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Research Paper

Intensified sweetpotato production in Papua New Guinea drives plant nutrient decline over the last decade

Ryosuke Fujinuma[a,*], Gunnar Kirchhof[a], Akkinapally Ramakrishna[b], William Sirabis[b], Jeffery Yapo[b], Deane Woruba[c], Geoff Gurr[c,d], Neal Menzies[a]

[a] *The University of Queensland, School of Agriculture and Food Sciences, St Lucia, Australia*
[b] *National Agricultural Research Institute, Lae, Papua New Guinea*
[c] *Charles Sturt University, EH Graham Centre for Agricultural Innovation, Orange, Australia*
[d] *Fujian Agriculture and Forestry University, Institute of Applied Ecology, Fuzhou, China*

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ABSTRACT

Sweetpotato (*Ipomoea batatas*) is the staple food of the Papua New Guinea Highlands and is primarily grown in swidden-type production systems. Because of high population growth and limited available land to expand agricultural production, land use must be intensified to ensure food security. In this study, changes in sweetpotato production systems were assessed by comparing field surveys conducted in 2005 and 2014. During the nine years between surveys, the length of fallow period decreased by 48%, from an average length of 12.1 in 2005 to 6.3 years in 2014. This reduction coincided with a reduced growth period for sweetpotato production gardens from 13.1 to 9.6 month (27%). The time required to reach gardens from the family home increased by 60% from 2005 to 2014. This surrogate measure shows that increasing land pressure has forced farmers to use more remote sweetpotato gardens. The clear driver for increased production was increased demand for sweetpotato as a cash crop; 83% more sweetpotato was sold, rather than consumed by the producer. Despite the increase in production, the management of soil fertility remained unchanged, and farmers continued not to use mineral fertilisers for sweetpotato production. The intensification of land use reduced the occurrence of traditional bush/tree fallow species, such as *Casuarina oligodon*, which were traditionally used as fallow species in the sweetpotato system, but have been replaced by food legumes, e.g., beans and peanuts. As a consequence of land use intensification, there was a clear decline in soil fertility, particularly for soil N, P, Fe, and Zn, and plant tissue concentrations of N, S, Ca, Fe and B. Given the present rate of population growth and limited land area available to expand, land use intensification will continue. Comparison of the two surveys reported here, indicated that nutrient rundown of the system is occurring. To prevent further depletion of soil nutrients, especially as further intensification of the system is anticipated, nutrient inputs to the sweetpotato production system will need to be increased. In the short to medium-term, this may be through landscape nutrient redistribution strategies such as mulching with organic matter from outside the garden area in a cut and carry or cut and place method, but in the longer-term we anticipate that high levels of production can only be sustained through the addition of mineral fertilisers.

1. Introduction

In developing countries with high population growth, continuing overexploitation of the land resource and decline in soil fertility are major consequences of land use intensification in response to increasing demand for food (Matson et al., 1997). Increasing agricultural production to meet growing food demand can be achieved in some instances through the expansion of agricultural lands, as observed in many African countries (Arnason et al., 1982; Vlek, 1990; Tully et al., 2015). However, in most smallholder agricultural systems there are constraints to the expansion of the area used for agriculture, and increased food production must be achieved through the intensification of land use (Zimmerer et al., 2015). In the Highlands of Papua New Guinea (PNG), the area of land used for agriculture has remained relatively stable despite an increasing population and consequent increased demand for food (Bourke, 1997, 2001). The sweetpotato (*Ipomoea batatas*) production system in PNG is a key component of increasing smallholder production in the Highlands because it provides

* Corresponding author.
E-mail addresses: r.fujinuma@uq.edu.au, rfujinuma@gmail.com (R. Fujinuma).

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the staple food in this region throughout the year. Considering that the population in PNG tripled in the last three decades, with the largest increases occurring in the Highlands (Allen, 2007), increased production from the sweetpotato-based production system is apparent, and land use intensification is implied but has not been measured directly.

To meet future demands for food in the Highlands of PNG, more sweetpotato must be produced per unit of available land, but this must be done in a way that sustains the productive capacity of the land. There is a clear need for assessment of how the sweetpotato based production system has already changed to meet the demand for food, and of how well existing soil fertility management practices are sustaining soil fertility. Previous studies in PNG have examined only a limited number of paired sites (Sillitoe and Shiel, 1999; Bailey et al., 2008). Due to the highly complex mosaic of diverse soil types in the Highlands of PNG (Bailey et al., 2009), the limited number of observations from paired sites does not provide region-wide information on trends in land management practices. The assessment of geographically widely distributed data points for this region is essential to adequately describe the complexity of soil fertility and to develop effective field management tools.

Numerous inferred projections demonstrate changes in land use; however, tangible data that show the magnitude of intensification and the subsequent effects on the land resource and soil properties are rare (Hartemink et al., 2008). Comparing farmer surveys conducted over time provides important information to guide research investment to meet changing needs, and is particularly useful regarding questions on land use intensification. The common chronological order for such a survey is to begin when the projects are commenced and then survey again some years (i.e., approximately 10 years) after project completion. The comparison of baseline and post-intervention data provides accurate assessments of actual long-term changes in the field (Hartemink, 2006; Winters et al., 2010). Unfortunately, this approach is rarely implemented with biophysical projects because of changes in funding bodies, staff profiles, and laboratory procedures (Hartemink, 2003b). Clear and unambiguous data from identical surveys conducted at different time points are rare in general and, in the Highlands of PNG are especially scarce. Filling this gap is important to understand and quantify the effects of land use intensification on natural resources, and on the agricultural systems themselves, in order to guide future soil fertility management practice.

