the greatest amount of sweet potato of 6.4 tonnes (*Table 3*). The Tolai sold more bananas, Chinese taro and peanuts than any other group, this being 1.6, 3.0 and 0.7 tonnes respectively. It should also be recorded that part of the 0.3 tonnes of betel nut delivered by the Tolais was shipped from East New Britain. Often this method is used to pay shipping fares and other travelling expenses from Rabaul to Kimbe, a pattern also noted in Bialla (Wapi 1978). The Tolais delivered significant amounts of coconuts mainly from the Dagi Coconut Settlement Scheme. Tolais representing 16% of sellers at Kimbe Market delivered 21% or 10.7 tonnes of produce for sale (*Table 3*). The quantity and variety of foods delivered for sale to Kimbe Market by the Tolais was substantial, with many market sellers originating from the Dagi Settlement Scheme.

The total amount of food delivered to Kimbe Market by the 1148 sellers over the survey period was approximately 50

Table 3. – **Quantity of food types delivered for ethnic groups in Kimbe Market (tonnes) per market fortnight**

Ethnic origin	Sweet potato	Taro	Banana	Chinese taro	Peanut	Greens	Coconut	Fruit & nut	Betel nut	Maize	Other carbo-hydrate foods	Meat, fish, shell-fish	Other veg.	Miscell-aneous	Total
Villages Kombe Bakovi Nakanai	0.34	0.32	0	0	0	0	4.48	0.43	4.66	0.08	0.99	0.56	0.45	0.42	12.73
Sepik	2.48	0.32	0.11	0.81	0.13	1.28	0	0.26	0	0	0.19	0	1.63	0.61	7.82
Chimbu	1.35	0	0.03	0.10	0.25	0.75	0	0.10	0	0	0.01	0	0.97	0	3.56
Morobe	6.40	4.12	0.13	0.34	0.10	1.16	0	0	0	0	2.08	0	0.94	0.08	15.35
Tolai	1.27	0.16	1.64	2.98	0.74	0.40	1.67	0.20	0.34	0	0.34	0	0.52	0.40	10.66
Total	11.84	4.92	1.91	4.23	1.22	3.59	6.15	0.99	5.00	0.08	3.61	0.56	4.51	1.51	50.12
% Unsold	20.00	49.00	27.00	9.00	1.00	16.00	15.00	8.00	6.00	0	24.00	11.00	11.00	14.00	18.00

tonnes. This figure gives an indication of the fortnightly requirement of traditional vegetables and their importance to Kimbe Township.

Figure 2 shows clearly the types of food each group delivered to Kimbe Market and emphasises the villagers production of coconuts, betel nut and fish foods and the settlers' contribution of food crops. The relative proportion each group contributed is shown diagramatically.

Amount of produce sold and unsold, and estimated value

Table 3 shows the amount of produce delivered and unsold for each food group in the Kimbe Market over the survey period. Chinese taro, peanuts, fruits and betel nut, meats and fish all were in demand and sold well, 1%-11% being unsold of the total delivered.

Other items such as sweet potato, bananas, vegetables, coconuts and other carbohydrate foods sold moderately well with between 16%-27% of the total delivered being unsold. Calculations from a price survey conducted concurrently with the market survey gave an estimated total value of food delivered, sold and unsold for each of the four markets. *Table 4* shows the results of this and the monetary importance of each market. Kimbe Market with an approximate value of K6000 per fortnight was the major market. The value of food sold was just over K5000. The Mosa Market food deliveries amounted to almost K2000 per fortnight in value, mostly purchased by Mosa plantation employees. The value of produce delivered at Kavugara was K700 per market fortnight. This represents a major part of the cash and barter economy between the villagers and settlers in an area where both settlers and villagers are far from retail outlets. Talasea Market with only K375 worth of food delivered and approximately K350 worth sold per fortnight was a small market.

DISCUSSION AND CONCLUSION

The settlement schemes and squatter areas have been shown to provide the surveyed markets with the major proportion of traditional food and vegetables. This important factor is likely to reappear in similar settlement schemes within the country, e.g. Bialla and Popondetta Oil Palm Schemes, and should be regarded as a benefit offered by such schemes to the surrounding communities.

In this situation, the squatter population provides substantial food supplies and thus deserves recognition within the community.

The villager-settler food interrelationship and balance is an important result of settler introduction in the Hoskins-Talasea area. This pattern is apparently being followed in the new oil palm settlement scheme at Bialla (Benjamin unpubl. data). From the results of these four market surveys, the importance of settler food crop contribution can be clearly seen. The balance that exists between villagers, contributing coconuts, fish and betel nut with settlers contributing food crops and vegetables has also been demonstrated. Other examples of people from settlement schemes supplying town areas occur elsewhere in the country, such examples being Mt. Hagen and Rabaul markets (Bourke, pers. comm. 1979).

