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Intensification of agricultural systems in Papua New Guinea

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Abstract: *This paper provides an overview of the ways in which villagers have intensified agricultural systems in Papua New Guinea, focusing on the last 60 years. The intensification techniques used by villagers include: adoption of more productive staple crops, in particular sweet potato, cassava, Xanthosoma taro, Solanum potato and maize; adoption of more productive cultivars, especially of banana and sweet potato; shortening the fallow period; extending the cropping period; certain soil fertility maintenance techniques, other than natural regrowth fallows (composting, managed tree fallows, especially using casuarina, a legume/root crop rotation, and soil erosion control); and some other intensification techniques including soil tillage, drainage, construction of garden beds, garden segregation, mounding and irrigation. People often use more than one technique and the techniques used vary between the major agricultural zones. The adoption of new food crops and more productive cultivars of existing food crops has facilitated many of the other changes, particularly longer cropping periods and shorter fallow periods.*

Keywords: *Papua New Guinea, land use, intensification, crop introductions, soil fertility maintenance*

Ester Boserup posits a positive relationship between increasing human populations, agricultural innovation and land use intensification. Since 1966, the population of Papua New Guinea has more than doubled and it continues to grow at about 2.3 per cent per year. Most Papua New Guineans are rural villagers who produce most of their own food. But McAlpine and Freyne (this volume) demonstrate convincingly that there has not been a large increase in the area of agricultural land (current food gardens and fallow land). There is no evidence of a major decline in nutritional standards, although child malnutrition is very poor in some areas. Food imports have increased, but at

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or near the population growth rate. It has to be assumed therefore, that additional food is being produced through more intensive land use. The object of this paper is to show how new agricultural technologies have been invented or adopted and how Papua New Guinea agricultural systems have been changed, in order to produce more food.

Changes in Papua New Guinea agricultural systems have been occurring for a long time. Recently, however, significant changes commenced, in the lowland areas, with settlement by Europeans, Asians and other Pacific islanders. This occurred from the early 1870s onwards. In the highlands, the changes started several hundred years ago with the adoption of the New World crop sweet potato, which was introduced to the Western Pacific by European travellers following transport from its South American homeland (Yen, 1974). This paper focuses on the period from 1940 to the present as more is known about this time, and also because the last sixty years has been a period of rapid change and intensification of land use.

Ten years ago I wrote a paper on change in subsistence food production (Bourke, 1990). In that, I gave an outline of how villagers were intensifying land use, focusing on recent change. Since then the Land Management Group at the Australian National University has described village agriculture in detail in the Mapping Agricultural Systems in Papua New Guinea Project (MASP) (see for example Allen *et al.*, 1995; Allen *et al.*, 2001; Allen and Ballard, this volume, Bourke *et al.*, 1998). The classification used in the MASP Project built on research elsewhere in the tropics (summarised by Ruthenberg, 1980) and in particular on Harold Brookfield's classification of agricultural systems in Papua New Guinea (Brookfield, 1962). The MASP Project was based on extensive fieldwork in all rural Papua New Guinea. Much of what is summarised here has been proposed or described by others, for example by Wood and Humphreys (1982). However, following the comprehensive fieldwork undertaken as part of the MASP project, we can now give an overview of intensification with more confidence and completeness.

BACKGROUND

The majority of Papua New Guineans are rural villagers (circa 85 per cent) and they produce most of their own food. Gibson estimates that rural people derive 84 per cent of calories from locally produced food (Gibson, 2001). For most people, arable agriculture provides the basis of their livelihood. Subsistence is based on the production of root crops, banana, green vegetables and other horticultural produce.

Tree crops also provide food, notably sago (*Metroxylon sagu*), which is an important food for about 10 per cent of rural villagers (Allen *et al.*, 2001). The significance of tree crops varies considerably between environments. They are most common on small islands where coconut, breadfruit (*Artocarpus altilis*) and Polynesian chestnut (*Inocarpus fagifer*) are often major food sources. Tree crops provide food in inland locations in the lowlands and the fringe of the central highlands where breadnut (*Artocarpus camansi*), *marita* fruit pandanus

Figure 1. Papua New Guinea showing locations mentioned in the text

(*Pandanus conoideus*), *ton* (*Pometia pinnata*), *okari* nut (*Terminalia kaernbachii*) and *Pangium edule* are commonly eaten in certain locations.

People eat animal products from pig, chicken, dog, goat, *cuscus*, deer and game, as well as fish in many riverine and coastal locations, with pigs, chickens and fish being the most significant. In the central highlands, pigs were and remain an important source of wealth. The significance of fish varies considerably in coastal and on inland rivers, even over short distances. In some places, people trade fish and other marine produce for garden produce, rather than producing their own. For example, in the middle Sepik River, villagers trade fish for sago. In certain locations, people trade manufactured items for food.[1]

INTENSIFICATION OF LAND USE

Attention now turns to the intensification of land use for village food production that has occurred over recent decades and continues to occur. Intensification is taken to mean greater production of food from the same area of agricultural land. In this context, agricultural land includes that used for current production (food gardens) and land under vegetation regrowth, that is, land being fallowed (Saunders, 1993). The population has more than doubled over the past 34 years, increasing from 2.2 million in 1966 to 5.1 million people in 2000. The rural population is increasing at a slightly lower rate than the national average, but all indications are that it will again double over the next 35 years.

