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Soil fertility in sweetpotato-based cropping systems in the highlands of Papua New Guinea

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Editor: Gunnar Kirchhof

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Telephone: 61 2 6217 0500
<aciar@aciar.gov.au>

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Cover: Sweetpotato sellers at the local market in Kainantu, Eastern Highlands province, Papua New Guinea. Photo: Gunnar Kirchhof

Foreword

High population growth is a problem in most developing countries. Projections for many countries are that the increased demand for food will outstrip the capacity of the land to produce that food. In Papua New Guinea (PNG) the population has doubled since 1966 and the current growth rate is around 2.7%. Despite this high growth rate, the area under agricultural production has remained stable, but land use has intensified. Fallow periods have decreased from several decades to less than one decade. This trend towards more continuous cropping systems is linked to high population densities—as the population increases, the demand for food and cash crops increases. Thus, the need to identify promising management practices to expand both food and cash crops, while sustaining soil fertility, is becoming increasingly important for PNG.

This problem is not new: nor is it unique to PNG. Theoretical solutions to the problem of increasing crop productivity while sustaining soil productivity exist, but often they are not applicable to the local agroecological and socioeconomic conditions. For example, use of mineral fertiliser could easily offset production constraints due to depletion of nutrients as a result of continuous cropping, but fertiliser is not accessible for most resource-poor farmers in PNG. Therefore, novel integrated soil-, crop-, nutrient- and water-management practices best suited to local conditions should be developed, pilot tested and transferred to the farmers.

Prior to engaging in research to improve or overcome soil constraints, it is imperative to understand current land management systems and the socioeconomic drivers behind these systems. Surveys of farmers play an important role in understanding their current practices and identifying the main constraints to increasing crop productivity. Such information is beneficial in the investigation of management practices that optimise the integrated use of all locally available nutrient sources for sustainable crop production, but have minimal adverse effects on the environment.

This report summarises the results from a pilot study on soil fertility management funded by the Australian Centre for International Agricultural Research (ACIAR), and reviews sweetpotato-based cropping systems in the highlands of PNG. It also describes the lessons learnt from survey methodologies used to assess the socioeconomic and biophysical constraints to sweetpotato production in this area. Case studies from similar surveys done in Nigeria and northern New South Wales, Australia, are included as examples.

Peter Core
Chief Executive Officer
ACIAR

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Abbreviations

CIP	International Potato Centre
CV	coefficient of variation
EHP	Eastern Highlands province
EP	Enga province
IAA	indole acetic acid
IITA	International Institute of Tropical Agriculture
MASP	Mapping Agricultural Systems in Papua New Guinea
NARI	National Agricultural Research Institute
NGS	northern Guinea savanna
PNG	Papua New Guinea
PNGRIS	Papua New Guinea Resource Information System
PRAP	Pacific Regional Agricultural Programme
PT	pathogen-tested
RRA	rapid rural appraisal
RUDEP	Rural Development Project
SCT	soil conservation technology
SHP	Southern Highlands province
SP	Simbu province
Spw	sweetpotato weevil
WHP	Western Highlands province
WP	Western province

Sweetpotato in highlands agricultural systems of Papua New Guinea

R. Michael Bourke[1] and Akkinapally Ramakrishna[2]

Abstract

Sweetpotato was introduced into Papua New Guinea (PNG) from eastern Indonesia about 300 years ago and now dominates agricultural production in the PNG highlands. The environments in which it is grown in the highlands are briefly reviewed. The main components of the agricultural systems in which it is grown are noted, including type of fallow vegetation cleared for cultivation, fallow period, cropping period before fallow, intercropping, seasonality, soil fertility maintenance techniques, mounding and drainage. The importance of the crop in highlanders' diets and agricultural systems is briefly reviewed, as is the crop's role as pig fodder and the quantity sold in fresh food markets. Some possible future trends for sweetpotato in the highlands conclude the paper.

Introduction of sweetpotato to Papua New Guinea

Sweetpotato was domesticated by people in South or Central America. It came to the New Guinea highlands from eastern Indonesia. Plants were taken to Portugal on Columbus's first voyage to the Americas, thus arriving in Europe in 1493 AD. Portuguese travellers later transferred the crop to Africa, India and Indonesia. It was present in the Moluccan Islands in eastern Indonesia by 1633, but was possibly there earlier. It is likely to have been taken by traders from the eastern Indonesian islands to western New Guinea, probably by the mid 1600s. Archaeological and oral history research indicate that the crop was adopted in the Papua New Guinea highlands in about 1700 AD, not long after a volcanic eruption of Long Island and the widespread deposition of ash in the New Guinea highlands in 1665 (Golson 1977; Ballard 1995; Bayliss-Smith et al. 2005; Bourke 2009).

Oral history research in Enga province (EP) has identified the route of the first introduction up the Lagaip Valley (Wiessner 2005). That research has also described the diffusion of the new crop in EP, the rate of adoption in different locations, the consequent population movements and the adoption of major ceremonial exchange systems. Throughout the highlands, sweetpotato replaced the previous staple food, taro, which was supplemented by banana and yam. This process probably occurred over a relatively short period, perhaps one to three generations.

The adoption of sweetpotato in the PNG highlands about 300 years ago had a profound impact on many aspects of the economic and social life of highlanders, particularly as the tubers are excellent pig fodder. This is not reviewed here but, from the 1920s onwards, when European explorers first entered the highlands valleys, sweetpotato was by far the most important food for both humans and

1 Department of Human Geography, Research School of Pacific and Asian History, The Australian National University, Canberra ACT 0200, Australia <mike.bourke@anu.edu.au>

2 National Agricultural Research Institute, Bubia, Lae 411, Papua New Guinea

pigs, the main domestic animal, and this situation continues. There was only one small area in the central highlands east of the Strickland River where sweetpotato did not dominate agriculture at the time of first contact with outsiders (1920 to 1970). This area was in parts of the Lamari and the Imani valleys south of Kainantu, where the total population was less than 4,000 people. Sweetpotato and cassava have displaced taro and yam in this area over the past 30 years. In the highlands west of the Strickland River—in the Oksapmin and Telefomin areas of Sandaun province and adjacent parts of Western province (WP)—taro was the most important staple food at the time of contact. Again, sweetpotato and, to a lesser extent, cassava have increased in importance in this region over the past 30 years.

The environments where sweetpotato is grown

Sweetpotato is grown in a wide range of environments in PNG.[3] It grows from sea level to 2,700 m altitude, and occasionally up to 2,850 m in parts of Enga and Simbu provinces. Mean maximum and minimum temperatures at 2,700 m are 18 °C and 8 °C, respectively. The highlands are usually defined as the 1,200–2,800 m altitude zone, and the crop dominates agriculture over this range, with a somewhat greater diversity of food crops between 1,200 m and 1,500 m altitude.

In the highlands mean annual rainfall is in the range 1,800–5,000 mm. Most of the PNG highlands experiences 0–2 dry months per year on average, but there is greater rainfall seasonality to the east. Henganofi in Eastern Highlands province (EHP) is the driest highlands location, with 5 dry months per year.[4]

Sweetpotato is grown on a wide range of soil types in the highlands, with soil texture ranging from sandy loams to heavy clays, and in soils with a wide range in fertility. It is grown on all landforms in the highlands, including hills, colluvial fans and alluvial terraces. Slopes range from near flat to very steep, with some sweetpotato gardens recorded on 45° slopes.

[3] See Bourke (2005a) for a more detailed description of the environments in which sweetpotato is grown and how people respond to environmental limitations.

[4] A dry month is defined as one in which mean annual rainfall is less than 100 mm.

Sweetpotato in highlands agricultural systems[5]

Most agricultural systems in the PNG highlands are based on one or more years of cropping followed by a period of some years where land is under a naturally growing fallow. In some locations the species composition of the fallow vegetation is managed by planting or encouraging tree species that hasten soil fertility restoration. In certain places land is rarely fallowed and soil fertility is maintained by transferring organic matter into large planting mounds (green manuring or composting).

A number of fallow vegetation types are cleared for cultivation in the highlands, including tall woody regrowth, low woody regrowth, a mix of tall grasses and woody regrowth, tall grasses and short grasses. The most commonly used fallow vegetation types in Southern Highlands province (SHP), EP, Western Highlands province (WHP) and Simbu province (SP) are tall grasses or a mix of grasses and woody regrowth. In the seasonally dry part of EHP, short grass fallows are the most common. The length of the long fallow period ranges from no fallow to over 15 years of fallow. In WHP and SP the most commonly used period is between 5 and 15 years; in EP long fallows are not used widely; while in SHP and EHP there is a wide range of fallow periods.

The most common number of plantings before land is fallowed is two to five but, again, there is a wide range, with only one planting in some locations on the edge of the highlands and very extended plantings (over 40 years) in the 'composting zone'. The combination of cropping and fallow periods can be used to calculate the intensity of land use. There is a wide range of land use intensities in highlands agricultural systems, with the most intensive systems found in SHP, EP and WHP, and low intensity systems being more common in SP and EHP.

Sweetpotato is commonly intercropped with other food crops, particularly in the first planting following a fallow. With subsequent plantings, fewer other crop species are planted as the soil fertility declines. In most plots sweetpotato is the dominant species, even where crops such as maize, common bean, highlands pitpit (*Setaria palmifolia*),

[5] See Bourke and Allen (2009) for more detailed information on components of PNG agricultural systems, including distribution maps and the number of people using the techniques discussed here.

amaranthus, *Rungia klossii* and other food crops are interplanted with it. A planting of sweetpotato is most commonly followed by another planting of sweetpotato—sequences of different species are not the norm. The main exception to this is where a planting of peanuts or, less commonly, winged bean (*Psophocarpus tetragonolobus*) is made. These crops fix nitrogen, and the break in the continuous planting of sweetpotato may reduce the incidence of pests and diseases. These other crops are followed by further plantings of sweetpotato.

A number of techniques, other than long fallows of naturally occurring vegetation, are used to maintain soil fertility. Green manuring (or 'composting' as it is known in PNG) is widely practised in parts of EP, SHP and WHP. Organic matter, such as sweetpotato vines from a previous planting, weeds and grass, is buried in a mound or placed on a bed and covered with soil. Mounds are used at 1,800–2,800 m altitude, with beds used down to 1,100 m, in SHP. Application rates of fresh organic matter are in the range 5–30 t/ha, with about 20 t/ha a common amount above 1,800 m altitude (see Taraken and Ratsch in these proceedings for detailed descriptions of the technique in EP).

In some areas trees are planted or protected in sweetpotato gardens so that they dominate the fallow phase. The most important of these is *Casuarina oligodon*, which is also planted near houses and in woodlots, and is used to shade coffee plots. Casuarina is most commonly planted in sweetpotato gardens in parts of SP, but this approach is used in all highlands provinces. A rotation of peanuts, and occasionally winged bean, is commonly used to maintain soil fertility in parts of EHP, SP and WHP but not in wetter areas, including EP and SHP. Another practice used to maintain soil fertility by preventing erosion is the erection of soil retention barriers. This is most commonly done in parts of SP but also in other locations in the other highlands provinces. The technique involves construction of low barriers across the slope to slow the flow of water and prevent soil and organic matter from being washed downslope.

Some people grow introduced vegetables intended for sale in a rotation with sweetpotato in parts of the highlands near urban centres. Usually, the vegetables are grown using fertilisers, and the residues also benefit the subsequent sweetpotato plantings.

In almost all highlands locations sweetpotato is planted in mounds or on drained beds so as to remove excess soil moisture and facilitate tuber growth. The only locations where some form of soil moisture control is not done are very steep slopes and in some low-intensity systems on the edge of the highlands. Small mounds are defined as those that are 10–40 cm high and 40–100 cm in diameter; medium-size mounds are 40–70 cm high and 100–250 cm in diameter; and large mounds are more than 70 cm high and more than 250 cm in diameter. Organic matter is placed in medium-size and large mounds but not in small ones. It may also be placed in long beds in SHP. Beds are defined by their shape—either square or long rectangular. Drains separate the beds used for planting sweetpotato and other food crops. They generally range from 20 cm to about 1 m deep, but are up to 5 m deep in the Tari Basin in SHP.

Small mounds are used in almost all locations in EHP and SP. Medium-size mounds are commonly used in most of SHP, in some locations in EP and in a few high-altitude locations in WHP. Large mounds are most common in parts of EP and a limited number of locations in WHP. Square beds are widely used in a number of valleys, especially the Wahgi Valley in WHP and SP. Long beds, with small mounds on them, are common in much of EHP.

The importance of sweetpotato in the PNG highlands

The most important product of sweetpotato in the highlands is the tubers, which are the staple food for people and are also fed to pigs. Leaf tips are occasionally eaten, but this is unusual in the PNG highlands. A significant quantity of tubers is fed to pigs, particularly undersize ones, those unfit for human consumption and kitchen scraps. A small proportion, but still a significant quantity, of total tuber production is sold in local and distant food markets.

Sweetpotato dominates agricultural production in the PNG highlands. Intensive village-level studies at different locations indicate that between 60% and 90% of the area of land planted with food crops is devoted to sweetpotato.[6] The crop provided 65–94% of food energy and 33–73% of protein intake prior to the addition of rice- and wheat-based foods in highlanders' diets in the early 1970s. The contribu-

[6] Studies up to the mid 1980s are summarised in Bourke (1985). See Bourke (2005b) for an overview of the current importance of sweetpotato in PNG, including the highlands.

tion of sweetpotato to food energy and protein has dropped with the incorporation of imported foods into highlanders' diets, but it still typically provides about half of their food energy.

Throughout PNG, locally grown staples (root crops, banana and sago) provide an estimated 68% of food energy, and sweetpotato provides 65% of this amount. Thus, sweetpotato provides 44% of the food energy consumed by people in PNG. No other locally grown or imported food provides more than 10% of food energy (Bourke et al. 2009). In 2000 sweetpotato production in the five highlands provinces was estimated as 2.1 million t, which was 75% of the total PNG production of 2.8 million t (Bourke and Vlassak 2004). This is equivalent to 1,200 kg of tubers for every person in the highlands. Highlands production is estimated to be 2.7 million t in 2008 given population growth and static or declining consumption of imported food.

However, not all these tubers are consumed by people—a significant proportion is fed to pigs, which are the most important domestic animal in the highlands. Bourke and Vlassak (2004) estimated that about one-third of the sweetpotato produced in the highlands (and about one-quarter of all sweetpotato tubers in PNG) is fed to pigs. Hide (2003, pp. 63–71) summarised data from 20 studies on the quantity of sweetpotato fed to pigs in the PNG highlands, and found that the proportion ranged from 38% to 70% by weight, with a mean of just over 50%.

Sweetpotato tubers are sold in all urban and rural fresh-food markets in the highlands. A significant quantity is also moved to lowland urban centres for sale, particularly Madang, Lae and Port Moresby (Benediktsson 2002). The proportion of production that is sold is unknown, but if it was 1–2% of all production in the highlands, this would be 28,000–56,000 t/year. It is known that both the quantity sold and the income generated are significant, particularly by producers in EHP and WHP.

Conclusion and possible future trends in sweetpotato production

Sweetpotato now dominates highlands agriculture following its introduction about 300 years ago and subsequent widespread adoption as the most important staple food crop. There has been some further displacement of the older staples of taro and yam in recent decades in a limited number of locations in the south-east of EHP and west of the Strickland River in Sandaun province and WP. The only other significant carbohydrate food crops that supplement sweetpotato in the highlands are *Solanum* potato, particularly above 2,000 m altitude; cassava, particularly at 1,200–1,500 m altitude; maize, particularly in seasonally dry locations in EHP; and banana in most locations up to its altitudinal limit of 2,150 m. However, these other food crops are much less important than sweetpotato as food sources in the highlands.

Some effort has been made from the 1950s to the present to encourage villagers to grow rice and, to a much lesser extent, wheat and some other grain crops in the highlands. Despite this, current rice production is negligible and no villagers grow wheat or other grain crops, with the exception of maize. Given poor returns to people's labour inputs for grain production compared with sweetpotato, there are no realistic chances of the widespread adoption of rice, wheat or other grain crops in the highlands. Hence, it is critical that factors that limit sweetpotato production, including soil fertility, viruses, other diseases and insect pests, be addressed by research and outreach.

References

Ballard C. 1995. The death of a great land: ritual, history and subsistence revolution in the Southern Highlands of Papua New Guinea. Unpublished PhD thesis, The Australian National University, Canberra.

Bayliss-Smith T., Golson J., Hughes P., Blong R. and Ambrose W. 2005. Archaeological evidence for the Ipomoean revolution at Kuk swamp, upper Wahgi Valley, Papua New Guinea. Pp. 109–120 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Benediktsson K 2002. Harvesting development: the construction of fresh food markets in Papua New Guinea. Nordic Institute of Asian Studies: Denmark.

Bourke R.M. 1985. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. Papua New Guinea Journal of Agriculture, Forestry and Fisheries 33(3–4), 89–108.

Bourke R.M. 2005a. Sweet potato in Papua New Guinea: the plant and people. Pp. 15–24 In 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Bourke R.M. 2005b. The continuing ipomoean revolution in Papua New Guinea. Pp. 171–179 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Bourke R.M. 2009. History of agriculture in Papua New Guinea. In 'Food and agriculture in Papua New Guinea' ed. by R.M. Bourke and T. Harwood. The Australian National University: Canberra.

Bourke R.M. and Allen B. 2009. Village food production systems. In 'Food and agriculture in Papua New Guinea', ed. by R.M. Bourke and T. Harwood. The Australian National University: Canberra.

Bourke R.M., Gibson J., Quartermain A., Barclay K., Allen B. and Kennedy J. 2009. Food production, consumption and imports. In 'Food and agriculture in Papua New Guinea', ed. by R.M. Bourke and T. Harwood. The Australian National University: Canberra.

Bourke R.M. and Vlassak V. 2004. Estimates of food crop production in Papua New Guinea. Land Management Group, The Australian National University: Canberra. <http://rspas.anu.edu.au/lmg/pubs/estimates_food_crop.pdf>.

Golson J. 1977. No room at the top: agricultural intensification in the New Guinea highlands. Pp. 601–638 in 'Sunda and Sahul: prehistoric studies in Southeast Asia, Melanesia and Australia', ed. by J. Allen, J. Golson and R. Jones. Academic Press: London.

Hide R. 2003. Pig husbandry in New Guinea: a literature review and bibliography. Australian Centre for International Agricultural Research: Canberra.

Wiessner P. 2005. Social, symbolic and ritual roles of the sweet potato in Enga, Papua New Guinea. Pp. 121–130 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Sweetpotato agronomy in Papua New Guinea

Michael J. Hughes[1], Eric A. Coleman[2], Issac T. Taraken[3] and Passinghan Igua[4]

Introduction

Sweetpotato (*Ipomoea batatas*), normally called *kaukau* in Papua New Guinea (PNG), is an important root crop staple, especially in the highlands. It is grown throughout the country, from sea level to over 2,700 m altitude. In the short period since its introduction to PNG around 300 years ago, it has become the sole staple crop of the highlands region and one of the staple crops in a number of coastal areas of PNG. It has been suggested by Yen (1974; cited Bourke 1985) that more varieties could be collected in PNG than from any other area in the world. With such a range of varieties in the highlands, each with different characteristics, this paper will deal with the agronomy of sweetpotato in general terms. The importance of sweetpotato as a food crop has increased for the past 40 years, with the food energy that it supplies increasing from 45% in 1961 to 66% in 2000 (Bourke 2006).

Significance of sweetpotato in PNG

Social significance and food security

Sweetpotato is the major root crop staple in PNG. It provides the primary source of dietary energy for 60% of the population (Bourke and Vlassak 2004). Sweetpotato has replaced or displaced some of the traditional staples throughout the country, e.g. taro (*Colocasia esculenta)*, yam and winged bean (*Psophocarpus tetragonolobus)* in the highlands and taro in Morobe province. In the lowlands, where there are alternatives such as taro, banana, sago and yam, sweetpotato is of lesser value (Figure 1).

Sweetpotato has fitted well into the cultural and social settings of PNG, especially in the highlands. It is the main feed for pigs, which are used in bride price, compensation payments and other ceremonial activities. About half of all sweetpotato (mainly the smaller roots) produced in the highlands is fed to pigs (Allen and Bourke 1997). In addition to normal consumption, the larger roots are often harvested and used in festival feasts and mourning ceremonies.

As the major staple food in the country, there is concern over food-security issues, highlighting the importance of addressing yield decline as land use intensifies and climate change occurs. The introduction of new production technologies and research to address the major yield-limiting factors are needed to ensure that there continues to be an adequate supply of this staple crop.

Varietal significance

There are many sweetpotato varieties in PNG. Bourke (1985) estimates that there are probably 5,000 varieties grown; French and Bridle (1978) state that highlands families often use 15–20 varieties; and Bourke (2005a) indicates that the range used is between 6 and 71 varieties, with a mean of 33. The National Agricultural Research Institute's (NARI) Highlands Program Experiment Station at Aiyura currently maintains 1,131 varieties in their germplasm collection. Of these, 966 are thought to be highlands accessions, 146 were assembled by the

[1] Department of Primary Industry and Fisheries, Kairi Research Station, PO Box 27, Kairi Queensland 4872, Australia <michael.hughes@dpi.qld.gov.au>
[2] Department of Primary Industry and Fisheries, PO Box 6014, CQ Mail Centre, Rockhampton Queensland 4700, Australia
[3] National Agricultural Research Institute, Highlands Program, PO Box 210, Ukarumpa, SIL, Aiyura, Eastern Highlands Province, Papua New Guinea
4 The University of Goroka, Faculty of Science – Agricultural Education Section, Goroka, PO Box 1078, Eastern Highlands Province, Papua New Guinea

Pacific Regional Agricultural Programme (PRAP) project[5], and there are 10 commercial varieties assembled by the Australian Centre for International Agricultural Research (ACIAR) project SMCN/2004/071[6] and 9 early-maturing varieties, of which 5 were originally selected for drought tolerance. Approximately 100 varieties are currently at Tambul Research Station and are soon to be added to the Aiyura collection (Anna Apa, pers. comm. 2008).

During 1990–98 the PRAP project evaluated approximately 1,200 cultivars in the lowlands environment of Keravat in East New Britain province. From these, 79 first-class and 27 second-class varieties were identified (Maltby 2008).

Research significance

There is anecdotal evidence from both PNG farmers and scientists of a steady decline in sweetpotato yield in recent years, and there are concerns for food security. The yield decline may not be due to a single factor but to a complex of many that may be interacting to reduce overall yield. For example, factors limiting production include susceptibility to pests and diseases, declining soil fertility due to population pressure on arable land, unstable performance of varieties in different environments and yield decline due to virus complexes. As a result of evidence of yield decline, there are several projects currently being implemented by NARI. These include the development of a process for plant pathogen (virus) removal[6], soil fertility studies[7] and identification of sweetpotato varieties with one or more of the following characteristics: tolerance to drought, tolerance to excess soil moisture, early maturity, high yields.

Economic significance

Sweetpotato is very important as a fresh food staple as well as a cash crop. It has unexplored potential as value-added, shelf-stable processed products such as starch noodles and chips. Its major

[5] PRAP Project 4: 'Selection, trial and dissemination of sweet potato germplasm'

[6] ACIAR project SMCN/2004/071: 'Reducing pest and disease impact on yield in selected PNG sweetpotato production systems'

[7] ACIAR project SMCN/2004/067: 'Soil fertility management in the PNG highlands for sweetpotato based cropping systems'

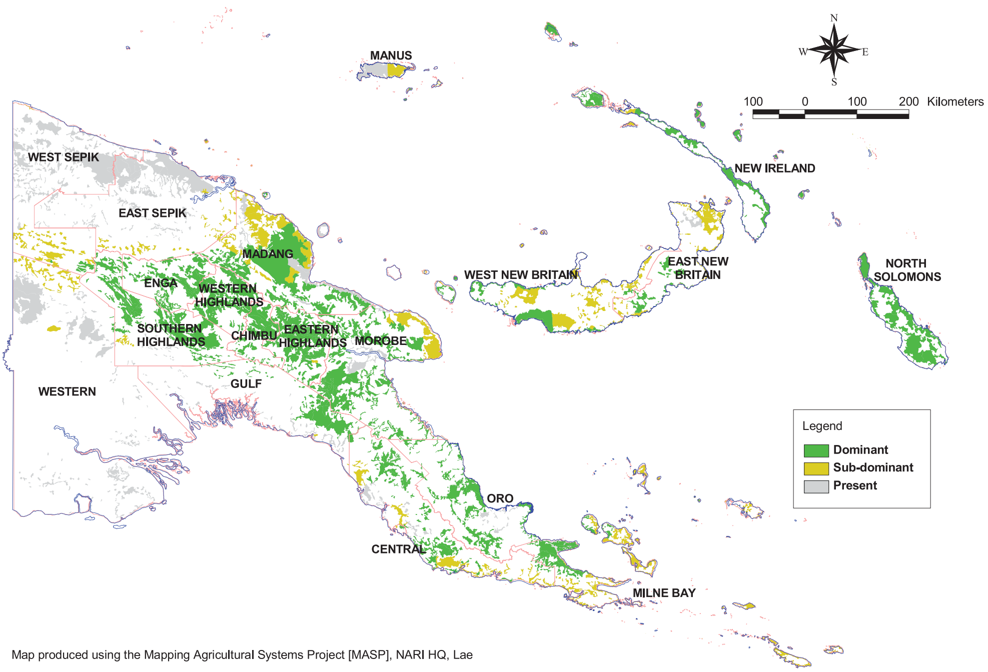

Figure 1. Map showing sweetpotato growing areas of Papua New Guinea

economic advantage over rice as a starch source is that it can be grown locally. As a food crop it is therefore much cheaper than rice. This is particularly important at present due to increasing rice prices as a consequence of the global food shortage. Bourke (2005b) estimated that sweetpotato production in PNG probably had a retail value of K1,790 million (US$450m). PNG spends about K300m/year importing over 200,000 t of rice (Julie Sip, pers. comm. 2008). According to a study done by Gibson (1995), sweetpotato has the potential to replace rice and wheat flour, as urban dwellers do not view these foods as superior to sweetpotato and other staples such as taro and banana.

Sweetpotato farmers from the highlands transport their fresh produce roots to the Lae, Port Moresby and Madang markets. One to two larger or medium-size roots are sold for K2.00 at these local markets, while two to three smaller roots achieve the same price. This creates self-employment for sweetpotato farmers and the local rural dwellers in PNG, especially in the highlands. There are large postharvest losses between the loading depots/centres in the highlands like Mt Hagen and the selling centres of Port Moresby, Lae and Madang. It is estimated that 20% of roots get badly damaged, affecting shelf life and marketability, with another 10% lost to due to bacterial and fungal breakdown.

There is also potential to produce noodles, chips, flour and other products such as ethanol out of sweetpotato. A few innovative farmers are already producing sweetpotato noodles for their own consumption, and sweetpotato chips are currently being sold at restaurants in the urban centres of Port Moresby, Lae, Mt Hagen and Goroka. Although sweetpotato processing has the potential to cater for an industry of its own, it has not yet been exploited (Rangaii and Kanua 1988).

Crop environmental requirements

Altitude and temperature

Bourke (2005a) reported that altitude is the main factor for sweetpotato production. In the equatorial regions of PNG it has a profound effect on ambient temperatures, and thus influences crop growth and production. In PNG sweetpotato can generally be grown from sea level to the higher levels of the agricultural production zones, at approximately 2,700 m. Occasionally it is grown as high as 2,850 m in parts of Enga province (EP), Simbu province (SP) and Western Highlands province (WHP) (Bourke 1989a). Crops grown at lower altitudes in higher temperatures establish and come to maturity faster than those grown at cooler temperatures (see Taraken and Ratch, these proceedings). Plantings typically mature after 13–22 weeks at sea level; 20–35 weeks at 1,500–2,000 m; and as long as 35–50 weeks when grown above 2,000 m (Bourke 2005a).

The crop is susceptible to frost, which occurs at locations above 2,200 m on average about once a decade. This affects production but does not prevent villagers from growing the crop (Bourke 2005a). Farmers in these higher altitude regions cannot rely on regularly producing a crop and need to have strategies in place for crop failures (Bourke 2005a).

Water

Most parts of PNG receive between 2,000 and 3,500 mm of rain per year (McAlpine et al. 1983). The drier areas such as Port Moresby, Markham in Morobe province, and Bena Bena areas in Eastern Highlands province (EHP) receive 1,000–2,000 mm/year, while the wettest parts can receive as much as 8,000–10,000 mm/year. Sweetpotato is grown in locations where the mean annual rainfall is in the range 1,000–6,500 mm/year (Bourke 2005a).

Sweetpotato roots do not tolerate waterlogging well. PNG trials have shown clear results of reduced yield in crops that have had high rainfall conditions over the entire cropping cycle (Bourke 1989b). Plants grown in wet conditions will often show excessive top growth but minimal root production, and this is particularly so if there is excess moisture during the storage root initiation phase of growth (2–8 weeks after planting in the lowlands or 3–10 weeks after planting in the highlands) (Bourke 2005a). Crops require good drainage and need to be planted on mounds, ridges, or raised beds with drains in wet areas.

Sweetpotato has some tolerance to extended dry periods, which are common in some parts of the highlands. There is abundant evidence that production can be increased by irrigation when soil moisture levels are very low (Bourke 1989b). Dowling et al. (1995) found in pot trials that water stress dramatically reduced sweetpotato growth and masked the effects of nutrient stress. While sweetpotato will not die during dry conditions, there is a reduction in the yield potential of the plants.

Recent research in Australia (Coleman et al. 2006) has shown that the critical period for adequate water (not waterlogging) is the first 21 days after planting. It is during this period that plant roots establish and the storage roots are initiated. This determines the yield potential of the plant, and further water availability and adequate resources during growth will enable the plant to produce to this potential. Research into sweetpotato root development and soil moisture by Pardales and Yamauchi (2003) supports these findings.

Bourke (1989b) states that a combination of very wet crop start followed by drought in the bulking period reduces yield more than the effect of either drought or wet season alone. While irrigation is a management option to improve crop yields in Australia, it is not available in the PNG highlands. Minimising moisture stress after planting is partly possible by planting at appropriate soil water conditions. Where feasible, cuttings need to be planted into moist soils, preferably just before it rains. In 2005 during a farm interview at Frey Frey Mountain in the Lufa district (ACIAR project SMCN/2005/043)[8], the interviewing group was told by one farmer that he had increased the survival rate of his vines by changing his practice from planting them in the morning, where they had to endure the sun all day, to planting in the afternoon, immediately before the rains. He believed this change of practice had resulted in improved yields. He was so sure of the benefits of this system that he would not plant if he felt that the rains would not eventuate, but would hold the cuttings until he was sure it would rain (usually a day or two).

Landforms and soils

Sweetpotato is grown on almost all the landforms and soil types in PNG, apart from swamps or waterlogged areas. Bourke (2005a) stated that production of good root yields is not possible in landforms that are subject to extended or permanent inundation. Such areas are common in coastal and subcoastal parts of Gulf and Western provinces, and on the levee banks along the Sepik River that are flooded for 4–6 months each year. However, farmers do establish drainage systems in the swampy and flooded plains of the Kandep Valley in EP to grow sweetpotato and other crops with the aid of the composted mounding technique (see Taraken and Ratsch, these proceedings).

The crop prefers a friable, sandy-loam soil, although it is grown on soil textures ranging from light sandy loams to heavy clays. Water stress and decreased nutrient availability can be problems on sands and heavy clays, resulting in restricted root growth.

Growing the crop

Ground preparation

As sweetpotato is grown across a diverse range of PNG's climatic and social environments, there are a number of different ground preparation methods that have been developed. Bourke (1985) has identified eight of these:

1. Minimal tillage

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

2. Soil tilled sufficiently only to form mounds 20–30 cm high

The entire soil surface is not tilled. This method is practised in forested areas on slopes in EHP and parts of SP. It is also used on light-textured soils, such as sandy loams on river terraces, in both the lowlands and highlands

3. Complete soil tillage but no or minimal mounds (10 cm high)

This is done on grassland areas on very steep slopes in SP. Horizontal soil-retention fences made from branches are often used in this system

4. Complete tillage with mounds (30 cm high) formed on beds

In EHP long drained beds are used, while in SP square beds are used. The entire soil surface is tilled prior to mounding. This system is used mostly in grassland soils but it is also practised in forest soils. A peanut (*Arachis hypogaea*) or winged bean (*Psophocarpus tetragonolobus*) rotation is commonly employed to maintain soil fertility.

[8] ACIAR project SMCN/2005/043: 'Analysis of biophysical and socioeconomic constraints to soil fertility management in the PNG highlands'

5. Complete tillage in long drained rectangular or square beds without mounds

This method is used in grassland soils in Southern Highlands province (SHP) south of the composting zone

6. No soil tillage

Drains 30–50 cm deep are dug to form beds 4–5 m square. The soil from the drains is thrown on top of the beds and sweetpotato is planted into this loose soil. This system is used in the Whagi, Baiyer and Nebilyer valleys of WHP. A peanut or winged-bean rotation is often used with this system

7. Very large mounds 1.5–5 m in diameter

Compost is formed within the mounds by placing grass and other organic material inside. This system is generally practised in grasslands in EP, SHP and the western part of WHP

8. Mechanical soil tillage

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

Bourke (1985) also notes that the cropping intensity of the systems tends to increase from system 1 to system 7. At one extreme a single sweetpotato crop may be followed by a long forest fallow of up to 40 years, while at the other extreme (in the Tari Basin) sweetpotato has been cropped continuously for over 200 years with fallows of only 2–3 months between crops.

Crop nutrition

Nutrient requirement

Sweetpotato has a moderate need for nitrogen (N) and a low requirement for phosphorus (P), and is a high user of potassium (K). While N is required for adequate vegetative growth and good root yield, excessive N leads to vigorous vegetative growth at the expense of root formation and yield. The greatest nutritional requirement of the crop is for K, which must be abundantly available for high root yields (Bourke 2005a) and also aids the crop to resist diseases. Phosphorus is required for good root development and improves the quality of the crop. However, because sweetpotato is efficient at extracting P from the soil, it has a low requirement for additional application of P. This characteristic is advantageous in the highlands of PNG and coastal areas such as Oro, New Britain and Madang provinces, where P is a limiting factor due to inherently low P levels in the volcanic ash soils found there.

While N deficiency has been reported in many PNG soils, deficiencies of P and K tend to be localised issues. Symptoms of P deficiency are often seen at altitudes above 2,000 m (Bourke 2005a). The only micronutrient that has been reported as deficient is boron (B) (Hartemink and Bourke 2000).

Sweetpotato is able to be grown on a range of soils from strongly acidic to neutral. Ila'ava et al. (2000) found that sweetpotato in pot trials is moderately tolerant to acid solutions, and that there would be no significant yield increases by liming strongly acid soils to improve sweetpotato growth.

Indigenous soil-fertility management practices

The indigenous soil-fertility management techniques developed to cultivate sweetpotato crops include building of contours on the hillsides to minimise soil erosion, fallowing, shifting cultivation, slash–burn–plant, casuarina tree fallowing, composted mounding and rotation of food legumes with other crops. These methods are still applicable in sweetpotato cultivation today.

Fallowing was the main method used by the ancestors to restore soil fertility. It continues as a significant practice and is achieved by abandoning gardens and returning them to cultivation at a later time. The lapse of time was the principal factor determining regrowth of natural vegetation and restoration of soil fertility (Kimber 1974). The resting period ranged from 3 to many years, but has now declined to less than 12 months in some areas, due to population pressure.

Shifting cultivation is the next most common method, where sweetpotato is continuously cultivated for about three to five seasons and the land is then left to fallow for about 1–2 years. The farmers return after the fallow period to cultivate further crops.

The slash–burn–plant method is associated with fallowing and shifting cultivation, and is used when there is substantial natural regrowth on fallowed land. The vegetation is slashed, left to dry and then burnt, and sweetpotato is planted in the dispersed ashes. In this process all of the N content is lost from the materials during burning.

Casuarina tree fallowing is common in the highlands where casuarina trees are intentionally planted to restore soil fertility when the gardens are left to rest for more than a year. Legume crop rotation is another technique used. Since 1961 peanut has been recognised as a common rotation crop in EHP and WHP (Anonymous 1961). In some areas winged beans is the rotation crop of choice.

Composted mounding techniques are practised in EP and parts of SHP and WHP (see Taraken and Ratsch, these proceedings).

Fertiliser

Inorganic. Numerous trials have been conducted in PNG looking at the effects of inorganic fertilisers on sweetpotato growth. Bourke (1985) has reviewed a number of these trials (many of them unpublished) and found the results, overall, to be inconsistent. He questioned whether some of the inconsistent results may be a reflection of different soil types or the effects of different cultivars. Hartemink and Bourke (2000) indicate that some soils have benefited from the addition of P and K. Experiments by Kanua (1998) showed positive yield responses when P and K fertilisers were applied in SP. There were varying responses, and the interaction patterns for P and K differed for the varieties tested. Floyd et al. (1987) found that large responses to P occurred in some of the poorer volcanic ash soils in SHP, and that the most economic fertiliser option was the addition of 168 kg/ha of K. Generally, P application has not been recommended as it has variable requirements and more economic responses are gained from K application.

In recent years a number of 'commercial' sweetpotato growers in the Hagen Central region of WHP who are specifically growing large quantities for the urban markets (predominately Port Moresby, Lae, Madang and the New Guinea islands) have started to grow sweetpotato in rotation with Irish potato (*Solanum tuberosum*). They have developed this system as they discovered that sweetpotato crops respond well to the residual fertiliser from their potato crops. This fertiliser is usually potato mix (N10:P25:K17+B) applied at 1,000 kg/ha or N:P:K mix (12:12:17+2MgO) applied at 750 kg/ha (triple superphosphate is often added to this N:P:K mix at a rate of 250 kg/ha).

Agnes Jonah (village extension worker in Gusamg village, Minj) and Angela Pinge (South Whagi extension advisor at the Fresh Produce Development Agency) both commented at a sweetpotato workshop in May 2008 that 'commercial' sweetpotato growers in their regions are actually applying these fertiliser mixes directly to their sweetpotato crops at planting. This is probably providing fertiliser in excess of the plants' needs. During a farm interview at Kotiufa village, Ifiufa district, EHP, in 2006 (ACIAR project SMCN/2004/071), growers commented that 'if you want to grow really big sweetpotato, plant the cuttings with a matchbox full of potato mix fertiliser'. In this area the soils are being intensively used without the benefit of extended fallow periods.

Organic. A number of trials have also studied the use of organic fertiliser. Bourke (1985) states that, in 12 out of 13 trials using organic fertiliser, there was an increase in sweetpotato root yield. The situations where this has not occurred have often been on highly fertile soils.

Composting trials, particularly in the composted-mound-type system, have shown an increasing benefit from the addition of composting materials. Over 20 agronomic trials have clearly established that composting increases sweetpotato yield (Bourke 2001). On occasion this increase in yield has continued past the point where addition of composting materials is socially and economically viable (S. Preston, pers comm. 1988). (More information on composting is presented by Taraken and Ratsch, these proceedings.)

Coffee pulp is a good source of N and K and has been found to increase yields. Konabe and Ivahupa 1996 cite recommendations by Bourke (1982) of an application rate of 15–30 t/ha but caution that higher rates than this may suppress yields due to excess N.

Trial results of the use of pig manure as organic fertiliser for sweetpotato by Kimber (1973; as presented in Thiagalingam and Bourke (1982)) show an increase in yields. This is supported by D'Souza and Bourke (1986). Again, Konabe and Ivahupa (1996) cite recommendations by Bourke (1982) of an application rate of 15 t/ha but caution that higher rates may suppress yields due to excess N. In parts of the highlands pigs are often tethered to a stake in gardens. This practice removes weeds, grubs and insects, and improves soil fertility by adding dung and urine (Sitango 2005).

Plant population

The standard plant spacing used by researchers in planting trials is 1 m × 1 m, with two to three sweetpotato vines planted per planting hole. This gives a total plant population of 20,000–30,000 plants/ha. Bourke (2005a) indicates that surveys from 180 village plots in five provinces showed a density in the range 15,000–172,000 plants/ha, with the average being 43,000–76,000 plants/ha.

Trials have indicated that, despite these plant population differences, there is no tendency for great differences in the yield of roots over 100 g. However, the higher planting densities tend to have increased numbers of roots weighing less than 100 g (Bourke 1985). Levett (1993) agrees with this in general but also suggests that there is an association between some varieties and plant spacing on yield. Varieties that produce large roots are more affected by plant spacing than those that produce small roots.

Some commercial farmers and institutions grow sweetpotato in single rows with a single cutting per planting position. These producers often plant at a population density of around 22,000 plants/ha. This density is also considered ideal in Australia, where plant spacing is commonly used to control size and delay maturity. There has been little work in PNG on the effect of planting density on time to maturity, with the majority of opinion favouring altitude (albeit temperature) as the main factor governing time to maturity.

Vine selection

In PNG vegetative planting material is collected from established gardens that are 8–12 months old. There is little if any production of sprouts from sweetpotato planted as a dedicated seed bed. In EP vines are also collected from old composted-mound gardens. Vine tip cuttings are used in preference to back cuttings (i.e. sections that do not include the vine tip). The young/new leaves found on tip cuttings are known to have higher levels of the auxin, indole acetic acid (IAA) (Coleman et al. 2003), which has a known role in activating adventitious root growth on many plant cuttings. It is suggested by Coleman et al. (2003) that this is a major contributing factor in the experience farmers often have with faster establishment when they use tip cuttings instead of back cuttings.

There is some variation in the length of vine used as planting material, with those in the drier regions tending to use shorter cuttings. Farmers in EP, SHP, WHP and SP use 15–40 cm vine cuttings to plant sweetpotato gardens, while those in drier growing areas in EHP use 10–15 cm vine cuttings. Experiments in Australia by Coleman et al. (2006) have shown that cuttings need to be at least 20 cm long to provide enough leaf area at planting for optimal early plant establishment.

The selection of planting material from an established crop is another potential factor in yield decline (Coleman et al. 2003). This material may already be infested with sweetpotato weevil at planting (R. McCrystal, pers. comm. 2008), have a high virus load, and have poor physiological plant vigour and, ultimately, yield.

Vine planting

Traditionally, highlands farmers tend to plant two to four cuttings per planting hole depending on the size of the vines. Larger vines are planted in pairs per hole, while the smaller ones are planted three or four per hole. This is probably as a form of insurance that at least one of the plants will establish successfully. Sweetpotato vines are either planted directly after collection or can be kept under shade for a few days prior to planting, to encourage root growth.

An issue that may arise as people start to move into the 'commercial' market is that quality parameters such as shape begin to play a more important role. Planting multiple cuttings in the same planting hole results in competition for root space, and misshapen and, consequently, unmarketable roots will often be produced. It is interesting to see that some of the major commercial sweetpotato growers in WHP have recognised this and reduced the number of cuttings per hole to one. The other situation where single planting is often used is at, for example, large schools, where ground preparation is by mechanical means and sweetpotato is planted on long raised rows/ridges.

When planting, the vines are either pushed vertically or horizontally into the soil. Trials by Levett (1993) concluded that '…the potential for increasing sweetpotato yields by modifying the planting method appear to be limited and cultivar dependent. For a fixed length of cutting, the orientation of the planted slips generally has a minimal effect on yield or root size'. Experiments by Coleman et al. (2006) contradict this result, with findings that horizontally planted cuttings with three nodes buried gave significantly better results than vertically or V-shaped planted cuttings with three nodes buried. Marketable roots were produced at a number of underground nodes when the vines were planted horizontally, while vertically planted and V-shaped plantings had variable storage root numbers and shape was particularly affected by overcrowding (Figure 2). This research found that a more critical factor for growth and yield is water availability, particularly during the first 10 days of establishment. Plantings that suffered moisture stress and elevated soil temperatures immediately after being planted had significantly lower marketable yields at harvest.

Figure 2. Roots produced by (a) horizontally planted vine and (b) vertically planted vine

Weeds

Weeding is important, particularly in the early growth stages. As the plants develop, their capacity to compete with weeds develops considerably. Generally, the garden is weeded three times, correlating with the different growing stages of the vines. The first weeding is done at establishment phase (4–8 weeks after planting), followed by the second at vegetative phase and the final one at root bulking stage (see Taraken and Ratsch, these proceedings). In some areas vines may be pruned and smaller roots even culled between the second and final weedings to stimulate root bulking. Culling of smaller roots is normally practised in the EHP.

Main insect pests

Sweetpotato weevil

A review conducted at the Aiyura sweetpotato workshop in June 2004 concluded that sweetpotato weevil (Spw) (*Cylas formicarius)* was the greatest insect constraint to sweetpotato production and that improved management practices were urgently required. While Spw can be found in most production areas, it is predominantly a pest of dry growing conditions, for example in the drier parts of the highlands such as Bena Bena in EHP. Sweetpotato weevils reduce yield in two ways: first, by burrowing into the stem, particularly at the crown of the plant, and reducing the ability of the plant to translocate photosynthetic assimilate to the roots; and second, by causing unsightly damage to the storage roots, resulting in the production of terpenes that alter the roots' taste and make them inedible. Stock will even refuse to eat the roots. The damage inflicted also makes the roots more susceptible to postharvest rot. Van de Fliert and Braun (2000) noted that Spw caused an estimated yield loss of 30–50%, or even 100% during dry seasons.

Farmers in EP use the composted mounding technique to cultivate sweetpotato in wet areas, thus minimising root loss to Spw (see Taraken and Ratsch, these proceedings). Mulching techniques can be used to grow sweetpotato in the drier regions of PNG and, during dry seasons, to minimise the effects of Spw on roots. Irrigation practices can also be used to grow sweetpotato but, currently, this does not occur in PNG.

A common source of infection is through the transfer of Spw eggs on vines selected as planting material. Currently, world literature recommends dipping of vines in insecticide to avoid infection; however, appropriate safety procedures must be followed if this practice is to be followed. Another way in which the transfer of eggs and weevil can be avoided (particularly in the commercial sector) is by the use of pathogen-tested (PT) sweetpotato cuttings, which are grown in insect-proof enclosures to ensure that eggs cannot be laid on the vines. The PT process is currently being introduced into PNG. The other major source of Spw comes from populations building up in the vine and root residues of previous crops. To stop Spw build-up, it is important that crop residues are removed.

Trials conducted in EHP during 2007 have shown that pheromone lures will attract male Spws. There is anecdotal evidence that some villages near Aiyura have reduced sweetpotato damage by using these lures in trapping programs to remove males from their gardens. A 2007–08 mass-trapping experiment in Australia using pheromone lures removed 90,000 Spws from a 400 ha farm in 4 weeks (R. McCrystal, pers. comm. 2008). This experiment also noted that an essential aspect of any mass-trapping program is good crop hygiene. Areas where vines or roots were left on the soil surface were quickly reinfected to near previous weevil levels.

Early indications from other trials on Spw control show that chemical treatments are effective. Non-chemical treatments such as deep planting of vines, hilling up of vines to stop Spw entry to roots, and application of mulches with known insecticidal properties (such as Persian lilac) also appear to have had some effect on this pest (O. Ngere 2007, unpublished data).

The naturally occurring fungus Beauveria is a natural enemy of Spw. In 2007, samples of this fungus were collected from farms in EHP province. It has since been isolated to a pure strain and undergone laboratory pathogenicity testing with good results. NARI is currently examining options for using this fungus as a control.

PNG has naturally occurring predatory ants, *Pheidole megacephala* and *Tetramorium guineense*, which are known to prey on Spw in Cuba. Meteyufa villagers in EHP are growing sweetpotato in association with these ants, and research to further understand this association is now underway.

Hawkmoth

Sweetpotato hawkmoth (*Agrius convolvuli*) larvae feed on the underside of the leaves. They tend to be a more serious pest in coastal areas and elevations below 1,500 m, and in dry conditions. While they have natural parasites and predators, other control methods include hand picking the larvae off leaves or digging the ground to expose the pupae. Insecticides can also be used for control of this pest (French 2006).

Gall mite

Gall mite is becoming an increasing problem in the highlands. The mite, which is microscopic, injects chemicals when it feeds that cause galls to form on the stems and leaves of susceptible plants. There has been little research conducted on this pest, and current control is through growing non-susceptible varieties.