Settlers are providing plentiful supplies of reasonably priced traditional root crops and vegetables to the markets supplying the towns and major industries in the area surveyed. Abundant supplies should be a major factor in restricting increases in the cost of living by avoiding situations of low supply and high demand presently seen in other large population centres.

The food crops delivered by the various ethnic groups reflect the major garden produce grown on the settlement blocks by each group.

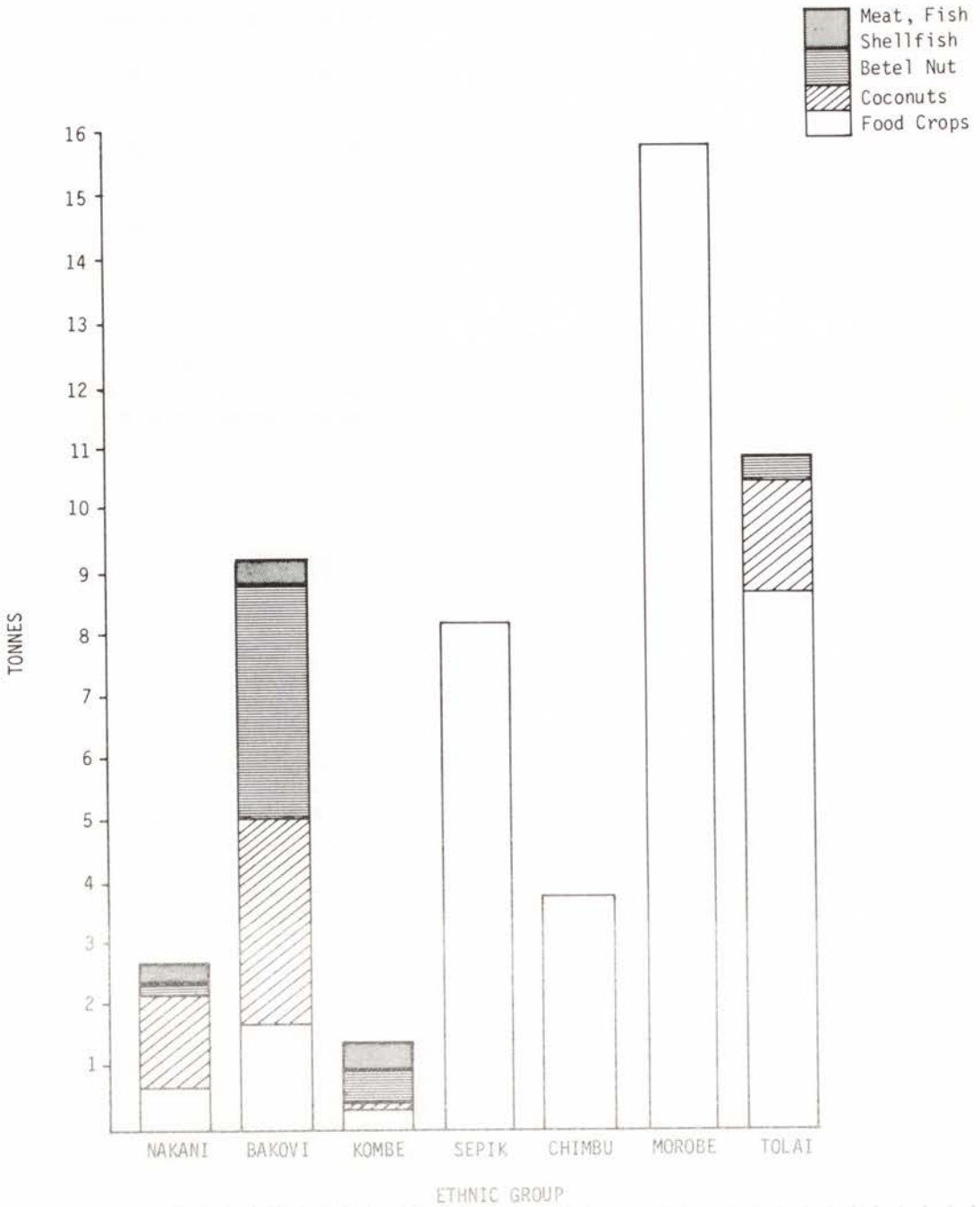

Figure 2. — **Quantity of food types delivered by various ethnic groups to Kimbe Market per fortnight (February 1977)**

Table 4. — **Estimated value of produce delivered and sold (Kina) per market fortnight**

Market	Kimbe	Mosa	Kavugara	Talasea
Produce delivered	6,000	1930	700	370
Produce sold	5120	1765	660	350
Value of unsold produce	880	165	40	20

The importance of maintaining areas (2-3 ha) set aside for subsistence cropping on settlers' oil palm blocks is vitally important for the food supply to the settlers and the markets alike. In a survey conducted by the Department of Primay industry on the West Nakanai (Hoskins) Oil Palm Scheme (Benjamin 1978) an average of 55% of all block holders stated that food was sold from their gardens in the markets with 56% of this group making sales more than twice weekly.