Despite this population increase, there has not been a large increase in agricultural land, that is, land used for food production. Over the period 1975 to 1996, the area of land used for food production increased by 10 per cent,

while the rural population grew by an estimated 50 per cent (McAlpine *et al.*, 2001; McAlpine and Freyne, this volume). Rural people are continuing to feed themselves, but with little increase in the total area devoted to agricultural production. Some of the additional food is supplied by imported food, especially rice, flour-based products, tinned fish and tinned beef. However, imported items contribute only 16 per cent of the calories consumed by rural people (Gibson, 2001).[2] There are no indications of declining food availability for the great majority of villagers in rural locations.

I suggest that the additional food is being provided through more intensive land use; that is, more food is being produced from a given area of land. A summary of the intensification techniques that villagers are using is now given.

INTENSIFICATION TECHNIQUES

The intensification techniques used by villagers may be classified as follows:

1. Adopting more productive staple crops, in particular sweet potato, cassava, Xanthosoma taro, Solanum potato and maize.
2. Adopting more productive cultivars, especially banana and sweet potato.
3. Shortening the fallow period.
4. Extending the cropping period, often by making a second or third planting of sweet potato or cassava before land is fallowed.
5. Using soil fertility maintenance techniques, other than natural regrowth fallows.
6. Using other intensification techniques including soil tillage, drainage, construction of garden beds, segregation of gardens into different types with different management, mounding and irrigation.

The relative importance, timing, and sequence of adoption varies considerably between locations and between each of the major ecological zones. This will not be discussed in detail, but a distinction will be made between the lowlands (taken here at sea level to 1200 masl) and the highlands (1200–2800 masl). Villagers often use more than one technique to intensify land use.

Adoption of more productive crops

Food crops have been introduced into Papua New Guinea over many thousands of years, but new crop species are defined here as those introduced after the year 1870. This is because in the early 1870s, European missionaries, traders, planters and explorers, and people associated with them from Asia and other Pacific islands, commenced permanent settlement in Papua New Guinea. Immediately a large number of new crops were introduced, many of which were adopted into village agriculture.

Staples prior to 1870 were sweet potato in the highlands and some highland fringe areas; Colocasia taro, yam (mainly *Dioscorea esculenta* and *D. alata*), sago and banana. Sugarcane, breadfruit and coconut were also important foods (Table 1). Recent research using biomolecular markers has confirmed that

Table 1. The antiquity of species which provide starchy food in Papua New Guinea[1]

Scientific name	Common name	Notes
Traditional species[2]		
Alocasia macrorrhiza	Giant taro	Possibly domesticated in Melanesia[3]
Amorphophallus paeoniifolius	Elephant-foot yam	
Artocarpus altilis	Breadfruit	Domesticated in Melanesia[3]
Colocasia esculenta	Taro	Domesticated in Melanesia[3]
Cyrtosperma chamissonis	Swamp taro	Possibly domesticated in Melanesia[3]
Dioscorea alata	Greater yam	Domesticated in Melanesia[3]
Dioscorea bulbifera	Potato yam	
Dioscorea esculenta	Lesser yam	
Dioscorea hispida	–	
Dioscorea nummularia	Nummularia yam	
Dioscorea pentaphylla	Five leaflet yam	
Ipomoea batatas	Sweet potato	Introduced after ca 1750 AD
Metroxylon sagu	Sago	Possibly domesticated in Melanesia[3]
Musa cvs	Banana	Domesticated in Melanesia[3]
Pueraria lobata	Pueraria	
Saccharum officinarum	Sugar cane	Domesticated in Melanesia[3]
Post-1870 introductions		
Canna edulis	Queensland arrowroot	
Dioscorea rotundata	African yam	
Manihot esculenta	Cassava	Possibly introduced a little before 1870
Oryza sativa	Rice	
Solanum tuberosum	Potato	
Xanthosoma sagittifolium	Chinese taro	
Zea mays	Maize	Early adoption, but almost certainly introduced post-1870

Notes:
1 For a compendium of all food crops used in Papua New Guinea, see French (1986). There are many more minor traditional and introduced species.
2 The term 'traditional' means crop species used prior to widespread crop introductions by Europeans and other outsiders from 1870 onwards. It corresponds to descriptions by villagers of a species as belonging to the ancestors ('bilong tumbuna') as distinct from those introduced by Europeans or other outsiders ('bilong ol waitman').
3 After Lebot (1999). Some species, including Colocasia taro and yam (*Dioscorea alata*) may have been domesticated in both western Melanesia and in Asia.

banana, breadfruit, sugarcane, Colocasia taro and yam (*D. alata*) were domesticated in the distant past in New Guinea and further east in Melanesia (Lebot, 1999).

