Implications of soil resources for vegetable crop options and agronomic practice for sustainable production – a comparison of Eastern Highlands and Central Provinces, Papua New Guinea

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Abstract
Soil resources of the Eastern Highlands Province and Central Province of Papua New Guinea are outlined, with particular emphasis on the implications of their characteristics for agronomic practice and soil management under conditions of increasing demand for food because of population increase. Implications for crop options are also examined. Key areas of irrigation and drainage, acid soil infertility, organic matter based farming and nutrient management, with particular emphasis on nitrogen, phosphorus and potassium supply and availability in soils, are examined in a sustainability context. Cation balance, micronutrient and sulphur supply are also considered. The risk of soil degradation is examined briefly, and the need to select appropriate sites for sustainable intensive production highlighted.

Key Words
Sustainable, vegetables, soil resources, soil management

Introduction

Soil resources and climatic conditions interact strongly influence crop options and agronomic practices. This interaction is particularly important in developing countries where purchased chemical inputs are usually scarce and expensive, and often inaccessible to local producers because of cost. Value chain analysis provides an holistic framework for guiding the research focus on the bio-physical limitations and variables, for example soil physical characteristics and soil fertility, that will have the optimum socio-economic impact. Soils of the Eastern Highlands and Central Province of Papua New Guinea (PNG) are highly variable, as discussed in Doyle *et al.* (2010) – this paper concentrates on those with the greatest agricultural potential, and examines the implications of soil characteristics and limitations for crop options and agronomic practices, within the constraints of a developing country. Climatic limitations are a relatively minor constraint in the PNG highlands, with adequate rainfall in most months, and moderate maximum and minimum temperatures throughout the year (Table 1). The main climatic constraint is likely to be excessive rainfall causing excess runoff and perched water tables. The coastal lowland areas lie in the seasonally dry tropics, and tend to have excessive rainfall from November to April and dry conditions for the balance of the year, with a tendency for improved distribution towards the east. Temperatures are high throughout the year (Table 1).

Table 1. Mean monthly rainfall (mm) and maximum and minimum temperatures (^{o}C) at Goroka (Eastern Highlands Province) and Port Moresby (Central Province, coastal lowlands area), Papua New Guinea.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Goroka													
Rain	153.4	214.5	272.2	175.7	151.9	43.8	70.4	49.2	150.1	132.1	145.4	163.8	1722.5
Max	26.7	26.5	26.5	26.9	26.3	26.1	25.6	26	26.2	27.0	27.0	27.5	-
Min	15.5	16.2	16.2	15.7	15.4	15.1	14.9	14.9	15.6	15.4	15.7	16.1	-
Port Moresby													
Rain	192.2	140.6	189.8	105.2	56.2	21.6	13.8	12.0	14.4	15.2	40.0	47.8	848.8
Max	32.1	31.6	31.4	31.3	31.0	30.3	29.9	30.3	31.0	32.0	32.5	32.4	-
Min	23.7	23.5	23.4	23.5	23.5	23.1	22.4	22.6	23.2	23.5	23.6	23.7	-

Source:PNG National Weather Service (2009)

Summary of soil resources characteristics

The Eastern Highland Province (EHP) of PNG is characterised by areas of recent volcanic and associated geomorphic activity, giving rise steep slopes and deep incision of the landscape which often constrains access and increases the risk of land degradation. The most intensively used arable soils are the Andisols which are oxy-hydroxide rich, fine textured soils with variable drainage characteristics formed from volcanic ash. They have high levels of organic matter, but low chemical fertility and acidic soil reaction trends. The exchange complex is dominated by aluminium with low levels of all exchange cations but with potassium particularly limiting. The soil acidity and high iron oxide levels mean P fixation is an issue (Bleeker 1983, Harding and Hombunaka 1998; Radcliffe and Kanua 1998,). Other nutrient deficiencies include boron, zinc, molybdenum, copper and manganese (Radcliffe and Kanua 1998; Harding and Hombunaka 1998).

In Central Province, the highly dissected Sogeri Plateau forms an elevated area inland from Port Moresby which is accessible by road. Here the dominant soils used for agriculture are well structured, deep Oxisols. However steep slopes in this deeply incised landscape mean a high soil erosion risk exists across much of the area. Hanson *et al.* (2001) indicate high land potential in this area, despite the likelihood of acid soil infertility, strong P fixation and other nutrient deficiencies similar to those in EHP. In the peri-urban areas near Port Moresby, National Capital District (within Central Province), landforms vary from steeply sloping hills and mountains, with shallow soils of low natural fertility derived from siliceous sedimentary rocks to alluvial valleys associated with numerous streams flowing southward from the Owen Stanley Ranges. The alluvial soils are typically deep, dark, and fine textured being derived from mixed felsic and mafic parent materials.

