THE EFFECTS OF SHIFTING CULTIVATION ON SOIL PROPERTIES: AN EXAMPLE FROM THE KARIMUI AND BOMAI PLATEAUX, SIMBU PROVINCE, PAPUA NEW GUINEA

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ABSTRACT

The analysis of soil samples removed from both rainforest and subsistence food gardens on the Karimui and Bomai Plateaux revealed that shifting cultivation has a marked effect on soil chemical properties. With cultivation there is a reduction in available P, exchangeable Ca and Mg, cation exchange capacity and %C and %N. The decline in soil fertility with cultivation is thought to be due mainly to a reduction in soil organic matter resulting from the clearance of the rainforest vegetation.

The likely effects of resettlement are discussed, and it is thought that only about 5500 people could be resettled on the plateaux under the existing system of shifting cultivation. A further increase in population would require more intensive cultivation techniques to be developed, and these could result in soil deterioration and environmental disturbance.

INTRODUCTION

This paper is based on the results of a soil and land use survey carried out in September 1977 by a group of staff and students from the Department of Geography, University of Papua New Guinea (Wood and Pain 1978). The survey followed a request from the Simbu Provincial Government for more information on soil fertility and the land use possibilities of the Karimui and Bomai areas.

The Karimui and Bomai Plateaux are situated in southern Simbu Province of Papua New Guinea (latitude 6°30′ S., longitude 144°50′ E.) and occupy an intermediate position between the highlands to the north and the lowlands to the south. The plateau areas lie between 800 and 1200 m and form the greatest area of flat and gently undulating terrain in Simbu Province. The two plateaux are formed on volcanic lavas, agglomerates, mudflows and volcanic ash from the extinct Pleistocene volcanoes of Mt. Karimui and Mt. Au shown in *Figure 1* (Bain and Mackenzie 1975). These volcanic deposits have covered the Tertiary and Cretaceous sediments in the area. The two plateaux are separated by the Tua River, a major tributary of the Purari.

The climate of the area is warmer and wetter than the north of the province. The lower elevation results in mean minimum and maximum temperatures being 2 to 3°C higher in Karimui (Min. 18°C; Max. 28°C) than in Kundiawa (Min. 14.6°C; Max. 26.1°C). Annual rainfall totals are significantly higher: 3386 mm at Karimui, 4855 mm at Unani on the Bomai plateau, and only 2224 mm at Kundiawa (Simpson 1975).

Much of the Karimui and Bomai Plateaux are covered with lower montane rainforest vegetation, and true montane forest occurs on Mt. Karimui and Mt. Au.

The population in the south of the province is concentrated on the plateau areas, although densities are quite low, with about 24 persons per km^2 on the Karimui Plateau and only 4 persons per km^2 on the Bomai Plateau.