Main crop diseases

Sweetpotato scab

This disease is found wherever sweetpotato is grown. Although it affects only the leaves and stems, it does reduce yields. Small spots or lesions develop on the stems, petioles and veins on the underside of the leaves, which then become distorted. Cool wet weather conditions favour the development and spread of the disease, which usually occurs through the introduction of infected cuttings and rain splash. Control is generally achieved by growing resistant varieties. Studies have also shown that control is possible by using fungicides (Kokoa 2001), and the use of PT planting materials may also reduce the infection rate of the disease.

Scurf

Scurf is a cosmetic disease that affects the skin on the roots of the plant but generally does not penetrate into the flesh. In many areas of PNG it is not recognised as a disease, and in some areas it is thought of as a sign of maturity of the root. This disease survives for 3–7 years in soil even after sweetpotato production stops, and is likely to become more prevalent in PNG as sweetpotato production intensifies. Symptoms are dark brown to black spots on the roots that gradually enlarge and may eventually cover the entire root. Transmission is generally through infected planting material. The best control is through use of clean planting material and by cutting vines at least 2 cm above the soil surface. The use of PT planting materials may see some reduction in this disease, as it reduces the spread of the disease in planting materials. There is also some varietal resistance.

Viral diseases

A number of viral diseases have been identified in PNG but there has been minimal study of them. Plants may have single viral infections or complexes of more than one virus.

Symptoms of viruses vary among plants as well as varieties, and a general list of symptoms that plants may show (Amante et al. 2003) includes:

- feathery mottling
- vein clearing and yellowing of the main veins
- purple to brown rings and/or line patterns on the older leaves
- curling or malformation of leaves
- reduction in leaf size
- stunting of growth.

Research from overseas indicates that complexes of viruses are probably a major factor in yield decline. Experiments in Australia have shown an up to 100% increase in marketable yield of sweetpotato when viruses and other pathogens have been removed from the plant (Coleman et al. 2005). Currently, research is underway in PNG to develop a process to remove viruses from infected plants, and it is hoped that, in the future, producers will be able to obtain PT vines for their planting materials. As well as being free from viruses, these vines should reduce the incidence of other diseases such as scab and scurf, and even pests such as Spw, that are generally transported to new gardens in the planting material.

Nematodes

While sweetpotato is generally a poor host of nematodes, they can do considerable damage by reducing yield and quality of the roots. The symptoms of nematode presence are yellowing of leaves, galls on the roots, cracking and necrosis. Surveys have indicated that, while nematodes are widespread throughout the highlands, serious damage generally occurs only in areas where the fallow period is short. Control can be achieved by rotation with non-host crops or by using nematode-resistant sweetpotato varieties (Kokoa 2001).

Crop harvest

With the exception of some 'commercial' producers, sequential harvesting is the norm for highlands crops. By digging with hand or stick, people feel/dig gently around the plants and only remove those roots considered to be developed to the required size. A second and sometimes third harvest follow over the next 3–4 months as the remaining roots develop. The number of harvests varies with variety and the growing conditions of the crop.

Sweetpotato yields throughout PNG are quite variable. Bourke (2005b) reported that experimental yields of 15–20 t/ha are recorded in the lowlands and 20–30 t/ha in the highlands, while mean yields are probably 15 t/ha in the highlands and somewhat lower in the lowlands. In the zones of the highlands where composted mounding is practised, average sweetpotato yield is in the range 20–60 t/ha. The range for village plantings of sweetpotato plots with minimum interplanting with other crops is 5–50 t/ha (Bourke 2005b). Australian production is in the vicinity of 50 t/ha (E.A. Coleman, pers. comm. 2007)

Conclusion

During the relatively short time that sweetpotato has been in PNG, the crop has had a significant impact on the country, particularly the highlands regions. It is credited with allowing population growth, mass migration to new areas, utilisation of poorer soils and development of new leadership styles and ceremonies. In areas such as those of the Huli in SHP, it has transformed the agricultural systems (Ballard 2005).

Among the diverse environments of the country, farmers have developed their own agronomic practices for growing sweetpotato. Although these have been suitable for traditional production of the crop, issues such as increased population, intensification of cropping land, and farmers growing sweetpotato for cash sale have increased the strains on these systems. In recent years there has been a growth in the sweetpotato tonnage being sent to the major urban centres but, even with this increase, the supply of sweetpotato to Port Moresby supermarkets is still ad hoc, with shoppers rushing to buy when new shiploads arrive (J. Wright and supermarket shoppers, pers. comm. 2008).

Recent and ongoing research, both national and international, is providing a better understanding of sweetpotato. New technologies such as the PT capability are being developed in-country to enhance the quality of this research and improve food security. The use of techniques such as mass trapping of Spw using pheromone lures may reduce the destructive impacts of this pest. Agronomists, researchers, extension personnel and producers need to be aware of these and other developments, and be able to adjust their farming patterns to utilise those agronomic practices that will best benefit their particular production systems.

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References

Allen B.J. and Bourke R.M. 1997. Report of an assessment of the impacts of frost and drought in Papua New Guinea. Australian Agency for International Development. At: <http://coombs.aun.edu.au/SpecialProj/PNG/lhtmls/AllenBourke.html>. Accessed 23 June 2008.

Amante V. dR., Vasquez E.A., O'Sullivan J.N. and Norton G.A. 2003. A field guide to sweet potato problems in the Philippines. The University of Queensland.

Anonymous 1961. Legume trials. Annual report, Department of Agriculture, Stock and Fisheries: Port Moresby, Papua New Guinea.

Ballard C. 2005. Still good to think with: the sweetpotato in Oceania. Pp. 1–13 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Bourke R.M. 1982. Growing sweetpotato for sale in the highlands. Harvest 8(2), 47–51.

Bourke R.M. 1985. Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. Papua New Guinea Journal of Agriculture, Forestry and Fisheries 33(3–4), 89–108.

Bourke R.M. 1989a. Altitudinal limits of 230 economic crop species in Papua New Guinea. Unpublished paper. Department of Human Geography, The Australian National University: Canberra.

Bourke R.M. 1989b. Influence of soil moisture extremes in sweet potato yield in the Papua New Guinea Highlands. Mountain Research and Development 9(3), 322–328.

Bourke R.M. 2001. Intensification of agricultural systems in Papua New Guinea. Asia Pacific Viewpoint 42(2–3), 219–235.

Bourke R.M. 2005a. Sweet potato in Papua New Guinea: the plant and people. Pp. 15–24 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Bourke R.M. 2005b. The continuing ipomoean revolution in Papua New Guinea. Pp. 171–180 in 'The sweet potato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Bourke R.M. 2006. Recent research on sweetpotato and cassava in Papua New Guinea. 'Proceedings of the 2nd International Symposium on Sweetpotato and Cassava', ed. by S.L. Tan. Acta Horticulturae 703, 241–245. International Society for Horticultural Science.

Bourke R.M. and Vlassak V. 2004. Estimates of food crop production in Papua New Guinea. Land Management Group, The Australian National University: Canberra.

Coleman E.A., McCrystal R., Maltby J.E. and O'Donnell W.E. 2003. Development of smooth skinned easy to peel sweetpotato literature review. HAL project VG02114. Horticulture Australia report.

Coleman E.A., Maltby J.E., O'Donnell W.E. and McCrystal R. 2006. Developing smooth skin easy to peel sweetpotatoes. Horticulture Australia final project report VG02114.

Coleman E.A., Maltby J.E., Harper S.M., O'Donnell W.E., Hughes M., Boreel S., Jones C. and Scholl P. 2005. Improving sweetpotato agronomy to meet new market opportunities. Horticulture Australia final project report VG01010.

Dowling A.J., Blamey F.P.C. and Hoa T. 1995. Limitations to sweet potato growth in small volumes of soil imposed by water and nutrient stress, acidity and salinity. Papua New Guinea Journal of Agriculture, Forestry and Fisheries 38(1), 3–10.

D'Souza E.D. and Bourke R.M. 1986. Intensification of subsistence agriculture on the Nembi Plateau, Papua New Guinea. 2. Organic fertilizer trials. Papua New Guinea Journal of Agriculture, Forestry and Fisheries 34(1–4), 29–39.

Floyd C.N., D'Souza E.J. and Lefroy R.D.B. 1987. Phosphate and potash fertilization of sweet potato on volcanic ash soils in the southern highlands of Papua New Guinea. Department of Primary Industry Technical Report 87/7.

French B. 2006. Insect pests of food plants of Papua New Guinea—a compendium. At: <http:www//foodplantsinternational.com/resources3Insects%20on%20food%20plants%20in%20PNG.pdf>, p 54. Accessed 14 July 2008.

French B. and Bridle C. 1978. Sweetpotato. Pp. 10–11 in 'Food crops of PNG'. Vudal College of Agriculture: Madang, Papua New Guinea.

Gibson J. 1995. Food consumption and food policy in Papua New Guinea. Discussion paper No. 65. Institute of National Affairs, Port Moresby.

Hartemink A.E. and Bourke R.M. 2000. Nutrient deficiencies of agricultural crops in Papua New Guinea. Outlook on Agriculture 29(2), 97–108.

Ila'ava V.P., Blamey P. and Asher C.J. 2000. Effects of lime and gypsum on growth of sweet potato in two strongly acid soils. Australian Journal of Agricultural Research 51, 1031–1037.

Kanua M. 1998. The response of three sweetpotato cultivars to inorganic fertilisers on an Andisol in the highlands of Papua New Guinea. Papua New Guinea Journal of Agriculture, Forestry and Fisheries Special Issue: Soil research and management in PNG, 41(1).

Kimber A.J. 1974. Crop rotations, legumes and more productive arable farming in the highlands of Papua New Guinea. Department of Agriculture, Stock and Fisheries, Highlands Agricultural Experiment Station, Aiyura, Eastern Highlands Province, Papua New Guinea. Science in New Guinea 2(1).

Kokoa P. 2001. Review of sweet potato diseases in PNG. In 'Food security for Papua New Guinea', ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. Proceedings of the Papua New Guinea Food and Nutrition 2000 conference, PNG University of Technology, Lae, 26–30 June 2000. ACIAR Proceedings No. 99, 730–735

Konabe B. and Ivahupa S. 1996. The agronomy and mineral nutrition of sweet potato (*Ipomoea batatas*) in the highlands of Papua New Guinea. In 'Mineral nutrient disorders of root crops in the Pacific', ed. by E.T. Craswell, G.J. Asher and J.N. O'Sullivan. Proceedings of a workshop, Nuku'alofa, Kingdom of Tonga, 17–20 April 1995. ACIAR Proceedings No. 65, 70–79.

Levett M.P. 1993. The effects of methods of planting cuttings of sweet potato (*Ipomoea batatas*) on yield. Tropical Agriculture (Trinidad) 70(2), 110–115.

McAlpine J.R., Keig G. and Falls R. 1983. Climate of Papua New Guinea. Commonwealth Scientific and Industrial Research Organisation and Australian National University Press: Canberra.

Maltby J. 2008. Report on lesson learned workshop, 12–14 May 2008, Madang, Papua New Guinea. Unpublished report as part of ACIAR project SMCN/2004/071.

Pardales Jr. J.R. and Yamauchi A. 2003. Regulation of root development in sweet potato and cassava by soil moisture during their establishment period. Plant and Soil 255, 201–208.

Rangaii S.S. and Kanua M.B. 1988. Indigenous technologies and recent advances in sweet potato production, processing, utilisation and marketing in Papua New Guinea. PNG Department of Agriculture and Livestock Discussion Paper No. 885, 12.

Sitango K. 2005. Status of plant nutrient management in Papua New Guinea. In 'Improving plant nutrient management for better farmer livelihoods, food security and environmental sustainability'. Proceedings of a regional workshop, Beijing, China, 12–16 December 2005. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok. At: <http:www.fao.org/docrep/010/ag120e/AG120E00.htm>. Accessed 2 July 2008.

Thiagalingam K. and Bourke R.M. 1982. Utilization of organic wastes in crop production. Proceedings of the 2nd Papua New Guinea Food Crops Conference, part 2, 218–226. Publications Section, Department of Primary Industry: Port Moresby, Papua New Guinea.

Van de Fliert E., and Braun A.R. 2000. Farmer field school for integrated crop management of sweetpotato. Field guides and technical manual. International Potato Center, Regional Office of East, South-East Asia and Pacific, Bogor, Indonesia.

Sweetpotato cultivation on composted mounds in the highlands of Papua New Guinea

Issac T. Taraken[1] and Rainer Ratsch[2]

Abstract

This paper explains the concept of composted mounding, which is used to cultivate sweetpotato/kaukau (*Ipomoea batatas*) in many locations in Enga province and parts of Southern Highlands and Western Highlands provinces of Papua New Guinea (PNG). It draws both from published literature and recent findings on sweetpotato cultivation in the PNG highlands. The practice of composted mounding allows permanent land use and intercropping, and facilitates successive multiple harvests of sweetpotato tubers and other vegetables. It counteracts the risks of frosts and soil-borne pests and diseases, and reduces soil erosion. It offsets the inherent soil-fertility problems associated with the dominant volcanic ash soils in the mounding zone of the PNG highlands. The method utilises locally available organic materials such as garden debris, weeds, grasses and farmyard manure as compost. Numerous agronomic trials have been conducted to evaluate the effects of composted mounding on sweetpotato yield. However, further research is needed on the decomposition process to assess the beneficial effects of mounding in terms of reduced risk of frost, and pest and disease damage, and to evaluate the benefits of using ever-greater rates of compost in the light of the extra costs of collecting the compost material.

Introduction

Compost-containing soil mounds for growing sweetpotato (*Ipomoea batatas*) were first developed by the inhabitants of Enga province (EP) in the highlands of Papua New Guinea (PNG) and are thus often referred to as 'Engan' mounds or, simply, composted mounds. The mounds are round or plano-convex in shape, and to this day are the central feature of Engan agricultural systems (Waddell 1972; Wohlt 1986). The mounding technique involves placing garden debris and cut grasses on the ground and covering the compost materials with soil to make the mounds. Cuttings of sweetpotato vines, and seeds or cuttings of other crops, are subsequently planted on the mounds (Figure 1). The technique is practised over a wide range of environments in the altitude range 1100–2850 m, where maximum temperatures are 16–27 °C, minimum temperatures are 8–18 °C and annual rainfall is 2,850–5,000 mm (Bourke et al. 1991).

The use of composted mounds in cropping systems helps to maintain soil fertility, which in turn improves and maintains crop yields and promotes permanent land-use systems as opposed to shifting cultivation. It also counteracts the risk of frost and prevents sweetpotato tubers from rotting. The mounds help to raise crops above the watertable in gardens close to swamps or flooded plains. On sloping areas, instead of the normal plano-convex mounds, long composted mounds called *kanaparo mondo* or snake mounds are used to reduce soil erosion.

[1] National Agricultural Research Institute, Highlands Program, PO Box 210, Ukarumpa, SIL, Aiyura, Eastern Highlands Province, Papua New Guinea <issac.taraken@nari.org.pg>

[2] National Agricultural Research Institute, High Altitude Highlands Program, PO Box 120, Mt Hagen, Western Highlands Province, Papua New Guinea

The practice and importance of composted mounding for sweetpotato production is discussed here based on published literature reports, as well as recent experimental findings and survey information, and from the perspective of the authors' personal experience.

Origin of mound cultivation in Enga province

Oral histories of Engan culture indicate that the large composted mounding technique for cultivating sweetpotato was developed by a man from the Itokone tribe in the middle Lai Valley, Wabag Central district, after the introduction of sweetpotato. Wiessner and Tumu (1998) stated that Tuingi, a tribal big-man of the fourth generation, was the first to plant a large-mounded sweetpotato garden. During the harvest he held the first sweetpotato feast and called it *mapu yae* following the term for a pig feast, *mena yae*.

The use of composted mounds for sweetpotato cultivation in EP was found to improve soil fertility and crop yield, and facilitate multiple harvests of tubers. Later it may have spread to other parts of the highlands. According to Bourke et al. (1991), the mounding zone covers much of EP and Southern Highlands province (SHP) and the western part of Western Highlands province (WHP). It extends as far east as the Wiru Plateau (Pangia district), as far south as Erave, to the north of the main inhabited valleys in Enga, and beyond Lake Kopiago almost to the Strickland River in the west. The boundary between locations where the technique is used and those where it is not used is narrow in the east (Baiyer, Wahgi and Nebilya valleys) and more diffuse elsewhere (Figure 2).

Mound construction

During the last harvest from the sweetpotato mounds of old gardens[3], the mounds are demolished into crater-type shapes and the land is left to fallow. After the fallow period the bush is slashed by family members and left in the garden for 2–4 weeks to dry. The dried mulch is placed in the craters of the demolished mounds and the circular bank of bare soil around the central crater is used to cover the mulch, thus producing a new mound. The whole process takes 1–2 months. In shorter fallow periods the bush is slashed directly into the craters prior to mounding. If the soil is wet or sticky and it is difficult to produce a good tilth, the mounds are rested for 1–2 months to allow the sods to crumble on exposure to sun and rain. After the resting period the soil clod on the mounds is loosened by men and young women using spades and digging sticks because the work is very heavy at this stage of mound creation. Elderly women then follow, further loosening the granules and shovelling the loose soil particles onto the mounds, making them ready for planting crops (Figure 3).

In a new garden[4] the secondary regrowth vegetation is slashed and left for 1–2 weeks to dry, and

3 The term 'old garden' here refers to a garden or land that has been cultivated for many years since it came out of its original bush fallow. The fertility of the soil is maintained by composting short-fallow grass or weed species and garden debris in the mounds.

4 The term 'new garden' here refers to a garden or land that has just come out of its original or secondary bush fallow, where first cropping is usually done through the slash–burn–plant method. Composted mounding is subsequently used to maintain the fertility of the soil in cultivating succeeding crops for many years and even decades.

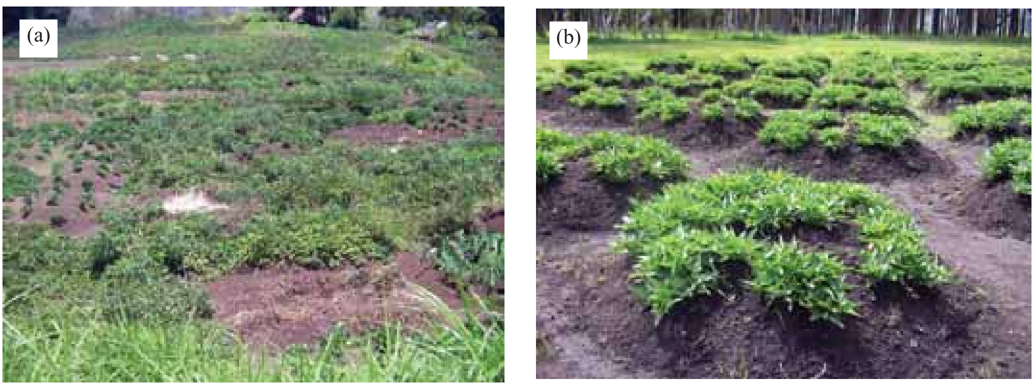

Figure 1. (a) Intercropped and (b) sweetpotato monocropped composted mounds

then gathered into round-shaped heaps in rows. The bare soil between the heaps is used to cover the mulch, hence producing mounds. This is done immediately after gathering the compost material into the craters or heaps, although, in rare cases, the compost is allowed to decompose prior to mounding (Wohlt 1986). The space between the mounds remains hard and functions as a drainage conduit. Mounds are built in rows, with the numbers of rows and mounds being dependent on the size of the garden. The depth of soil tilth covering the compost material is expected to be 40–80 cm in valleys and old gardens where topsoil is relatively deep.

Composting materials

Care is taken to avoid including stones, sticks and hard woody shrubs in the compost heaps. Fresh sweetpotato vines and tubers are also excluded to avoid regrowth. Grasses or weeds that are difficult to control are gathered at the sides of the garden and destroyed using a spot-burn practice, and the ash is

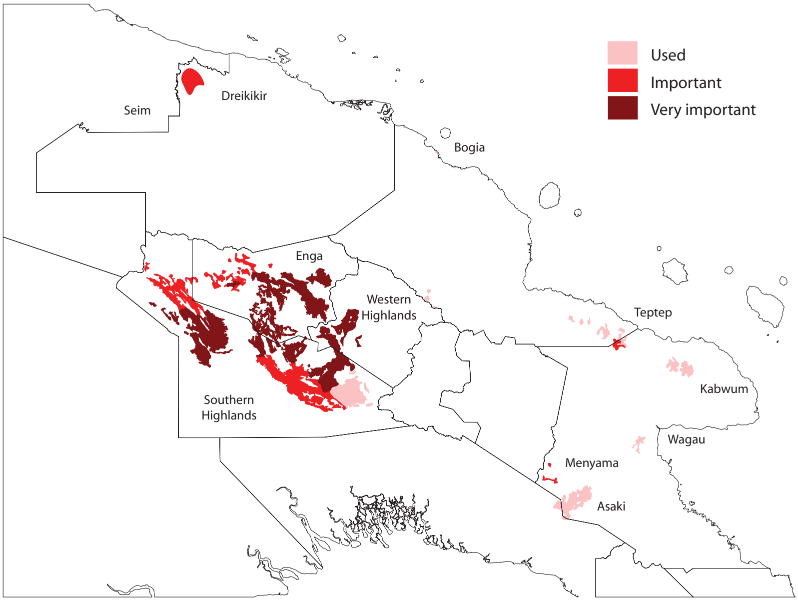

Figure 2. Map of Enga province and parts of Southern Highlands and Western Highlands provinces where composted mounding (green manuring) is usually practised

Figure 3. (a) Gathering compost and (b) mound construction'

added to the compost or else used to grow vegetables. Fresh or dried weeds, grass clippings, chopped leaves and stems of soft woody and herbal plants such as banana and corn, dried sweetpotato vines and decayed tubers are all used as compost materials. Manure from pigs, poultry, goats, guinea pigs, rabbits and kitchen wastes, if available, can be added to supplement the nutrient value of the compost.

When compost materials on the garden sites are insufficient, grasses or weeds at the edges of the garden or from adjacent bushy areas are slashed and transported to the garden. The amount of compost placed per mound varies. Estimating the right amount per mound depends very much on local skills and knowledge, especially of the women. The amount of compost used is based on its availability and on the labour required to collect it, and not on any premeditated attempt to maximise crop yield (Floyd et al. 1987). Sweetpotato yield, however, has been shown to increase in proportion to the rate of compost used (D'Souza and Bourke 1984; Floyd et al. 1987). Survey results suggest that farmers in the highlands spend 70% of their gardening time on sweetpotato gardens, and that the same amount of time is spent by both mound builders and non-mound builders. Hence, any premeditated attempts to collect additional compost and build the mounds could increase crop yield and justify the extra time and labour required. However, a cost–benefit analysis is needed before recommending that increased rates of compost be used (Floyd et al. 1987).

Different constructions for different environments

Two types of composted mounds are used for sweetpotato cultivation in EP. The first or common type is round or plano-convex in shape and is found on flat lands or on gently slopping or undulating areas. Mounds vary in size depending on the type of soil. In valleys, where topsoil is relatively deep and fertile, mounds range from 2 to 4 m in diameter and 0.5 to 1.5 m in height. Waddell (1972) found that two-thirds of the total cultivated area contained large plano-convex mounds averaging 3.8 m in diameter and 0.6 m in height.

The second type of mound has a long plano-convex shape and is normally called *kanaparo mondo* or snake mound. As the name suggests, its shape is elongated. It is generally constructed on sloping areas, lengthwise across the slope to reduce the speed of water run-off. Eroded sediments in the run-off are captured as the water drains around the mound perimeters, thereby reducing soil erosion. These mounds range in size from 4 to 6 m in length, 1 to 2 m in diameter and 0.4 m in height.

In frost-risk areas more compost is added to mounds to counteract the frost. These areas include Kandep, Surunki and the higher altitude areas of Lagaip in Porgera district. However, the mounds built in these areas are smaller (diameter 1.5–2.3 m and height 0.6–1.2 m) than those of Ambum Kompiam, Wabag Central, Laiagam and Wapenamanda (diameter 2.5–3.8 m and height 0.7–1.5 m). After 1–2 days of frost, the vines of premature and matured (8–12 months old) sweetpotato are slashed and the bases of the vines are covered with soil. Frost continues to fall and slide to the foot of the mounds during the day, but the tubers are saved inside the mounds by the heat of the decomposing organic matter. Bourke et al. (1991) argued, however, that composting may not reduce the impact of chilling or freezing temperatures, and that frosting remains a significant hazard at altitudes above 2,200 m.

In swampy areas and flooded plains, drainage systems are first established to drain out excess water, resulting in a pattern of blocks separated by drains. Mounds are then created within the blocks as described previously, but a greater amount of compost is incorporated to raise the height of the mounds compared to those built on dry grounds. Wohlt (1978, 1986) stated that, in unusually wet gardens and flooded plains, mounds occasionally increased in height (up to 1.2 m) and that compost rates used in gardens next to the swamps may exceed 30 kg per mound. This is done to lift the rooting zone of the crop above the watertable and enable floodwaters to pass between the mounds; hence, growth and production are maintained.

Mound agronomy

It is normal practice to plant sweetpotato vines and other crops on the same day that the mound is made. However, in large gardens the process may take several days until planting is completed. Mostly, the female members of the family do the planting. Vines more than 8 months old are cut and transported from previous gardens. About 8–20 stations (planting points) are made per mound depending on its size, and two to three vines are planted per station. Different varieties of vines can be planted in a mound but, generally, only one variety is planted per station. Sweetpotato vines are planted around the upper part of the mounds and other crops around the lower parts and between sweetpotato stations. In other words, monocropping with sweetpotato and intercropping with other crops are both practised on 'Engan' mounds (Figure 4).

Monocropping of sweetpotato is done in old gardens, and on degraded or shallow and infertile soil, to avoid soil-nutrient competition between crops and to encourage better sweetpotato tuberisation. Sweetpotato is sometimes intercropped with common beans in such areas. In fertile situations intercropping is usually practised. The main crops intercropped with sweetpotato include legumes such as common beans and peas, cucurbits, leafy vegetables, maize and potato. Bananas can be planted between mounds. Sugarcane and pineapples can be planted either between mounds or around their edges. Intercropping was relatively uncommon as recently as 1966 (Waddell 1972) but is now a common practice, presumably because of increased population pressure. Gardens are normally weeded three times during the life of the sweetpotato crop. The first weeding is done at establishment, the second at the vegetative phase and the final at tuberisation. Vine pruning is also done at this stage to initiate tuberisation. Weeds and thinned crop materials are placed as mulch at the foot of the mounds. These residues reduce erosion, capture eroded sediments and act as a cushion for cucurbit fruits.

Mound dynamics and rationale

It is believed that the crop absorbs nutrients during the establishment phase from the soil tilth gathered on the surface of the mound. For the rest of the crop's life, it absorbs nutrients that are slowly released by the decomposing compost materials within the mound. Sillitoe (1996) reported that plants absorb nutrients largely from the decomposing vegetation concentrated at the centre of the mounds, as roots grow through it, rather than from the soil complex. Recent work at Tambul Research Station in WHP has shown that tiny feeder roots of sweetpotato rapidly penetrate the decomposing compost some 40 cm below the mound surface, and that tubers form as early as 10 weeks after planting. However, little is known about how and when decomposition starts, how long it lasts, or how much

Figure 4. Mound planting

Table 1. N, P and K contents (kg/ha) of organic nutrients at recommended application rates

Material	Total N	Total P	Total K	Application rate (t/ha)
Coffee pulp	70	5	140	30
Pig manure	85	50	60	15
Grass compost	75	110	75	20
Chicken manure	5	3	1.5	n/a
Cow manure	2	1.5	2	n/a

Source: after Radcliffe (1983)

heat and nutrient are released. The nutrient contents and recommended rates of some composting materials are shown in Table 1 (Radcliffe 1983).

Based on his work at Keravat, Leng (1982a, b) concluded that decomposition releases nutrients slowly, thereby preventing excessive vegetative growth on sweetpotato, which takes place at the expense of tuber yield. He also found that identifiable remains of the compost matter (sweetpotato vines) had disappeared from the mounds by the 12th week after planting the new vines. In cooler climates of the highlands, however, it might take longer for organic matter in a mound to decompose completely.

Harvesting sweet potato from composted mounds

The length of time to crop maturity varies from district to district, and even from one place to another within a district, and depends very much on climatic conditions and on the landforms and type of soil in the particular location or garden. It also depends on the variety and types of crops planted on the mounds. For example, it takes about 6–10 months for sweetpotato grown in villages near Wabag Town, in the 1,800–2,000 m altitude range, to reach maturity. In villages at higher altitudes, in the 2,100–2,800 m range, e.g. Surunki, Kandep, Laiagam and Porgera, it takes 12–14 months for the crops to reach maturity.

A selective multiple-harvest method is used to harvest sweetpotato tubers from mounds, and women primarily do this work. They commence selective harvesting of tubers at 1–3-month intervals, making use of a small stick called *kapu yari*, which is sharpened at one end. The sharpened end of the stick is used to harvest the larger tubers. Particular care is taken during the harvests to avoid damage to vines or roots, thus enabling smaller tubers to grow for future harvests. The most common harvesting system is a progressive harvest in which large tubers are removed from the soil as they are needed (Bourke 1982). Wiessner and Tumu (1998) suggest that, if harvesting is done skilfully, one could get three to five harvests at about 1–2-month intervals.

After harvesting all the tubers the garden is managed for about 6–8 months to allow vine recovery and regrowth, and to facilitate the final selective harvest prior to demolishing the mounds. Good and healthy vines from this garden are used as cuttings for the succeeding crop in another prepared garden. The final selective harvest is called *hea apingi pupingi*. Again, care is taken that the vines and new roots are left undisturbed. The garden is then left alone for recovery and regrowth for another 8–12 months prior to demolishing. After the recovery period, the mounds are demolished into crater-like shapes. Sweetpotato tubers are harvested from the mounds and also from the drainage systems between the mounds. The slashed weeds, vines, leaves and grasses are spread over the demolished mounds to cover the soil surface, and there decompose, adding nutrients to the soil. The garden is then left to fallow. The fallow length varies from zero (no fallow) to 12 months or more depending on the family's need.

Densely populated areas near Wabag Town and the fertile soil of the Tsak and Ambum valleys are cultivated continuously to cater for the increase in population over the last 10 years. The mounds are demolished and remounded by using freshly slashed grasses and debris as compost, and sweetpotato vines are replanted. In other words, zero fallowing is used in such areas to continuously cultivate sweetpotato on the mounds compared to the usual fallow period of greater or less than 12 months prior to mounding. Since development of the mounding technique, longer fallow periods have declined dramatically. In a recent soil fertility scoping study, 64% of the farmers surveyed in EP reported that fallow periods have declined to less than 12 months (Kirchhof 2006). Although this technique of zero fallow appears to be advantageous in areas experiencing land use pressure, there is a need to compare the productivity of this system with that of the old system using short fallowing.

Yield varies from garden to garden or place to place depending on the landforms, soil type, mound size, sweetpotato variety and climatic conditions. The estimated yield ranges from 20 to 60 t/ha in the mounding zone of the highlands. Preliminary data from ongoing research at Tambul Research Station indicate an average yield of 16.2 t/ha on composted mounds compared to 10.8 t/ha on non-composted mounds.

Research conducted on composted mounds

Bourke et al. (1991) stated that 20 agronomic trials had been conducted to assess the effects of composted mounding on sweetpotato yields. Almost all the trials were conducted in the traditional composting zone of the highlands, i.e. in EP and SHP. The results of all 20 trials indicated that composting improved crop growth or yields relative to non-composted mounding cultivation. From a series of trials conducted in the Gazelle Peninsula in East New Britain, Leng (1982a) also concluded that mounds had positive effects on crop growth or yields, and served to control major pests and disease infestations. However, it has been observed in our recent survey (Ratsch 2008) that pests and diseases seemed to be a major concern in the mounding zone compared to the non-mounding zones—this needs proper investigation. At Wau Ecology Institute in Morobe province, Gagne (1977) conducted contour mounding trials, and intercropped vegetables of different species with both exotic and native fruit and nut trees. The crops performed well but they seemed to have been affected by pests and diseases. Preston (1990) investigated the use of compost and fertiliser on mounds in EP and found that compost increased yield by 2.6 t/ha in the absence of potassium fertiliser (KCl) and by 6.4 t/ha in its presence, whereas KCl depressed tuber yield in the absence of compost.

A number of investigations have stated that, in volcanic ash soils with inherently low available water holding capacity, maintenance of a loose, friable soil structure is likely to be detrimental to crop growth during dry periods because it has the potential to further reduce soil water content through evaporation (Floyd et al. 1987; Sillitoe 1996; Waddell 1972). However, this may be of little importance in the highlands region since the climate is one of excessive rainfall. D'Souza and Bourke (1984) and Bourke (1988) also argue that sweetpotato is tolerant of very low levels of available soil moisture, and that compost holds moisture in the soil and helps plants to do better in drought. Waddell (1972) suggests that soil freshly broken from a grass fallow is likely to contain very high percentages of raw organic matter, mostly in the form of roots. Further addition of mulch may cause nitrogen and phosphate deficiencies, which could seriously affect sweetpotato productivity. Kirchhof (2006) stated that, in both old and new gardens surveyed in the highlands, the composted mounds produced significantly higher yields than all other systems, with no significant yield differences between old and new gardens under composted mound cultivation.

Potential benefits of composted mounding

There are a number of possible benefits that composted mounds confer. They:

- improve soil texture and structure, thus increasing aeration and rainwater infiltration and drainage
- increase topsoil depth and improve water-holding capacity in shallow and sandy soils, and maintain soil moisture
- provide food and appropriate conditions for soil organisms, and improve soil fertility and crop yield through organic matter decomposition
- improve soil structure and reduce soil cracking, and the resultant crumb structures probably prevent the entry of pests like sweetpotato weevil (*Cylas formicarius*)
- maintain soil bulk density in ranges favourable to root penetration regardless of permanent sweetpotato cultivation on the same piece of land (Sillitoe 1996)
- release heat through the decomposition process, which speeds up tuberisation
- reduce the effects of frosts on crops
- reduce soil-borne pests and diseases, e.g. tuber rot in wet soils or caused by the fungus *Ceratocystis fimbriata* (Preston 1990; Sillitoe 1996)
- raise crops above watertables in swamps and flooded plains
- reduce soil erosion by run-off both on slopes and flat lands by channelling water between the mounds
- ease population pressure on land use by allowing shorter and even zero fallow periods, and hence permanent systems of land cultivation
- reduce the risk of spreading pests and diseases through the burial of affected crop residues within the mounds
- allow subsequent multiple harvests and the maintenance of planting materials
- enable farmers to use locally available organic residues for sustainable sweetpotato production rather than expensive inorganic fertilisers
- enable more efficient land use as different crops can be intercropped with sweetpotato for subsequent multiple harvests.

Composted mounding compared to shifting cultivation

The population of PNG is increasing rapidly, causing pressure on land use. Consequently, the soil and the land have been undergoing a gradual degradation process, and shifting cultivation adds to this process. Shifting cultivation is labour intensive and land demanding. Recent survey results have revealed that composted mounding promotes shorter fallow periods and permanent cultivation. For example, only 30% of the land was under crop and 70% was under fallow at Kandep in EP, where composted mounding is dominant, compared to Tambul in WHP and other highlands provinces, where shifting cultivation is dominant. Hence, more virgin land and forests can be preserved for future generations by using the composted mounding technique instead of shifting cultivation.

Possibilities of introducing composted mounding

Although improved agricultural technologies have been introduced into PNG over the last 30 years, the farming systems still resemble those of earlier times. One of the major factors responsible for this stagnation is cultural attitudes and an aversion to new technologies. Such attitudes hinder the introduction of new technologies for improving agricultural production or, indeed, the extension of composted mounding outside its traditional highlands zone (Figure 2). The mounding technique, however, could be extended to other highlands provinces and coastal areas that have the same altitudinal and temperature ranges and soil conditions as those of the mounding zones, e.g. the higher altitude regions of Morobe, Oro, West and East New Britain, Bougainville and Madang provinces.

Conclusions and recommendations

The mounding technique for cultivating sweetpotato was developed and adopted by the ancestors of EP and is still practised today. The technique was later adopted by other people in parts of SHP and WHP and along the Strickland River. The technique helps to maintain soil fertility and crop yield, and reduce soil erosion, by channelling run-off through the drains in between the mounds. It reduces the risk of frosts and raises crops above the watertable in swampy and flooded plains. It permits permanent land-use systems and multiple harvests, and aids in conserving virgin land and forests for future generations—unlike shifting cultivation, which is land demanding and forest squandering. It would be advantageous if the mounding technique was extended throughout the highlands region and into the mountainous parts of coastal provinces such as Morobe, Madang and Oro, which have similar volcanic ash soils to those in the mounding zone.

Agronomic trials to date have focused only on the effects of composted mounding on sweetpotato yield. Further research is needed to investigate the decomposition process within mounds, and the types and rates of nutrients released. A cost–benefit analysis is needed to assess the beneficial effects on crop yield of using ever-greater rates of compost, and the costs of the method in the light of the extra labour and time required to collect the additional compost materials. There is also a need to compare the yields produced by composted mounds with zero, short and long fallow periods. The beneficial effects of composted mounding in minimising the risk of frosts, weevil damage and soil-borne pests and diseases also need further research.

Dedication and acknowledgments

We wish to dedicate this paper to Tuingi, an Itokone big-man of Wabag Central, who first developed the technique of large composted mounds for sweetpotato cultivation. We also wish to pay tribute to the fourth generation of Engans and Southern Highlanders who willingly adopted the technology and disseminated it to other parts of the mounding zone.

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References

Bourke R.M. 1982. Growing sweetpotato for sale in the highlands. Harvest 8(2), 47–51.

Bourke R.M. 1988. Time hangere, variations in subsistence food supply in Papua New Guinea Highlands. Unpublished PhD thesis, Australian National University, Canberra.

Bourke R.M, Allen B.J, Humphreys G.S., Ballard C., Grau R. and Hide H.L. 1991. The composted mounds of the Papua New Guinea Highlands. Pp. 3–18 in 'New perspectives on the Papua New Guinea Highlands: an interdisciplinary conference on the Duna, Huli and Ipili peoples'. Department of Human Geography, The Australian National University: Canberra, Australia.

D'Souza E. and Bourke R.M. 1984. Compost increases sweetpotato yields in the highlands. Harvest 8(4), 171–174.

Floyd C.N., D'Souza E.J. and Lefroy R.D.B. 1987. Composting and crop production on volcanic ash soils in the Southern Highlands of Papua New Guinea. Technical Report No. 12 (87/6), 1–25. Agricultural Field Trials, Systems, Evaluation and Monitoring Unit (AFTSEMU): Mendi, Southern Highlands Province, Papua New Guinea.

Gagne W.C. 1977. Entomological investigations of agro-silviculture using the composted contour mound method in Papua New Guinea. Science in New Guinea 5(2), 85–93.

Kirchhof G. 2006. Analysis of biophysical and socio-economic constraints to soil fertility management in the PNG highlands. Pp. 20–21 in 'Report on ACIAR soil fertility scoping study'. ACIAR: Canberra.

Leng A.S. 1982a. Maintaining fertility by putting compost into sweetpotato mounds. Harvest 8(2), 83–84.

Leng A.S. 1982b. Making compost. Harvest 8(4), 165–166.

Preston S.R. 1990. Investigation of compost × fertilizer interactions in sweetpotato grown on volcanic ash soils in the highlands of Papua New Guinea. Food Crops Unit, Division of Primary Industry: Wabag, Papua New Guinea, pp. 1–6.

Radcliffe D.J. 1983. Managing properties of Andisols in Southern Highlands province, Papua New Guinea. Technical Report No. 1, 18. Agricultural Field Trails, Studies, Extension and Monitoring Unit (AFTSEMU), Southern Highlands Rural Development Project: Mendi, Southern Highlands province.

Ratsch R. 2008. Scoping study and problem assessment for the cultivation of sweet potato (*Ipomoea batatas*) in the high altitudes of Papua New Guinea. Unpublished National Agricultural Research Institute research report.

Sillitoe P. 1996. A place against time: land and environment in the Papua New Guinea highlands. Harwood Academic Publishers: Netherlands, pp. 380–390.

Waddell E. 1972. The mound builders: agricultural practices, environment and society in the Central Highlands of Papua New Guinea. University of Washington Press: United States of America, pp. 42–67.

Wiessner P. and Tumu A. 1998. Historical vines: Enga networks of exchange, ritual and warfare in Papua New Guinea. Smithsonian Institution: United States of America, pp. 60–114.

Wohlt P.B. 1978. Ecology, agriculture and social organization: the dynamics of group composition in the highlands of Papua New Guinea. 4th International Crop Science Congress, September 2004, Brisbane, Australia, pp. 130 and 134.

Wohlt P.B. 1986. Kandep: challenge for development. Technical Bulletin No. 2, 32–42. Department of Enga province, Division of Primary Industry, Subsistence Unit: Wabag, Enga province.

Genetics and disease as factors in the yield decline of sweetpotato in the Papua New Guinea highlands

Eric A. Coleman[1], Michael J. Hughes[2], Grahame V.H. Jackson[3], Birte Komolong[4] and Elick Guaf[4]

Introduction

Yield decline in sweetpotato crops occurs worldwide, although the reason is still uncertain (Clark et al. 2002; Clark and Hoy 2006). Genetic change and virus infections have been suggested as possible causes (Dangler 1994; Sloan 1994; Villordon and LaBonte 1995, 1996) as well as, more recently, simultaneous infections of different viruses (Clark and Hoy 2006; Mukasa et al. 2006). Our research in Papua New Guinea, mostly on sweetpotato diseases, adds to the debate. It documents information compiled as a result of two research projects[5] involving the National Agricultural Research Institute and the Fresh Produce Development Agency.

PNG sweetpotato germplasm

It has been suggested that Papua New Guinea (PNG) is a secondary centre of diversity of sweetpotato. Zhang et al. (1998) confirmed this on a small number of accessions. They used random amplified polymorphic markers to compare genetic variation in 18 cultivars from South America and a similar number from PNG (cultivars originating from both the highlands and lowlands). The samples were considered to be representatives of two genepools, although diversity within PNG was narrower than that within South America.

In PNG the highlands germplasm collection is maintained ex situ at Aiyura (approximate elevation 1,550 metres above sea level (masl)), Eastern Highlands province (EHP), with a much smaller one at Tambul (approximate elevation 2,300 masl), Western Highlands province (WHP). A collection of lowland origin is maintained at Keravat (approximate elevation 20 masl), East New Britain. Outside PNG there are in-vitro collections held by national, region and international organisations.

The Aiyura collection has approximately 1,130 accessions: 966 were collected many years ago, 146 are preliminary selections of highlands and Pacific island cultivars assembled by the Pacific Regional Agricultural Programme (PRAP) project[6] (collected in the 1990s); 10 are commercial varieties assembled by Australian Centre for International Agricultural Research (ACIAR) project SMCN/2004/071[5] (collected in 2006); and 9 are early-maturing cultivars from the highlands, of which 5 were originally selected for drought tolerance (collected in 2003–04). A large proportion of the cultivars appears susceptible to scab (*Elsinoe*

[1] Department of Primary Industry and Fisheries, PO Box 6014, CQ Mail Centre, Rockhampton Queensland 4700, Australia <Eric.Coleman@dpi.qld.gov.au>

[2] Department of Primary Industry and Fisheries, Kairi Research Station, PO Box 27, Kairi Queensland 4872, Australia <Michael.Hughes@dpi.qld.gov.au>

[3] 22 Alt Street, Queens Park New South Wales 2022, Australia <gjackson@zip.com.au>

[4] National Agricultural Research Institute, Sir Alkan Tololo Research Centre, PO Box 4415, Lae, 411, Morobe Province, Papua New Guinea <birte.komolong@nari.org.pg>; <elick.guaf@nari.org.pg>

[5] ACIAR projects SMCN/2004/067: 'Soil fertility management in the PNG highlands for sweetpotato based cropping systems'; and SMCN/2004/071 'Reducing pest and disease impact on yield in selected PNG sweet potato production systems'

[6] PRAP Project 4: 'Selection, trial and dissemination of sweetpotato germplasm'. It was commissioned with the aim of evaluating all PNG germplasm.

batatas). Symptoms of virus in this collection are common; consequently, it should not be distributed unless the accessions have been pathogen indexed and, where necessary, subjected to therapy to remove the viruses.

During the last 30 years a large number of PNG cultivars have been sent to germplasm repositories outside the country. Much of this germplasm is available free from pathogens.

Important germplasm issues for PNG

Stable germplasm

A major challenge for PNG is to develop a collection of cultivars for distribution and breeding that has stable yields over successive generations of planting. However, stability has not yet been assessed. The process of eliminating less desirable accessions based on six successive plantings was done for the lowlands collection (PRAP assembled more than 1,000 cultivars initially) but it is still required for the highlands collection. There is evidence from trials in Australia, done under project SMCN/2004/071, that yield stability does exist in some PNG cultivars at least, with little difference in yield between pathogen-indexed plants and those infested with viruses found in Australia (unpublished data).

Maintenance of germplasm

Currently, there is a small collection of PNG sweetpotato germplasm in tissue culture at Aiyura in EHP. The use of tissue culture to maintain this material is currently working well and seems to be a sound approach for the future preservation of PNG germplasm.

Field collections at Aiyura and elsewhere are costly to maintain and the standard of care fluctuates depending on the availability of funds. If not well maintained, accessions become mixed or they die. At the present time all the accessions are being maintained, rather than removing those that have disease susceptibility. The accessions in this field collection are also exposed to many pathogens and the local environment, and true morphological evaluation may be hard, especially when mixed virus infections distort leaf shape and colour (see Figure 4).

An alternative would be to reduce the collection to a manageable number by removing those accessions with disease susceptibility or poor agronomic characteristics. This core collection would need to be based on morphological and genetic markers, and agronomic performance, to avoid losing the genetic diversity of the collection. Another, simpler way of achieving this would be to collect and store seed from the current collection. The core collection developed should also be conserved in vitro as pathogen-indexed plantlets in tissue culture, either within the country or offshore. If PNG accedes to the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA), assistance might be provided by the Global Crop Diversity Trust for the cost of maintenance of, say, a core set that is representative of the genetic diversity that exists. As part of the multilateral system of crops listed under the treaty, the collection would be available for international exchange under a comprehensive material transfer agreement, which contains provisions for benefit sharing.

Identifying and developing new germplasm

New cultivars become available in PNG in three ways: they are bred at research stations within the country, imported from breeding or selection programs elsewhere, or collected as cultivars from farmers' fields. There is nothing exceptional about the first two—they are the methods practised throughout the world. Breeding within PNG has the advantage that the germplasm is likely to be well adapted to local growing conditions. Importing new varieties has a number of benefits too, serving to widen the genetic base and possibly bringing higher yield and disease tolerance or other valuable agronomic characteristics not present in PNG. Of course, there is also the chance that varieties may bring less desirable qualities.

The last method is more unusual, and nearly all varieties currently in use have originated from this system. It relates to current farmers' practices, where farmers continuously find seedlings in their fields which they evaluate and select as new cultivars. This natural breeding program is extremely important because as cultivars decline in yield, others are readily brought into service. Compared to breeding at a research station, it has several advantages: those varieties selected as cultivars are adapted to the particular place of selection; they have favoured organoleptic qualities; there is more sharing of plant material and higher chances of adoption compared to researcher-bred varieties; and there are many farmers searching for new varieties based on local criteria that researchers may not consider. However, this method of producing new varieties, like that at research centres, involves a certain amount of chance—there is no certainty that new, acceptable cultivars will be produced. Also, those that are produced are mostly unstable in terms of their yield. They decline, for whatever reason, and so the search for others has to be continuous.

Distribution of true-to-type varieties

Sweetpotato is a crop that can experience significant genetic drift, which occurs when there are random changes in alleles from one generation to the next. It is thought that approximately one in 10,000 plants is significantly different from its parent material in those species that are continuously vegetatively propagated. Genetic drift is thought to contribute to yield decline in sweetpotato, although the allele changes that occur and the significance of these changes differ between cultivars (Sloan 1994; Villordon and La Bonte 1996).