Following Iberian exploration in the Americas, there was a major exchange of germplasm between the Old World and the New World of South, Central and North America. Two crops from the Americans reached Papua New Guinea prior to permanent settlement by Europeans. These were sweet potato and tobacco, both of which were introduced into Southeast Asia and elsewhere by Spanish and Portuguese colonisers.[3]

Sweet potato was introduced about 300–350 years ago from Indonesia. It became the most important staple food in most of the central highlands, so that by the time European missionaries, goldminers and explorers and their Papua New Guinea associates entered this area, from about 1920 onwards, sweet potato dominated the agriculture. Sweet potato was already present in some lowland and island locations by the time of direct European contact, but nowhere in the lowlands was it a major food prior to 1900. Subsequently it has been adopted, so that it is now a major food in many lowland locations. Either by itself, or with one other staple food, it is the main crop grown by over 60 per cent of rural villagers (Allen *et al.*, 2001) and it now provides more calories to rural villagers than banana, sago, Colocasia taro, Xanthosoma taro, yam, cassava and sugarcane combined (Gibson, 2001).

Cassava was introduced after 1870, although possibly somewhat earlier in the western parts adjoining Irian Jaya. Since the 1950s, it has increased in importance in many locations and continues to do so. It tends to be most common in locations with a marked dry period, but it is also grown in places where the rainfall is extremely high, such as the interior of New Britain and on the highland fringe. In a limited number of locations, for example around Cape Hoskins on the north coast of New Britain, it is now the main food eaten (Bourke and Vovola, 2000).

Xanthosoma taro was introduced after 1870, most likely by Pacific island missionaries. It was a minor food crop until after 1950 when it became a staple food, particularly in inland New Britain, the Huon Peninsula and parts of Kaintiba District in inland Gulf Province. It has assumed greatest significance in the intermediate altitude zone from about 300 to 1000 masl. Xanthosoma taro has declined in importance since the mid-1980s because of a root disease.

Solanum potato has been adopted at high altitude locations (above 2200 masl) since the early 1970s. Potato is now an important supplementary food to the main staple, sweet potato, at some very high altitude locations. It is also grown as a food crop for villagers at lower altitudes in the highlands, but there it is regarded more as a cash crop.

Maize was introduced by Europeans at a number of locations in the early-to mid-1870s (Table 1). It has been widely adopted. It is most common in locations with a marked seasonal rainfall pattern, particularly in the Benabena area of the Eastern Highlands, but maize is grown in most environments up to its altitudinal limit of 2500 masl.

The newly adopted food crops have a number of advantages over the older staples of Colocasia taro, diploid bananas, and yam. They are generally higher yielding, especially under declining soil fertility conditions; it is much easier to manage the planting material than for taro and yam; some are adapted to a wider range of environments, especially sweet potato and cassava; and the new foods generally suffer fewer pest and disease problems.[4]

These species have increased productivity because of their greater yields per unit area, even as soil fertility has declined. However, they have also facilitated other aspects of intensification, especially shorter fallow periods and a longer cropping before land is fallowed. Again it is sweet potato which has had the

greatest impact in this regard, but cassava and Xanthosoma taro have also played a role in greater intensity of land use.

Adoption of new cultivars of existing crops

Many new cultivars of a number of existing food crops have been adopted. This applies especially to banana and sweet potato, but to a lesser degree to yam and Colocasia taro. Prior to 1870, villagers grew diploid banana cultivars, with limited yield potential even under optimum growing conditions, and some triploid cultivars. Over the past 130 years, a number of introduced triploid banana cultivars have been widely adopted, especially those of the hardy ABB group. In a number of locations, such as on the south side of Cape Vogel in Milne Bay Province, the recent adoption of hardy triploid banana has greatly altered the agricultural system and allowed more intensive production because of an extended cropping period of about eight years.

There is little information on how many banana cultivars have been adopted and their spread. The local names sometimes indicate that a cultivar is relatively new in that area, but this does not indicate whether it originated elsewhere in Papua New Guinea or overseas. For example, in south Fergusson Island in Milne Bay Province, four banana cultivars were introduced in the 1930s before the Pacific War. These are known locally as India, Finschhafen (a location on the New Guinea mainland), Wanpaun (one pound) and Tusilin (two shillings).

There has been very widespread adoption of new sweet potato cultivars in both highland and in lowland locations where it is a common food. For example, on the Nembi Plateau in the Southern Highlands, villagers plant 25 cultivars of sweet potato. Eleven of these are of pre-European origin and fourteen have been adopted post-contact. At least another 25 pre-European cultivars are no longer maintained or grown there.

The widespread adoption of these newer cultivars suggests that they are higher yielding or have other desirable characteristics, but this hypothesis has rarely been tested. The triploid banana cultivars, which are spreading at the expense of other crops or the less productive diploids, clearly give a greater yield than the older cultivars, but they also produce for extended periods (up to 30 years if they are weeded regularly) and under declining soil fertility conditions. While there is little solid evidence for the impact of the recently adopted banana and sweet potato cultivars, it is likely that they are contributing to increased productivity and to greater land use intensity.