Food crops can be successfully grown or intercropped with oil palm only in the first two or three years of planting the palms; after that the canopy closure creates insufficient light for successful food crop cultivation. It is therefore important that areas set aside for subsistence gardening on the oil palm blocks are not drastically reduced by further cash cropping or the consequences may be that the balances and benefits discussed will be severely affected to the detriment of the community.

ACKNOWLEDGEMENTS

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SHORT COMMUNICATION:

POLLINATION AND FRUIT SET IN TWO SPECIES OF PUMPKIN IN LOWLAND PAPUA NEW GUINEA

J.A. Sutherland* and P.B. Bull†

ABSTRACT

Two species of pumpkin were grown under lowland conditions in Papua New Guinea (PNG). These were Cucurbita moschata *Duchesne, the most widely used species in lowland PNG and* Cucurbita maxima *Duchesne for which there is an unsatisfied market demand. The numbers of pollinators visiting open female flowers of* C. moschata *was significantly higher for flowers which developed into fruits. Although planted in adjacent plots and available to the same populations of pollinators, very few* C. maxima *flowers developed into fruits; female flower bud loss was the cause of low yields in this species. Hand pollination caused an apparent slight increase in yield for* C. maxima. *It was concluded that the failure of* C. maxima *to fruit satisfactorily in lowland PNG was due to physiological factors and not a lack of insect pollinators.*

INTRODUCTION

In Papua New Guinea, pumpkin is a popular vegetable grown for leafy tips as well as fruit. It will grow from sea level to an altitude of 2400 m (R.M. Bourke, pers. comm.). The traditional species found in village gardens is *Cucurbita moschata* Duchesne, but more recently other pumpkin species have been introduced. Most markets are well supplied with local types, but there is an unsatisfied demand for fruit of the variety Queensland Blue (*Cucurbita maxima* Duchesne) (Bourke 1984). This variety fruits poorly in the lowlands (below 600 m a.s.l.) but well at higher altitudes (P.B. Bull, unpublished data). In the lowlands the poor fruit set has been attributed to inadequate pollination and provision of bee hives near commercial crops has been recommended (G. Gorogo, pers. comm.). The family Cucurbitaceae is generally considered dependant on insect pollination although published data on the genus *Cucurbita* is scarce (McGregor 1976). Two trials were conducted with the two species, at separate lowland sites; one to quantify and identify insect pollinators and the other to determine whether regular hand pollination would increase fruit set.

MATERIALS AND METHODS

Two species were used in each trial; a selection 'Rabaul' (*C. moschata*) originating from East New Britain, and 'Queensland Blue' (*C. maxima*) an Australian seed line. Trial I was conducted at Bubia Agricultural Research Centre (30 m a.s.l.), 15 km north west of Lae. Seeds were sown in Jiffy-7 peat pots and transplanted 12 days later on 18th November 1981. Plots consisted of two rows 8 m long. The plant population was equivalent to 2500 plants ha^{-1}. There were two replications of each species. Trial II was grown at Laloki Research Station (30 m a.s.l.), Port Moresby. Seed was sown in single row, 6 m long plots on

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24th September 1982. After emergence, plants were thinned to give a population equivalent to 350 plants ha^{-1}. There were six replications of each species. In three of the blocks, plots were visited at about 0800 h, three times weekly from 10th November to 22nd December. Any open female flowers were hand pollinated with male flowers from the same plot. Hand pollinated flowers were not screened from natural pollination.

No fertilisers, herbicides or insecticides were used in either trial. Plots were hand-weeded as necessary. Irrigation was applied when necessary in Trial II. Rainfall and temperature (maximum and minimum) recordings were made daily.

To establish the proportion of potentially pistillate flowers in Trial I, the sex of 15 flower buds at the distal end of 21 main vines, was determined for each species (29th January 1982).

Recordings of insect pollinators in Trial I, were started once production of both male and female flowers was established. Numbered aluminium tags were loosely attached to the pedicels of newly opened flowers. As each flower was labelled the pollinators inside the flower, and the cloud cover (in octas) were recorded. Two species of hymenopteran pollinators were present, *Apis mellifera* Linnaeus (Apidae) and *Lasioglossum* sp. (Halictidae). Observations on the first flower were made at 0715 h on each occasion and subsequent recordings taken at ten minute intervals for ninety minutes. A total of ten observations were made for each flower, and 115 flowers were observed between 26th January 1982 and 26th February 1982 (29 staminate and 53 pistillate *C. moschata* and 30 staminate and 3 pistillate *C. maxima*). To identify the date of any fruit loss, daily inspections were subsequently made of the numbered fruits.