Implications for crop options and agronomic practices

Crop options

Because of limitations of availability and cost of fertilisers, crop selection must consider the adaptation of indigenous and exotic crops to soil fertility limitations. This implies, for example that crops that efficiently extract P from low availability sources in highly P fixing soils, for example sweet potatoes, peanuts and soybeans should be preferred over introduced temperate crops. The low availability of K in many highland soils constrains yield of many crops, particularly the high K requiring crops such as sweet potatoes. However, there are dietary, financial and social factors that impinge on crop selection, sweet potatoes being a staple crop of social significance to PNG peoples, while social change and dietary preference favours temperate vegetables such as Brassicas for urban markets. These latter crops require high levels of fertility, including specific requirements for boron and molybdenum, and therefore require either purchased inputs or new land in which to be grown. The latter option remains available while land supplies are non-limiting, but with increasing population placing pressure on land resources, cannot continue indefinitely. Clearly, areas of production of high nutrient demand crops will need to be carefully selected, but carry the risk of nutrient exploitation, followed by reduced productivity and lack of sustainability of production and the soil resource. Soil nutrient constraints will limit cropping options and require increasingly sophisticated rotations and increased nutrient inputs from local and imported sources. Further, soil limitations will be a major determinant of expansion of crop production to meet the needs of increasing urban populations in Port Moresby and other cities of PNG.

Drainage and irrigation options

In the Eastern Highlands, the topsoils are generally well structured with good drainage. However, some subsoils are more limiting with occurrence of impeding clayey layers, causing permanent and seasonal gleying, perched water tables and formation of iron and manganese segregations, nodules and pans. They indicate that artificial drainage will be necessary for long term production in the lower lying and flatter parts of the high rainfall environments. In the coastal lowland areas, high ground water tables and seasonal flooding will limit crop options and season of production. On the slopes around Port Moresby, irrigation is necessary because of limited soil depth and poor water holding capacity. Currently, migrant highlanders occupy this land without security, and use reticulated (urban) water for irrigation, an unsustainable situation.

Options for managing acid soil infertility

Lack of financial capacity to import ground limestone or dolomite means approaches to soil pH adjustment used in developed countries are not viable. Amelioration of soil pH in the Andisols and Oxisols in the Highlands and Sogeri, utilising limestone in uplift areas of the Owen Stanley Ranges is possible. Local processing to suitable particle size may be viable in the longer term, however, preparation of burnt lime using crop residues as the heat source in small kilns and taking advantage of the cultural importance of fire may offer a way forward (Bailey *et al.* 2008). Though not expected to be a widespread limitation in the alluvial areas, soil acidity is likely to constrain production on the slopes around Port Moresby, and combined with erosion risk on these soils, severely constrain their long term use. Amelioration of soil pH in these sloping areas is unlikely to be considered given the lack of security of tenure of migrant settlers.

Organic matter based farming
The moderate to high levels of organic matter measured in the topsoils of the highlands soils (Bailey *et al.* 2008) suggests nitrogen supply from well managed minearlisation should be sufficient for most crops. However, high C:N ratios may limit N supply, particularly during periods of high crop demand. Also, and the adequacy of N supply and other nutrients partly sourced from organic matter (e.g. sulphur) may not be sustainable as rotations are intensified in response to increased food demand (Bourke 2001). The current practises of burning most crop residues reduces the plant nutrient pool, and leads to degradation of soil structure, adversely affecting crop production and land resource conservation. Further, increasing population pressure is forcing production onto poorer soils with lower organic matter levels and weaker structure, placing these at risk further degradation. These problems are already evident in some of the more intensively farmed areas e.g. Sogeri Plateau and peri urban hillsides near Port Moresby. By contrast, the river valleys of the coastal lowlands are less intensively used for vegetable production, and offer opportunities for increased and sustainable production.

Nutrient management options
Regardless of location in the highlands or coastal lowlands, increased production with shortened rotations will bring new nutrient management challenges and intensify existing limitations. Of the macronutrients, shortened rotations will render nitrogen constraints more widespread and severe, and place increased demands on all other nutrients through crop uptake and removal in harvested product. Consequently, purchased nitrogen, either as fertiliser or imported organic matter (mulch or compost from other cropped or non-cropped areas) or rotations including legumes will be required. Importantly, additional N entering the system is likely to further acidify already acid soils, creating demand for liming materials.

Phosphorus supply represents a major challenge, because of P fixation by several major agricultural soils, inadequate current soil supply, and high cost of P fertilisers. There are also no sources of phosphate rock for fertiliser manufacture (Fixen 2009). Importing plant material from non-crop areas and return of domestic waste, and if available, industrial by-products could assist but are unlikely to meet the needs for soil P especially on highly fixing soils. Thus, in the short term at least, production of P efficient crops e.g. peanuts and perhaps mycorrhizal crops on highly fixing sites and high P demand and P inefficient crops e.g. tomatoes, brassicas on comparatively P fertile sites in lowland alluvial areas emerge as the preferred strategies, provided market conditions allow. In the longer term, though, there appears no alternative to purchased P fertiliser. K supply in many Highland soils is inherently low (Bleeker 1983), and long term production of high K demand crops such as sweet potatoes has exacerbated the situation. Importing organic matter and burning it to release K or using it as mulch (Bailey *et al.* 2008) can provide some K, but simply transfers K from one location to another. Return of domestic and other waste may also provide some K. However, the amounts returned are likely to be small compared to total need and with limited reserves of slowly available K in soils of the highlands, the importation of K fertiliser seems inevitable. Alluvial soils are better supplied, so K application may not be needed for some time.