Shortening fallow periods

A decrease in the fallow period is one of the most common techniques used by villagers to intensify land use. There is much field evidence of this occurring and villagers commonly give specific examples of declining fallow periods. They relate height of fallow vegetation, which reflects the fallow period, to stages of their own lives, such as youth, marriage and their children's

marriages. The relative importance of the various intensification techniques varies considerably between locations, but reducing the fallow period is often one of the first stages of land use intensification. In a limited number of lowland locations, fallow periods are only one or two years long and are insufficient to maintain crop yields, even for hardy crops such as sweet potato and cassava.

Extended cropping periods

Land use intensity is also being increased by longer cropping periods. In the highlands, this means more plantings of the main food, sweet potato. For example in some locations, over the past forty years, people have increased from two to five, the number of plantings before land is fallowed.

In the lowlands, people sometimes increase the number of plantings of the traditional staples, but this is rare. More commonly, villagers add sweet potato, cassava or banana, either alone or in combination, as a second (or third) planting after the first planting of taro or yam has been harvested. Where people have replaced the original staple with a more productive one, land use has been intensified by increasing the number of plantings before fallowing. For example, prior to 1941, the agricultural system on Bougainville Island was based on a single planting of Colocasia taro. Following an epidemic of taro blight in the early 1940s, villagers switched to sweet potato as the main staple food. Intensity of land use has been increased over the past 60 years by reducing fallow period and increasing the cropping period, with three to five plantings of sweet potato now occurring in most locations.

Soil fertility maintenance techniques

Soil fertility is restored after the cropping phase by self-sown natural forest or grassland fallows. People have developed other techniques to increase soil fertility, especially in the highlands. There the increased productivity associated with sweet potato occurred several hundred years ago and there is no other suitable new food crop to replace or complement sweet potato. However, in a limited number of lowland locations, people are using some of these techniques. An example is managed tree fallows on some very small islands where land use intensity is very high for that environment. The most important soil fertility maintenance techniques other than natural fallows are composting, planted tree fallows, a legume/root crop rotation and the use of soil erosion barriers. A number of other minor techniques are also used. A brief description of each of these techniques follows.

Composting. In the highlands, this takes the form of importation of organic matter, such as grass, into a garden, or recycling of weeds and crop residues within the garden area. The organic material is placed in a pile and covered with soil to form a mound, sometimes up to 1.2 m high and with a diameter of over 2.5 m. This technique is practised in a discrete region in the western part of the highlands (Figure 2). At lower altitude locations in the Southern

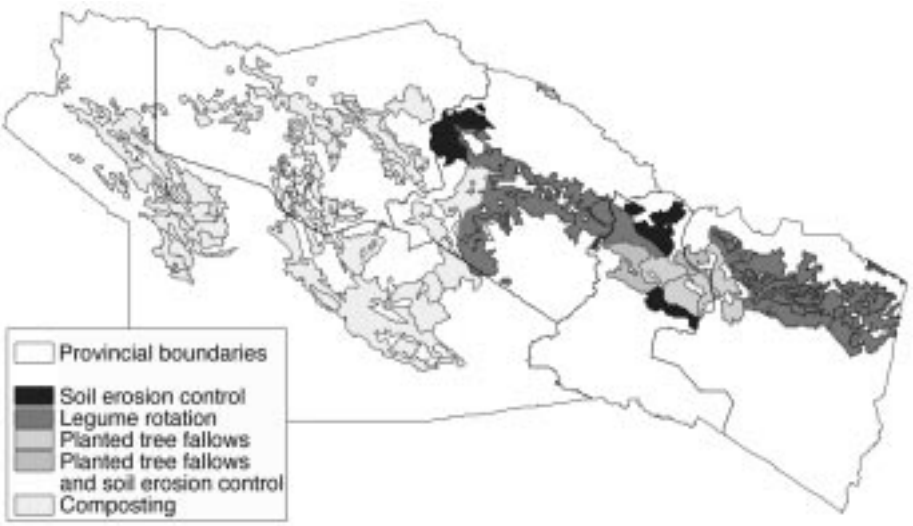

Figure 2. Locations in the highlands where villagers practise composting, planted casuarina fallows, a legume/sweet potato rotation and soil erosion control

Highlands Province, organic matter is incorporated into drained beds rather than mounds. The position of the mound may remain constant for every planting or it may be moved to the inter-mound space from the previous planting. The technique allows extended cropping periods. In many locations within the composting zone, land use is permanent or semi-permanent, with food gardens maintained for one or two generations (over 40 years).

Composting is practised in a wide range of environments, over an altitudinal range of 1100–2800 masl (the range for composted mounds is 1500–2800 masl). In the composting zone, the rainfall varies from 2500 to 5000 mm per year, with little rainfall seasonality. The technique is most common on soils derived from volcanic ash. Over 20 agronomic trials have clearly established that the technique increases sweet potato yield, both within and outside the traditional composting zone. Thus the technique could be used in a wider geographic area in the highlands. This, together with the discrete distribution of the technique, suggests that it spread relatively recently and rapidly from the location of its initial development.

