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CONTENTS

SCALE INSECTS (HOMOPTERA: COCCOIDEA) ON COFFEE IN PAPUA NEW GUINEA

D.J. Williams*

ABSTRACT

The spread of some injurious scale insects on coffee in Papua New Guinea (P.N.G.) has coincided with an increase in coffee cultivation. Loss of yield caused mainly by the green scales Coccus celatus *De Lotto and* Coccus viridis *(Green), has stimulated interest in biological control. As a result of recent surveys to assess the extent of green scales, a list is presented of all scale insects on coffee in P.N.G.*

INTRODUCTION

Coffee has been grown in Papua New Guinea (P.N.G.) for about 70 years and Dwyer (1954) has given a short account of its earlier history in the Territory. Since 1945, coffee production has increased dramatically, but in recent years there has been concern about the spread of injurious scale insects. This spread has probably coincided with the increase of coffee cultivation. However, there is reason to believe that the most injurious scale insects on coffee were in P.N.G. before 1945.

Coffee is normally a shade-loving plant and successful cultivation depends on the use of suitable shade trees. These trees, however, often act as hosts for scale insects and injurious species may transfer from the trees to coffee.

Early accounts were given by Froggatt (1936b, 1938) of damage to coffee by the mealybug *Ferrisia virgata* (Cockerell) in the Rabaul area, but similar damage has never been reported since.

After extensive collecting in the 1950s and 1960s, Szent-Ivany & Stevens (1966) recorded severe damage to coffee roots by the mealybug *Cataenococcus leveri* (Green), but there have been no further records of similar damage, although the mealybug must still be present.

Williams (1982b) showed that *Planococcus citri* (Risso) was not yet present in P.N.G. and that all previous records of this species should refer to the related species *P. pacificus* Cox. *P. citri* has since been found in P.N.G. and although not reported on coffee, it is a potential pest. *P. pacificus* seems to be particularly common on coffee in P.N.G., although little damage has been reported. Control is effected in the Wau Valley mainly by the coccinellid *Cryptolaemus affinis* (Crotch) (Szent-Ivany and Stevens 1966). Another related species, *P. lilacinus* (Cockerell), discussed by Williams (1982b) poses a problem. It is commonly called the Coffee Mealybug throughout southern Asia, where it is probably endemic and does cause damage. Although it is fairly widespread in P.N.G., it seems to infest mainly *Theobroma cacao* and *Citrus* spp. and has never been reported on coffee, but it must remain a potential pest.

Recently the most important pests seem to be the soft scales *Coccus viridis* (Green) and *C. celatus* De Lotto (Smith and Thistleton 1984). *C. viridis* may have been present in P.N.G. for many years. It is a tropicopolitan and polyphagous species, but has been noticed

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on coffee in P.N.G. since the early surveys recorded by Froggatt (1936a) and is now widespread on coffee in P.N.G. Probably more important is *C. celatus*, discussed recently by Williams (1982a). This species may be endemic to E. Africa but has spread to parts of the Oriental Region and was first collected in P.N.G. at Kieta, Bougainville in 1938. It is now common on coffee throughout P.N.G., and the damage it causes to the young leaves and green berries is seriously affecting yield (S.T. Murphy, pers. comm.). The incidence is complicated by the presence of ants attending and protecting the scales for honeydew. Both the *Coccus* species are commonly called 'green scales' and sometimes both species are present on the same tree. When prepared on microscope slides, the differences between the two species are striking, but there is still no satisfactory method of distinguishing the species in the field. Local entomologists consider that *C. celatus* is by far the more important species and, at present, the Commonwealth Institute of Biological Control (C.I.B.C.) is engaged in controlling it. Suitable control agents may be found eventually in East Africa. Recent surveys in P.N.G. by Dr. S.T. Murphy of the C.I.B.C. have shown the extent of infestation of *C. celatus* and the localities are listed herein.

This seems a fitting time, therefore, to list all the scale insects at present known on coffee in P.N.G. The first entries under each species refer to the material examined by the author followed by certain literature records. Almost all the material has been sent, at one time or another, to the Commonwealth Institute of Entomology, London, for identification and is deposited in the collections of the British Museum (Natural History). The only species recorded, but not seen at present, is the *Pulvinaria* sp., listed by Szent-Ivany and Stevens (1966), but this may eventually prove to be *Coccus celatus*.

The following abbreviations in the text are used for provinces:

C.P., Central Province
Chimbu P., Chimbu Province
E.N.B.P., East New Britain Province
E.H.P., Eastern Highlands Province
E.S.P., East Sepik Province
Madang P., Madang Province
Manus P., Manus Province
Milne B.P., Milne Bay Province
Morobe P., Morobe Province
N.P., Northern Province
N.S.P., North Solomons Province
W.H.P., Western Highlands Province

Abbreviations for collectors' names are as follows:

F.A., F. Arndt
G.B., G. Baker
J.H.B., J.H. Barrett
A.C., A. Catley
K.S.C., K.S. Cole
G.S.D., G.S. Dun
J.L.F., J.L. Froggatt
J.H., J. Healy
W.T.B.H., W.T.B. Heath
J.W.I., J.W. Ismay
B.J.K., B.J. Kebby
J.H.M., J.H. Martin
R.M., R. Montgomery
S.T.M., S.T. Murphy
D.S., D. Shaw
B.M.T., B.M. Thistleton
J.J.H.S.I., J.J.H. Szent-Ivany
G.Y., G. Young

FAMILY PSEUDOCOCCIDAE

Cataenococcus leveri (Green) (*Pseudococcus leveri*, *Paraputo leveri*)

Morobe P., Mumeng, Sum Suum Plantation, on *C. arabica*, 12.vii.19060 (A.C.). Snake River Valley, Sunshinne Plantation, on roots of *C. arabicca*, 2.vii.1963, attended by *Pheidole meggacephala* (Fabricius) (J.J.H.S.I. & B.J.KK.)

Milne B.P., Inanianene Village, on roots of *C. canephora*, ix.1959 (K.S.C.).

Szent-Ivany and Stevens (1966) discussed these records in greater detail. Apparently the mealybugs were killing trees by damaging the roots. On *C. canephora* mealybugs were protected under a layer of the symbiotic fungus *Diacanthodes philippinensis* and were attended by the ants *Paratrechina* (*Nylanderia*) sp., *Monomorium* sp. and *Odontomachus simillimus* (Smith).

This mealybug species is known also from the Solomon Islands, Vanuatu, Fiji and Tonga on various host-plants and Beardsley (1966) has recorded it from the Caroline Islands.

Dysmicoccus brevipes (Cockerell)

C.P., Goilala, Tapini, on *C. arabica*, 13.vi.1960 (J.J.H.S.I.).

This widespread and polyphagous species may be found on coffee in other parts of P.N.G., but it is doubtful if it is injurious.

Ferrisia virgata (Cockerell)

E.S.P., Maprik, Tamaui Plantation, on *C. robusta*, 13.x.1957; Kimbangua, on *C. robusta*, 29.ii.1959 (J.J.H.S.I.).

Milne B.P., Dogura, Anglican Mission, on *C. robusta*, 29.vi.1959 (J.H.).

This species was first mentioned on coffee from P.N.G. by Froggatt (1936a) as 'Mealy Bug' without locality, and by Froggatt (1936b) as *Pseudococcus* sp. on coffee in E.N.B.P., Rabaul area, where it was the worst infestation to date. Froggatt observed it also on *Erythrina* sp., introduced for the development of permanent shade of coffee, and *Cryptolaemus* sp. gave a good measure of control. Froggatt (1938) stated that the mealybug was *F. virgata*. Specimens are at hand, sent by Froggatt, on *Erythrina* sp., and these are identical with specimens, discussed by Williams (1985) as the biparental strain of *F. virgata*.

Szent-Ivany (1956) recorded the species from E.S.P., Maprik, on *C. robusta*, when the leaves and branches of *C. robusta* were heavily attacked.

The mealybug is known from other localities in P.N.G. on various host-plants and it is one of the most widespread of the tropicopolitan mealybugs.

Planococcus pacificus Cox

C.P., Sogeri, Koitaki Estate, on *C. arabica*, 13.iv.1962 (J.J.H.S.I.), 25.ix.1962 (G.S.D. & J.J.H.S.I.); Tapini, on *C. arabica*, 12.v.1960, 13.vi.1960 (J.J.H.S.I.).

E.N.B.P., New Britain, Keravat, on *C. canephora*, v.1960, vii, 1961, 3.x.1961 (G.S.D.).

E.H.P., Goroka, on *Coffea* sp., 12.v.1963 (J.H.B.).

E.S.P., Maprik, Bainyik, on *C. robusta*, 2.iii.1960 (J.J.H.S.I.), on *C. canephora*, xii.1962 (F.A.); Tamani, on *C. robusta*, 25.x.1957 (J.J.H.S.I.).

Madang P., Madang Agricultural Sta., on *C. robusta*, 9.x.1959 (J.H.).

Milne B.P., Naura, on *C. robusta*, v.1960 (W.T.B.H.).

Morobe P., Wau, on *C. arabica*, 30.v.1957, 1.vi.1957, 24.ix.1957 (J.J.H.S.I.), 2.vii.1963 (J.J.H.S.I. & B.J.K.).

N.S.P., Bougainville, Kieta, on *Coffea* sp., 19.ix.1937, 11.x.1937, 17.viii.1938 (J.L.F.).

The distribution of this species in the southern tropical Pacific area has been discussed by Williams (1982b) who stated that *Planococcus citri* did not occur in P.N.G., and that all previous records of *P. citri* in P.N.G. should refer to *P. pacificus*. Since the paper was published, *P. citri* has been found in the W.H.P., but not on coffee. *P. pacificus* is widespread in many parts of the world

and probably has a similar host-plant range to that of *P. citri*.

Szent-Ivany (1956) recorded it as damaging flower clusters in the Wau area in 1956–1957 but it was kept under control by *Cryptolaemus affinis*. On *C. robusta*, damage was not so severe. Later Szent-Ivany & Stevens (1966) stated that this mealybug represented 90–95% of the scale insect populations.

Barrett (1966) discussed the mealybug from the Highlands area, giving notes on the life history and control.

Pseudococcus longispinus (Targioni Tozzetti) (*P. adonidum* (L.))

E.H.P., Aiyura, on *Coffea* sp., 25.ix.1959 (J.H.B.).

Szent-Ivany and Stevens (1966) have recorded this mealybug from Morobe P., Wau area, on coffee, and from E.H.P., Okapa, Etesena Coffee Block, on *C. arabica*. The insect does not appear to cause damage. It is one of the most widespread of mealybugs and has been reported on numerous host-plants.

FAMILY COCCIDAE

Ceroplastes destructor Newstead (*Gascardia destructor*)

Morobe P., Wau, on *C. robusta*, 24.xi.1979 (J.H.M.).

W.H.P., nr Banz, on *Coffea* sp., 3.iii.1980 (B.M.T.).

Szent-Ivany and Stevens (1966) reported this species from Morobe P., Wau Valley on *C. arabica*, where the damage was insignificant. However, at the Sunshine Plantation, Snake River Valley, almost every bush was infested in 1965. The species is fairly widespread in P.N.G. on numerous host-plants but it is now effectively controlled by the encyrtid wasp *Paraceraptrocerus nyasicus* (Compere) introduced from Australia in 1982.

Chloropulvinaria psidii (Maskell) (*Pulvinaria psidii*)

C.P., Goilala District, Tapini, on *C. arabica*, 12.v.1960 (*J.J.H.S.I.*).

E.H.P., Kainantu District, Norikori Plantation, on *C. arabica*, 18.ix.1984 (S.T.M.); Aiyura, on *Coffea* sp., 13.i.1959 (J.H.B.).

E.N.B.P., Keravat, on *Coffea* sp., 30.xi.1961 (G.S.D.), on *C. canephora*, v.1959.

This is a tropicopolitan and polyphagous species, but it is often found on coffee where it sometimes causes concern. Szent-Ivany (1958) recorded it from the Western Highlands P. on *C. arabica* where it was controlled by *Callineda* sp., and from the Eastern Highlands P., Asaro Valley, Lunapieve Plantation, where outbreaks were also controlled by *Callineda* sp. collected in the Bena Valley.

Coccus celatus De Lotto

N.S.P., Bougainville, Kieta, on *Coffea* sp., 17.viii.1938.

Morobe P., Bulolo, on *Coffea* sp., 29.vii.1980 (G.Y.), on *C. arabica* 23.xi.1980 (G.Y.); Bubia, on *C. canephora*, 18.xi.1980 (G.Y.); Eurakor, on *C. arabica*, 22.xi.1980 (G.Y.); Wau, on *C. robusta*, 24.xi.1979 (J.H.M.), on *C. arabica*, 22.xi.1980 (G.Y.), 21.ix.1984 on *C. arabica* (S.T.M.), Blue Mountain Estate, on *C. arabica*, 21.ix.1984 (S.T.M.); Lae, Bumayong High School, on *C. robusta*, 22.ix.1984 (S.T.M.).

W.H.P., (all on *C. arabica*, S.T.M.), Baiyer District, Lapramba village, 8.ix.1984, Kainwa Estate, 8.ix.1984, Mants Farmers Plantation, 8.ix.1984; N. Wahgi District, Koban Plantation, 10.ix.1984, Kimil Estate, 10.ix.1984, Mintal Estate, 10.ix.1984; S. Wahgi

District, Kurumul Plantation, 11.ix.1984; Hagen District, Raglamp Estate, 11.ix.1984.

Chimbu P., (all on *C. arabica*, S.T.M.), Kerowagi District, D.P.I., Kumgi, 13.ix.1984, Siure, 13.ix.1984; Kundiawa District, Mirane, 15.ix.1984; Gumine District, Munma, 15.ix.1984, Kup, 15.ix.1984.

E.H.P., (all on *C. arabica*, S.T.M.), Kainantu District, Mamaa Estate, 18.ix.1984, Norikori Plantation, 18.ix.1984, Mareya Plantation, 19.ix.1984; Goroka District, Asaro Estate, 24.ix.1984, Samoyufa Estate, 24.ix.1984, Bena Bena, 24.ix.1984.

E.N.B.P., Keravat, on *C. canephora*, v.1959 (G.S.D.).

This was discussed recently by Williams (1982a), and is now regarded as one of the most important insects on coffee in P.N.G. It is associated with the ant species *Technomyrmex albipes* (Smith), *Iridomyrmex* sp., *Iridomyrmex* (*anceps* group), *Pheidole* sp., *Anoplolepis longipes* (Jerdan) *Polyrachis* (*rostella* group), *Crematogaster* sp., *Paratrechina* sp. and *Oecophylla smaragdina* (Fabricius).

Coccus viridis (Green)

C.P., Laloki, on *C. robusta*, 17.ix.1958 (R.M. & D.S.)

E.H.P., (all on *C. arabica*), Kainantu District, Norikori, 17.ix.1984, Korona, 18.ix.1984, NPMA Plantation, 19.ix.1984 (all S.T.M.); Goroka District, 21.i.1981 (G.Y.), Samoyufa Estate, 24.ix.1984 (S.T.M.).

E.S.P., Maprik, Bainyik, on *C. robusta*, 2.ii.1960, 3.iii.1960 (J.J.H.S.I.).

Madang P., Madang, on *C. robusta*, 9.x.1959 (J.H.).

Manus P., Manus, Lorengau, on *C. canephora*, 20.i.1963 (J.J.H.S.I.).

Milne B.P., East Cape, on *C. robusta*, 20.vii.1959 (W.T.B.H.).

Morobe P., Bubia, on *C. canephora*, 18.xi.1980 (G.Y.); Bulolo, on *C. arabica*, 23.xi.1980 (G.Y.); Wau, Kosali Plantation, on *C. arabica*, 3.vii.1965 (J.J.H.S.I. & B.J.K.), on *C. arabica*, 22.xi.1980 (G.Y.); Lae, Bumayong High School, on *C. robusta*, 22.ix.1984 (S.T.M.).

N.S.P., Bougainville, Kieta, on *Coffea* sp., 17.vii.1938 (J.L.F.).

N.P., Mamba Plantation, on *C. robusta*, 1.iii.1983 (J.W.I.).

W.H.P., Hagen District, Kara Estate, on *C. arabica*, 7.ix.1984 (S.T.M.), Koma Estate, 7.ix.1984 (S.T.M.), Mt Hagen, on *Coffea* sp., 1.xi.1981 (B.M.T.), on *C. arabica*, 25.ii.1973 (G.B.); Minj, on *Coffea* sp., 11.xii.1975 (B.M.T.); N. Wahgi District, Koban Plantation, 10.ix.1984 (S.T.M.); Nebilyer Valley, Mala Plantation, 12.ix.1984 (S.T.M.).

This species was first recorded on coffee from P.N.G. by Froggatt (1936a) and it has since been found in many localities. Froggatt (1936b) recorded copious honeydew production on which sooty moulds developed over much of the foliage. The species was later recorded by Szent-Ivany (1958) from the Highlands area where nearly every coffee plantation was infested, but the scale was controlled by the coccinellids *Menochilus sexmaculatus* (Fabricius) and *Callineda* sp. The scale insect was later discussed by Szent-Ivany and Stevens (1966) from the Wau Valley on *C. arabica* but many insects were killed by entomophagous fungi.

Further information on the life history and control in the Highlands area were given by Barrett (1966).

Ant species attending this scale have been reported as *Iridomyrmex nitidus* Mayr, *Iridomyrmex* (*anceps* group), *Polyrhachis wagneri* Wiehmeyer, *Technomyrmex albipes*, *Rhoptromyrmex melleus* Emery and *Oecophylla smaragdina*.

Parasaissetia nigra (Nietner) (*Saissetia nigra*)

Morobe P., Wau, on *C. robusta*, 24.xi.1979 (J.H.M.)

W.H.P., Hagen District, Kara Estate, on *C. robusta*, 7.ix.1984 (S.T.M.).
E.H.P., Henganofi, on *Coffea* sp., 2.xi.1961 (J.H.B.).

This species is widespread in P.N.G., on numerous host-plants. Large populations were reported by Szent-Ivany (1958) in E.H.P. on virus disease-infested *Crotalaria anagyroides* planted as shade trees to coffee.

Saissetia coffeae (Walker)

Chimbu P., D.P.I. Kumgi, on *C. arabica*, 13.ix.1984 (S.T.M.).
E.H.P., Norikori, on *C. arabica*, 17.ix.1984 (S.T.M.).
Morobe P., Wau, on *C. arabica*, 22.x.1980 (G.Y.); Bulolo, on *C. arabica*, 23.x.1980 (G.Y.).
W.H.P., Hagen District, Kara Estate, on *C. arabica*, 7.ix.1984 (S.T.M.).

This species was recorded by Szent-Ivany (1958) from the Highlands area where it was controlled by *Callineda* sp. and two species of *Orcus*.

Szent-Ivany and Stevens (1966) recorded it from Morobe P., in the Wau Valley and Bulolo-Snake River area in almost every plantation of *C. arabica*, but there were low population densities. The species is one of the most widespread and polyphagous of all scale insects.

Barrett (1966) has given useful information on the life history and control in the Highlands area.

FAMILY DIASPIDIDAE

Hemiberlesia lataniae (Signoret)

C.P., Port Moresby, on *C. robusta*, 5.ii.1960 (A.C.).

This is a cosmopolitan and polyphagous species, known in many parts of P.N.G., on other host-plants. It has been recorded by Szent-Ivany & Catley (1960).

Hemiberlesia palmae (Cockerell)

C.P., Port Moresby, on *C. robusta*, 5.ii.1960 (A.C.).

This cosmopolitan species is known throughout P.N.G. on numerous host-plants. The record on coffee by Szent-Ivany & Catley (1960) is the only one so far.

Ischnaspis longirostris (Signoret)

C.P., Port Moresby, on *C. robusta*, 5.ii.1960 (A.C.).

This is known in many parts of the world as the 'black thread scale', and although polyphagous it is often found on coffee. It is known from a few localities in P.N.G. on different host-plants and will probably be widespread on coffee. It was recorded on coffee by Szent-Ivany & Catley (1960).

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The author is much indebted to the many entomologists working in P.N.G., who have collected scale insects over the years and have sent them for identification. Thanks are due to Dr. S.T. Murphy, Commonwealth Institute of Biological Control, Kenya Station, who has supplied much useful information on the distribution of the green scales and information on the ant species.

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A KEY TO *PHYTOPHTHORA* SPECIES FOUND IN PAPUA NEW GUINEA WITH NOTES ON THEIR DISTRIBUTION AND MORPHOLOGY

Frans Arentz*

ABSTRACT

A simple key is given for the most common Phytophthora *species found in the soils of Papua New Guinea. Species listed are* P. cinnamomi, P. colocasiae, P. cryptogea, P. heveae, P. katsurae, P. megasperma *var* sojae, P. nicotianae *var* nicotianae, P. nicotianae *var* parasitica, P. palmivora *and a* Phytophthora *species placed nearest* P. cryptogea. Peronophythora litchii *has been included because of its close resemblance to* Phytophthora. *All isolations held at Bulolo are listed, together with notes on their morphology.*

INTRODUCTION

A survey of the occurrence and distribution of *Phytophthora* species in Papua New Guinea was commenced in 1974 and over 600 isolations have been made. Two isolation techniques were used. In the first, soil samples were collected from localities throughout Papua New Guinea and baited with blue lupins using the technique of Chee and Newhook (1965). The second technique involved the direct isolation of *Phytophthora* from plant material by plating the material onto 1.7% water agar. The species were identified using the key of Waterhouse (1963), and the identities and mating types of representative isolates confirmed by Dr. J. Stamps, Commonwealth Mycological Institute (C.M.I.), Kew. This paper presents a simple key for the identification of *Phytophthora* species found in Papua New Guinea (see *Figure 1*), together with notes on their morphology and geographical distribution.

Phytophthora heveae Thompson

Morphology: sporangia ellipsoid to obpyriform, papillate, (32 –)43 (– 57) × (23 –)30(– 40)µm, l:b ratio of 1.4; sex organs abundant in single strain culture; oogonia spherical with a tapering base, (22.5 –)24.6(– 28.1)µm; antheridia amphigynous, 10 µm.

Collections: sixteen isolations have been made:- Bulolo accession no. 7083 (IMI 198425), soil under *Eucalyptus tereticornis*, Sirinumu Dam; 7114 & 7115 (IMI 211484), soil under mixed *Castanopsis-Araucaria hunsteinii* forest, Garaina; 7116, soil under *Castanopsis* forest, Manki, Bulolo; 7161, soil under *A. cunninghamii*, Wutung; 7210, soil under *Anisoptera* dominated forest, Lasanga Island, Buso; 7214, soil under *A. hunsteinii*, Garaina; 7233, soil under lowland rainforest, Sapi River, Madang; 7384 (IMI 229096) & 7385, soil under lowland rainforest, Sapi River, Madang; 7394, soil under *A. cunninghamii* forest, Fergusson Island; 7445, soil under *Agathis robusta*, Sogeri; 7473 & 7474, soil under rubber plantation, Balimo; 7570 & 7572, soil associated with *A. hunsteinii* seedlings, Garaina.

Notes: a further 42 isolations were made at Sapi River, Madang, but were not included in the collection. Also, two isolates, 7454 & 7455, from limestone soil under rainforest near Kavieng, differed from *P. heveae* in that oogonia did not have a tapering base.

* Forest Research Station, Bulolo, P.N.G.

The isolates appeared to be near *P. boehmeriae* Sawada but this identification has not been confirmed by CMI, Kew.

Phytophthora katsurae Ko and Chang

Morphology: sporangia ovoid, conspicuously papillate, sometimes with two exit pores, (38−)48(−60) × (30−)37(−42)µm, l:b ratio of 1.3; sex organs abundant in single strain culture; oogonia spherical (26−)28(−31) × (22−)26(−28)µm, with tapering base, wall verruciform when mature; oospores spherical, (20−)22(−24)µm; antheridia amphigynous, spherical to oval in shape, (9−)10(−11)µm.

Collections: twelve isolations have been made:- 7127 (IMI 198426), soil under *Araucaria hunsteinii*. Garaina; 7216 (IMI 211487) & 7217, soil under *A. cunninghamii*, Fergusson Island; 7367 & 7368, soil associated with *A. cunninghamii* seedlings, Woitape; 7396 & 7397, soil associated with *Agathis* seedlings, Yapsei, Sepik River; 7448, mixed lowland rainforest, Kaut Logging Area, Kavieng; 7469, 7470 & 7471, soil under *Nothofagus pullei*, Melkoi, near Pomio; 7571, mixed *Castanopsis-A. hunsteinii* forest, Garaina.

Peronophythora litchii Chen ex Ko et al.

Morphology: sporangia papillate, formed in 'umbels', 34(−44) × 21(−29)µm; sex organs formed in single strain culture; oogonia spherical, 24.5 µm; antheridia amphigynous and paragynous, 11.5 × 8.8 µm.