Calcium and magnesium supplies are low in acidic volcanic soils with low CEC in the Highlands, but be less limiting in alluvial coastal soils. Though not currently recognised as a significant production limitation, intensification and intensification of rotation cycles is likely to result in deficiencies, expressed, for instance as blossom end rot in tomatoes (Ca deficiency). Raising soil pH as outlined earlier would also reduce the risk of metal, especially aluminium, toxicities, while enhancing solubility of micronutrients such as molybdenum. The challenge, in the PNG context, is to provide liming materials at an affordable price.
Inherent sulphur supply in tropical soils depends on the ability of the profile to retain sulphur through adsorption. This in turn depends on parent material. Soils developed on basic parent material will have a greater sulphate adsorption capacity, particularly at depth, than soils developed on acid igneous rocks or sediments (Barrow 1978). This sulphur is much less strongly adsorbed than phosphorus or molybdenum (Barrow 1978), and is therefore relatively available to plants. The capacity of soils to sorb sulphur also increases with annual rainfall because higher rainfall increases weathering and makes soils more acid. As cropping intensifies, depletion of inherent sulphur will occur, and continued supply in the topsoil will depend on inputs of either organic matter or S-containing fertilisers.

Of the micronutrients, boron and molybdenum are most widely recognised as deficient in the highlands of PNG (Bleeker 1983; Bailey *et al.* 2008), but little if any information is available for the coastal lowlands. Raising soil pH can improve molybdenum solubility, otherwise supply of molybdenum as a seed dressing or fertiliser will be required. There is little option but to supply boron as fertiliser to crops that are susceptible to boron deficiency e.g. brassicas, for production to continue in current locations. Alternatively, their production could be increased in more favourable sites in the Highlands or Lowlands, provided market and infrastructure conditions allowed.

Soil degradation and its control
Soil erosion in the regions studied is limited by the small patchwork nature of the production gardens. Even on steep slopes; the cover upslope, well maintained field drains, good soil structure and short slope lengths all combine to limit erosion risk. However the increasing pressure to expand the areas of production, and in particular the drive to grow on poorer more weakly structured soils, notably in the peri urban setting, represents a major soil erosion risk. There is a need to better select intensive production regions to protect the peri urban environment, harness the better regional resources (soil, water, people) and ensure a sustainable and consistent food supply chain.

Conclusion
Suitable soil resources for sustainable vegetable production are available in EHP and CP of PNG. However, limitations of chemical fertility, topographic position and in some locations soil depth will limit crop options and long term sustainability of production. Key areas of irrigation and drainage, acid soil infertility, organic matter based farming and nutrient management, with particular emphasis on nitrogen, phosphorus and potassium supply and availability in soils will require solutions that are affordable for local producers and sustainable. In the longer term, cation balance, micronutrient and sulphur supply are expected to become increasingly limiting and require similar solutions. The risk of soil degradation is a significant production limitation in elevated areas, emphasising the need to select appropriate sites for sustainable intensive production.

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References
Bailey J, Ramakrishna A, Kirchoff G (2008) Relationships between important soil variables in moderately acidic soils (pH> 5.5) in the highlands of Papua New Guinea and management implications for subsistence farmers, *Soil Use and Management* **24**, 281-291

Bleeker P (1983) 'Soils of Papua New Guinea'. (CSIRO Publishing: Canberra).

Bourke RM (2001) Intensification of agricultural systems in Papua New Guinea. *Asia Pacific Viewpoint* **42**, 221-238.

Doyle R, Sparrow L, Birch C, Bonney L (2010) Increasing food security for Port Moresby, PNG – issues of land suitability, technology, tenure, and tribalism. In 'Proceedings of the 19th World Congress of Soil Science, Brisbane, 1-6 August 2010'.

Fixen PE (2009) World fertilizer nutrient reserves – a view to the future. *Better Crops* **93**, 8-11.

Hanson LW, Allen BJ, Bourke RM McCarthy TJ (2001) 'Papua New Guinea Rural Development Handbook'. (Research School of Pacific and Asian Studies, Department of Human Geography, Australian National University: Canberra).

Harding PE, Hombunaka PH (1998) A review of coffee nutrition research in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries* **41**, 44-64.

PNG National Weather Service (2009) 'Climatological Information, PNG National Weather Service' http://www.worldweather.org/077/01246.htm.

Radcliffe DJ, Kanua MB (1998) Properties and management of Andisols in the highlands of Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries* **41**, 29-43.