Maintaining pathogen-indexed germplasm in tissue culture is practised in many countries. It is a cost-effective method of germplasm maintenance in most instances (Jarret and Florkowski 1990). Not only does it reduce the threat of genetic drift due to environmental and pest pressures compared to field collections (Jarret and Florkowski 1990), but it also allows rapid multiplication of large numbers of pathogen-indexed plants. Maintaining and distributing varieties with known characteristics and yield potential provides a level of certainty for farmers that continuous breeding does not, and this is important in times of need, for example after an environmental disaster such as a drought.

Important diseases of sweetpotato in PNG

Scab, *Elsinoe batatas*

Scab is probably the most serious fungal disease of sweetpotato throughout the tropics (Collins 1988). It is essentially a wet-weather disease, with severity increasing with rainfall. It is widespread in PNG, and many of the accessions in the Aiyura collection show symptoms of infection.

Symptoms

The disease appears as small, brown, scabby areas mostly along the leaf midrib, veins and petioles, at first l–5 mm in diameter and later joining together into lesions of several centimetres. Numerous pinpoint spots occur in the patches between the veins. The lesions on the petioles and stems are more elongated than those on the leaf blade and slightly sunken. Here, too, they may join together. Severe distortion of leaves occurs, as early infection of veins prevents normal leaf expansion. Leaves are small, curled, cup-shaped and with deeply torn edges, and petioles are short and twisted (Figure 1), but storage roots are not infected (Jackson et al. 1984; Clark and Moyer 1988; Collins 1988; Moyer et al. 1989; Jackson and McKenzie 1991). On susceptible varieties the growing points may be killed, but on those with some resistance, infection is restricted to the top of the petiole and lower parts of the midrib, causing the leaves to twist and the undersurfaces to become exposed (Jackson and McKenzie 1991).

In the PNG highlands, trials with two cultivars showed that storage root yields and numbers of roots were nearly twice on plants sprayed with benomyl at

Figure 1. *Elsinoe batatas* (sweetpotato leaf scab) on sweetpotato plants growing in Eastern Highlands province, Papua New Guinea, 2007
Photos courtesy of J. Lovatt, Department of Primary Industries, Bundaberg, Queensland

2–3-week intervals compared to those left untreated (Goodbody 1983). Other trials in the highlands showed a 19% yield difference (34% marketable yield) resulting from scab infection (Floyd 1988).

Selection of cultivars with resistance to this disease is a key management issue. It should also be noted that plants derived from tissue culture as part of a pathogen-testing scheme are free from this disease, at least initially.

Dispersal and management

Most commonly, scab is spread to new crops when infected cuttings are used as propagating material. The fungus probably survives between crops in the decayed vines of harvested plants. Survival of this kind is only important where sweetpotato is grown continuously on the same land, as can happen in the highlands of PNG. No alternative hosts are known (Jackson and McKenzie 1991).

A lack of crop rotation is another factor contributing to spread of this disease. The following advice is taken from Jackson and McKenzie (1991).

> Sweetpotato should not be planted continuously on the same land. It is best to practice crop rotation or fallow the land for at least 12 months between crops. If this is impractical, then the old vines, which may harbour the fungus, should be destroyed and new plantings should not be made near those already infected with the disease.

Intensification of the crop in PNG, to meet increased dependency on the crop, makes many of these suggestions impractical. Practices such as dipping planting material in running water, and general hygiene such as volunteer removal of plants from the area to be planted, also help to minimise the spread of the disease and are more practical solutions for PNG.

It is important to select planting material that is free from the disease. If that is not possible, growers should be encouraged to produce disease-free cuttings by planting small tubers in nursery beds. After 1 month the sprouted vines can be cut and planted in the field. It is unlikely that plants grown from these cuttings will stay free of scab throughout the cropping period, but epidemics of the disease will be delayed and yields will be higher as a consequence.

Fungicides can be used to control scab disease but are not usually recommended except for commercially grown crops. They might be used to control scab on susceptible cultivars grown because of superior taste, or some other preferred quality, which command a high market price.

Resistant varieties

Cultivars in Indonesia (Sudarijanto et al. 1996; Hartana and Renwarin 1998), PNG (Lenné 1991), Solomon Islands (Jackson and McKenzie 1991) and Taiwan (Anon. 1987, 1990) show varying degrees of resistance to scab. In 1992 the World Vegetable Center (AVRDC) identified 33 highly resistant and 24 resistant varieties from PNG (Lutulele 2001). Further work was carried out under PRAP. A total of 1,139 lowland sweetpotato cultivars from different collections in the country, as well as introductions from overseas, were evaluated for various important characteristics between 1990 and 1998 (van Wijmeersch and Guaf 2004). These characteristics included the incidence of scab disease based on a five-point scale ranging from no lesions (immune) to numerous lesions on both leaf and vine (very susceptible). The project recommended 79 first-class and 14 second-class varieties for the lowlands of PNG. All selected varieties showed moderate to high levels of resistance to scab.

Scab is considered a greater problem in the highlands compared to the lowlands. While some of the highlands cultivars show moderate to high levels of resistance to scab (Kokoa 2001; Van Wijmeersch 2001), there appears to be a large number of varieties in the Aiyura collection with low levels of resistance.

Scurf, *Monilochaetes infuscans*

Scurf is the common name of a fungal disease caused by *Monilochaetes infuscans* that attacks storage roots. Severely affected roots are said to lose water and shrink more than healthy ones (Clark 1989). Importantly, they are unsightly and, because of this, may lose market value in some countries. Scurf is widely distributed in the highlands of PNG but is not seen as a problem by farmers as there is no market penalty for affected storage roots.

Symptoms

Small brown lesions form, limited to the surface or periderm of the storage root. They coalesce and may cover the entire surface, resembling a stain (Clark et al. 1981). Although the fungus does not penetrate beyond the outer layers of the periderm, the root is nevertheless unsightly (Figure 2). Lesions present at harvest continue to develop in storage, where root-to-root spread is possible from airborne spores (Collins 1988).

Figure 2. *Monilochaetes infuscans*—sweetpotato scurf; left: affected storage roots in a Papua New Guinea (PNG) market (photo courtesy of J. Lovatt, Department of Primary Industries, Bundaberg, Queensland); right: discolouration caused by scurf in a farmer's field, Western Highlands province, PNG, 2007.

Dispersal and management

Scab lesions coalesce and spread from the roots to the sprouts (if the storage roots are used for planting), and from there to the developing roots. Scurf is endemic in PNG; however, it is not seen as a disease by many farmers, who consider it a sign of storage root maturity. Consequently, market prices are the same irrespective of the disease.

A gradual increase in the incidence and severity of the disease occurs when traditional cultivation practices are not followed. Cultural control measures include rotation and avoidance of infested fields (Collins 1988). A minimum period of 3 years between crops susceptible to scurf has been recommended (MacNab and Zitter undated). Increased intensification with reduced crop rotation has most probably contributed to the increased occurrence of this pathogen.

Hot water immersion of roots (50 °C for 10 minutes) has been used to control scurf, as well as *Rhizoctonia* and *Fusarium*, as part of a program to demonstrate that those fungi are involved in root discolouration on Jersey type varieties, irrespective of the presence or absence of russet crack virus (Hildebrand 1969). In other studies, treating roots with water at 55 °C for half a minute or at 49 °C for 5 minutes provided good control, but best control was achieved by dipping roots into a Ferbam[7] dip at 55 °C for half a minute or at 49 °C for 5 minutes (Daines 1971). In other trials thiabendazole and Benlate[8], each at 1.5 g/L of water, were effective for the control of scurf. Dips at 49–55 °C gave significantly better control than dips at 18 °C (Daines 1972).

As with the control of scab, the distribution of pathogen-free planting material is another method of reducing the prevalence of this disease.

Resistant varieties

Breeding programs in the USA target scurf as well as pathogens such as *Fusarium oxysporum*, *Ceratocystis fimbriata*, *Streptomyces ipomoea* and the nematodes *Meloidogyne* spp. (Hammett et al. 1982). In China the use of pathogen-tested planting material is said to restore resistance to scurf and other pathogens (Gao et al. 2000; Yang et al. 2000). There has been no assessment of the Aiyura collection for resistance to scurf.

Sweetpotato viruses

Currently, 22 viruses are recognised that infect sweetpotato worldwide (Table 1) although some have a limited distribution. However, despite progress in virus diagnostics, virus diseases in sweetpotato are still poorly understood, especially their aetiology, epidemiology and occurrence as complexes (Clark and Moyer 1988; Salazar et al. 2000).

[7] Ferbam is a trade name for ferric dimethyldithiocarbamate

[8] Benlate is a common trade name for Benomyl; manufacture of this fungicide was discontinued by DuPont at the end of 2001 for reasons of risks to human health.

Table 1. List of recognised viruses known to infect sweetpotato (Salazar et al. 2000; O'Sullivan et al. 2005; Tairo et al. 2005)

Virus	Abbreviation	Genus	Vector	Distribution
Approved species				
Sweetpotato feathery mottle virus	SPFMV	Potyvirus	Aphid	Worldwide including Papua New Guinea (PNG) (russet crack and O strain confirmed PNG, 2008)
Sweetpotato virus G	SPVG	Potyvirus	Unknown	Uganda, Egypt, India, China, USA (confirmed PNG, 2008)
Sweetpotato virus-II	SPV-II	Potyvirus	Aphid	Taiwan
Sweetpotato latent virus	SPLV, syn. SPV-N	Potyvirus	Aphid	Africa (Uganda, Kenya); Asia (Indonesia, Egypt, China, India, the Philippines, Taiwan, Japan); Peru
Sweetpotato mild speckling virus	SPMSV	Potyvirus	Aphid	Argentina, Peru, Indonesia, the Philippines
Sweetpotato mild mottle virus	SPMMV	Ipomovirus	Whitefly	Africa, Indonesia, PNG, the Philippines, India, Egypt, Peru, Australia
Sweetpotato chlorotic stunt virus	SPCSV, syn. SPSVV	Crinivirus	Whitefly	Worldwide (Australia[a])
Cucumber mosaic virus	CMV	Comovirus		Israel, Kenya, Egypt
Tentative species				
Ipomoea yellow vein virus	IYVV	Begomovirus	Unknown	Spain
Sweetpotato vein mosaic virus	SPVMV	Potyvirus[a]	Aphid	Argentina
Sweetpotato leaf curl virus	SPLCV	Begomovirus	Whitefly	Taiwan, Japan, Egypt
Sweetpotato leaf curl Georgia virus	SPLCGV	Begomovirus	Whitefly	USA, Peru[b], China[c], Sicily[d]
Sweetpotato virus Y	SPVY	Potyvirus	Aphid	USA, Taiwan, Spain, South Africa, Zambia, Australia
Sweetpotato leaf speckling virus	SPLSV	Luteovirus	Aphid	Peru, Cuba
Sweetpotato yellow dwarf virus	SPYDV	Ipomovirus	Whitefly	Taiwan, Far East
Ipomoea crinkle leaf curl virus	ICLCV	Geminivirus	Whitefly	USA, Israel
Sweetpotato chlorotic fleck virus	SPCFV, syn. SPSV, C-2, C-5 virus	Carlavirus	Unknown	Peru, Japan, Brazil, China, Cuba, Panama, Colombia, Bolivia, Indonesia, the Philippines (confirmed PNG 2008)[e]
Sweetpotato caulimo-like virus	SPCaLV	Caulimovirus	Unknown	Puerto Rico, Madeira, Solomon Islands, Australia, PNG
Sweetpotato ringspot virus	SPRSV Reo-like Ilar-like C-6	Nepovirus Potyvirus?	Unknown Unknown Unknown Unknown	PNG, Kenya Asia Guatemala Uganda, Indonesia, the Philippines, Peru

[a] awaiting confirmation; [b] Fuentes et al. (2002); [c] Luan et al. (2006); [d] Briddon et al. (2006) found on *Ipomoea indica;* [e] Brian Takaboi, pers. comm.

Virus diseases have been suggested as a major cause of yield decline in sweetpotato (Feng et al. 2000; Lian 2000; Mariscal 2000; Salazar et al. 2000). Experiments conducted by the International Potato Centre (CIP) showed that diseases caused by a single virus or combinations of several viruses can result in an 18–100% reduction in yield (Milgram et al. 1996; Feng et al. 2000; Salazar et al. 2000). Sweetpotato virus disease (SPVD) is the most important and is caused by the sweetpotato feathery mottle virus (SPFMV) (Figure 3) and the sweetpotato chlorotic stunt virus (SPCSV) (Hahn 1979; Tairo et al. 2005).

Sweetpotato virus diagnosis and identification

Symptoms caused by different viruses are often similar and difficult to distinguish. They vary with virus strain, sweetpotato variety, plant age, nutrition, weather and the number of viruses present. Nutritional deficiencies also cause symptoms similar to those of some viruses (Lucas et al. 1992).

Figure 3. Typical leaf symptom of sweetpotato feathery mottle virus taken in Western Highlands province, Papua New Guinea, 2007

Viruses are obligate pathogens that cannot be cultured outside the host, and they are too small to be detected by standard light microscopy. For a long time detection and identification relied on the use of electron microscopes and indicator plants, for example *Ipomoea setosa* in the case of sweetpotato. More sensitive diagnostic methods are needed to enable the production and dissemination of virus-free planting material as part of the international exchange of germplasm between countries, and the safe distribution within each country. CIP in Peru has been leading this research and has developed serological tests using enzyme-linked immunosorbent assay (ELISA) techniques and those based on the polymerase chain reaction (Salazar et al. 2000).

Indicator plants

Some plant species are very susceptible to virus infection and show symptoms in a well-defined and consistent manner compared to those that appear on the primary host. In the case of sweetpotato the most widely used indicator plant is *Ipomoea setosa*. Usually, shoots of the plant under test are grafted to *I. setosa,* or the indicator species is mechanically inoculated with sap (Beetham and Mason 1992).

Other indicator plants are *I. incarnata, I. nil, Nicotiana glutinosa* and *Chenopodium quinoa.* These are sometimes used in conjunction with *I. setosa* to confirm the presence of a specific virus. While there is no evidence in the literature to suggest that any known virus is eluding detection by *I. setosa*, Tairo (2006) states that the main disadvantage of indexing is that it cannot discriminate between individual virus species/strains; therefore, it needs to be used in conjunction with molecular tests.

Sweetpotato viruses in PNG highlands

Surveys by project SMCN/2004/071 at over 20 locations in EHP and WHP showed that symptoms of sweetpotato virus are widespread. Prior to the surveys, only SPMMV, SPRSV and SPCaLV had been reported (see Table 1) (Atkey and Brunt 1987). The occurrence of SPFMV was unconfirmed. Atkey and Brunt (1987) state that the virus is present in PNG but present no data to substantiate the claim. However, more recent sample collections as part of project SMCN/2004/071 have confirmed the presence of two SPFMV strains (russet crack and O). In addition, SPCFV and SPVG (see Table 1) have been detected and another virus is yet to be identified (Lee McMichael, Queensland Department of Primary Industries, pers. comm.).

In general, seed transmission of sweetpotato viruses does not occur, although it is possible that SPRSV is seed borne. However, the major isolated viruses, i.e. SPFMV and SPVG, are not seed borne, and this may explain why PNG farmers find that selections derived from seedlings are vigorous and high yielding compared to those that were popular previously but have since declined.

Sweetpotato virus complexes

When two or more viruses infect sweetpotato plants simultaneously, the effect can be highly debilitating, for example the so-called sweetpotato virus disease in Africa caused by SPFMV and SPCSV (see Table 1). Other synergies have been documented, such as sweetpotato chlorotic dwarf disease, a complex of SPFMV and SPMSV, and SPFMV and SPVG (see Table 1; Figure 4) (Clark and Hoy 2006). The role of viruses and the way they interact is still being studied, but it is now apparent that they are a major cause of yield decline in sweetpotato (Clark et al. 2002). In PNG, too, they seem to have a role: plants infected with SPFMV and SPVG have been found in EHP showing foliar symptoms that are so severe that root yield reduction is likely, although no measurements have been done as yet.

Discussion

From our results from limited surveys, it is becoming clear that there are numerous viruses infecting sweetpotato in PNG, and often they occur as complexes. So far, sweetpotato virus disease has not been found, but it is possible that combinations of other viruses will prove to be just as debilitating. It is too early to say that viruses are a factor in sweetpotato yield decline. This will not be possible until trials are carried out comparing pathogen-tested and virus-infected plants. However, six viruses have been recorded so far, with another being identified, so there is at least circumstantial evidence that they play a role.

Figure 4. Mixed virus infection of sweetpotato feathery mottle virus and sweetpotato virus G at Aiyura, Papua New Guinea, 2007

Part of the work in establishing a pathogen-tested sweetpotato scheme has involved assessing the sweetpotato gene banks that exist in the country, especially that maintained in the field at Aiyura. It has been a useful source of viruses and also cultivars to pair with pathogen-tested plants from overseas in-vitro collections. However, rationalisation of the collection is timely, and it is suggested that an active core collection be established and maintained ex situ, and also in tissue culture within PNG or elsewhere, after the accessions have been pathogen tested. There is sufficient evidence from several laboratories that have maintained sweetpotato from PNG for more than 20 years that this form of conservation is ideally suited to PNG circumstances.

References

Anon. 1987. Screening for resistance to sweet potato scab. 1985. Progress report. Asian Vegetable Research and Development Center: Taiwan.

Anon. 1990. Scab confirmation screening under seminatural field conditions. 1988 progress report, Asian Vegetable and Development Centre: Taiwan.

Atkey P.T. and Brunt A.A. 1987. Electron microscopy of an isometric caulimo-like virus from sweet potato (*Ipomoea batatas*). Phytopathology 118, 370–376.

Beetham P. and Mason A. 1992. Production of pathogen-tested sweet potato. ACIAR Technical Reports No. 21. Australian Centre for International Agricultural Research: Canberra.

Briddon R.W., Bull S.E. and Bedford I.D. 2006. Occurrence of sweet potato leaf curl virus in Sicily. Plant Pathology 55(2), 286.

Clark C.A. 1989. Principal bacterial and fungal diseases of sweet potato and their control. Pp. 275–289 in 'Exploration, maintenance, and utilization of sweet potato genetic resources. Report of the 1st Sweet Potato Planning Conference, 1987'. International Potato Centre: Lima, Peru.

Clark C.A. and Hoy M.W. 2006. Effects of common viruses on yield and quality of Beauregard sweetpotato in Louisiana. Plant Disease 90, 83–88.

Clark C.A., Lawrence A. and Martin F.A. 1981. Accumulation of furanoterpenoids in sweet potato tissue following inoculation with different pathogens. Phytopathology 71, 708–711.

Clark C.A. and Moyer J.W. 1988. Compendium of sweet potato diseases. APS Press: St. Paul, Minnesota.

Clark C.A., Valverde R.A. and Moyer J.W. 2002. Research for improved management of diseases: cultivar decline. Proceedings of 1st International Conference on Sweetpotato. Acta Horticulturae 583, 103–112.

Collins A. 1988. Bacterial and fungal diseases of sweet potato. International Potato Center (CIP): Lima, Peru, pp. 73–77.

Daines R.H. 1971. The control of black rot of sweet potatoes by the use of fungicide dips at various temperatures. Phytopathology 61, 1145–1146.

Daines R.H. 1972. Effects of fungicide dips at various temperatures on the occurrence of the sweetpotato scurf. Plant Disease Reporter 56, 122–126.

Dangler J.M. 1994. Sweetpotato foundation programs provide sweetpotato growers with high quality pathogen-free stock. Compendium of sweetpotato foundation programs. HortTechnology 4, 224.

Feng G., YiFu G. and PinBo Z. 2000. Production and deployment of virus-free sweetpotato in China. Crop Protection 19(2),105–111.

Floyd C.N. 1988. Control and effect of leaf scab (*Elsinoe batatas*) in sweet potato. Tropical Agriculture (Trinidad) 65(1), 6–8.

Fuentes, S. and Salazar, L.F. 2002. First report of sweetpotato leaf curl virus in Peru. Plant Disease 87, 98.

Gao F., Gong Y.F. and. Zhang P.B. 2000. Production and deployment of virus-free sweetpotato in China. Crop Protection 19, 105–111.

Goodbody S. 1983. Effect of sweet potato leaf scab (*Elsinoe batatas*) on sweet potato tuber. Tropical Agriculture 60, 302–303.

Hahn S.K. 1979. Effects of viruses (SPVD) on growth and yield of sweet potato. Experimental Agriculture 15, 253–256.

Hammett H.L., Hernandez T.P., Martin W.J. and Clark C.A. 1982. Breeding sweet potato for disease resistance. Pp. 321–329 In 'Sweet potato'. Proceedings of the 1st international symposium, Taiwan, 23–27 March 1981.

Hartana A. and Renwarin J. 1998. Evaluation of Indonesian sweet potato germplasm for yield, nutritional values, and resistance to foliar pathogens. Acta Horticulturae 467, 163–167.

Hildebrand E.M. 1969. Russet crack, a menace to the sweetpotato industry. 3: Role of fungi in the root-lesion phase of russet crack. Plant Disease Reporter 53(2), 103–107.

Jackson G.V.H. and McKenzie E. 1991. Sweet potato scab. Pest Advisory Leaflet 24. South Pacific Commission: Suva, Fiji.

Jackson G.V.H., Pearson M.N. and Zettler F.W. 1984. Sweet potato little leaf. SPC Advisory leaflet 19. South Pacific Commission: Noumea, New Caledonia.

Jarret R.L. and Florkowski W.J. 1990. In vitro vs field genebank maintenance of sweetpotato germplasm; major costs and considerations. Hortscience 25(2), 141–146.

Kokoa P. 2001. Review of sweet potato diseases in PNG. In 'Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference', PNG University of Technology, Lae, 26–30 June 2000, ed. by R.M. Bourke, M.G. Allen and J. Salisbury. ACIAR Proceedings No. 99, 730–735. ACIAR: Canberra.

Lenné J.M. 1991. Diseases and pests of sweet potato: South-East Asia, the Pacific and East Africa. Natural Resources Institute Bulletin No. 46. Natural Resources Institute: Kent, United Kingdom.

Lian T.S. 2000. Problems related to yield performance decline in sweetpotato in Malaysia. Pp. 27–32 in 'Sweetpotato cultivar decline study', ed. by Y. Nakazawa and K. Ishiguro. Department of Upland Farming, Miyakonojo, Japan.

Luan Y.S., Zhang J. and An L.J. 2006. First report of sweet potato leaf curl virus in China. Plant Disease 90, 1111.

Lucas G.B., Campbell C.L. and Lucas L.T. 1992. Introduction to plant diseases (1st edition). Kluwer Academic: Boston.

Lutulele R. 2001. Sweet potato variety developments in the PNG highlands: implications for future research and extension focus. In 'Food security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference', PNG University of Technology, Lae, 26–30 June 2000, ed. by R.M. Bourke, M.G. Allen and J. Salisbury. ACIAR Proceedings No. 99, 683–688. ACIAR: Canberra.

MacNab A.A. and Zitter T.A. undated. Do rotations matter within disease management programs? Department of Plant Pathology: Ithaca, NY, USA. At: <http://vegetablemdonline.ppath.cornell.edu/NewsArticles/McNab-Rotations.htm>.

Mariscal A.M. 2000. Problems and subjects of performance decline of sweetpotato in the Philippines. Pp. 70–81 in 'International Workshop on Sweetpotato Cultivar Decline Study', ed. by Y. Nakazawa and K. Ishiguro. Department of Upland Farming, Kyushu National Agricultural Experiment Station: Miyakonojo, Japan.

Milgram M., Cohen J. and Loebenstein G. 1996. Effects of sweet potato feathery mottle virus and sweet potato sunken vein virus on sweet potato yields and rates of reinfection of virus-free planting material in Israel. Phytoparasitica 24(3),189–193.

Moyer J.W., Jackson G.V.H. and Frison E.A. 1989. FAO/IBPGR technical guidelines for the safe movement of sweet potato germplasm. Food and Agriculture Organization of the United Nations: Rome; and International Board for Plant Genetic Resources: Rome.

Mukasa S.B., Rubaihayo P.R. and Valkonen P.T. 2006. Interactions between a crinivirus, an ipomovirus and a potyvirus in co-infected sweetpotato plants. Plant Pathology 55, 458–467.

O'Sullivan J., Amante V., Norton G., van de Fliert E., Vasquez E. and Pardales J. 2005. Sweetpotato DiagNotes: a diagnostic key and information tool for sweetpotato problems. Centre for Biological Information Technology: University of Queensland, Australia.

Salazar L.F., Fuentes S. and Moyer J.W. 2000. Current knowledge on major virus diseases of sweet potatoes. Pp. 14–19 in 'International Workshop on Sweet Potato Cultivar Decline Study', September 8–9 2000, Miyakonojo, Japan, ed. by Y. Nakazawa Y. and K. Ishiguro. Department of Upland Farming, Kyushu National Agricultural Experiment Station: Miyakonojo, Japan.

Sloan Jr. R.C. 1994. Mississippi sweetpotato foundation seed program. HortTechnology 4, 230–232.

Sudarijanto A., Martanto E.A. and Paiki F.A. 1996. Natural resistance selection of several sweet potato cultivars for scabies infections (*Elsinoe batatas* (Saw.) Jenkins et Viegas). Hyphere (Indonesia) 1(2), 54–57.

Tairo F. 2006. Molecular resolution of genetic variability of major sweetpotato viruses and improved diagnosis of potyvirsues co-infecting sweetpotato. Doctoral thesis, Swedish University of Agricultural Sciences, Uppsala.

Tairo F., Mukasa S.B., Jones R.A., Kullaya A., Rubaihayo P.R. and Valkonen J.P.T. 2005. Unravelling the genetic diversity of the three main viruses involved in sweet potato virus disease (SPVD) and its practical implications. Molecular Plant Pathology 6(2), 199–211.

Van Wijmeersch P. 2001. The status of sweet potato variety evaluation in PNG and recommendations for further research. In 'Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference', PNG University of Technology, Lae, 26–30 June 2000, ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 674–682. ACIAR: Canberra.

Van Wijmeersch P. and Guaf E. 2004. Sweet potato variety evaluation in Papua New Guinea: achievements and methods. Technical Bulletin No. 8. National Agricultural Research Institute: Lae, Papua New Guinea.

Villordon A.Q. and LaBonte D.R. 1995. Variation in randomly amplified DNA markers and storage root yield in 'Jewel' sweetpotato clones. Journal of the American Society for Horticultural Science 120, 734–740.

Villordon A.Q. and LaBonte D.R. 1996. Genetic variation among sweetpotatoes propagated through nodal and adventitious sprouts. Journal of the American Society for Horticultural Science 121, 170–174.

Yang X.J., Chen F.R. and Zhang L.X. 2000. Screening of fungicides for control of *Ceratocystis fimbriata* Ellis et Halsted. Plant Protection 26, 38–39.

Zhang D., Ghislain M., Huamán Z., Gomirzaie A. and Hijmans R. 1998. RAPD variation in sweetpotato (*Ipomoea batatas* (L.) Lam) cultivars from South America and Papua New Guinea. Genetic Resources and Crop Evolution 45, 271–277.

Soil management in the northern Guinea savanna of Nigeria

Gunnar Kirchhof[1], Azubuike Chidowe Odunze[2] and Salako Felix Kolawole[3]

Abstract

A survey of soil management practices was conducted in the northern Guinea savanna of Nigeria. Fifteen villages were randomly selected from a geographical grid covering an area of 100 × 200 km located in the benchmark area of the Ecoregional Program for the Humid and Sub-humid Tropics of Sub-Saharan Africa. In each village the chief and several farmers were interviewed to assess their soil management methods and attitude towards the need to conserve soil. A total of 181 farmers were interviewed in late 1996.

The most common crop rotation systems were food legumes with non-legume crops (40%), followed by monocropping (28%). Fifty-three per cent of the farmers who included food legumes in their rotations did so for soil fertility considerations, while 49% of the farmers who practised monocropping did so to maximise their output. These practices indicate that farmers were well aware of the importance of legumes for maintaining soil fertility. Only 2% of the farmers practised mulching with crop residue. The most common use of crop residue was for fodder, the remainder largely being used as building material or else burnt. As a consequence, soil surfaces were generally bare at the onset of the rainy season and hence prone to soil erosion.

Ridging was the most important land preparation technique (88%), with farmers perceiving benefit in terms of improved crop emergence (56%) and water conservation (11%). Other benefits included weed control. Ridging was generally practised along contours, with most farmers citing soil conservation benefits, e.g. water conservation, and erosion control as the reasons for using contour ridging. Those farmers who purposely ridged up and down the slope did so for drainage purposes. All farmers used the same method to build ridges—the ridge from the previous year was cut in the middle and the two halves of neighbouring ridges were combined to form a new ridge in the furrow from the previous year. According to the farmers, this method controlled weeds and improved emergence. None of the farmers practised rebuilding old ridges, similar to permanent ridges. Such a practice might be acceptable to farmers in that it may be less labour intensive to rebuild partially collapsed ridges compared to reridging completely. Soil physical benefits from semi-permanent ridging would include increased soil structural stability, reduced soil compaction and increased root proliferation into the subsoil. Negative side effects might include reduced crop emergence and increased weed infestation. The most commonly used tools for soil preparation were hand hoes (80%), followed by draft animals (16%) and tractors (3%).

[1] School of Crop, Land and Food Sciences, The University of Queensland, Brisbane Queensland 4072, Australia <g.kirchhof1@uq.edu.au>
[2] Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
[3] Department of Soil Science and Land Management, University of Agriculture, Abeokuta, Nigeria

Introduction

Sub-Saharan Africa has about 389 million ha of lowland moist savannas (Jagtap 1995), the savanna zone being below an altitude of 800 m. In this zone 116 million ha is referred to as northern Guinea savanna (NGS). It is characterised by a growing period of 151–180 days and a daily mean temperature during this period of > 20 °C (Jagtap 1995). The largest areas of NGS are found in Nigeria (11.5 million ha), Sudan (21 million ha) and Mozambique (21.3 million ha).

Soil degradation in the NGS of Sub-Saharan Africa is a well-recognised problem. Soil loss through water erosion is brought about by highly erosive rainfall in this agroecological zone and large areas of easily erodible soils, coupled with high population growth rates and concomitant overuse of the available soil resource. Despite these unfortunate circumstances, the NGS is an underused resource for the production of a range of agricultural crops that could sustain high population densities. Sustainable use of this resource requires the development and adoption of conservation farming techniques by local communities. The traditional slash-and-burn farming system with long fallow periods between cropping cycles is no longer appropriate because fallow periods decrease in length as population density increases. Under intensive agriculture, technologies to maintain soil fertility and conserve the soil exist and are well known. In developed countries they include engineering solutions such as contour bunding and strategic placement of stable waterways. Biological measures include cover cropping and agroforestry. The latter methods have the potential for farmer adoption in developing countries, but expensive high-cost engineering solutions are unfeasible in such regions, and particularly in the resource-poor parts of West Africa.

Substantial research effort has gone into the development of agroforestry systems and related alley farming techniques. No doubt, this technology provides a feasible basis for long-term stable crop production. Once established, such systems can effectively maintain soil fertility and control soil erosion. However, opinions differ about the suitability and adoptability of these systems by local farmers. Dvorák (1996) pointed out that the adoption potential of alley cropping systems for soil conservation or fertility management was very low. She attributed major constraints to agronomic factors such as a time lag before crop production benefits become apparent, coupled with the inflexibility and sensitivity of labour-intensive alley cropping systems management. Leihner et al. (1996) gave similar reasons for non-adoption of alley farming in southern Benin, summarising the main reasons as: low immediate returns to farmers, labour intensiveness, and benefits to the farmer being strongly dependent on how they understand and implement new technology due to its dissimilarity to traditional mixed-cropping farming systems.

It is also important to note that alley farming systems require fertiliser inputs if nutrient depletion is to be avoided in the long term. In contrast, Adesina et al. (1997) conducted a survey of alley cropping adoption in the Cameroon forest zone and found that 38% of 840 farmers interviewed were using alley cropping or some modified form of this technique. One of the key issues from this latter survey was that farmers changed the technology to suit their needs. Dvorák (1996) identified two basic approaches for farming systems research: (i) testing new technologies to identify constraints on adoption, similar to past research on alley farming, and (ii) studying the production systems to build on and improve available technology. The latter strategy may be preferred over the former, as it involves input from farming communities from the outset of research planning. Planning soil conservation work in the NGS therefore requires knowledge and understanding of local farming practices if the research impact is to be maximised.

Little is known about the soil conservation techniques used by farmers in the NGS. An abundance of indigenous soil conservation techniques exists in developing countries worldwide. For Africa, Scoones et al. (1996) listed the following techniques:

- earth bunds (masakwa cultivation) in Nigeria
- U-shaped contour bunding (trus, tera) in Sudan
- soil planting mounds (wafipa mounds) in Tanzania
- mulch or vegetation barriers (dambos) in Mali
- U- or V-shaped open contour bunds (demi-lunes or half moons) in Niger
- stone bunds of lines (dhagga) in Ethiopia
- small basin irrigation using earth or stone ramps (dokki) in Nigeria
- crop rotation, mulching and burning (gay cultivation) in Ethiopia
- stone wall terracing (ishi-mgboko) in Nigeria

- round ridges (migoka) in Tanzania
- raised fadama beds (kilimo cha vinyungu) in Tanzania
- terrace farming (medoedoe) in Cameroon
- traditional planting pits (zaï) in Mali
- improved traditional planting pits (tassa) in Niger.

These traditional systems are spread over a wide area covering a range of soils and climatic conditions. However, each is probably only used relatively locally. All these techniques have in common that they employ some physical means to slow down or divert water flow by increasing soil surface roughness or protecting the soil surface through mulching.

It is also important to note that the farmer may not perceive soil conservation as an important issue. Despite this, they may still practise soil conservation for quite different reasons. *Mucuna* cover cropping, for example, has been adopted by farmers in southern Benin (IAEG 1997). High rates of adoption were not due to the influence of *Mucuna* on soil fertility but to its very effective suppression of the noxious weed *Imperata cylindrica*. This clearly showed that new techniques could be implemented more easily if they served more then one goal, and if the needs of the farmers are understood.

Soil conservation techniques may need to be applied over a long time period before benefits are obvious. This poses a potential problem as subsistence farmers are likely to be more interested in quick solutions to their current problems rather than long-term solutions to long-term problems. In particular, development of new technologies or improvements to traditional technologies through soil conservation research requires a thorough understanding of resource management in the current farming system. This paper presents selected results from a resource management survey in the Nigerian part of the NGS. Its aim was to assist future research planning into soil conservation in order to maximise technology transfer from researchers to farmers.

Methods

The work presented here was part of several surveys conducted by the Resource and Crop Management Division of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The aim of these surveys was the characterisation of the NGS benchmark area in the Ecoregional Program for the Humid and Sub-humid Tropics of Sub-Saharan Africa by IITA. This paper presents selected results on farmers' awareness and perception of soil conservation and how soil resources are managed.

The NGS benchmark area was located in northern Nigeria and covered an area of about 100 × 200 km. Its northernmost border was north of Zaria at 11° 25' N, and its southernmost border was south of Kaduna at 10° 25' N (Figure 1). Its easternmost border was east of Birnin Gwari at 6° 35' E and its westernmost border was east of Anchau at 8° 35' E. This area was divided into a grid of 72 cells, each 15 × 15 minutes in size. The benchmark area was defined as the cells contained within the area, excluding selected cells such as forest or nature reserves, which reduced the number of cells in the benchmark area to 65. During the field survey a geographic positioning system was used to locate and select the village that was closest to the central coordinate of each cell. For the survey on soil conservation, 15 villages were randomly selected out of the total of 65 villages located in the benchmark area.

After the questionnaire had been designed and tested in 29 villages, the survey was conducted from September to December 1996. Three enumerators were used to administer the questions in the local language, Hausa. Care was taken to obey local customs and to reduce the inherent suspicion of the farming community when strangers arrive for discussion. Approximately 12 farmers were chosen in each village for the farmer-level interview. The selection was not random—those farmers interviewed were those who wished to be interviewed. However, farmers were very eager to talk with us and it can be assumed that the sample of farmers was representative of the village in question. Only farmers who had not previously listened to an interview were chosen. When possible, farmers were interviewed alone, to ensure that their responses were independent.

All questions asked were open ended and the interview was conducted more as a conversation rather than a simple question–answer dialogue. In this way the interviewees were not forced to answer from a list of predefined responses. This paper reports the results from questions relating to cropping systems and soil surface management practices.

Results and discussion

Farmers in the NGS grow a very wide variety of crops ranging from cereals (maize, sorghum, millet, rice etc.), root and tuber crops (cassava, yam, sweetpotato etc.) to food legumes (groundnut, soybean, cowpea, bambara nut etc.). Some crops are produced as food crops for the farmers' own consumption, and others as cash crops for sale at local markets. By far the most important food crops were maize and sorghum, and the most important cash crop was maize. Food legumes play a much less important role as cash or food crops. In this survey the most important food legumes were groundnut and cowpea. Soybean appeared to have entered the cropping system relatively recently. However, inclusion of legumes is an important management tool for sustainable crop production. Despite the relatively low importance of food legume crops, they play an important role in the farmer's crop rotation system (Table 1).

Table 1. Crop rotations used by farmers

Rotation	Farmer response (%)[a]
Legume–non-legume	40
Monocropping	28
No specific system	12
Cereal–cereal	7
Cereal–tuber	6
Sorghum–maize	5

[a] The total is not 100% due to rounding.

The reason why farmers used their specific crop rotation system was largely either as a means of improving or maintaining soil fertility (43% of responses) or of maximising their output (40%). Both are probably related, as sufficient soil fertility is required for adequate yields. However, it also suggested that farmers' attitudes differed and that they were primarily either conservation or income oriented. More than half the farmers who included legumes in their crop rotation system did so for reasons related to soil fertility maintenance, but almost half the farmers who monocropped did this as a means of maximising their incomes (Table 2). This clearly shows that most farmers are well aware of the importance of legumes in their farming operation.

Table 2. Reason for crop rotations used by farmers

Rotation	Soil fertility related (%)[a]	Income related (%)
Legume–non-legume	53	29
Mono cropping	5	49
Cereal–cereal	16	7
Cereal–tuber	8	3
Sorghum–maize	16	12

[a] The total is not 100% due to rounding.

Figure 1. Location of the benchmark area in northern Nigeria (including Zaria and Kaduna)

Together with crop rotation systems, maintenance of a soil surface cover is an important method of reducing soil erosion. However, only a very few farmers indicated that they leave crop residue after harvest on the soil surface as a mulch (Table 3). In almost all cases the farmers removed the crop residue, leaving a bare soil surface at the onset of the next rains and growing season. We were unable to determine if farmers were aware that the removal of surface trash is detrimental to soil conservation. However, it is very likely that they do not have any other option but to remove the crops residues as all groundcover is used for stock feed, fencing etc. or is burnt. This poses significant problems for the implementation of soil conservation practices in the savanna areas.

Table 3. Use of crop residues

Residue use	Farmer response (%)
Collect and feed	52
Collect and burn	13
Graze	13
Graze and burn	10
Use for fencing	7
Use for fuel	3
Mulch	2

The problem of crop residue removal is compounded by the soil preparation techniques used. Ridging and mounding were by far the most common land preparation methods (88%), with the remainder being flat tillage. Thus, the most common soil preparation methods, largely accomplished using hand hoes (Table 4), cause considerable soil disturbance. The main reason for ridging or mounding is seedling emergence (56% of responses). The simple fact that this is what they do traditionally was listed by 24% of the farmers, while 11% listed reasons related to water conservation.

Table 4. Tools use for soil management

Tool used	Farmer response (%)[a]
Hand hoe	80
Animal draft	16
Tractor	3
Other	2

[a] The total is not 100% due to rounding.

Farmers used a common method to ridge or mound the soil—the ridge or mound from the previous year is cut in the middle and the two halves of neighbouring ridges are combined to form a new ridge in the furrow of the previous year. This means that the topsoil is moved around on the subsoil at yearly intervals, which may render the soil surface very prone to erosion. There may be scope to investigate if a system similar to a permanent bed could be used instead. Such a system may stabilise the soil but may also reduce seedling emergence.

During the survey farmers responded that the fallow period between cropping phases is approximately half the length of the cropping period. In most cases 4 years of cropping was followed by 2 years of fallow. Despite the decrease in length of the fallow phase from a number of decades to about 2 years, two-thirds of the farmers interviewed did not perceive this reduction as an indication of decreasing land availability. This lack of appreciation that land may indeed become limited in the future may be owed to the absence of severe famines in the NGS. However, given the population growth and ongoing soil degradation, there is little doubt that land availability will indeed become a problem.

Conclusion

The results from this survey show that farmers in the NGS understand the importance of including legumes in crop rotations, which is an important soil management strategy to maintain soil productivity. Removal of crop residues and subsequent bare soil surfaces at the onset of the growing season are extremely common. At the same time, maintaining groundcover is the simplest method to minimise soil erosion. Given that virtually all groundcover is used for stock feed, fencing etc. or is burnt, any soil conservation strategy that promotes groundcover maintenance is likely to fail. Manual tillage using hand hoes is the main soil preparation method, with little prospect of agricultural mechanisation. Ridging and mounding are the most common soil preparation methods, which cause considerable soil disturbance and increase the erodibility of the soil. Promotion of minimum tillage can be an effective management strategy to minimise soil loss and saves labour.

References

Adesina A.A., Mbila D. and Tonye J. 1997. Integrating women in the development and targeting of agroforestry technologies in Sub-Saharan Africa: gender and alley farming technology in Cameroon. Agroforestry

Systems. International Institute of Tropical Agriculture: Ibadan.

Dvorák K.A. 1996. Adoption potential of alley cropping system. Final Project Report. Resource and Crop Management Research Monograph No. 23. International Institute of Tropical Agriculture: Ibadan, Nigeria.

IAEG (International Assessment and Evaluation Group) 1997. Annual impact report. IAEG, Consultative Group on International Agricultural Research.

Jagtap S.S. 1995. Environmental characterisation of the moist lowland savanna of Africa. Pp. 9–30 in 'Moist savannas of Africa: potentials and constraints for crop production. Proceedings of an IITA/FAO workshop, 19–23 September 1994, Cotonou, Republic of Benin', ed. by B.T. Kang, I.O. Akobundu, V.M. Manyong, R.J. Carsky, N. Sanginga and E.A. Kueneman.

Leihner D.E., Doppler W. and Bernard M. 1996. Special Research Programme 308. Part II: Agro-ecological on-farm evaluation of selected technologies to improve soil fertility in southern Benin, pp. 383–409. The University of Hohenheim: Stuttgart, Germany.

Scoones I., Reij C. and Toulmin C. 1996. Sustaining the soil: indigenous soil and water conservation in Africa. Pp. 1–27 in 'Sustaining the soil', ed. by C. Reij, I. Scoones and C. Toulmin. Earthscan Publications Ltd: London.

Overview of soil conservation technologies and their perception by farmers in Nigeria

Birte Junge[1], Olanike Deji[2], Robert Abaidoo[1], David Chikoye[1], Karl Stahr[3] and Gunnar Kirchhof[4]

Abstract

In Nigeria, West Africa, soil degradation has been one of the most critical environmental problems for a long time. Hence, there has been and still is an urgent need to develop effective soil resource management systems that can reverse the trend. Sustaining soil productivity will enhance food security and alleviate poverty. An extensive literature search that started in 2006 has shown that soil conservation has a long tradition, and earlier and present initiatives have resulted in various on-farm and off-farm technologies. As these have rarely been evaluated to establish adoption rates, an assessment study was performed in 2007 to analyse the effectiveness and adoption of past and present soil conservation initiatives. Villages with different types of conservation technologies were visited and farmers in south-west Nigeria were interviewed to obtain information on their experiences. Mulching, cover cropping and contour tillage are likely to be effective on-farm soil conservation measures practised in Nigeria. They are generally adopted by farmers as they are compatible with the existing farming system, and cheap and easy to install and maintain. Education, knowledge on soil conservation, labour availability and membership in organisations have a positive influence on the adoption rate of technologies.

Introduction

Soil degradation, including erosion and physical, chemical and biological deterioration of the natural resource, is a common phenomenon in Nigeria. Its severity is light for 37.5% of the area (342,917 km^2), moderate for 4.3% (39,440 km^2), high for 26.3% (240,495 km^2) and very high for 27.9% (255,167 km^2) (FAO AGL 2005). The most widespread type of soil degradation is the loss of topsoil by water in the southern and middle part, and by wind in the northern part, of the country (Igbozurike et al. 1989). Sheet erosion dominates, whereas rill and gully erosion are common in the eastern part and along rivers in northern Nigeria (Federal Surveys of Nigeria 1992).

Soil erosion has been greatly accelerated by human activities in recent decades, as the traditional shifting cultivation system has been replaced by more intensive but generally unstable cropping systems (Lal 1993a). The main reason for the land use intensification was and still is the required increase in food production to feed the rapidly growing population. The Nigerian population has increased from 115 million in 1991 to 140 million in 2006 (Federal Republic of Nigeria 2007). The expansion of agriculture into marginal areas, defor-

[1] International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria <B.Junge@cgiar.org>
[2] Department of Agricultural Extension & Rural Development, Obafemi Awolowo University, Ile-Ife, Nigeria
[3] Institute of Soil Science and Land Evaluation, University of Hohenheim, 70593 Stuttgart, Germany
[4] School of Land, Crop and Food Sciences, University of Queensland, Brisbane Queensland 4072, Australia

estation, the shorter duration or absence of fallows, inappropriate farming practices and low input inevitably cause on-site degradation of the natural resource, especially in Sub-Saharan Africa where the resilience ability of the soil is low (Lal 1993a). Off-site problems, such as the siltation of reservoirs, are also common consequences of soil erosion. Hence, the avoidance of soil loss by improved management and the conservation of the natural resource are important to maintain its productivity, and contribute to food security and poverty alleviation for today's and future generations (Ehui and Pender 2005).

Research on soil conservation has been done for many years in different parts of Nigeria, resulting in a range of on-farm and off-farm soil conservation technologies (SCTs). But, up till now, an overview of all measures is still missing, and an evaluation of initiatives has been done only for single erosion control techniques (e.g. Onu 1990). The initiatives also raise questions about their efficiency, their adoption and farmers' perceptions of their impact, as well as concerns about costs and benefits.

The study intends to assess former and present soil conservation initiatives in Nigeria. It includes a literature review to compile information on the variety and location of these initiatives as well as interviews with farmers to study the effectiveness and adoption of SCTs. In conclusion, an identification of the most promising SCTs for the Nigerian savanna is made.

Material and methods

Literature review

A literature review was conducted in 2006 and 2007. Due to the size of the country and its numerous organisations, a selection of appropriate scientific, government and non-government institutions working on soil conservation was necessary. First, the resources of the International Institute of Tropical Agriculture (IITA), an Africa-based international research-for-development organisation, were checked for appropriate records. A search for literature on SCTs was also done by checking various international scientific journals on the internet. In addition, the most important national research institutes; the universities at Abeokuta, Ife, Nsukka, Maiduguri and Zaria; and the Lake Chad Research Institute, Maiduguri, were visited. To obtain more information about the work of government organisations, the Agricultural Development Program (ADP) in Maiduguri, the Federal Environmental Protection Agency (FEPA) in Kaduna and Maiduguri, the Agricultural Land Development Authority (NALDA) in Maiduguri and the Rural Development Projects (RUDEP) in Kaduna were also contacted. Ministries, such as the Federal Ministry of Environment and Water Resources, Ibadan; the Federal Ministry of Forestry, Kaduna; and the Federal Department of Agriculture, Minna, were also visited. In addition, the non-government organisations (NGOs) Justice, Development and Peace (JDP); and the Nigerian Environmental Study/Action Team (NEST), Ibadan, were contacted (Figure 1). A database of all references was generated and most literature was reviewed to identify the kind and location of installed SCTs and to select villages for survey by questionnaire.