Composting is associated with intensive land use in one region of the highlands. I suggest that the technique was devised by villagers in the main valleys of Enga Province about 150 years ago. It is likely that the technique was adopted mainly to grow more sweet potato for pig fodder, although the resulting increase in production would have provided food for both pigs and people. There is some evidence of the adoption of the technique over the past 40 years on the fringe of the composting zone. It is postulated that, following the invention of the technique in one location, it was adopted quite quickly, perhaps over 40–80 years, over a much wider region. It is further suggested that the main motivation for the adoption of composting, and the associated large mounds, was to increase sweet potato for pig production.

Photo: R. M. Bourke

Photo 1. In some medium intensity agricultural systems of Highlands Papua New Guinea, food gardens are planted with trees to protect soils from erosion and to enhance soil fertility

Managed tree fallows. The second soil fertility maintenance technique used is management of the fallow phase by planting trees, as seen in Photo 1. The most important species used is *Casuarina oligodon*. Minor species used include *Parasponia rigida*, *Schleinitzia novo-guineensis*, *Albizia* spp. and *Piper aduncum*. The following summary is based on a review by Bourke (2000).

Casuarina oligodon is a multi-purpose species which is grown throughout the highlands. It provides timber for fencing, firewood and house construction. As well, in four sub-regions in the highlands, villagers transport self-sown seedlings into sweet potato gardens towards the end of the cropping phase to enhance soil fertility.[5] These seedlings grow to form dense stands of trees which dominate the fallow phase. About 1.3 million people plant some casuarina trees and about one-fifth of these manage fallow species composition using casuarina.

As with composting, there is a discrete distribution to the practice of managing fallows with casuarina planting, but it is practised in four sub-regions (Figure 2). Managing the fallows with casuarina trees is most commonly done in locations with an altitudinal range of 1400−2100 masl; where slopes are steep (over 20º); the landform is hills or mountains; the lithology is sedimentary; vegetation in grasslands; and annual rainfall is in the range of 2000-3000 mm. Land use intensity in these locations is very low to low. Limited soil analysis indicates that casuarina increases levels of nitrogen and carbon in the soil.

In two of the four sub-regions where casuarina is planted in sweet potato gardens as a fallow management strategy, the practice has been adopted since the 1920s. In the third sub-region, this usage has increased greatly since the 1930s. (We have no information regarding adoption in the fourth sub-region). It is hypothesised that the management of fallows composition using casuarina

has been adopted relatively recently, that is within the past 150 years, in response to increasing human and pig populations.

Legume/ root crop rotation. The third soil fertility maintenance technique used is a rotation of a leguminous food crop with a root crop. The legume crop is usually peanuts, but sometimes winged bean (*Psophocarpus tetragonolobus*) is used; the root crop is almost always sweet potato, but very occasionally yam (*D. alata*) is planted in this rotation. Villagers who practise this rotation report that it is successful in maintaining sweet potato yields for an extended period.

The technique is most commonly used in parts of the highlands region (Figure 2) and on the Gazelle Peninsula of New Britain. The environments where the technique is used may be characterised as follows: below an altitude of 1900 masl (usually the upper limit for both peanuts and winged bean); on flat or gently sloping land; on soils containing volcanic ash which are well drained and well structured; where grasslands fallows rather than woody fallows are used; and where land use intensity is high.

In highland locations where the technique is used, people typically plant sweet potato as the first crop after fallowing. Sweet potato is replanted until yields decline, and then one or more crops of peanuts or winged bean are planted. Several more crops of sweet potato are planted until yields decline further. At this stage, land is most likely to be fallowed, but further peanut plantings may follow. On the Gazelle Peninsula of New Britain, the sequence is the opposite to that used in the highlands, with the first planting after a grassland fallow being peanuts, and sweet potato planted after one or two peanut plantings.

The distribution of the three techniques discussed so far is quite discrete, with virtually no overlap in their usage. This pattern reflects the environments in which each technique is most useful. It is also likely that the distribution in the use of composting reflects a specific historical sequence of adaptation.

Soil erosion control. A fourth soil fertility maintenance technique is soil erosion control using soil retention barriers and terraces. Again, this technique is more common at higher altitudes, but it is sometimes used in the lowlands.[6] The technique described here is confined to some locations in Simbu Province, and nearby parts of adjacent provinces (Figure 2), to parts of the north and south side of the Huon Peninsula; and to the Rabaraba area, Goodenough Island and Amphlett Islands in Milne Bay Province.

Overall, soil erosion control is not a common practice. It is used on steep land and in locations where agriculture is less intensive and the population density lower. The antiquity of the technique is unknown, although there are a few indications in Simbu of expansion of the technique in recent decades.

In Simbu, modifications to reduce soil erosion take a number of forms. In the simplest, people peg trunks or branches of casuarina or other tree species across the slope. It is also common to build small brush fences in parallel lines 5–10 m apart, each fence rising 20–30 cm above the soil surface (Humphreys and Brookfield, 1991). The impact is not permanent and the benefit rarely lasts beyond twelve months. More permanent live fences of close-spaced *Cordyline fruticosa* have the same, but more enduring, effect and over time a soil step

(talud), a metre or more in height builds up behind them (Humphreys and Brookfield, 1991). These two techniques are commonly done in association with planted casuarina fallows and in the same broad environment. Villagers in Simbu are currently adopting the use of vetiver grass (*Vetiveria zizanioides*) to control soil erosion (Shelton and Mondo, 2001).