Collections: two isolations have been made:- 7388 (IMI 229097), soil under mixed lowland rainforest, Sapi River, Madang; 7393, soil under mixed lowland rainforest, North Coast Road, Madang.

Notes: although belonging to a different family, *P. litchii* is included because of its close resemblance to *Phytophthora*. Ko *et al* (1978), in describing the new family Peronophythoraceae, distinguished it from Pythiaceae by the lack of growth renewal of the sporangiophores after the development of sporangia, although zoospores were released as in *Phytophthora*.

Phytophthora megasperma var *sojae* Hildebrand

Morphology: sporangia practically non-papillate, 40.5 × 27.0 µm, l:b ratio 1.5; sex organs formed in single strain culture; oogonia spherical, 26 µm; antheridia mostly paragynous, 8.5 × 9.1 µm.

Collection: one isolation has been made:- 7402 (IMI 229098), from soil taken from under natural lowland rainforest at Sapi River, Madang.

Notes: The isolate was examined at CMI, Kew, and was placed nearest to *P. megasperma* var *sojae* on the basis of oogonia and temperature relations. The sporangia were atypical in that they failed to proliferate internally (J. Stamps, pers. comm.).

Phytophthora colocasiae Raciborski

Morphology: sporangia elongated ellipsoid, papillate, 45–60 × 23 µm (Waterhouse, 1963); isolates heterothallic; sex organs produced when crossed with compatible mating type; oogonia spherical, 35 µm; antheridia amphigynous, 17 × 13 µm.

Collections: numerous isolations have been made but only seven isolates have been retained in the collection. All isolates have been of A2 mating type:- 7158, 7159 & 7160, from leaf of *Colocasia esculenta*, Lae; 7181, from leaf of *C. esculenta*, Madang; 7182, from leaf

***Figure 1.*–Key to *Phytophthora* species found in Papua New Guinea**

1. Oogonia usually formed in single culture 2
1. Oogonia usually not formed in single culture 5

2. Antheridia predominately amphigynous 3
2. Antheridia predominately paragynous 4

3. Oogonial walls smooth when mature ..... *P. heveae*
3. Oogonial walls verriculose when mature ..... *P. katsurae*

4. Sporangia in umbels, papillate ..... *Peronophythora litchii*
4. Sporangia produced singly, scarcely papillate .... *P. megasperma* var *sojae*

5. Sporangia markedly papillate 6
5. Sporangia not papillate 9

6. Usually isolated from *Colocasia* ..... *P. colocasiae*
6. Usually isolated from hosts other then *Colocasia* 7

7. Oospores plerotic, no hyphal growth at >35°C ..... *P. palmivora*
7. Oospores aplerotic, hyphal growth at >35°C 8

8. Hyphae uniform, to 5µm diam ..... *P. nicotianae* var. *nicotianae*
8. Hyphae irregular, to 9µm diam ..... *P. nicotianae* var. *parasitica*

9. Chlamydospores produced in culture ..... *P. cinnamomi*
9. Chlamydospores not produced in culture 10

10. Hyphae with irregular swellings ..... *P. cryptogea*
10. Hyphae smooth ..... *Phytophthora* sp. ..... nearest *P. cryptogea*

of *C. esculenta*, Wewak; 7191, from leaf of *C. esculenta*, LAES, Kerevat; 7192, from leaf of *C. esculenta*, SDA College, Sonoma, Rabaul.

Notes: isolates were difficult to separate morphologically from *P. palmivora* although there was a tendency for oogonia to be larger.

***Phytophthora palmivora* (Butler) Butler**

Morphology: sporangia papillate, caducous, with short pedicles < 10 µm, 49 × 29 µm, l:b ratio 1.6; isolates heterothallic; oogonia spherical 27 µm diameter; antheridia amphigynous, 14.5 × 12.0 µm; no growth on CMA at 35°C.

Collections: 122 non-cocoa isolations were made:- 7038 (IMI 198423) & 7040, A2 mating type, cleared secondary shrub, Bulolo; 7047, A2 mating type, cleared rainforest, Bulolo; 7058, A1 mating type, Teak plantation, Brown River; 7059, A2 mating type, soil under *Citrus*, Hohola; 7060, A2 mating type, nursery soil, Brown River; 7068–9 & 7071, A2 mating type, *Eucalyptus deglupta* plantation, Mt Lawes; 7080, A1 mating type, *E. deglupta* plantation, Brown River; 7082, A2 mating type, Teak plantation, Brown River; 7090, A2 mating type, soil under *Pandanus* sp., Maiama; 7093, A2 mating type, lowland rainforest, Maiama; 7095, A2 mating type, edge of *Araucaria cunninghamii* plantation, Bulolo; 7100, A2 mating type, *A. hunsteinii* plantation, Heads Hump, Bulolo; 7102, A2 mating type, *A. cunninghamii* plantation, Nauti, Bulolo; 7103, A2 mating type, cleared rainforest, Nauti, Bulolo; 7123, A2 mating type, soil under *Citrus*, Garaina; 7133 & 7134, A2 mating type,

Rubber plantation, Kwikila; 7142–7144, A2 mating type, lowland rainforest, Cape Rodney; 7145 (IMI 229089) & 7146, A1 mating type, lowland rainforest, Open Bay; 7150, A2 mating type, grassland, Kwikila; 7152, A2 mating type, lowland rainforest, Open Bay; 7162, A2 mating type, rainforest on road to Ossima; 7163, A2 mating type, *E. deglupta* plantation, Vanimo; 7165, A2 mating type, nursery soil, Vanimo; 7170–7171 & 7174, A2 mating type, *E. deglupta* plantation, Baku, Madang; 7175, A1 mating type, lowland rainforest, Naru, Madang; 7176, A2 mating type, rainforest, Bumbu; 7177, A2 mating type, lowland rainforest, Popondetta; 7179, A2 mating type, rainforest, Kokoda; 7183, A2 mating type, nursery soil, Wewak; 7184, A2 mating type, grassland, Dumpu; 7196, A2 mating type, lowland rainforest, Gabensis; 7207 (IMI 211486), A1 mating type, sago swamp, Buso; 7208, A1 mating type, *Anisoptera* forest, Buso; 7209, A1 mating type, mangrove, Buso; 7211, A1 mating type, sago swamp, Buso; 7223 & 7224, A2 mating type, lowland rainforest, Sapi River, Madang; 7226, A1 mating type, lowland rainforest, Sapi River, Madang; 7227, A1 mating type, logged rainforest near Baku, Madang, 7228 & 7229, A2 mating type, *E. deglupta* plantation, Baku, Madang; 7230 & 7231, A1 mating type, *E. deglupta* plantation, Baku, Madang; 7232, A2 mating type, *E. deglupta* plantation, Baku, Madang; 7235, A2 mating type, lowland rainforest, Sapi River, Madang; 7236, A1 mating type, logged rainforest, Baku, Madang; 7257, 7259–7261 & 7268, A2 mating type, *A. cunninghamii* plantation, Taun Ck, Bulolo; 7265, 7267, 7269 & 7270, A1 mating type, *A cunninghamii* plantation, Taun Ck, Bulolo; 7271 & 7172, Teak plantation, Cape Hoskins; 7273–7275, 7277–7278, 7280, 7286–7287, 7289–7292, 7294–7295, 7298–7299, 7301–7302, 7304–7306, 7308 & 7311, A1 mating type, lowland rainforest, Sapi River, Madang; 7276, 7281–7285, 7288, 7293, 7296–7297, 7300, 7310, 7313 & 7322, A2 mating type, lowland rainforest, Sapi River, Madang; 7279, 7303, 7307, 7309 (IMI 229092), 7312 & 7315, "sterile", lowland rainforest, Sapi River, Madang; 7342, A2 mating type, lowland rainforest, Sapi River, Madang; 7343, A1 mating type, lowland rainforest, Sapi River, Madang; 7345–7347, A1 mating type, natural *A. cunninghamii* stand, Okasa; 7382, A1 mating type, under *Pinus kesiya*, Pindiu; 7399, A1 mating type, soil under *Ficus*, Angoram; 7418, A1 mating type, lowland rainforest, Huambe, Sepik; 7460 & 7461, A1 mating type, new village garden, Sivauna; 7468, A2 mating type, Coconut plantation, Alotau; 7632, A1 mating type, lowland rainforest, Sapi River, Madang; 7633, A2 mating type, lowland rainforest, Sapi River, Madang.

138 direct isolations were made from cocoa pods, or from soil under cocoa plantations:- 7147 & 7148, A2 mating type, soil, Kokopo; 7149, A2 mating type, soil LAES, Keravat; 7151, A2 mating type, soil, Ulaveo; 7239, A2 mating type, pod, Cape Hoskins; 7240 & 7243, A2 mating type, soil, Cape Hoskins; 7245 & 7246, A2 mating type, pod, Arawa; 7400, A2 mating type, soil, Siassi; 7401, A1 mating type, soil, Siassi; 7410, A2 mating type, canker, Access. no. 10748, DPI, Konedobu; 7437, A2 mating type, pod, Arawa; 7438, A2 mating type, pod, Wakunai; 7439, A2 mating type, pod, Buka; 7440, A2 mating type, pod, Tinputz; 7441, A2 mating type, pod, Aropa; 7442–7444, A2 mating type, pod, Tinputz; 7466 & 7467, A2 mating type, soil, Alotau; 7475–7478, A1 mating type, pod, Madang; 7479, A2 mating type, pod, Wewak; 7480 & 7481, A2 mating type, pod, Numanuma, North Solomons; 7485 & 7486, A2 mating type, pod, Baia, New Ireland; 7487 & 7488, A2 mating type, pod, Koka, New Ireland; 7489–7491, A2 mating type, pod, Kalili, New Ireland; 7492 & 7493, A2 mating type, pod, Kimadan, New Ireland; 7494–7496, A2 mating type, pod, Lawatmere, New

Ireland; 7497–7499, A2 mating type, pod, Patlangat, New Ireland; 7500 & 7501, A2 mating type, pod, Bopire, New Ireland; 7502–7503 & 7505, A2 mating type, pod, Matakrus, North Solomons; 7504, A1 mating type, pod, Matakrus North Solomons; 7506–7509, A2 mating type, pod, Sabah, North Solomons; 7510–7513, A2 mating type, pod, Wakunai, North Solomons; 7514–7535, A1 mating type, pod, Mililat, Madang; 7536–7540, A1 mating type, pod, Murnass, Madang; 7541, A1 mating type, pod, Wagug, Madang; 7542, A1 mating type, pod, Banup, Madang; 7543 & 7544, A2 mating type, pod, Bubia; 7545, A2 mating type, pod, Boiken, East Sepik; 7546–7548, A2 mating type, pod, Usaigam, East Sepik; 7549 & 7550, A2 mating type, pod, Bagumata, East Sepik; 7552–7555, A2 mating type, pod, Dublai, East Sepik, 7556 & 7557, A2 mating type, pod, Maguer, East Sepik; 7558, A2 mating type, pod, Kanam, New Ireland; 7559, A2 mating type, pod, Nalik, New Ireland; 7560 & 7561, A2 mating type, pod, Mageh, New Ireland; 7562, A2 mating type, pod, Kara, New Ireland; 7563, A2 mating type, pod, Pinnikindu, New Ireland; 7564, A2 mating type, pod, Lossu, New Ireland; 7574 & 7575, A2 mating type, pod, Suvai, North Solomons; 7576 & 7577, A2 mating type, pod, Buin; 7578 & 7579, A2 mating type, pod, Awawata, Northern Province; 7580, A2 mating type, pod, Kokoda; 7581, A2 mating type, pod, Hamara, Northern Province; 7582–7584, A2 mating type, pod, Lejo, Northern Province; 7585, A2 mating type, pod, Ambene, Northern Province; 7586, A2 mating type, pod, Arehe, Northern Province; 7594–7596, A2 mating type, pod, Utan, Northern Province; 7597 & 7598, A1 mating type, soil, Mililat, Madang; 7600, A2 mating type, soil, Kokoda; 7602, A2 mating type, pod, Baku, Madang; 7603, A1 mating type, pod, Kuman, Madang; 7618, A2 mating type, pod, Finschhafen; 7619, A2 mating type, Vetubakoetu, North Solomons; 7620 & 7621, A2 mating type, pod, Konga, North Solomons; 7622, A2 mating type, pod, Koikoi, North Solomons; 7623, A2 mating type, pod, Malasang, North Solomons; 7626–7629, A2 mating type, pod, Madehas, North Solomons.

Notes: the chromosomes of isolates 7207, 7267, 7268 & 7300 were examined by Sansome (1980), and all were shown to be of the "S" type. Erselius and Shaw (1982) looked at the morphology and isoenzymes of isolates 7207, 7245, 7267, 7268, 7300, 7306, 7309, 7400 & 7401. Of these, all except 7267 and 7268 had the stellate colony morphology typical of *P. palmivora* from other countries. Five of the isolates examined produced deciduous sporangia with short stout stalks. Isolates 7267 and 7268 produced sporangia which were non-deciduous and often with more than one papilla. The chromosomes of these two isolates were similar to those of *P. palmivora*. Enzyme analysis of the isolates indicated a variety of lactate dehydrogenase and acid phosphatease patterns. Although the enzymes were more varied than those of West African isolates examined, it was concluded that the P.N.G. isolates clearly belonged to *P. palmivora* (Erselius and Shaw, 1982). The variation was considered to be a reflection of the different habitats from which the isolates were obtained. Isolate 7245, from cocoa pod, was identical to West African isolates in all the characters examined, which was taken to imply that the gene pool of *P. palmivora* in any one area is large and that only a fraction of this gene pool is sampled by the cocoa pod (Erselius and Shaw, 1982).

Phytophthora nicotianae var *nicotianae* van Breda de Haan

Morphology: hyphae uniform; sporangia papillate, (32–)42(–52) × (22–)31(–38) µm, l:b ratio, 1.35; isolates heterothallic; oogonia spherical, (24–)25 (–26) µm; antheridia amphigynous, (12–)13.0(–14) × (8–)10.8

(−14) µm (crossings were made with *P. nicotianae* var *parasitica*).

Collections: two isolations have been made:- 7164 (IMI 211485), A2 mating type, nursery soil, Vanimo; 7268, A2 mating type, soil under unthrifty *Araucaria cunninghamii*, Taun Ck, Bulolo.

Phytophthora nicotianae var *parasitica* (Dastur) Waterhouse

Morphology: hyphae irregular; sporangia papillate, (30−)38(−50) × (23−)30(−38) µm; isolates heterothallic when first isolated; oogonia (24−)26 (−30) µm; antheridia (11−)12.4(−13) × (7−)9.3(−11) µm; good growth on CMA at 35°C.

Collections: fourteen isolations have been made:- 7004 (IMI 198418), A1 mating type, soil under *Pinus luchuensis*, Rd 35, Bulolo; 7007, A1 mating type, soil under *Pinus cubensis*, Rd 35, Bulolo; 7016, A1 mating type, nursery soil, Lae; 7033, A1 mating type, nursery soil, Lapegu; 7037, A1 mating type, cleared secondary shrub, Rd 67, Bulolo; 7057, A2 mating type, soil under *Araucaria cunninghamii*, Divide, Bulolo; 7076, A1 mating type, soil under *Eucalyptus deglupta* plantation, Oomsis; 7079, A2 mating type, at base of dying *E. deglupta*, Forest Research Station, Bulolo; 7110, A1 mating type, soil under coffee, Wau; 7111, A1 mating type, soil under *Pinus merkusii*, Rd 35 Bulolo, 7137, A1 mating type, soil under *Legustrum*, Kwikila; 7222, A2 mating type, soil under lowland rainforest, Sapi River, Madang; 7234, A2 mating type, under *E. deglupta*, Baku, Madang; 7392, "sterile", from *Citrus*, DPI station, Normanby Island.

Notes: isolate 7007 was of A1 mating type when first isolated. However, after repeated sub-culturing of one of the two stock cultures of the isolate over several years, the mating type was found to be A2. Dr. Eva Sansome examined the chromosomes of the two sub-cultures and suggested that the change in mating type was the result of somatic crossing-over of segments within the chromosomes (Sansome, 1985).

Phytophthora cinnamomi Rands

Morphology: sporangia non-papillate, generally ovoid to obpyriform, non-caducous, (49−)56(−64) × (29−)34(−40) µm; chlamydospores produced singly, terminal or on short, lateral branches, 35.6 µm diameter; isolates heterothallic; sexual organs produced when crossed with a compatible mating type; antheridia amphigynous, 18.6 × 19.5 µm, sometimes with sterile hyphal protuberance, sometimes bicellular; oogonia spherical, mean diameter 40.2 µm.

Collections: eighty-seven isolations have been made:- 7009 & 7011, A1 mating type, *Nothofagus* forest, Nakanai Plateau; 7013 (IMI 198420), A2 mating type, *Castanopsis* forest, Mt Kaindi; 7030, A1 mating type, *Castanopsis* forest, Tari; 7063, A1 mating type, *Castanopsis* forest, Manki, Bulolo; 7086, A2 mating type, natural *Araucaria cunninghamii* stand, Wau; 7087–7089, A2 mating type, *Pinus caribaea* plantation, Wau; 7096, A2 mating type, *Castanopsis* forest, Manki, Bulolo; 7099 (IMI 211483), A1 mating type, *A. cunninghamii* plantation, Heads Hump, Bulolo; 7117, A2 mating type, *Castanopsis* forest, Manki, Bulolo; 7126, A1 mating type, mixed *Castanopsis* – *A. hunsteinii* forest, Garaina; 7128, A1 mating type, old village garden site, Garaina; 7157, A2 mating type, *Nothofagus* forest, Mt Kaindi; 7167–7169, A1 mating type, *A. cunninghamii* forest, Oksapmin; 7186, A1 mating type, mixed *Castanopsis* – *A. cunninghamii* forest, Paiella; 7190–7193, A1 mating type, *Nothofagus* forest, Onim, Mt Giluwe; 7195, A1 mating type, *Pinus caribaea* plantation, Bulolo; 7200–7202, A2 mating

type, *Pinus kesiya* plantation, Aiyura; 7215, A2 mating type, at base of *Rhododendron*, Edie Creek; 7218, A1 mating type, DPI gardens, Erave; 7249, A2 mating type, Forestry College flower bed, Bulolo; 7316–7321, 7330–7341, 7348–7352, 7355–7360, 7364, 7366, 7371–7378, 7380 & 7383, A1 mating type, *Nothofagus* forest, Mt Giluwe; 7369 & 7370, A1 mating type, mixed *Castanopsis* – *A. cunninghamii* forest, Woitape; 7404 & 7405, A2 mating type, *Pinus caribaea*, Andersons, Wau; 7482–7484, A1 mating type, *Dacrydium* swamp, Mendi; 7587, A2 mating type, rubber plantation, Sogeri; 7612–7615, A2 mating type, Avocado, Agricultural College, Mt Hagen; 7617, A1 mating type, Avocado, DPI Research Station, Kuk; 7634, A2 mating type, roots of dead *Pinus douglasianae*, Nompia.

Notes: the genetic variation in nine A2 (7013, 7086, 7096, 7157, 7200, 7215, 7249, 7587 & 7612) and eight A1 (7011, 7063, 7126, 7618, 7186, 7334, 7369 & 7617) mating type isolates of *P. cinnamomi* was assessed by electrophoresis at 20 isozyme loci (Old, Moran and Bell, 1984). Little variation was found in the A2 mating type which appeared to be identical to isolates from Australia, whereas the A1 mating type showed greater genetic variability compared with Australian isolates.

Phytophthora cryptogea
Pethybridge and Lafferty

Morphology: hyphae irregular in width, with swellings; sporangia non-papillate, ovoid to obpyriform, (25 –)38 (– 48) × (17 –)26(– 32) µm; isolates heterothallic; sex organs produced when crossed with a compatible mating type; oogonia 26–31 µm diameter; antheridia amphigynous, 14 × 15 µm. Crossings were carried out with A2 *P. cinnamomi*.

Collections: 105 isolations have been made, all of A1 mating type:- 7001, nursery soil, Henganofi; 7002, *Pinus cubensis* plantation, Bulolo; 7003, 7006 & 7008, *P. caribaea* plantation, Bulolo; 7015 (IMI 198421), natural stand *Eucalyptus deglupta*, Open Bay; 7022–7024, *P. kesiya* plantation, Lapegu; 7028, natural forest, Kassam Pass; 7029, nursery soil, Mendi; 7034–7036, chlorotic *P. caribaea* seedlings, Lapegu nursery; 7039, 7041 & 7042, secondary shrub, Bulolo; 7043, *Araucaria cunninghamii* plantation, Bulolo; 7045 & 7046, cleared rainforest, Geshes, Bulolo; 7048, *P. kesiya* plantation, Watut; 7049–7056, *P. radiata* stand, Divide, Bulolo; 7061, *E. confertiflora* plantation, Brown River; 7062, Teak plantation, Brown River; 7067, 7070, 7072 & 7073, *E. deglupta* plantation, Mt Lawes; 7075, *E. deglupta* windbreak, Tamiloa Plantation, Lae; 7077, nursery soil, Oomsis; 7081, *E. deglupta* tree, Botanical Gardens, Lae; 7084, natural *E. tereticornis*, Sirinumu Dam, Sogeri; 7085, *P. caribaea* plantation, Wau; 7092, lowland rainforest, Maiama; 7094, *A. cunninghamii* plantation, Bulolo; 7097, *P. caribaea*, Wau; 7104 & 7105, cleared rainforest, Nauti, Bulolo; 7106 & 7107, *P. radiata* stand, Bulolo; 7108, *E. delegatensis*, Heads Hump, Bulolo; 7113, *P. oocarpa*, Bulolo; 7118–7121, *E. deglupta* windbreaks, Garaina; 7122, Citrus, Garaina; 7124, *E. grandis*, Garaina; 7125, gardened *Castanopsis* stand, Garaina; 7129–7131, *E. deglupta* plantation, Keravat; 7135, rubber plantation, Kwikila; 7136, grassland, Kwikila; 7138 & 7139, edge of creek, Kwikila; 7153, *E. deglupta* windbreak, Jimi Valley; 7155, *E. deglupta* plantation, Vudal; 7156, natural *E. deglupta*, Open Bay; 7172 & 7173, *E. deglupta* plantation, Baku, Madang; 7178, lowland rainforest, Oro Bay; 7180, grassland, Kokoda; 7189, nursery soil, Lapegu; 7194, *P. caribaea* plantation, Bulolo; 7204, *P. kesiya* plantation, Aiyura; 7225, lowland rainforest, Sapi River, Madang; 7237, *E. deglupta* plantation, Baku, Madang; 7238, Avocado, Bulolo; 7242, *E. urophylla* plantation, Kaisenik, Wau; 7247 & 7248, Forestry College

garden, Bulolo; 7250, root of *Rhododendron*, Wau; 7254, soil under *Rhododendron*, Wau; 7314, lowland rainforest, Sapi River, Madang; 7379, coffee plantation, Pindiu; 7381, *A. hunsteinii* windbreak, Pindiu; 7386, lowland rainforest, Sapi River, Madang; 7389, *E. grandis* windbreak, Mt Hagen; 7390, lowland rainforest, Fergusson Island; 7395, nursery soil, Garaina; 7408, coffee plantation, Finschhafen; 7420, *P. chiapensis* plantation, Kainantu; 7428, coffee plantation, Lapegu; 7429–7433, soil ex coffee nursery, Lapegu; 7434, soil ex *P. patula* seedling, Lapegu; 7464 & 7465, Coconut plantation, Alotau; 7588, pepper plantation, LAES, Kerevat; 7605, nursery soil, Menyamya; 7606–7608, *E. deglupta* plantation, Angoram; 7610, cleared rainforest, Gogol, Madang.

Notes: isozyme analysis carried out on 20 isolates by CSIRO Div. of Forest Research, Canberra, showed very little genetic variation between the isolates (K.M. Old, pers. comm.).

Phytophthora species, nearest *P. cryptogea*

Morphology: hyphae fairly uniform; sporangia non-papillate, (35–)46(–56) × (24–)29(–37) µm, isolates heterothallic; sex organs formed when crossed with compatible mating type oogonia (36–)41(–46) µm; antheridia amphigynous, 20 × 19 µm; no chlamydospores formed.