Questionnaire

Elwure and Owode-Ede (7°42'N 4°29'E) and Esa Oke (7°44'N 4°50'E), located in Osun State, southwest Nigeria, were selected as the areas characterised by sheet erosion (Figure 1). The climate is humid to subhumid (mean annual rainfall 1,350 mm, mean annual temperature 26.8 °C). The dominant soils are Lixisols (Sonneveld 1997). Farmers prepare the land by using hoes or hiring tractors, and primarily cultivate food crops such as cassava and maize. The farmers of these villages had been trained on farming issues since 1996 and on soil conservation by RUDEP since 2002. About 40 farmers were interviewed in May 2007 to obtain information on their personal and socioeconomic characteristics and their experiences with SCTs. Statistical data analysis, including analysis of frequencies, correlation and variance, was carried out to examine possible relationships between different parameters.

Results and discussion

Literature review

Research and implementation of soil conservation cover different kinds of strategies. This paper includes selected references that focus on on-farm erosion control in Nigeria.

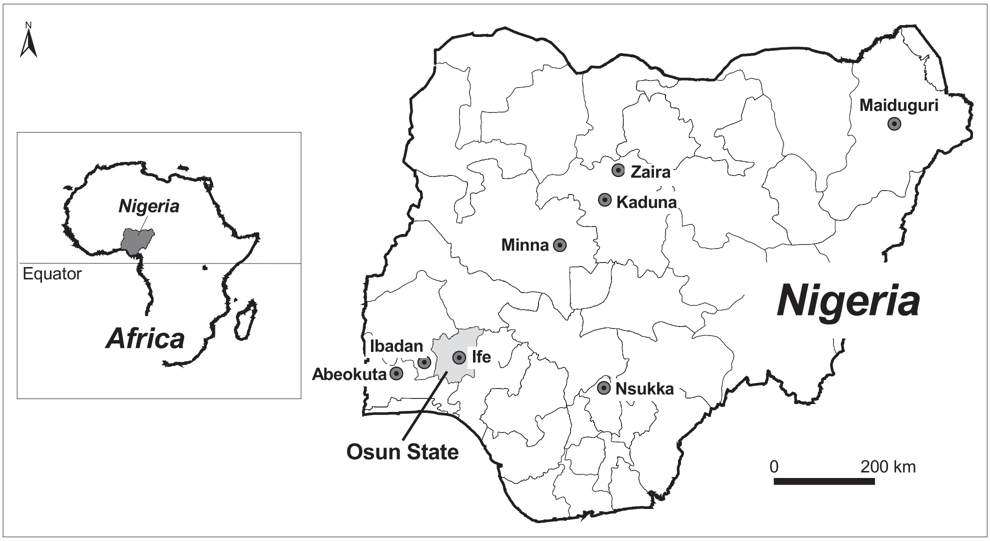

Figure 1. Location of the sites visited for literature search and questionnaires in Nigeria, West Africa

Agronomic measures

Agronomic measures use the effect of surface covers to reduce erosion by water and wind (Morgan 1995). Mulching means covering the soil surface with crop residues or other organic or inorganic materials brought to the field. Its impact in reducing rain splash, run-off and soil loss has been demonstrated in many field experiments conducted on several Nigerian research stations (Orimoyegun 1988; Odunze et al. 2002).

For example, Lal (1993a) measured soil loss of about 152.9 t/ha from a plot with bare fallow and 0.1 t/ha from a plot with maize and mulch. There are various investigations on the beneficial effects of mulching on the physical, chemical and biological soil properties which influence the soil's erodibility. Hulugalle et al. (1985) found that the bulk density is decreased, and infiltration capacity, hydraulic conductivity and soil moisture are increased, by mulching. The size and stability of soil aggregates are increased because of the higher activity of earthworms (Salako et al. 1999). As the content of organic matter and nutrients is enhanced as a result of residue decomposition, soil productivity and crop yields are also increased (Mbagwu 1991).

Lal (2000) also recorded the limitations of mulching as an SCT. As 70–75% of the soil surface should be covered by mulch for an effective result, a large quantity of material (4–6 t/ha/year) is needed. Kirchhof and Odunze (2003) mentioned that providing enough crop residues is a problem, especially in the northern part of Nigeria where this material is often completely removed from the field for use as animal fodder, firewood or as construction material. Other possible disadvantages are the carryover of pests and diseases by residues from the previous crop, and difficulties in controlling weeds. Extra costs for the purchase and transport of brought-in material to the field, increased labour demand for distributing mulch on the farmland, and problems with planting through residues all make this strategy less appealing for farmers (Lal 1995). In spite of these limitations, mulching is likely to be the most useful erosion control technology in Nigeria as it both reduces soil loss and enhances soil productivity and crop yields (Lal 1993a).

Crop management

Crop management is another way to prevent or reduce soil loss. Multiple cropping involves different kinds of systems, depending on the temporal and spatial arrangement of different crops on the same field (Morgan 1995). It has been traditionally practised and is still very common in Nigeria (Olukosi et al. 1991). Research preferentially focuses on increasing soil productivity and crop yields. For example, Carsky et al. (2001) investigated the intercropping of cereals with legumes, and Van der Kruijs and Kang (1988) conducted field trials with root- and tuber-based systems. Agroforestry, a land-use system in which woody perennials are integrated with crops and/or animals on the same land management unit, is another SCT. Investigations on alley cropping, where multipurpose trees are planted as contour hedges between strips of cropland, were part of the research program on many stations. Field trials with the leguminous trees *Leucaena leucocephala* or *Gliricidia sepium* were made by, for example, Kang et al. (1990), Lal (1989) and Vanlauwe et al. (2001). Lal (1989) collected 3.8 t/ha sediment from a plot ploughed and cultivated with sole maize and 0.03 t/ha from a plot planted with *Leucaena* at 2 m spacing. The records also show that the trees improved the soil structure, maintained a high infiltration rate and increased the water-holding capacity, reducing run-off.

Cover crops also play an important role in soil conservation. Research on *Pueraria phaseoloides* or *Mucuna pruriens* was done by, for example, Lal (1978) and Tian et al. (1999). The investigations show that cover crops have positive effects on the soil, such as improving the structure, increasing nitrogen levels by the use of N_2-fixing legumes (Lal 1978) and suppressing weeds such as *Imperata cylindrica* (Chikoye et al. 2002).

Long fallow periods that were part of the traditional shifting cultivation system are no longer possible in many locations. Research on improved fallows of shorter periods is therefore important to encourage soil recovery. Appropriate investigations were made by Juo and Lal (1977) and Tarawali et al. (1999).

The benefits of multiple cropping systems are various, as erosion is reduced and the physical, chemical and biological soil properties are improved. Additional advantages are a decreased risk of total crop failure, and economic value for the farmers as product diversification and higher yields ensure both subsistence and disposable income (Kang 1993). But Diels et al. (2000) observed reduced yields of maize when grown in combination with leguminous trees, which might be caused by competition for growth factors. Hence, special knowledge on the selection of species and good crop management are needed.

Soil management

Conservation tillage includes different kinds of soil preparation methodologies. The practice where soil preparation is reduced and 15–25% of residues remain on the soil surface is called minimum tillage. Seeding a crop directly into soil that has not been tilled since the previous crop was harvested is described as no-till or zero-tillage (Morgan 1995). Research on quantifying the effects of conventional and conservation tillage on run-off and erosion were conducted by, for example, Armon (1980), Lal (1984) and Kirchhof and Salako (2000). The latter collected 2.8 t/ha sediment from plots with bare fallow, 1.8 t/ha from conventionally tilled plots and 1.3 t/ha from plots without tillage. This clearly shows the suitability of conservation tillage as an effective soil erosion control measure. In particular, Lal carried out many field experiments focusing on the influence of different tillage methodologies, performed manually or mechanically, on soil properties and crop yields. He stated that soil surface management is the key for solving problems associated with land-use intensification in the tropics (Lal 1982). Several studies showed that reduced and zero-tillage systems contribute to long-term maintenance of the soil structure, as pores and soil aggregates are disturbed less or not at all (Lal 1993b; Franzen et al. 1994).

It can be concluded that minimum tillage and no-till are effective SCTs as they reduce soil loss by water and also have many beneficial effects on soil properties. But tillage can also be necessary where soil compaction prevents rainwater from infiltrating the soil. Ridging, the practice of planting or seeding crops on the top of, along both sides of or between ridges is very common all over Nigeria (Lal 1990). Tied ridging or furrow diking, which includes the construction of additional cross-ties in the furrows, is primarily conducted in the semi-arid northern part of the country to conserve both soil and water (Chiroma et al. 2006). Mixing the topsoil with nutrients and moisture from the subsoil facilitates the growth of crops (Eziakor 1990) and improves aeration of the roots during wet periods. The accumulation of soil material supports the production of root and tuber crops by increasing the rooting zone (Kowal and Stockinger 1973). These examples show that ridge tillage has beneficial effects in areas with low and variable rainfall and compacted soils.

Mechanical measures

Mechanical measures can break the force of winds or decrease the velocity of run-off to reduce soil erosion. Contour bunds made of earth or stones or terraces are permanent erosion control technologies (Morgan 1995). Research on contour banks was done by Couper (1995), who also prepared an implementation guide for farmers, including the description of the design and construction of graded contour banks. Field trials on terraces made by Lal (1995) in Ibadan showed that the mean soil loss from a catchment without any erosion control measures was 2.3 t/ha and from a terraced catchment was 0.7 t/ha. Terraces were also built in Maku near Udi-Nsukka (Igbokwe 1996) and in the Pankshin area, Jos Plateau (Slaymaker and Blench 2002). The permanent structures are effective SCTs as soil loss is reduced. But the high labour intensity, time-consuming regular inspections, high consumption of scarce farmland and large amounts of construction material required are factors that stop farmers from installing or maintaining them (Igbokwe 1996).

Structural barriers made of stones or vegetation installed along contour lines are another mechanical erosion control measure (Morgan 1995). As they operate as filters, they may not reduce the run-off amount but retard its velocity. Hence, they encourage sedimentation, increase infiltration and facilitate the formation of natural terraces (Lal 1990). Malgwi (1992) investigated the effectiveness of vetiver (*Vetiver zizanioides*), a perennial grass with a deep and fibrous root system, in northern Nigeria. He recommends this grass as an appropriate STC for semi-arid zones because it withstands denudation, fire, drought and flood. Lal (1995) published a list of grass species commonly used for establishing vegetative hedges in the humid tropics, and states their ability to prevent rilling, gullying and tunnelling due to their thick root systems.

In general, mechanical measures are effective SCTs as they reduce soil loss. But, as the installation and maintenance are usually labour-intensive, these structures are not likely to be adopted by farmers.

Questionnaire

Personal and socioeconomic characteristics of all respondents

About half of the farmers interviewed were male (57.5%) and between the ages of 46 and 65 years (Table 1). Thirty per cent of the respondents had no formal education, while 35% had post-secondary education. The majority of the households (65%) included between 7 and 12 persons, and the average number of labourers additionally hired for fieldwork was up to 5 (60%). The interviews also revealed that most of the respondents (50%) had about 6–10 ha of land where they cultivated primarily food crops (57.5%). Many respondents were part-time farmers as they were additionally occupied in trading (40%). The average annual income of the farmers was generally low, 62.5% earning less than US$100.

Differences in personal and socioeconomic characteristics between adopters and non-adopters of SCTs

Most of the adopters of SCTs (72.2%) were male (Table 1). The results also show that most of the non-adopters (68.2%) were between 46 and 65 years old, whereas many farmers who had adopted SCTs were younger. Very few (16.7%) of the adopters had no formal education, compared to about 40.9% of the non-adopters. More of the farmers who practised soil conservation (50%) generally employed more labourers (6–10 persons) than non-adopters (22.2%), even if the farm sizes of both groups were comparable. It was obvious that all adopters often or very often contacted extension agencies, whereas non-adopters only seldom or infrequently contacted these organisations. The interviews revealed that 50% of the non-adopters were involved in trading, whereas only 27.8% of the adopters were additionally occupied in this activity. Another difference between adopters and non-adopters was their average annual income. There were fewer adopters (55.6%) than non-adopters (68.5%) who earned less than US$100 from farming per year, and hence more adopters of SCTs with increased revenues.

Awareness and adoption of SCTs by respondents

The farmers in the study area knew about the SCTs of mulching, intercropping, cover cropping, fallowing, agroforestry, contour tillage and cut-off drainage. Most of the respondents (82.5%) knew between one and three technologies for conserving the soil of their farmland (Table 2). The major sources of information were the ancestors, schools and RUDEP. Mulching, crop management and conservation tillage were regarded as indigenous farming practices. Agroforestry, mulching and contour tillage were not used any longer but were disseminated again as on-farm soil erosion control technologies through RUDEP. All respondents had heard about cut-off drainage through this extension agency.

Common SCTs in the study area were mulching, cover cropping, contour tillage and cut-off drainage. About 45% of the farmers interviewed had adopted

Table 1. Personal and socioeconomic characteristics of all respondents, and separated into adopters and non-adopters of soil conservation technologies

Subject	All respondents (*n* = 40)		Adopters (*n* = 18)		Non-adopters (*n* = 22)	
	Freq.	%	Freq.	%	Freq.	%
Gender						
Male	23	57.5	13	72.2	10	45.5
Female	17	42.5	5	27.8	12	54.5
Age (years)						
< 25	1	2.5	1	5.6	–	–
26–45	8	20.8	5	27.8	1	4.5
46–65	21	52.5	7	38.9	15	68.2
> 65	10	25.0	5	27.8	6	27.3
Level of education						
No formal education	12	30.0	3	16.7	9	40.9
Primary school	9	22.5	6	33.3	3	13.6
Secondary school	5	12.5	4	22.2	1	4.5
Post-secondary education	14	35.0	5	27.8	9	40.9
*Household size (*persons)						
< 6	8	20.0	4	22.2	4	18.2
7–12	26	65.0	10	55.6	16	72.7
13–18	6	15.0	4	22.2	2	9.1
No. of labourers hired for fieldwork (persons)						
< 5	24	60.0	9	50.0	15	68.2
6–10	14	35.0	9	50.0	5	22.7
> 10	2	5.0	–	–	2	9.1
Farm size (ha)						
< 2	14	35.0	7	38.9	7	31.8
2–6	4	10.0	1	5.6	3	13.6
6–10	20	50.0	9	50.0	11	50.0
> 10	2	5.0	1	5.6	1	4.5
Type of crop cultivated						
Food crops	23	57.5	10	55.6	13	59.1
Food + cash crops	17	42.5	8	44.4	9	40.9
Minor occupation						
None	18	45.0	9	50.0	9	40.9
Professional	1	2.5	–	–	1	4.5
Tailoring	3	7.5	2	11.1	1	4.5
Trading	16	40.0	5	27.8	11	50.0
Others	2	5.0	2	11.1	–	–
Membership in social organisations						
< 2	25	62.5	8	44.4	17	77.3
> 3	15	37.5	10	55.6	5	22.7
Contact with extension agents						
Never						
Seldom	17	42.50	6	33.3	11	50.0
Often	19	47.50	8	44.4	11	50.0
Very often	4	10.00	4	22.2	–	–
Average annual on-farm income (US$)						
< 100	25	62.5	10	55.6	15	68.2
101–250	7	17.5	3	16.7	4	18.2
251–500	5	12.5	4	22.2	1	4.5
> 501	3	7.5	1	5.6	2	9.1

Note: freq. = frequency; totals may not equal 100% due to rounding these technologies, but 55% had not adopted any of them (Table 2). One reason for this low adoption rate might be the severity of sheet erosion in the study area. Most of the farmers regarded it as low, which therefore did not require much effort to combat. Anyanwu (1996) also noted that the farmers generally considered sheet erosion less serious than rill and gully erosion as the damage was less obvious. Most of the farmers (51.4%) who had adopted one or more of the SCTs rejected it or them later. The majority of the remainder (37.8%) adopted only one measure, and a few two or three. The level of adoption, as expressed in the continuation of a new technology, was generally low. Most farmers (72.2%) had just started their first usage of SCTs, even though training on soil conservation had already begun in 2002. The interviews also revealed that SCTs were implemented on only small parts of the farmland. The results showed that implementation of soil conservation measures apparently needed testing for some years before they would be continued. The farmers might reduce any risk by testing SCTs on relatively small areas first.

Table 2. Awareness and adoption of soil conservation technologies (SCTs) by respondents ($n = 40$)

Subject	Freq.	%
No. of SCTs known		
0	3	7.5
1–3	33	82.5
≥ 4	4	10.0
Adoption		
No	22	55.0
Yes	18	45.0
Number of SCTs rejected or adopted		
SCT rejected	19	51.4
1 SCT adopted	14	37.8
2 SCT adopted	2	5.4
3 SCT adopted	2	5.4
Level of adoption		
First instalment	13	72.2
Instalment completed	2	11.1
Instalment abandoned	2	11.1
Instalment maintained	1	5.6
Average no. of years of continuous adoption		
≤ 5	12	66.7
6–10	1	5.5
≥ 11	5	27.8
Average field size covered by SCT (ha)		
0.2–0.8	9	56.3
0.8–1.2	4	25.0
1.2–2.0	3	18.7

Assessment of adopted SCTs by respondents

The respondents in the study sites characterised the most popular SCTs on the basis of labour demands, compatibility, costs, complexity and availability of equipment. Mulching and cover cropping were regarded as not labour-intensive, highly cost-effective, compatible with the existing farming system, and easy and cheap to adopt. A disadvantage might be the required amount of mulch. Farmers recognised the value of cover crops as they were sources of food for people and animals, and improved soil fertility through N_2-fixation and decomposition. But they also saw cover crops as competitors for soil nutrients. Tillage along the contour line was also accepted as it was easy and cheap to adopt and practise. Farmers also installed cut-off drainage on the fields to get rid of surplus water. This SCT is highly labour-intensive and costly as hired labourers have to maintain the channels regularly. Another issue that reduces the adoption of this erosion control measure is its incompatibility with the culture. Digging holes in the ground was associated with burying the dead and, it was thought, would lead gradually to the death of people in the community without a cause until the dug ground was closed.

These results are comparable to records made about the influence of factors on the adoption of technologies in other African locations. For instance, Muhr et al. (2001) stated that ease of establishment was important for local farmers in accepting new technologies, and that high labour demands were a drawback.

Correlation between personal and socioeconomic characteristics of the respondents and number of SCTs adopted

Education generally influenced the adoption of SCTs. The level of education, knowledge of appropriate technologies and farming experience were positively correlated with the number of SCTs adopted (Table 3). The higher level of education among adopters might have influenced their positive disposition towards soil conservation, as literate people are usually more experienced and aware of the significance of new technologies to livelihood than illiterate people (Bodnar and De Graaff 2003).

Table 3. Correlation (r) between selected personal and socioeconomic characteristics of the respondents and number of soil conservation technologies (SCTs) adopted

Socioeconomic characteristic	r
Age	–0.081
Level of education	0.133
No. of years experience in farming	0.078
No. of SCTs known	0.319*
No. of memberships in social organisations	0.396*
Total annual on-farm income	0.061
No. of labourers assisting on the farm	0.363*
Farm size	0.008

Note: * ANOVA significant at 0.05 level

Membership in several social organisations also positively influenced the adoption rate of SCTs, possibly because of the exchange of information. The positive correlation between the capital of a farmer and the number of SCTs adopted shows that wealth is another important factor. Farmers with an increased income can spend more money on new technologies and afford more hired labourers, who are required for installing and maintaining new measures in the field. Wealthy farmers are also known for being less timid about managing risks and for having a longer term planning horizon (Franzel 1999). The correlation between age and the number of SCTs adopted was negative, which means that older farmers apparently accept new technologies less frequently than younger ones. Obeta and Nwagbo (1991) also recorded a similar result and explained this phenomenon as a common behaviour of human beings, who are generally more adventurous when young. Another reason might be the high number of elderly people interviewed within this study. They were selected as they are representative farmers who dominated in the villages due to the prevailing rural to urban migration of the youth.

Differences between area of farmland covered by adopted SCTs, number of years of continuous adoption and willingness to manage risks associated with their adoption

The analysis showed that contour tillage was the SCT favoured by farmers in the study area, as it covered most of the farm land and had been used for the longest period (Table 4). As stated by the farmers, this technology was easy to understand and cheap to practise. Hence, SCTs characterised by low labour demand, availability of common equipment, low costs of application, ease of practice and compatibility with the existing farming system are likely to be adopted and maintained in the long term by farmers in south-west Nigeria.

Lessons learnt

The results of the survey should be used to improve future adoption of SCTs. Research on soil conservation generally ought to include more on-farm field trials for testing the technologies under local farmers' practices. An intensive cooperation between researchers and farmers will improve the development of innovations, as impracticability and incompatibility will be recognised at an early stage and changed if possible. Land users' awareness of soil degradation will also increase as the farmers' attention will be drawn to the problem early. As the farmers will already know the erosion control measures by assisting in on-farm trials, the period for testing the technologies on their own field will be reduced and the adoption rate increased.

The study revealed that the adoption process of SCTs was not gender neutral as most of the adopters were male. This might be caused by a lack of consideration of gender-equity issues in the design and introduction of SCTs to the farmers. Another probable reason is the general low land security for women due to the largely patrilineal inheritance system existing in many West African countries. It is therefore important to address inequity by introducing other technologies to women farmers that do not require secure long-term land rights. The adoption rate among younger farmers was generally higher than among older people. Hence, the process for introduction of improved technologies should always include a certain number of young farmers even if they generally have to let older inhabitants go first due to the traditional hierarchical structure in village life.

The interviews showed the importance of knowledge of soil conservation as a factor influencing the adoption rate of SCTs. Hence, greater emphasis is needed on exposing farmers to improved technologies by strengthening the training of farmers on innovations. Contact between farmers and extension agents, and memberships in an agricultural cooperative, are other major sources of information on innovations that need to be supported by frequent meetings of extensionists with farmers and through field visits. This requires sufficient funds to provide transportation to villages and equipment for the training sessions.

Table 4. Difference (*P*) between area of farmland covered by adopted SCTs and number of years of continuous adoption of SCTs

Subject	*P*
Farm area covered by mulching	0.97
Farm area covered by cover cropping	0.28
Farm area covered by contour tillage	0.05*
Farm area covered by cut-off drainage	0.86
Period of continuous adoption of mulching	–
Period of continuous adoption of cover cropping	0.13
Period of continuous adoption of contour tillage	0.01*
Period of continuous adoption of cut-off drainage	0.97

Note: * ANOVA significant at 0.05 level

Conclusions

The literature review and the interviews both showed that mulching, crop management and conservation tillage were appropriate technologies for conserving the soil in the savanna of Nigeria. The use of residues, multiple cropping and contour tillage are known to protect the soil from the impact of rain and the formation of run-off, which are especially high in the tropics. These technologies are generally adopted by farmers as they are compatible with the existing farming system and their implementation is characterised by ease and low costs. Education and training in soil conservation seem to increase the adoption rate of technologies, and this highlights the importance of agricultural extension agencies in the country.

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References

Anyanwu A.C. 1996. Attitudes of rural farmers towards soil erosion control in Anambra and Enugu states. Journal of Agriculture, Technology and Education 1(2), 11–15.

Armon M.N. 1980. Effect of tillage systems on soil and water conservation and soil physical properties. MSc thesis, University of Nigeria, Nsukka, Nigeria.

Bodnar F. and De Graaff J. 2003. Factors influencing adoption of soil and water conservation measures in Southern Mali. Land Degradation & Development 14, 515–525.

Carsky R.J., Singh B.B. and Oyewole B. 2001. Contribution of early season cowpea to late season maize in the savanna zone of West Africa. Biological Agriculture and Horticulture 18, 303–315.

Chikoye D., Manyong V.M., Carsky R.J., Ekeleme F., Gbehounou G. and Ahanchede A. 2002. Response of speargrass (*Imperata cylindrica*) to cover crops integrated with handweeding and chemical control in maize and cassava. Crop Protection 21, 145–156.

Chiroma A.M., Kundiri A.M. and Ibrahim A. 2006. Review of sustainable productivity of dryland farming systems through furrow diking. University of Maiduguri: Nigeria.

Couper D.C. 1995. Use of graded contour banks for soil conservation. IITA Research Guide 6. International Institute of Tropical Agriculture: Ibadan, Nigeria.

Diels J., Lyasse O., Sanginga N., Vanlauwe B., Aihou K., Houngnandan P., Aman S., Tossah B., Iwuafor E., Omueti J., Manyong V., Akakpo C., Falaki A.M., Deckers S. and Merckx R. 2000. Balanced nutrient management systems for maize-based systems in the moist savanna and humid forest zone of West Africa. Annual Report 2000 (Report No. 4), International Institute of Tropical Agriculture, Ibadan, Nigeria. K.U. Leuven: Belgium.

Ehui S. and Pender J. 2005. Resource degradation, low agricultural productivity and poverty in sub-Saharan Africa: pathways out of the spiral. Agricultural Economics 32(1), 225–242.

Eziakor I.G. 1990. Comparative analysis of the effectiveness of manual versus mechanized tillage among Third World smallholders: a case study in Bauchi State of Nigeria. Agriculture, Ecosystems & Environment 31(4), 301–312.

FAO AGL. 2005. Global assessment of the status of human-induced soil degradation (GLASOD). At: <http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp>.

Federal Republic of Nigeria 2007. Official gazette: legal notice on publication of the details of the breakdown of the national and state provisional totals 2006 census.

Government Notice Nr. 21. Nr. 24. Vol. 94. Lagos, Nigeria.

Federal Surveys of Nigeria. 1992. General soil erosion map of Nigeria 1:6,000,000. Map. Federal Surveys: Lagos.

Franzel S. 1999. Socioeconomic factors affecting the adoption potential of improved tree fallows in Africa. Agroforestry Systems 4, 305–321.

Franzen H., Lal R. and Ehlers W. 1994. Tillage and mulching effects on physical properties of a tropical Alfisol. Soil and Tillage Research 28, 329–346.

Hulugalle N.R., Lal R. and Opara-Nadi O.A. 1985. Effect of tillage system and mulch on soil properties and growth of yam (*Dioscorea rotundata*) and cocoyam (*Xanthosoma sagittifolium*) on an Ultisol. Journal of Root and Tuber Crops 1–2, 9–22.

Igbokwe E.M. 1996. A soil and water conservation system under threat: a visit to Maku, Nigeria. In. 'Sustaining the soil: indigenous soil and water conservation in Africa', ed. by C. Reij, I. Scoones and C. Toulmin. Earthscan Publication Ltd: London, UK.

Igbozurike U.M., Okali D.U.U. and Salau A.T. 1989. Profile on Nigeria: land degradation. Nigerian Environmental Study/Action Team Report submitted to Commonwealth Secretariat, London, UK.

Juo A.S.R. and Lal R. 1977. The effect of fallow and continuous cultivation on the chemical and physical properties of an Alfisol in western Nigeria. Plant and Soil 47, 567–584.

Kang B.T. 1993. Alley cropping: past achievement and future directions. Agroforestry Systems 23, 141–155.

Kang B.T., Reynolds L. and Atta-Krah A.N. 1990. Alley farming. Advances in Agronomy 43, 315–352.

Kirchhof A.C. and Salako F.K. 2000. Residual tillage and bush-fallow effects on soil properties and maize intercropped with legumes on a tropical Alfisol. Soil Use and Management 16, 183–188.

Kirchhof G. and Odunze A.C. 2003. Soil management practices in the northern Guinea savanna of Nigeria. Paper presented at 16th Triennial Conference of International Soil Tillage Research Organization (ISTRO), 'Soil Management for Sustainability', 14–18 July 2003, Brisbane, Australia.

Kowal J. and Stockinger K. 1973. Usefulness of ridge cultivation in Nigeria agriculture. Journal of Soil and Water Conservation 28(3), 136–137.

Lal R. 1978. No-till farming after various grass and leguminous cover crops in tropical Alfisols. I: Crop performance. Field Crops Research 1, 71–84.

Lal R. 1982. Effect of slope length and terracing on runoff and erosion on a tropical soil. International Association of Hydrological Sciences (IAHS) Publication 137, 23–31.

Lal R. 1984. Mechanized tillage systems effects on soil erosion from an Alfisol in watershed cropped to maize. Soil and Tillage Research 4, 349–360.

Lal R. 1989. Agroforestry systems and soil surface management of a tropical Alfisol. Agroforestry Systems 8, I: Soil moisture and crop yield, 7–29; II: Water runoff, soil erosion, and nutrient loss, 97–111; III: Changes in soil chemical properties, 113–132; IV: Effects on soil physical and mechanical properties, 197–215; V: Water infiltrability, transmissivity and soil water sorptivity, 217–238.

Lal R. 1990. Soil erosion in the tropics: principles and management. McGraw-Hill: New York, USA.

Lal R. 1993a. Soil erosion and conservation in West Africa. Pp. 7–28 in 'World soil erosion and conservation', ed. by D. Pimentel. Cambridge University Press: Cambridge, UK.

Lal R. 1993b. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil and Tillage Research 27, 1–8.

Lal R. 1995. Sustainable management of soil resources in the humid tropics. United Nations University Press: New York, USA.

Lal R. 2000. Mulching effects on soil physical quality of an Alfisol in western Nigeria. Land Degradation and Development 11, 383–392.

Malgwi G.S. 1992. Setting up contour guidelines on farmers field. Proceedings of Monthly Technology Review Meeting (MTRM) of Borno State Agricultural Development Programme (BOSADP), 6 June 2000, Maiduguri, Nigeria. BOSADP: Maiduguri, Nigeria.

Mbagwu J.S.C. 1991. Mulching an Ultisol in southern Nigeria: effects on physical properties and maize and cowpea yields. Journal of the Science of Food and Agriculture 57, 517–526.

Morgan R.P.C. 1995. Soil erosion and soil conservation. Longman: Essex, UK.

Muhr L., Tarawali S.A., Peters M. and Schulze-Kraft R. 2001. Acceptability of forage legumes for improved fallows: first experiences of agro-pastoralists in sub-humid southwest Nigeria. Experimental Agriculture 37, 495–507.

Obeta M.E. and Nwagbo E.C. 1991. The adoption of agricultural innovations in Nigeria: a case study from an improved IITA cassava technology package in Anambra State. Pp. 231–245 in 'Appropriate agricultural technologies for resource-poor farmers', ed. by J.O. Olukosi., A.O Agungbile and B.A. Kalu. National Farming Systems Research Network.

Odunze A.C., Iwuafor E.N.O. and Chude V.O. 2002. Maize/herbaceous legume inter-crops and soil properties in the northern Guinea savanna zone, Nigeria. Journal of Sustainable Agriculture 20(1), 15–24.

Olukosi J.O., Elemo K.A., Kumar V. and Ogungbile A.O. 1991. Farming systems research and the development of improved crop mixtures technologies in the Nigerian savanna. Agricultural Systems in Africa 1(1), 17–24.

Onu D.O. 1990. Factors associated with small scale farmers' adoption of improved soil conservation technologies under intensified agriculture in Imo state, Nigeria. PhD thesis, Department of Agricultural Extension, University of Nigeria, Nsukka, Nigeria.

Orimoyegun S.A. 1988. Influence of forest litter and crop residue on soil erosion. Pp. 380-391 in 'Proceedings of National Workshop on Ecological Disasters in Nigeria: Soil Erosion', 8–12 September 1986, Owerri, Nigeria. Federal Ministry of Science and Technology: Lagos, Nigeria.

Salako F.K, Babalola O., Hauser S. and Kang B.T. 1999. Soil macroaggregate stability under different fallow management systems and cropping intensities in southwestern Nigeria. Geoderma 91, 103–123.

Slaymaker T. and Blench R. 2002. Volume I: Country overview. In 'Rethinking natural resource degradation in Sub-Saharan Africa: policies to support sustainable soil fertility management, soil and water conservation among resource-poor farmers in semi-arid areas', ed. by R.M. Blench and T. Slaymaker. Cyber Systems: Tamale, Ghana.

Sonneveld B.G.J.S. 1997. Compilation of a soil map for Nigeria: a nation-wide soil resource and land form inventory. Nigerian Journal of Soil Research 6, 71–84.

Tarawali G., Manyong V.M., Carsky R.J., Vissoh V., Osei-Bonsu P. and Galiba M. 1999. Adoption of improved fallows in West Africa: lessons from *Mucuna* and *Stylosanthes* case studies. Agroforestry Systems 47, 93–122.

Tian G., Kolawole G.O., Salako F.K. and Kang B.T. 1999. An improved cover crop-fallow system for sustainable management of low activity clay soils of the tropics. Soil Science 164(9), 671–682.

Van der Kruijs A.C.B.M. and Kang B.T. 1988. Intercropping maize and cassava with leguminous shrubs on Ultisol. IITA Resource and Crop Management Program; annual report for 1986. International Institute of Tropical Agriculture: Ibadan, Nigeria.

Vanlauwe B., Aihou K., Aman S., Tossah B.K., Diels J., Sanginga N. and Merckx R. 2001. Leaf quality of selected hedgerow species at two canopy ages in the derived savanna zone of West Africa. Agroforestry Systems 53(1), 21–30.

Changing tillage management practices and their impact on soil structural properties in north-western New South Wales, Australia

Gunnar Kirchhof[1] and Ian Daniells[2]

Abstract

A study was conducted in 1998 in north-western New South Wales to assess how changes in tillage practices and farmers' perceptions of 'good' or bad' paddocks relate to soil structural properties. Forty landholders were visited and interviewed to obtain background information on their current and past management practices, crops and cropping systems used, and what they expect in the future. The majority of the soils were Vertosols (78%), with some Kandosols and a few Chromosols.

Conventional tillage was practised on 63% of the fields surveyed. Conservation tillage (minimum or zero-tillage) was only practised on swelling clay soils. On these soils 26% of the fields had been converted from conventional to conservation tillage during the past 3 years, while on 14% of the fields conservation tillage had been practised since they were brought into crop production (3–10 years previously).

Saturated hydraulic conductivities on the farmed black Vertosols with a history of conventional tillage were lower than those of the virgin sites, but increased after conversion from conventional to conservation tillage. Fields that were brought into cropping during the last 10 years using conservation tillage only had higher saturated conductivities than the virgin sites. There was little effect of cropping history on saturated hydraulic conductivity on the grey Vertosols. Soil organic carbon on the control sites was always greater than on the corresponding cultivated sites, regardless of whether conventional or conservation tillage was practised. Tillage history did not affect any of the measured soil chemical properties. Platyness of soil structure was a clear indicator for wheel-induced compaction. Platy structure was not shown on any of the swelling clay soils at the never-cultivated sites, and tended to be more frequent on the 'poor' sites. This was most pronounced for the grey Vertosols, where 80% of the 'poor' and 50% of the 'good' sites were platy, and on the black Vertosols, with 42% and 31% respectively. The overall close agreement between platyness and the farmers' perceptions of 'good' and 'poor' sites indicated that platyness has an impact on soil productivity and that soil compaction continues to be a limiting factor for crop production. We also concluded that black Vertosols respond better to conservation tillage than grey Vertosols, possibly due to their greater resilience and better ability to self-ameliorate. The absence of conservation tillage adoption on non-swelling clay soils in this region (at the time of the study) may reflect the length of time required before conservation tillage improves soil structure and, ultimately, yield.

[1] School of Land Crop and Food Sciences, The University of Queensland, Brisbane Queensland 4072, Australia <g.kirchhof1@uq.edu.au>

[2] NSW Department of Primary Industries, Tamworth Agricultural Institute, 4 Marsden Park Road, Calala New South Wales 2340, Australia

Introduction

Decline in soil health has been of growing concern in the dryland farming regions of northern New South Wales (NSW), Australia, for quite some time. Deterioration of soil structure is brought about by excessive and inappropriate tillage, a decline in organic matter content, sodicity, erosion and compaction induced by wheel traffic. This results in low water-use efficiency, which is likely to limit crop yields. Off-site effects such as increased salinisation, run-off and sediment deposition are likely to impact upon the environment. The detrimental impacts of degraded soil structure such as crusting, sealing and compaction are well recognised for irrigated cropping, largely for cotton. Under dryland conditions, however, knowledge of the effect and persistence of physically degraded soil layers on crop yield is still limited. There was a need to investigate the state of soil structural degradation, its causes and potential effect on soil productivity, and to evaluate easily measurable parameters to assess soil structure. Through a survey of farmers' fields, this study aimed to collect baseline data to evaluate changes in soil structure due to changed tillage methods.

Materials and methods

A study was conducted on 40 dryland farms in northern NSW in 1998. Selection of the farms was based on a management survey of 50 farms conducted from 1983 to 1985 (Martin et al. 1988). Their selection was a stratified random procedure.

Questions asked related to crops grown, fertiliser usage, tillage methods and crop production limitations. Tillage methods were separated into four broad categories:

- conventional (the use of disced or tined implements for most soil preparation and weed control)
- zero-till (soil preparation without any soil disturbance except for the planting operation and weed control based on herbicides only)
- minimum tillage (minimum conventional tillage and weed control largely herbicide based)
- controlled traffic (minimum or zero tillage on permanent wheel tracks).

It is important to note that this survey evaluated farmers' tillage operations, and hence a clear categorisation was not always possible. In such cases we decided on the category that described the tillage method 'best'. Farmers were also asked what they do at present, what they did in the past (more than 3 years ago) and what they expect to do in the future (in more than 3 years).

Each landholder was asked to point out two cropped paddocks and an area that had never been cropped (pasture or virgin), all on the same soil type. The two cropped paddocks were what the farmer perceived as a 'good' and a 'poor' paddock. On each site the morphology of the soil profile to 30 cm depth was described following McDonald et al. (1984). The farmer's records or recollections were used to categorise the fields according to past (more than 3 years ago) and current (the last 3 years) tillage methods.

At each location disc permeameters were used to determine near-saturated hydraulic conductivity at intake potentials of –1.5, –2.5 and –3.5 cm (Reynolds and Elrick 1991). To speed up the time to reach a constant flow rate and to minimise soil deformation due to confined swelling for subsequent laboratory measurements, the soil was pre-wetted if it was too dry and cracked. Undisturbed soil cores, 10 cm in diameter and 7 cm in height, were collected 50 cm from the disc permeameters at depths of 3–10 cm and 15–22 cm. Disturbed samples were also collected from the same depths.

Total soil organic carbon and labile soil organic carbon were determined on the disturbed samples following the procedures of Heanes (1984) and Blair et al. (1995) respectively. Soil pH was determined in a 1:5 soil:0.01M $CaCl_2$-solution (Rayment and Higginson 1992a) and electrical conductivity in a 1:5 soil:water suspension (Rayment and Higginson 1992b). Exchangeable cations were determined following the procedure by Gillman and Sumpter (1986). Water content at –1.5 MPa was determined using a pressure plate apparatus.

Saturated hydraulic conductivity was used as an indicator for soil permeability, and size and continuity of macropores. The soil water release curve was used to determine macroporosity and plant available water. For these measurements the undisturbed cores were slowly wetted to saturation water content over a period of at least 4 weeks. Saturated hydraulic conductivity was determined using the falling head method. Cores were then equilibrated on a tension table and equilibrium water content recorded at –1, –5, –20 and –100 cm suction. Time required for the soil water content to equilibrate was at least 4 weeks for each suction. If observed, shrinkage was recorded at each suction through height change of the soil in the core and lateral shrinkage away from the core wall. Plant available water was calculated as the difference in water content between –100 cm (field capacity) and –1.5 MPa (permanent wilting point), and converted to a volume basis using bulk density at field capacity.

Soil structural quality indicators obtained from the in-situ and laboratory measurements were related to current and past tillage methods to assess changes in soil structure due to tillage history in farmers' fields.

Results and discussion

The survey area

Sampling locations covered farms west of Glen Innes, south of Mungindi, east of Walgett and north of Coonabarabran (Figure 1).

The soil types observed on the farms were black Vertosols (31% of fields surveyed), brown Vertosols (14%), Chromosols (7%), Kandosols (15%) and grey Vertosols (31%). Using USDA taxonomy (Soil Survey Staff 1994), the Chromosols in this study tend to fall under Alfisols, and the Kandosols under Alfisols and Ultisols. They were combined into the category non-swelling clay soils. The grey and brown Vertosols were similar to chromic Vertisols and the black Vertosols similar to pellic Vertisols. The black Vertosols tended to be located on the eastern (wetter) part, and the grey Vertosols on the western (drier) part, of the surveyed area. The brown Vertosols, Chromosols and Kandosols were scattered throughout the survey area.

Tillage history

Most of the non-swelling clay soils in this area supported dry sclerophyll woodlands as their native vegetation. When agriculture expanded into this region more than 100 years ago, these soils on undulating slopes were the first to be used for crop production. The more clayey soils of the plains were not cropped and were mainly used for grazing. This was largely due to the European origin of the farmers, who had little knowledge of how to crop the heavy swelling clays, and the lack of sufficiently powerful machines to cultivate them. In a climate of erratic but occasionally very heavy rainfall, coupled with intrinsic low soil structural stability, erosion has led to massive topsoil loss. Today, wheat yields on these soils are often as low 2 t/ha but they are still cropped. Despite the exposure of the subsoil and poor soil structural conditions on these soils, they had not (in 1998) been converted to conservation farming practices (Table 1). This is probably due to the strong degree of degradation, where prolonged periods of conservation tillage may be needed before financial benefits from conservation farming are evident. Felton et al. (1995) reported that it took

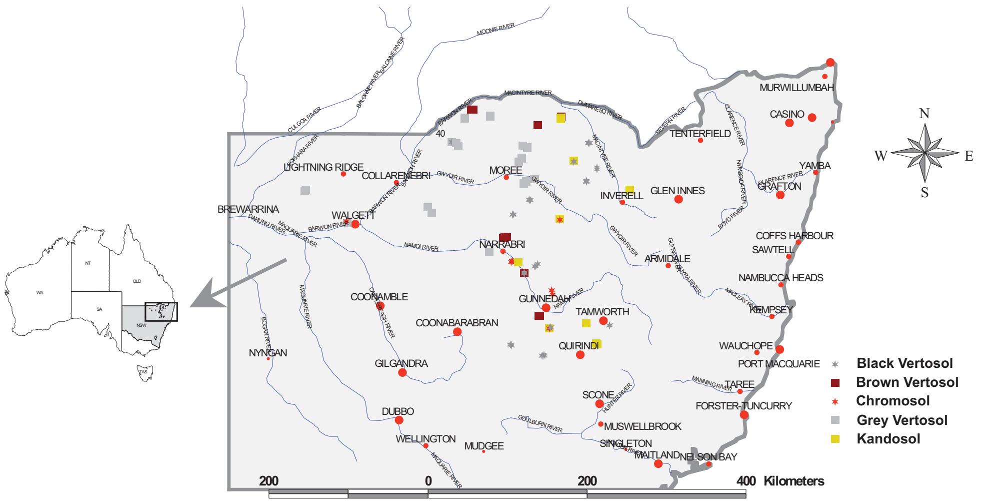

Figure 1. Map of the survey area and soil types

5 years of zero-tillage before yields on a non-swelling clay outyielded conventional tillage.

The virgin vegetation of the black Vertosols in northern NSW was mainly grassland with some scattered trees and pockets of open woodlands. Information on the virgin vegetation on the grey and brown Vertosols is scarce. This is due to the low occurrence of remnant virgin vegetation and is compounded by the land use of the Indigenous peoples pre-dating European settlement. Based on remnant vegetation, it is often stated that these soils carried mainly shrubs and open woodlands (Cunningham et al. 1992; Howling 1997). However, considerable anecdotal evidence exists from early explorers' diaries and early surveys that these remnant patches are a consequence of reduced burning after European settlement, and that the *original* virgin vegetation on these soils was reduced to grasslands (Beadle 1948) millennia ago through the ancient practice of burning by the Aboriginal people of this area.

The advent of powerful agricultural machinery enabled tillage on these swelling clays. Cropping began on the black Vertosols around 4–5 decades ago and on the grey and brown Vertosols less than 40 years ago. Conventional tillage was still practised (Table 1) on most fields, but conservation tillage had been adopted on about one-quarter of the sites surveyed. Conservation tillage was always practised on the fields that were brought into cropping less than a decade ago.

Crop types and fertiliser use

More than two-thirds of the farms visited had cereal as the major crop, followed by grain legumes (Table 2). Farmers' expectations for future crops were less cereal and more legumes. This may be related to an expected decrease in nitrogen (N)-fertiliser use in the future—44% of farmers responded that they currently use N-fertiliser but only 21% expected to use it in the future. It is important to note that N-fertiliser is used by farmers mainly in the eastern part of the survey area, while some farms in the western areas have been producing wheat for well over a decade without applying any fertiliser.

Compared to past oilseed planting and expected future oilseed planting, very few paddocks were planted to oilseed crops (Table 2). This trend is probably a reflection of market-driven demand as well as an indication of farmers' attitudes towards crop diversification.

Table 2. Farmers' responses to change in crop type[a]

Crop	Past (%)	Present (%)	Future (%)
Cereal	57	73	33
Fibre	1	6	7
Legume	19	12	36
Oilseed	16	4	15
Other	–	–	3
Pasture	6	5	7
Total	99	100	101

[a] Totals may not equal 100% due to rounding

Farmers' perceptions of paddock quality

Farmers' classification of 'good' and 'poor' paddocks showed that wheat tended to be grown on the good sites, and barley on the poor sites, on all soils except the few sites on Chromosols and grey Vertosols (Table 3). This observation was probably a reflection of soil N-content and crop value. Wheat is a higher value crop compared to barley, in particular if soil N-content is relatively high. If barley is

Table 1. Change in tillage method on the major soil types in northern New South Wales, Australia

Type of cultivation		Soil type (%)[a]			
Current (1998) (the last 3 years)	Past (more than 3 years previously)	Non-swelling	Black Vertosols	Grey and brown Vertosols	Total
Conservation	Conservation	0	10	18	12
	Conventional	0	24	28	23
Conventional	Conservation	0	0	4	2
	Conventional	100	67	51	63
Total		100	101	101	100

[a] Totals may not equal 100% due to rounding

grown for malting, high soil N-values may reduce grain quality; hence, barley tends to be grown on the lower N, or less fertile, paddocks.

The age of paddocks ranged from just entered into cropping to over 50 years of cropping. Good paddocks tended to be farmed for a shorter period of time than poor paddocks. None of the poor paddocks had been cropped for less than 10 years. This indicates a decline in productivity with paddock age, as reported and well published by other studies. It could, however, also indicate that farmers perceive 'younger' paddocks to be 'better' than older paddocks.

Soil organic carbon on the control sites was always greater than on the corresponding cultivated sites, regardless of whether conventional or conservation tillage was practised and irrespective of paddock age. Cation exchange capacities and exchangeable sodium percentages were largely unaffected by cropping and tillage practices on the different soil types assessed in this study.

Platy soil structure is an indication of soil compaction. It may be induced by wheel traffic or under natural conditions due to tree roots or grazing animals. The never-cultivated sites did not show platy structure except on 13% of the Kandosols and 8% of the grey Vertosols.

Except on the brown Vertosols, platy structure tended to be more frequent on the poor sites (Figure 2). On swelling soils this was most pronounced for the grey Vertosols compared to the Black Earths, which suggested that the grey Vertosols might be more prone to compaction than the black Vertosols. This is likely to be due to their lower clay content and hence greater ability to pack to high bulk densities, and their lower shrink–swell characteristics and hence lower ability to self-ameliorate upon wetting and drying. The general close agreement between platyness and the farmers' perceptions of good and poor sites indicated that platyness has an impact on soil productivity and that soil compaction continued to be a limiting factor for crop production.

Despite the reasonably close agreement with the pedological identification of platyness and the farmers' perceptions of productivity, soil physical measurements such as bulk density, hydraulic conductivity, soil water release curve and plant available water did not always relate well to the visual observation of compaction. For example, bulk density appeared to be an indicator of soil compaction on black Vertosols and Chromosols but could be misleading on Kandosols (Figure 3). This trend was similar for saturated hydraulic conductivity.

However, on all soil types a platy structure tended to have a lower organic carbon content compared to an uncompacted soil structure (Figure 4). This may be attributed to a higher compactability of soils with low organic matter content. It also suggests, however, that farmers' perceptions of low productivity of poor paddocks is due to a lack of N rather than soil physical restrictions.

Occurrence of hardsetting was observed on 14% of the never-cultivated sites and on 4% of the cropped sites, suggesting that hardsetting soils tend not to be cropped.