All surviving numbered fruits in Trial I were harvested on 25th February 1982. The weight of each fruit and the numbers of mature seeds were counted. In Trial II, all the mature fruits were harvested on 21st January 1983. Two fruits were selected at random from each plot and the number of seeds in each was counted.

RESULTS

In each trial both species grew well although the vine of *C. moschata* was the more vigourous, developing faster and giving better ground cover. Mosaic symptoms, identified as cucumber mosaic virus (M. Pearson, pers. comm.) were apparent on the leaves of both species. In Trial II, *Aphis gossypii* (Glover) was present.

The conditions during the five sampling days for insect pollinators in Trial I, were very similar with fine weather and hazy cloud cover. Analysis of variance indicated no significant differences in the number of bees in flowers at the various sampling times. The mean numbers of pollinators visiting the different flower types, the mean fruit weight and the mean number of mature seeds at harvest are shown in *Table 1*. The numbers of bees visiting flowers varied with the species, sex and ultimate fate of the flower; differences were highly significant. None of the harvest and pollinator data for *C. moschata* showed any significant correlations, ($p < 0.05$), *Table 2*.

The ratio of staminate to pistillate flower buds for the 15 distal buds was 5:1 for *C. moschata* and 7:1 for *C. maxima*. Despite the similar number of pistillate flower buds on both species, only three *C. maxima* flowers opened during the recording period. Of these only one developed into a harvestable fruit. A total of 53 female *C. moschata* flowers were studied, of which 19 (35.8%) developed into fruits.

The yield, mean fruit weight and mean seed number per fruit for Trial II, are

Table 1.—**The mean numbers of pollinators visiting different flower types and the mean fruit weight and seed number at harvest Trial I, Bubia**

Species and flower type	*A. mellifera* mean No./ flower	*Lasioglossum* sp. mean No./flower	Both spp. mean No./ flower	Mean fruit weight (kg)	Mean seed numbers
C. moschata					
Successful female	1.85	0.14	1.99	2.39	273
Unsuccessful female	1.21	0.15	1.36	—	—
Male	0.28	0.17	0.44	—	—
C. maxima					
Successful female	0.10	0.80	0.90	2.65	1374
Unsuccessful female	0.05	0.55	0.60	—	—
Male	0.18	0.41	0.58	—	—

Table 2.—**Correlation coefficients (17 df) for parameters measured on *Cucurbita moschata* flowers and fruits. Trial I, Bubia**

	Number of *A. mellifera*	Number of all pollinators	Fruit weight
Fruit weight	0.042 (n.s.)	0.016 n.s.	n.a.
Number of mature seeds	0.252 (n.s.)	−0.250 n.s.	−0.020 (n.s.)

Table 3.—**The effect of hand pollination on the yield, mean fruit weight and mean seed number of *C. maxima* (Queensland Blue) and *C. moschata* (Rabaul) pumpkins. Trail II, Laloki**

	Yield t/ha			Mean fruit weight (kg)			Mean seed No./fruit		
	Natural pollination	Hand pollination	Mean	Natural pollination	Hand pollination	Mean	Natural pollination	Hand pollination	Mean
Variety									
C. maxima	7.1	20.9	14.0	2.54	2.76	2.65	518	440	479
C. moschata	57.2	46.4	51.8	2.43	2.77	2.60	306	376	341
Mean	32.1	33.6	32.9	2.48	2.76	2.62	412	408	410
Significant effects									
pollination × variety			n.s.			n.s.			n.s.
pollination			n.s.			n.s.			n.s.
variety			*			n.s.			n.s.
L.S.D. (Variety $p<0.05$)			25.50						

shown in *Table 3*. Hand pollination had no significant effect ($p < 0.05$) on yield, fruit weight or seed number, although there was a trend to higher yields from hand pollination of *C. maxima*. *C. moschata* with 51.8 t ha^{-1} had over three times the yield of *C. maxima*.

Mean maximum and minimum temperatures were 32/25.5°C and 33.6/21.7°C for Trial I and Trial II, respectively.

DISCUSSION

Total yields for Trial I were not measured, but an adjacent block of *C. moschata* yielded over 60 t ha^{-1} (Sutherland, in preparation), which is similar to the yield obtained in Trial II and in other trials at Laloki (P.B. Bull, unpublished data). Fruit weights and seed number for *C. moschata* were similar in each trial.