Collections: 49 isolations have been made:- 7017 (IMI 198422), A1 mating type, *Nothofagus* forest, Onim, Mt Giluwe; 7025, A1 mating type, *Pinus kesiya* plantation, Lapegu; 7026, 7027 & 7031, A1 mating type, roadside drain, Daulo Pass; 7032, A1 mating type, nursery soil, Ialibu; 7064, A1 mating type, *Pinus* sp., Aiyura; 7074, A1 mating type, *Araucaria cunninghamii* seed orchard, Bulolo; 7098, A1 mating type, *P. caribaea* plantation, Wau; 7101, A1 mating type, *Casuarina* windbreak, Mt Hagen; 7112, A1 mating type, *P. merkusii* plantation, Bulolo; 7166, A1 mating type, natural *A. cunninghamii* stand, Oksapmin; 7185, 7187 & 7188, A1 mating type, mixed *Castanopsis-A. cunninghamii* forest, Paiella; 7203, A1 mating type, *P. kesiya* plantation, Aiyura; 7205, A1 mating type, *P. kesiya* plantation, Lapegu; 7206, A1 mating type, grassland, Lapegu; 7213, A1 mating type, lowland rainforest, Buso; 7220 (IMI 229090), "sterile", nursery soil, Laiagam; 7241 (IMI 229091), "sterile', *E. grandis* windbreak, Kainantu; 7323, "sterile", *Pinus* sp., Kindeng; 7324, 7325, 7327, 7328 & 7329 (IMI 229093), "sterile", kunai – pitpit swamp, Karpena; 7326, A1 mating type, *Eucalyptus robusta* plantation, Karpena; 7344 (IMI 229094), "sterile", *A cunninghamii*, Aiyura; 7353 & 7354, "sterile", *Trifolium* sp., Onim, Mt Giluwe; 7421–7427, A1 mating type, nursery soil, Lapegu; 7456, "sterile", *P. patula* plantation, Wapenamanda; 7457–7459, "sterile", *P. caribaea* plantation, Laiagam; 7472, "sterile", *P. patula* plantation, Marafunga; 7565, "sterile", *Pinus* sp., Kainantu; 7567–7569, "sterile", *P. patula* plantation, Lapegu; 7590, "sterile", *P. patula* plantation, Goroka.

DISCUSSION

The identities of nine of the species of *Phytophthora* isolated during the survey were verified by CMI, Kew. In addition one isolation was made of each of two mangrove species, tentatively identified as *P. spinosa* Fell and Master and *P. vesicula* Anastasiou and Churchland. These have not been included in the key as their inclusion in the genus *Phytophthora* has been questioned (Waterhouse *et al.* 1983). A non-papillate species, identified by CMI as "near *P. cryptogea*", has been included in the key because of the large number of isolations made in Papua New Guinea. However, a number of isolations were made of *Phytophthora* species which could not be identified,

and these have not been included in this paper as more work with them is required.

Zentmyer *et al.* (1978) have described *P. heveae* as an uncommon species with a limited host range and geographical distribution. In Papua New Guinea the species was isolated from widely separated sites, and in one instance a large number of isolations were made from an intensively sampled rainforest site. *Phytophthora heveae* was found on one occasion in the same general locality as *P. katsurae*, a relatively new species described previously for Taiwan, Japan, Hawaii (Ko and Chang 1979), and Australia (J. Stamps, pers. comm.). In Japan *P. katsurae* was reported to cause a trunk rot on chestnut (Katsura 1976), but all isolations in Papua New Guinea were made from soil.

Phytophthora palmivora was a common component of the soil flora, especially in the lowland rainforests of Papua New Guinea. Both mating types were recovered, often within a short distance of each other. The isolates of *P. palmivora* recovered from rainforest soil were not pathogenic on cocoa pods (unpublished data), and the morphological variation shown for isolates obtained from soil compared with those taken from cocoa pods (Erselius and Shaw 1982), has raised the question as to whether there was a system of selection operating between soil and parasitic populations of *P. palmivora* and between different hosts (Brasier 1983).

Phytophthora nicotianae var *parasitica* and *P. nicotianae* var *nicotianae* could be distinguished from *P. palmivora* on the basis of sporangial shape and length-breadth ratio, and growth at 36°C. It was difficult to separate *P. nicotianae* var *nicotianae* from *P. palmivora* on the basis of hyphal morphology alone.

The distribution pattern of the two mating types of *P. cinnamomi* has led to the suggestion that the two mating types have different origins to Papua New Guinea, the A2 mating type being of more recent origin (Arentz and Simpson 1986). In view of the importance of the A2 mating type as a pathogen overseas (Zentmyer 1980), it is anticipated that this mating type will become more significant as a pathogen of agricultural and forest crops in Papua New Guinea in the future.

There appears to be some confusion surrounding the taxonomy of some of the non-papillate heterothallic species of *Phytophthora*. Tucker (1931) raised a new species, *P. drechsleri* Tucker, which was considered distinct from *P. cryptogea* because of its high optimum temperature, and its growth on corn meal agar at 35°C. Bumbieris (1974), after a comparison of named isolates of the two species, found considerable overlap in growth at different temperatures, and suggested that they should be considered as the one species, the name *P. cryptogea* having priority over *P. drechsleri*. In Papua New Guinea three distinct heterothallic species with non-papillate sporangia were obtained. One of these species could be readily identified as *P. cinnamomi* on the basis of production of chlamydospores and size of sporangia and gametangia. The other two species did not produce chlamydospores, and the sporangia were smaller than for *P. cinnamomi*. The two species differed from each other in the size of the gametangia and in the appearance of the hyphae, with hyphal swellings common in one species but not occurring at all in the other. The species with hyphal swellings, identified as *P. drechsleri* by CMI (J. Stamps, pers comm.), is considered to be *P. cryptogea* as redefined by Bumbieris (1974). The species with uniform hyphae had initially been misidentified as *P. cambivora* (Petri) Buisman (Arentz 1976), but closer examination of oogonia did not show any bullate protuberances on the walls.

Dr. Stamps (pers. comm.), after examining several representative isolates, placed the species nearest *P. cryptogea* on the basis of sporangia size. The morphological differences between isolates of these two species suggest that the species whose identity could not be confirmed may represent a new species of *Phytophthora*. However more work will be required to verify this.

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INTENSIFICATION OF SUBSISTENCE AGRICULTURE ON THE NEMBI PLATEAU, PAPUA NEW GUINEA
1. GENERAL INTRODUCTION AND INORGANIC FERTILIZER TRIALS

E. D'Souza*† and R. Michael Bourke*††

ABSTRACT

*A crop intensification programme was conducted in an area of high population density, extended periods of land use, low crop yields, and consequent high child malnutrition rates. Sweet potato (*Ipomoea batatas *(L.)Lam.) is grown in continuously cropped fields without fertilizers or crop rotation and supplementary crops are planted seasonally. In this first of three papers, the Nembi Plateau environment is described and results are given from inorganic fertilizer trials undertaken to investigate nutrient imbalances and deficiencies.*

The first fertilizer trial included nitrogen (N), phosphate (P), potassium (K), minor elements, and boron (B). Sweet potato tubers and top growth showed a large response to K. P increased tuber yield, and minor elements increased top growth yield. B significantly depressed tuber yield whilst increasing top growth yield. A marked K deficiency was confirmed by sweet potato leaf analysis and soil analysis.

A further small trial examined the effect of boron fertilizer on Casuarina oligodon *Johnson. A very marked response to B was found. Another trial examined the effect of minor elements and B on peanuts (*Arachis hypogaea L.*), cowpea (*Vigna unguiculata *(L.) Walpers var.* unguiculata*) and winged bean (*Psophocarpus tetragonolobus *(L.) A.P. de Candolle). There were no significant responses.*

GENERAL INTRODUCTION

The 1978 national nutrition survey of Papua New Guinea showed that the child malnutrition rate on the Nembi Plateau of the Southern Highlands Province was particularly high. To determine the cause, an intensive agricultural and land use survey was conducted in September 1978. It found that the very high population densities on the Plateau had led to extended periods of subsistence food garden usage without adequate fallow periods. This has resulted in very low yields of sweet potato (*Ipomoea batatas* (L.) Lam.) which is the major subsistence crop, and chronic food supply problems. The sweet potato supply is variable and for certain periods the supply is especially inadequate. These food shortages contribute importantly to the particularly high malnutrition rates (Allen 1984b; Allen *et al.* 1979). Subsequent measurements in food gardens indicated subsistence sweet potato yields of 6.3 t/ha (Bourke and D'Souza 1982) and 7.1 t/ha (Crittenden 1982, p. 402). These represent some of the lowest sweet potato subsistence yields ever recorded in

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Papua New Guinea (Bourke 1984) and gave support to the hypothesis that child malnutrition was related to stress in the agricultural system.

Following the initial multidisciplinary survey, an agricultural research programme was initiated on the Plateau, which examined intensification of subsistence agriculture and seasonality of food supply. One of the authors lived on the Plateau between July 1979 and July 1981 and continued the research programme there until June 1982. In this series of papers we report on aspects of the intensification programme.

The environment

The Nembi Plateau (about 143°30'E, 6°15'S) is located between the Wage and Nembi Rivers in the Southern Highlands, some 20 km southwest of Mendi. The Plateau is dominated by limestone ridges and pinnacles with associated dolines and underground karst drainage. Rainfall recordings at Hol (1800 m) over the two year period commencing July 1979 indicated a mean annual rainfall of 2700 mm and a weak suggestion that the period May to November tended to be drier. The rainfall pattern is likely to be similar to that of Nipa which has a mean annual rainfall of 3200 mm and lower rainfall in June and July (McAlpine *et al.* 1975). The average maximum daily temperature is 25.7°C and the average minimum temperature is 14.1°C, with low variability throughout the year.

The Plateau ranges in altitude from 1650 m to 2300 m with agriculture practised between 1650 m and 2000 m. The trials reported here were conducted between 1650 m and 1800 m. Some clans have land near the Wage River at lower altitudes. There is no road access to the Wage River; medical facilities and stores are lacking; and there is reportedly a high incidence of malaria. For these reasons few people cultivate land or reside at the lower altitude location. The major agricultural soil is a Humic Brown Clay derived from volcanic ash (Wood 1984). Gross human population densities are high and are considerably higher on arable land. For example, population densities on arable land for three clans were recorded as 140 to 184 persons per km^2 by Allen (1984c).

Agriculture

Agriculture on the Plateau is dominated by sweet potato gardens which are made on the valley and doline slopes. Sweet potato is planted in long raised beds with drains running up and down the slope on the steeper land and in rectangular mounds on the flatter land. The land is cultivated continuously with breaks of up to a few months only between crops. During this short fallow phase, the ground is covered with the vines of the previous crop. Garden ages typically range from 15 to over 30 years. Some of the sweet potato vines, weeds and fallow vegetation are incorporated into the beds/mounds at replanting, but application rates are lower than in other highland areas.

The other important garden type is the mixed vegetable and coffee gardens situated on the deep, dark clay soils of the doline floors, on alluvial soils, and on the more fertile sites on the slopes. Soil tillage in these gardens is minimal. Fallow periods range from 1 to 10 years. The fallow vegetation is cut, piled and burned. The soil surface is lightly worked with a digging stick before planting. Crops in the mixed gardens include highland 'pitpit' (*Setaria palmifolia* (Koenig) Stapf), sugar cane (*Saccharum officinarum* L.), bananas (*Musa* cvs), pumpkins (*Cucurbita moschata* Duchesne ex Poiret), *Rungia klossii* S. Moore, winged beans (*Psophocarpus tetragonolobus* (L.) A.P. de Candolle), corn (*Zea mays* L.), taro (*Colocasia esculenta* (L.) Schott), Chinese taro

(*Xanthosoma sagittifolium* (L.) Schott), cabbage (*Brassica oleracea* L.), common beans (*Phaseolus vulgaris* L.), sweet potato, *Oenanthe javanica* A.P. de Candolle, *Ficus copiosa* Steudel, *Amaranthus tricolor* L., pak choi (*Brassica chinensis* L.), and lima beans (*Phaseolus lunatus* L.). The crops are mix cropped at the cultivar and species level.

Mixed crop gardens are planted seasonally in September to December. Traditionally only one planting of crops is made and the gardens are abandoned to grass fallow or are planted with *Casuarina oligodon* Johnson fallow as the food is harvested. In many instances, coffee is now being interplanted with the food crops and the garden are being converted to coffee gardens. See *Plates I* and *II*.

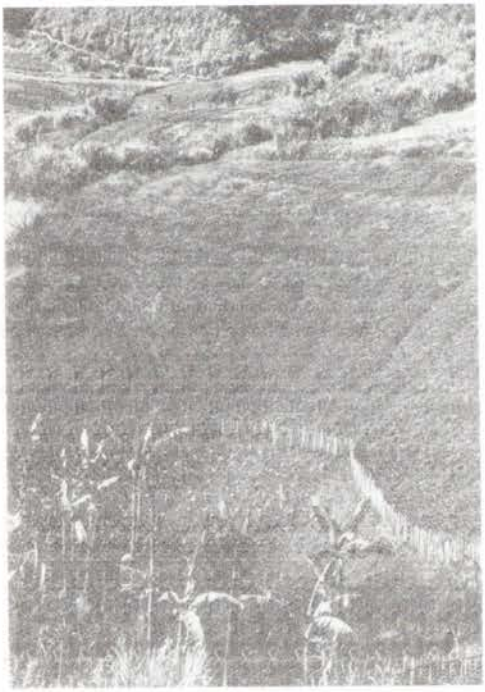

Plate I. **Sweet potato gardens (on slope) and a mixed vegetable garden (foreground) on the Nembi Plateau. Sweet potato gardens are planted for up to 30–40 years whilst mixed gardens are planted to one crop only before fallow**

Plate II. **A villager displays typical sweet potato tubers from a garden. Sweet potato yields are some of the lowest ever recorded in Papua New Guinea**

Intensification programme

The intensification research programme was conducted to identify agricultural technologies which would increase food supply. It was directed at the subsistence food sector as there are only limited possibilities to obtain cash to purchase food. The ultimate aim of the research programme is to provide technologies that can improve people's nutritional status.

All experimental work was conducted entirely in villagers' gardens, mostly under the land owners' management. Work was concentrated in sweet potato gardens as the malnutrition problem is viewed as a result of inadequate calorie intake linked to low sweet potato yields (Allen *et al.* 1979). All trials were low input ones. Unless stated otherwise, no fertilizer was added or pest control conducted. Because of problems in obtaining blocks of adequate

area in the one location, guard rows were not used in the trials.

The intensification programme borrows heavily from component technologies that are being used elsewhere in the Papua New Guinea highlands under similar agroclimatic conditions. These include sweet potato composting, use of casuarina fallows, and legume/sweet potato rotations. These technology components were not formulated to fit into existing seasonal labour patterns or to alleviate seasonal food shortages as little data on these were available when the project was initiated. Some suggestions are made for a more holistic approach for agricultural intensification research by D'Souza and Bourke (1984). In this series of papers we report results of the intensification research as follows:

1. Inorganic fertilizer trials with sweet potato, *Casuarina oligodon* and three grain legumes. These trials were done to identify soil nutrients limiting crop growth.
2. Organic fertilizer trials. Three compost trials with sweet potato; an *Azolla*, pig manure and coffee pulp trial with sweet potato; and an *Azolla* trial with taro were conducted.
3. Evaluation of introduced sweet potato cultivars, other introduced food crops and crop rotation trials. The following trials were done: three sweet potato cultivar trials; a comparison of five grain legumes; evaluation of potato, cassava and pigeon pea as new food crops; and three rotation trials evaluating a peanut/sweet potato rotation.

INORGANIC FERTILIZER TRIALS

SWEET POTATO FERTILIZER TRIAL

This trial was conducted to define what nutrient imbalances and deficiencies occur in the continuously cropped sweet potato gardens. Inorganic fertilizers have no role in the agricultural systems of the Plateau because people cannot afford them.

Materials and methods

The aim of the trial was to define the limiting nutrients for sweet potato cultivation on Plateau soils. The method used (Mukerjee 1963) involves locating each replicate on a uniform soil type and slope in different farmers' fields. All of the replicate sites had been cropped continuously with sweet potato from 7 to 30 years and represented a spectrum of typical sweet potato gardens.

A factorial design with 7 replicates and the following treatments was used: 3 levels of nitrogen, 2 of phosphate, 2 of potash, 2 of minor elements and 2 of boron ($3N \times 2P \times 2K \times 2M \times 2B$). Treatment details are given in *Table 1*. The boron levels in the B treatment and the minor element treatment were adjusted to give identical per plot values (1.5 kg B/ha), which effectively gave three boron treatments of 0 (M_0B_0 plots), 1.5 (M_0B_1 and M_1B_0 plots) and 3.0 (M_1B_1 plots) kg B/ha. The boron treatment was added after a boron deficiency was proven on *Casuarina oligodon* on the Plateau. Symptoms of boron deficiency on sweet potato (Nusbaum 1946) have also been observed on the worst soils on the Plateau.

Treatments were randomized within each replicate. Plot size was 5 m^2. The area covered by a single replicate at each site was 240 m^2. No guard rows were used. Seven replicates were planted with a local cultivar (Sumbil), at a density of 24,000 cuttings/ha. Terminal cuttings 30 cm long were used.

Residues of the previous sweet potato crops were removed, the soil cultivated by hand, fertilizer applied, the traditional rectangular mounds

Table 1.–**Treatments used in sweet potato inorganic fertilizer trial**

Nutrient	Treatment	Fertilizer	Nutrient % of fertilizer	Rates of element applied
Nitrogen	N_0,N_1,N_2	Urea	46	0,75,150 kg N/ha
Phosphorus	P_0,P_1	Triple superphosphate	25	0,75 kg P/ha
Potassium	K_0,K_1	Muriate of potash	56	0,75 kg K/ha
Minors	M_0,M_1	Minors mixture	(1)	0,454 kg compound/ha
Boron	B_0,B_1	Borax	10	0,1.5 kg B/ha

Note: 1 Minor element mix contained 3.8% Mg, 4.8% Fe, 2.8% Zn, 1.2% Mn, 2.5% Cu, 0.33% B, 0.05% Mo, 0.01% Co plus sulphur. This gives application rates of 17.3 kg Mg/ha, 21.8 kg Fe/ha, 12.7 kg Zn/ha, 5.4 kg Mn/ha, 11.4 kg Cu/ha, 1.5 kg B/ha, 0.2 kg Mo/ha and 0.05 kg Co/ha.

formed and the runners planted. Regular hand weeding was done by the farmers until a good ground cover was established. The only pest or disease problem was minor infestation of sweet potato scab caused by the fungus *Elsinoe batatas* Jenkins and Viegas. Rainfall during the growing period (28 weeks) was 1690 mm.

At harvest marketable tuber weight (tubers over 100 g in weight), number of marketable tubers, total tuber weight and top growth weight (stem, petioles, leaves) were recorded per plot. A month prior to harvest, leaf samples were taken from 12 selected treatments, as follows: $N_{(0,1,2)}P_0K_0M_0B_0$, $N_{(0,1,2)}P_0K_1M_1B_0$, $N_{(0,1,2)}P_1K_0M_0B_1$ and $N_{(0,1,2)}P_1K_1M_1B_1$. The sampling scheme was a quarter fractional replicate with aliases of boron/phosphate and minor nutrients/potash. Ten leaf blades were collected from the first fully expanded leaf for each treatment above for all replicates. Samples were oven-dried at 40°C and a composite sample formed for each treatment from the seven replicates. Kjeldhal's digestion was used for nitrogen and nitric perchloric acid for all other elements (P, K, S, Ca, Mg, Na, Fe, Mn, Zn, Cu, B).

Results

Nitrogen had no significant effect on tuber or top growth yield (*Table 2*). Phosphate gave a small but significant increase in marketable and total tuber yield. Potash resulted in large and highly significant increases in tuber number, marketable and total tuber yield and top growth yield and an increase in mean tuber weight (260 to 300 grams). The minor elements significantly increased top growth yield. Boron depressed total tuber yield and increased top growth yield.

Applied potassium resulted in a large and significant increase in the leaf potassium content (*Table 3*). There was an apparent significant reduction in leaf Mg level in the minor fertilizer treatment. Boron fertilizer gave a large and significant increase in the boron level in the leaves.

Discussion

Nitrogen. The failure of nitrogen to increase vine yield was unexpected. These results are inconsistent with those reported elsewhere (Tsuno, no date; Bourke 1977). It is possible that the cultivar used (Sumbil) does not respond to nitrogen fertilizer, as certain cultivars in the highlands have been found to be unresponsive to N (W. Akus, pers. comm.). Alternatively, soil N levels may be adequate for top growth production.

Results of the leaf analysis (*Table 3*) show no significant increase in leaf

Table 2.–**Effect of inorganic fertilizer on sweet potato tuber and vine yield**

Treatment	Number of marketable tubers ('000/ha)	Marketable tuber yield (t/ha)	Total tuber yield (t/ha)	Top growth yield (t/ha)
N_0	31.3	8.1	9.1	20.8
N_1	32.4	7.9	8.9	21.0
N_2	30.2	7.6	8.7	22.8
P_0	30.3	7.4	8.5	20.8
P_1	32.3	8.3	9.4	22.3
K_0	26.1	5.8	6.8	16.9
K_1	36.5	9.9	11.0	26.2
M_0	32.2	8.1	9.2	20.4
M_1	30.4	7.6	8.6	23.5
B_0	33.6	8.3	9.4	20.3
B_1	31.4	7.9	9.0	21.7
B_2	28.8	7.3	8.3	24.0
Significant effects	K***	P* K***	P* K*** B*	K*** M** B**
L.S.D. (0.05) N	4.68	0.90	0.94	2.49
L.S.D. (0.05) P,K,M	3.82	0.74	0.77	2.04
L.S.D. (0.05) B	5.40	1.04	1.09	2.88
C.V. (%)	57	44	40	43

Table 3.–**Level of nutrients in sweet potato leaf blades versus rate of applied fertilizer**

Treatment	N (%)	P (%)	K (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)
N_0	4.7								
N_1	4.7								
N_2	4.8								
P_0		0.31							
P_1		0.31							
K_0			1.38						
K_1			1.81						
M_0				0.87	405	22.5	85	19.5	
M_1				0.75	450	23.5	89	19.0	
B_0									36
B_1									61
B_2									78
Level of significance	n.s.	n.s.	***	*	n.s.	n.s.	n.s.	n.s.	***
L.S.D. 0.05	0.4	0.02	0.17	0.11	97	1.6	16	1.6	7
C.V. (%)	5.5	5.4	8.1	10.0	17.6	5.7	13.9	6.5	5.8

nitrogen levels with application of N which is consistent with the lack of a response by tubers and top growth. N levels recorded in the leaves were above 4 per cent which is well above the critical limit for nutrient deficiencies (*Table 4*; Hahn 1977; Tsuno, no date). Soil analyses from sweet potato gardens on the Plateau (Wood 1984) indicate that soil N levels are adequate, although some problems of unavailability of N are possible because of a high C:N ratio (*Table 5*).

Phosphorus. The small response in tuber yields to phosphate (*Table 2*) is consistent with other work in Papua New Guinea where small yield responses to P have been recorded (Bourke 1977; Kimber 1982). The high level (over 0.3 per cent on a dry matter basis) of P in leaf tissue and the failure of applied P to increase leaf P levels also suggests that soil phosphate levels are adequate for sweet potato growth (*Tables 3* and *4*).

Potash. Potash application, even at the moderately low rate of 75 kg K/ha, increased tuber yield and top growth by almost 60 per cent. This suggests that the sweet potato soils of the Plateau are deficient in potash. The large increase in top growth is unexpected as top growth responses to K are usually small (Bourke 1977; Tsuno, no date).

Further evidence for a potash deficiency comes from the increases of K levels in leaves with increasing levels of applied K (*Table 3*). The leaf values of 1.4 to 1.8 per cent are high compared with critical leaf concentrations for potash of 0.5 to 0.75 per cent (*Tables 3* and *4*) but below the level of about 2.7 per cent for leaf blade at maturity given by Tsuno (no date). Soil analysis

Table 4.—**Critical concentrations of nutrients in sweet potato leaves for nutrient deficiency symptoms to occur (% dry weight basis)**

Material	N	P	K	Mg	Ca	S	Source
Stems and leaves	2.5	0.12	0.75	0.16	0.2	0.08	Spence and Ahmad (1967)
Leaf blade	1.5	0.10	0.5	0.05	0.2	0.08	Bolle-Jones and Ismunadji (1963)

Table 5.—**Chemical composition of black topsoil from sweet potato gardens, Nembi Plateau (adapted from Wood 1984)**

Parameter	Mean value	Comments on levels
pH	5.5	Somewhat acidic
Avail. P (ppm)	5.0	Low
Exch. Ca (m.e.%)	6.7	Medium
Exch. Mg (m.e.%)	2.6	Medium
Exch. Na (m.e.%)	0.3	Low
Exch. K (m.e.%)	0.2	Low
Total exch. bases (m.e.%)	9.9	Medium
C.E.C. (m.e.%)	56.3	Very high
Base saturation (%)	18	Low
Organic carbon (%)	8.2	High
Total N (%)	0.61	High
C:N ratio	13.5	Slightly high. May restrict N uptake
Mg:K ratio	13	High. Likely to restrict K uptake
Ca+Mg:K ratio	47	Very high. Likely to restrict K uptake

(Wood 1984) also indicates low soil K levels in sweet potato gardens and the possibility of magnesium and calcium antagonism (*Table 5*).