Table 3. Current (during the survey) type of crop on the different soils on 'good' and 'poor' paddocks

Soil type	Location	Current crop (1998) (%)									
		Barley	Chick-pea	Corn	Cotton	Fallow	Pasture	Sorghum	Sun-flower	Wheat	Total[a]
Black Vertosol	good		7		7	14	7	29	7	29	100
	poor	8	15	8	8		31	8		23	101
Brown Vertosol	good		14			43	14	14		14	99
	poor	20				20	20	20		20	100
Chromosol	good						50			5	100
	poor					25				75	100
Kandosol	good						25			75	100
	poor	40					20	20		20	100
Grey Vertosol	good		17		8	8	17			50	100
	poor	26				9	17		13	35	100

[a] Totals may not equal 100% due to rounding

Site observation and morphological indicators

One of the most important reasons for the adoption of conservation tillage methods is to arrest or control soil erosion. Minor sheet erosion was observed on 67% of the cropped grey and brown Vertosols and 45% of the cropped black Vertosols, with little effect of type of cultivation. The difference between the two soil types may be associated with higher sodium content and hence weaker structure of the grey and brown Vertosols, as

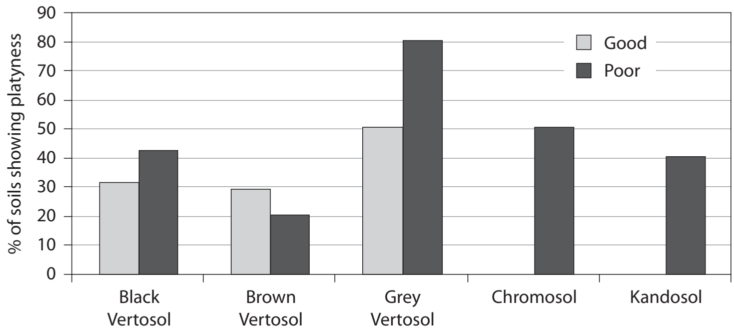

Figure 2. Percentage of soils showing platyness on different soil types and on 'good' or 'poor' paddocks

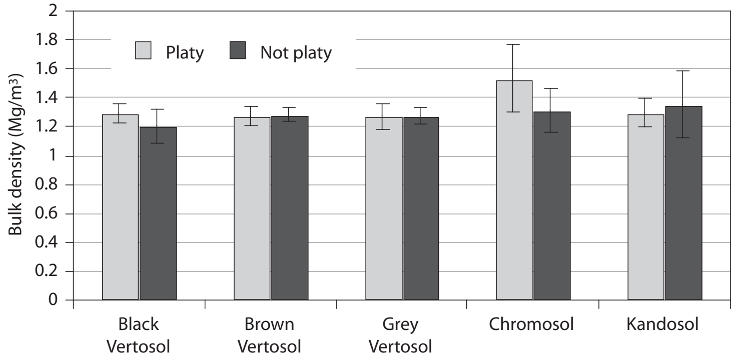

Figure 3. Soil compaction and average topsoils bulk density (Mg/m^3). Note: Bulk density on swelling soils corrected to 0.38 g/g water content.

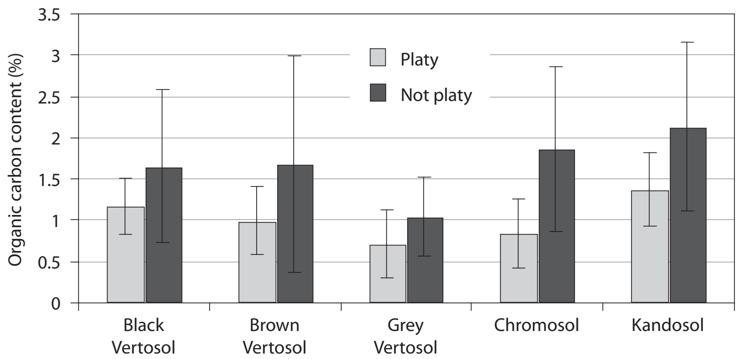

Figure 4. Soil compaction and average topsoil organic carbon content (%)

reported by McIntyre (1979) and Cook and Muller (1997). Moderate sheet erosion was only observed on fields that remained under conventional cultivation. Although rates of soil loss were not quantified, observations clearly showed that conservation tillage reduced erosion in farmers' fields.

Soil crusting and sealing is a major limiting factor for soil water recharge, particularly in areas where rainfall is erratic and unpredictable. Of the conventionally tilled grey and brown Vertosols, 28% showed surface crusts. No surface crusts were observed on fields where conservation tillage had been used since fields were brought into cropping. None of the black Vertosols had surface crusts, probably due to their stronger soil structure.

Soil physical indicators

Saturated hydraulic conductivity on the virgin black Vertosols was similar to that of the virgin pasture sites (Figure 5). Converting natural grassland to pasture does not require excessive land clearing. In view of the resilient nature of these soils, surface soil compaction due to livestock had little impact on the change in soil permeability. However, conventional tillage substantially reduced soil permeability. Changing to conservation tillage increased permeability, and prolonged use of conservation tillage increased permeability over and above that of the virgin vegetation. Saturated hydraulic conductivity is often considered a high-quality indicator of soil structure (Blackwell et al. 1991) because it relates

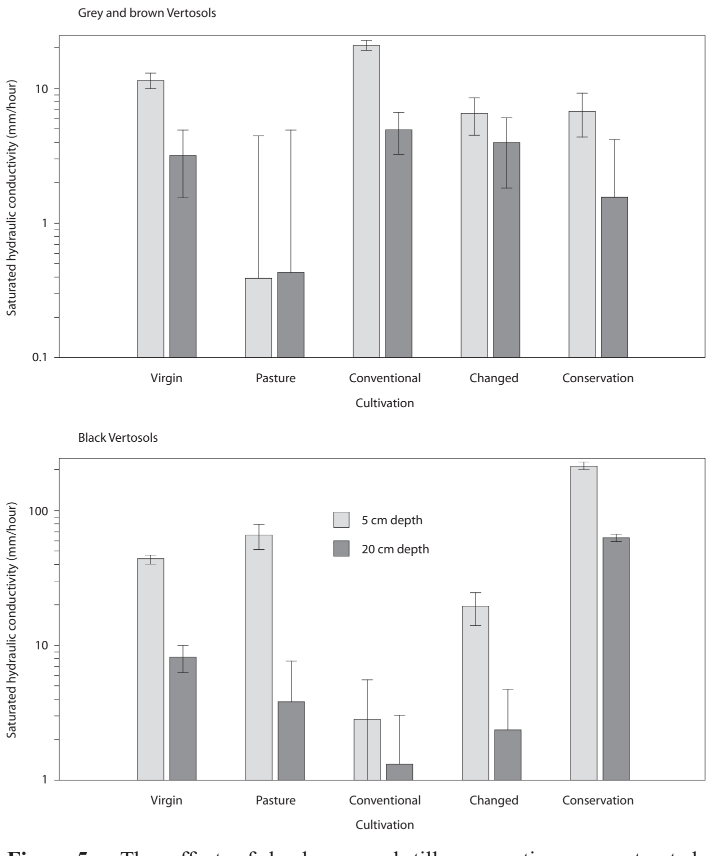

Figure 5. The effect of land use and tillage practices on saturated hydraulic conductivity of swelling clay soil. Note: conventional = always conventional tillage; changed = conservation tillage adopted 3 years ago; conservation = conservation tillage used since fields were cropped 3–10 years ago

well to the presence and continuity of structural macropores. Conservation tillage has thus improved soil structure over and above that of black Vertosols under virgin conditions.

In contrast to the strong effect of tillage history on the soil permeability of black Vertosols, there was little effect on the grey and brown Vertosols. However, it is interesting to note that the change from virgin vegetation to pasture tended to reduce soil permeability strongly, particularly in the top 10 cm of soil depth. This is probably a reflection of compaction induced by livestock.

Unsaturated hydraulic conductivities followed the same trend as saturated conductivities on the swelling clays, but differences due to changing tillage practices were less pronounced. The bulk density at field capacity was not related to changing tillage method, but did confirm that grey and brown Vertosols were much denser under pasture then under native vegetation. Macroporosity, expressed as air-filled pores at field capacity, and plant available water were not related to land use. The lack of tillage effect on plant available water extends the results from da Silva and Kay (1997) to heavier clay soils. They reported that tillage did not influence the soil water release curve of light-textured soils. However, soil organic matter can increase plant available water on lighter soils (Kay et al. 1997). We did not observe such a relationship on these heavy clay soils.

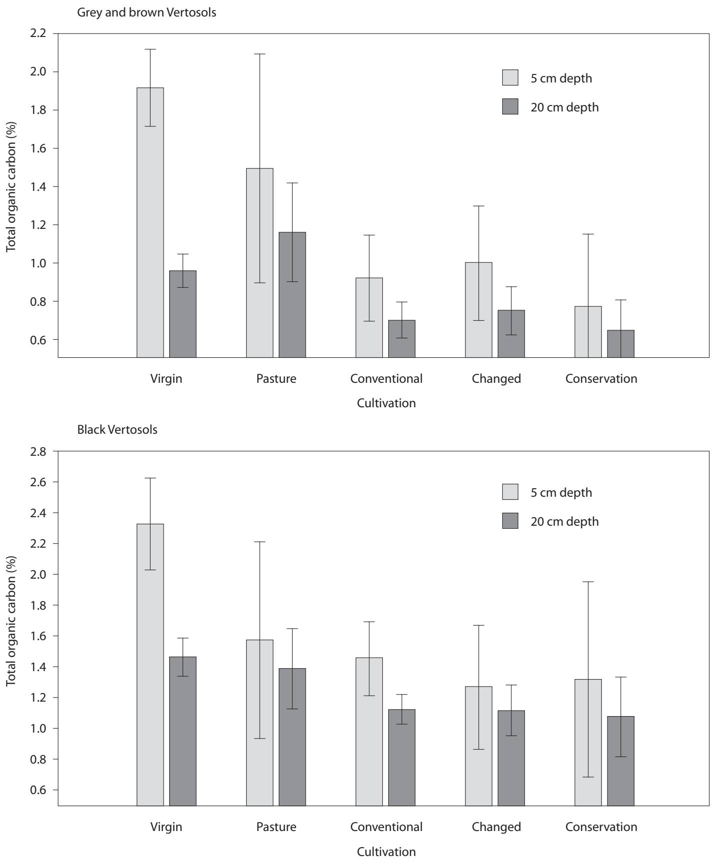

Figure 6. The effect of land use and tillage practices on total organic carbon of swelling clay soil. Note: Conventional = always conventional tillage; changed = conservation tillage adopted 3 years ago; conservation = conservation tillage used since fields were cropped 3–10 years ago

Soil chemical indicators

Soil organic carbon on the control sites was always greater than on the corresponding cultivated sites, regardless of whether conventional or conservation tillage was practised (Figure 6). Total organic carbon, labile organic carbon or derived indices to quality organic matter were not related to tillage history. For this dataset the lack of evidence that conservation tillage improves quality of organic carbon may be caused by the close relationship between labile and total organic carbon ($r^2 = 0.94$, $n = 227$) and the difficulty in obtaining a suitable reference site. Although the size of this dataset was limited, it highlights the difficulty in promoting a change from conventional to conservation tillage to increase soil organic matter levels. Other soil chemical measures (cation exchange capacity, exchangeable sodium percentage, pH and electrical conductivity) were not related to land use, tillage method or change thereof. The lack of any chemical response to the change in tillage method is probably associated with the high clay content of these soils.

Although there is no doubt that soil organic matter plays an important role for many soil properties and processes (i.e. ionic exchange properties, pH buffering, nutrient availability, energy source for microbes), its relative importance may become less as clay content increases. The same may apply to soil structure, in which case the most important role for soil organic matter may be as a supplier of soil N. The issue of soil organic matter in a soil health context on heavy clay soils remains unresolved. Although similar data from controlled field experiments have shown links between soil organic matter and soil structure on Vertosols (Blair and Crocker 2000), the wide range of farmers' practices probably masks these effects in this survey.

Conclusion

Soil compaction continued to be a problem in northern NSW, but it was related to a measurable deterioration of soil physical condition only on black Vertosols. Platy structured soils had reduced organic carbon contents. Saturated hydraulic conductivity was found to be a responsive indicator of change in tillage methods. Of the soil types surveyed in this study, we concluded that black Vertosols are most responsive to the adoption of conservation tillage because they are more resilient to soil structural decline due to their strong shrink–swell properties. The results of this study also question whether cultivated soils under cropping necessarily always have inferior structure, despite having lower soil organic matter, compared to never-cultivated soils of this region.

An attempt to promote carbon credits by governments as an incentive to farmers to adopt conservation tillage is faced with the problem that changing tillage methods might not lead to a well-defined change in soil organic matter. There is a need to extend this pilot study due to the problem of extensive variability in what causes the changes in soil organic carbon in an open system (i.e. the farmer's field). At present, it seems more appropriate to promote conservation tillage for what it really does for the farmer in the short run—reduce erosion, improve soil structure and make better use of available rain.

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References

Beadle N.C.W. 1948. The vegetation and pastures of western New South Wales. Department of Conservation of New South Wales. Government Printer: Sydney.

Blackwell P.S., Jayawardane N.S., Green T.W., Wood J.T., Blackwell J. and Beatty H.J. 1991. Subsoil macroporespace of a transitional red-brown earth after either deep tillage, gypsum or both. I: Physical changes and short-term effects. Australian Journal of Soil Research 29, 123–140.

Blair G.J., Lefroy R.D.B and Lisle, L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Australian Journal of Agricultural Research 46, 1459–1466.

Blair N. and Crocker G.J. 2000. Crop rotation effects on soil organic carbon and physical fertility of two Australian soils. Australian Journal of Soil Research 38, 71–84.

Cook G.D. and Muller W.J. 1997. Is exchangeable sodium content a better index of soil sodicity than exchangeable sodium percentage? A reassessment of published data. Soil Science 162(2), 343–349.

Cunningham G.M., Mulham W.E., Milthorpe P.L. and Leigh J.H. 1992. Plants of western New South Wales. Inkata Press: Sydney, Melbourne, Oxford, Stoneham.

da Silva A.P. and Kay B.D. 1997. Estimating the least limiting water range of soils from properties and management. Soil Science Society of America Journal 61, 877–883.

Felton W.L., Marcellos H. and Martin R.J. 1995. A comparison of three fallow management strategies for the long-term productivity of wheat in northern New South Wales. Australian Journal of Experimental Agriculture 35, 915–920.

Gillman G.P. and Sumpter E.A. 1986. Modification to the compulsive exchange method for measuring exchange characteristics of soil. Australian Journal of Soil Research 24, 61–66.

Heanes D.L. 1984. Determination of total organic-C in soils by an improved chromic acid digestion and spectrophotometric procedure. Communications in Soil Science and Plant Analysis 15, 1191–1213.

Howling G.M. 1997. Remnant vegetation in the central west catchment: issues and options for the future. Central West Catchment Management Committee: Orange, New South Wales, Australia.

Kay B.D., da Silva A.P. and Baldock J.A. 1997. Sensitivity of soil structure to changes in organic carbon content: predictions using pedotransfer functions. Canadian Journal of Soil Science 77(4), 655–667.

Martin R.J., McMillan M.G. and Cook J.B. 1988. Survey of farm management practices of the northern wheat belt of New South Wales. Australian Journal of Experimental Agriculture 28, 499–509.

McDonald R.C., Isbell R.F., Speight J.G., Walker J. and Hopkins M.S. 1984. Australian soil and land survey: field handbook. Inkata Press: Melbourne.

McIntyre D.S. 1979. Exchangeable sodium, subplasticity and hydraulic conductivity of some Australian soils. Australian Journal of Soil Research 17, 115–120.

Rayment G.E. and Higginson F.R. 1992a. Soil pH, 4B1. P. 19 in 'Australian laboratory handbook of soil and water chemical methods'. Inkata Press: Melbourne.

Rayment G.E. and Higginson F.R. 1992b. Electrical conductivity. Pp. 15–16 in 'Australian laboratory handbook of soil and water chemical methods'. Inkata Press: Melbourne.

Reynolds W.D. and Elrick D.E. 1991. Determination of hydraulic conductivity using a tension infiltrometer. Soil Science Society of America Journal 55, 633–639.

Soil Survey Staff 1994. Keys to soil taxonomy. United States Department of Agriculture, Agricultural Handbook No. 436. Government Printer: Washington DC, USA.

Survey methodology to assess socioeconomic and biophysical constraints—lessons learnt in the highlands of Papua New Guinea

Gunnar Kirchhof[1], Issac T. Taraken[2], Rainer Ratsch[3], Debbie Kapal[2] and Passinghan Igua[4]

Abstract

Among developing countries, Papua New Guinea (PNG) has one of the highest population growth rates. As land under cultivation has been stable for decades, the increasing demand for food is placing unprecedented pressure on the land resource under agriculture. An exploratory farmer survey in the highlands of PNG was conducted to assess farming practices in relation to soil productivity decline over time as population increases. The survey comprised farmer interviews as well as the collection of a biophysical dataset, including soil and plant analyses, to underpin farmer perceptions of a potential problem regarding soil fertility. Unlike most farmer surveys, this survey combines socioeconomic data with biophysical measurements. This type of exploratory survey was considered to be necessary to delineate the need for further research intervention. The baseline dataset is also useful to measure post-project impact and adoption, which is often inferred from auxiliary data if baseline data are missing. A main deficiency of the exploratory survey was bias in sample location caused by village access problems and safety concerns. The willingness of farmers, male or female, to participate in the interviews, and sample collection for the biophysical assessment of their gardens, were not problems.

Introduction

Farmer surveys are commonly used in developing countries to obtain a generalised view of their socio-economic environment. They aim to understand the current situation in order to increase the value of aid intervention through research, financial or in-kind assistance. The most common practice is to ask the farmers a series of questions to gauge their opinion about issues such as income constraints, production impediments and social problems. In the end a survey can ask an endless array of questions to any problem, but the results invariably depend on the information farmers provide. There is no fixed or standard methodology on how to design such surveys, and they can vary from informal and exploratory to formal and standardised. Rapid rural appraisal (RRA) is a methodology used since the early 1980s and refined by the Farming Systems Research and Extension Section of the Food and Agriculture Organization of the United Nations. It is often used and promoted by the Consultative Group

[1] School of Land Crop and Food Sciences, The University of Queensland, Brisbane Queensland 4072, Australia <g.kirchhof1@uq.edu.au>
[2] National Agricultural Research Institute, Highlands Program, PO Box 210, Ukarumpa, SIL, Aiyura, Eastern Highlands Province, Papua New Guinea
[3] National Agricultural Research Institute, High Altitude Highlands Program, PO Box 120, Mt Hagen, Western Highlands Province, Papua New Guinea
[4] The University of Goroka, Faculty of Science – Agricultural Education Section, Goroka, PO Box 1078, Eastern Highlands Province, Papua New Guinea

on International Agricultural Research (CGIAR) centres. The RRAs are a bridge between formal, often expensive, surveys and unstructured informal survey methods. They are particularly useful in areas with poor infrastructure or facilities and most commonly used for marketing research. Even though they use a multidisciplinary survey approach, there are often few or no links to any measured biophysical conditions under which farmers operate (Goma and Rahim 2001; Dordelly and Wambeke 2005; Omekwu 2005; Stocking 2005; Chikoye and Ellis-Jones 2006; Iqbal and Ireland 2006).

The most comprehensive survey of agriculture in Papua New Guinea (PNG), the PNG Resource Information System (PNGRIS) and Mapping Agricultural Systems Project (MASP), was conducted by King and Hackett (1990), Allen and Lowe (1997) and Bourke et al. (1998). Despite the wealth of data available from these databases, detailed information at the farmer level, including farmers' perceptions about soil management and in-depth soil analytical data needed to assess soil productivity decline, is not available.

Biophysical surveys, in particular most types of mapping appraisals, aim to assess the inventory of the resource base for a number of reasons. The results have a wide array of applications ranging from recommendations of where different types of production systems are possible and crop suitability to an assessment of environmental degradation. There is often no link to the socioeconomic conditions under which farmers operate.

In this study a survey similar to an RRA, but with the additional collection of biophysical data, was adopted to strengthen the results gained from both farmer interviews and biophysical assessment of the land resource.

The information sought from this study was:

- current farming practices
- changes in practices over time
- perceived limitations to productivity posed by environmental, social and economic conditions.

Methods

The survey was designed to assess a range of socio-economic and biophysical measures to formulate a relationship between (i) the farmer's perceived problems, (ii) their socioeconomic needs, (iii) the ability to adopt new land management practices and (iv) measured production properties (e.g. soil quality linked to existing crop and soil management practices).

The soft data (i to iii) were obtained through informal surveys of village chiefs and farmers using open-ended questionnaires. An important aspect was to capture farmers' knowledge about soil fertility, its management and problems. For example, the interviews included questions about production limitations. To validate the verbal answers, the respondent was asked after the informal interview to take the enumerators to one productive and one less productive field, from where soil and plant samples were taken for analysis (point iv). The aim was to capture the range of social and biophysical variables as a mix of soft and hard data. Statistical analysis of the data included multivariate procedures, cluster analysis or tree regressions.

Table 1. General farmer questions

Question category	Information sought
Wealth and family	Income source Number of children and if they go to school Family size Sex and age
Sweetpotato	Use as cash crop Pest resistance Change in crops produced other then sweetpotato
Land use	Land availability for expansion Presence of non-productive land
Enumerator observations	Length of interview Location of interview start Recent weather conditions General observations

Questionnaire

The survey included general questions focusing on each individual farmer and specific questions about his/her gardens.

General questions were related to wealth and family circumstances, production and use of sweetpotato and other crops, and land availability (Table 1). This part of the questionnaire included about 30 questions plus enumerator observations.

Specific questions were related to two different gardens the farmer managed. The two gardens were selected by the farmer and represented a 'new' and an 'old' garden (Table 2). The new garden had recently been brought into sweetpotato production following a fallow period; the old garden was supposed to be converted to fallow soon. The qualifiers 'recently' and 'soon' were relative to the farmer's other gardens. Given that the survey collected non-trial, actual farmer data, it was not possible to clearly quantify old or new and recent or soon, except that the two gardens differed in the number of seasons sweetpotato had been cropped.

Questions to the farmer about each garden focused on fallow management, soil preparation, soil fertility management, sweetpotato production techniques and livestock. The enumerators avoided asking the same question twice if farmers had already volunteered the information earlier or if answers applied to both gardens. Farmers were asked for permission to harvest sweetpotato at two different locations in each garden. Tubers were inspected for pests and diseases, yield was measured and tuber appearance was described. Soil and plant samples were also collected from these gardens (described later).

Table 2. Farmer survey for old and new gardens

Question category	Information sought
Fallow management	Length of previous fallow and current cropping Condition to enter a fallow period Type of fallow and fallow vegetation Burning Change in fallow length
Soil preparation and soil fertility management	Soil preparation method and why Ability to produce corn and/or beans
Sweetpotato production	Number of crops Age of crop and number of harvests Time between planting and commencement of harvest Age at final harvest Yield estimate and reason for estimate Treatment of vines for planting Sweetpotato variety Future cropping plans
Non-sweetpotato crops	Crop type
Livestock	Livestock presence after cropping and why Livestock presence between plantings and why
Enumerator observations	GPS coordinates Planting system Fertility management Geometry of planting system and size Number and size of tubers per station Weight of tubers per station Skin and flesh colour of tubers Tuber cracking Tuber insect damage Weevil presence Depth of topsoil General observations

Specific questions were:

- What determines the farmer's land management strategy?
  - Are his/her decisions about land use *economic* (cash driven, wealth creation, what is 'wealth' to them), *social* (who decides on land use, land ownership or perceived land ownership, tradition, status) or *biophysical* (soil quality, soil resilience, land pressure)?
- What changes in land use has the farmer observed?
  - Have the types of crop changed (his/her recollection of the past, observation of now and expectation for the future)?
  - What are the crops he/she grows used for (was there a change of what the farmer identifies as cash or food crops over time)?
  - What are the limitations for crop production (his/her recollection of the past, observation of now and expectation for the future)?
  - What are the farmer's main concerns for crop production in the future?
  - How much land does the farmer use (his/her recollection of the past, observation of now and expectation for the future)?
  - Is there land that is no longer used and why; is there more land available, either fallow or new land?
- How does the farmer manage soil fertility in the garden and in its surroundings?
  - What is the cropping sequence after fallowing; did it change compared to the past sequence of crops or intercropping? Which fallow type and period (R-factor) are chosen? If short fallows are used, what are the methods to manage fertility: legume rotation; planted tree fallows; composting; soil tillage; drainage; mounding; use of beds for planting; burning practices; soil retention barriers; cropping periods (also critical); crop sequences; placement of pigs into sweetpotato plots between plantings?
  - How is the soil quality described (colour, growth of specific plants/trees, friability etc.)?
  - What are the tillage operations used and why (beds, mounds etc)?
  - What soil amendments are added and why does the farmer use them (e.g. mulch, compost, fertiliser, ash from burning, grass or legume cuttings; are these incorporated or surface applied, or used for other purposes)?
- If crops don't grow well, when does it happen and what does he/she do about it (i.e. relating to crop establishment problems, nutrient leaching, soil water deficit/surplus)?
- What is the farmer's most important item on a wish list and what is his/her main concern?

The survey was co-designed and tested by local staff, beta-tested on farmers in the Aiyura area, revised and then delivered to the target area with the intention not to exceed a 1-hour interview time for each farmer. The interviews were conducted informally.

Survey locations

The objective of the survey was to capture a reasonably representative sample of soil management practices in relation to sweetpotato production constraints in the PNG highlands. Due to access problems, diversity of the area, time and financial constraints, a random sampling technique was not possible. Our criteria for the selection of villages and farmers for the survey were based on:

- an even spread across highlands provinces
- an even spread across districts within provinces
- easy accessibility but avoiding bias towards the vicinity of main roads
- a willingness of villagers and farmers to participate
- time and safety.

This survey included four highlands provinces. In each province three districts were selected, and within each district four to seven villages were chosen with a maximum of four farmers per village, giving a total of 95 farmers (Table 3). The survey was conducted from October to November 2005. Following the execution of the general survey (Table 1), farmers were asked to show one garden that had recently been brought back into production after fallow, the 'new' fertile garden, and another garden that was about to go into fallow, the 'old' run-down garden. The garden-specific questionnaire (Table 2) was conducted in the respective gardens. A total of 190 gardens from 95 farmers were investigated.

Soil and plant sampling

During or after the completion of the garden-specific questionnaire, the farmer was asked for permission to harvest one sweetpotato station from each of two locations in each garden.

Table 3. Survey locations

Province	District	Village	Farmers (*n*)
Eastern Highlands	Asaro	Kopiaka Korekoreto Nipiamuka Urisaro	1 4 1 2
	Henganofi	Komoga Kumuina Ogogona–Finitugo Orimu	2 2 1 2
	Lufa	Fogudavi Kami Lagaiu Lupave	1 3 2 2
Enga	Ambum Kompiam	Aimates village Lyongekam village, Yampu Meraimanda village Par village, Muliyau clan Rakapos village Yaramanda village	2 1 2 1 1 1
	Kandep	Kandaso Kiripiso village Lopote village Tolename village Yak village	1 2 2 2 1
	Wapenamanda	Kinapos, Kumbaskam village Konemandi village, Tsak Valley Kwia village Limanda village Munimand, Kumbaskam village Yokonas village, Tsak Valley	1 1 2 2 1 1
Simbu	Gumini	Baul (Dom) Gaima Kalmekul (Kaukau) Kel Moromaule Omkolai (Kaukau)	1 3 1 1 1 1
	Kundiawa–Gembogl	Bomkane Goglme Greenland Kegesugl Kenyaundo Tawiadumo	2 2 1 1 1 1
	Sina Sina	Gapakama Gapakure Jerico village, Kamtai, Sina Sina Kamtai Koralmil	1 1 1 2 3

Table 3. (Cont'd) Survey locations

Province	District	Village	Farmers (n)
Western Highlands	Banz	Banz	1
		Fatima	4
		Kamal	2
		Sipilin	1
	Hagen Central	Bagl	1
		Dikoron	1
		Glebina	1
		Gor	1
		Kongop	1
		Manda	1
		Pulka	2
	Upper Kaugel (Tambul)	Anambo	1
		Laigam	2
		Malke (Tambul)	2
		Panjamu	1
		Tambul	1
		Yawer	1

The two sampling locations were at least 10 m apart. In case growth of sweetpotato was very variable, two locations with different growth vigour were chosen and photographs were taken. First, leaf samples were taken, if available from well-established but immature plants or, alternatively, from plants with average growth at that location. Four dominant active shoot tips were selected and the youngest open leaf identified. The seventh to ninth leaves (excluding the stalk) down the shoots were collected as well. Nutrient-deficient or soil-covered leaves were avoided. Samples were stored in a paper bag and air-dried in a food dehydrator the same day. A total of 380 samples were collected and a subset of 218 leaf samples was analysed.

Second, soil samples were taken at the same location where leaves were collected to ensure that leaf analysis matched the location of the soil analysis. The 0–10 cm depth was sampled using a hand spade. Depths > 10 cm were sampled using a 50 cm long, 5 cm diameter corer. The second sample was taken to a maximum depth of 50 cm. The entire core (10–50 cm) was collected if the subsoil was > 50 cm depth, or 10 cm to subsoil depth in case the corer entered the subsoil. Subsoil depth was recorded where relevant. A total of 762 soil samples were collected and a subset of 433 samples was analysed.

Third, the sweetpotato stations were harvested. Tuber cracking, presence of insect holes, presence of weevils, tuber and flesh colour, tuber variety and tuber weight were recorded. The yield in t/ha was calculated from the geometry of the mound or planting system, its area, the number of vines per plant and the total tuber mass per vine. Root samples were collected for visual inspection for nematodes under a light microscope.

Lessons learnt

In this section a discussion of the problems we encountered in developing and conducting the survey is presented. This assessment of lessons learnt should serve as a guide for future surveys that aim to combine the RRA approach with biophysical assessment of the resource base in question.

Geography and infrastructure

The survey was designed by a truly multidisciplinary team of local staff and scientists from Australia (socioeconomists, geographers, soil and plant scientists). The inclusion of all these personnel in the survey design was imperative to ensure that our aims were possible to achieve and practicable to carry out.

A major limitation was where the survey could be conducted. Most areas of the PNG highlands, except those close to accessible roads, are very difficult to reach.

Many villages either do not have road access or road conditions are very poor. Travel to the nearest townships from these remote villages is only possible by foot through very rugged terrain and might take several days. Unlike the stratified sampling approach based on a geographic grid (see Kirchhof, Odunze and Salako, these proceedings), which is suitable for the relatively easily accessible savannah areas in West Africa, this survey had to be conducted in villages that were reasonably easy to reach by car. Given that most of the population resides in or near the larger towns and along roads, we acknowledged this as an acceptable limitation. Besides the main problem of village access, there were several other factors for bias.

Farmer collaboration

It is recommended to plan farm visits well ahead of time. This involves establishing communication with village chiefs or clan leaders through local government agencies, church groups or other non-government organisations (NGOs) working in the same area. Such planning activities are time consuming and expensive, but it is of the utmost importance to follow local customs. Nevertheless, organisational problems in pre-arranging village visits still appeared quite often. Causes for these problems were numerous and ranged from communication problems to reprioritisation of work schedules. In practice this meant that the survey team sometimes arrived in villages whose inhabitants were supposed to have been informed about the survey but had no idea. In all cases there were no problems conducting the interviews, so this raises the question of how important it is to pre-arrange farm visits. It may indeed be important in some areas but it may be an administrative requirement that can simply be avoided in other areas. The author's (Kirchhof's) personal experience in conducting farmer surveys in a completely different environment, the West African Guinea savannahs, are similar to the experiences in PNG, and there was no need to arrange village visits. In other words, it is important not to get bogged down with formalities that may not be justified.

The data collection was limited to farmers who were interested in participating in the interview and in spending time with the enumerators. This proved to be no hindrance as most farmers were interested in the production of sweetpotato. They also needed to agree on the collection of plant and soil samples and the harvest of sweetpotato samples. The latter was considered a major problem and it was expected that farmers would request appropriate payment. However, this expected and potentially quite expensive problem rarely occurred.

Farmers were very cooperative but made it very clear to the survey team that they expected to get the results from the study. The informal information gained was that, from their experience, agencies conducted surveys but results were never made available to them. Besides ruining the agency's credibility, this perception will have several undesired effects. The adverse impact could not only reduce the farmers' readiness to collaborate with future survey teams, but it could also obstruct the willingness of farmers to attend field schools, and hence impede the adoption of new or improved technology.

Communication

An important part of the questionnaire was to gauge farmers' recollections of land use and management changes; that is, what happened in the past and what happens now. The interpretation of 'past' and its quantification was a major problem for the interview team. It is fair to say that most peasant farmers have little or no understanding of the concept of 'years'. What happened in the past is more related to key events in their lives. This may be marriage, birth of children, natural calamities, past tribal fights. To ask a farmer how long he has fallowed his land is a difficult question and the answer is likely to be meaningless. This also means that formal surveys, where predefined questions are asked, are impossible to implement. We tried to overcome this problem by engaging the farmers in a conversation where the survey team could interpret answers in relation to their understanding of time and convert it to how we measure time. While this was the only possible approach, it did somehow reduce data reliability.

Related to this problem was the identification of new and old gardens. The definition of a 'new garden' was one that had recently come out of a fallow period, and an 'old garden' was one that was about to go into fallow. During the testing of the survey, farmers invariably showed gardens where sweetpotato had just been planted as the new garden, and a garden where all sweetpotato had been harvested as the old garden. The questions were redefined in the context of fallow periods to ensure that the correct definitions of new and old were applied.

These two examples highlight the need for thorough testing of the questionnaire and a required awareness of the social and traditional factors affecting the day-to-day lives of the peasant farming community.

Gender

Polygamy is common in the highlands of PNG and the society is primarily patriarchal. Males tend to engage in the initial heavy physical labour in garden preparation, while females complete the preparation and look after the gardens. However, decisions about the establishment or abundance of a garden are made by the head of the family or clan. This makes it difficult to decide which person in the household has the best knowledge about soil management. It is also not possible to determine who will be interviewed—male or female. In other words, it is not possible to control gender influence on the survey other than recording if the interviewee was male, female or a group, and hence assess if responses are gender specific. Despite the patriarchal structure of the Melanesian culture, there is generally no problem interviewing or talking with female farmers.

Safety

PNG has the unfortunate reputation of being a country with high crime rates and violence, which is obviously a major limitation for research based on surveys. Safety increases the bias in conducting surveys and any other research. While it is essential to acknowledge this bias, it is also important to remember that the bias cannot be removed without some potentially rather undesirable effects on the research team. In other words, if researchers or those who review research are not practical and work within these constraints, the investigation cannot be conducted. There is no rule about how to handle this problem, and it is not unique to PNG that research has to operate within the bounds of the ambiguous context of ‘what is practicable’.

Data reliability and verification

Any farmer surveys, including RRAs, rely on the information provided by the farmers. In many cases the enumerators can decide if the answer they get to a question is plausible. However, the judgment about plausibility is an opinion based on experience and there is no way of corroborating this opinion. Control questions can be used to see if the farmer is sincere with his information or if he/she is taking the enumerators ‘for a ride’. These control questions can simply be asked worded differently or as a different question relating to the same answer, e.g. one question may ask ‘is the soil fertile?’ and a second ‘can you grow corn?’—and growing corn is only possible if the soil is fertile.

A much more unbiased method to verify the responses from farmers is to combine the socio-economic dataset with biophysical measurements. One will underpin the other and together give a much more rigorous assessment of production constraints. The common problem in combining these two survey approaches is cost. Conducting interviews increases expenses, but collecting samples for further analysis requires considerably more resources than talking with farmers.

A well-defined and organised RRA survey in combination with the collection of samples for biophysical assessment of the resource base will also provide the base data for impact assessment. After project completion and allowing some time for adoption, such a survey can be repeated to provide an unambiguous measure of impact.

Summary

The main benefit of surveys that combine RRA with biophysical assessment of the resource base is the measurement of verifiable parameters to underpin farmers’ perceptions of a problem. Conducting such exploratory surveys prior to project implementation will generate unbiased data that will allow either justification or abandonment of conjectured objectives. In either case it will produce baseline data that can be used after project completion to assess impact and adoption, or serve as comparative data to evaluate changes over time that will be useful for future potential research requirements. It is also likely that the process of farmer interaction during the initial survey, project implementation and a post-project survey will assist the adoption of new or alternative technologies as it demonstrates ongoing agency commitment to farmers’ problems. From our experience with farmers in the PNG highlands, feedback from the researchers to the farmers after the survey is a main problem. It seems very common for agencies to collect data from farmers but not to report back to them. This communication breakdown can result in diminished farmer interest in both participatory research and adoption, as the credibility of the surveying agency is lost. Much greater importance needs to be placed on providing feedback to farmers after the assessment of the survey is completed. This can be achieved through local media—perhaps radio, TV or newspaper—as well as flyers prepared by agency staff in a form that is amenable to farmers.

Specific problems for conducting surveys in PNG are difficulties in village access and safety concerns. The willingness of farmers, male or female, to participate in the survey, as well as to consent to the collection of plant and soil samples in their gardens. was not a problem. However, despite all efforts to collect data from a random sample, as required for rigorous statistical analysis, this was not possible, and results always have to be analysed within the limitations of what is practically possible.

The use of a combination of RRA and biophysical surveys to gather baseline data for more efficient planning of larger research activities will also set the prerequisite to assess adoption after the research has been completed. If similar surveys are conducted both before and some time after the research intervention, unambiguous data will be obtained to measure impact, unlike merely implying or extrapolating impact. The main problem with this approach, however, is that projects only run for a few years, often no more then 3 years, and priorities change, so that is it rare that a thorough pre- and post-intervention dataset becomes available.

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References

Allen B.J. and Lowe M. 1997. User's guide for PNGRIS and MASP. Agricultural Systems of Papua New Guinea Working Paper No. 24. Department of Human Geography: Australian National University, Canberra.

Bourke R.M., Allen B. J., Hobsbawn P. and Conway J. 1998. Papua New Guinea: text summaries. Pp. vi, 221 in 'Agricultural Systems of Papua New Guinea Working Paper No. 1'. Two volumes. Department of Human Geography, Research School of Pacific and Asian Studies, Australian National University: Canberra.

Chikoye D. and Ellis-Jones J. 2006. Farmers' perceptions of the speargrass (*Imperata cylindrica*) problem and its control in the lowland sub-humid savannah of Nigeria. Journal of Food, Agriculture & Environment 4(3–4), 118–126.

Dordelly L.E.G. and Wambeke J.V. 2005. From land-use management to food security. Land Reform, Land Settlement and Cooperatives 1, 34–43.

Goma H.C. and Rahim K. 2001. Participatory studies for agro-ecosystem evaluation. Agriculture, Ecosystems & Environment 87(2), 179–190.

Iqbal S.M.M. and Ireland C.R. 2006. A logistic analysis of the factors determining the decision of smallholder farmers to intercrop: a case study involving rubber–tea intercropping in Sri Lanka. Agricultural Systems 87(3), 296–312.

King G.A. and Hackett C. 1990. Use of a geographic information system with a crop modelling system in a rapid rural appraisal in Papua New Guinea. Science in New Guinea 16, 46–54.

Omekwu C.O. 2005. Research-extension-farmer system interface: lessons from a review of concepts and models. Quarterly Bulletin of IAALD 50(1/2), 16–20.

Stocking M. 2005. Field assessment of erosion and soil productivity from the perspective of the land user. Pp. 149–158 in 'Renewable natural resources management for mountain communities'. International Centre for Integrated Mountain Development (ICIMOD): Kathmandu, Nepal.

Statistical methods for a soil fertility management survey analysis in Papua New Guinea

Olena Kravchuk[1], Trevor Wilson[2] and Gunnar Kirchhof[1]

Abstract

This paper is a short communication about methods used in the analysis of biophysical data from the scoping stage of a soil fertility management survey in Papua New Guinea conducted in September–October 2005 (Australian Centre for International Agricultural Research project SMCN/2005/043). The goal of this communication is to describe and promote the good practice of statistics in application to biophysical surveys. A step-by-step analysis is presented of the difference in sweetpotato yield between newly established gardens and gardens that have been cultivated for a long period. We comment on the strengths and limitations of statistical techniques used in the analysis, and also relate the techniques to the corresponding software procedures (R15, Minitab Inc., Chicago). Although we refer to various general methods, the analysis presented is specific to one particular survey. This paper may be useful for agricultural researchers as a case study of the data analysis of field surveys in research or extension projects.

Introduction

In this paper we discuss in detail the exploratory and inferential statistical analysis we conducted on sweetpotato yield in farmers' gardens for a soil fertility management survey conducted in Papua new Guinea (PNG) in 2005 (Australian Centre for International Agricultural Research (ACIAR) project SMCN/2005/043[3]). That analysis was a part of the data analysis presented in the final report of the survey. Going step-by-step through the analysis, we reflect on the decision-making process of statistical analysis. There are plenty of methods and techniques easily available in statistical packages nowadays, and an informed decision has to be made about which particular method of analysis to select. As we show, that decision is based on the design of the survey, the focus of the analysis and the distributional properties of the experimental data.

The structure of the paper corresponds to the structure of the actual analysis: the original design of the survey; the corresponding original plan for the data analysis; the analysis of non-responses and missing cases; alterations to the initial plan of analysis after the data have been collected; the implementation and interpretation of simple robust statistical analysis; and the implementation of more complex, model-based, methods of analysis and estimation of parameters. In the discussion of this case study we skip the data management and data cleaning/validation steps, and concentrate only on the analysis of reliable experimental results.

Statistical design of a pilot survey

At the pilot stage (or scoping study) of any survey of this type, little is known about what exactly to

1 School of Land, Crop and Food Science, University of Queensland, Brisbane Queensland 4072, Australia <o.kravchuk@uq.edu.au>
2 Queensland Department of Primary Industries and Fisheries, Primary Industries Building, 80 Ann Street, Brisbane Queensland 4000, Australia
3 ACIAR project SMCN/2005/043: 'Analysis of biophysical and socioeconomic constraints to soil fertility management in the PNG highlands'

expect from the data that will be collected. The pilot stage is only a preliminary investigation. Its design is thus governed by the experience of the project investigators and information from relevant literature: rough ideas about possible trends in experimental data, approximate estimates of the variation in samples to be collected in seemingly similar conditions, and some indications of the ranges of climatic, soil and other environmental conditions. One aim of a pilot survey is to collect objective evidence of the trends of interest and then to quantify the variation in sampling conditions. One of the goals of this scoping study was to collect information about the decline in productivity of sweetpotato gardens over time.

Commonly, the number of samples in a pilot survey is limited to a certain quota, which should be reasonably large but still affordable within the budget and time constraints. The scope of the sweetpotato survey was set at interviewing 23–25 farmers in 1 month in each of four provinces: Eastern Highlands (EHP), Simbu (SP), Western Highlands (WHP) and Enga (EP). Only farmers who could be accessed by vehicle were included in the survey. The sampling design, therefore, was decided more by convenience (and safety) rather than being a simple random design. That obviously limited the inference from the survey as no information was collected about farmers far from accessible roads.

Establishing how to define a representative sample is the responsibility of researchers who have a good knowledge of biophysical processes and are familiar with the local conditions. The completeness of survey records and the quality of data in the survey is important, as missing responses (so-called non-responses) or unreliable records can introduce bias into interpretation of the evidence collected (Manly 1992). Unambiguous and appropriate selection criteria have to be established in order to ensure that the sample is representative of the conditions of interest, and to reduce the risk of non-response. No complex statistical design is required at the scoping stage—the simpler the design the better. Simple random sampling would normally provide a truly representative sample from the population of interest. However, when there are limitations on the number of samples, judgment sampling is often used instead (Cochran 1977). In the sweetpotato productivity survey, data collectors made an informed judgment on whether each farmer's circumstances were representative before including the farmer in the survey. Moreover, the actual sampling of sweetpotato plants was also done according to judgment sampling, where a representative plant was selected by the data collectors in each garden. Several training sessions for data collectors were organised in the project, to ensure the uniformity of their judgment. Although the sampling method used resembles random selection, it does not give a true picture of the actual yields in the country. For example, no extreme cases would ever be selected by data collectors. This lack of randomness at the data collection stage limits the inference one can draw from the analysis to a certain 'representative' group of farmers.

A properly designed stratified survey would generally provide higher accuracy of estimation of parameters of interest, and allow one to save on time and resources, in comparison to simple random, unguided, sampling (Lohr 1999). In practice, however, stratification factors may be chosen simply as a matter of convenience. In that case the stratification does not improve the accuracy of the survey, and often complicates the analysis and confuses the interpretation of results. In the sweetpotato scoping study the four provinces were only nominal strata. Dividing the survey into provinces did not reflect any objective distinction in the soil properties, climate or environmental characteristics. The design would be more efficient if the survey was stratified based on biophysical conditions that were likely to affect the sweetpotato yield. For example, the sweetpotato cultivation practice would be a sensible stratification factor. Unfortunately, the more complex the design, the more time is required for training. In the scoping study, due to time constraints, a complex stratified design was not feasible.

Finally, in any survey, data collectors have to be trained in conducting the actual sampling in an unbiased way. Such training includes interview techniques as well as handling and storing biophysical samples. Accurately preparing and handling experimental samples, using an efficient and safe coding of data, and storing the data by using a robust data storage system are all crucial and commonly learned only with practice (Gomez and Gomez 1984). The research team made a substantial effort to ensure that the samples collected and data coded were reliable.

Often, the data collected in the field are not immediately suitable for the analysis. One criterion of productivity in the sweetpotato survey was the yield of sweetpotato available on the sampling day. The tuber mass of the representative plant and the density of plants per square metre were measured in each garden. Based on this, the total yield available at harvest was estimated and recorded in tonnes per hectare (t/ha) for each garden. Because a plant could have been continuously harvested before the sampling, the yields so estimated were not explicitly comparable between gardens. This means that the difference in yield between recently established and old gardens could be defined, and interpreted, differently if it was possible to obtain data about the actual yield of sweetpotato produced in each garden.

A pilot survey is essentially an observational study. One would not expect a sophisticated in-depth analysis at this preliminary stage of projects. Instead, it is more important that the analysis is focused, simple and robust. This is why it is crucial to formulate clearly, at the design stage, only a small number of focus points, which will be later discussed in the survey report. The widely accepted rule is that any recommendation based on a pilot survey should be further confirmed in a targeted survey in which more causal factors are thought over and more biophysical understanding is available. This also suggests that one should avoid doing a complex analysis of a preliminary study. The main aims of the sweetpotato pilot survey were to establish a reliable way of collecting the information about the soil–plant relationship and to suggest whether there were noticeable differences in the productivity of farmers' gardens with age. We also planned to investigate whether the productivity decline, if any, could be associated with a decline in soil fertility.

Because of the descriptive nature of the analysis of pilot surveys, we were very flexible with the significance of statistical comparisons (Nelsen 2002). The significance level was not fixed in the analysis, but we decided that we would report the actual probability levels (*P*-values) for each statistical test. The probability levels of common statistical tests are derived on the assumption that the data are drawn at random from the population of interest. Therefore, the *P*-values in the analysis of this pilot survey should be treated with caution, rather descriptively, as the actual sampling was not random.

Data collection protocol and the initial plan of data analysis

There were 95 farmers from four provinces included in the survey: 23 from EHP and 24 each from EP, SP and WHP. The geographical distribution of samples is shown in the final report of the soil fertility management survey (ACIAR project SMCN/2005/043).

Farmers were asked to show data collectors both their old and newly established gardens. A farmer could show more than one garden of each age. In each garden the data collectors uprooted a representative sweetpotato plant and weighed the tuber mass per plant. Based on the density of planting, these weights were then transformed into the estimated available yield expressed in t/ha, which was used in the data analysis.

The aims of the analysis were to establish whether there was evidence to suggest that yield declines with age, and if this was related to changes in the soil characteristics; and to quantify the magnitude of, and variation in, the decline in yield among provinces as well as farmers.

Initial plan of the data analysis

At the design stage the approach to the analysis looked simple and certain: to collect the sample data relating to yield per plant in each garden, to estimate the yields available in newly established and old gardens for each farmer, and to compare those available yields among farmers. The rules for comparison were: (i) if the new gardens produced consistently higher yields in comparison to the old gardens of the same farmer, to conclude that there was a decline in yield with age; and (ii) if the difference in yields for individual farmers was not consistent, to conclude that there was not enough evidence to suggest an age-associated decline in yield. Analysis of the yield data was to be conducted at the linear scale as well as the logarithmic scale, commonly used for analysing biological growth.