The ratio of staminate to pistillate flower buds, for both species, was comparable with the only other data for *Cucurbita* spp., a ratio of 10:1 for *C. pepo* (Battaglini 1969). This suggests that potential fruit production was good in both species. In the case of *C. maxima* the potential was never realised with most pistillate buds failing to develop to flowers, whilst the few that opened usually aborted. There was no evidence that this was due to insect attack. Staminate flowers on *C. maxima* opened normally, as did both staminate and pistillate on *C. moschata*.

The female flowers on *C. moschata* can be divided into two categories, those which were successful and developed into fruit and those which did not. A significantly ($p < 0.001$) larger number of *A. mellifera* visited the former (*Table 1*), and presumably provided adequate pollination. There were no correlations approaching significance between the numbers of *A. mellifera* visiting the flowers and the fruit weight or seed number at harvest (*Table 2*), neither did hand pollination affect these parameters. This is a little surprising since it has been shown with some *Cucurbita* spp. that increased amounts of pollen on the stigma increases the fruit weight and seed number (Hayase 1953). It does not appear from our results that pollination is limiting seed number or fruit weight for *C. moschata*. Flowers which failed to develop into fruits (*C. moschata*) were visited by a lower number of bees, this may have been the cause of the failure to fruit or it may have been some intrinsic property of the flowers which made them both less acceptable to bees and more likely to abort. Without more detailed study of individual flowers it is not possible to know which. Very few *Lasioglossum* sp. were found in flowers of *C. moschata*, and it is unlikely that this small halictid, although undoubtedly a pollinator, plays a significant role in the pollination of pumpkin when *A. mellifera* is present. Staminate flowers of *C. moschata* were less attractive to *A. mellifera* than the pistillate, and from observations made during the trial, visits by bees to staminate flowers were of much shorter duration than those to the female. The nectaries on the female flowers are much larger than those on the male, and this is the likely reason.

Since hand pollination had no significant effect on fruit set, fruit weight or seed production of *C. moschata*, insect pollination would appear to be adequate. Although the data for pollinators visiting the female flowers of *C. maxima* are very limited (3 flowers) it is not unreasonable to assume that again pollinators are not limiting since sufficiently large numbers of both *A. mellifera* and *Lasioglossum* sp. were in the trial area and the morphology of the flowers is very similar. *C. moschata* is recognised as being better adpated to the lowland tropical climate than other *Cucurbita* spp. (Cobley and Steele 1976). The fact that very few female flowers of *C. maxima* developed, suggests that this species is not as well adapted.

This supports our contention that *C. maxima* ('Queensland Blue') is adversely

affected by the climate in lowland Papua New Guinea and not limited in its productivity by a lack of pollinators. Further trials to study pistillate flower abortion in *C. maxima* would be worthwhile.

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BOOK REVIEW

"CLIMATE OF PAPUA NEW GUINEA"

McAlpine, J.R. and Keig, Gael with Falls, R. (1983). CSIRO and ANU Press, 200 pp. Aus$12.95.

The aim of the authors is to describe the climate of Papua New Guinea and, with the aid of the description, to produce a climatic classification especially suited for that nation. They directed their work toward a wide audience, including experts in the life sciences, engineers and planners.

Beginning with an account of the development and nature of the network of meteorological stations, they proceed to a discussion of the features of the circulation in the West Tropical Pacific that help to explain the climate of New Guinea. Maps of vector mean wind speed and direction at the surface and at the 700 millibar level are shown for four different months while line disturbances of the trades, shifts in the intertropical convergence zone and tropical cyclones are depicted with a series of satellite images. A brief history of tropical cyclones is supplemented with a map of their tracks. An exposition on the linkage between frequently occurring synoptic patterns to precipitation would have been useful at this point.

In a chapter on local controls and surface winds there is an excellent account of the effects of physiographic features — mountains and valleys, land and seas on air movements, ascending and descending, converging and diverging. Maps at a scale of about 1:3,000,000 illustrate the general patterns of these phenomena. Other maps display resultant surface winds at six stations for the months of January, April, July and October at 0900 and 1500 h local time. Two figures show the seasonal variation of the mean three-hourly observations of wind speed and direction at Rabaul and Lae.

Rainfall is given a generous treatment with many maps that show: mean annual rainfalls, January and July mean monthly rainfall, time of occurrence of maximum monthly rainfall, distribution of the index of seasonality, coefficient of variation of annual rainfall, regional and national correlations of logarithms of annual and of selected monthly values of rainfall, average number of days per year with rainfall exceeding specified amounts, maximum recorded daily rainfalls and maximum daily rainfalls likely every two years. Graphs indicate: mean monthly distribution of rainfall for six stations; mean number of rainy days per month for the same six stations; percentile ranges of annual rainfall for 12 stations; monthly rainfall variability expressed as percentile ranges for the same 12 stations plus one; rainfall intensity-duration combinations with return periods of two and twenty years for six stations; average number of daily occurrences by month according to time of day for eight stations; mean length of rainy and rainless periods for six stations by season; diurnal cycle of rainfall for six stations; frequency distribution of rainless periods for six stations over a 5-year standard period.