Minor elements. Top growth yield was increased significantly by applied minor elements (Mg, Fe, Zn, Mn, Cu, B, Mo, Co, S) (*Table 2*). However, there was no indication from foliar analysis that increased uptake occurred for any applied micronutrient except boron. The increase in top growth yield to the applied micronutrients is likely to be a response to the boron in the mix.

Boron. Boron fertilizer gave a significant increase in top growth yield and a significant decrease in total tuber yield (*Table 2*). Leaf analysis indicated that a large and statistically significant uptake of B occurred (*Table 3*). Eaton (1944, cited by Chapman 1973) gives boron levels in sweet potato tops of 16 ppm for deficiency, 118 ppm as medium and 310 to 1410 ppm as toxic. However, average levels of boron in sweet potato leaves in the Pangia, Tari and Upper Mendi areas of the Southern Highlands are in the range 25 to 34 ppm (n = 44) (M. Anders, pers. comm.). Thus the level in the control treatment in this trial of 36 ppm may be within the normal range and a toxic uptake of boron may have led to the reduced tuber yield.

CASUARINA BORON TRIAL

Casuarina oligodon trees on the Plateau display marked symptoms of boron deficiency including severe stunting and shortening of internodes and tip dieback giving the trees a characteristic, round, bushy appearance. Borax was applied to five affected casuarina trees with severe symptoms growing adjacent to the Plateau access road. Symptoms are generally more severe adjacent to roadsides because the plants are growing in subsoil transported during road construction. The borax was applied at a rate of 30 g per tree (3 grams B/tree). Adjacent trees were left as controls.

Treated trees grew more than twice as tall (an average of 115 per cent in height) compared with the control trees over a growth period of 20 months. This result occurred on the poorest soils containing the least organic matter. A more modest response by casuarina would be expected on slopes used for sweet potato gardens and possibly no response to B on doline and valley floors where casuarina are most common.

LEGUMES FERTILIZER TRIAL

A third trial was conducted to investigate the application of a minor element mixture and boron on the yields of peanuts (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* (L.) Walp. *unguiculata*) and winged beans (*Psophocarpus tetragonolobus* (L.) DC.). These species were considered as possible rotation crops in sweet potato gardens. A randomized block design was used with 10 replicates, although some plots were lost and the final replicate number harvested varied from 8 to 10. Plot size was 6 m^2. Plots were planted in existing sweet potato gardens. Cultivars used were Virginia Bunch Upright, Gutpela Cowpea and UPS 122 for peanuts, cowpea and winged beans respectively. The minor element mix was applied at 165 kg/ha and borax (11% B) at 3.3 kg B/ha. The minor element mix contained 2% MgO, 2% Fe, 2% Zn, 1.5% Mn, 0.5% Cu, 0.5% B plus molybdenum and cobalt.

None of the applied fertilizer had a significant effect on crop yield (*Table 6*). Yields of cowpea and winged bean were low and variability high. Highly variable soil fertility and uneven germination of the winged bean was responsible for the variable crop yields.

Table 6.—**Effect of minor elements and boron on yield of peanuts, cowpea and winged bean (kg/ha)**

Crop	Control	Minor elements	Boron	Significant effects	L.S.D. (0.05)	C.V.
Peanuts	1010	1240	1120	n.s.	200	17
Cowpea	400	490	520	n.s.	150	34
Winged beans	90	140	100	n.s.	80	65
Winged bean tubers	2420	1670	1760	n.s.	1400	66

CONCLUSIONS

Results of a single fertilizer trial supported by leaf and soil analysis data indicated a severe potassium deficiency in sweet potato soils of the Nembi Plateau. A small response to phosphate fertilizer by sweet potato tubers indicates a minor P deficiency also exists. The wide dispersal of the replicates and the large increase in tuber yield following potash application give confidence in the results obtained. The very low sweet potato yields recorded on the Plateau in subsistence gardens are likely to be caused by a potassium deficiency. Fertility maintenance techniques of composting with material rich in potash, such as coffee pulp, and crop rotations are necessary to correct the potash deficiency so as to increase sweet potato yields.

A boron deficiency was also identified in *Casuarina oligodon*, although boron fertilizer reduced sweet potato tuber yields in the field experiment. This deficiency has implications for crops that are particularly susceptible to B deficiency, in particular *Casuarina* and *Pinus*.

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INTENSIFICATION OF SUBSISTENCE AGRICULTURE ON THE NEMBI PLATEAU, PAPUA NEW GUINEA
2. ORGANIC FERTILIZER TRIALS

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ABSTRACT

*Four sources of organic fertilizer were compared as part of a research programme to find means of intensifying subsistence agriculture on the Nembi Plateau. The organic fertilizers tested were: compost formed within sweet potato (*Ipomoea batatas *(L.) Lam.) mounds using the technique that is traditional in the Papua New Guinea highlands but not widely used in the study area; the aquatic nitrogen fixing fern* Azolla pinnata *R. Br.; pig manure; and coffee pulp. The following were conducted: (a) three sweet potato rate-of-compost application trials, (b) a sweet potato organic fertilizer trial that compared* Azolla pinnata, *pig manure and coffee pulp, (c) a trial evaluating the effect of* Azolla pinnata *and soil cultivation on taro (*Colocasia esculenta *(L.) Schott) in a drained doline.*

Large responses were obtained to compost in each trial. An optimum economic application rate of 33 t/ha of fresh organic matter was indicated. A lower application rate of 20 t/ha is recommended for the Plateau. Azolla pinnata *did not increase taro yields and resulted in a non-significant increase in sweet potato yield. Pig manure gave a significant yield response when applied to sweet potato and had a positive residual effect on sweet potato yield in a demonstration plot. Coffee pulp gave the largest increase in sweet potato yields. Examination of the major nutrients supplied in the sweet potato trial suggests that the response was due mostly to potash contained in the various organic fertilizers. Limitations on the usage of various organic fertilizers are discussed.*

The use of compost and coffee pulp as fertilizers should be promoted in sweet potato gardens on the Plateau. Pig manure will have an important role in improved farming systems, but further research is needed on this and also on the usefulness of Azolla pinnata.

INTRODUCTION

This paper reports on trials to evaluate organic fertilizers which are available on the Nembi Plateau: compost, pig manure, coffee pulp and *Azolla pinnata*. Compost is used by villages to fertilize sweet potato in other parts of the Southern Highlands and Enga Provinces, but the practice is uncommon on the Nembi Plateau. Pig manure is abundantly available around houses and along walking tracks in the village and garden area, but it is not used by villagers to fertilize sweet potato in Papua New Guinea. Earlier work has shown that pig manure increases sweet potato yields (Kimber 1982). A limited amount of coffee is grown as a cash crop on the Plateau and the pulp of the

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cherry is available from village processing. Coffee pulp has been shown to increase sweet potato yields (B.F. Siki, unpublished data). *Azolla pinnata* is a small floating aquatic fern. It has a nitrogen-fixing, blue-green alga (*Anabaena azollae* Strasburger) living within the cavities of its leaves. *Azolla* is extensively used as an organic fertilizer in paddy rice cultivation in China and Vietnam (FAO 1977). It grows on ponds on the Nembi Plateau, entirely covering the water surface in some locations.

The experiments are described under the following three groups:

Series A. Sweet potato compost trials.
Series B. Sweet potato organic fertilizer trials (*Azolla*, pig manure and coffee pulp).
Series C. Taro organic fertilizer trial (*Azolla*).

SERIES A. SWEET POTATO COMPOST TRIALS

Composting of sweet potato is practised in much of the Southern Highlands and Enga Provinces (D'Souza and Bourke 1982). In the Wapenamanda area of Enga Province large sweet potato mounds are broken open after the final harvest of the sweet potato crop and sweet potato vines, weeds, leaves of sugarcane (*Saccharum officinarum* L.) and *Setaria palmifolia* (Koenig) Stapf are placed in a hollow in the mound. After about 10 weeks, the mound is reformed and planted with sweet potato (Waddell 1972). Waddell recorded that 20.2 kg of fresh organic matter were applied per mound. At Waddell's quoted mound density of 840 mounds per hectare, this gives an application rate of 17.0 t/ha of fresh material. At a high altitude location in the Kandep area, P. Wohlt (pers. comm.) recorded that the application rate of green matter for compost was 25 kg per mound and people make 1160 mounds per hectare, giving an application rate of 29.0 t/ha. On the Nembi Plateau levels of organic matter applied to form compost are low. Our measurements of nine composted gardens indicate a mean application rate of 4.8 t/ha (fresh weight).

Materials and methods

Three trials were conducted in sweet potato gardens on Humic Brown Clay soils (*Table 1*). The sites had been cropped continuously with sweet potato for 8, 20 and 12 years respectively, prior to the trials. Typical Nembi rectangular mounds were used. Thus, any treatment response would be due solely to composting, not to different shaped or sized mounds. Soil from the centre of the rectangular mound was dug out leaving a hollow for grass emplacement. Fresh grass of *Ischaemum polystachyum* Presl was cut and placed in the hollow. A different cultivar was planted in each trial. The three cultivars used represent between them some 62% of cuttings planted in sweet potato gardens on the Plateau (*Table 1*).

The trials were harvested once only and the total tuber weight recorded. The weight of sweet potato top growth was recorded in Trial 3 only. Samples of *Ischaemum* for chemical analysis were collected from an old sweet potato garden, a doline floor and the edge of a current sweet potato garden.

Results

The samples of *I. polystachyum* gave a mean fresh weight yield of 76.4 t/ha with a moisture content of 63.4%. The chemical composition (dry weight basis) was 1.03% N, 0.13% P, 0.99% K, 0.12% S, 0.31% Ca, 0.22% Mg, 108 ppm Fe, 127 ppm Mn, 40 ppm Zn, 33 ppm B and 5 ppm Cu. The quantity of N, P and K supplied in the various treatments and the sweet potato tuber yields are given in *Table 2*.

Table 1.–**Sweet potato compost Trials 1, 2, 3: materials and methods used**

Materials and methods	Trial 1	Trial 2	Trial 3
Trial design	Completely randomized	R.B.D.(1)	R.B.D.
No. of replicates	5	7	7
Plot size (m^2)	5	4	4
Cultivar used	Sokol	Gonime	Peripam
Proportion of this cv. in village gardens (%)	38	7	17
Planting density (cuttings/ha)	50,000	125,000	22,500
Treatments (t/ha fresh grass)	0,12,24,36	0,10,20,30	0,10,20,30,40
Period between placing grass and closing mounds/planting (weeks)	0	6	7
Crop duration (weeks)	23	25	26
Rainfall during crop (mm)	1010	1460	1380

Note: (1) Randomized block design

Table 2.–**Application rate of compost (fresh/dry weights); N, P, K content of applied compost; tuber yields; and top growth yield (Trial 3) in sweet potato compost Trials 1, 2, 3**

Applic. rate (fresh wt.) (t/ha)	Applic. rate (dry wt.) (t/ha)	Nutrients applied			Total tuber yield			Top growth yield Tr.3 (t/ha)
		N (kg/ha)	P (kg/ha)	K (kg/ha)	Tr.1 (t/ha)	Tr.2 (t/ha)	Tr.3 (t/ha)	
0	0	0	0	0	8.9	7.6	4.6	9.7
10	3.7	38	5	36		10.3	10.9	12.2
12	4.4	45	6	44	11.9			
20	7.3	75	10	73		12.7	16.0	16.3
24	8.8	90	11	87	13.7			
30	11.0	113	14	109		11.9	16.2	19.5
36	13.2	136	17	131	14.1			
40	14.6	151	19	145			18.4	20.5
Level of significance					**	n.s.	***	***
L.S.D. (0.05)					2.75	4.32	2.15	3.15
C.V. (%)					30	27	15	18

Compost gave large increases in tuber yield in all three trials (*Figure 1*). The response curve in all trials was quadratic, that is, sweet potato yield was increased by compost application initially, but with further application the rate of yield increase declined. Compost increased top growth significantly in Trial 3 (*Table 2*). A linear relationship was found between the rate of compost application and the top growth, as follows:

$$Y = 9.86 + 0.289x \qquad r = 0.985^{***}$$

where Y = top growth yield (t/ha) and x = application rate of compost (t/ha).

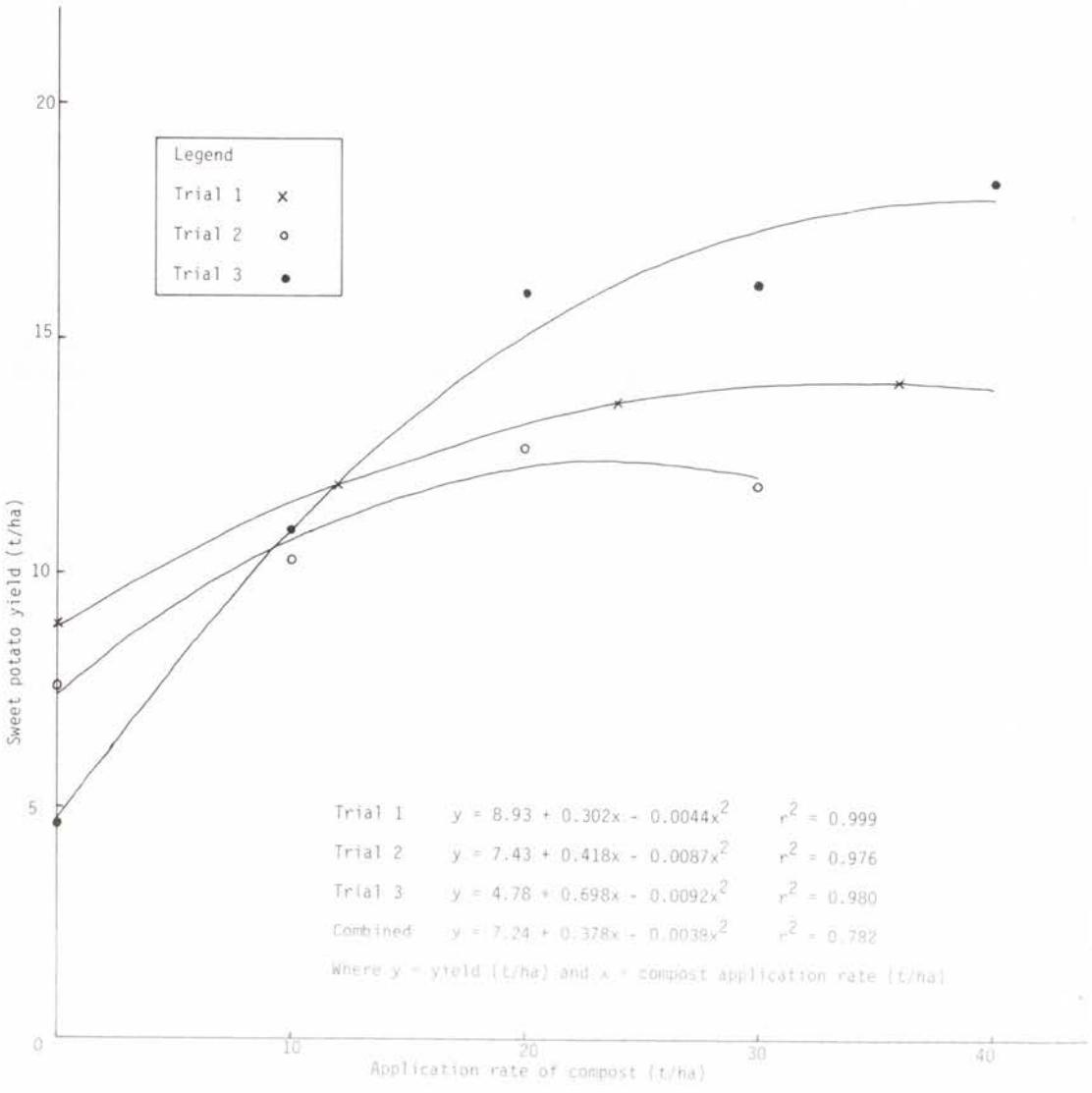

Figure 1.–**Sweet potato composting trials 1,2,3. Tuber yield (t/ha) vs application rate of fresh compost (t/ha)**

SERIES B. SWEET POTATO *AZOLLA*, PIG MANURE AND COFFEE PULP FERTILIZERS TRIAL

Materials and methods

This trial compared three sources of organic fertilizer for sweet potato. They were *Azolla pinnata*, pig manure and Arabica coffee pulp. Trial design was a randomized block with five replicates and four treatments. Plot size was 5 m^2. The treatments were control, *Azolla pinnata* at 30 t/ha, pig manure at 20 t/ha and coffee pulp at 30 t/ha. Average N, P and K composition of the organic fertilizers are given in *Table 3* and the application rate of these nutrients is presented in *Table 4*.

All of the organic fertilizers were applied as fresh material and were collected locally. Traditional rectangular mounds 50 cm high were constructed that ensured deep placement of the organic material. The local cultivar Sumbil was used. Terminal cuttings 30 cm in length were planted at a density of 22,500 cuttings per hectare.

A partial tuber harvest was made 24 weeks after planting and a final harvest at 42 weeks to simulate the local method of progressive harvesting. Recordings were made of marketable tuber yield (tubers heavier than 100 g) and total tuber yield at both harvests. Top growth yield was recorded at the second harvest. Rainfall during the crop life was 1920 mm.

Results

Marketable and total tuber yields and top growth showed a significant response to pig manure and coffee pulp (*Table 4*). Tuber and top growth yield in the *Azolla* treatment was not significantly greater than the control.

Regressions derived between the total tuber yield and top growth yield and the quantity of the major nutrients supplied in the organic fertilizer show a significant relationship between the rate of K applied and the tuber and top growth yields. The relationship was linear in the case of tuber yield (*Figure 2*) and quadratic for top growth (*Figure 3*). The quantity of nitrogen and phosphate applied in the organic fertilizers was not correlated with tuber yield. This suggests that the major effect from the organic fertilizers was from the potash contained in them.

Table 3. **Average moisture and major nutrient contents of three organic fertilizers (dry weight basis)**

Organic fertilizer	Moisture percentage	N (%)	P (%)	K (%)	Data source (1)
Azolla pinnata	90	2.32	0.16	1.0	(2)
Pig manure	79	2.70	1.52	1.89	(3)
Arabica coffee pulp	87	1.88	0.14	3.57	(4)

Notes: (1) The composition of organic fertilizers is dependent on the diet of the animals producing the manure or the nutritional status of plant material used. The material for analysis came from different locations and was analysed in different laboratories. For these reasons, the average compositions quoted are approximations only.
(2) Analysis done by University of Technology from sample collected at Aiyura.
(3) Average of three values given by FAO (1977) and Loehr (1974).
(4) Average of three values given by Barrie (1967), Hart (1960) and B.F. Siki, (unpublished data).

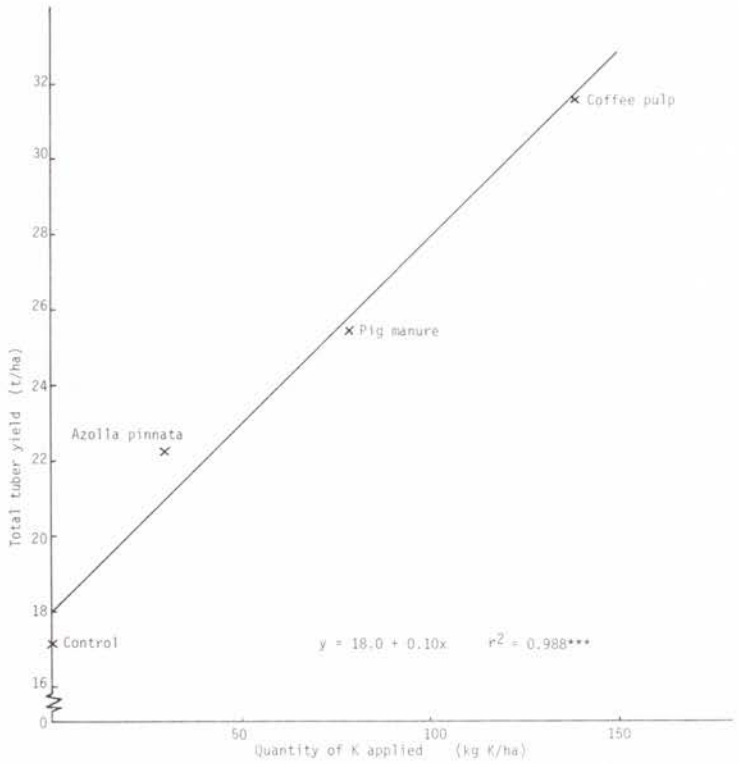

Figure 2.–**Sweet potato organic fertilizer trial. Total tuber yield (t/ha) vs quantity of potash applied in various fertilizers**

SERIES C. TARO *AZOLLA* FERTILIZER TRIAL

The objective of this trial was to assess the effectiveness of *Azolla pinnata* as an organic fertilizer on taro (*Colocasia esculenta* (L.) Schott.). The trial was located in a specific land type, a flooded limestone depression (doline). Thus any recommendation from the trial would be specifically for this land type which is common on the Plateau.

Materials and methods

An existing doline pond containing a dense cover of *Azolla pinnata* was carefully drained enabling the *Azolla* to settle on the pond floor. This natural seeding rate was measured at 30 t/ha of *Azolla* as fresh material. The soil in the doline was a heavy clay. A randomized block design was used with four replicates. Plot size was 5 m^2. Treatments were:

1. control (removal of *Azolla* from the surface); no soil cultivation
2. removal of *Azolla*; soil cultivated by spade to a depth of 25 cm
3. *Azolla* left on the surface; no soil cultivation
4. soil cultivated to 25 cm and *Azolla* incorporated into the soil.

After the pond was drained, the *Azolla* was left on the soil surface for two weeks and the treatments were applied. The experiment was then planted with setts of a local taro cultivar, Daylakae, at a density of 24,000 setts/ha. This is said to be a wetland cultivar. The crop was harvested at

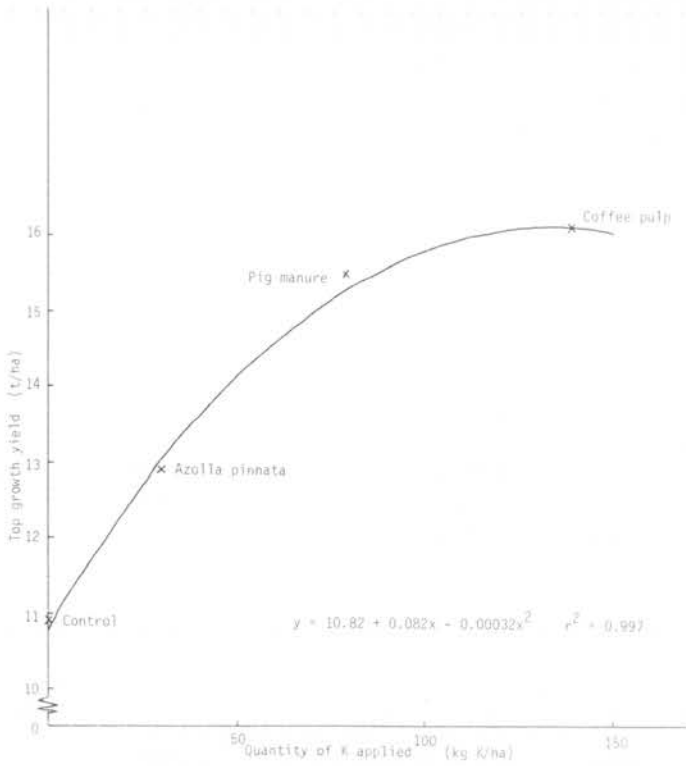

Figure 3.—**Sweet potato organic fertilizer trial. Top growth yield (t/ha) vs quantity of potash applied in various fertilizers**

nine months after planting. Corms were cleaned to edible portions before the yield was recorded.

Results

At this altitude, taro normally matures at 11 to 12 months. The early harvest was necessitated because of a number of disease and pest problems which did considerable damage to the crop, including a fungal attack suspected to be due to *Phyllosticta colocasiophila* Weedon, and infection by dasheen mosaic virus (D.P.I. Plant Pathology section, pers. comm.). Minor damage by taro beetle (*Papuana* spp) was observed at harvest.

The mean corm yield in the trial was 7.5 t/ha. There were no significant differences between treatments (*Table 5*). Nor were there visible differences in petiole and leaf dimensions between treatments during the crop's growth.

DISCUSSION

Compost

Compost made from freshly cut grass increased sweet potato yields in all three trials (*Table 2*). Its usefulness as an organic fertilizer is clearly indicated by these trials.