Non-responses and unreliable records in the survey

Even this simple survey resulted in an incomplete dataset. For 14 farmers the yields were not recorded. The missing records were reasonably evenly scattered across provinces: two in EHP, seven in EP, two in SP and three in WHP. The prevalence of non-responses in EP may need to be looked at more closely. We checked whether the non-response rate was significantly non-random with a chi-square test of equal proportions. We did not find that the overall differences in non-response among provinces were not due to chance ($P > 0.15$, chi-square goodness of fit test in Minitab). This does not mean, however, that the information was missing at random and we were facing a potential non-response bias in our analysis. In order to avoid that bias, we had to investigate what happened in each case. Based on the reports from data collectors, we concluded that the missing data happened at random: errors in data collection sheets, missing records etc. The rate of complete records was fairly high, 85%, so there were enough data for the analysis.

Post-grouping of responses in the survey analysis

The distribution of available yields estimated in the survey for the remaining 81 farmers is depicted in Figure 1. Some farmers (47) had both new and old gardens on their land, while other farmers (34) had only one type of garden—either new (15) or old (19).

The distribution of the 34 farmers (Figure 1b) who had only new or old gardens was reasonably random among the provinces (chi-square test of goodness-of-fit, $P > 0.20$). However, whether a farmer only showed old gardens or newly established gardens was confounded among provinces, as can be seen in Figure 1 and Table 1. The chance that a farmer would only show new gardens was significantly higher in SP ($P < 0.03$). In other provinces the frequencies of old and new single gardens were not significantly different ($P > 0.20$; the conclusions are based on the individual components of the chi-square test for independence). As mentioned previously, provinces were only nominal factors in the survey design. It could be suggested that this difference in the instances of new gardens was mostly due to differences in the cultivation practices among provinces. For example, the fallow period is long in SP, so the majority of farmers who only showed gardens of one age there were farmers with new gardens.

Nineteen farmers (56%) showed two gardens and 14 farmers only showed one garden (41%); that discrepancy was fairly random between provinces ($P > 0.4$, chi-square test of independence). The yields for farmers who had only newly established or long-cultivated gardens are summarised in Table 1.

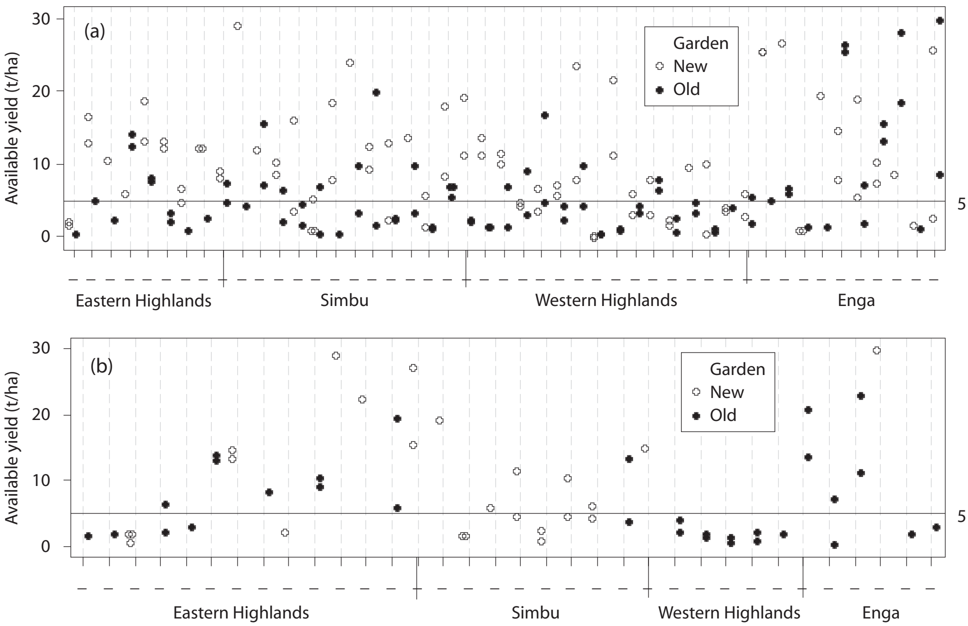

Figure 1. Distribution of available yields in new and old gardens estimated in the survey

However, these data were not used for comparing the yields in new and old gardens.

To avoid confounding the comparison between gardens of different ages with differences among provinces, we separated farmers who had only new or old gardens from those who had both.

Alterations to the original plan of the analysis

Finally, we were able to implement the initial plan of the analysis—to compare the old and new gardens of each farmer. At that point, after adjusting for non-responses and incomplete responses, we only had 47 farmers instead of the initial figure of 95. On the other hand, for those 47 farmers we were able to separate the garden age effect from other factors such as farming practice, province, cultivation system and so on. In the analysis we simply thought of farmers as being random blocks, in which old and new gardens were exposed to the same environmental conditions and cultivation and crop management practices.

There were 167 gardens accessed. Most farmers (74%) showed two old or newly established gardens to the data collectors, and some (24%) only showed one garden of each age.

Robust comparison of yields in old and new gardens

Several criteria for comparison were used in the analysis. Some criteria were applied on the original linear scale and some required further data transformation. Correspondingly, we used distribution-free methods, as well as methods based on the assumptions of normality and pooled (combined and averaged) variance of data.

The simplest robust criterion was a sign difference. This did not require any strict assumption about the expected shape of the histogram of data. The approach was very simple: if the average performance was consistently higher in the newly established gardens, we could conclude that there was a decline in productivity associated with the age of the garden. In 35 out of 47 cases the average yield in new gardens was higher than the average yield in old gardens. The 12 cases in which the trend was opposite were reasonably uniformly spread across provinces: one in EHP, five in EP, one in SP and five in WHP ($P > 0.15$, chi-square test of goodness of fit, equal proportions). The overall decline in yield in old gardens was obvious, and its significance was estimated statistically with the sign test on the yield differences ($P = 0.001$, the sign-test procedure on the differences between the average yields in Minitab). With 95% confidence the estimate of the median decline in yield was (0.67, 7.2) t/ha (i.e. the true median decline could be as little as 0.67 t/ha or as high as 7.2 t/ha).

The sign-test procedure, however, is known not to be efficient for the normal- or log-normal-like distributions we would expect for yields. This lack of efficiency leads to a large standard error of the median estimate. In order to get more power from the analysis of the yield data, and produce a more accurate estimate of the decline, we used another non-parametric procedure—a signed-rank test on the yield differences. This test does not make any

Table 1. Yields in new and old gardens estimated for farmers who only had gardens of one age

	Province			
	Eastern Highlands	Simbu	Western Highlands	Enga
No. of new garden surveys (no. of gardens)	5 (8)	8 (14)	1 (1)	1 (1)
Average yield ± SD in new gardens (t/ha)	13.65 ± 12.17	8.61 ± 7.48	n.a.	n.a.
No. of old garden surveys (no. of gardens)	8 (12)	1 (2)	5 (9)	5 (8)
Average yield ± SD in new gardens (t/ha)	6.66 ± 4.78	n.a.	1.64 ± 0.77	8.39 ± 7.80

n.a. = not applicable

strict assumptions about the distribution of the yield differences and requires no data transformation. With the signed-rank test it was also concluded that the decline was significant ($P = 0.004$). The 95% confidence estimation of the true median decline by that procedure was narrower at (2.36, 6.34) t/ha.

In the two tests described above we oversaw possible differences among provinces. In order to follow the actual design of the survey, we checked whether the distribution of yield differences was significantly different among the provinces, and concluded that both the median yield declines ($P > 0.10$, Kruskal-Wallis rank test on differences) and the deviations of yield differences around their corresponding medians ($P = 0.08$, Levene's test for the difference in variances) were not significantly different. This diagnostics check allowed us to report only the overall yield estimate, which was constructed for the whole group of 47 farmers.

Although the provinces were not significantly different in terms of the distribution of declines in yield, we additionally conducted separate comparisons of new and old gardens in each province for the sake of completeness. Those comparisons are independent from each other and the analysis closely follows the original design of the survey. However, as there are fewer surveys at the province level, the analysis for each individual province is less powerful than the overall comparison. The overall and province-based estimates are given in Table 2. The test failed to detect that the yield decline was significant in EP. This could be due to the unfortunate combination of a small number of farmers and a slightly higher variation in gardens in this province.

The analysis on absolute differences does not take into account the yield baseline. The importance of the same magnitude of yield decline may be perceived differently by farmers depending on how large is the yield in their old gardens. Consequently, we also analysed the relative change in yield by calculating the ratio of average yield in new gardens to average yield in old gardens for each farmer. Similarly to the analysis of the differences in yield, we confirmed that the relative change was significant ($P = 0.002$, signed-rank test). Overall, with 95% confidence, the yield in new gardens could be from 1.9 to 3.6 times higher than in old gardens of the same farmer. We also checked whether the overall estimation is reliable or if the difference in provinces should be taken into account. We did not find a significant difference in the medians of the distributions ($P > 0.1$, Kruskal-Wallis test) and the spread of the ratios was also not significantly different among provinces ($P > 0.1$, Levene's test). We thus reported the overall estimation of the relative change in yield as the main result of the test for the relative decline in yield. For the sake of completeness we additionally performed the analysis for each province. The differences were significant in all provinces but EP (again, we could blame the small number of surveys for this lack of power of the test). The estimated ratios and their significance are shown in Table 2.

In the analyses reported so far, we did not make any assumptions about the distribution of yields or their ratios and differences. We confidently concluded that the decline with age was significant. The interpretation of the age effect is best illustrated in Figure 2, where the majority of farmers had an increase in yield in new gardens (the difference is positive and the ratio is larger than 1).

This analysis was sufficient to achieve the first goal of the data analysis of the survey—that the experimental evidence suggested that sweetpotato yield declines with age. Based on the survey, therefore, it could be recommended that further research explore the productivity decline in terms of changes in the soil and plant characteristics.

Table 2. Estimated median absolute and relative increases in yield in new gardens

Province (number of farmers)	Change is significant	Estimated median change (95% CI)	Estimated median ratio (95% CI)
Overall (47)	Yes ($P < 0.01$)	(2.36, 6.34) t/ha	1.86:3.64
Eastern Highlands (8)	Yes ($P = 0.022$)	(0.38, 9.60) t/ha	2.4:5.6
Simbu (13)	Yes ($P = 0.001$)	(2.61, 12.08) t/ha	1.6:4.9
Western Highlands (15)	Yes ($P = 0.022$)	(0.13, 7.60) t/ha	1.1:4.9
Enga (11)	No ($P > 0.10$)	n.a.	n.a.

n.a. = not applicable; CI = confidence interval

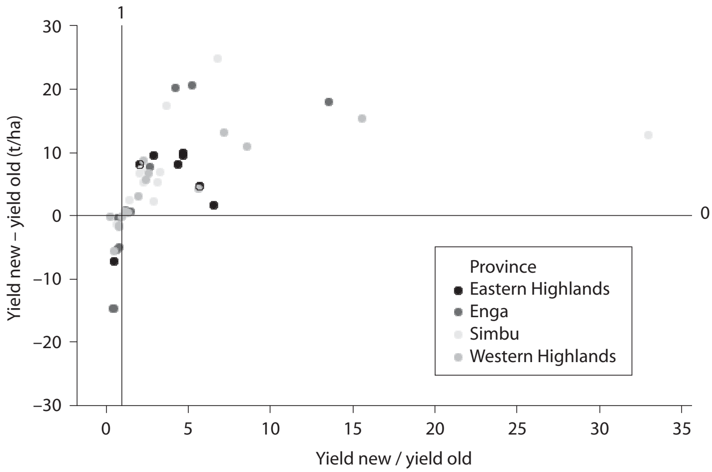

Figure 2. Absolute and relative changes in yield between new and old gardens of individual farmers in the four provinces in the survey

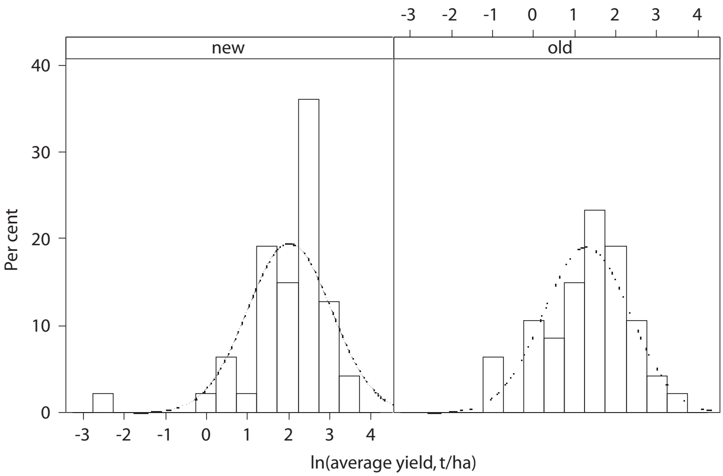

Figure 3. Distributions of log-transformed yields in new and old gardens

Analysis of variation in the survey

Figure 1 illustrates a high variation in yields among farmers and between individual gardens of the same farmer. Although we have already detected a significant overall change in the productivity of gardens with age, it is also important to estimate the degree of variation around that overall trend at the level of individual farmers.

We can quantify the variation in yield decline by using the analysis of variance (ANOVA) technique. This technique may be applied to the absolute yields as well as the relative changes in yields. The ANOVA technique requires that the distribution of the data is normal-like and that the variation in data remains constant across the survey.

Being log-transformed, the histograms of log-yields in Figure 3 look reasonably normal. The transformed yields meet the Anderson-Darling criterion for normality in new as well as old gardens ($P > 0.10$ in both). Log-transformation also stabilises the variation in the yield data; for example, in Figure 1 there was a larger degree of variation and larger average yields in EP than in WHP. This trend is deleted by log-transformation. The transformed data meet the essential assumptions of normality and constant variance. The interpretation of the analysis of log-transformed data is straightforward in this survey analysis. Using the ratio of yields in the data analysis is essentially equivalent to normalising the yield data by log-transformation.

We conducted the ANOVA of the linear mixed model, where farmers were a random factor and provinces were a fixed factor, directly on the log-yield data. The sequential split of the total sum of squares for this ANOVA is given in Table 3. At the log-scale the influence of occasional high-yielding gardens is not influential, and the difference among the provinces is not significant overall ($P > 0.10$) (Figure 4). It is interesting to note that, being compared pair-wise, the expected yield in EP is significantly larger than the expected yield in WHP ($P = 0.004$). For all provinces the yield was consistently higher in new gardens ($P < 0.001$) and the relative changes in yield were similar (no significant interaction effect, $P > 0.10$).

At the log-scale it can be seen that the variation among farmers is larger than the variation between their gardens (the test for the effect of farmers on the variation in yields in Table 3, $P < 0.01$). This may suggest that a farmer's practice and the environmental conditions significantly and equally affect the productivity of the new and old gardens. The intraclass correlation coefficient in the survey was 35%, meaning that the yields in new and old gardens tend to be equally affected by the differences among

Table 3. Minitab output from the ANOVA of general linear models (mixed model: farmers are random, and provinces and garden age are fixed)

Source	Degrees of freedom (DF)	Sequential split (SS)	*P*-value
Province	3	13.0710	0.244
Farmer (province)	43	110.0243	0.000
Garden age	1	18.7990	0.000
Province*garden age	3	3.0012	0.368
Error	43	39.8759	
Total	93	184.7715	
Variance components			
Source	Value		
Farmer (province)	0.4981		
Error	0.9273		

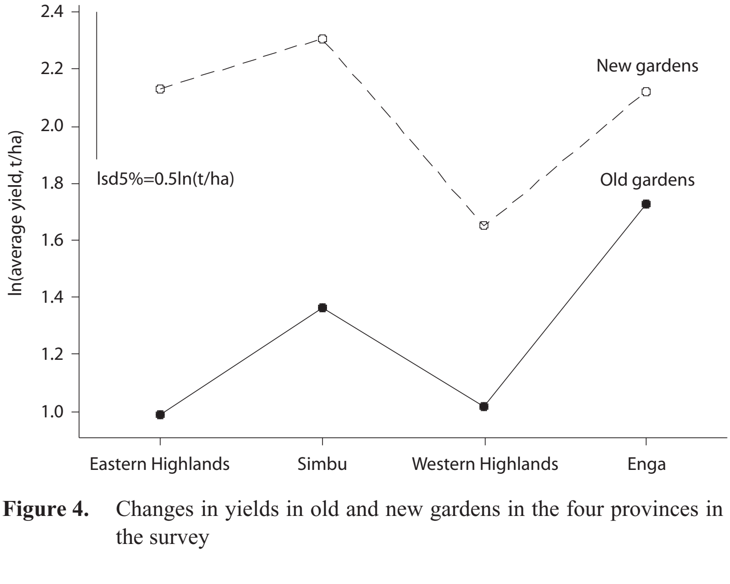

Figure 4. Changes in yields in old and new gardens in the four provinces in the survey

farmers (i.e. the intraclass correlation coefficient is the common correlation between the yields in new and old gardens of the same farmer). A 95% confidence interval of the common correlation between the yields in new and old gardens of the same farmer is (23%, 74%).

We can use this estimate of the common correlation between yields in new and old gardens to estimate the proportion of farmers whose new gardens would produce smaller yields than the old gardens. We can predict, with 95% confidence, that a decline in yield may not be observed in at least 15% of the population of farmers represented by our survey. This also agrees with the fact that 12 out of 47 (25%) farmers in the survey did not have a decline in yield.

Summary of the analysis

The following results of the analysis were reported:

- There is an association between age of garden and yield—the yield is higher in new gardens.
- The average yield is higher in EP than in WHP.
- The variation between gardens and among farmers is high. On the log-scale the variation among farmers is higher than the variation between individual gardens. This means that there is a potentially significant effect of farmers' soil fertility management and environmental conditions on the yield of sweetpotato.

Concluding remarks

This paper only presents our reflection on a small part of the analysis of the soil fertility management survey. We tried to communicate the essence of the statistical analysis. Doing a data analysis, one has to respect the experimental data, know as much about the experimental data as possible, and select statistical procedures in accordance with the quality of the data and the importance of the final recommendations that will be given after the analysis.

Several references on the subject of survey design and analysis are given below. Some of them are more formal but they all contain interesting practical examples and recommendations.

Acknowledgments

The authors wish to acknowledge the help of all farmers who participated in the survey. Special thanks are also extended to the group leaders and enumerators who conducted the survey, sometimes under difficult conditions. We would like to express particular appreciation to Issac Taraken, Debbie Kapal, Passinghan Igua, Pus Wesis, Kud Sitango, Rainer Ratsch and Johnny Wemin. Without their help we would not have been able to present the data included in this paper.

References

Cochran W.G. 1977. Sampling techniques, 3rd edition. John Wiley & Sons: Sydney, Australia

Gomez K.A. and Gomez A.A. 1984. Statistical procedures for agricultural research. John Wiley & Sons: Brisbane, Australia.

Lohr S.L. 1999. Sampling: design and analysis. Brooks/Cole: California.

Manly B.F.J. 1992. The design and analysis of research studies. Cambridge University Press: Melbourne, Australia

Nelsen T.C. 2002. The state of statistics in agricultural science. Journal of Agricultural, Biological and Environmental Statistics 7(3), 313–319.

An analysis of village garden management in the Papua New Guinea highlands

Malcolm Wegener[1], Gunnar Kirchhof[2] and Trevor Wilson[3]

Abstract

A survey of approximately 100 village gardeners in the Papua New Guinea (PNG) highlands was conducted in 2005 as a preliminary step in setting up an Australian Centre for International Agricultural Research project to improve the nutrition of sweetpotato in the highlands.

Sweetpotato is the main staple crop in the PNG highlands, which had a population of around 2 million (or 40% of the country's population) at the 2000 census, with around 2–3% annual growth. Despite these high growth rates, the area under agricultural production has remained fairly static, resulting in increasing pressure on land resources. Farmers are concerned about yield decline, as sweetpotato yields from fallowed land, or land recently brought back into production as part of the recycling of gardens that occurs in the highlands, tend to be much higher (2–8 t/ha tubers) than yields from old gardens. Despite high apparent nutrient stocks and favourable carbon:nitrogen ratios in the soil, most sweetpotato tissue samples have shown low nutrient levels, in particular of nitrogen, phosphorus, potassium and boron.

The survey was conducted to assemble background information on farm locations, farm practices, crop yields, and soil and plant analysis. The conceptual framework proposed to guide the analysis was that background factors (such as location, garden type, land availability, age and sex of farmer, number of children in household and sources of other income) affect management practices. These management practices (soil preparation, planting system, fertility management including fallowing, use of animals such as goats and pigs in the farming system, and crop rotations) influence outcomes such as plant and soil analyses; sweetpotato yields; plant symptoms; tuber characteristics such as weight, size, colour and cracking; presence of nematodes; and ability to grow other crops. A preliminary analysis of the survey data has been conducted and results are reported in this paper.

Introduction

At the 2000 census the estimated population of Papua New Guinea (PNG) highlands was approximately 2 million people or around 40% of the nation's total population. With a population growth rate of 2–3% per annum, the PNG highlands is one of the world's fast population growth areas. Despite these high growth rates, the area under agricultural production has remained relatively stable, with consequent intensification of land use. This is placing unprecedented pressure on the land resource and on the long-term productivity of the main staple crop, sweetpotato.

A scoping study to analyse soil constraints in sweetpotato-based cropping systems and a survey of highlands farmers were conducted in 2005–06 (Australian Centre for International Agricultural

[1] School of Natural and Rural Systems Management, The University of Queensland 4072, Australia <malcolm.wegener@uq.edu.au>

[2] School of Land, Crop and Food Sciences, The University of Queensland 4072, Australia

[3] Queensland Department of Primary Industries and Fisheries, Primary Industries Building, 80 Ann Sreet, Brisbane Queensland 4000, Australia

Research (ACIAR) project SMCN/2005/043)[4]. They confirmed that farmers were well aware of yield decline in sweetpotato and concerned about their situation, relating the decline to deteriorating soil fertility and the use of old sweetpotato varieties. Sweetpotato yields from gardens that had been fallowed and recently brought back into production ('new' gardens) may be as much as 50% higher than yields from gardens that were due to go back under fallow ('old' gardens). On average, this difference equates to a 2–8 t/ha reduction in tuber yield, and poor crop nutrition might be presumed as the cause. However, low soil fertility in the region is unusual due to the young age of the soils in the highlands and their high levels of soil organic carbon. The study observed very high levels of soil organic carbon (up to 20%) and favourable carbon:nitrogen (C:N) ratios (of around 12). Despite high apparent nutrient stocks in these soils, most sweetpotato tissue samples had low nutrient levels, particularly of N, phosphorus (P), potassium (K) and boron (B). The N and K levels were particularly low in old gardens. This confirmed that low yields were associated with suboptimal nutrient uptake.

Companion project CP/2004/071[5] addresses the problem of low sweetpotato yields from the perspective of varieties and viral pathogens. However, it does not deal with the entire production system, in particular the interaction of improved and pathogen-tested varieties with different levels of crop nutrition and soil fertility in different rainfall and temperature environments. This is the focus of the current project. Development of new varieties must link with improved soil fertility management to understand and capture the full potential of the system.

The primary target group for the current study comprised smallholder producers in the more accessible and densely populated parts of the PNG highlands who are producing at least some of their crop for small-scale commercial marketing, and who therefore have some capacity to invest limited resources into intensifying their production systems.

Before the project started, a preliminary survey of small-scale farmers in the Eastern Highlands province (EHP), Western Highlands province (WHP), Simbu province (SP) and Enga province (EP) was conducted in September 2005. This paper reports some preliminary results from that survey.

Number and location of producers surveyed

The 97 farmers surveyed in the PNG highlands were interviewed to obtain background information about their sweetpotato cropping and other farming operations before ACIAR project SMCN/2004/067[6] commenced. Ninety-two usable responses were available from the survey.

The farmers were located in EHP (23 farms), WHP (24), SP (24) and EP (24) (Table 1), and precise locations for each farm were recorded using GPS technology. A mix of male and female farmers was interviewed, including a significant group of respondents as family couples. Most interviews took place in the farmer's garden, while other locations included the farmer's house, on the roadside near the garden or, in a few instances, the roadside in the village. Some interviews were also conducted at the site of village meetings. A team of 11 enumerators was involved in conducting the survey. They noted how long it took to walk to the garden. The mean time was nearly 9 minutes but estimates ranged from 1–2 minutes, indicating that the gardens were adjacent to the meeting point, to up to 45 minutes, indicating that the gardens were often located some considerable distance from the farmer's house.

Income

Ninety-seven producers answered the question: What are your main sources of income? Coffee was the most frequent response (with 35 responses, 36.1% of the total) followed by food crops (in general) (12), other vegetables (14), sweetpotato (12) and livestock (9). The responses to this question are presented in Table 2.

Secondary sources of income included food crops (type not specified) (11 responses), peanuts (13), other vegetables (9), potato (5), sweetpotato (6), coffee (6) and banana (2) as well as brassicas, corn, carrots, garlic, peas, sugarcane, wheat, fruit such as

[4] ACIAR project SMCN/2005/043: 'Analysis of biophysical and socioeconomic constraints to soil fertility management in the PNG highlands'

[5] ACIAR project CP/2004/071: 'Reducing pest and disease impact on yield in selected PNG sweetpotato production systems'

[6] ACIAR project SMCN/2004/067: 'Soil fertility management in the PNG highlands for sweetpotato-based cropping systems'

pineapples, and livestock. A few farmers worked off-farm as paid labour and still others operated non-farm enterprises to generate income. The 36 farmers who identified coffee as their principal source of income were distributed broadly across most districts with no particular concentration. However, half of the producers (6 out of 12) who nominated sweetpotato as their main source of income were located in Asaro district in EHP.

Table 1. Location of surveyed farms by province/district, Papua New Guinea

Province/district	Number of farmers surveyed
Eastern Highlands	**23**
Asaro	8
Henganofi	7
Lufa	8
Western Highlands	**24**
Banz	8
Hagen Central	8
Upper Kaugel (Tambul)	8
Simbu	**24**
Sina Sina	8
Kundiawa-Gembogl	8
Gumini	8
Enga	**24**
Ambum Komplan	8
Kandep	8
Wapenamanda	8
Total	**95**

Table 2. Main sources of income for sweetpotato producers surveyed in Papua New Guinea highlands, 2005

What are your main sources of income?	Number of responses
Coffee	36
Food crops (type not specified)	12
Other vegetables	14
Sweetpotato	12
Livestock	9
Cash crops	1
Pandanus nut	1
Peanuts	1
Sugarcane	1
Wheat	1
Subsistence farming	1
Non-agricultural sources	1
Total	90

Commercial sales

When asked how much and how often these farmers sold sweetpotato, their answers ranged from nothing in the case of 15 farmers to 8 who regarded themselves as commercial suppliers selling significant quantities on a regular basis. The full range of responses to this question is set out in Table 3.

In summary, there is a relatively small proportion of producers (< 10%) who regard themselves as commercial suppliers selling significant quantities of sweetpotato on a regular basis. They are predominantly located in the WHP districts of Upper Kaugel (Tambal; 4 farmers), Banz (2) and Hagen Central. The other commercial supplier was located in Gumini district, SP. The largest category of producer (with 35 survey respondents) comprised those who sell small quantities of sweetpotato irregularly, presumably when they have more than needed for family consumption. They are mainly located in Kundiawa-Gembogl district (8 farmers) and Gumjini district (6) of SP, as well as Hagen Central in WHP (5). Producers selling large quantities of sweetpotato irregularly were mainly located in Asaro in EHP.

Cropping combinations

Typical cropping combinations for these farmers included coffee either on its own as the major income source or combined with food crops (type not specified), other vegetables or peanuts. Likewise, the combination of food crops with coffee was also mentioned several times. Food crops (without specifying the type) with no other enterprise was a fairly frequent response, followed by livestock with other vegetables, and other vegetables with peanuts or sweetpotato. Sweetpotato was listed as the primary source of income by 11 farmers along with one of several other crops including peanuts, sugarcane, wheat or coffee as a secondary source.

While sweetpotato may be the main staple food in the area, it rates less importantly than quite a few other enterprises as a source of income for farmers in the PNG highlands.

The farmers were asked whether they had stopped growing any crops in the past 10 years and whether they had introduced any new crops, to try to assess changes to the farming system. Four farmers did not answer the question but 53 said they had stopped growing a crop and 38 were continuing to grow the same crops as 10 years ago.

Table 3. Frequency of commercial sweetpotato sales reported by farmers in Papua New Guinea highlands, 2005

How much and how often do you sell sweetpotato?	Number of responses
Do not sell sweetpotato	15
Opportunistic supplier: selling surplus only (small quantities sold irregularly)	35
Small quantities (50–100 kg) sold occasionally (less than 3 times/year)	18
Small quantities sold regularly	8
Larger quantities (50–100 kg) sold occasionally (less than 3 times/year)	7
Commercial supplier (significant quantities sold on a regular basis)	8

There was a long list of crops that the farmers had stopped growing. Many of them had ceased growing ordinary potatoes (because of disease problems) in spite of their popularity and good returns in the market. There were 26 reports that farmers had ceased growing potatoes and 10 instances where they had ceased to grow old sweetpotato varieties. Among the other crops that farmers reported they had stopped growing were pineapples, pitpit, big beans, winged beans, taro, cabbage, carrots, mami, peanuts, onions, taro, corn, cardamom, rice and vegetables. Unfortunately, the survey did not gather information on the reasons why farmers had stopped growing these crops.

There were 55 farmers who intended to grow new crops in the next 2–3 years, including new sweetpotato varieties (5 growers), ordinary potatoes (8) and rice (6). Beans, broccoli, cabbage, cauliflower, carrots, coffee, cucumber, lettuce, peanuts, pineapples, taro, tomato, sugarcane, sunflowers, vegetables, wheat and yams were each mentioned as potential new crops by at least one farmer.

There is obviously considerable turnover in the suite of crops selected for production. While no reasons were sought in the survey, it seems that economic forces have a strong influence over the choice.

Land availability

Of the 93 farmers who gave a usable answer to the question: 'Is there more land available for gardens if you need it?', 77 replied positively while 16 said they had no more land. Likewise, the area of land that was once cropped and cannot be used any more was also significant. Fifty-two farmers answered 'yes' to this question. The reasons they gave for being unable to use the land included low production or poor fertility (14 responses), being fallowed (9), labour constraints (4), tribal fights/disputes (4), and land destroyed by flooding (2) or wild pigs (1). Other reasons given were that the land had been converted to a cemetery, it was regarded as surplus land, or the farm family was too lazy to work it.

The issue of land availability in the PNG highlands is a difficult one to report on. Visually, one gets the impression that land is almost unlimited, with vast areas covered with grassland and not apparently used. However, whenever producers are questioned about availability of land, the answer usually implies that land is limited. While the traditional farming system takes quite a lot of land out of production for extensive periods of time (rotations as long as 50–100 years have been noted), there seem to be other strong cultural controls that prevent apparently usable land from being cropped. Further information on this particular cultural system needs to be gathered.

Pest and disease resistance

The farmers were asked to comment on whether there were sweetpotato varieties that were resistant to pests and diseases. Among the respondents, 60 replied 'no', 9 were 'not sure', and 17 replied that there were cultivars that could withstand pests and diseases. These all have local names, including Big leaf, Dumabesta, Inkiso, Kalakai, Konoma, Mea, Nigl gai, Pink (variety for pigs), Pora west, Tiki, Waghibesta (mentioned several times), Yakii, carrot kaukau (recalling that *kaukau* is the pidgin name for sweetpotato), mamoli-wanmum, Onga nambo, Ten and Wanmum.

Yield and productivity

In order to get some understanding of the importance of fallowing in determining sweetpotato yields, the survey asked farmers how long was their garden under fallow last time. Responses ranged from less than 1 year to over 100 years. The range of answers is shown in Table 4.

When asked how they decided that the garden should be fallowed, most of the respondents identified poor plant growth (7), yield decline (30) or declining fertility (12), or closely related reasons. There were 19 farmers who did not answer this question and some of the replies from some of those who did were unusual. Thus, there were responses from 'don't know' and 'no reason' though to 'tribal warfare' and even to suggest that 'others made the decision'. In some cases the question was irrelevant since the land was continuously cropped or had never been cropped before, while in some instances the current operator did not know about the history of the land being cropped.

Table 4. Length of fallow period (years since the current garden was fallowed last time)

How many years was this garden under fallow last time?	Number of responses
Less than 1	2
1	8
2	10
3	5
4	2
5	5
6	2
8	2
9	2
10	2
12	3
15	5
16	2
20	6
30	4
40	8
50	4
100	2

In the vast majority of cases (77 out of 82 farmers who responded to the question) the fallow was regarded as a 'natural fallow'. In only four cases was there a specific attempt to manage the fallow and use improved practices. In one case manure was added in addition to fallow, being regarded as 'improved fallow'. Various grasses including pitpit (an edible grass species, *Setaria palmifolia*), kunai, elephant grass and other unnamed species were the most common form of fallow vegetation, followed by casuarina and other forms of forest regrowth. Most frequently (18 replies), the fallow vegetation, including all of the small number of improved fallows, was burnt prior to establishing the new crop in the garden. There were 17 farmers who did not answer this question. Many reasons for burning fallow vegetation were given by the farmers but many acknowledged that burning fallow vegetation made the work of planting a garden easier and quicker. Many farmers also recognised the effect of the release of nutrients and subsequent improved fertility from burning the previous vegetation.

Demographic information

The survey sought to provide various demographic information to describe this group of farmers.

Age distribution

Enumerators were asked to estimate the approximate age of the farmers in the survey in fairly broad categories: less than 25 years, 26–35 years, 36–45 years and over 45 years. The age distribution of farmers surveyed is shown in Table 5, with the majority being in the 26–35 and 36–45 years age categories.

Table 5. Age distribution of farmers surveyed

Estimate of farmer's age	Number of farmers
Less than 25 years	8
26–35 years	30
36–45 years	36
Over 45 years	19

Household size

The distribution of household size shown in Table 6 is centred around a household of two to four adults (more than half of the sample—47 households), with a long tail skewed towards larger households.

Respondents were also asked for the number of children under 14 years of age in the household and for how many children (older than Grade 7) they were paying school fees. The responses are presented in Table 7.

It is interesting to note that, of the 12 households who reported no children, only 7 also reported that they did not pay school fees, while one claimed to pay school fees for one child and another one for three. In addition, two households without children, and one with three children, did not report whether they paid school fees. The result is that row and column totals in the table do not correspond. The general observation is that about half of the households pay school fees for one or two children.

Table 6. Number of adults per household surveyed

Household size (number of adults over 14 years of age)	Number of households
1	5
2	23
3	16
4	16
5	9
6	6
7	5
8	2
9	3
10	2
11	1
13	1
All households[a]	89 Mean = 3.8 adults Median household size = 3 adults

[a] Eight households failed to nominate the number of adults in the household and were recorded as zero.

Some families can have four or even five children in school, representing a significant drain on family resources. In order to estimate annual household expenditure, Wilson and Hehona (2008) surveyed a sample of households with no off-farm source of income in EHP, WHP, East New Britain, Morobe and Milne Bay provinces. They estimated both fortnightly household spending and household expenditure on large items for the quarter after Christmas 2007. The figures from their survey are reproduced in Table 8.

The report noted that school fees were the largest item of expenditure in all provinces. In the period after Christmas 2007 they were equal to K704 in EHP, K736 in WHP and K667 for the whole sample. On an annualised basis (multiply numbers above by three), school fees are estimated to account for about K2,000 per household in 2007, representing more than 20% of average total annual household expenditure.

Conclusions

The analysis so far has been directed at understanding the context in which these PNG highlands farmers operate. In that regard the survey and its

Table 7. Number of children per household surveyed and number of school fees paid

Number of children	Number of households	Number of households paying school fees					
		0 children	1 child	2 children	3 children	4 children	> 4 children
0	12	7	2	0	1	0	0
1	27	10	11	4	1	1	0
2	19	7	4	6	1	1	0
3	17	5	5	2	4	0	0
4	9	4	0	3	1	0	1
5	5	1	0	2	1	0	1
6	2	1	0	1	0	0	0
8	2	0	1	1	0	0	0
10	1	0	0	0	1	0	0
Total	94	35	23	19	10	2	2

Table 8. Estimates of annual household expenditure in selected provinces

Income level	Eastern Highlands	Western Highlands	Total sample
Less than K2,000 (%)	5	2	8
K2,001–5,000 (%)	33	16	29
K5,001–10,000 (%)	38	42	32
More than K10,000 (%)	24	40	31
Mean (K)	7,815	10,389	9,149
Range (K)	1,412–26,770	1,060–49,954	582–50,161

Source: Adapted from Wilson and Hehona (2008)
Note: K = kina (PNG currency); the figures in the table include monetary customary payments but do not include the value of in-kind gifts and payments of fresh produce and livestock.

analysis have been quite successful. However, with farmers involved in such a diverse range of activities, and with a relatively small sample size for the survey, the aim of obtaining definite relationships between soil physical data and crop yields was difficult to realise.

Acknowledgments

The authors wish to acknowledge the help of all farmers who participated in the survey. Special thanks are also extended to the group leaders and enumerators who conducted the survey, sometimes under difficult conditions. We would like to express particular appreciation to Issac Taraken, Passinghan Igua, Debbie Kapal, Pus Wesis, Kud Sitango, Rainer Ratsch and Johnny Wemin. Without their help we would not have been able to present the data included in this paper.

Reference

Wilson T.D. and Hehona D. 2008. Report on 2008 FPDA socio-economic survey to board of directors. Fresh Produce Development Agency. Uniquest: Brisbane.

Biophysical constraints of sweetpotato-based cropping systems in the Papua New Guinea highlands

Gunnar Kirchhof[1], Issac T. Taraken[2], Akkinapally Ramakrishna[3], Rainer Ratsch[4] and Passinghan Igua[5]

Abstract

Population growth in the Paua New Guinea highlands is among the highest in developing countries. While the 2000 census reported a rate of 3%, more realistic estimates may be closer to 2%. Even if exact rates are unknown, the trend of expanding population will continue and could result in a doubling of the population to around 4 million in just over 3.5 decades. This will place unprecedented pressure on the land resource. However, it is still unclear if the resource-base 'soil' is indeed being depleted at a greater rate than it can be restored, given the potentially high productivity of the soils in the region. We surveyed farmers and assessed their gardens to evaluate if soil fertility and associated production of the most important staple food, sweetpotato, is indeed declining as a consequence of increasing land pressure, shortening fallow periods and a number of other factors, including pests and diseases. This survey included 95 farmers in four highlands provinces with an average of three districts in each province. Farmers' perceptions on soil fertility decline and management options were obtained. They were then asked to show us one garden that had recently been brought back into production after fallow, the 'new' fertile garden, and another garden that was about to go into fallow, the 'old' run-down garden. Plant and soil samples were collected from these two gardens to quantify changes as a result of cropping over time.

Introduction

Population growth in the Papua New Guinea (PNG) highlands is among the highest for developing countries. Exact rates of population growth are unreliable but they are likely to range between 3% (2000 PNG census) and 2% (R.M. Bourke, pers. comm.). Even in the absence of reliable growth rate data, the trend of increasing population is likely to continue in the near future and could result in doubling of the population to around 4 million in less than 3.5 decades. Despite high growth rates, the area under agricultural production has remained relatively stable (Bourke 1997, 2001), with accom-

1 School of Land Crop and Food Sciences, The University of Queensland, Brisbane Queensland 4072, Australia <g.kirchhof1@uq.edu.au>

2 National Agricultural Research Institute, Highlands Program, PO Box 210, Ukarumpa, SIL, Aiyura, Eastern Highlands Province, Papua New Guinea

3 National Agricultural Research Institute, Bubia, Lae, 411, Papua New Guinea

4 National Agricultural Research Institute, High Altitude Highlands Program, PO Box 120, Mt Hagen, Western Highlands Province, Papua New Guinea

5 The University of Goroka, Faculty of Science – Agricultural Education Section, Goroka, PO Box 1078, Eastern Highlands Province, Papua New Guinea

panying intensification of land use. Reports on changes in length of fallow periods are variable due to the extensive variety of land-use practices. Sem (1996) reports reduction from several decades to less than one decade. However, in some parts of the highlands fallow periods may still exceed 20 years, while in others areas, in particular the composting zone, very little fallowing is done (R.M. Bourke, pers. comm.). Overall, the length of fallow periods has undoubtedly decreased as population has expanded. In the long term this increasing population will lead to further shortening of fallow periods and lengthening of cropping cycles. There are already indications that the running down of soil fertility is impacting on the productivity of the main staple food in the area, sweetpotato, which accounts for 55–90% of land under arable agriculture. However, at this stage it is still unclear if the resource base 'soil' is indeed being depleted at a greater rate than it can be restored, given the potentially high productivity of the soils in the region.

Current soil management practices in sweetpotato-based cropping systems are particularly diverse and include fallow rotations with *Casuarina oligodon* in an agroforestry-type system. In a few cases other tree species are used and grass fallows are becoming increasingly common. During the production phase, mound tillage is very common. The large composted Engan mounds are the best-known soil management systems in semi-permanent gardens. Which system is most appropriate and adaptable to counter soil fertility decline is unclear. Further complications arise out of likely interactions between sweetpotato varieties, type of planting material used, soil fertility run-down or build-up during the fallow phase, and incidence of pests and diseases. The factors driving productivity decline and how fallow systems restore productivity are not well understood. This may be partly due to the variability of how the sweetpotato cropping and fallow systems are managed, but it is also likely to be a reflection of the variability of altitude, climate and soil types.

The trend towards more continuous cropping systems is linked to high population density, which in turn is related to proximity to urban centres and the increasing dominance of cash crops. However, it will be limited by the ability of the soil resource to remain productive. The driving force for the change from a cropping sequence to fallowing is yield decline, which in turn is attributed to soil fertility run-down. The length of fallowing and the subsequent length of cropping are very variable between and within regions as well as within farming communities. There is also considerable variation in population density, ranging from around 1 to > 100 people/km^2 in rural areas (e.g. Mountain Ok people in the highlands fringe at ~1.4/km^2; Huli in the central highlands at 20–150/km^2; Ohtsuka 1996). The extent of this socioeconomic variability, coupled with land resource and land management diversity, is extremely pronounced in PNG, and is undoubtedly a major reason why production constraints remain unclear. Few quantitative data exist presently to clearly link productivity decline to decreasing soil fertility and incidence of pests and diseases, and there is a clear need to address these issues within the context of biophysical and socioeconomic variability. Soil fertility 'hotspots' are useful indicators for potential future problems. They can provide the basis for targeted research to guide future intervention into the production systems.

Although farmers' informal observations on soil productivity are invariably based on quantifiable biophysical parameters, the link between the informal observation and the so-called hard biophysical data is often missing. An assessment of how farmers manage their agroforestry systems or crop production systems per se, why they do it in a particular manner and what yields they achieve would provide information and clarify the issue of productivity decline and what drives it.

The objective of this study was to provide the information necessary to appropriately design and correctly target future R&D investments into soil fertility and crop management in selected production systems of the PNG highlands, with special emphasis on sweetpotato systems.

Materials and methods

The target area and cropping systems were the highlands of PNG and sweetpotato systems, respectively. We used farmer surveys to assess their perception of soil fertility, and linked these soft data with biophysical observations and measurements to evaluate if soil fertility and associated production of the most important staple food, sweetpotato, are indeed declining as a consequence of increasing land pressure, shortening fallow periods and a number of other factors, including pests and diseases.

The following activities were selected to achieve our objective:

- development of a benchmark dataset delineating production constraints in relation to soil fertility, crop productivity and basic socioeconomic determinants of farmer decision-making
- conduct of a constraints analysis to delineate the maximum impact sites for R&D on productivity decline in soil fertility in the PNG highlands.

Farmer survey design

The methodology used is described and discussed in the paper by Kirchhof, Taraken, Ratsch, Kapal and Igua in these proceedings.

Soil and plant analysis

Leaf samples were wet ashed by nitric/perchloric acid digestion, and analysed for total concentrations of Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S and Zn using inductively coupled plasma mass spectroscopy (Varian Vista Pro ICPOES). Leaf C and N results were obtained by dry combustion furnace (LECO CNS 2000 analyser set at 1,100 °C). Soil samples were analysed for CEC and exchangeable cations by ammonium acetate extraction; the availability of micronutrients (Cu, Fe, Mn, Zn) by DTPA extraction, available SO_4-S, and Colwell P; total C and N by dry combustion; and EC and pH in a 1:5 water extract.

The database and statistical analysis

All data have been stored in an MS-Access database to allow fast and easy access to linked sub-datasets for statistical analysis. Additional links were added to interface the data from this study to the Mapping Agricultural Systems in Papua New Guinea (MASP) and Papua New Guinea Resource Information System (PNGRIS) databases. Minitab (release 14.13, 2004) was used for statistical analysis. The procedures adopted ranged from simple descriptive statistics and cross-tabulation to general linear models, regression procedures and multivariate analysis including principal component analysis. It is important to emphasise that the sampling procedure could not be random given the nature of the study. This and the small number of farmers surveyed limited the use of inferential statistics.

Results and discussion

Survey locations

The survey covered Eastern Highlands province (EHP), Simbu province (SP), Western Highlands province (WHP) and Enga province (EP), a north-west–south-east distance of around 250 km, and a south-west–north-east distance of 70 km. The altitude of the area surveyed ranged from around 1,400 m in the east to above 2,600 m in the west (Figure 1). The surveyed villages were evenly spread

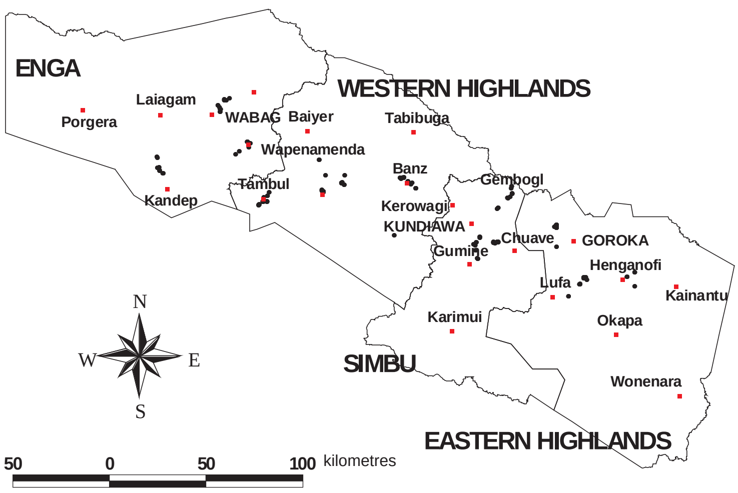

Figure 1. Survey locations
Note: black circles = survey points; red symbols = localities

across the four provinces but some clustering occurred within provinces. This could not be avoided due to constraints in terms of time required to arrange village visits, access and safety. Most survey locations were within easy access to the Highlands Highway, where most of the population resides. The average walking distance to the gardens was 10 minutes, but some gardens were up to 45 minutes from the original meeting place with the farmer. The median distance between village and provincial capital was 1 to 2 hours' drive for 30% of the villages, 30 minutes to 1 hour for 19%, and closer than 1 hour or further then 2 hours for the remainder. Most villages (50%) were between 30 minutes' and 1 hour's drive from the Highlands Highway, 19% were closer than half an hour and 31% further than 1 hour, with some exceeding a 2-hour trip. This spread of distances to landmarks showed that the farmers surveyed could be classified as typical highlands farmers. There was no bias towards villages that were located close to large urban centres, where industrial crop production may be more important than subsistence agriculture. At the same time it is important to emphasise that some bias towards easy access locations remained, which is typical for real-farm surveys.

Sweetpotato varieties

The total number of sweetpotato varieties observed in the gardens was around 120. The most common varieties, i.e. those that were present in more than 1.5% of all locations sampled, are listed in Table 1. However, there is some ambiguity in the naming of the varieties. For example, carrot kaukau and pumpkin kaukau could be the same. All these are traditional varieties and none is pathogen tested. The use of traditional and/or unclean planting material is certainly also a major contributing factor for low yield, but it is unclear if pathogen-tested varieties would suffer nutrient deficiencies comparable to those of traditional varieties. Due to the vast number of varieties grown in the highlands, it was not possible to relate any production parameter to variety.