In this study, we compared the results of two surveys and analyses of two sets of field samples from 2005 and 2014, for a set of identical sites, to address a general question of how sweetpoato swidden cultivation has changed over the years with the following hypotheses: (i) fallow periods have decreased during the nine years, and (ii) food demand has forced an expansion of the cultivation area. In the comparison of the surveys, plant and soil samples, the objectives were to (i) assess fallow length, (ii) evaluate the cultivation system, (iii) investigate whether the location of farming activities changed, (iv) assess farmer awareness of fertility problems, and (v) assess soil fertility. The first farmer survey was conducted in 2005 as a pilot study for a project on managing soil fertility decline in sweetpotato-based cropping systems in the Highlands of PNG. Nine years later in 2014, the survey was repeated to provide direct, tangible data on changes in land use practices.

2. Materials and methods

This study was conducted in the Highlands region of PNG. This region contains varied terrain up to 4000 m above sea level with long steep slopes, narrow valleys and complex ridge formation (Bailey et al., 2008). The majority of agricultural lands are distributed in the 1200–2800 m elevation area (Bourke, 2007) where daily temperature ranges from 14 to 25 °C and annual precipitation ranges from 2000 to 4000 mm year^{-1} (McAlpine et al., 1983). Natural vegetation of the region was lower or upper montane forests depending on the altitude (Bleeker, 1983), however the vast majority of the agricultural area has been converted to open grasslands and agricultural fields (Bleeker 1983; Bailey et al., 2008).

Sweetpotato was predominantly cultivated on small rectangular fields, typically of around 300 m^2 in area. In gardens with poor drainage, farmers dug drain ditches every 2–3 rows of mounds. Farmers, particularly women and children, patrol through the gardens regularly to control weeds until sweetpotato forms a closed canopy and suppresses weed growth (approx.. 6–7 weeks after planting). Previous work identified that hundreds of sweetpotato varieties were cultivated in the Highlands of PNG using cuttings from the well-performing gardens nearby (Roullier et al., 2013). Farmers have managed soil fertility predominantly by natural fallow (Bourke, 2007). The species constituting fallow vegetation commonly include: *Cyda rubifolia* (local name: Broomstick), *Epinedium grandiflorum* (local name: Goat weed), *Bidens alba* (local name: Shepaerd's needle), *Crassocephalum crepidioides* (local name: Thick head), and *Digitaria sanguinalis* (local name: Crabgrass). The common land preparation practice after the fallow is slash-and-burn to reduce the mass of plant residues first, then hand-tilling before forming mounds and drain trenches. The size of the mounds was predominantly 40–70 cm diameter in the surveyed region described below.

In 2005, survey data was collected from farmers distributed in nine districts within four provinces (Eastern Highlands, Western Highlands, Simbu, and Enga) (Wegener et al., 2009). To facilitate comparisons across time, a subset of five villages that had been surveyed in 2005 were visited again in 2014 (Lufa [6°17′S, 145°25′E]; Asaro [6°00′S, 145°18′ E]; Sina sina [6°05′S, 145°01′E]; Gumine [6°11′S, 144°56′E]; and Hagen Central (hereafter Hagen) [5°49′S, 144°18′E] representing Eastern Highlands, Simbu and Western Highlands provinces). In each village, six or seven farmers were selected to represent the area after negotiations with the communities in both 2005 and 2014. In the 2014 survey, we revisited the same villages with the aim to locate and meet the same farmers (or successors) as much as possible. In some cases, farmers from the 2005 survey were absent or deceased; therefore, as an alternative, nearby farmers were selected from the identical village with a preference for neighbours of the farmers who participated in the 2005 survey. Overall, a total of 35 farmers contributed to the 2005 survey, while 33 farmers contributed in 2014.

Surveys in both 2005 and 2014 included one-on-one interviews and subsequent sampling of surface soils to link the responses of farmers to biophysical parameters. For each interview, a total of 87 questions and 40 observations were included to cover four areas of concern in the socioeconomic and biophysical environment: (1) farming system, (2) farmer perception of problems in soil and their management, (3) farmer perception of pest and disease problems and their management, and (4) measurements of production indicators. Questions related to the farming system assessed socioeconomic information (i.e., cash crops as income source, frequency of selling) and farm setting (i.e., distance to gardens, land availability for expansion). Questions related to soil problems and their management assessed farmers perceptions (i.e., recognition of yield decline and soil fertility condition) and their management decisions (i.e., length of fallow, time between planting to harvest, condition to enter the fallow period, fertility management, and fallow management). The detail of questions and outcomes for farmer perceptions of pest and disease problems and their management are not reported in this study because they are described and discussed in Gurr et al. (2016). Further details of the survey questions are described in previous studies (Kirchhof et al., 2008, 2009; Bailey et al., 2009). Each interview required approximately 1.5 h, and then soil samples were collected from the garden of the farmer. Details of soil and plant sample collection are provided later in the methods section.

In both 2005 and 2014 surveys, the sweetpotato gardens were separated into new and old gardens based on the management at the moment of the surveys. A new garden was defined as a garden in which sweetpotato was planted after the end of a fallow period. Fallow vegetation ranged from predominantly grass in areas near villages which