In order to calculate the optimum economic application rate of compost, it is necessary to know the 'cost' of gathering and transporting the organic material for the compost. At Aiyura, in an observation of labour inputs, 4.5 man-days were needed to cut and transport one tonne of fresh grass about

Table 4.– **Sweet potato organic fertilizer trial: application rate; N, P, K content of three organic fertilizers, marketable tuber yields, total tuber yields and top growth yields**

Organic fertilizer	Applic. rate (t/ha)	Nutrients applied N (kg/ha)	P (kg/ha)	K (kg/ha)	Yield Marketable tubers (t/ha)	Total tubers (t/ha)	Top growth (t/ha)
Control	–	0	0	0	16.4	17.1	10.9
Azolla pinnata	30	70	5	30	21.2	22.2	12.9
Pig manure	20	113	64	79	24.4	25.4	15.5
Coffee pulp	30	73	5	139	30.8	31.5	16.1
Level of significance					**	**	***
L.S.D. (0.05)					6.76	6.82	2.31
C.V. (%)					21	21	12

Table 5.– **Effect of *Azolla pinnata* (at 30 t/ha) and soil cultivation on taro yield**

Treatment	Yield edible corm (t/ha)
1. Control (*Azolla* removed)	8.3
2. *Azolla* removed; soil cultivated	6.9
3. *Azolla* left on soil surface; no cultivation	7.8
4. Soil cultivated and *Azolla* incorporated	7.0
Level of significance	n.s
L.S.D. (0.05)	2.55
C.V. (%)	21

100 metres. Wohlt (1978, pp. 131, 430 and pers. comm.) found in the Kandep area that about 33 woman-hours are required to gather and transport a tonne of organic matter for composting sweet potato mounds. This is about 4.2 woman-days/tonne. If a shadow value for people's labour is placed at K2 per day, compost 'costs' K9 per tonne. Our market survey data in 1979 to 1981 indicate that sweet potato is valued at about K70 per tonne (7 toea/kg) on the Plateau. These figures and the combined quadratic equation for the three trials (*Figure 1*) indicate that the optimum economic application rate of fresh organic matter is 33 t/ha.

There are two reasons why this economic optimum should not be recommended. Firstly, this calculation is strongly influenced by the very marked response in Trial 3. The lower response in the other two trials, which agree closely with each other, would indicate a lower optimum. Secondly, the use of an optimum economic application rate is only applicable if all of a grower's crop is to be treated with compost. In the Nembi Plateau situation, it is more likely that only part of the crop would receive compost in early stages of adoption. In this situation, it is better to apply compost at a lower rate as the tuber response is greater per tonne of compost applied at a lower rate. Accordingly we recommend an application rate of 20 t/ha, comparable with the

application rate being used in the nearby Enga Province.

Azolla

Azolla gave a non-significant increase in tuber and top growth yield of sweet potato (*Table 4*). It has no effect on taro yield (*Table 5*), though the yield potential may have been reduced by disease problems. Judging from the excellent initial growth of the taro crop, the site was inherently very fertile. It is possible that *Azolla* may have increased taro yields in all plots in this trial as the *Azolla* had been growing in the doline for many months before the trial.

Azolla grows only on a limited number of natural ponds, which restricts its potential as an organic fertilizer. Because of difficulties in transporting *Azolla* to gardens, any possible usage is likely to be restricted to locations near these ponds. These include taro and mixed vegetable gardens in or near dolines. *Azolla* is moderately rich in nitrogen on a dry weight basis (*Table 3*). It is thus more likely to be useful for crops that have a high requirement for N, such as taro or leafy green vegetables.

In the two trials in which it has been tested so far, *Azolla* has not been shown to have much potential as an organic fertilizer. However, it should be tested further, especially on crops that are grown in or near flooded dolines.

Pig manure

Pig manure increased sweet potato tuber and top growth yield (*Table 4*) confirming results obtained by Kimber (1982) in the Eastern Highlands. We calculate that there is sufficient pig manure available on the Plateau to fertilize 115 m^2 of sweet potato garden for every person. This is derived from the following data and assumptions: there is a pig to person ratio of 0.77:1 for the Puit clan (Bourke 1984); each pig produces 1000 kg of manure per year (A. Campbell and G. Malynicz, pers. comm.); 30 per cent of available pig manure can be recovered; pig manure is applied to sweet potato at a rate of 20 t per ha per year. The mean area of sweet potato cultivated per person is ca 400 m^2 per year (D'Souza and Bourke 1984). Hence a large proportion of the cultivated sweet potato could be fertilized by the available pig manure.

The disadvantage of pig manure as a fertilizer for sweet potato is that it is high in nitrogen and phosphate but only moderately rich in potassium (*Table 3*). Sweet potato has a high requirement for K, a lesser requirement for N and a low requirement for P (Tsuno, no date), and Plateau soils are deficient in potash for sweet potato, but nitrogen and phosphate levels are adequate (D'Souza and Bourke 1986).

The available pig manure may be better utilized by applying it to a crop with a high requirement for nitrogen and phosphate, such as corn. The corn could be grown in rotation with sweet potato to maintain the sweet potato yields. A demonstration plot of corn followed by sweet potato gave support to this concept. Pig manure was applied to corn at a rate of 22 t/ha. A control plot yielded 3.0 t/ha of corn whilst the fertilized plot yielded 5.2 t/ha. In the subsequent sweet potato crop, the plot that had previously received pig manure yielded 11.0 t/ha of tubers compared with the control plot yield of 4.5 t/ha. See *Plate I*.

Highlanders are said to have an aversion to pig manure which could preclude its use as a fertilizer for food crops. We observed however that village people stole tubers from our demonstration plots which they knew had

Plate 1.– **Corn fertilized with pig manure (left of figure) and unfertilized (right) on the Nembi Plateau. Pig manure increased the yield of corn and a subsequent sweet potato crop**

been fertilized with pig manure.

Further research is needed to examine the technical and social possibilities of using pig manure to fertilize sweet potato, either directly, or indirectly by fertilizing another crop grown in rotation with the sweet potato.

Coffee pulp

Coffee pulp applied to sweet potato at 30 t/ha gave the greatest increase in yield of all the organic fertilizers tested (*Table 4*), a result which confirms large responses by sweet potato to coffee pulp at Aiyura (Siki, in preparation). The nutrient composition of coffee pulp makes it an ideal fertilizer for sweet potato as it is rich in potash, moderately rich in nitrogen and low in phosphate (*Table 3*).

The potential of coffee pulp as a fertilizer on the Plateau is limited by the small quantities available. We calculate that only 11 kg of coffee pulp is available per person per year. This is calculated from the following data and assumptions: there is 0.0034 ha of coffee per person amongst Puit clan members (Bourke 1984); coffee yields 1140 kg/ha of parchment (Anderson 1977); the parchment to cherry ratio is 1:5.5 and the pulp to cherry ratio is 1:2. At a fertilization rate of 30 t/ha, this amount of pulp would fertilize only 4 m^2 of sweet potato per person per year. This is only about 1% of the area of sweet potato needed to support each person for a year.

All available coffee pulp on the Plateau should be used to fertilize sweet potato gardens. If there are no sweet potato gardens located near the site of pulping, the pulp should be used

on other crops, such as vegetables or bananas.

Effect of various organic fertilizers

Organic fertilizers with differing nutrient content were compared in the sweet potato organic fertilizer trial (Series B) to investigate which nutrients were most effective in increasing sweet potato yield. Responses cannot be definitely attributed to individual nutrients as each organic fertilizer contains a number of nutrients. Other benefits from the organic fertilizer, such as improved soil aeration, may also be influential.

Nevertheless, the very high correlations between the levels of potash applied in the various organic fertilizers and tuber and top growth yields suggest that the responses were due mainly to potash applied in the organic matter (*Figures 2* and *3*). *Figure 2* suggests that potash rates higher than the 140 kg K/ha applied in the coffee pulp treatment would give additional yield increases. This is consistent with results from the sweet potato inorganic fertilizer trial (D'Souza and Bourke 1986).

CONCLUSIONS

Compost, pig manure and coffee pulp have been shown to increase sweet potato yields. The technique of composting sweet potato gardens should be promoted on the Plateau. Fresh organic matter should be applied at a rate of 20 t/ha. All available coffee pulp should be used to fertilize sweet potato gardens or other crops.

Pig manure is likely to have an important role in improving crop yields, as it is available in large quantities in the villages. Further research is needed to identify its place in improved farming systems. A likely role may be as a fertilizer for non-root crops, particularly in mixed vegetable gardens, which are grown in rotation with sweet potato.

Azolla pinnata has not been shown to be a useful organic fertilizer, but further experimentation is needed before it can be dismissed because it may have a role where there are flooded dolines.

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INTENSIFICATION OF SUBSISTENCE AGRICULTURE ON THE NEMBI PLATEAU, PAPUA NEW GUINEA
3. SWEET POTATO CULTIVAR TRIALS; CROP ROTATION TRIALS; AND CROP INTRODUCTIONS

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ABSTRACT

*Three sweet potato (*Ipomoea batatas*) cultivar trials were conducted in village gardens on the Nembi Plateau. Local cultivars were compared with selections from Aiyura. The Aiyura selection, Markham 1, had the highest yield in all three trials. Its taste is acceptable to the villagers and its use should be promoted on the Plateau. In one of the cultivar trials plots were split for nematicide application as root knot nematode (*Meloidogyne *sp.) had been previously identified from sweet potato stems. No response to the chemical was obtained.*

*A second series of trials evaluated a number of species for use as rotation or fallow crops in sweet potato gardens. Five grain legumes were compared. These were cowpea (*Vigna unguiculata unguiculata*), peanut (*Arachis hypogaea*), rice bean (*Vigna umbellata*), soyabean (*Glycine max*) and winged bean (*Psophocarpus tetragonolobus*). Peanuts gave the highest yield and are acceptable as a supplementary food. Three rotation trials were then conducted to compare a sweet potato/peanut rotation with continuous planting of sweet potato. No beneficial effect was recorded for sweet potato crops that followed peanuts.*

*Three food crops that are presently not much used on the Plateau were evaluated. Potatoes (*Solanum tuberosum*) gave a mean tuber yield of 8.1 t/ha when grown in a trial that compared three micro environments. No significant difference between environments was found. Potatoes have potential as a food crop. Cassava (*Manihot esculenta*) plots planted on poor soils in sweet potato gardens yielded 2.2 t/ha. No potential is seen for cassava on these soils. Pigeon pea was grown in mixed garden soils and yielded reasonably well. It may have a role as a vegetable crop grown in mixed vegetable gardens.*

INTRODUCTION

This is the third paper in a series which deals with crop intensification techniques for subsistence agriculture on the Nembi Plateau. The experiments described in this paper are: Series A, Sweet potato (*Ipomoea batatas* (L.) Lam.) cultivar trials; Series B, Crop rotation trials; Series C, Crop introductions and evaluation.

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SERIES A. SWEET POTATO CULTIVAR TRIALS

Introduction

Introduction of new cultivars of a staple crop that are high yielding, of

acceptable taste to the people and have other desirable characteristics, is one of the best ways to improve subsistence agriculture. Two experiments were conducted to compare high yielding cultivars from the Highlands Agricultural Experiment Station at Aiyura with popular local cultivars. Members of the Puit clan on the Plateau grow 25 cultivars of sweet potato (Bourke 1984a), but only six of these cultivars account for 93 per cent of cuttings planted. These six cultivars were evaluated in Cultivar Trial 1 against six cultivars selected at Aiyura. In the second cultivar trial, another six introduced cultivars were compared with three of the more promising cultivars from Trial 1.

A crop of sweet potato that followed a winged bean (*Psophocarpus tetragonolobus* (L.) A.P. de Candolle) time-of-planting trial, was shown to be damaged by root knot nematode. Root knot nematodes (*Meloidogyne* sp.) were recorded from the basal parts of vines, prior to tuber formation. Consequently, in the third sweet potato cultivar trial which compared nine cultivars previously tested, plots were split for a nematicide treatment.

Materials and methods

In Trials 1 and 2, replicates were located in various farmers' fields (Mukerjee 1963). In Trial 3 the replicates were located next to each other. All blocks were located in typical sweet potato gardens. A randomized block design was used for Trials 1 and 2. A split plot design was used in Trial 3. There were 13 replicates in Trial 1, 10 replicates in Trial 2 and 4 replicates in Trial 3. Because of losses caused by pig damage and stealing of vines and tubers, only six replicates were used for analysis for Trials 1 and 2. A plot size of 5 m^2 was used in Trials 1 and 2, and 9 m^2 in Trial 3. The cultivars evaluated are given in *Tables 1, 2* and *3*. Terminal cuttings 30 cm long were used as planting material. Planting densities were 24,000 cuttings/ha in Trials 1 and 2 and 27,000 cuttings/ha in Trial 3. Traditional techniques of land preparation and mounding were used for all trials.

In Trial 3 each plot was split for a nematicide treatment and a control. The trial was located at a site that was infested with root knot nematode. The nematicide carbofuran was applied to the treated plots prior to planting at a rate of 3 kg a.i./ha.

Two harvests were made in Trials 1 and 2. The first was at 26 weeks after planting and the second was at 38 weeks. In Trial 3, a single harvest was made at 28 weeks. Total tuber yield was recorded in all trials and top growth yield in Trial 2. Tubers and vines were collected from Trial 3 at harvest to check for nematode infestation.

Results

Statistically significant differences between cultivars were obtained in all three trials (*Tables 1, 2* and *3*). The cultivar Markham 1 from Aiyura yielded the highest in all three trials. No statistically significant yield response was found to nematicide application and material collected from control plots was not infested with nematodes (D.P.I. Plant Pathology Section, pers. comm.).

Discussion

These results indicate that Markham 1 is high yielding and displays a stable yielding pattern. It has good cooking and eating qualities. Following its introduction to the Plateau for these trials, planting material came into great demand by the villagers who recognized its value. Planting material and tubers were selectively stolen from our trials. Further information on this cultivar and other releases from Aiyura is given by Akus (1982). An immediate programme of distribution

Table 1.–**Sweet potato cultivar Trial 1. Origin of cultivars and tuber yields**

Cultivar	Origin	Tuber yields (t/ha)		
		1st harvest	2nd harvest	Total yield
Markham 1	H.A.E.S., Aiyura	11.3	2.2	13.6
Sokol	Nembi Plateau	10.5	2.3	12.8
Sumbil	Nembi Plateau	9.9	2.7	12.6
Ma'alua	H.A.E.S., Aiyura	9.1	2.8	11.9
Goroka	Nembi Plateau	9.2	2.3	11.4
Naveto	H.A.E.S., Aiyura	8.0	3.3	11.3
Kiko	Nembi Plateau	7.5	1.2	8.7
Merikan	H.A.E.S., Aiyura	7.7	0.8	8.5
Peripam	Nembi Plateau	6.2	1.7	7.9
Wanmun Kabiufa	H.A.E.S., Aiyura	5.9	0.6	6.5
Gonime	Nembi Plateau	3.8	1.6	5.4
Serenta (large leaf type)	H.A.E.S., Aiyura	1.5	0.2	1.6
Level of significance		**	*	**
L.S.D. (0.05)		4.41	1.84	5.35
C.V. (%)		51	89	50

Table 2.–**Sweet potato cultivar Trial 2. Origin of cultivars, tuber and top growth yields**

Cultivar	Origin	Tuber yields (t/ha)			Top growth yield (t/ha)
		1st harvest	2nd harvest	Total yield	
Markham 1	Aiyura	11.1	5.1	16.2	8.6
Tumun	Mt Hagen	6.5	3.2	9.7	10.8
Merenge	Aiyura	2.8	6.8	9.6	21.7
Mata	Aiyura	6.3	2.2	8.5	8.5
Sokol	Nembi	4.9	3.4	8.3	27.5
Serenta (small leaf)	Aiyura	5.4	2.6	8.0	7.1
Naveto	Aiyura	4.0	1.9	5.9	20.2
Deka	Aiyura	1.0	4.1	5.1	21.5
Kani	Aiyura	3.1	1.3	4.4	3.3
Level of significance		**	n.s.	*	***
L.S.D. (0.05)		4.40	4.30	6.90	9.50
C.V. (%)		74	107	70	59

of planting material of this cultivar should be initiated on the Plateau.

The local cultivar Sokol is the most popular on the Plateau (Bourke 1984a) and accounts for some 38 per cent of all cuttings planted. This cultivar performed unevenly in the trials with a rank of second, fifth and seventh in the three trials respectively. The Nembi cultivar Sumbil was the third highest yielding in Trial 1 and the fourth highest in Trial 3. A number of the cultivars tested matured later than the others, as shown by the higher yields in the second harvest relative to the first. This applied to Merenge and Deka.

None of the other introduced cultivars yielded consistently well. Those

Table 3.–**Sweet potato cultivar Trial 3. Tuber yields (t/ha)**

Cultivar	Tuber yield
Markham 1	12.6
Naveto	8.6
Goroka	8.4
Sumbil	7.3
Merenge	6.3
Ma'alua	6.1
Wanmun Kabiufa	5.9
Sokol	4.9
Gonime	3.0
Level of significance	***
L.S.D. (0.05)	3.2
C.V. (%)	37

that performed reasonably well such as Tumun, Naveto and Merenge should be tested further. The later maturity of Merenge would spread tuber production over a longer period, an advantage in a mixed cultivar situation. Tumun was introduced to the Plateau by students of the Highands Agricultural College in 1976. Some of the other introduced cultivars that performed reasonably well were already present on the Plateau under different names. This applies to Mata and Ma'alua which are known as Erave and Balus respectively.

SERIES B. ROTATION TRIALS

A number of grain legumes were evaluated for suitability as rotation/fallow crops in the sweet potato gardens. Peanuts were identified as the most suitable species. The effectiveness of a peanut/sweet potato rotation in increasing sweet potato yields was then tested.

GRAIN LEGUME EVALUATION

Materials and methods

The following grain legumes were tested as potential rotation crops with sweet potato: cowpea (*Vigna unguiculata* (L.) Walpers var. *unguiculata*), peanut (*Arachis hypogaea* L.), rice bean (*Vigna umbellata* (Thunberg) Ohwi and Ohashi), soyabean (*Glycine max* (L.) Merrill), and winged bean (*Psophocarpus tetragonolobus*). Four to eight plots (5 m^2 in area) of each species of grain legume were planted in existing sweet potato enclosures. Planting densities were 111,000 seeds/ha for peanut; 250,000 seeds/ha for cowpea, rice bean and winged bean; and 333,000 seeds/ha for soyabean. Cultivars used are given in *Table 4*. Observations were made on pest and disease problems. Grain weight was recorded on an air-dry weight basis at crop maturity.

Results and discussion

Peanuts clearly out-yielded other species tested (*Table 4*). The yields obtained (1100–1200 kg/ha) are reasonably high. Kimber (1974) has shown that the cultivar used, Virginia Bunch, out-yields White Spanish in the highlands. Peanuts are also a very popular food amongst the people on the Plateau although they are only grown infrequently at present.

The following pest and disease problems were identified: root knot nematode (*Meloidogyne* sp.) on winged bean; the fungi *Phyllosticta* sp. and *Cercospora* sp. on cowpea; and a minor infestation of *Colletotrichum* sp. on peanuts. Symptoms of bean fly (*Ophiomyia phaseoli* Tryon) damage were identified on cowpea and winged

bean. Winged beans were also damaged extensively by an unidentifiable leaf miner. We have no data on how these organisms affected yield.

PEANUT/SWEET POTATO ROTATION TRIALS

Peanuts and winged beans are widely used as rotational crops with sweet potato in parts of the Eastern Highlands and Western Highlands Provinces. In the Aiyura Valley of the Eastern Highlands, for example, the village gardeners insist that peanuts restore sweet potato yields when the two crops are grown in a rotation. Having identified peanuts as the most suitable grain legume for the Plateau, the effectiveness of a peanut/sweet potato rotation was then examined in a series of trials.

Materials and methods

Trial sites were located in typical Nembi Plateau sweet potato gardens. The trials followed crops of sweet potato in all cases. Treatments were:

1. *Control.* Sweet potato crop followed by sweet potato. This is the traditional practice in the area.
2. *Rotation treatment.* Peanut crop followed by sweet potato.

Three trials were conducted over one rotation. The experimental design was a randomized block design with ten replicates in Trials 1 and 2 and five replicates in Trial 3. Plot size was 5 m^2 for each trial. Peanut cultivar Virginia Bunch Upright was planted at 120,000 seeds/ha in the first cycle. Sweet potato cultivar Sokol was planted at a density of 24,000 cuttings/ha.

On completion of the first crop, peanuts and sweet potato were harvested simultaneously. In Trial 1 the trash was removed, the plots reworked and immediately planted with sweet potato. In Trial 2 the trash was returned to plots from which it was taken at the end of the first crop. In Trial 3 all trash was returned and potash fertilizer was applied to all plots at a rate of 100 kg K/ha because the first sweet potato crop displayed typical potash deficiency symptoms and failed to yield a crop.

Results and discussion

No statistical difference in yield between the two treatments was found in any of the trials (*Table 5*), which suggests that a peanut/sweet potato rotation does not improve sweet potato yields on the Nembi Plateau. The environments in the Eastern and Western Highlands where a peanut/sweet potato rotation is widely used are drier than the Nembi Plateau, which may be significant in explaining the contrast between these results and growers' experience elsewhere in the highlands.

Despite these results, peanuts should be recommended for planting within the sweet potato gardens. It is likely that protein as well as energy is deficient in the villagers' diet and both protein and calorie intake must be increased to improve nutritional status (Heywood and Nakikus 1982; P. Heywood, pers. comm.). Peanuts are a popular food and are high in protein. Planting of small crops of peanuts between successive sweet potato crops is not likely to reduce sweet potato, and hence calorie, production greatly, particularly if the peanuts replace a sweet potato cover rather than a producing crop.

SERIES C. CROP INTRODUCTIONS

A number of crops that are rarely grown on the Plateau were introduced and evaluated. The species selected were potato (*Solanum tuberosum* L.), cassava (*Manihot esculenta* Crantz), and pigeon pea (*Cajanus cajan* (L.)

Table 4.–**Yields of five species of grain legumes in grain legume evaluation plots and grain legume minor elements fertilizer trial**

Legume species	Cultivar used	Yield of air dry grain (kg/ha)	
		Grain legume trial	Fertilizer trial (1)
Peanuts (2)	Virginia bunch	1230	1120
Rice bean	Local	450	–
Cowpea	Gutpela	280	470
Soyabean	Yellow	260	–
Winged bean (3)	Local/UPS122	40	110

Notes: 1 After D'Souza and Bourke (1986a)
2 Peanut yields are recorded as shelled nuts
3 A local Nembi cultivar of winged bean was used in the grain legume yield trial and UPS122 was used in the fertilizer trial. In the fertilizer trial, winged bean also yielded 1530 kg/ha of edible tubers.

Table 5.–**Sweet potato rotation Trials 1, 2, 3. Tuber and top growth yields**

Treatment	Total tuber yield (t/ha)			Top growth yield (t/ha)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
After sweet potato	0.86	4.9	5.3	4.5	8.0	20.3
After peanuts	0.91	5.8	4.8	4.5	6.9	18.4
Level of significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
L.S.D. (0.05)	0.31	1.51	2.66	0.58	1.47	4.11
C.V. (%)	34	28	30	13	20	12

Millspaugh). Potato and cassava are of interest because potato is quick-maturing and cassava does not have a fixed maturity period and tubers can be stored in the ground. Both crops may have a role in reducing the effect of variability in sweet potato supply. Cassava could be used as pig feed when the supply of sweet potato is inadequate. Pigeon pea produces a high protein bean and pulse.

POTATOES

Materials and methods

A trial was planted with various locations serving as treatments. The locations were:

1. Upper slopes of hillside sweet potato gardens;
2. Middle slopes of hillside sweet potato gardens;
3. Doline floors planted to mixed garden or under fallow.

A randomized block design was used with five replicates. Plots were 8 m^2 in area. Setts of the recommended D.P.I. cultivar, Sequoia (Nitschke and Nitschke 1982), were planted at a density of 25,000 setts/ha.

Results and discussion

The crop matured in 12 weeks. Yields for the three treatments were 7.5, 8.4 and 8.4 t/ha respectively. Differences between treatments were not statistically significant. Three of the five replicates were affected by bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith). Affected tubers were not in-

cluded in yield assessments. Minor incidence of target spot, caused by the fungus *Alternaria solani* Sorauer, also occurred.

The failure of plots planted on the doline floor to out-yield plots in sweet potato slope gardens was unexpected. Soil fertility is higher on the doline floors (Wood 1984) but this result may have occurred because soil nitrogen was unavailable in these soils as the crop followed immediately after a grass fallow.

The mean yield of 8.1 t/ha is reasonably high for an unfertilized crop when the low fertility of the soils is considered. A potato yield of 8 t/ha in 12 weeks is better than sweet potato yields of 6–7 t/ha from 23–28 weeks, but bacterial wilt may be a serious constraint. Potatoes have a role in farming systems on the Plateau as a quick maturing root crop that could supply food when sweet potato is in short supply.