Mean maximum and minimum temperatures for January and July are displayed on maps while graphs show mean monthly maxima and minima and extreme temperatures for 11 stations, lapse rates, diurnal temperature cycles for two stations and maximum temperature cumulative probability curves by fortnight for six stations. In a discussion of lapse rates and vegetation boundaries asso-

ciated with altitude it would have been well to add that vegetation boundaries rise rapidly from the margins to the interior of the Highlands. Upper limits of agriculture correspond quite neatly with the levels at which afternoon clouds hang on the mountains, levels whose altitude also increases rapidly as one penetrates the mountains. Also a more detailed account of the effects of local relief features and aspects on temperature would have been worthwhile as many of the inhabitants of New Guinea do live in the mountains and are influenced by topoclimate. For example the favored ridge crest house sites are relatively cool in the day and relatively warm at night. There seem to be few data about topoclimates. Even so, characteristic patterns might well be described and explained for the benefit of the lay reader.

Mean monthly relative humidity index ("the ratio of the 9 a.m. vapor pressure to the saturation vapor pressure at the average mean temperature") is mapped for January and July. Another map shows Class A pan evaporation as estimated from mean monthly temperature, relative humidity, sunshine and wind data, while graphs indicate: the annual cycle for relative humidity index for 9 stations; the effect of altitude on seasonal variability of relative humidity index; daily variation in relative humidity index by fortnight for six stations; mean three-hour relative humidities for January and July at 11 stations; and seasonal variation in measured U.S. Class A pan evaporation at 7 stations. There is some confusion in the use of the terms evapotranspiration and evaporation.

Information about the levels at which clouds hang on the mountains would be quite useful, since the clouds strongly influence temperatures, relative humidity, evapotranspiration and insolation. Also fog drip may contribute appreciably to precipitation.

Maps display global solar radiation for four months of the year as well as for the whole year, while graphs show monthly variation in daylength, times of sunrise and sunset, cumulative probabilities of cloudiness by fortnights at 0900 and 1500 h. Other graphs depict: monthly variation in mean daily sunshine hours; cumulative probabilities of sunshine duration by fortnights; annual variation in the ratio of mean daily recorded sunshine hours per month to maximum possible duration of bright sun; mean daily solar radiation per month; ratio of mean daily global solar radiation per month to mean daily total radiation per month received above the atmosphere.

In contrast with this work's depiction of a winter minimum for most of New Guinea, global radiation measurements taken by H.I. Manner near Jimi River Patrol Post indicated a maximum in the winter dry season. Street's observation, in this same area, of a concentration of anthropogenic grasslands on north-facing slopes accords well with Manner's findings.

Maps show frequency and intensity of soil moisture deficiencies and mean annual water surplus while graphs display statistics on mean monthly water balance components, mean weekly soil moisture storage, frequency distribution of specified levels of soil moisture, frequency of drought periods during a standard 15-year period; frequency and lengths of periods of possibly saturated soil; mean weekly water surplus; frequency distribution of specified levels of water surplus; variability of annual water surplus. Unfortunately the description of the water balance model on p. 134 is quite confused.

The final chapter presents on maps the climates of New Guinea according to Thornthwaite, Köppen, Holdridge and Terjung classifications. A new classification of climate that "can satisfactorily distinguish all the major climatic types which are generally and locally recognised" is based on altitude and average precipitation and presented in a

table and graphs.

Concluding efforts to link climate with vegetation, land use and resource assessment are weak, ineffectual and probably clouded by error. Medical geography, which in New Guinea is strongly influenced by climate, was accorded but a sentence; a brief essay at agricultural geography produced such controversial statements as: "The almost universal use of hill terrain for traditional agriculture is most likely a response to the need for adequate drainage"; and, with reference to the general lack of inhabitants in the premontane zone, it "is too cold for optimum production of lowland crops and too warm for highland crops." The authors might better to have brought to the attention of their readers some of the excellent new literature in bioclimatology.

An extensive appendix contains tables of data for from 2 to 95 stations on aspects of winds, rainfall, temperature, relative humidity, estimates of pan evaporation, sunshine hours and solar radiation. Also there are a list of about 100 references and an index.