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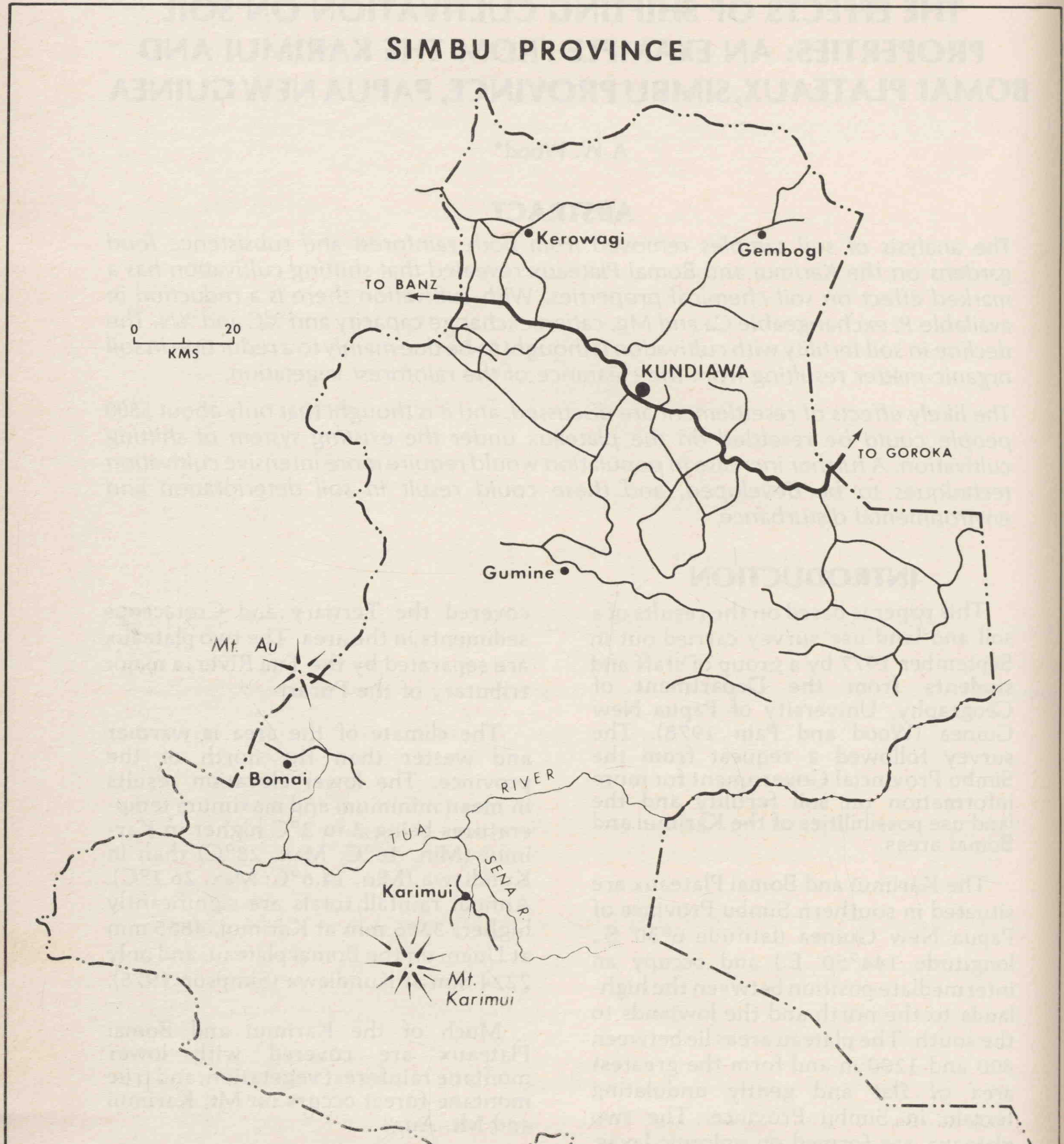

Figure 1. — Map of the Simbu Province

SURVEY METHODS

Fifteen gardens around Karimui and twelve around Bomai were examined in detail. Information was collected on soil and site characteristics, crop types, age and cultivation history, cultivation techniques and land ownership for each garden. This information was collected both by interview and by observation.

The boundaries of each garden were plotted by compass traverse, and distances were measured either with a tape measure or by pacing. A plan of each garden was drawn up on squared paper and the area was calculated.

Soil samples were removed from each garden for chemical analysis. The sampling technique consisted of removing a number of samples (usually about 10) from the cultivated topsoil (0-15 cms) in a garden, and then mixing these into one bulk sample. Samples were also removed in a similar manner from the top 15 cms of soil under rainforest and in old gardens under grass fallow, with a view to finding the changes in soil properties which occur with cultivation.

A selection of soil samples was taken for chemical analysis and standard procedures were used. pH was measured electrometrically on a 1:5 soil:water mixture, and available phosphorous was measured by the method of Olsen *et al.* (1954). The exchangeable cations were determined by atomic absorption spectrophotometry after leaching the soil with neutral ammonium acetate, and the exchange capacity was found by measuring the ammonium ions absorbed by the soil exchange complex, using the method described in Black (1965). Organic carbon was determined by the method of Walkley and Black (Black 1965:1372) and total nitrogen by the Kjeldahl procedure (Black 1965:1162).