CASSAVA

Four plots of cassava each 30 to 50 m^2 in area were planted in sweet potato gardens at a density of 10,000 setts/ha. The plots were located at the top of gardens on the poorest soils. The variety was a popular yellow-fleshed one from the Eastern Highlands.

An unidentified fungal infection caused severe dieback and defoliation during very wet conditions. Consequently the crop was harvested at ten months after planting. The mean tuber yield of 2.2 t/ha was very poor. The plots were located at an altitude of 1700 m. The altitudinal limit of cassava in Papua New Guinea is 1800 m (Bourke *et al.* 1984). Yield is likely to have been depressed by low temperatures as the altitudinal limit of all crops in the Southern Highlands tends to be lower than elsewhere in the highlands (Bourke 1984b). The very low yields obtained suggest that cassava has no potential as a crop grown on very poor soils in sweet potato gardens. It may, however, have a place on better soils in mixed vegetable gardens.

PIGEON PEA

An observation plot of pigeon pea was planted in a traditional mixed vegetable garden on an alluvial soil. Observations were made on growth and flowering. Maximum crop growth was achieved by seven months after planting. Flowering also occurred at this time. Short term crops in the garden, such as amaranthus, common bean, winged bean, *Nasturtium schlecteri* O.E. Schulz and hyacinth bean, had been harvested prior to maximum growth of the pigeon pea. Crops in the garden that were still growing were sugarcane, bananas, highland 'pitpit' (*Setaria palmifolia* (Koenig) Stapf), taro (*Colocasia esculenta* (D.) Schott) and *Rungia klossii* S. Moore. Only the last three crops would be expected to suffer from light competition from the pigeon pea grown in a mixed vegetable garden. Rungia and taro are shade tolerant.

Hence pigeon pea may have a role as a vegetable crop grown in the mixed vegetable gardens. It was first introduced to the Plateau for distribution to the villagers in 1978 by Mr. J. Tompkins of Adult Education in Mendi. Since then it has gained limited acceptance as a green bean crop. It should be promoted further.

CONCLUSIONS

Three sweet potato cultivar trials showed that the Aiyura release Markham 1 yields well under Nembi conditions and is acceptable to the villagers. It should be widely promoted on the Plateau. No response to nematicide was recorded in a sweet potato nematicide trial. Further work is needed to

define the effect of nematodes on sweet potato yield.

Evaluation of five grain legume species showed that peanuts are the most suitable species in terms of yield and acceptability. The average yield of peanuts from a fertilizer trial, a grain legume evaluation and a rotation trial was 1100 kg/ha of air dried seed. Three rotation trials that evaluated a peanut/sweet potato rotation did not indicate any significant increase in sweet potato yield from the use of this rotation. Preliminary evaluation of potatoes, cassava and pigeon pea as food crops suggests that potatoes and pigeon pea have some potential for further expansion.

Results of some of the research reported in this series of papers are preliminary only and require further evaluation. Other results could be applied immediately, including the greater use of compost in sweet potato mounds, the use of pig manure and coffee pulp as fertilizer for sweet potato, and the cultivation of sweet potato cultivar Markham 1, potatoes and pigeon pea. These techniques are discussed in detail in two extension articles (D'Souza and Bourke 1982; 1983). Application of these technical solutions alone is not likely to solve the problems of low crop yields on the Nembi Plateau. However, their application, in conjunction with programmes to assist villagers to seek solutions to their problems, has the potential to have an impact on subsistence agriculture.

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COLLAR AND ROOT ROT OF AIBIKA (*ABELMOSCHUS MANIHOT*) I. PATHOGENICITY AND EFFECT OF SYSTEMIC FUNGICIDES

B.N. Muthappa* and P.B. Bull†

ABSTRACT

Collar and root rot disease of aibika (Abelmoschus manihot *(Linnaeus) Medicus) is caused by the fungus* Phytophthora nicotianae *var.* nicotianae *B. de Hann. A pathogenicity study conducted in the glasshouse showed that the fungus infects the collar region of the stem and then progresses downwards to destroy the root system, killing the plant. Field and glasshouse trials using three systemic fungicides, Ridomil 5G (metalaxyl), Le-San DX 70 WP (fenaminosulf) and Plantvax 5G (oxycarboxin) were carried out to study their effect on the disease. Aibika plants were inoculated with the fungus. In the field trial fungicides were applied at 5 g product per plant after the plants became infected. Ridomil and Le-San DX gave significant control of the disease and increased yields. In the glasshouse trial the fungicides were applied at 2, 5 and 10 g product per plant. Ridomil and Le-San DX were effective at 5 g. At 10 g both fungicides were phytotoxic. These two fungicides had a curative effect on the disease. Time of application of fungicides appeared to be critical in obtaining control of the disease.*

INTRODUCTION

Aibika (*Abelmoschus manihot* (Linnaeus) Medicus) is the most important of the traditional leafy green vegetables grown in Papua New Guinea. It is particularly important in the lowlands, where it is grown in over 75% of food gardens (Koley 1981, 1982). The young leafy shoots are harvested and used as food. Aibika has a higher nutrient content than most other green leafy vegetables (Westwood and Kesavan 1982). It is a woody perennial, usually grown as an annual and it is propagated vegetatively by stem cuttings.

Aibika suffers from a disease affecting the collar region of the stem and the root system, leading to the death of the whole plant. In several sites at Laloki Horticultural Research Station near Port Moresby the disease appeared to be severe, killing many plants. Graham (1971) recorded this disease in Fiji caused by *Phytophthora nicotianae* var. *parasitica* (Dastur) Waterhouse and listed other hosts of this fungus. Detailed studies were started at Laloki in September 1981 to investigate the causal factors of the disease and its control. In this report the role of the causal organism and the effect of systemic fungicides are described.

Symptoms of the Disease

The major symptoms of the disease are yellowing of the mature lower leaves, wilting of younger foliage and the growing tip, followed by defoliation. Rotting of the stem begins at the collar region and progresses downwards to the root system. Uprooting

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the diseased plant in an advanced stage shows the whole root system rotted. Affected plants eventually die.

Identification of the Pathogen

A species of *Phytophthora* de Bary was isolated on V8 juice agar from the infected roots and collar region of stems of aibika. It was identified as *P. nicotianae* B. de Haan. An isolate of this fungus sent to the Commonwealth Mycological Institude, England, was confirmed as *P. nicotianae* var. *nicotianae* (A2 mating type), O.J. Stamps (pers. comm.), (CMI No. IMI 262913).

MATERIALS AND METHODS

Three trials were conducted:

1. Pathogenicity test in the glasshouse

Cuttings of aibika, cv. Laloki 2, with eight vegetative buds per stem were planted in 15 cm diameter pots filled with sterile soil. Thirty days after planting when the new vegetative growth was about 20 cm in length, the plants were inoculated with *P. nicotianae* var. *nicotianae*. For inoculation the fungus was grown in pure culture on 2% V8 juice agar in 12 cm Petri plates. The inoculum was prepared from seven day old cultures by mixing with sterile water in a Waring blender at the rate of 100 ml of water per Petri plate culture to obtain a heavy inoculum. One hundred ml of the inoculum were poured around the base of the stem after the soil was removed to a depth of about 3 cm. The soil was replaced. Twenty five plants were inoculated. A further 25 plants were treated with sterile water to serve as the uninoculated control.

2. Field fungicide trial

The field trial was conducted at Laloki Horticultural Research Station, Port Moresby. The systemic fungicides tested were Ridomil 5G (metalaxyl, Ciba-Geigy), Le-San DX 70 WP (fenaminosulf, Bayer) and Plantvax 5G (oxycarboxin, Uniroyal Chemical). Ridomil and Le-San DX are recommended fungicides for the control of *Phytophthora* diseases of many crops. Plantvax has been reported to be effective as a soil fungicide against *P. palmivora* (Butler) Butler the cocoa pod rot fungus (Okaisabor 1970) and *Pythium aphanidermatum* (Edson) Fitzpatrick the causal organism of stem rot of tomato (Matta 1972).

These fungicides each applied at 5 g product per plant, were compared with an untreated control in a randomized block design with seven replications. The plots were four ridges (spaced 1.3 m apart) wide and 8 m long. There were 32 plants per plot, but all assessments were made on the twelve plants in the centre two ridges. The plants were inoculated with *P. nicotianae* var. *nicotianae* 35 days after planting when the new vegetative growth was about 25 cm in length. The inoculation procedure was the same as that described for the pathogenicity trial in the glasshouse. The fungicides were applied 10 days after inoculation when the symptoms of the disease (yellowing of lower leaves, wilting and discolouration of the stem at the collar region) were obvious on many plants. Although the disease symptoms started appearing 3 to 4 days after inoculation, the fungicides could not be applied between the 4th and 9th days because the soil was too wet after heavy rain. Soil was removed around the stem to a depth of about 3 cm, the fungicide was sprinkled around the base of the stem and the soil was put back to cover the fungicide. The control plants were inoculated but received no fungicide treatment. A pre-treatment count of infected plants was made before application of the fungicides. Three subsequent counts were made at 10 day intervals. These counts were analysed

by covariate analysis with adjustment for the pre-treatment count. Three harvests were made of all the leafy shoots 11, 13 and 15 weeks after transplanting to determine total shoot weight.

3. Glasshouse fungicide trial

A trial using the same three fungicides was laid out in the glasshouse. There were three rates of application, 2, 5 and 10 g of product per plant. Plants were raised and inoculated as described under the pathogenicity test. Plants were arranged in a set of five plants in a row to form a block with 10 plants in two rows for each treatment. Fungicides were applied, using the same method as in the field trial, four days after inoculation when the disease symptoms were observed.

RESULTS

1. Pathogenicity test

Plants inoculated with the fungus showed yellowing of lower leaves in three to five days. The collar region of the stem appeared water soaked and discoloured. This was followed by wilting of growing tips in about six to eight days, followed by defoliation. These plants died three weeks later. On uprooting these plants, it was observed that the infection apparently started from the collar region, progressed downwards and killed the root system. Uninoculated control plants were healthy with vigorous vegetative growth. *P. nicotianae* var. *nicotianae* was reisolated from the collar and roots of the infected plants.

2. Field fungicide trial

The percentage of diseased plants before and after the fungicide application is given in *Table 1*. Thirty days after application the proportion of diseased plants was significantly lower for Ridomil and Le-San DX treated plots compared to Plantvax and the untreated control. Ridomil and Le-San DX treated plants appeared to be more robust and vigorous in growth (*Table 1*).

3. Glasshouse fungicide trial

All plants died due to infection in the untreated control, and in all three

Table 1.—**Effect of systemic fungicides on collar and root rot of aibika (field trial)**

Fungicide	Percent infected plants (angular transformation) (1)		Total shoot weight t/ha
	Pre-treatment	Post-treatment(2)	
Le-San DX	30.4 (25.6)	50.9 (60.2)	2.55
Ridomil	31.4 (27.2)	48.6 (56.3)	2.25
Plantvax	38.6 (38.9)	67.7 (85.6)	0.76
Control (no fungicide)	27.2 (20.6)	74.9 (93.2)	0.50
Mean	31.9	60.5	1.52
s.e.d. (d.f 18)	7.11	5.49	0.515
C.V. (%)	28.3	9.1	33.9
Significant effect ($p<0.05$)	n.s.	11.58	1.082

Notes: (1) Back transformed values are shown in brackets.
(2) Post-treatment means are adjusted by co-variance analysis for pre-treatment means.
n.s. Not significant.

rates of Plantvax. The two higher application rates of Ridomil completely controlled the disease. At 5 grams of product per plant, Le-San DX gave 70% survival of plants. Infected plants showed signs of recovery two weeks after the fungicide application. Plants shed all the old leaves and new ones started growing. After four weeks the plants had healthy foliage. At the higher application rates, both Le-San DX and Ridomil caused phytotoxicity symptoms of leaf scorching and defoliation (*Table 2*).

DISCUSSION

Pathogenicity studies established that *P. nicotianae* var. *nicotianae* is the causal organism of collar and root rot disease of aibika. The site of infection appears to be the collar region of the stem. Further studies are needed to understand the mode of entry of this fungus at the site of infection. The fungus caused total loss of vegetative growth by killing the plants. The short incubation period of three to five days showed that this fungus was a virulent pathogen.

Two of the systemic fungicides tested in the field, Ridomil and Le-San DX gave significant control of the disease and increased yields. However, an additional 17% and 21% of plants died during the post-treatment period in the Ridomil and Le-San DX treated plots respectively. This may have been due to the delay in application of the fungicides. On the other hand in the glasshouse, Ridomil and Le-San DX afforded effective control at 5 g product per plant, applied four days after inoculation when the early symptoms of the disease were observed. These plants recovered. This implies that the time of fungicide application is critical. Le-San DX at 10 g was phytotoxic and as a result 60% of the treated plants died. The remaining plants, though they survived, showed toxic symptoms of necrotic spots and scorching.

Effective control of the disease appears to be possible with Ridomil and Le-San DX if applied as soon as the early symptoms are observed. Le-San DX has a LD 50 of 60 mg/kg which is very toxic for a fungicide; it is not recommended for use by small holding farmers. The granular formulation of Ridomil is easy for field application and the cost of chemical per plant is K0.04 at the selling price of K8.00 per kg of Ridomil 5G in 1983.

Table 2. **Effect of three systemic fungicides in controlling artifically induced infections of collar and root rot of aibika applied four days after inoculation (glasshouse trial)**

Fungicide (in grams product/plant)		Pre-treatment		Post-treatment(1)	
		Infected	Health	Infected	Healthy
Control (no fungicide)		4	6	10	0
Plantvax	2g	3	7	10	0
Plantvax	5g	5	5	10	0
Plantvax	10g	2	8	10	0
Ridomil	2g	5	5	4	6
Ridomil	5g	3	7	0	10
Ridomil	10g	6	4	0	10*
Le-San DX	2g	2	8	8	2
Le-San DX	5g	5	5	3	7
Le-San DX	10g	4	6	6**	4*

Notes: 1 Four weeks after treatment
* Phytotoxic symptoms on leaves
** Plants died due to phytotoxicity

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COLLAR AND ROOT ROT OF AIBIKA (*ABELMOSCHUS MANIHOT*) II. EFFECT OF PRE-PLANTING TREATMENT WITH FUNGICIDES

B.N. Muthappa* and P.B. Bull†

ABSTRACT

*Pre-planting treatment in the field of aibika (*Abelmoschus manihot *(Linnaeus) Medicus) cuttings with protectant copper fungicides, Bordeaux paste and Cuprox (copper oxychloride) paste controlled the collar and root rot disease caused by* Phytophthora nicotianae *var* nicotianae *B. de Haan. There was a significant increase in shoot numbers and usable shoot weight. Ridomil 25 WP (metalaxyl), a systemic fungicide paste, controlled the disease but drastically affected the root formation, reduced vegetative growth and produced phytotoxic symptoms on the foliage at the rate used in this study. In Bordeaux paste treated plants root formation was profuse and the dry root weight was greater than for Cuprox paste or Ridomil 25 WP.*

INTRODUCTION

The effect of systemic fungicides on the control of *Phytophthora nicotianae* var. *nicotianae* B. de Haan, the causal organism of collar and root rot of aibika, has been discussed (Muthappa and Bull 1986). Further studies were conducted using fungicides in the form of paste for pre-planting treatment of aibika cuttings. The effects of one systemic and two protectant fungicides on the control of collar and root rot disease is described in this paper.

MATERIALS AND METHODS

The field trial was conducted at the Laloki Horticultural Research Station near Port Moresby. Two protectant fungicides, Bordeaux mixture and cuprox 50 WP (copper oxychloride, ICI), and a systemic fungicide Ridomil 25 WP (metalaxyl, Ciba-Geigy) were used. The fungicides were applied as pastes to the aibika cuttings before planting. The fungicidal pastes were prepared employing the following proportions.

1. **Bordeaux paste**: Copper sulphate, 1 kg; hydrated lime, 2 kg; and water 15 litres. Copper sulphate and hydrated lime were dissolved separately in equal quantities of water, then mixed together to obtain the paste.

2. **Cuprox paste**: Cuprox 50 WP, 1 kg in 5 litres of water.

3. **Ridomil paste**: Ridomil 25 WP, 1 kg in 5 litres of water.

The concentration of the fungicide was necessarily high in these pastes. The reason for using pastes was that they adhere well to the plant surface. Also it was intended to study the effect of fungicides in the field with a single application for prolonged protection.

The three fungicide treatments with an untreated control were compared in a randomized block design with seven

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replications. Trial design and plant spacing were the same as in an earlier trial (Muthappa and Bull 1986).

Aibika cuttings with eight vegetative buds were dipped in the desired fungicidal paste to cover the basal half of the cutting. Following treatment both treated and untreated cuttings were kept overnight before planting. Twenty four hours after planting they were inoculated with *P. nicotianae* var *nicotianae*. For inoculation *P. nicotianae* var. *nicotianae* was grown in pure culture on two percent V8 juice agar in 12 cm Petri plates. The inoculum was prepared from seven day old cultures, by mixing with sterile water in a Waring blender, at the rate 100 ml of water per Petri plate to obtain a heavy inoculum. One hundred ml of the inoculum was poured around the base of the stem after removing the soil to a depth of about 3 cm. The soil was replaced after the inoculum was absorbed into the soil. The control cuttings were inoculated but received no fungicide. Counts to record the diseased plants were made once a week up to 70 days. Three harvests were made of the leafy shoots 8, 10 and 12 weeks after transplanting. Five cuttings for each treatment were planted separately without inoculum to study the root system after 70 days.

RESULTS

The percentage of diseased plants 70 days after planting is given in *Table 1*. The three fungicides were significantly effective ($p<0.05$) in controlling the collar and root rot disease of aibika. Whilst there was no significant difference between the fungicides in their effects, Ridomil paste was toxic to aibika cuttings. Root formation was poor, leaves were reduced in size and were yellowish green with necrotic spots on the lamina. Vegetative growth was slow up to about 50 days. However, leaves formed after 50 days were broad, dark green and seemed healthy. Bordeaux paste and Cuprox were not phytotoxic. Plants grew up with broad, dark green coloured, healthy foliage. Death of plants was sporadic during the period of observation. Profuse root formation was observed when examined after 70 days. Roots produced by Bordeaux paste treated cuttings were unusually thick with profuse feeder roots. The mean dry weight of roots of each treatment is given in *Table 2*.

The plots treated with Cuprox and Bordeaux paste gave significantly higher yields ($p<0.05$) than those treated with Ridomil and the untreated control. The total usable yields, mean shoot number and the mean weight of leafy shoots over the three harvests are given in *Table 1*.

DISCUSSION

P. nicotianae var. *nicotianae* infected the untreated aibika cuttings and the disease was severe as 80% of the plants were killed. The protectant fungicides, Cuprox and Bordeaux pastes, were significantly effective in controlling the collar and root rot disease of aibika.

Mean shoot number and total yield were significantly higher with these treatments. These two fungicides were not phytotoxic when applied as paste. Copper fungicides appeared to give prolonged protection since the death rate of plants did not increase even after 60 days towards the end of the trial. The same trend of protection can be expected in naturally infected soil if aibika cuttings are subjected to a pre-planting dip in copper fungicidal paste.

Ridomil, in spite of its phytotoxicity, was effective in protecting the plants against *P. nicotianae* var. *nicotianae*, however yields were less than in the copper fungicide treated plots. Dark green, healthy leaves formed 50 days

Table 1.–**Effect of pre-planting treatment with fungicides on collar and root rot of aibika**

Fungicide	Percent diseased plants* (angular transformation)	Total shoot weight ($t \cdot ha^{-1}$)	Total shoot number ($'000 \cdot ha^{-1}$)
Bordeaux paste	11.7(4.1)	3.95	22.1
Cuprox paste	15.4(7.1)	4.11	21.7
Ridomil paste	23.5(15.9)	2.33	14.1
Control (no fungicide)	63.5(80.1)	1.75	9.0
Mean	28.5	3.03	16.7
s.e.d. (d.f 18)	7.81	0.513	3.03
C.V. (%)	51.2	31.6	33.9
Significant effect ($p < 0.05$)	16.41	1.078	6.37

Notes: * Back transformed values are shown in brackets.

Table 2.–**Effect of pre-planting treatment of aibika cuttings with fungicides on root growth (70 days after planting)**

Fungicide	Total of five plants Fresh root wt(g)	Total of five plants oven dry root wt(g)	Mean root weight/plant (g) (oven dry)
Bordeaux paste	105	93	18.6
Cuprox paste	68	57	11.4
Ridomil paste	33	27	5.4
Control (no fungicide)	40	32	6.4

after the pre-planting treatment showing that phytotoxicity lasted for about seven weeks. At the rate used, Ridomil 25 WP was not lethal to the plants but drastically reduced root formation. Using Ridomil as a paste for pre-planting treatment of aibika at this rate of application seems inadvisable. Copper fungicide treated cuttings produced profuse root systems and vigorous vegetative growth besides effectively controlling the disease. Pre-planting treatment of aibika cuttings with a copper fungicidal paste would be useful where aibika is grown in *P. nicotianae* var. *nicotianae* infected soil.

One litre paste of Bordeaux or Cuprox can be used to treat 100 cuttings of aibika. The price quoted by the supplier (ICI, PNG. Ltd) was Cuprox K2.82, copper sulphate K1.40 and hydrated lime K0.52 per kilogram. Using this price the cost in 1983 of fungicides for 1000 cuttings worked out to Bordeaux paste K1.64 and Cuprox paste K5.64. Cuprox paste was easier to prepare than Bordeaux paste.

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THE DISTRIBUTION AND PRODUCTION OF ANCHOVIES IN PAPUA NEW GUINEA WATERS

P. Dalzell*

ABSTRACT

There are 20 members of the family Engraulidae in Papua New Guinea waters. The distribution of these species is determined by environmental aspects of the various coastal habitats, with the greatest number of species found in the Gulf of Papua. The annual catch of anchovies in the Gulf of Papua is estimated to be between 60–1300 tonnes. A predictive model for catches of S. heterolobus *and* S. devisi *in the inshore coralline waters was constructed where: C/f. km² = 0.394 − 0.64 × 10⁻⁴f. The maximum annual sustainable yield of* S. heterolobus *and* S. devisi *is 0.61 t/km². Expansion of anchovy fishing is unlikely in the Gulf of Papua but there may be potential for sun dried stolephorid anchovies from the inshore coralline areas as an export product.*

INTRODUCTION

Papua New Guinea (PNG) has, in common with its neighbours in the Indo-Pacific region, a diverse anchovy fauna. In Malaysia, Indonesia and the Philippines the abundance of some anchovy species is such that they support substantial industrial and artisanal fisheries (Tiews *et al.* 1970; Tham 1972). In PNG there has been relatively little exploitation of this resource until recently. Large catches of anchovies in Papua New Guinea are not used for food but constitute part of the discarded by-catch of the Gulf of Papua prawn fishery (Kailola and Wilson 1978) and are used as live bait in the domestic pole-and-line skipjack tuna fishery (Dalzell 1980).

As with many of PNG's marine fish stocks there is potential for expansion of the anchovy fisheries by artisanal fishermen (Anon 1979a). The catching and processing of anchovies requires low levels of technical expertise which are readily applicable to an artisanal fishery.

The objectives of this paper are to summarise the data on the distribution, abundance and yields of PNG's anchovies. If there is interest in expanding this fishery in the future then this paper may provide a basis for development and management strategies.

ANCHOVY FAUNA

The family Engraulidae is represented in PNG waters by 20 species (*Table 1*), 16 of which are contained within two genera, *Stolephorus* and *Thryssa* (Munro 1967; Kailola and Wilson 1978; Wongratana 1983). The stolephorid anchovies are the smallest of the Engraulidae found in PNG waters and the largest species in this genus is *Stolephorus indicus* (van Hasselt) which reaches a maximum size of 14 cm. The genus *Stolephorus* is characterised by highly deciduous scales and translucent bodies with gold and silver lateral bands. (Munro 1967). The other anchovy genera are larger in both length and body depth and have non-deciduous scales; they have a dark

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dorsal surface and have a silver ventral surface.

DISTRIBUTION

Anchovies are found around the entire coast-line of PNG but the environmental features of the coast determine the distribution of individual species. The PNG coastline can be divided into three broad geographic types.

TYPE 1: 'Oceanic'. Open ocean water with isolated coral reefs, coral atolls and islands of which the Hermit, Ninigo and Nukumanu islands are typical. Salinity varies over a narrow range of 34.5 to 36.5 ppt. (parts per thousand) (Donguy and Henin 1978). The low influx of nutrients of terrestrial origin means that the water remains generally clear.

TYPE 2: 'Inshore coralline'. The coralline coastal waters of the mainland and larger islands such as New Ireland and New Britain. Salinity in these areas is linked with gross environmental changes. Mean rainfall and salinity data collected at Kavieng between 1981–1983 indicate that high rainfall in these areas depresses salinity (*Figure 1*). Water clarity is generally high although it is reduced during periods of strong winds and heavy rainfall. Coral reefs consisting of either barrier, fringing or patch formations are numerous, except in immediate proximity to river mouths.