On the Huon Peninsula, people construct terraces up to 1.5 m high, 1–4 m wide and 15–25 m long. Stakes are placed around the contour and soil is moved to create a terrace up to 4 m wide. In the Milne Bay locations, soil erosion is reduced by placing logs across the slope and these are held in place with pegs. The technique is similar to that used in Simbu, but brush is not usually placed behind the logs in Milne Bay.

Other soil fertility maintenance techniques. A number of other very minor techniques are used. Inorganic fertiliser is used for commercial vegetables only, mainly in the highlands. Where a plot of vegetables, such as brassicas, are grown in rotation with sweet potato or other subsistence food crops, there may be a small carry-over effect, but the impact is trivial. Very occasionally people use animal manure, especially chicken manure, and other organic fertilisers, such as the pulp of coffee berries, to maintain soil fertility. This is more common than the use of inorganic fertiliser and again is usually confined to commercial vegetables in the highlands. However, people sometimes apply coffee pulp, chicken manure or fire ash to subsistence food gardens in relatively small amounts. In the western part of the highlands, villagers commonly plant vegetables, tobacco and other crops in small areas of fire ash. These are crops that require high soil fertility levels for maximum yield. The fires are made expressly for this purpose, using casuarina leaves and twigs. It is likely that the hot burn results in the release of nitrogen from soil micro-organisms and this is responsible for the large yield increase observed rather than potash or magnesium released in the ash.

In a number of highland and lowland locations, food gardens are located on river terraces which are flooded from time to time. The silt enhances soil fertility and allows much more intensive land use than would have been possible without the silt deposition. This is not an active soil enhancement technique, but use of these sites does facilitate land use intensification. Following pacification in the highlands (1930–60), it is now possible for villagers to use such sites with much less risk of attack from enemy clans. Hence, these sites, generally on the flatter and more fertile land, are now much more widely used than previously.

Other intensification techniques

A number of other techniques are used to intensify land use and increase productivity.

Garden segregation. Another method of intensifying land use is to segregate plantings of different crops or groups of crops into different garden types which are managed differently. In many highland locations where land use is intensive, people create ‘mixed gardens’, which contain vegetables and

minor starch foods such as taro. They are managed quite differently from the more intensive sweet potato gardens, which dominate land use. The mixed gardens are planted for shorter periods, with typically only one planting before fallowing; the fertility is sometimes enhanced in these sites by planting casuarina trees; and they may contain 10−15 species of food. Sweet potato is rarely planted in them. They generally occupy wetter sites than sweet potato gardens. The location depends on local landforms. Mixed gardens are not universal, and are generally confined to the altitudinal range of 1500−2000 masl, partly because many of the species grown in these gardens have an upper altitudinal limit of about 2000 masl.

Household gardens are small food gardens located near houses. They are almost universal in the highlands, common on the fringes and are sometimes used in the lowlands. Typically, these contain vegetables such as *aibika* (*Abelmoschus manihot*), sugarcane and pumpkin. Soil fertility is usually enhanced by the addition of household food scraps, fire ash, discarded organic rubbish, such as sugarcane peel and sweepings from village compounds.

Soil tillage. In low intensity agriculture, the soil is not usually tilled following a woody fallow. However, in grassland agriculture, tillage is much more common, presumably as it releases soil nutrients. Tillage is associated with grassland fallows in both highland and lowland regions.

Photo: B. J. Allen

Photo 2: Soil fertility maintenance in intensive agricultural systems includes a rotation of peanuts and sweet potato. Drains, tillage and beds are used in these Eastern Highlands gardens

Drainage and garden beds. Drainage and use of garden beds are some of the most common techniques used to modify the natural environment and increase productivity. This is especially so for sweet potato as high tuber production is very dependent on adequate soil aeration during the tuber formation phase. Drains with both regular and irregular spacing are common in

food gardens or around garden perimeters, especially in the highlands. Drains are commonly dug down the slope so as to remove excessive rainfall and to reduce the chance of mass soil movement caused by soil slumps, but in some locations, a network of drains across and down the slope are employed to lower the water table and to remove excess water. In the highlands, regularly spaced drains are typically 3–5 m apart and 20–40 cm deep. The irregular spaced ones tend to be deeper.

The use of beds for food gardens, especially sweet potato, has a strong geographical distribution. The technique is common in the northern part of the Eastern Highlands (see Photo 2), in parts of Simbu Province, in a number of valleys in the Western Highlands and in parts of the Southern Highlands. Beds and large mounds are generally mutually exclusive in their distribution, as the large mounds perform the same function as beds. Both raise plant roots above the water table and remove excess rainfall quickly. The form of the beds (height, length and width) varies between regions.