Of the farmers who responded, 18% said that there were no pest- and disease-resistant sweetpotato varieties available, 10% were not sure and 10% listed several varieties that they had found were pest and disease resistant. The most commonly listed varieties were Waghi besta (23%) and Mea (8%), which were also among the varieties most commonly grown (Table 1). Given that farmers use these varieties and consider them superior in respect to resistance to pest and diseases, they should be used for further studies.

Table 1. Sweetpotato varieties in the highlands

Variety	Percentage of the total of 380 sweetpotato stations observed
Waghi besta	12.4
Carrot kaukau	4.4
Mea	3.2
Ten mapu	3.2
Wanmun	3.2
Lumba	2.9
Dumambu	1.9
Goroka gai	1.9
Maraaso	1.9
New ten	1.9
Liane more	1.6
Pumpkin kaukau	1.6

Sweetpotato yield trends and nutritional disorders

Tuber yield per area was obtained from yield of individual stations and the size and geometry of the planting systems. Due to the sequential harvesting methods in farmers' fields, the data presented refer to single harvest yields. In both old and new gardens single-harvest yields of up to 30 t/ha were observed, with a median yield of 6 t/ha (Figure 2). However, the yield distribution is clearly different between the old and new gardens. Although there are still high yields in the old gardens, most of the observations show a yield below 6 t/ha. This effect is more clearly visible after normalisation of yield figures by log-transformation, as shown in the box plot of Figure 3. Due to sequential harvesting, these yields were considerably lower than the average total yields of 13–15 t/ha for lowlands and highlands systems reported by Bourke and Vlassak (2004). The large variation in measured yields and cultivars prevented the use of covariates, such as number of previous harvests and age of sweetpotato plant, to estimate total yields. However, our observations are similar to both the 5 t/ha in a 2001 report by the Food and Agriculture Organization of the United Nations and to Elick Guaf's observations (pers. comm. 2006) from a European Union-funded project on early maturing sweetpotato varieties in the lowlands, executed by the National Agricultural Research Institute.

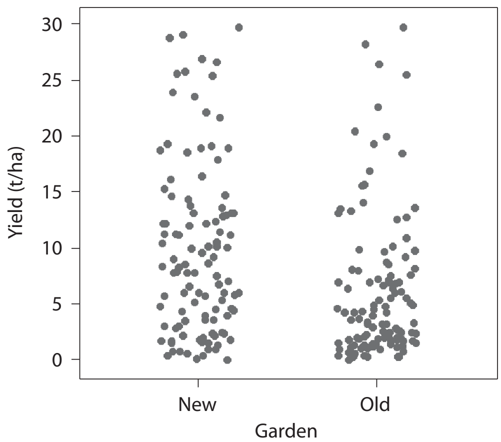

Figure 2. Single-harvest sweetpotato yields in new and old gardens (with random horizontal jitter added to the plot of the two garden types to make individual points more visible)

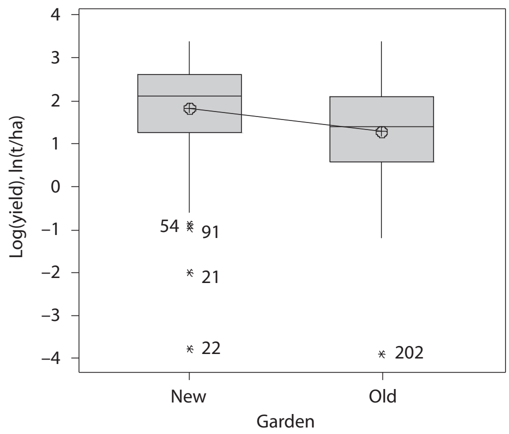

Figure 3. Box plot of normalised (log-transformed) yield in new and old gardens

Table 2. Leaf nutrient concentration for highlands sweetpotato

Plant nutrient	Critical concentration[a]	Adequate range[a]	Median for highlands sweetpotato
N[b] (%)	4.2	4.3–5.0	3.2
P (%)	0.22	0.26–0.45	0.2
K[b] (%)	2.6	2.8–6.0	2.2
Ca (%)	0.76	0.90–1.2	1.0
Mg (%)	0.12	0.15–0.35	0.4
S (%)	0.34	0.35–0.45	0.3
B[c] (ppm)	40	50–200	36.4
Mn (ppm)	19	26–500	49.9
Zn (ppm)	11	30–60	15.8
Cu (ppm)	4–5	5–14	10.5

[a] levels after O'Sullivan et al. (1997); [b] slightly lower concentrations in old gardens; [c] slightly higher concentrations in old garden

Likely causes for the low yields were nutrient deficiencies, pests, diseases and the presence of viruses in the sweetpotato planting material (traditional and improved). Nutrient deficiencies were evident despite the predominantly volcanic ash soils in the highlands being regarded as very fertile. Based on threshold levels for nutrient deficiencies published by O'Sullivan et al. (1997), more than 50% of sweetpotato tissue samples collected during this study were deficient in N, P, K, S and B (Table 2). Simple comparisons for means or medians in plant tissue concentrations did not show significant differences between old and new gardens. However, the distribution of plant tissue concentrations for N and K was different between gardens (Figures 4 and 5). Due to the skewed distribution of observations, they were normalised for further comparison. Using the median N (3.2%) for highlands sweetpotato (Table 2) and comparing how many samples from new and old gardens occurred at that median, there was a 15% difference between new and old gardens and a corresponding 10% difference for K concentrations. These comparisons strongly suggest that N and K levels in old gardens were lower compared to new gardens. However, these statistical procedures did not show any differences for the other nutrients.

The differences between new and old gardens became more evident when analysing N and K tissue concentrations together (clustering) rather than in isolation, as above. Clustering without complex data transformation was particularly appropriate for N and K concentrations because they are numerically similar. The percentage of N and K together clearly showed that, at the lower level of K concentration, old gardens tend to have lower N and new gardens tend to have higher N (Figure 6). The corresponding chi-square test was significant ($P < 0.01$).

This type of cluster analysis is useful to assess interactions between nutrients and should be expanded to include the full breadth of nutrients. However, its application for the current data is limited given the vast number of sweetpotato varieties we sampled at different physiological ages, including the complex interaction between leaf nutrient concentrations and root thickening. Detailed studies of nutrient interactions will be particularly useful for new and pathogen-tested varieties. Eliminating the variety effect and monitoring root thickening in relation to leaf nutrient concentration under more controlled conditions is a potential vehicle for assessment, and hence being able to improve sweetpotato productivity. At this stage we were not able to show that plant nutrient differences significantly contributed to the difference in yields.

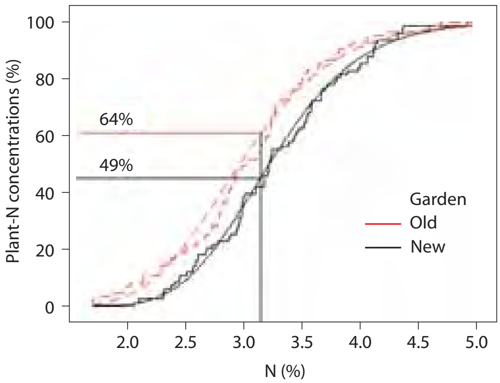

Figure 4. Distribution of plant-N concentrations for new and old gardens with percentage of values observed at the median concentration of 3.2% N

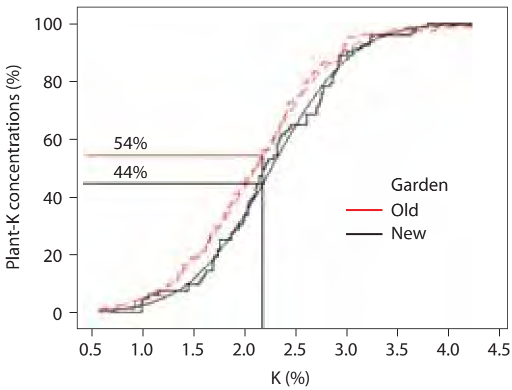

Figure 5. Distribution of plant-K concentrations for new and old gardens with percentage of values observed at the median concentration of 2.2% K

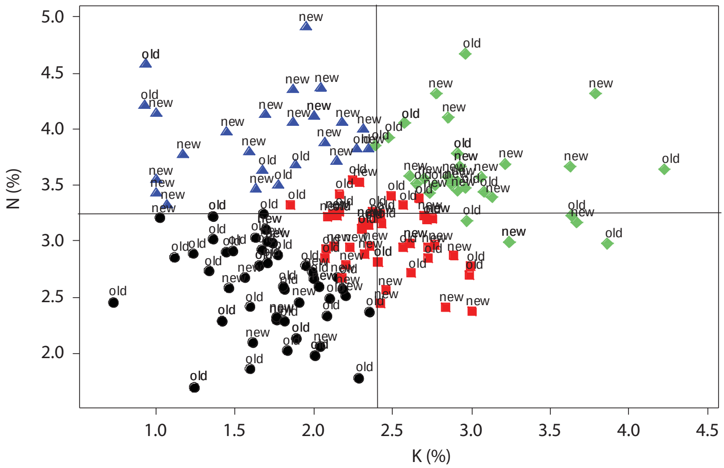

Figure 6. Cluster diagram of N and K plant tissue concentrations (different colours correspond to different N–K clusters)

Although yields were low, there were subtle differences between the new and the old gardens. The median yield in the old garden was 4 t/ha and in the new garden 8 t/ha. Given the very large variation in yield, it is more realistic to assess expected yield difference between the gardens. Within a 95% probability the expected yield difference ranged from 2 to 8 t/ha. This large difference clearly showed substantial changes in production potential when gardens are being continuously used for sweetpotato production. If the factors driving yield in new gardens are known and can be managed, substantial yield reductions as gardens age can be avoided, even within traditional sweetpotato varieties.

Tuber mass per vine behaved similarly to yield in t/ha. In the old gardens, however, there were groups of old and small tubers that were also affected by obvious weevil damage. This suggested that weevils are a contributing factor to low yields in old gardens. Tuber counts were consistent between the old and new gardens (Table 3) but the old gardens had smaller size tubers than the new gardens (Table 4).

Pests and diseases: the cause of low yields in old gardens?

There was no difference in the degree of insect infestation of tubers between old and new gardens (Table 5). There was also no significant difference

Table 3. Tabulated statistics for tuber counts

Garden		Tuber count			
		<6	<11	<15	All
New	Observed counts	87	18	3	108
	Expected counts	90.0	15.1	2.9	108.0
Old	Observed counts	98	13	3	114
	Expected counts	95.0	15.9	3.1	114.0
All	Observed counts	185	31	6	222
	Expected counts	185.0	31.0	6.0	222.0

Note: Pearson chi-square = 1.299, DF = 2, $P = 0.52$

Table 4. Tabulated statistics for tuber sizes

Garden		Tuber size			
		Very small	Small	Medium	All
New	Observed counts	55	41	12	108
	Expected counts	66.5	33.2	8.3	108.0
Old	Observed counts	81	27	5	113
	Expected counts	69.5	34.8	8.7	113.0
All	Observed counts	136	68	17	221
	Expected counts	136.0	68.0	17.0	221.0

Note: Pearson chi-square = 10.628, DF = 2, $P = 0.005$

Table 5. Tabulated statistics for tuber insect infestation

Garden		Presence of insect holes in tubers				
		None	Few, just detectable	Many holes in tubers	Obvious, easily visible	All
New	Observed counts	96	9	2	1	108
	Expected counts	89.8	14.8	2.0	1.5	108.0
Old	Observed counts	86	21	2	2	111
	Expected counts	92.3	15.2	2.0	1.5	111.0
All	Observed counts	182	30	4	3	219
	Expected counts	182.0	30.0	4.0	3.0	219.0

Note: Pearson chi-square = 5.643, DF = 3, $P = 0.13$

in the expected percentage of cracked tubers between old and new gardens (*P*-value > 7%). Tuber cracking may be associated with age of the sweet-potato plant and tuber size. For example, 3 out of the 11 cracked tubers in the old gardens were harvested from old vines (age > 15 months) and all the observed cracked tubers were from vines with a small number of tubers (counts < 7). Additionally, 8 out of the 11 cracked tubers in the old gardens had insect holes. However, the average yield of vines with cracked tubers was higher in the new gardens, indicating that new gardens produce higher yields even though the tubers may have cracks (which may be related to excessive N supply in the new gardens).

Nematode counts ranged from 0 to 160 and were skewed towards the small tuber numbers in both old and new gardens. Further statistical analysis required normalisation of data, which was achieved by applying a square-root transform. Despite higher yields, the new gardens tended to have larger counts of nematodes (Figure 7, *P* = 0.05), suggesting either that the nematodes could be non-parasitic or that the infestation is not a critical factor driving yield.

The distribution of weevils was significantly different between the old and new gardens, with the chance of weevils or larvae being present being significantly higher in old gardens (Table 6). Weevil infestation also increased with the number of times

Table 6. Tabulated statistics for weevil infestation

Garden		Weevil infestation			
		No infestation	Larvae are present	Tunnels are visible or weevils are present	All
New	Observed counts	91	12	5	108
	Expected counts	82.4	14.3	11.3	108.0
Old	Observed counts	76	17	18	111
	Expected counts	84.6	14.7	11.7	111.0
All	Observed counts	167	29	23	219
	Expected counts	167.0	29.0	23.0	219.0

Note: Pearson chi-square = 9.518, DF = 2, *P* = 0.009; likelihood ratio chi-square = 9.974, DF = 2, *P* = 0.007

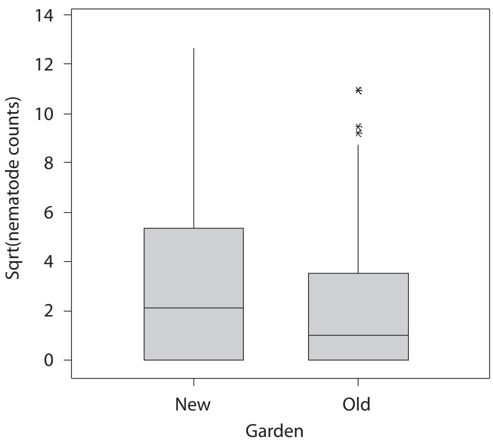

Figure 7. Box plot of normalised (square root-transformed) nematode counts in roots of new and old gardens

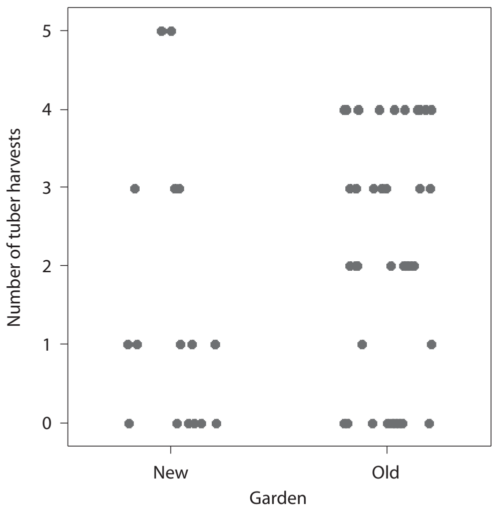

Figure 8. The influence of number of harvests on weevil infestation in new and old gardens (with random horizontal jitter added to the plot for the two garden types to make individual points more visible)

old gardens were harvested (Figure 8). Combining the effect of garden type with weevil infestation showed that differences between new and old gardens persisted even after adjusting the yields for weevil infestation.

Location and soil properties

The observation of deficient levels of P and S in plant tissue samples did not match the availability of soil nutrients that we measured. Except for B, our soil analysis suggested that the available micronutrients should not limit production (Table 7). Neither P nor S levels could be linked to yield decline or garden type. Altitude did not affect soil nutrient levels of B, S, P and K.

Table 7. Soil nutrient levels of PNG highlands soils in relation to critical levels

Available soil nutrient concentration (ppm)	Low or critical level	Median for highlands soils
Colwell P	<20.0	47.6
S	<2.0	6.5
Cu	<0.3	6.9
Mn	<1.0	8.3
Zn	<0.5	1.5
B	<0.5	0.2

The amount of soil organic matter is often used as an indicator of soil fertility. However, actual soil organic matter is rarely measured due to analytical cost and difficulties. The most common surrogate for soil organic matter is soil organic carbon (SOC), which is usually converted to soil organic matter by multiplying by 1.72. However, this conversion factor is not the same for all soils.

The range of SOC that we observed was 0.5% to 21%, with a median of 4.5%. At first these high SOC levels suggest that soil fertility should not be limiting. This initial assumption holds because larger SOC values were generally associated with higher rainfall and altitude, where sweetpotato yields indeed tended to be highest. High altitude, and cool and humid climate, tends to cause a build-up of SOC. Separating altitudes into low (< 2,200 m) and high (> 2,200 m) confirmed that soils at high altitudes have considerably higher total N and SOC (N ~0.9%, SOC ~12%) than those at lower altitudes (N ~0.6%, SOC ~ 5%). However, yields overall were very low (see Figure 2), which is in contrast to the expectation based on SOC levels only. Further, there is the large yield difference between new and old gardens, which was not related to differences in SOC between gardens. It is also important to note that yield differences between old and new gardens persisted after adjusting yields for altitude.

This is of particular interest because SOC as an important indicator of soil health and fertility evidently does not apply to Andisols. Besides the proportion of SOC that contributes to nutrient availability and nutrient cycling (i.e. soil fertility), these soils contain two inert carbon fractions that do not affect soil fertility: (i) allophanes with a high percentage of humic Fe–Al complexes and (ii) charcoal. Although total amounts of these inert fractions are not known at this stage, charcoal particles < 1 mm were clearly identifiable under a light microscope (Figure 9).

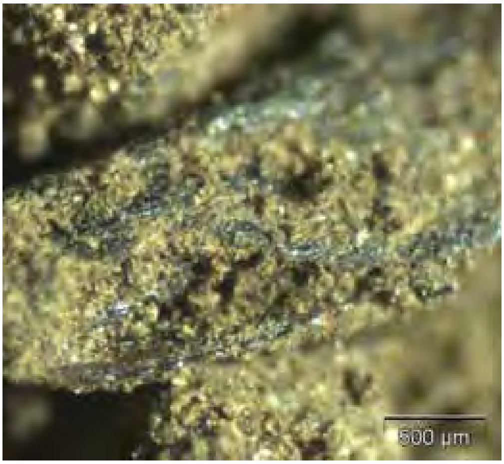

Figure 9. Charcoal in soil with 10% soil organic carbon

The carbon:nitrogen ratio (C:N) is often used as an indicator of nutrient availability. The C:N of recalcitrant humic substances or humic Fe–Al complexes tends to be just above 10, while the charcoal does not contain any N (i.e. C:N is infinite). Micro-charcoal or charred plant material with very long residence times is common in Andisols, in particular those where burning is, or has been, a common practice (Golchin et al. 1997; Basile-Doelsch et al. 2005). An adequate C:N range where nutrient cycling is not limiting is usually between ~15 and ~30. In our study we recorded a range of 7–21, with a median of 13, but this was the average for all fractions. The difficulty of using whole soil C:N as an indicator for soil quality has been highlighted by Pineiro et al. (2006). In this study substantial amounts of charcoal would increase the average C:N of the remaining fraction, but substantial amounts of recalcitrant C would reduce the C:N of the remaining C-fraction responsible for nutrient cycling and soil fertility.

It is most likely that the presence of a lighter fraction of less stable and decomposed organic matter and plant residue is the main driver for nutrient cycling on these soils. But the breakdown of the light fraction organic material is likely to be very fast in the highlands climate. Coupled with frequent rainfall, nutrient losses beyond the root zone are also likely. In other words, N turnover rates of stable organic matter are likely to be very low as the release of N depends on the presence of a light fraction of organic matter or compostable plant material. The expected low C:N of the active fraction is therefore likely to cause an imbalance between plant nutrient demand and soil nutrient release. This is particularly so for N in old gardens, where lower amounts of light fraction N can be expected compared to new gardens. Due to the low density of the light fraction, substantial volumes of plant residue would be required to ensure ongoing nutrient cycling. This may have also led to the development of the large composted Engan mounds as a basis for a reasonable permanent cropping system.

Considerable process-based research effort has gone into attempts to understand organic matter dynamics and how the SOC fraction influences N release. Some progress has been made but results are generally only applicable to the sites where the research has been conducted. One example is the use of $KMnO_4$ to quantify the size of the active (i.e. labile or 'easy oxidisable') SOC fraction developed by Blair et al. (1995). The problem with this commonly used method is the close relation between total SOC and labile C. One fraction can be predicted from the other with high precision ($r^2 = 0.94$, $n = 227$; Kirchhof et al. 2000), which raises the question of why it is measured in the first place. The issue of soil organic matter in a soil health context remains unresolved. Although similar data from controlled field experiments have shown links between soil organic matter and productivity (Blair and Crocker 2000), the wide range of farmers' practices probably masks these effects in this survey, in particular for sweetpotato systems. An in-depth understanding of nutrient cycling on PNG highlands soils is needed as a rational basis before appropriate soil and nutrient management techniques can be derived.

A further compounding effect is the influence of available soil N during the different stages of sweetpotato yield formation. While the first 3–6 weeks of planting require low amounts of available soil N to initiate root thickening, higher amounts are needed later to ensure ongoing root thickening (tuber formation). We were only able to assess total N during root thickening, which has no relation to plant available N. It may, however, be an approximate indicator of potentially available N at the time but, due to the possible fast turnover rates of available N in these soils, it is not known how much available N after planting impacted on the yields we observed. This is in addition to the lack of relation we observed between yield and other major soil nutrients plus B. To develop and implement improved nutrient and water management options for sweetpotato-based cropping systems in the PNG highlands, it will be necessary to gain a thorough understanding of nutrient interaction and sweetpotato physiology, in particular in light of the expected uptake of new, improved and pathogen-tested varieties.

Validity of standard soil analysis for Andisols

Except for some limestone-derived soils in SP, most of the highlands soils are assumed to have been influenced, if not formed from, volcanic ash (tephra). This parent material is responsible for several unique properties of these Andisols (US taxonomy, since 1992) or Andosols (FAO taxonomy, since 1974). However, the PNGRIS database lists the occurrence of 9% of the soils in the area we surveyed as Andisols (despite the fact that the US Soil Taxonomy did not recognise the Andisol order until 1975). Within the surveyed area Inceptisols (21%), Mollisols (11%) and Histosols (10%) could well be reclassified as Andisols, and even some Entisols (16%) could be Andisols. It is reasonable to assume that, due to the continual and recent reclassification of the Andisol soil order, many highlands soils may have been misclassified as other than volcanic ash soils. However, irrespective of the classification conundrum, weathered volcanic ash and accompanying allophanes are likely to be abundant in these soils, even if they were initially derived from other geologic substrates. The extraordinarily high levels of SOC support this hypothesis.

The most important properties that set tephra-derived soils apart from other soil orders is their domination by a low-order crystalline structure. This is due to the fast weathering of volcanic glass in a wet climate, which prevents the formation of highly crystalline, ordered clay minerals. Clay-sized particles are governed by variably charged clays, which can also have considerable anion exchange capacity. The charge properties affect not only the availability of cations but also anions such as P and N. High levels of Fe and Al in the mineral structure further complicate and hasten the potential fixation of P. The charge properties on their own make the use of most of the standard soil chemical analysis techniques questionable. This is of particular importance because all standard soil analysis is done on air-dried soil, and air-drying of volcanic ash soils causes irreversible changes in the clay fraction microstructure (Buytaert et al. 2006). This phenomenon is best illustrated by a comparison by Shoji et al. (1993) of the soil water content at –1.5 MPa (permanent wilting point) from two identical soil samples, one determined after air-drying and the other on field-moist soils. They reported absolute differences between the dried and fresh soil samples of 50% soil water content. It is therefore not surprising that our soil analysis results do not relate well to crop performance. Given the sensitivity of these soils to drying, it is also questionable if any soil test based on air-dried soils could give a meaningful result. It seems far more sensible to assess the soil nutrient concentration of these soils in situ and avoid laboratory artefacts altogether.

Farmer characteristics and crop production

Farmers listed around 30 different types of cash income source. The vast majority of income types were related to agriculture, with only about 4% of the responses stating non-agricultural sources (e.g. public motor vehicle, guesthouse or labour). Most farmers (55%) listed fruit and vegetables as an income source, while coffee as a supplementary income was reported by 22% of the farmers. Livestock was listed by only 7% as a cash-generating commodity. Sweetpotato also played an important role for income generation to 12% of the farmers.

About two-thirds of the farmers were opportunistic or small suppliers of sweetpotato at markets, 17% did not sell sweetpotato, and 16% considered themselves large suppliers (Table 8). This showed that sweetpotato is a marketable good over and above being a subsistence crop. The importance of sweetpotato as a cash crop and a staple food suggested that either farmers prefer to produce higher value cash crops and purchase their staples, or they are not able to meet their demand through own supply. The former may apply to farmers close to urban centres but the latter is more likely in rural areas where low sweetpotato yields, in particular in old gardens, may have created a market niche. Although the data in Table 8 do not provide information about total quantities of sweetpotato sold or consumed, they clearly identify two main groups of suppliers: those who produce commercially and those who supplement their income from sweetpotato sales. The regular sellers and, in particular, the commercial suppliers are likely to be driven by market signals, and may have some capacity to invest either in fertilisers or other resources such as labour. These two groups are likely to gain the greatest benefit from research leading to an improved understanding of soil management and fertility management in sweetpotato systems. They should be targeted and included in future research initiatives.

Until the outbreak of potato blight in the highlands, Irish potato played an important role as a cash crop, in particular in the higher altitude areas of EP and WHP. Irish potato, together with old sweetpotato varieties, were the most commonly reported crops that are no longer grown (Table 9). These were also the most important new crops farmers wished to

Table 8. Sweetpotato as a cash crop

Method of sweetpotato marketing	Percentage of farmers
Does not sell sweetpotato	16.5
Opportunistic supplier, selling surplus only; small quantities on irregular basis	38.5
Small quantities regularly	8.8
Small quantities (< 100 kg or 50K) occasionally (< 3 times a year)	19.8
Larger quantities (> 100 kg or 50K) occasionally (< 3 times a year)	7.7
Commercial supplier, selling significant quantities on regular basis	8.8

Note: K = kina (PNG currency)

grow in the future (sweetpotato 8%, Irish potato 17%, of farmers' responses). Among the wide variety of potential new crops, carrot was the most often mentioned (11%).

Farmers' perceptions of soil fertility and land shortage

Despite our expectation that land availability was limited, farmers overwhelmingly noted that there is land available for agricultural purposes, with 83% of the farmers in EHP, 96% in SP, 83% in EP and 63% in WHP responding 'yes' to this question. However, this does not imply that expansion of land is possible or feasible. It is probably a reflection of a general impression that vast areas of land are not used for agricultural production, in particular in remote areas where lack of infrastructure prevents access and hence expansion. The farmers' assessment of land availability was not related to family characteristics such as family size or number of children.

While land availability per se did not appear to be a problem for farmers, there was agreement between them that irreversibly degraded land exists. However, responses were quite different between provinces. Except in EP, the majority of farmers (80% in EHP, 64% in SP and 62% in WHP but only 29% in EP) were aware of degraded land. The latter statistic suggested that the practice of Engan farmers in using large composted mounds in a semi-permanent system prevents degradation and is more appropriate than the soil management systems used elsewhere in the highlands. Farmers listed fallowing (23%) and low fertility/suitability (26%) as causes of land being unproductive. These causes relate to low productivity or the potential restoration of low productivity; that is, the reason why land is not productive is related to low soil fertility. There were no differences between provinces.

There was a clear sense from the farmers that fallow periods are shortening (Table 10). This was more pronounced in old gardens, possibly due to a bias in farmers' perceptions of how much time the old garden can be given for a fallow period. The lengths of fallow period reported were most commonly less then 12 months (EHP 28% of responses, EP 64% and

Table 9. Farmers' responses (%) to changes in crop production and identification of crops they had ceased producing

Stopped growing crops?	EHP (*n* = 22)	SP (*n* = 22)	WHP (*n* = 24)	EP (*n* = 26)	Total (*n* = 94)
No	50.0	59.1	33.3	26.9	41.5
Yes	50.0	40.9	66.7	73.1	58.5
Total (chi-square = 6.4; *P* = 0.094)	100.0	100.0	100.0	100.0	100.0
Crops no longer produced	Number of growers				
Big beans		1			1
Cardamom	1				1
Carrots				1	1
Corn				1	1
Old sweetpotato varieties	2	1		9	12
Onions				1	1
Pineapples			2		2
Pitpit	3	1			1
Potatoes	1	2	13	12	28
Rice		1			1
Taro	1				1
Vegetables			1	1	2
Winged beans				1	1
Yams	3				3
Cabbages				2	2
Mami				1	1
Peanuts			1		1

Note: EHP = Eastern Highlands province; SP = Simbu province; WHP = Western Highlands province; EP = Enga province

WHP 57%) except for SP, where farmers most commonly listed more then 5-year fallow periods (50% of responses). This may be attributed to the generally poorer soils in the area, which may need longer fallow periods to recover. The most commonly listed causes for the shortening of the fallow period were land shortage (23% of responses), population pressure (11%) and a combination of population pressure and land availability (17%). The latter is somehow ambiguous because land availability was considered not to be a problem when the question of whether land is available for agricultural expansion was asked. The contradictory response is probably a result of the farmers' interpretation of the question. Land may indeed appear unlimited in the overall context of the greater area, but in individual farmers' perceptions it may be limited.

The farmers' collective response to the survey was a strong willingness to cooperate. They were eager to collaborate as partners and requested feedback from our work. Farmers related yield reduction to soil fertility decline—their observation was that yields in older gardens were lower than in newer gardens, and they blamed poor soil conditions for this decline. As a control question to assess farmers' ability to judge soil fertility, we asked them whether they could grow corn or common bean. The responses to both questions were closely related—farmers thought that the new gardens were more suitable for growing corn or common bean than the old gardens (corn $P = 0.04$, bean $P = 0.08$). However, the farmers' soil fertility assessment was not related to the sweetpotato yields we observed, but supported the argument that soil fertility differences exist between old and new gardens.

Soil fertility management and planting systems

Yields in the new gardens were not affected by planting systems, but yields in the old gardens were highest if farmers used large mounds (Figure 10). Mounds more than 70 cm high were associated with fertility management such as composting in both old and new gardens, and with short fallow in old gardens. The analysis of high mounds showed no difference in yield between old and new gardens ($P > 0.10$), whereas the analysis of yield in other planting systems showed that there was a significant difference between old and new gardens ($P < 0.01$). Moreover, in both old and new gardens the high mounds produce significantly higher yield than all other systems ($P < 0.05$).

The high mounds system was mostly associated with high altitude. However, the difference in planting systems does not explain all the effects of altitude ($P < 0.01$), with rainfall having an additional effect on the expected yield. The rainfall, the planting systems in old and new gardens, and altitude effects together explain 25% of the observed variability in yield. In the planting systems other than the high mound system, the rainfall and altitude effects and the difference between the old and new gardens explain 30% of the observed variability in yield.

The use of MASP and PNGRIS databases may be limited in delineating garden-scale soil management practices due to their scale. For example, the relief, slope and planting systems reported by our enumerators did not match the corresponding variables listed in the GIS systems. They showed much

Table 10. Farmers' responses (%) to change in fallow length in new and old gardens

Province	Garden	Length of fallow			
		Don't know	Longer	No change	Shorter
EHP	New	0	31.3	0	68.8
	Old	0	12.5	0	87.5
EP	New	17.4	17.4	26.1	39.1
	Old	0	0	41.7	58.3
SP	New	5.9	35.3	0	58.8
	Old	0	26.7	6.7	66.7
WHP	New	21.7	26.1	4.4	47.8
	Old	6.7	0	0	93.3

Note: EHP = Eastern Highlands province; SP = Simbu province; WHP = Western Highlands province; EP = Enga province greater variability within landforms than the GIS systems suggest. For example, rugged terrain may still contain flat gardens and management of gardens depends on the smaller scale. It is important to use the GIS coverage in conjunction with plot-scale variability to devise appropriate soil management options.

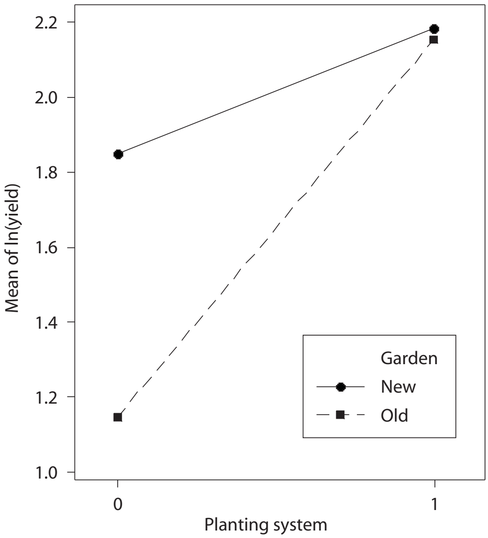

Figure 10. Effect of planting system on normalised sweetpotato yield in old and new gardens
Note: Planting system: 0 = mounds higher than 70 cm; 1 = other planting systems

Summary and conclusions

The survey showed considerable yield differences between new and old gardens. Some of this yield decline was related to weevil infestation but, more importantly, it was associated with soil fertility drivers, irrespective of planting systems, altitude and rainfall. Large mounds and composting were the planting systems and soil fertility management practices, respectively, with the highest yield and the smallest yield decline under continuous sweetpotato cropping. However, more than 50% of sweetpotato tissue samples were deficient in N, P, K, S and B despite the soils in the highlands being regarded as fertile due to their high levels of organic matter. Unclean, virus-infected planting material was also a major contributing factor in low yields, but it is unclear if pathogen-tested varieties would suffer nutrient deficiencies compared to traditional varieties, and if superior yields of new pathogen-tested varieties would exacerbate the problem of soil productivity decline in the absence of external fertiliser input.

Soil fertility indicators as measured on soil samples were not related to sweetpotato yield. This is of particular interest because soil organic carbon is often regarded as an important indicator of soil health and fertility but, evidently, this does not necessarily apply to the high organic matter content soils in the PNG highlands. The mechanism for low soil fertility in this case is thought to be related to the presence of allophonic materials with a high percentage of humic Fe–Al complexes and charcoal from burning, which has been prevalent since the PNG highlands were settled for agriculture. Poor C:N ratios, either too low due to the presence of humic Fe–Al complexes or too high due to the presence of charcoal, are likely to result in low mineralisation rates if fresh, undecomposed plant material is absent. A compounding effect for sweetpotato is the influence of available soil N during the different stages of sweetpotato yield formation.

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References

Basile-Doelsch I., Amundson R., Stone W.E.E., Masiello C.A., Bottero J.Y., Colin F., Masin F., Borschneck D. and Meunier J.D. 2005. Mineralogical control of organic carbon dynamics in a volcanic ash soil on La Reunion. European Journal of Soil Science 56, 689–703.

Blair G.J., Lefroy R.D.B. and Lisle L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Australian Journal of Agricultural Research 46, 1459–1466.

Blair N. and Crocker G.J. 2000. Crop rotation effects on soil organic carbon and physical fertility of two Australian soils. Australian Journal of Soil Research 38, 71–84.

Bourke R.M. 1997. Management of fallow species composition with tree planting in Papua New Guinea. Resource Management in Asia Pacific Seminar Series, working papers 1997/5, 1–11.

Bourke R.M. 2001. Intensification of agricultural systems in Papua New Guinea. Asia Pacific Viewpoint 42, 221–238.

Bourke R.M. and Vlassak V. 2004. Estimates of food crop production in Papua New Guinea. Land Management Group, The Australian National University: Canberra. At: <http://rspas.anu.edu.au/lmg/pubs/estimates_ food_crop.pdf>.

Buytaert W., Deckers J. and Wyseure G. 2006. Description and classification of nonallophanic Andosols in south Ecuadorian alpine grasslands (paramo). Geomorphology 73, 207–221.

Golchin A., Baldock J.A., Clarke P., Higashi T. and Oades J.M. 1997. The effects of vegetation and burning on the chemical composition of soil organic matter of a volcanic ash soil as shown by C-13 NMR spectroscopy. 2: Density fractions. Geoderma 76, 175–192.

Kirchhof G., Daniells I. and Schwenke G. 2000. Changing tillage methods and their effect on soil structure on major dryland cropping soils in north western New South Wales, Australia. In 'Tillage at the threshold of the 21st century: looking ahead', Proceedings of the 5th Conference of the International Soil Tillage Research Organisation (ISTRO), Fort Worth, Texas, USA, 2–7 July 2000.

Ohtsuka R. 1996. Agricultural sustainability and food in Papua New Guinea. In 'Population, land management and environmental change', ed. by Juha I. Uitto and Akiko Ono. The UNU global environmental Forum IV. The United Nations University: Tokyo, Japan. At: <http://www.unu.edu/unupress/unupbooks/uu03pe/uu03pe00.htm#Contents>. Accessed June 2005.

O'Sullivan J.N., Asher C.J. and Blamey F.P.C. 1997. Nutrient disorders of sweet potato. ACIAR Monograph No. 48. ACIAR: Canberra.

Pineiro G., Oesterheld M., Batista W.B. and Paruelo J.M. 2006. Opposite changes of whole-soil vs. pools C:N ratios: a case of Simpson's paradox with implications on nitrogen cycling. Global Change Biology 12, 804–809.

Sem G., 1996. Land-use change and population in Papua New Guinea. In 'Population, land management and environmental change', ed. by J.I. Uitto and O. Akiko. The UNU Global Environmental Forum IV. The United Nations University: Tokyo, Japan. At: <http://www.unu.edu/unupress/unupbooks/uu03pe/uu03pe00.htm#Contents>. Accessed June 2005.

Shoji S., Dahlgren R. and Nanzyo M. 1993. Morphology of volcanic ash soils. Pp. 7–35 in 'Volcanic ash soils: developments in soil science', ed. by S. Shoji, M. Nanzyo and R. Dahlgren.

An evaluation of nutritional constraints on sweetpotato production in the Papua New Guinea highlands using the Diagnosis and Recommendation Integrated System (DRIS)

John Bailey[1]

Abstract

Soil fertility in the highlands of Papua New Guinea has been declining for some time, and action is urgently needed to reverse the trend if basic food and income requirements of the highlands populations are to be met. In addressing this problem it is important to first identify the nutrients most limiting to crop production in different situations and regions. With this in mind, crop data generated in a recent Australian Centre for International Agricultural Research-funded soil fertility project were subjected to a new system of data interpretation, the Diagnosis and Recommendation Integrated System (DRIS), to try to identify the main nutritional constraints on sweetpotato production in different garden types (old and new) and on different soil types (volcanic and non-volcanic) throughout the highlands.

The results suggested that potassium (K) deficiency was the primary cause of poor crop production. affecting almost one-third of sweetpotato gardens, but was more of a problem in old gardens than in new. Phosphorus (P) deficiency was also important on volcanic soils and sulfur (S) deficiency on non-volcanic soils. These latter deficiencies, however, were at least as prevalent in new gardens as in old. Important factors contributing to K and S depletion from garden systems were removal of K- and S-rich vines from cultivation areas, shortening of fallow periods and burning of weed and crop residues, the latter releasing S as SO_2 to the atmosphere. Correction of K and S deficiencies may require the recycling of old vines back into sweetpotato cultivation areas and the adoption of a zero-burn policy for fallow management. Correction of P deficiency may necessitate the use of P-accumulating fallow species, e.g. wild Mexican sunflower (*Tithonia diversifolia*).

Introduction

The population in the highlands of Papua New Guinea (PNG) is increasing by about 3% each year (2000 PNG census), thereby placing unprecedented pressure on the land resource for food and cash-crop production. A recent scoping study and survey of the central highlands provinces with regard to sweetpotato production (Australian Centre for International Agricultural Research (ACIAR) project SMCN/2005/043)[2] confirmed that farmers are aware of the decline in soil fertility and are concerned about its implications. It is incumbent on agricultural researchers to come up with solutions to this soil fertility problem so that the basic food and income requirements of the highlands populations can be met.

[1] National Agricultural Research Institute, Highlands Programme, Aiyura, PO Box 210, Ukarumpa SIL, Eastern Highlands Province, Papua New Guinea <john.bailey@nari.org.pg>

[2] ACIAR project SMCN/2005/043: ‘Analysis of biophysical and socioeconomic constraints to soil fertility management in the PNG highlands’

In the past, researchers have sought to identify the causes of crop underperformance using 'critical concentrations' of nutrients in crop tissue as diagnostic criteria. These criteria have been evaluated for a wide range of crops including sweetpotato (O'Sullivan et al. 1997). In the latter case, however, they were derived using leaf nutrient concentrations and the yields of sweetpotato vine cuttings grown for just 4 weeks in solution culture (O'Sullivan et al. 1997). Therefore, although useful diagnostics for young plants channelling energy and resources into vine production, they may or may not equate with the critical leaf nutrient concentrations needed to support 90% of maximum tuber production in mature plants. Apart from this, the critical concentration approach is somewhat erroneous in that 'critical nutrient concentrations' are not independent diagnostics, but can vary in magnitude as the background concentrations of other nutrients increase or decrease in crop tissue (Walworth and Sumner 1986; Bailey 1993). Recognition of this problem has led to the use of nutrient ratio pairs (e.g. N:K and N:S) in certain situations, rather than single nutrient concentrations, as more reliable diagnostic criteria (Stevens and Watson 1986; Walworth and Sumner 1986; Dampney 1992). However, this latter approach only assesses the sufficiency status of a single nutrient (e.g. K) on the basis of its abundance relative to one other nutrient (e.g. N), and makes no allowance for potential imbalances with other essential nutrients.

The Diagnosis and Recommendation Integrated System (DRIS) goes much further than the single nutrient ratio approach in that it employs a minimum of three nutrient ratios per diagnosis, and often as many as six or seven (Walworth and Sumner 1987). In other words, the sufficiency status of an individual nutrient in plant tissue is diagnosed on the basis of its abundance relative to the abundances of at least two, and often as many as eight, other plant nutrients, thereby taking account of the state of nutrient balance within plant tissue. In addition, by simultaneously comparing the effects of different nutrients on crop yield, DRIS automatically ranks nutrient deficiencies or excesses in order of importance (Walworth and Sumner 1987).

DRIS methodology has been used successfully to interpret the results of foliar analysis for a wide range of crops such as rubber and sugarcane (Elwali and Gascho 1984); vegetables, potatoes and wheat (Amundson and Koehler 1987; Meldal-Johnsen and Sumner 1980); and forage grass (Bailey et al. 1997). As yet, though, it has not been applied to subsistence crops such as sweetpotato, largely because of the lack of available data to establish the DRIS norms and their associated statistical parameters. However, the crop yield and plant tissue data from the recent survey of sweetpotato production in the central highlands of PNG (ACIAR project SMCN/2005/043) may be sufficient for this purpose. The data from this project are important because they provide measures of soil nutrient levels, and associated crop yield and crop nutrient status, for a wide range of garden sites throughout the highlands on both volcanic and non-volcanic soils. Such data could well hold the key to resolving the problem of declining soil fertility within the highlands region.

The aim of the present study was to develop DRIS model parameters for sweetpotato using tuber yield and tissue nutrient concentration data generated in project SMCN/2005/043, and then use the results of the DRIS analyses to investigate differences in yield-limiting nutritional factors between old and new sweetpotato gardens on the two main soil types (volcanic and non-volcanic) in the highlands.

Methods

Data

The data used for the present investigation were crop yield and tissue nutrient data collected during the recent ACIAR scoping study and survey. A total of 140 sweetpotato gardens, 29 from Eastern Highlands province (EHP), 35 from Simbu province (SP), 36 from Western Highlands province (WHP) and 40 from Enga province (EP), were selected for the survey (Figure 1). About half of these gardens were old continuously cultivated gardens about to go into fallow, and about half were new gardens recently reclaimed from fallow. Sixty-two different sweetpotato varieties were present in the 140 gardens. Each garden was simultaneously sampled for soil and leaf material and assessed for yield at one or two planting stations during the 2005 growing season, giving a total of 209 sampling stations. However, because insufficient leaf material for tissue analysis purposes was obtained from six of the planting stations, the total number of samples was reduced to 203.

Planting stations selected in each garden were at least 10 m apart. At each planting station, four dominant active shoot tips were selected on each plant present, and the youngest or first fully opened leaf was identified. The seventh to ninth leaf blades (minus petioles) along each vine numbered from this first leaf were then collected. Leaves displaying visible nutrient deficiency symptoms or disease or pest damage were avoided, as were those covered with soil dust. Leaf samples from all plants at each planting station (typically three plants) were then combined, placed in a paper bag and air-dried in a food dehydrator the same day. Subsequently, they were oven dried (at 60 °C) and milled for chemical analysis. Soil samples, 0–10 cm in depth, were collected at each planting station using a hand spade. Sweetpotato plants at each planting station were then harvested and the total weight of tubers recorded per station. For present purposes the yield expressed in kilograms (kg) of tubers per planting station was used rather than the scaled-up estimates of tuber yield in tonnes per hectare (t/ha), which makes allowance for the size and spacing of mounds. The former assessments are more closely related to the nutrient status per se of the sampled plants, whereas the latter estimates are influenced appreciably by the physical spacing of the mounds and ridges within the garden areas.

Leaf samples were wet ashed and analysed for Ca, K, Mg, P, S, Cu, Mn, Fe and Zn by inductively coupled plasma mass spectroscopy (ICP-MS). Dry samples were analysed for N by dry combustion. Soil samples were analysed for exchangeable cations by (1M) ammonium acetate extraction, available SO_4-S and Colwell-P; total C and N by dry combustion; and pH in a 1:5 soil:water extract (Rayment and Higginson 1992). The mean concentrations of soil variables in volcanic and non-volcanic soils are given in Table 1, the non-volcanic soils being present largely in EHP and SP, and the volcanic soils predominating in WHP and EP.

DRIS methodology

Using crop (tuber) yield and leaf tissue nutrient concentration data, DRIS norms and coefficients of variation (CVs) were derived according to the procedure by Walworth and Sumner (1987). Scatter diagrams of yield versus nutrient concentrations and all conceivable nutrient ratio combinations were constructed and subdivided into high-yielding and low-yielding subpopulations. The cut-off point between the two subpopulations was arbitrarily set

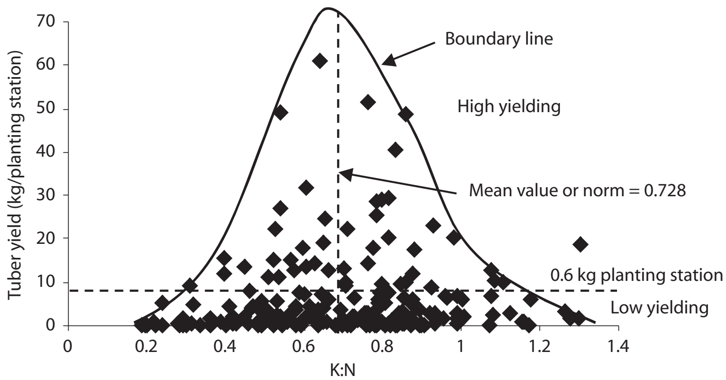

Figure 1. Scatter diagram of tuber yield versus K:N ratio in sweetpotato leaves

Table 1. Mean concentrations of soil variables in non-volcanic and volcanic soils

Soil variable	Non-volcanic soils	Volcanic soils
Soil pH	6.2	5.6
Soil Colwell P (mg/kg)	43	67
Soil exchangeable K (meq/100 g)	0.31	0.26
Soil exchangeable Ca (meq/100 g)	9.73	4.87
Soil exchangeable Mg (meq/100 g)	3.73	1.54
Soil extractable S (mg/kg)	6.2	15.2
Soil total C (g/kg)	48	97

at 0.6 kg/planting station (in the region of 4–8 t/ha), the rationale for this subdivision being that nutrient data for high-yielding plants are usually more symmetrical than those for low-yielding plants (Walworth and Sumner 1986, 1987). The yield at which the division between the two subpopulations was set was a compromise between maximising the potential for data symmetry in the high-yielding subpopulation (i.e. by excluding data for low-yielding planting stations) and including as many data points as possible for statistical credibility (Walworth and Sumner 1987).