CULTIVATION TECHNIQUES

The traditional method of cultivation in the area is a form of shifting cultivation or bush fallowing, which is widely used in the zone of intermediate elevation (500-1500 m) in Papua New Guinea (Powell 1976). Gardens are prepared by clearing the forest: the bush is cleared away, the smaller trees are felled and some of the larger ones are ring barked.

The debris from the clearing is commonly piled up around the base of the larger trees and is fired. Gardens are usually fenced and weeded before planting. The size of gardens studied ranged from 0.06 to 2.01 ha, with an average size of 0.65 ha. A typical garden on the Bomai Plateau is shown in *Plate* I.

The main crop is sweet potato and this is planted by dibbling, with no further working of the soil. A large range of other crops is grown including banana, beans, cabbage, cassava, cucumber, groundnut, maize, paw paw, pineapple, pit pit, pumpkin, sugar cane, taro, tobacco, and various greens.

Gardens are cultivated for 1-2 years and are then left fallow as yields decline. Some crops such as bananas continue to be harvested while gardens are being fallowed.

SOIL TYPES AND PROPERTIES

The main soil type is a Humic Brown Ash soil which has many similarities with soils developed on volcanic material throughout the Papua New Guinea Highlands. It is characterised by a dark brown, friable organic topsoil of clay texture ranging from 15-35 cm in depth, which overlies yellowish brown to brown clay. The organic topsoil is generally thinner and lower in organic matter than those of highlands volcanic ash soils, and this is probably due to

Plate I. — A large garden cut in rainforest on the Bomai Plateau. This garden was cleared about 6 months before the photograph was taken.

the warmer temperatures in southern Simbu which promote a more rapid breakdown of organic matter.

The soils around Karimui and Bomai have formed in volcanic parent materials. Those around Karimui appear to have formed largely in airfall volcanic ash, whereas those near Bomai are formed in reworked ash. The Bomai soils are more massive than those around Karimui and in places contain large rounded boulders of lava. The Bomai soils probably occur on volcanic mudflows which have moved down the slopes of Mt. Au.

The soils of the Bomai Plateau have been surveyed by Hartley and Aland (1962) who termed them "highly leached organic clays of low overall fertility". Only the organic topsoils were considered to contain adequate nutrient supply.

The chemical properties of the soils analysed are shown in *Table 1* which gives mean values and the range of values for the chemical analysis of topsoils (0-15 cm) under different types of vegetation. Only a small number of samples were analysed, and the range for some analyses is wide. However, these are the only results available for this area which illustrate the effects of cultivation on soil chemical properties.

Soils under rainforest show the highest fertility status with a moderate acidity, moderate levels of available P, high exchangeable Ca and Mg, high cation exchange capacity, high base saturation, and moderately high organic matter levels (%C and %N). With forest clearance and cultivation there is a marked reduction in available P, exchangeable Ca and Mg, and cation exchange capacity. Organic matter levels are lower and this probably accounts for the reduction in cation

Table 1. — Chemical analyses for topsoils under different types of vegetation

Vegetation Types	Number of Soil Samples	pH	Available P (Olsen) p.p.m.	Exchangeable Cations me%				Cation Exchange Capacity me %	Base Saturation %	% C	% N
				Ca	Mg	K	Na				
Rainforest	3	5.8 (5.4–6.4)	11.7 (8.8–15.6)	35.2 (29.1–43.3)	7.3 (6.2–9.6)	0.9 (0.5–1.4)	0.5 (0.4–0.6)	41.1 (34.3–53.3)	97 (91-100)	10.8 (9.9–11.7)	1.0 (0.9–1.1)
Cultivated Gardens	6	5.8 (5.2–6.1)	7.2 (4.3–9.8)	20.7 (12.0–28.6)	3.9 (1.6–6.8)	1.2 (0.5–2.4)	0.5 (0.2–0.9)	29.4 (25.4–32.5)	81 (53–90)	8.5 (5.8–10.1)	0.9 (0.6–1.0)
Fallow Gardens	1	5.4	2.8	15.0	2.4	0.8	0.3	19.2	96	6.8	0.7

Mean values are shown and the range is given in brackets.

exchange capacity. The abandoned garden under fallow shows a much lower fertility status with more acid conditions, low available P, lower values for exchangeable cations, and only moderate exchange capacity and organic matter levels.