Mounding. Planting crops in mounds is another form of intensification enhancing crop yield. Sweet potato is the crop most often grown in mounds, but yam and occasionally Colocasia taro are also planted this way. The discussion here refers to smaller mounds, typically 20–40 cm high and 40–60 cm in diameter, as distinct from the large composted mounds discussed above. The mounds may be located on drained beds or not associated with them. As with large composted mounds, they serve to quickly remove excessive soil moisture.

Irrigation. This is a very minor practice, hardly surprising given that excessive moisture is a greater environment hazard than inadequate soil moisture. It is likely to have been more common when Colocasia taro was an important food in locations with a marked annual seasonal rainfall pattern. There are a number of reports of the practice in the literature for the period 1930–70, but in almost all locations, irrigation is no longer practised. The only place where irrigation remains important is in the Rabaraba-Wamira area of mainland Milne Bay Province. Here taro, and sometimes other crops such as cassava, are grown using irrigation. In a number of other locations, for example, near Kabwum on the Huon Peninsula and in the Lamari Valley in the Eastern Highlands, very minor areas of taro were still being irrigated in the 1990s. It is likely that the apparent decline in this technique over the past 50 years (and probably longer) reflects the rise in importance of food crops that are more tolerant of mild water stress, especially sweet potato and cassava, as well as the greater food security that these imported foods have given to villagers.

DISCUSSION

Shortening the fallow period is generally the technique used first by villagers to intensify land use in response to an increase in population. Initially fallow periods are reduced from very long to shorter periods that are still adequate to maintain crop production levels, for example, from 50 years to 15 years.

Depending on environmental factors, reducing the fallow period eventually results in declining crop yields. At this stage, villagers use other intensification techniques, including the adoption of more productive crops and extending the cropping period; eventually soil fertility maintenance techniques other than natural fallows are employed. Our field observations indicate that the sequence and timing of these changes vary considerably between locations and environments.

A large number of new food crops have been introduced into Papua New Guinea and adopted into village agriculture.[7] The adoption of sweet potato and cassava in particular has allowed people to alter both the cropping and the fallow periods. In the highlands, the greatest impact arose following the adoption of sweet potato as food for both people and pigs 300−350 years ago. In the lowlands, the adoption of new food crops has occurred over the past 130 years, and especially over the past 60 years. The impact on productivity and intensity of land use has been great. Villagers are still expanding their plantings of sweet potato, cassava and some other crops, but the rate of adoption has slowed as crops have been taken up in suitable environments. There are few food crops from other parts of the world that are likely to be adopted in Papua New Guinea, as many new species have been tried locally and there are unlikely to be many untried but suitable species. The African yam (*D. rotundata*) has been steadily adopted since its introduction in the mid-1980s (Risimeri *et al.*, 2001). It is likely that it will continue to be planted more widely, but this may be the last of the new food species to be widely adopted.

I now return briefly to the paper written almost 20 years ago to see what new insights the MASP Project has added to our understanding. In the earlier paper, the main elements discussed here were described. These included the adoption of new species, new cultivars, decreased fallow periods, extended cropping periods and the three main soil fertility practices: that is, composting, planted casuarina fallows and a legume/sweet potato rotation. The rich detail in the MASP database has led to a somewhat different emphasis on crop species and the significance of drainage. Here I give more emphasis to cassava and potato than in the earlier paper. This partly reflects the increasing importance of these two crops over the past 20 years. I have given less emphasis to Xanthosoma taro, because of the dramatic decline in this crop's importance in some locations during the 1980s. No mention was made of African yam (*D. rotunda*) in the earlier paper as it was not present until the mid-1980s. An important change in emphasis is acknowledging the importance of drainage. This does not represent a real change over the past 20 years, but recognition on our part of something that is so widespread that it was previously not given due recognition.

As recorded here, there are a number of intensification techniques used in village agriculture. There is no single measurement or unit that summarises these sometimes complex changes. One useful parameter for measuring intensity of land use is the R-value, defined by Ruthenberg (1980: 15) as: 'the number of years of cultivation multiplied by 100 and divided by the length of the cycle of land utilization'. Because the value for each location incorporates

information on both the cropping and the fallow period, R-value can be a powerful summary of land use intensity. Allen (this volume) examines the R-value in detail and compares it with another measure of land use intensity. However, as this paper shows, it is crucial to take into account all methods of measuring intensification of land use because of the diverse nature of the landscape and culture.

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NOTES

1 See Bourke *et al.* (1998) and other MASP provincial papers for further details.
2 Imported food provides a much higher proportion of calories consumed by urban people (fifty per cent of calories) (Gibson, 2001).
3 A number of other species may have been introduced into Papua New Guinea from the west a little before 1870, but it is more likely that they were introduced after 1870 and were adopted in the early colonial period. These are *Bixa orellana* (used for its pigment), cassava, lima bean (*Phaseolus lunatus*) and kangkong (*Ipomoea aquatica*).
4 The root rot that afflicts Xanthosoma taro is an exception to this.
5 Casuarina is very occasionally planted in Colocasia taro gardens. More commonly, it is planted in land intended for mixed vegetable gardens, but discussion here focuses on the main sweet potato gardens.
6 In many lowland locations, people place sticks and logs across steep slopes and on flat land in gardens. They say this is to delineate plots to facilitate planting, weeding and harvesting and not to reduce soil erosion. Given the generally low intensity of land use in much of the lowlands, and the associated low rates of soil erosion, this is likely. The discussion here refers to locations where people construct barriers specifically to control soil erosion.
7 In one highland village where I studied land use, villagers grew 87 species of food, narcotic and cash crops during the period 1978 and 1983. Sixty per cent (52 species) of these had been adopted since about 1920.