As simply (and importantly) a source of numerical data on the climate of eastern New Guinea the book is excellent. Presentation of climate in terms of probabilities of, for example, droughts and water surpluses of various magnitudes, makes the work especially useful for planning. Larger scale fold-out topographic maps with climate superimposed would make it even more useful.

As mentioned above, there is room for improvement in the explanation of the climate and in the discussion of its relationship to public health and agriculture.

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BOOK REVIEW

"SOILS OF PAPUA NEW GUINEA"

P. Bleeker (1983). CSIRO and ANU Press, 352 pp. Aus$14.95.

Soil is one of our most important natural resources. It must be managed carefully so that our children and their children are able to grow their food crops and obtain an income in the future. The key to wise management of soil is an understanding of soil itself. Therefore it is good to have a book that contains much of our present scientific knowledge of the soils of Papua New Guinea.

As a soil scientist I found the book to be interesting, readable and a good summary of the soil research which has been carried out on Papua New Guinea soils.

The book has 16 chapters and the first deals with the environment of Papua New Guinea. It covers landforms, geology, climate and its effect on soils, and vegetation. Chapter 2 is entitled Soil Classification and Mapping and gives a good overview. The United States Department of Agriculture scheme of Soil Taxonomy is used and this chapter contains a good introduction to its use in Papua New Guinea. The limitations of Soil Taxonomy are discussed in this chapter together with its advantages.

Chapters 3 to 10 cover the eight soil orders which occur in Papua New Guinea. The 61 great soil groups are described in terms of morphology, genesis, occurrence association, fertility and land use. These chapters also contain useful maps and diagrams of the distribution of the soils together with interesting photographs. However, the tables on chemical fertility are a little difficult to understand. They are, in fact, tables of the number of soils in a given fertility class rather than actual chemical data.

Chapter 11 contains useful information on the assessment of land for various crops. Chapter 12 has a good discussion on soil erosion and highlights the need for further study of erosion in Papua New Guinea.

Chapter 13 brings together the studies on weathering of soils of Papua New Guinea and chapter 14 deals with primary and micro nutrients (incorrectly called minor elements). Chapter 15 is an interesting chapter on soil microrelief and chapter 16 is a discussion of traditional food crop agriculture in relation to soil properties.

The book contains very few errors. Perhaps the most serious is the statement on p. 236 that fertiliser applications may do little to rectify phosphorus fixation problems. Work by Sanchez and associates, in Brasil and Peru, and others have shown that it is possible to overcome phosphorus fixation on soils containing iron oxides. However, there may be a continuing fixation problem in Andepts which contain large amounts of allophane.

The author uses total nitrogen levels together with C/N ratios to estimate the nitrogen status of the soils. One has to be very cautious in using the data in this way since plants use a very small part of the total soil nitrogen. Nitrogen deficiency may be quite widespread in food crops, particularly maize, as shown by a number of DPI trials in Papua New Guinea.

The author has given an excellent review of the soils of Papua New Guinea. The book will be essential for those who

plan to do research on these soils in the future. It is highly recommended for soil scientists and libraries dealing with soils.

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INSTRUCTIONS FOR CONTRIBUTORS

Original research reports, review papers, notes, bibliographies and book reviews on Agriculture, Forestry or Fisheries in Melanesia and the South Pacific region will be considered for publication. Articles must not be previously or simultaneously published or submitted for publication elsewhere.

1. Presentation — Papers should be double-spaced throughout with wide margins on both sides. The first line of each paragraph should be indented three spaces. A4 size paper should be used. Send the top copy plus three carbon copies or photocopies to the editor of the journal. Captions to plates and figures must be typed on a separate sheet at the end of the text. Tables should also be typed on separate sheets. All pages of typing including references, appendices, captions and tables should be numbered consecutively at the top right.

2. Title — The title should be as brief as possible but should clearly indicate the content. It is not necessary to start the title with "A..." or "The..." or other non significant words.

3. Author's name — First names or initials can be used according to the preference of the author, however, authors are strongly advised to use the same style for their name in all publications to avoid giving the impression that they are two or more different authors. The address of each author at the place where the work was done is given in a footnote. If there has been a change of address, the present address is also given for the first author.

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5. Headings — In experimental papers the general order of headings is: Abstract, Introduction, Materials and Methods, Results, Discussion, Acknowledgements, References, Appendix. In descriptive, or other types of papers, refer to similar papers. No headings should be underlined.

6. Text — Papers should be concise. Extensive introductions referring to the work of earlier authors should be avoided. Lengthy discussions and detailed descriptions should be reduced by the use of tables and diagrams. The text should not repeat in detail what is apparent from a table or diagram.

Names of countries or organisations may be abbreviated to capitals without full stops but must be given in full at the first mention.