Mean values or norms for each nutrient expression, together with their associated CVs and variances (V_{high} and V_{low}), were then calculated for the two subpopulations. The mean values in the high-yielding subpopulation of six nutrient expressions involving four nutrients (N, P, K and S) were ultimately chosen as the diagnostic norms for sweet-potato (Table 2).

Table 2. Nutrient ratios and DRIS parameters for the high-yielding plant population

Nutrient ratio	Norm (mean)	CV[a] (%)
P:N	0.08	31.6
K:N	0.73	26.7
N:S	12.70	21.6
K:P	10.50	33.9
S:P	1.17	26.6
K:S	9.22	31.1

[a] CV = coefficient of variation; DRIS = Diagnosis and Recommendation Integrated System

Having evaluated the DRIS model parameters, DRIS indices were then calculated using a series of equations as given by Walworth and Sumner (1987). For optimum crop yield the DRIS indices for all four nutrients should be zero or close to zero. When nutrients are in a state of imbalance, those that are undersupplied will have negative DRIS index values and those that are oversupplied will have positive DRIS index values. The greater the –ve or +ve values of the indices, the greater the nutrient undersupply and oversupply, respectively.

Analysis of variance (ANOVA)

DRIS data for the old and new gardens in each of the four provinces were subjected to analysis of variance (ANOVA) using a general linear model to simultaneously test the effects of garden type and soil type (volcanic and non-volcanic) on these parameters. Before conducting ANOVA on the DRIS data, a constant (100) was added to each index value to ensure that all were positive. This constant was subsequently removed when reporting the mean DRIS index values. The effects of garden type and soil type on factors limiting to production were also investigated by comparing the percentages of planting stations in old versus new gardens, and on volcanic versus non-volcanic soils, where specific nutrients were most limiting to production, i.e. had the most negative indices in a DRIS N, P, K and S sequence. The selected ‘most-limiting’ nutrients had DRIS index values ≤ –10 and were therefore indicative of significant nutritional limitations on tuber production.

Results

Garden type had a significant effect on tuber yield, the average yield on new gardens (0.77 kg/planting station) being twice that on old gardens (0.34 kg/planting station). Soil type did not significantly affect tuber yield. The effects of garden type and soil type on leaf DRIS indices are presented in Figure 2. On average, old gardens had more negative DRIS K indices than new gardens, and the difference was statistically significant ($P < 0.05$). In contrast, new gardens had significantly ($P < 0.05$) lower DRIS P indices than old gardens, with the average DRIS P index for new gardens being –1.6. For both old and new gardens average DRIS N and S indices were positive, and did not differ significantly between garden types.

Soil type had highly significant ($P < 0.001$) effects on DRIS N, P and S indices. The mean DRIS P index for non-volcanic soils was positive (7.0) whereas that for volcanic soils was negative (–6.6). In contrast, the mean DRIS S index for non-volcanic soils was negative (–3.7) and that for volcanic soils was positive (8.7). For both soil groups mean DRIS N indices were positive; however, the value for the volcanic soils was highest (6.3). The mean DRIS K indices for both soil groups were negative and did not differ significantly.

The effects of garden type and soil type on nutrient factors limiting to production were further investigated by comparing the percentages of planting stations in old and new gardens, and on volcanic and non-volcanic soil types, where specific nutrients were most limiting to production, i.e. had the most negative DRIS indices. Potassium deficiency was the biggest problem in both old and new gardens; this nutrient was most limiting to tuber production at 34% of old garden planting stations and 24% of new garden planting stations. At many of these planting stations K deficiency was acute (Figure 3a), with very negative DRIS K indices (< –30) and low leaf K concentrations (< 14.0 g/kg).

The next most important problems for tuber production in both old and new gardens were P and S deficiencies. The P deficiency problem was greatest in new gardens, where it affected 22% of planting stations. DRIS P indices were as low as –18 and leaf P concentrations < 1.69 g P/kg, indicative of moderate to acute P deficiency. The S deficiency problem was similar in old and new gardens and affected 13–15% of planting stations. DRIS S indices were as low as –22 and leaf S concentrations < 1.9 g/kg, indicative of moderate to acute S deficiency (Figure 3b). In both old and new gardens N deficiency was of minor importance, affecting less than 10% of planting stations in either garden type.

On non-volcanic soils, K and S deficiencies were the main factors limiting tuber production at almost 50% of planting stations, K being most limiting to

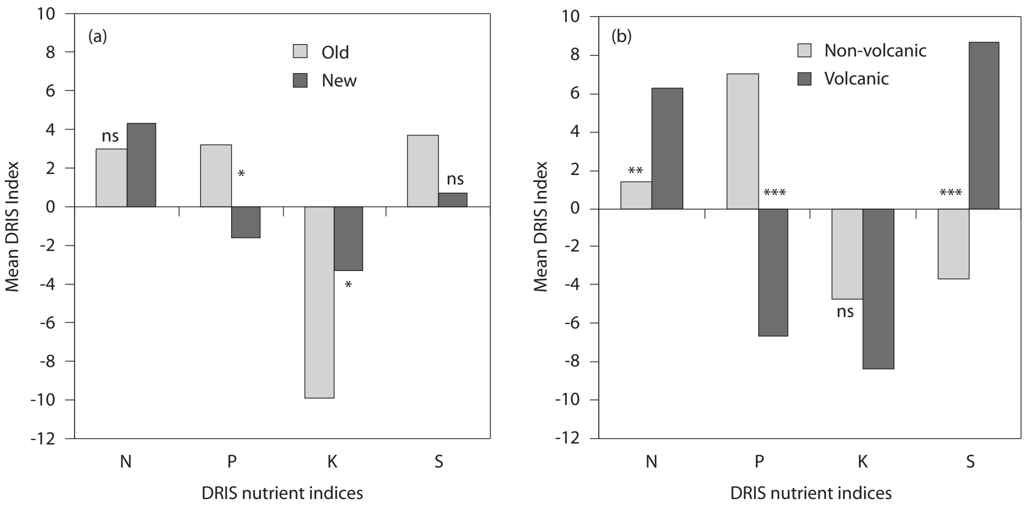

Figure 2. The effects of (a) garden type (old versus new) and (b) soil type (non-volcanic versus volcanic) on the mean leaf DRIS N, P, K and S indices at sweetpotato planting stations
Note: significant differences between means denoted as * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 3. Photographs from Eastern Highlands province showing sweetpotato plants suffering from (a) acute K deficiency (DRIS K = –64, leaf K concentration = 7.5 g/kg and zero yield) and (b) acute S deficiency (DRIS S = –23, leaf S concentration = 1.2 g/kg and zero yield).

production at 22% of planting stations and S at 24% of planting stations. Phosphorus deficiency was of minor importance on these non-volcanic soils. For gardens situated on volcanic soils, K and P deficiencies were the main factors limiting to production, K at 36% of planting stations and P at a further 28% of planting stations. On both soil types N deficiency was of minor importance.

Discussion

The results of DRIS analysis on data from the 2005 sweetpotato survey suggest that inadequacies in K, S and P supply may be largely responsible for the underperformance of sweetpotato crops across much of the highlands region. The most serious nutritional problem, which affected almost one-third of planting stations in the survey, was acute K deficiency, as indicated both by very negative DRIS K indices and low leaf K concentrations (O'Sullivan et al. 1997). While crops growing in old gardens were clearly the worst affected by this deficiency, a sizeable proportion of those growing in new gardens were also affected. In other words, although K deficiency is the most likely nutritional reason for old garden abandonment in the PNG highlands (Sillitoe 1996), current fallowing practices in periods following garden abandonment (i.e. prior to bringing sites back into cultivation as 'new' gardens) appear to be only partially alleviating this K-undersupply situation. It is probable that the dramatic shortening of fallowing periods in recent times from several decades to less than 1 year (Sem 1996; Bourke 2005) has prevented the natural replenishment of soil K reserves. Insufficient time is being allowed for deep-rooted woody species to establish and draw K from the subsoil and deposit it in root and foliar detritus. In keeping with the significantly lower concentrations of exchangeable K in volcanic soils compared to non-volcanic soils (Table 1), K deficiency was most prevalent in volcanic soils, affecting more than one-third of planting stations in sweetpotato gardens. In both types of soil, however, the relatively low mean concentrations of exchangeable K indicate that yield responses to additional K inputs might be expected in many garden situations (Goodbody and Humphreys 1986).

Continual cultivation leading to nutrient removal by tubers, and the progressive shortening of the fallow period, are obviously two of the primary factors responsible for the depletion of K reserves in old sweetpotato gardens. Almost equally important, however, is the fact that old sweetpotato vines are removed from the cultivation area in both old and new gardens. Throughout the highlands, the vines are routinely removed following the last tuber harvest and applied as compost or ash to other cash and food crops. These vines contain one-third of the total K taken up by the crop (tubers plus vines) (O'Sullivan et al. 1997). Their removal from the cultivation area therefore exacerbates the nutrient depletion process and is undoubtedly contributing to major K deficiency problems in sweetpotato gardens on both volcanic and non-volcanic soils. Correcting this problem may require a combination of actions including the recycling of old K-containing sweetpotato vines back to the cultivation area as compost or ash, the use of fast-growing deep-rooted fallow species to tap subsoil K reserves and, as a final resort, the application of K fertiliser.

On volcanic soils, next to K deficiency, P deficiency was the factor most limiting to sweetpotato production. Surprisingly, though, going from old to new gardens actually increased the incidence of P deficiency rather than alleviating it. Normally, the burning of fallow vegetation causes P to be released into the soil in new garden sites. It is possible, though, that the substantial twofold increase in yield from old to new gardens had increased plant demand for P to the extent that deficiencies had been triggered. Phosphorus deficiency is a widespread problem on volcanic ash soils throughout the tropics. If current fallowing practices in the PNG highlands are not alleviating the problem, alternatives must be sought. In parts of Africa, wild Mexican sunflower (*Tithonia diversifolia*) has proved very useful as a fallow species since it has a great capacity to extract the P held in non plant available forms from soil (Kendall and van Houten 1997; Sanchez 2002). As yet, however, farmers in PNG have not attempted to use this species as a soil fertility restorative, despite it being found growing wild along roadsides.

On non-volcanic soils, next to K deficiency, the factor most limiting to sweetpotato production was S deficiency. As shown in Table 1, non-volcanic soils, on average, had much lower extractable S content than did volcanic soils. In addition, they had much lower organic C content and, by inference, organic S content than volcanic soils. Significantly, however, going from old to new gardens did not alter the incidence of

S deficiency in sweetpotato crops. During fallow periods fallow species have the capacity to scrub SO_2 from the atmosphere and from precipitation, absorbing it onto and into leaf tissue, and ultimately transferring it to the soil in leaf litter and detritus (Marschner 1995). Deep-rooted species can also recycle sulfate from the subsoil. On the other hand, the slash-and-burn process used to prepare new garden sites liberates much of the S in slashed material to the atmosphere as SO_2 (Weischet and Caviedes 1993; Mackensen et al. 1996), thereby negating much of the benefit of fallowing with respect to site S status. Moreover, the practice of removing old vines from sweetpotato cultivation areas undoubtedly exacerbates the problem of S deficiency. Vines contain almost two-thirds of the total S taken up by sweetpotato crops (O'Sullivan et al. 1997). Correcting the problem of S deficiency therefore may require the recycling of old sweetpotato vines back to the cultivation area as compost, and the minimal or zero burning of vegetation when clearing gardens and bringing new areas into cultivation.

Conclusions

The most important nutritional problem affecting sweetpotato production in the PNG highlands is K deficiency, followed by S deficiency on the non-volcanic soils and P deficiency on the volcanic soils. Current fallowing practices are only partially alleviating the K-undersupply situation, and are having no effect whatsoever on the P and S undersupply situations. Correction of K deficiency may require the recycling of old vines back to sweetpotato cultivation areas, the use of fast-growing deep-rooted fallow species and, ultimately, the use of K fertiliser. Correction of S deficiency may necessitate the adoption of a zero-burn policy for fallow management, whereas correction of P deficiency may require the use of P-accumulating fallow species, e.g. wild Mexican sunflower (*Tithonia diversifolia*).

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References

Amundson R.L. and Koehler F.E. 1987. Utilization of DRIS for diagnosis of nutrient deficiencies in winter wheat. Agronomy Journal 79, 472–476.

Bailey J.S. 1993. Sustainable fertiliser use. Proceedings of the Fertiliser Society No. 343.

Bailey J.S., Beattie J.A.M. and Kilpatrick D.J. 1997. The diagnosis and recommendation integrated system (DRIS) for diagnosing the nutrient status of grassland swards. I: Model establishment. Plant and Soil 197, 127–135.

Bourke R.M. 2005. Sweetpotato in Papua New Guinea: the plant and people. Pp. 15–24 in 'The sweetpotato in Oceania: a reappraisal', ed. by C. Ballard, P. Brown, R.M. Bourke and T. Harwood. Ethnology Monographs 19, University of Pittsburgh: USA; Oceania Monographs 56, University of Sydney: Australia.

Dampney P.M.R. 1992. The effect of timing and rate of potash application on the yield and herbage composition of grass grown for silage. Grass and Forage Science 47, 280–289.

Elwali A.M.O. and Gascho G.J. 1984. Soil testing, foliar analysis and DRIS as guides for sugarcane fertilization. Agronomy Journal 76, 466–470.

Goodbody S. and Humphreys G.S. 1986. Soil chemical status and the prediction of sweetpotato yields. Tropical Agriculture (Trinidad) 63, 209–211.

Kendall B. and van Houten, H. (eds). 1997. Using the wild sunflower tithonia in Kenya for soil fertility and crop yield improvement. International Council for Research in Agroforestry (ICRAF): Nairobi.

Mackensen J., Holscher D., Klinge R. and Folster H. 1996. Nutrient transfer to the atmosphere by burning of debris in eastern Amazonia. Forest Ecology and Management 86, 121–128.

Marschner H. 1995. Mineral nutrition of higher plants. Academic Press: London.

Meldal-Johnsen A. and Sumner M.E. 1980. Foliar diagnostic norms for potatoes. Journal of Plant Nutrition 2, 569–576.

O'Sullivan J.N., Asher C.J. and Blamey F.P.C. 1997. Nutrient disorders of sweetpotato. ACIAR Monograph No. 48. ACIAR: Canberra, Australia.

Rayment G.E. and Higginson F.R. 1992. Australian laboratory handbook of soil and water chemical methods. Inkata Press: Melbourne, Australia.

Sanchez P.A. 2002. Benefits from agroforestry in Africa, with examples from Kenya and Zambia. Pp. 109–114 in 'Agroecological innovations: increasing food production with participatory development', ed. by N. Uphoff. Earthscan Publications Ltd: London.

Sem G. 1996. Land-use change and population in Papua New Guinea. In 'Population, land management and environmental change', ed. by J.I. Uitto and O. Akiko. The UNU Global Environmental Forum IV. The United Nations University: Tokyo, Japan.

Sillitoe P. 1996. A place against time: land and environment in the Papua New Guinea highlands. Harwood Academic Publishers: United Kingdom.

Stevens R.J. and Watson C.J. 1986. The response of grass for silage to sulphur application at 20 sites in Northern Ireland. Journal of Agricultural Science (Cambridge) 63, 209–219.

Walworth J.L. and Sumner M.E. 1986. Foliar diagnosis: a review. Pp. 193–241 in 'Advances in plant nutrition', vol. III, ed. by B.P. Tinker. Elsevier: New York.

Walworth J.L. and Sumner M.E. 1987. The diagnosis and recommendation integrated system (DRIS). Pp. 149–188 in 'Advances in soil science', vol. 6, ed. by B.A. Stewart. Springer-Verlag: New York.

Weischet W. and Caviedes C.N. 1993. The persisting ecological constraints of tropical agriculture. John Wiley & Sons Inc.: New York.

Future potential of crops other than sweetpotato in the Papua New Guinea highlands

Akkinapally Ramakrishna[1] and Humphrey Saese[2]

Introduction

Agriculture sustains more than 85% of the population of Papua New Guinea (PNG) and is the mainstay of the rural people. Although characterised by low input and hence low productivity (Gwaiseuk 2001), the overall contribution of the food crop sector to the economy is estimated at 1.3 billion PNG kina (K) with a non-market component valued at K750 million (Gibson 2001a).The non-market component is generally consumed at home or the site of production. Although it looks substantial in value, the agriculture sector's overall contribution to GDP (at 1%) lags behind the population growth rate of 2.3% (Gwaiseuk 2001), presenting serious implications for policymakers, researchers and other stakeholders directly involved in the agriculture sector.

Nevertheless, for the next 30 years, a growing population will demand improved standards of living that will place great pressure on PNG's land resources (Bourke 1990). The population of PNG was 2.0 million in 1966, 3.9 million in 1990 and is conservatively predicted to reach 6.9 million by 2015 and 8.0 million by 2020 (Allen et al. 1995). The country's economy will be unable to provide waged employment for other than a very small proportion of this expanding population. In 1990 approximately 9.3% of the population of PNG aged between 15 and 64 years were in waged employment. Although a mining boom will provide 3–4% growth in waged employment (mainly in construction and utilities), it is estimated that labour force growth will exceed waged employment growth by 40,000 persons per year for the foreseeable future (Allen 1995).

PNG is an agricultural country and it is likely that its increasing population will continue to rely heavily on agriculture in the foreseeable future. More land will be brought into production, and it is in the dense population areas where population pressure on land is becoming a problem. Despite the reporting of critical shortages of land in the highlands, no systematic treatment has been undertaken to relate land use to population density. However, recent data from the PNG Agricultural Land Use Survey suggest that several areas could face similar land-use problems (Sem 1996).

In the highlands, agricultural productivity per land area has generally been high. However, most highlanders have depended heavily on sweetpotato cultivation for centuries, and their cultivatable lands have already been exploited and the fallow periods extremely reduced. This has eventually led to permanent cultivation in many locations (Ohtsuka 1996). As Wood (1984) suggested, soil erosion became manifest in the central highlands as early as the 1950s. Consequently, it will be difficult for highlands farmers to maintain their present agricultural productivity unless the agricultural system is modified.

Agriculture in the economy

Agricultural growth in the highlands is seen to be a catalyst for broad-based economic growth and development in the region. It links to the non-farming economy and generates considerable employment, income and growth in the rest of the economy. Agricultural growth and development is pursued in the highlands for the following reasons:

[1] National Agricultural Research Institute, Bubia, Lae 411, Papua New Guinea <a.ramakrishna@nari.org.pg>
[2] National Agricultural Research Institute, Highlands Program, PO Box 210, Ukarumpa, SIL, Aiyura, Eastern Highlands Province, Papua New Guinea

- to alleviate poverty through employment creation and income generation in rural areas
- to meet growing food needs (driven by population growth and urbanisation)
- to simulate overall economic growth, given that agriculture is the most viable lead sector for growth and development
- to conserve natural resources through sustainable farming practices.

Over one-third of PNG's population is concentrated in the highlands region, which is only 13.5% of the total land area. Although the average density for the 10 highlands regions is 22 persons/km^2, it is reported that in some fertile highlands valleys densities exceed 200 persons km^2 (Allen 1984), and it is in these areas that reports of population pressure on land have been most frequent. The farm size under subsistence cultivation was estimated to be between 0.08 and 0.24 ha per capita, with an average of 0.12 ha in the highlands (McAlpine 1967, 1970). No reliable information is available as to whether these statistics are still applicable in 2008, but local knowledge suggests that farm sizes for individual households have not changed.

Coffee is the main cash crop, with some cash income generated by the sale of food crops, spices and livestock. Sweetpotato dominates food production in the highlands. Other staple foods include banana, taro, cassava and yam. A wide range of traditional and introduced fruits and vegetables is also grown. There are generally two types of gardens—house gardens are small and intensively cultivated around the edge of settlements, whereas main gardens are often further away from the settlement. The combination of crops found in any garden is associated with the length of the preceding fallow period. New gardens display a greater variety of food types, indicative of higher fertility. As gardens age and fallows shorten, soil fertility declines and there is a progression to sweetpotato-dominant gardens.

Latitudinal differences in solar energy, temperature, rainfall and soil nutrients are some of the ecological constraints on agricultural systems (Bayliss-Smith and Feachem 1977). Often, a farmer is unable to directly control the constraints of solar radiation, temperature and rainfall but is able to adapt to changes brought about by these constraints. PNG farmers have been able to adapt to seasonal and annual climate fluctuations and socioeconomic conditions so that agriculture has remained the mainstay of rural societies (Bourke 1983). Some of these responses and mitigating factors have resulted in the development of elaborate farming techniques. These include mounding, terracing, mulching, ditching, draining and irrigation systems that are now considered to have developed independently of the major agricultural areas of the world. Some writers ascribe development of such techniques to the introduction of new crops, population growth and increased demands for social production (Brookfield 1972), plus a combination of all these factors. This technological change/innovation is a result of the agricultural intensification that is now evident in PNG.

It was only after the most recent droughts in 1997 that people in the region realised the fragility of the farming systems and, more importantly, the fact that food insecurity in both its transitory and chronic forms poses a real threat.

Any attempt to develop sustainable agriculture must be based on eradicating poverty and stemming urban drift. Production systems should serve the needs of small-scale farmers. This requires the knowledge and use of traditional indigenous technology as well as scientific research, especially into the biological processes that govern agricultural production. This approach would entail the development and adoption of diversified farming systems that make the most efficient possible use of external inputs, while having a minimal negative impact on the environment.

People in the highlands have been finding innovative solutions to these problems. One solution has been to intensify subsistence production by reducing the length of fallow periods and increasing cropping periods, and this has been occurring over the past 60 years or so. If left unchecked, this sort of intensification will eventually result in declining soil fertility. However, declining soil fertility and reduced garden areas have been offset by the adoption of new, high-yielding crops (both species and cultivars). More recently, farmers in the highlands have demonstrated their ability to adopt new technology by accepting large-scale farming, improved farming practices, mechanisation, irrigation and the use of fertilisers and pesticides. Semi-commercial and commercial farms of varying sizes on communal and private land have emerged as a result of favourable market prices for produce.

Food and nutrition and sustainability issues

The highlands diet is rich in carbohydrates but poor in protein, fats and vitamins. Protein deficiency is identified as a major problem despite adequate resources of high-energy, starchy foods such as taro, yam, sweetpotato and sago (Norgan et al. 1979). Children are particularly susceptible to protein deficiency because growth and development require daily intakes of protein. As a result, during colonial days legislation was made that stipulated the compulsory vitamin enrichment of imported foods like rice (Mills 2002). Many PNG children are malnourished according to the Food and Agriculture Organization of the United Nations standards, and malnutrition remains a basic cause of poor health for rural people. The vulnerable groups of people are children, pregnant and postpartum mothers, sick adults and the elderly (Benjamin et al. 2001). Malnourished children in the schooling age group, who are vulnerable to preventable diseases due to low resistance to infections, can miss their education, eventually resulting in illiteracy, poverty and low productivity among rural people. Attempts to supplement the local diets are well documented; for instance, in 1936 (Densley and Cairns unpublished) the labourers at Aiyura were fed wheat meal and soy meal rations.

At present almost 35% of the population, representing about 2.1 million people in PNG, are undernourished. Based on a household survey conducted in 1996 (Gibson 2001b), it was estimated that about 50% of the children in the rural areas showed stunted growth. This survey revealed that, while per capita daily calorie availability was very similar in both the rural and urban areas, there was significant disparity in per capita protein availability, with a difference of 31% between the rural and urban populations. As a result, rural children were more prone to malnutrition (Muntwiler and Shelton 2001). Generally, the malnutrition rate in PNG is on an 'upward trend', suggesting that more of the population (especially children) are being affected. When trends in the last 5 years are compared, the increases in malnutrition have been very nominal, in the range 0.1–0.3% between 2001 and 2004; however, during 2004–05 there was a dramatic increase by 2.6%, which depicts the possibility that malnutrition could worsen in the future.

Availability of protein in the diet seems to be a major contributing factor to malnutrition in PNG. In another study it was noted that socioeconomic factors such as more possessions (an indication of more disposable income) correlated positively with child health (Mueller 2001). However, the fact still remains that a large majority of the people are income disadvantaged, and the traditional source of protein from wild game is now critically in short supply.

What is crop diversification?

Crop diversification within the context of household food production is a risk aversion strategy adopted by farmers to spread the risk of crop failure, to add diversity to their diets and to adapt to the limitations imposed by the environment. Almost all gardens in the highlands grow more than one crop to meet household food and economic requirements. Studies in the Markham Valley demonstrated that, in a more marginalised environment, farmers tended to diversify the number of crops that were grown and the area occupied (Saese et al. 2007). Small (1995) defined crop diversification as 'programs of expanding the number of crops in a region, in the hope of increasing overall productivity and marketability'. Wallis et al. (1989) noted that it was important to have well-developed selection criteria to identify successful new crop industries in any region. Although the idea will not be dealt with extensively in this paper, crop diversification can also involve conventional crops.

This type of activity falls into a number of categories:

- adaptation of the crop to grow in new ecoregions; for example, the Markham Valley is currently underused for peanut production, and the development of new adapted germplasm could have a remarkable impact on productivity in the area
- research and development to identify unique components or constituents that can be extracted from conventional crops, such as the industrial extraction of starch from sweetpotato or cassava for ethanol
- development of cultivars that are adapted to specific production systems, such as varieties that perform well within organic cropping systems
- the use of transformation technologies to develop new types of conventional crops that have the capability of producing high-value products through the still-evolving tools of molecular biology (such as pharmaceutical products).

Development of such products must include a public education component regarding their value, as well as a secure system of production to ensure no risk to conventional production and marketing systems.

Why diversify?

Crop diversification is driven by several motivating factors (Connor 2001), including the following.

Low conventional crop prices

Efficient producers have a clear picture of how conventional crop prices will influence their profitability. When conventional crop prices fall due to overproduction and subsequent oversupply, they look for other alternatives (Thompson 1988). The overall goal of crop diversification is to increase profitability.

Innovation

The rapid inclusion of any new technology has provided a great opportunity for many industries. Producers and processors are always eager to get in on the 'ground floor' of a new idea that promises to be lucrative. Due to the increased level of knowledge available through new resources such as the internet, plus international contacts and the interest of some producers, much greater emphasis has been placed on the assessment of new crops. The aim is to establish the potential of species from other parts of the globe, for example oil palm in the lowlands and pyrethrum in the highlands of PNG.

Environmental protection

The inclusion of nitrogen-fixing legumes, tree crops, fibre crops and other bioproduct crops in cropping systems can have advantageous effects. These benefits can be obtained by reducing the requirement for application of inorganic fertilisers, decreasing the need for forest fibre through annually renewable agricultural sources, increasing the potential for minimum tillage in annual cropping systems, and establishing long-term perennial plantations.

Risk reduction

The inclusion of several species in a crop production plan can have the advantage of buffering low prices in a specific crop. Diversification allows a producer to balance low prices in one or two crops against reasonable returns in other commodities.

Biodiversity

An additional advantage to increased numbers of crops is that the enhanced biodiversity can reduce problem insects and diseases, as well as create new opportunities for innovative weed management through extended crop rotation.

Development of new production systems

The advent of herbicides and their availability in PNG has created a new window for crop diversification. Intercropping of annual crops (for both grain and fodder production) with coffee, cocoa, coconut, oil palm, timber and other perennial cropping systems can be considered to maximise yield and quality.

Opportunities for diversification in PNG highlands

PNG has been rated as one of the least developed countries because of poor living standards and poverty, which are manifested through malnutrition and undernourishment, low cash income and purchasing power, highly unbalanced income distribution, high unemployment and underemployment, consistent problems of law and order, high and rising food imports, and overall low rating as per the development index (UNDP 1999; World Bank 2006).

Cereal and grain legumes have emerged strongly since World War II and by now have become prominent in the PNG food basket. They contribute a significant part to national nutrition and calorie requirements, and thereby play a critical role in national food security. PNG has a high and increasing demand for cereal and grains, with annual imports estimated at 303,000 t with a total sale value of K526 million. This gives a per capita consumption of 70 kg/year and contributes about one-fifth of the total national calorie intake (Mills 2002). In addition, the rising trend of imports has obvious and serious implications for the food security and self-reliance of the nation. PNG has equally high but untapped production potential for cereal and grain crops, but concrete efforts in terms of research and development are lacking. This potential should be harnessed not only to reduce the import bill but also, and more importantly, to ensure food security, generate gainful employment, raise incomes and improve income distribution in the country.

Furthermore, there is a worldwide demand for edible oils, especially those with low cholesterol contents such as from corn, soybean, sunflower and peanut (Hymowitz 1990). The arable and fertile valleys of the highlands are highly suitable for the production of feed grains (sorghum and corn) and oilseed crops (soybean, sunflower and peanut). This presents an opportunity for export if these crops are effectively produced as well as processed in PNG.

Grain legumes in PNG are usually cultivated predominantly as intercrops or mixed crops with other traditional staple crops, with the exception of peanut which is generally cultivated as a sole crop. Apart from peanut, the majority of grain legumes are consumed primarily as green vegetables rather than directly as grain, or processed into other products like tofu (produced from soybean mainly in Asian countries) or feed products.

Grain legumes constitute an important part of household food consumption in the rural parts of PNG, where protein from meat and wild game are in seasonal supply and often very scarce. Protein availability in the diets of children in the rural areas is about 50% less than that in the urban areas (Muntwiler and Shelton 2001). As a consequence, it is estimated that more than half of the children in rural areas show stunted growth (an indicator for malnutrition) compared to 20% in urban areas (note that these are average figures as there are variations among urban populations which are dictated by the level of income earned by individuals, and differences in rural populations dependent on the staples produced).

Unlike protein from meat, which is quite expensive and not easily accessible to most rural households, the promotion and adoption of new and appropriate varieties of grain legumes in the farming systems will have a far-reaching impact on improving the nutritional status of the rural population in PNG. It is possible that, by doing so, the widespread malnutrition recorded in children in the rural population can be significantly reduced.

The subsistence production and consumption of legumes has increased, with an estimated 12.7% of the rural population now consuming legumes largely as fresh vegetable compared to 7.8% of the population in urban areas (Gibson 2001b). Although data on the volumes and type of grain legumes produced and consumed in the rural areas are not available, general observations reveal that several selections of grain legume are now being cultivated and consumed on a regular, if not daily, basis. Soybean (*Glycine max*), for instance, has a slightly longer history than other beans or peas. It was first reported as a potential crop in the highlands in 1936. Initial trials conducted in 1937 at Aiyura showed some promise, with mean pod yields of 750 lbs (equivalent to 341 kg) (Kimber 1969). Kimber noted that soybean was also grown as a pretreatment crop together with sweetpotato to speed up the decomposition of grass roots prior to the establishment of experimental coffee plots at Aiyura station; and then eventually grown regularly to substitute wheat meal and fats for labour rations on stations. This would be the first record of soybean used in human diets in PNG. After a long absence during World War II, regular consumption was reported in the Baiyer River, Pari, in Chimbu province in 1954. It is quite possible that soybean was transferred by labourers who had initially worked at Aiyura and had been introduced to its cultivation and consumption. Currently, soybean is regularly consumed after boiling and is sold in the markets.

The only exception to increased legume production would be pigeon pea (*Cajanus cajan*), which is not being grown widely as a crop. Farmers consider them to be ‘hedges’ and even ‘ornamentals’ because of their bright yellowish flower (or, in their own words, *mipela ting olsem em flower ya!*). Only a very few individuals use them as food; otherwise, the bulk of the population is not aware of their food uses. In fact, pigeon pea is well adapted and volunteer stands are noted at various sites in the highlands provinces. Unlike other legumes, which are ‘annuals’, pigeon pea is a perennial crop that can grow for up to 5–6 years, providing farmers with multiple harvests. Early reports of its use show that pigeon pea was consumed by students attending the Christ the King high school on Manus Island, and most recently in a few areas in Simbu and Western provinces (Mcqueen 1993).

During 1973–74 legume imports steadily increased and peaked at 700 t in 1975. Thereafter, volumes declined to 500 t and dropped to a record low due to the Bougainville crisis. After the crisis the volume of imports started to increase again. Generally, imports of processed and fresh legumes increased relative to increases in employment rate and income of urban dwellers.

Role of grain legumes in the cropping systems

Most farmers in PNG perceive legumes as soil ameliorators and associate them with increased crop vigour and health in the subsequent crop. The value of legumes in the fixation of atmospheric nitrogen is little known. Apart from this general experience, much of the crop rotation that is practised in the country with the assumption that legumes contribute to residual nitrogen (N) is based on experiences elsewhere. A compounding effect in the PNG highlands is the provision of an adequate N-supply for low N users such as sweetpotato.

Giller (2001) discussed the variation in the level of N contributed as residual N for each type of grain legume. Table 1 summarises the widely cultivated grain legumes in the tropics and the amount of N fixed and actual N taken up by the subsequent crop as residual N. Accordingly, peanut (*Arachis hypogaea*) and the *Vigna* species contribute a significant proportion of residual N compared to other legumes.

It is possible, therefore, to assert that not all grain legumes contribute net N benefit to the cropping systems. The general suggestion would be to select legumes that have the ability to serve the primary purpose of producing food and, at the same time, contribute N as residual nutrient that would be available for the next crop.

Studies in rice showed that mungbean produced 0.9 t of grain and straw when incorporated, and substituted 60 kg N/ha (De Datta 1989). Garside et al. (undated) recorded a 20–30% increase in each of the first and second ratoon sugarcane crop yields when peanut and soybean were rotated with the sugarcane, and concluded that grain legume rotation with sugarcane sustains crop yields. Although limited data are available in PNG on levels of N contributed by various legumes, Trukai Farms Limited has used peanut in rotation with rice for the last 10 years (1997–2007) in the Markham Valley. Peanut as a major rotation crop has been able to sustain rice crop yields. In similar practices adopted by Ramu Agribusiness Industries, cowpeas have been grown extensively in crop rotation with sugarcane and, recently, peanuts have been trialled (Kuniata, pers. comm. 2008). In the areas of the highlands where peanuts are produced, they are invariably rotated with sweetpotato. Observations have shown that this rotation results in a much healthier sweetpotato crop that is more resistant to pests, and there is reduced weed pressure.

Crop rotations with legumes and other alternative crops such as oilseeds, feed and fodder in the vast fallow lands in the region can help reduce the monocropping of sweetpotato. Environmental sustainability will be greatly enhanced, particularly on sloping and marginal lands (eroded soils), and crop productivity will potentially be increased.

The integration of livestock species and varieties with existing staple crops and new emerging crops will help diversify and increase protein-rich food production (Gama 1995). The integration of livestock in subsistence gardening will assist in transforming the current subsistence-based agrarian society and add to its overall farm productivity on smallholder farms. This will contribute significantly to improved food security and the nutritional status of the people.

Springhall (1969) evaluated several combinations of feedstuffs and reported that soybean meal produced significantly higher weight gains compared to other feed rations. Peanut hay was also trialled but did not produce any significant increase in live weight gain (LWG). Similar trials (two

Table 1. Amount of N fixed and contributions to soil fertility by grain legumes in the tropics grown as sole crops (modified from Giller 2001)

Grain legume	Duration (days)	Grain yield (t/ha)	Stover yield (t/ha)	Amount of N fixed (kg N/ha)	N in Stover (kg N/ha)	Residual effect (kg N/ha)
Arachis hypogaea	90–140	0.3–3.1	1.4–6.7	21–206	52–166	0–97
Cajanus cajan	90–241	0.2–1.4	1.8–13.8	0–166	12–50	0–67
Cicer arietinum	90–241	0.2–1.4	5.9–7.5	0–124	–	–
Glycine max	96–104	0.6–2.9	1.0–10.4	26–188	30–170	0–22
Phaseolus vulgaris	72–114	0.8–3.0	0.1–7.5	2–125	3–38	–
Vigna radiata	70–84	0.7–1.7	1.3–3.9	61–107	30–88	68–94
Vigna unguiculata	69–115	0.2–2.7	0.0–0.84	9–201	20–94	38–205

experiments) conducted by Malyvnicz (1974) showed that cooked soybean fed to pigs with sweet-potato markedly increased live weights of pigs; however, feeding raw soybean inhibited performance. Danbaro et al. (2001) reported that soybean as a protein supplement at 400 g/meal/day significantly improved LWG in pigs.

The untapped potential of grain legumes in the highlands cropping system

Since the introduction of grain legumes some 70 years ago in the PNG highlands, their potential to provide food and, to some extent, address issues in human and animal nutrition, soil fertility decline and income has been underexploited due to lack of promotion of their benefits. This will continue to be the case in the future if attention is not directed towards grain legumes' potential in cropping systems and the role they can play in addressing the widespread food nutrition issues at the household level in the highlands. Early work on grain legumes was driven by the need to provide nutritional balance in human diets. However, at a later time the need to replenish soil fertility degradation through the adoption of appropriate legume species has become very important. This is because the intensity of agricultural production has increased, as evidenced by the replacement of woody species fallow by grass or weed fallow across the highlands region. The change in production levels is driven by an increase in population and the general reluctance to cultivate new and marginal areas. As it stands now, agriculture researchers, policymakers and stakeholders involved in rural food production will have to balance the need for human nutrition with the wide-scale degradation in soil fertility.

However, while the arguments have remained unchanged, there has been a failure to ensure the wide-scale adoption of grain legumes in PNG and, in particular, the highlands since independence. For instance, between 1970 and 1980 several seminars and conferences were organised to assess the prospects of grain legume production together with cereal grains like maize, both in the highlands and the lowlands, to encourage wide-scale production. However, the progress made in mustering sustainable and viable grain legume production since then has failed to materialise. While the reasons for the failure remain unknown, lessons from the short-lived peanut industry in the 1960s, as highlighted by Densley and Cairns (unpublished), can shed some light on possible problems that could have hampered progress. In simple terms the failure of the peanut industry can be attributed to (i) a decline in seed viability because of the farmers' general practice of saving inferior seed materials, (ii) a lack of availability of improved varieties to keep pace with industry's demand, (iii) weed pressure created by continuous cropping and (iv) an outbreak of peanut rust (*Puccinia arachidis*) in 1974. A further factor, not listed by Densley and Cairns (unpublished) is the question of whether PNG farmers actually had a peanut industry in the 1960s.

Similar problems have been reported for soybean, whereby commercial trials in the Markham Valley produced poor yields due to insect pests like the green vegetable bug (*Nezara viridula*) and *Riptoris* sp. (Sumbak 1976). Also, soybean rust had been noted as a potential problem (Kimber 1969) in the lowlands, while suitable and appropriate farm machinery was noted as a constraint for small-scale commercial production in the highlands. The prospects for scaling up to commercial production were not possible due to the high cost of production. The inefficiency in operating large-scale commercial entities and the lack of standards also played their part in making commercial production in PNG undesirable. At present there is a lack of confidence in a potential local grain legume industry given the past experiences, the quality requirements and the huge capital requirements for producing grain legumes for both the food and the animal feed industries. Production on a commercial scale still remains unfeasible at present, but the need for adoption of appropriate grain legumes for household consumption and to counter soil degradation is of priority now.

One of the greatest impediments, not normally documented in the literature, is the effect of socio-economic factors. These have the potential to facilitate a wide-scale adoption or rejection of the crop species and technologies being introduced. PNG farmers, and farmers in general, are very pessimistic, risk averse oriented and generally unwilling to let go of technologies and crop species that have co-evolved with them over the years. These crop species and technologies are ingrained into their customs and cultural beliefs, which makes it very difficult to forgo them in the event of change. Researchers must therefore deal with this barrier in order to introduce what they believe is better than what the farmers have. In the western world, income, profit and wealth are the motivations for adoption of change, and farmers are ultimately covered by social security. In contrast, farmers in PNG will adopt crop diversification as insurance against hunger, which is equivalent in context to social security, and to maintain their social status in society. Of course, the crop or practices adopted must be acceptable within their culture and play an important role as a crop of social significance. Finally, if they are able to earn extra income, then farmers will adopt the technology or the crop.

As more diversified farming activities are attended to, together with daily social chores and commitments, the time and labour available become very limited. Any new crop or technology being introduced into the system must come with a strong socioeconomic justification and definite commercial incentive; otherwise, they end up merely being written up and shelved in libraries. This seems to have been the case for the early grain legumes research conducted in PNG.

Conclusions

'Crop diversification: been there, done it'
Editorial, *Western Producer* newspaper, Saskatoon, Canada (31 May 2001)

In the PNG highlands there has been measured success in a number of crop diversification innovations. Furthermore, alternative production systems have been examined, such as organic production and aquaculture. Therefore, crop diversification is not a new concept in PNG and can provide a set of choices for PNG highlanders offering increased productivity and profitability. However, the fact is that we still have to develop a national farm policy that ensures the long-term sustainability of our agricultural producers. Many of the potential opportunities within crop diversification are not attractive to many in the current demographic structure of these producers. Crop diversification is only one piece of a much more complex process that will lead to a renewed and optimistic outlook for the agricultural sector in the highlands.

Many hurdles must be overcome to increase crop diversification in PNG. Research funding has been identified as a key to continued success, although the resources needed to make progress are still not adequate. Crop diversification initiatives must compete with established crops for research funding and struggle to find donor money to 'match' public investment. Markets continue to fluctuate as global competition increases.

References

Allen B. 1984. Agriculture and nutritional studies on the Nembi Plateau, Southern Highlands. Department of Geography, Occasional Paper No. 4 (New Series), University of Papua New Guinea and Southern Highlands Rural Development Project, Port Moresby.

Allen B. 1995. Land management: Papua New Guinea's dilemma. Asia-Pacific Magazine 1, 36–42.

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

Bayliss-Smith T. and Feachem R.G. 1977. Subsistence and survival: rural ecology in the Pacific. Academic Press: London.

Benjamin A.K., Mofafi. I and Duke T.A. 2001. Perspective of food and nutrition in the PNG highlands. In 'Food security for Papua New Guinea', ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 94–99. ACIAR: Canberra.

Bourke R.M. 1983. Improving food production and people's nutrition. Harvest 9, 11–23.

Bourke R.M. 1990. Subsistence food production systems in Papua New Guinea: old changes and new changes. Occasional Papers in Prehistory, No. 18, Department of Prehistory, Research School of Pacific Studies, Australian National University, pp. 148–160.

Brookfield H.C. 1972. Intensification and disintensification in Pacific agriculture: a theoretical approach. Pacific Viewpoint 13, 3048.

Connor, D.J. 2001. Optimizing crop diversification. Pp. 191–212 in 'Crop science: progress and prospects', ed. by J. Nosberger, H.H. Geiger and P.C. Struik. CABI Publishing: Wallingford, UK.

Danbaro G., Vegofi G. and Kila A. 2001. Use of sweetpotato and soy beans for feeding exotic type pigs. In 'Food security for Papua New Guinea', ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 463–465. ACIAR: Canberra.

De Datta S.K. 1989. Integrated nutrient management in relation to soil fertility in lowland rice-based cropping systems. Pp. 148–150 in 'Rice farming systems: new directions'. International Rice Research Institute: Manila, The Philippines.

Gama. J.C. 1995. Opportunities for livestock mixed farming in the Markham Ramu Valley. Department of Agriculture and Livestock Technical Report 5, 35–43.

Garside A.L, Bell M.J. and Berthelsen J.E. undated. Species and management of fallow legumes in sugar cane farming systems. Proceedings of the 10th Australian Agronomy Conference, January 2001. The Australian Society of Agronomy.

Gibson J. 2001a. The nutritional status of PNG's population. In 'Food security for Papua New Guinea', ed by R.M. Bourke, M.G. Allen, and J.G. Salisbury. ACIAR Proceedings No. 99, 407–413. ACIAR: Canberra.

Gibson J. 2001b. The economic and nutritional importance of household food production in PNG. In 'Food security for Papua New Guinea', ed by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 37–44. ACIAR: Canberra.

Giller K.E. 2001. Nitrogen fixation in tropical cropping systems. CABI Publishing: Wallingford, UK.

Gwaiseuk W.R. 2001. The role of agriculture in the PNG economy. In 'Food security for Papua New Guinea', ed by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 30–36. ACIAR: Canberra.

Hymowitz T. 1990. Grain legumes. Pp. 54–57 in 'Advances in new crops', ed. by J. Janick. and J.E. Simon. Timber Press: Portland, OR.

Kimber A.1969. Soybean in the New Guinea highlands. Rural Digest, Department of Agriculture Stock and Fisheries, TPNG 10, 13–17.

McAlpine J.R. 1967. Population and land use of Bougainville and Buka islands. In 'Lands of Bougainville and Buka Islands, Papua New Guinea'. CSIRO Land Research Series No. 20. CSIRO: Canberra.

McAlpine J.R. 1970. Population and land use in the Goroka-Mt Hagen area. In 'Lands of the Goroka-Mt Hagen area, Territory of Papua New Guinea', ed. by H.A. Hanntjens. CSIRO Land Research Series No. 27. CSIRO: Canberra.

Mcqueen C. 1993 Pigeon pea-shrub for all seasons! Didiman Newsletter Vol. 25, 36–39.

Malynicz G.L. 1974. Whole soybeans as protein supplement for sweetpotato in pig rations. Papua New Guinea Agricultural Journal 25, 15–17.

Mills F. 2002. The book of rice in Papua New Guinea. Mills Media: Port Moresby NCD.

Mueller I. 2001. The spatial pattern of child growth in PNG In. 'Food security for Papua New Guinea', ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 414–431. ACIAR: Canberra.

Muntwiler M. and Shelton R.M. 2001. Survey of nutrition and protein intake in the rural families in the Eastern Highlands Province. In 'Food Security for Papua New Guinea' ed. by R.M. Bourke, M.G. Allen and J.G. Salisbury. ACIAR Proceedings No. 99, 432–442. ACIAR: Canberra.

Norgan N.G., Durnin J.V.G.A. and Ferro-Luzzi A. 1979. The composition of some New Guinea foods. Papua New Guinea Agricultural Journal 30, 1–3.

Ohtsuka R. 1996. Agricultural sustainability and food in Papua New Guinea. In 'Population, land management and environmental change', ed. by J.I. Uitto and O. Akiko. The UNU Global Environmental Forum IV, 25 May 1995. The United Nations University: Tokyo, Japan.

Saese H., Bafui J., Kolopen J. and Fahey G. 2007. Seed village and on-station trials of peanut production in the Lower Markham valley of Papua New Guinea. Annual report submitted to Australian Centre for International Agricultural Research (ACIAR) as part of ACIAR project ASEM/2004/041 (unpublished).

Sem G. 1996. Land-use change and population in Papua New Guinea**.** In **'**Population, Land Management, and Environmental Change', ed. by J.I. Uitto and O. Akiko. The UNU Global Environmental Forum IV, 25 May 1995. The United Nations University: Tokyo, Japan.

Small E. 1995. Crop diversification in Canada with particular reference to crop genetic resources. Canadian Journal of Plant Science 75, 33–43.

Springhall J.A. 1969. The use of selected local ingredients for pig rations in the territory of Papua and New Guinea. Papua New Guinea Agricultural Journal 21, 76–87.

Sumbak J. 1976. Trial work with soybeans and sugarcane particularly in the Markham Valley. Pp. 221–228 in '1975 Papua New Guinea Food Crops Conference proceedings', ed. by K. Wilson. and R.M. Bourke. Department of Primary Industry: Port Moresby, Papua New Guinea.

Thompson A.E. 1988. Alternative crop opportunities and constraints on development efforts. Pp. 1–8 in 'Strategies for alternative crop development: case histories', ed. by L.L. Hardman and L. Waters. Crop Science Society of America: Madison, WI.

UNDP (United Nations Development Programme) 1999. Human development report. At: <http://hdr.undp.org/en/media/HDR_1999_En.Pdf>.

Wallis E.S., Wood I.M. and Byth E.E. 1989. New crops: a suggested framework for their selection, evaluation and commercial development. Pp. 36–52 in 'New crops for food and industry', ed. by G.E. Wickens, H. Haq and P. Day. Chapman and Hall: London.

Wood A. 1984. Land for tomorrow: subsistence agriculture, soil fertility and ecosystem stability in the New Guinea Highlands. PhD thesis, University of Papua New Guinea, Port Moresby.

World Bank 2006. Equity and development. The World Development Report. At: <http://www.worldbank.org/INTWDR2006/Resources/WDR_on_Equity_FinalOutline_July_public.pdf>**.**

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