REFERENCES

Allen, B.J., R.M. Bourke and L. Hanson (2001) Dimensions of Papua New Guinea village agriculture, in R.M. Bourke, M.G. Allen and J.G. Salisbury (eds.), *Food Security in Papua New Guinea*, ACIAR Proceedings No. 99, Canberra: Australian Centre for International Agricultural Research.

Allen, B.J., R.M. Bourke and Hide, R.L. (1995) The sustainability of Papua New Guinea agricultural systems: the conceptual background, *Global Environmental Change 5*(4): 297–312.

Bourke, R.M. (1990) Subsistence food production systems in Papua New Guinea: old changes

and new changes, in D.E. Yen and J.M.J. Mummery (eds.), *Pacific Production Systems: approaches to economic prehistory. Papers from a Symposium at the XV Pacific Science Congress, Dunedin, New Zealand, 1983. Occasional Papers in Prehistory No 18*, Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University.

Bourke, R.M. (2000) Management of fallow species composition with tree planting in Papua New Guinea, in M. F. Cairns (ed.), *Voices from the Forest: farmer solutions towards improved fallow husbandry in Southeast Asia. Proceedings of a Regional Conference on Indigenous Strategies for Intensification of Shifting Cultivation in Southeast Asia*, Bogor: International Centre for Research in Agroforestry.

Bourke, R.M., B.J. Allen, P. Hobsbawn and J. Conway (1998) *Papua New Guinea: text summaries. Agricultural Systems of Papua New Guinea Working Paper No 1*, Two volumes, Canberra: Department of Human Geography, The Australian National University.

Bourke, R.M. and P. Vovola (2000) The current status of cassava in Papua New Guinea, in I. McL. Grant and M. G. Allen (eds.), *Proceedings of the NARI Cassava Workshop. NARI Proceedings Series Proceedings No. 3*, Lae, Papua New Guinea: National Agricultural Research Institute.

Brookfield, H.C. (1962) Local study and comparative method: an example from Central New Guinea, *Annals of the Association of American Geographers* 52: 242–254.

French, B.R. (1986) *Food Plants of Papua New Guinea*, Sheffield, Tasmania: Published privately.

Gibson, J. (2001) The economic and nutritional importance of household food production in Papua New Guinea, in R.M. Bourke, M.G. Allen and J.G. Salisbury (eds.), *Food Security in Papua New Guinea*, ACIAR Proceedings No. 99, Canberra: Australian Centre for International Agricultural Research.

Humphreys, G.S. and H. Brookfield (1991) The use of unstable steeplands in the mountains of Papua New Guinea, *Mountain Research and Development* 11(4): 295–318.

Lebot, V. (1999) Biomolecular evidence for plant domestication in Sahul, *Genetic Resources and Crop Evolution* 46(6): 619–628.

McAlpine, J.R., D.F. Freyne and G. Keig (2001) Land use and rural population change in PNG 1975–1995, in R.M. Bourke, M.G. Allen and J.G. Salisbury (eds.), *Food Security in Papua New Guinea*, ACIAR Proceedings No. 99, Canberra: Australian Centre for International Agricultural Research..

Risimeri, J.B., P.A. Gendua and J.B. Maima (2001) The status of the introduced white yam in Papua New Guinea, in R.M. Bourke, M.G. Allen and J.G. Salisbury (eds.), *Food Security in Papua New Guinea*, ACIAR Proceedings No. 99, Canberra: Australian Centre for International Agricultural Research.

Ruthenberg, H. (1980) *Farming Systems in the Tropics*, Oxford: Clarendon Press.

Saunders, J.C. (1993) *Agricultural Land Use of Papua New Guinea: explanatory notes and map. PNGRIS Publication No. 1*, Canberra: Commonwealth Scientific and Industrial Research Organization for Australian International Development Assistance Bureau.

Sheldon, R.M. and C. Mondo (2001) The adoption of vetiver grass for soil erosion control in Simbu Province, in R.M. Bourke, M.G. Allen and J.G. Salisbury (eds.), *Food Security in Papua New Guinea*, ACIAR Proceedings No. 99, Canberra: Australian Centre for International Agricultural Research.

Wood, A. and G.S. Humphreys (1982) Traditional soil conservation in Papua New Guinea, in L. Morauta, J. Pernetta and W. Heaney (eds.), *Traditional Conservation in Papua New Guinea: implications for today, Monograph 16*, Port Moresby: Institute of Applied Social and Economic Research.

Yen, D.E. (1974) *The Sweet Potato and Oceania: an essay in ethnobotany, BP Bishop Museum Bulletin 236*, Honolulu: Bishop Museum Press.