Numbers under 11 should be spelt out unless qualifying a unit of measurement. If a number over 10 and a number under 11 appear in the same sentence, both are written as numerals. Do not begin a sentence with a numeral. Fractions should be given as decimals or spelt out. All decimal numbers less than unity should have a zero before the decimal marker, e.g. 0.25. All units should be in the S.I. system.

All scientific names of animals and plants must be underlined to indicate that they should be set in italic type. The authority should be cited in full on the first occasion a scientific name is used. Where the same name is used repeatedly, the genus may be abbreviated to a capital letter after the first citation. For example,

use *Homo sapiens* Linnaeus on the first occasion and *H. sapiens* thereafter.

Common or local names may be used but the scientific name should be quoted on the first occasion. An agricultural chemical must be referred to by its generic or common name when it is first quoted.

7. Tables — Tables are much more time-consuming and thus costlier to set than ordinary text so thought should be given to the possibility of replacing tables with a graph. The presentation of the same data in tabular and graphic form is not permitted. Numerical results should be displayed as means with relevant standard errors rather than as detailed data. Standard errors should be given to one place of decimals more than the means to which they refer and the number of degrees of freedom should also be quoted. Tables should be complete in themselves so that they can be understood without reference to accompanying text. Each table should have a brief title.

8. Figures and photographs — Line drawings should be drawn in black waterproof ink on smooth tough paper. Labelling should be clear and preferably produced with stencils using black waterproof ink and should be legible when reduced. No alterations or additions to artwork can be made by the editors. Figures should be no larger than an A3 page and no smaller than final published size. Photographs should be glossy prints of good quality and must make a definite contribution to the value of the paper. Indicate the top of figures and photographs on the back. Also indicate clearly on the back: the plate number of each figure and photograph, the author's name, and the title of the paper. Do not write on the back of photographs: use an adhesive lable with the data previously written on it. Artwork should be of appropriate proportions for the final page dimensions.

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10. References — These should be cited in the text by the author's name and date as follows:

"Moran and Brown (1956) showed" or "Various workers (Wilson 1978, 1979a; Miller and Smith 1956; Adams *et al.* 1960) found..." The term *et al.* should be used when there are more than two authors. The letters a,b,c, should be used to distinguish several papers by the same author in one year.

All references in the bibliography should be given in full and in alphabetical order. For a journal the reference should include surname and initials of all authors, (year), title of paper, full title of the journal, volume, (part) and full page numbers. For a book the reference should include author's surname and initials, (year), title of chapter and page numbers if appropriate, full title of book, publisher and city and total page number. Conference proceedings should include the year and place of the conference. The title of the journal or book is underlined to be printed in italics. Examples are:

BOWET, C.M. and SMITH, L.N. (1950). Measurement of phosphorus. In *Methods of Soil Analysis*. Ed. C.A. Lack. Department of Primary Industry, Port Moresby. 400 pp.

SANDERS, A.J. (1940). Plant responses to molybdenum. *Papua New Guinea Agricultural Journal*, 48 (4): 981-995.

TROEN, M.M. (1973). Genetic fine structure in *Drosophila*. *Department of Primary Industry Research Bulletin* No. 102, pp. 196-197.

Internal reports, communications and memoranda are not valid references. The criteria for valid publications (in the scientific world) are that publications are distributed widely among those interested in the subject and are available to the international public in major libraries and from the publisher. This therefore excludes reports circulated only within a department and to a few outsiders and conference documents available only to those who attended the conference and the like.

Work that has not been accepted for publication (unpublished data) and personal communications are not included in the list of references but may be referred to in the text. References cited in an appendix should be included in the list of references at the end of the paper.

Special care should be taken to see that every reference in the text is included in the list of references and vice versa, and that there is consistency in the spelling of authors' names and the citation of dates throughout the paper.

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13. Recognised abbreviations in this journal are:

g	—	gram
kg	—	kilogram
t	—	tonne
/	—	litre
ml	—	millilitre
ha	—	hectare
mm	—	millimetre
cm	—	centimetre
m	—	metre
a.s.l.	—	above sea level
yr	—	year
wk	—	week
h	—	hour
min	—	minute
s	—	second
K	—	kina
n.a.	—	not applicable or not available
n.r.	—	not recorded
var.	—	variance
s.d.	—	standard deviation
s.e.m.	—	standard error of mean
s.e.d.	—	standard error of difference
d.f.	—	degrees of freedom

Levels of significance:

n.s.	—	not significant
⋆	—	$0.01 \leq p < 0.05$
⋆ ⋆	—	$0.001 \leq p < 0.01$
⋆ ⋆ ⋆	—	$p < 0.001$

Either kg/ha or kg·ha^{-1} is acceptable but larger combinations of units should be in the form kg·ha^{-1} to avoid possible mathematical ambiguity.