TYPE 3: 'Estuarine'. Areas of particularly heavy freshwater discharge, especially the Gulf of Papua and the estuaries of the Sepik and Markham rivers. Salinities in the Gulf of Papua are depressed for a considerable distance from the shore (Rapson 1955; Scully-Power 1973). Salinity of inshore waters in the Purari may range from 5–27 ppt. The heavy freshwater inflow results in very high turbidities (Liem and Haines 1977). These conditions account for the poor development of coral reefs in these areas (Whitehouse 1973).

Anchovies are present in all three of these habitats. In addition, one species of anchovy, *Thryssa scrathchleyi* (Ramsey and Ogilby), is found in the Strickland River which is entirely fresh water. The distribution of PNG's anchovy fauna is indicated in *Table 1*. Only one species, *Stolephorus punctifer* (Fowler), lives in oceanic water. Adults have been recorded up to 1120 km from the nearest land (Hida 1973), and the eggs and larvae have been taken in plankton tows 800 km offshore (Gorbunova 1971).

Stolephorus punctifer occasionally moves into coastal waters inhabited by *Stolephorus heterolobus* (Ruppel) and *Stolephorus devisi* (Whitley) (Wilson 1977; Lewis 1977; Kearney *et al.* 1979; Dalzell and Wankowski 1980). Dalzell (1984a) showed that the abundance of *S. punctifer* in coastal waters is strongly influenced by rainfall and hence presumably salinity. Spawning of *S. punctifer* appears to take place in the open ocean (Gorbunova 1971). Other factors such as food availability may be responsible for the movement of *S. punctifer* inshore.

The anchovy fauna of the inshore coralline waters is dominated by species of the genus *Stolephorus*. The two species *S. heterolobus* and *S. devisi*, are abundant along the South Papuan coast from Port Moresby eastwards, on the north coast of the mainland and around the larger island groups (Anon 1969; Lewis 1977; Cooper and Wankowski 1980; Dalzell and Wankowski 1980; Dalzell 1984b).

The larger members of the genus, *S. indicus*, *Stolephorus bataviensis* Hardenberg and *Stolephorus commersoni* (Lacépède), though less abundant, are relatively widely distributed and are occasionally caught in bait catches of

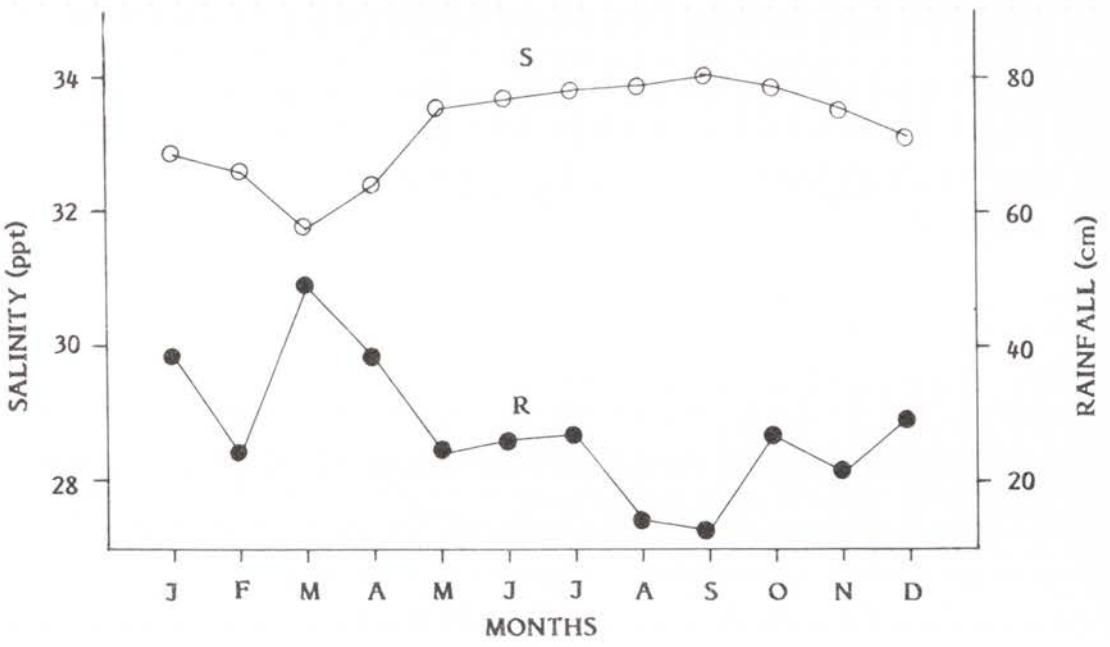

Figure 1.–**Mean monthly rainfall (R) and salinity (S) data for Kavieng Harbour from 1981–1983 (Dalzell, unpub. data)**

the domestic pole-and-line fleet (Lewis *et al.* 1974; Dalzell and Wankowski 1980). Elsewhere in the South East Asian region the dominance of *S. heterolobus* and *S. devisi* conforms with observations in PNG waters (Tiews *et al.* 1970; Tham 1972; Burhanuddin *et al.* 1975). In many of the island groups throughout Polynesia, Melanesia and Micronesia these two species also dominate the anchovy fauna of the inshore coralline waters (Kearney and Lewis 1978; Kearney and Hallier 1978abc; Kearney *et al.* 1978).

One other species, *Thryssa balaema* (Forsskål), is also found within the inshore coralline environment and is associated with the mangrove areas bordering reef and lagoon systems. Places where *T. balaema* appears in any large quantities, such as in commercial bait catches, are usually marginal habitats for *S. heterolobus* and *S. devisi* (Lewis 1977).

The remaining species are confined to areas where the freshwater influx is substantial, particularly the Gulf of Papua. Here the large *Stolephorus* anchovies are also present but the smaller species *S. heterolobus*, *S. devisi* and *S. punctifer* are absent (Kailola and Wilson 1978). The two newly described stolephorid anchovies, *Stolephorus carpenteriae* (Munro) and *Stolephorus brachycephalus* (Wongratana) have only been found in the Gulf of Papua in PNG waters (Wongratana 1983).

The presence of *T. scratchleyi* has probably developed through some past migration inland by an estuarine species. This species may be analogous to some of the African clupeids such as *Stolothrissa tanganicae* Stiendachner and *Limnothrissa miodon* Boulenger on Lake Tanganyika (Coulter 1974).

Many factors are responsible for the distribution of the majority of anchovy species in PNG waters. The oceanic

Table 1.–**The Papua New Guinea anchovy fauna. Distribution by environment is shown on the right of the table**

Species	Environment			
	Oceanic	Inshore Coralline	Estuarine	Fresh-water
Stolephorus punctifer (Fowler)	0	0		
S. heterolobus (Ruppel)		0		
S. devisi (Whitley)		0		
S. indicus (van Hasselt)		0	0	
S. bataviensis (Hardenberg)		0	0	
S. commersoni (Lacépède)		0	0	
S. tri (Bleeker)		0	0	
S. carpenteriae (Munro)			0	
S. brachycephalus (Wongratana)			0	
Thryssa balaema (Forsskäl)		0	0	
T. hamiltoni (Gray)			0	
T. kamalensis (Bleeker)			0	
T. mystax (Schneider)			0	
T. purava (Hamilton-Buchanon)			0	
T. setirostris (Broussonet)			0	
T. scratchleyi (Ramsey and Ogilby)				0
Setipinna taty (Valenciennes)			0	
S. godavari (Babu Rao)			0	
S. papuaensis (Munro)			0	
Papuaengraulis micropinna (Munro)			0	

and freshwater anchovies, *S. punctifer* and *T. scratchleyi* inhabit opposite ends of the salinity range in which anchovies are known to occur. Most anchovies have a wide tolerance of salinities (Longhurst 1970) although it is likely that both *S. heterolobus* and *S. devisi* are less tolerant than other species in the same genus (Tham 1972; Lewis 1977). An inverse relationship between increased stream discharge and abundance of *Stolephorus purpureus* Flower was observed by Weatherall (1977). This species has similar habitat preferences to *S. devisi* and *S. heterolobus*.

In the coastal waters of PNG the distribution of anchovies may be determined by the degree of food selection, rather than salinity. The smaller stolephorid anchovies are almost exclusively pelagic planktivores (Tham 1950; Hida 1973; Burhannudin *et al.* 1975; Muller 1976; Chapau 1983a). High primary productivity levels in surface and near surface waters have been shown to be necessary for the occurrence of *S. heterolobus* (Muller 1976) and a positive correlation between the abundance of both zooplankton and *S. heterolobus* in the Singapore Straits was demonstrated by Tham (1953). These species may be thus excluded from the turbid waters of extensive estuarine areas by virtue of their specialised feeding habits.

The anchovies found in the Gulf of Papua are less selective feeders than the small planktivorous stolephorids. The food of *Thryssa mystax* (Schneider) in Indian waters was found to be pelagic crustaceans, benthic polychaetes and shrimps (Venkatamaran 1956). Similar observations have been reported for *Thryssa hamiltoni* (Gray), *Thryssa purava* (Hamilton-Buchanon) and *Setipinna phasa* Hamilton-Buchanan (Mookerjee and Mookerjee 1950; Bal and Bapat 1950; Jones and Menon 1951). The larger *Stolephorus* anchovies, *S. indicus* and *S. bataviensis*, were shown to feed both in the pelagic and benthic zones of the Singapore straits (Tham 1950).

YIELDS

Most of the anchovy species present in PNG waters are found in the Gulf of Papua. Catch and effort data for the by-catch of the prawn fishery are limited and preliminary yield estimates of the potential anchovy catch of this region must be subjective until better data are obtained. The data from experimental trawl fishing between 1960 and 1968 in the Gulf of Papua were summarised by Kailola and Wilson (1978). The mean percentage composition by weight of clupeoids in the catch was 13%. The ratio of anchovies to other clupeoids (calculated from Kailola and Wilson's data) was 2.5:1 and this gave an index of anchovy abundance in the by-catch of 9% by weight. The ratio of by-catch weight to prawn weight in the Gulf of Papua has been reported to be within the range from 6:1 to 8.8:1 (Anon 1979b; Watson 1984). Taking the mean this gives an average by-catch ratio of 7.4:1 and from this the by-catch between the years 1977 to 1982 was calculated and is presented in *Table 2*. More data are required for precise estimates of the anchovy harvest from this fishery. The figures given here, however, serve to illustrate the order of magnitude of possible anchovy yields from this area.

For the bait-fish catches of the domestic pole-and-line fleet accurate catch (C) and effort (f) data are available for a number of years (Dalzell and Wankowski 1980; Dalzell 1984b) and an estimation of potential yield of *S. heterolobus* and *S. devisi* from the inshore coralline waters can be made. The method of fishing has been described in detail by Dalzell (1980). Baitfish are aggregated around an underwater light for several hours after dark and captured in a lift net. Catch (tonnes) and effort (boat-nights) data for *S. heterolobus* and *S. devisi* from the Ysabel Passage (New Ireland Province) and Cape Lambert (East New Britain Province) are given in *Tables 3* and *4*. The areas of the bait grounds were 336 km^2 for the Ysabel Passage and 407 km^2 for Cape Lambert. The catch/effort/km^2 for both species of anchovy combined are presented in *Table 5*.

Schaeffer (1954) developed a simple logistic model for yellowfin tuna catches in the eastern tropical Pacific which uses only catch and effort data to obtain estimates of maximum sustainable yield (MSY) and optimal fishing effort (f.opt). Since the initial application of this model by Schaeffer (1954), this model has been applied with success to a wide range of temperate and tropical fish stocks (Gulland 1983). In its simplest version the model takes the form:

$$C/f = a - bf \qquad (1)$$

which is a linear relationship and can be solved by plotting C/f on f. The model can be transformed into a parabola by multiplying through by f such that:

Table 2.– **Estimated anchovy catch in the Gulf of Papua trawl fishery. Prawn catch data from Kolkolo (1983)**

Year	Prawn catch* (tonnes)	By catch (tonnes)	Estimated anchovy catch (tonnes)
1977	882	6,527	587
1978	1,661	12,291	1,106
1979	1,962	14,519	1,307
1980	1,962	14,519	1,307
1981	1,710	12,654	1,139
1982	1,465	10,841	976

Notes: * Original figures multiplied by 1.7 to give whole prawn weight (Anon 1979b)

$$C = af - bf^2 \quad (2)$$

When the slope of the parabola is zero, at the apex, then this is the point of maximum sustainable yield (MSY) and optimum fishing effort (f. opt.) Alternatively these can be calculated from:

$$MSY = a^2/4b \quad (3)$$

$$f.opt = a/2b \quad (4)$$

From this model it was possible to determine the maximum sustainable yield of the combined stocks of *S. heterolobus* and *S. devisi* by the use of the

Table 3.–**Catch and effort data for the anchovy catches from the Ysabel Passage bait-fishery**

Year	Effort	Catch in tonnes		Total
	(Boat-nights)	*S. heterolobus*	*S. devisi*	
1972	1819	145.8	90.1	235.9
1973	1792	131.7	46.4	178.1
1976	3052	190.8	108.4	299.2
1977	3717	138.3	102.5	240.8
1978	4463	404.0	126.0	530.0
1979	3038	191.8	146.8	338.6
1980	3709	72.1	12.7	84.8
1981	2170	65.8	24.5	90.3

Table 4.–**Catch and effort data for the anchovy catches from the Cape Lambert bait-fishery**

Year	Effort	Catch in tonnes		Total
	(Boat-nights)	*S. heterolobus*	*S. devisi*	
1972	1780	115.8	66.8	182.6
1973	3360	210.2	115.4	325.6
1977	3288	39.4	132.3	171.7
1980	1377	106.7	39.5	146.2
1981	1223	132.3	49.7	182.0

Table 5.–**Combined catch, effort and area data in kg/boat-night/km² for the Ysabel Passage and Cape Lambert bait-grounds**

Effort (boat-nights)	kg/f/km²
1819	0.386
1792	0.296
3052	0.106
3717	0.193
4463	0.353
3088	0.326
3709	0.068
2170	0.124
1780	0.251
3360	0.238
3280	0.397
1377	0.258
1223	0.348

catch and effort data in *Table 5*. In this instance C/f/km^2 was plotted on f and a theoretical yield curve determined from:

$$C/km^2 = af - bf^2 \quad (5)$$

The relationship between catch per unit area and effort was:

$$C/f/km^2 = 0.394 - 0.64 \times 10^{-4}f. \quad (6)$$

Two points, one from the Ysabel Passage and one from the Cape Lambert data sets were excluded from the regression to obtain a better fit of the line (see *Figure 2*).

Table 6 gives the areas for several locations around PNG's coralline coast that have recognised anchovy resources. The predicted sustainable

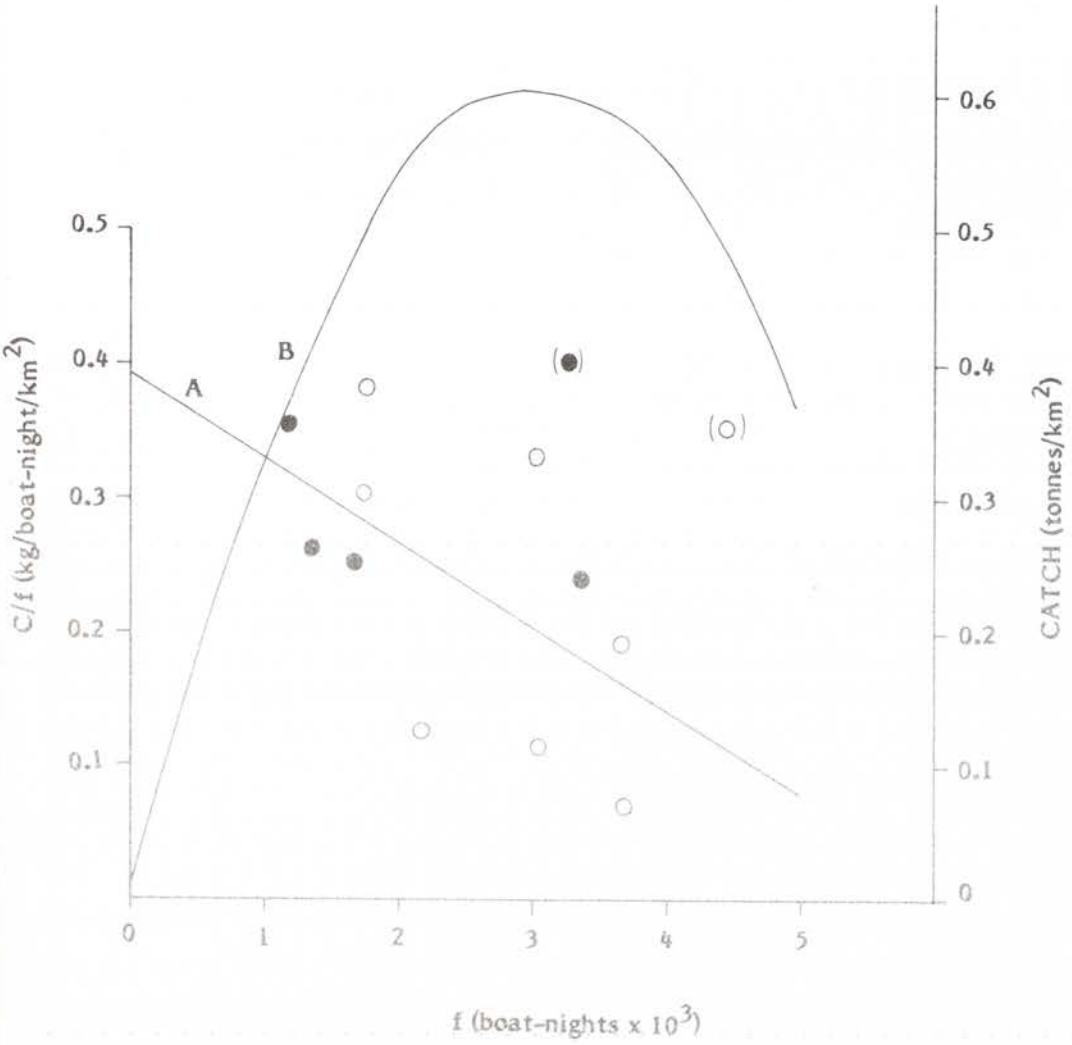

Figure 2.—The relationship between catch, effort and area for combined catches of *S. heterolobus* and *S. devisi* at the Ysabel Passage (o) and Cape Lambert (●). Points in parentheses have been excluded from the regression. Line A: C/f/km^2 = 0.394 − 0.64 × 10f, r = −0.62, p < 0.05. Line B: theoretical yield curve

yields from these areas were calculated from the model and are also presented. The total annual catch of *S. heterolobus* and *S. devisi* from these areas alone is 1,025 t. The locations listed in *Table 6* refer to bait grounds, where large (>20 m in length) boats can enter and fish nets of 20 m^2 can be hung safely without snagging on the bottom.

The conditions determining the kind of boats that can enter an area restrict the number of places *Stolephorus* anchovies can be caught in PNG waters. In areas inaccessible to such vessels the potential exists for the development of artisanal gear such as small lift nets, beach seines and fish traps, which would lead to an increase in total production. Given the extensive inshore coralline coastline of PNG it is reasonable to suggest that sustained annual catches of between 5,000–10,000 t could be achieved by increased exploitation of this resource.

DISCUSSION

From the data presented here it is clear that PNG has a substantial anchovy resource. Apart from catches in two specialised industrial fisheries the resource is under-exploited. The predictive estimates of anchovy catch in the Gulf of Papua whilst being empirical, indicate a substantial anchovy catch in this region. However, the primary target of the trawl fishery is prawns and the by-catch is discarded for economic reasons.

The anchovy yields that are predicted for the inshore coralline waters are based on *S. heterolobus* and *S. devisi* which are by far the most dominant species in this region. In estimating the yields for other locations it is assumed that conditions are similar to those at Ysabel Passage and Cape Lambert. Muller (1977) estimated the MSY of *S. heterolobus* in the Palau bait-fishery to be 0.48 t/km^2. The physical characteristics of the Palau bait-ground resemble those of the Ysabel Passage and Cape Lambert. All three locations are partially enclosed sheltered waters bordered by high islands and coral reefs. Rainfall averages between 200–400 mm/month (Muller 1976; Dalzell 1984a) and the temperature and salinity of the sea water in all three bait

Table 6.–**Area and potential annual yield of *S. heterolobus* and *S. devisi* at several locations in Papua New Guinea waters**

Location	Position	Area (km^2)	Potential yield (tonnes)
Sek Harbour	(145° 49'E, 5°06'S)	36.0	22.0
Seaddler Harbour	(147° 23'E, 2°00'S)	30.6	18.7
Stettin Bay	(150° 25'E, 5°15'S)	149.0	90.9
Open Bay	(151° 35'E, 4°55'S)	85.5	52.2
Riebeck Bay	(149° 55'E, 5°25'S)	175.5	107.1
Eleonora Bay	(149° 45'E, 5°30'S)	69.3	42.3
Emeline Bay	(149° 39'E, 5°30'S)	12.6	7.7
Rein Bay	(149° 15'E, 5°27'S)	12.6	7.7
Cheshunt Bay	(148° 28'E, 10°10'S)	58.5	35.7
Fairfax Harbour	(147° 05'E, 9°59'S)	2.7	1.6
Arawe Harbour	(149° 00'E, 6°05'S)	134.0	81.7
Ysabel Passage	(150° 30'E, 2°30'S)	336.0	204.9
Cape Lambert	(151° 40'E, 4°10'S)	407.0	248.3
Richthofen Bay	(149° 55'E, 6°20'S)	30.0	18.3
Gasmata Bay	(150° 18'E, 6°18'S)	40.0	24.4
Garua Harbour	(150° 03'E, 5°19'S)	40.0	24.4
Silver Sound	(150° 45'E, 2°40'S)	39.9	24.3
Three Island Harbour	(150° 10'E, 2°23'S)	21.0	12.8
Total		1,680.2	1,025.0

grounds are similar (Muller 1976; Chapau 1983b; Dalzell 1984b). An analysis of only the catch data pertaining to *S. heterolobus* (*Figure 3*) gave an annual sustainable yield of this species of 0.44 t/km^2. The predictive model used in this paper therefore appears to be reasonable.

The expansion of the anchovy fisheries in PNG waters would depend on suitable markets for such a product. The demand for anchovies at present within PNG is such that it would be uneconomic to separate them from the by-catch of the Gulf of Papua prawn trawlers. Further, the amount of fresh clupeoid or herring like fish such as anchovies in the diet of PNG nationals appears to be limited, based upon observations of coastal reef and estuarine fisheries (Opnai 1984; Wright and Richards 1985; Lock 1986).

There may, however, be an export potential of sun-dried stolephorid anchovies, caught in PNG's inshore coralline waters, to south East Asia, where high population densities put an ever increasing strain on the fisheries of the region. This increase in demand is reflected in the stolephorid anchovy catches which have increased from 149,000 t to 223,000 t between 1977 and

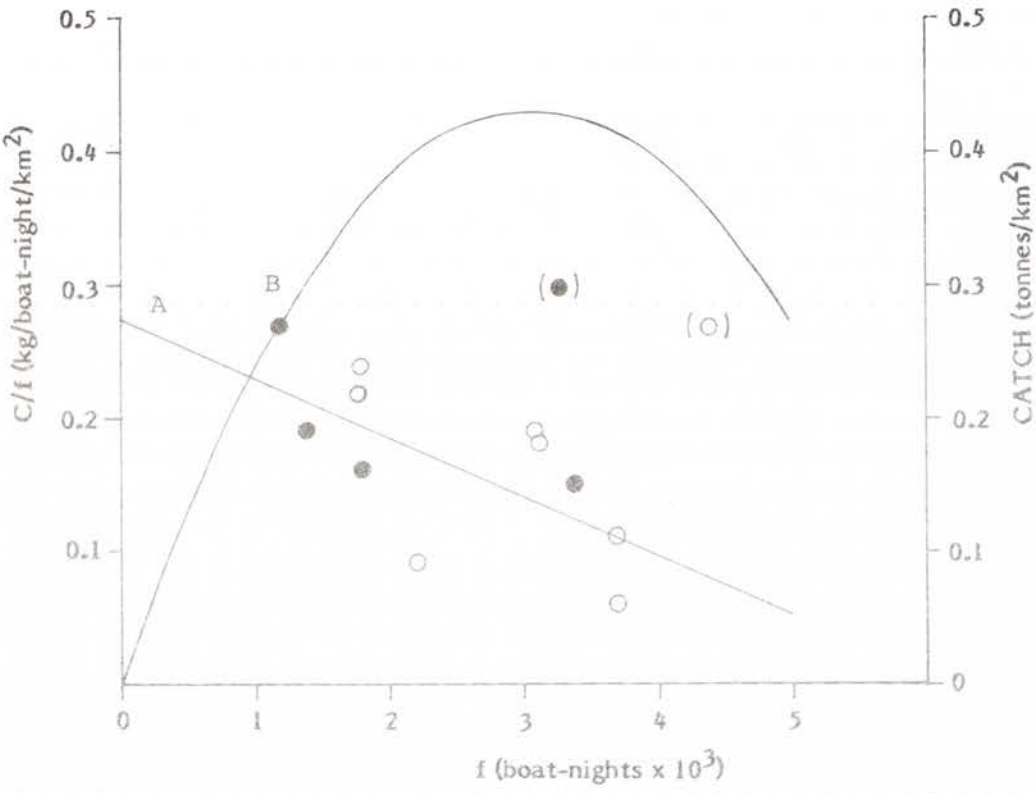

Figure 3.—The relationship between catch, effort and area for catches of *S. heterolobus* at the Ysabel Passage (o) and Cape Lambert (•). Points in parentheses have been excluded from the regression. Line A: $C/f/km^2 = 0.280 - 0.48 \times 10^{-4}f$, $r = -0.66$, $p<0.05$. Line B: theoretical yield curve.

1983 in this area (FAO 1984). This represents a net increase of 33% in the landings of these fish. The catching and processing of stolephorid anchovies requires only basic methods and sun-drying lends itself to the development of the resource without investment in costly freezers or transportation systems (I.A. Ronquillo unpub. manuscript).

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PATHOGENIC BACTERIA ISOLATED FROM CHICKENS SOLD AT THE LAE MARKET

Deon Mahoney* and Ralph Yamb†

ABSTRACT

Cloacal swabs were taken from live poultry sold at the Lae market and screened for the presence of pathogenic enteric bacteria.

Salmonella *was isolated from less than 1% of birds, while* Clostridium perfringens *type A and* Campylobacter jejuni/Campylobacter coli *were recovered from 15.5% and 35.9% of birds respectively. Although the carrier rates for these organisms are relatively low, foodborne disease may eventuate because of poor hygiene during preparation of the carcass, and inadequate storage facilities for dressed and cooked birds.*

INTRODUCTION

Enormous and varied microbial populations are associated with the feathers, skin, feet, and intestine of live poultry. The faeces are the most important source of pathogenic microorganisms, containing organisms such as *Salmonella, Clostridium perfringens, Campylobacter jejuni, Chlamydia psittaci, Escherichia coli,* and *Yersinia enterocolitica* (I.C.M.S.F. 1980). These organisms may be transferred to feathers and feet when the birds walk or sit on contaminated surfaces. Contamination of the flesh by enteric pathogens during slaughtering, evisceration, and processing, then cross-contamination during culinary preparation of the carcass are considered to play an important role in the spread of foodborne disease, especially as the meat is an excellent medium for the growth of most food poisoning bacteria.

Poultry and poultry products are significant vehicles of foodborne illness accounting for as much as 31 percent of outbreaks in England and Wales, with Salmonellae and *Clostridium perfringens* most frequently implicated (Vernon 1977). These organisms are commonly found in the gastrointestinal tract of poultry, so risks exist if poultry or poultry products are handled incorrectly, improperly cooked, or if other foods are cross-contaminated. Domestic poultry constitute the largest single reservoir of Salmonellae and represent a major source of human disease (Williams 1972; Silliker 1982), but there is growing concern over the increasing incidence of campylobacteriosis. *Campylobacter jejuni* is now recognised as a significant bacterial enteric pathogen of man (Blaser 1982; Kotula and Stern 1984) and has been isolated from the intestinal flora and carcasses of numerous farm animals (Bolton *et al.* 1982) including poultry (Shanker *et al.* 1982; Wempe *et al.* 1983).

A significant number of live birds are sold at markets around Papua New Guinea, and they represent a relatively cheap source of animal protein for low income earners. This paper reports the results of a survey on the incidence of Salmonellae, *Cl. perfringens* type A, and *Campylobacter jejuni/Campylobacter coli* in live poultry sold by private vendors at the Lae market.

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MATERIALS AND METHODS

Random duplicate cloacal swabs were obtained from 103 live birds (fowls and roosters) held in makeshift cages at the Lae market. Swabs were placed in Stuart transport medium (Unless otherwise stated, all laboratory media were manufactured by Oxoid Ltd, Basingstoke, England), stored at 4–7°C, and subcultured in the laboratory within 2 hours.

Salmonella

One cloacal swab was enriched in nutrient broth at 37°C for 24 hours. The broth was subcultured into both tetrathionate broth and mannitol selenite cystine broth and incubated at 37°C and 43°C respectively. After 24 hours the broths were each streaked onto brilliant green agar and bismuth sulphite agar and incubated at 37°C for 24–48 hours.

Typical colonies were Gram stained then inoculated into triple sugar iron agar and urea agar. Presumptive *Salmonella* were tested biochemically using the API 20E system (Analytab Products Inc., Montalieu-Vercieu, France).

Clostridium perfringens type A

Swabs were streaked onto tryptone sulphite cycloserine (TSC) agar (Perfringens agar base, 400 mg cycloserine per litre, and 80 ml of a 50% aqueous solution of egg yolk emulsion per litre) and incubated for 48 hours at 37°C under anaerobic conditions.

Typical colonies were Gram stained, purified by streaking onto TSC agar and tested against *Cl. perfringens* type A antitoxin (Wellcome Diagnostics, Dartford, England).

Campylobacter jejuni/ Campylobacter coli

One swab was streaked onto Skirrow selective media (Columbia blood agar base, 7% defibrinated horse blood (Commonwealth Serum Laboratories, Melbourne, Australia), and Skirrow selective supplement). All plates were incubated at 42°C for 48 hours under microaerophilic conditions (5% oxygen, 10% carbon dioxide, and 85% nitrogen).

Typical colonies were Gram stained and subject to further biochemical tests. Gram negative, oxidase and catalase positive, motile bacteria growing at 42°C and inhibited by nalidixic acid (inhibition zone > 20 mm) were reported as *C. jejuni/C. coli*. This method cannot distinguish *C. jejuni* from *C. coli*, nevertheless both these organisms are pathogenic.

RESULTS AND DISCUSSION

The results obtained from screening the cloacal swabs are shown in *Table 1*. *Salmonella* was isolated only once, with the isolate identified serologically as *S. virchow* (Institute of Medical and Veterinary Science, Adelaide). This was a most unexpected result as the presence of salmonellae in poultry flocks is well documented (Green *et al.* 1982).

Table 1. **Cloacal isolation of enteric pathogens from poultry sold at the Lae market**

Organism	Incidence	Percentage
Salmonella	1/103	1.0
Clostridium perfringens type A	16/103	15.5
Campylobacter jejuni/coli	37/103	35.9

Contaminated feeds have been identified as a primary source of Salmonella infection in animals. Cox *et al.* (1983) found salmonellae in 58% of mash samples, and in 92% of meat and bone meal used as ingredients in commercial feeds. Local poultry producers provide their flocks with commercial feeds, so any contaminated batches could result in widespread dissemination of the pathogen. Survey work suggests that contamination by Salmonellae of locally manufactured feeds occurs only sporadically (D. L'Huillier, personal communication).

Conditions during farming and marketing of poultry were found to be conducive to infection by *Salmonella*. Insects and rodents form an important part of the infection cycle for salmonellae, and since local producers house their birds in sheds constructed of bush materials, these pests may gain easy access to feedstuffs, water, and birds. Birds were transported to market in makeshift wooden cages (see *Plate 1*), and kept under overcrowded conditions for periods of up to eight hours. As a result there were frequent opportunities for cross-contamination by feed, faeces, and water between individual birds and separate flocks.

The cloacal swab technique only detects birds shedding *Salmonella*, while the caeca must be examined to establish carrier status. Shedding by market age poultry is common under the stress of transport and excessive handling, so the results demonstrate the incidence of *Salmonella* was exceedingly low. This is probably related to the way day old chickens are handled. Pivnick and Nurmi (1982) found that the exposure of newly hatched chickens to the intestinal microflora of adult birds increased their resistence to infection by *Salmonella*, as an established gut microflora helps to inhibit pathogenic microorganisms. The rearing environment of locally produced poultry is not sanitised, and in most cases consists of an earth floor covered with sawdust. As a result, day old chickens are soon exposed to the autochthonous microflora of older birds.

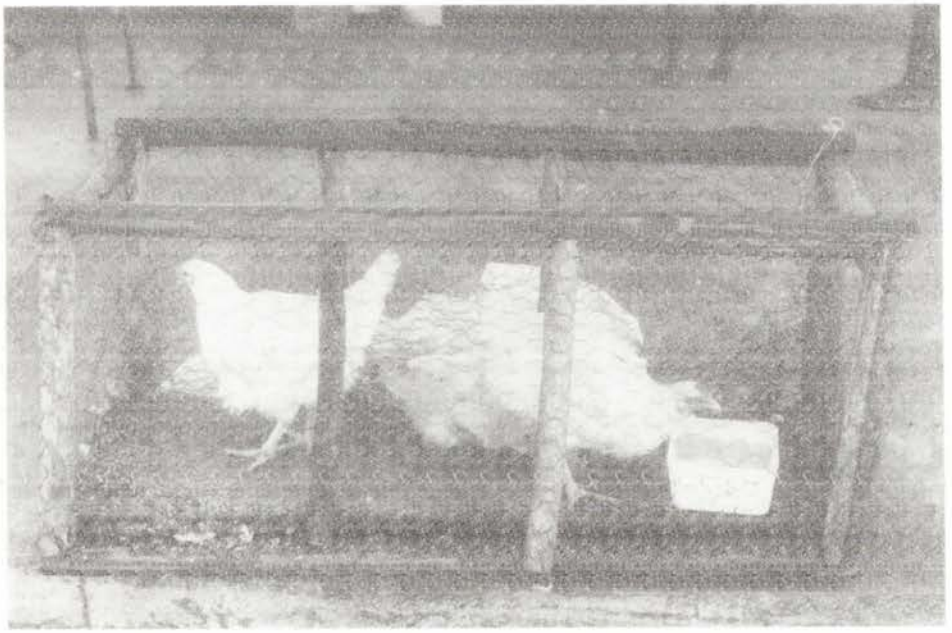

Plate 1—**Typical cage used to transport and market poultry**

Cl. perfringens type A was found in only 15.5% of the poultry surveyed. Poultry and poultry products are important vectors of foodborne illness by *Cl. perfringens*, as this organism is often present in large numbers in the intestinal tract. Contamination is expected to increase during preparation of the carcass because of the ubiquitousness of the organism, and poor hygiene during evisceration and handling. Prevention of this form of food poisoning is achieved by rapid cooling of the carcass, particularly after cooking as heat resistant spores of *Cl. perfringens* may quickly multiply to produce an infective dose.

C. jejuni/C. coli were isolated from 36% of birds swabbed. This level was not considered excessive as *C. jejuni* has frequently been associated with live, freshly slaughtered, and retail-ready poultry. Shanker *et al.* (1982) reported the isolation of *Campylobacter* from 41% of cloacal swabs from broilers at processing plants in Sydney. Wempe *et al.* (1983) isolated *C. jejuni* from the caeca of 71% of birds, while the breast feathers were contaminated in 18% of the birds examined. As with other enteric pathogens, the carrier status varied considerably between different lots.

Carcasses frequently become contaminated with *Campylobacter* during the process of slaughtering, and this has resulted in outbreaks of campylobacter enteritis as a consequence of cross-contamination or improper cooking (Doyle 1984). The handling or preparation of raw chicken has also been found to be a strong risk factor in *C. jejuni* enteritis (Hopkins and Scott 1983; Norkrans and Svedhem 1982). The presence of *C. jejuni* in the gastrointestinal tract of chickens marketed in Lae could, therefore, represent a potential source of human infection, as these chickens are often slaughtered under conditions of poor hygiene. There is little evidence that campylobacters can multiply to large numbers under normal conditions of food storage, nevertheless, infection may be induced by ingestion of only 500 organisms (Robinson 1981).

Most poultry sold at the Lae market were found to be in good condition, with a very low rate of shedding *Salmonella*. Nevertheless, appreciable numbers of birds were contaminated with *Cl. perfringens* and *C. jejuni/C. coli*, and the risk of foodborne disease exists if these birds are not prepared and stored under hygienic conditions.

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EFFECT OF DAY-OLD DEBEAKING AND FOWL POX VACCINATION ON THE PERFORMANCE OF BROILER CHICKENS IN PAPUA NEW GUINEA

R.E. Abdelsamie*

ABSTRACT

In a 2 × 2 completely randomised factorial design, 3000 day-old broiler chickens were assigned to four treatment combinations of debeaked, non-debeaked, fowl pox vaccinated and non-vaccinated groups.

By the end of the first three weeks, the control and vaccinated-only groups were slightly heavier than the two debeaked groups. At nine weeks of age, only the control group was slightly heavier. No significant differences were noted for the four groups as to feed efficiency or mortality.

In tropical developing countries it may be beneficial to not debeak broilers rather than to rely on unskilled labour to perform the operation. Vaccination had no real effect in this experiment. Non-vaccinated chickens, however, may be subjected to the risk of fowl pox.

INTRODUCTION

Debeaking and vaccination against fowl pox are carried out by hatcheries in Papua New Guinea on day-old broiler chickens before despatch to customers. Day-old debeaking is known to reduce the incidence of cannibalism. The effect on performance has been reported by many authors with conflicting results. Darrow and Stotts (1954) showed that removal of one third to one half of the maxilla at one day of age had no effect on body weight but feed efficiency was improved. Lee and Reid (1977) observed that the debeaked birds consumed less feed and were lower in body weight compared with non-debeaked birds, but feed efficiency was not affected. Combs *et al.* (1955), Huston *et al.* (1956), Andrews and Goodwin (1969) and Andrews (1977) observed that debeaking at one day of age had no effect on feed efficiency or growth rate.

Lubbehusen *et al.* (1936) suggested that vaccination at day old with fully potent fowl pox virus presented a considerable danger as the chicken's resistance to other diseases was lowered. However with the use of less potent pigeon pox vaccine and the administration of antibiotics in modern feed formulas, there appears to be no effect of vaccination on the performance of chickens (Hungerford 1962).

In tropical developing countries, the lack of skilled labour to perform debeaking and vaccination is evident. Unskilled labour may cause injury and stress to the chickens. In addition, vaccination and debeaking are carried out during the cooler period of the mornings and the chickens are transported during the hot afternoons. The chickens could be ready for despatch in the morning, and thereby avoid heat

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stress, if the time taken to perform vaccination and debeaking is saved.

The following experiment was conducted to investigate the value of vaccination and debeaking under the local conditions.

MATERIALS AND METHODS

Three thousand day-old broiler chickens of the Tegel TM 70 strain from Morobe Breeder Farm were used in this experiment. The chickens were divided into 4 groups of 750 chickens each. Vaccination and debeaking were carried out as follows:

Group (1) Debeaked only.
Group (2) Vaccinated only.
Group (3) Debeaked and Vaccinated.
Group (4) Without Vaccination and Debeaking (Control).

The control group was delivered at 0800h. The three other groups were vaccinated and/or debeaked at the hatchery and then delivered at 1400h. On arrival, each group was further divided into 3 equal groups of 250 chickens in each group to form 3 replicates per treatment.

All chickens received uniform management in an open sided bush material house with a deep litter floor of 0.1 m^2 per bird. They were fed a standard commercial broiler starter feed for the first 28 days and broiler finisher feed thereafter to 63 days of age. Measurements of mortality, body weight, feed intake and feed efficiency (grams feed/gram gain) were carried out when the chickens were 10, 21, 35, 49 and 63 days of age. At the same time, all chickens were examined for any signs of fowl pox and feather picking. The data were analysed by variance analysis; differences among means were tested for significance by the "t" test (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Analysis of variance of progressive body weights, and final feed conversion and mortality did not show significant interaction between debeaking and vaccination treatments. On the basis of these results the main effects of debeaking and vaccination were calculated (*Table 1*). There were numerically but not significantly lower body weights in the debeaked groups compared with the non-debeaked groups. Final feed conversion and mortality were not statistically different among all groups. There were no signs of feather picking even in males which are slow feathering. No symptoms of fowl pox were observed.

The results indicate that there were no real benefits of debeaking under the conditions of adequate management and balanced nutrition prevailing in

Table 1.– **Body weight, feed conversion and mortality in broiler chickens as affected by fowl pox vaccination and debeaking**

	Body weights in grams					Feed conversion at 63 days	Mortality at 63 days (%)
Treatments	10 Days	21 Days	35 Days	49 Days	63 Days		
Not debeaked	145.0	390.0	974.0	1612.0	2110.0	2.351	8.15
Debeaked	135.5	376.0	958.0	1602.0	2066.0	2.366	7.25
Not vaccinated	137.5	385.0	961.5	1612.5	2102.0	2.345	7.40
Vaccinated	143.0	381.0	970.5	1601.5	2075.0	2.372	8.00
SED*	3.84	9.42	13.10	17.60	37.70	0.0188	0.89

* SED–Standard error of the difference between means (8df).

this trial. Fowl pox vaccination had no effect on the chickens in this experiment. However, occasional risk of the disease if the chickens are not vaccinated cannot be ruled out.

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A STUDY OF NUTRITIONAL PROBLEMS AFFECTING THE SMALLHOLDER BROILER INDUSTRY IN PAPUA NEW GUINEA

R.E. Abdelsamie*

ABSTRACT

Nutrition deficiencies of lysine and methionine were investigated as possible factors in the poor performance of the smallholder broiler industry in Papua New Guinea. The commercial feed used by the growers was supplemented with lysine, methionine or lysine plus methionine at levels of 5, 10 and 20% of the requirements.

Significant responses of body weight and feed conversion ratio were achieved with lysine and lysine plus methionine supplementations. Methionine supplementations alone did not improve performance. No significant effects on feathering were noted.

INTRODUCTION

The smallholder broiler industry in Papua New Guinea was faced with problems of high mortality, poor growth rate and bare back. Previous investigation (Abdelsamie, unpublished) showed that incorrect brooding of day old chickens by the farmers was the main factor responsible for the high mortality and poor growth rate. Debeaking was effective in reducing the incidence of bare back. The study also showed that growth performance of chickens when managed correctly remained below the strain's performance as indicated by the breeder (A.A. Tegel Pty Ltd, Australia).

The investigation was extended to study the nutritional quality of the only commercial feed available to the growers as a possible factor contributing to the poor growth performance. Field trials indicated that the addition of soluble vitamins to the drinking water did not appreciably improve growth rate of chickens fed on that feed. The effect of lysine and methionine supplementations on growth performance and feathering is reported here.

MATERIALS AND METHODS

Two thousand one-day-old commercial broilers (A.A. Tegel Pty Ltd, Australia) were used in this investigation. Mild debeaking and vaccination against fowl pox were carried out on arrival of the chickens.

The basal feed used in this experiment was part of a large shipment intended for supply to the broiler growers. No information was available on ingredient composition of the feed. Biological determination of metabolizable energy was carried out on the feed using four week old broilers of the same strain following the method of Hill and Anderson, 1958. The amino acid profile of the feed was determined after hydrolysis with 6N HCL for 24 hours in an open flask using a Jeol JLC-6AH amino acid analyser with Model 1-DK integrator and Model-2 printer. Proximate analyses were also carried out (Association of Official Analytical Chemists 1975).

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The feed was supplemented with l lysine and dl methionine, or both at levels of 5, 10 and 20% of the broiler requirements (National Academy of Sciences – National Research Council 1971).

The day-old chickens were initially divided into 10 groups of 200 chickens in each group. They were brooded for one week. Nine groups were fed on the experimental feeds and one group received the basal feed and served as control. On day 8, each group was divided into four groups of approximately equal body weight, randomly allocated to the experimental pens and fed on the same feed (each initial group formed 4 replicates). Measurements of body weight, feed intake and feed efficiency (g feed/g gain) were carried out on the chickens every week for a period of five weeks when the experiment terminated. Treatments' effects on feather development were also assessed. Growth performance parameters were analysed statistically by analysis of variance (Steel and Torrie 1960).

RESULTS

The basal ration contained 88.5% dry matter and 12.34 MJ metabolizable energy/kg. The crude protein, ether extract and acid detergent fibre expressed on a dry matter basis were 25.6, 3.9 and 7.1%, respectively. Amino acid analysis indicated that the feed contained 0.87% lysine and 0.78% methionine plus cystine.

There was a stepwise increase in body weight over time as a result of lysine and lysine plus methionine supplementations. Methionine alone did not improve body weight above that of the control group when added at levels of 5 and 20% of the NRC requirements, but the addition of 10% methionine improved body weight.

Treatment means and comparisons between means for body weight and feed conversion of the chickens at 5 weeks of age are presented in *Table 1.* There were significant overall treatment effects for both variables ($P<0.01$). The methionine treatments gave a significantly ($P<0.01$) lower feed conversion than the control and no significant effect on body weight. For those treatments receiving lysine plus methionine, there was a slight but significant ($P<0.05$) effect on body weight and no significant effect on food conversion when compared with treatments receiving lysine alone. Qualitative observations on the effects of treatments on feather development did not show any abnormality among all groups.

DISCUSSION

The results of this experiment indicate that the feed was deficient in lysine. Lysine level in the feed (0.87%) was only 70% of the NAS-NRC (1971) recommended requirements for broilers up to six weeks of age (1.25% of the diet). There was a dramatic response of body weight and feed conversion to added lysine, and to a lesser extent when lysine plus methionine were added. On the other hand, methionine supplementation alone appeared to have no effect on body weight and significantly reduced the efficiency of feed conversion. This was evident at levels of inclusion of five and 20% of the requirements. No explanation can be offered for the discrepancy in the results of methionine supplementation (i.e. no effect on body weight as a result of adding 5 and 20% methionine, while 10% improved body weight and feed conversion). However, an error in formulating the feed (i.e. adding lysine instead of methionine for that particular batch) cannot be ruled out; since this treatment produced roughly the same effect as that of 10% lysine supplementation. It is also probable that the reason for the significant depression in feed conversion associated with methionine supplementations was

Table 1.—**Performance at 5 weeks of chickens fed diets supplemented with amino acids**

Treatments	Body Weight g	Feed Conversion
Control	549.8	2.129
5% Lysine	639.8	2.116
10% Lysine	655.8	2.081
20% Lysine	682.8	2.012
5% Methionine	540.4	2.330
10% Methionine	621.2	2.140
20% Methionine	548.6	2.407
5% Lysine + 5% Methionine	584.1	2.137
10% Lysine + 10% Methionine	654.9	2.061
20% Lysine + 20% Methionine	661.6	2.133
SED	21.7	0.055
F	14.25**	11.29**
Comparisons		
Control	549.8	2.129
Methionine	570.1	2.292
SED	17.7	0.045
F	1.13^{NS}	13.22**
Lysine	659.5	2.070
Lysine + Methionine	633.5	2.110
SED	12.5	0.032
F	4.28*	1.64^{NS}

Notes: SED: Standard error of the difference between means
NS: not signficant; *$p<0.05$; **$p<0.01$; ***$p<0.001$

due to amino acids imbalance (i.e. excess methionine in relation to other amino acids).

All treatments, including the control, showed normal feather development. These results contradict previous observations of poor feathering in which the same source of feed was used. It is possible that differences in environmental conditions could be responsible for the difference between the two experiments. This experiment was conducted during the wet season when the area experiences a mild temperature compared with the previous experiment which was conducted during the dry season when the temperature was higher.

The study demonstrated the danger of relying on a single source of feed supply. It appears that inadequacy of feed was one reason for the poor performance in the broiler industry. Diversifying of feed supplies to encourage competitiveness and careful monitoring of the feed should prevent similar problems occurring in the future.

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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.

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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.

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4. Abstract – An informative abstract suitable for use by abstracting publications and services should precede the introductory paragraph. Because it is not part of the paper an abstract should be intelligible on its own and should state the purpose, methodology, results and conclusions. It should be written as simply as possible to assist specialists in other countries for whom English is a foreign language. It should not include unfamiliar terms, acronyms, trade names, abbreviations or symbols without explanation. More than one paragraph may be used but the abstract should not exceed 2% of the total extent of the contribution; maximum 300 words.

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.

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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.

11. Review of papers – All copy will be submitted to suitable professional referees. Major changes will be referred to the author for consideration. Minor editorial changes will be made without consultation but will be presented to the author(s) at proof stage.

12. Offprints – Twenty five free offprints are given of the author. Where there are several authors, the senior author will be sent the offprints. Extra offprints may be ordered at the time the galley proofs are returned to the editor. Costs will be determined at the time of printing.

13. Recognised abbreviations in this journal are:

g – gram
kg – kilogram
t – tonne
l – 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
* – $0.01 \leqslant p < 0.05$
** – $0.001 \leqslant p < 0.01$
*** – $p < 0.001$

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