THE EFFECTS OF SHIFTING CULTIVATION

The impact of shifting cultivation on soil properties and soil fertility has been well documented for tropical areas, in particular by Nye and Greenland (1960). The main effect of forest clearance is to break the natural cycling of nutrients which operates between the rainforest vegetation and the soil. Once the trees have been felled and the vegetation cleared and burned, the major source of organic matter and plant nutrients is removed. Under cultivation the heavy rainfall and high temperatures encourage the rapid breakdown of organic matter and the leaching of plant nutrients. Available plant nutrients are also lost from the soil due to crop uptake.

The decomposition of organic matter is probably the most important result of clearing and cultivation. In the majority of tropical soils it is the organic matter that contains the bulk of the nutrients available to plants, including nearly all the nitrogen, most of the available phosphorous and some of the available potassium. Moreover with a decline in the organic matter content of the topsoil, the structural aggregates of soil are likely to break down. This causes a reduction in pore space and permeability, and increased run off, which could lead to an increase in the removal of topsoil by erosion.

The changes in soil chemical properties given in *Table 1* are similar to findings elsewhere in the tropics. Sanchez (1977) has described changes in fertility for South American soils under shifting cultivation and in some cases the decline in fertility occurs more slowly than in this situation. The chemical data show a gradual reduction in organic matter from rainforest soils to cultivated soils to those soils under fallow where the vegetation is beginning to regenerate. There is also a decline in the cation exchange capacity, which suggests that there is a strong relationship between organic matter levels and cation exchange capacity. The organic matter is the main "store" for plant nutrients in the soil. As organic matter levels decline, so will the soil's capacity for holding exchangeable cations, and these will be released and become more susceptible to removal by leaching.

Although the soil texture is clay in both the topsoil and subsoil, the permeability is high particularly in the topsoil which has a grannular or crumb structure. This allows leaching to proceed rapidly once the soil is exposed to heavy rainfall.

The effects of the reduction in cation exchange capacity and of leaching are illustrated by the figures for exchangeable cations in *Table 1,* all but potassium showing a decline. Base saturation remains high indicating that although the exchange complex remains almost saturated, the reduction in organic matter and cation exchange capacity leads to a reduction in available plant nutrients.

Available P also shows a marked decline with cultivation. Tropical soils, and particularly those developed on volcanic ash, are noted for their ability to "fix" phosphate and render it unavailable to plants (Parfitt and Mavo 1975). The organic matter in these soils contains most of the available phosphate and this will decline with a reduction in organic matter levels.

Thus the removal of the rainforest vegetation and the cultivation of the soil will lead to a decline in soil fertility, although it is not known how rapidly this decline takes place. Few gardens are cultivated for more than two years and this suggests that the change in the amount of available nutrients is fairly rapid. However, this may be a reflection of the low population densities in the area which allow the cultivators to move their gardens more regularly.

The main crop, sweet potato, is not generally planted more than three times before a garden is abandoned. The reason most commonly given by those farmers interviewed for abandoning a garden and moving to another site was that yields of the second or third crop had declined to such a low level that it was no longer worthwhile to continue cultivation of the garden. Charles (1976) has suggested that the multiplication of weeds, pests and diseases is a more important factor than declining soil fertility when explaining the fall off in productivity of subsistence gardens. The Karimui people, however, considered this to be less important than declining fertility when giving reasons for abandoning a food garden.

The soil which has been cultivated, gradually regains its fertility under fallow. Grasses and woody shrub species appear first, then larger trees begin to recolonise the area. With the restoration of the nutrient cycle, organic matter levels are built up. This in turn increases the cation exchange capacity of the soil and fertility levels begin to rise. Fallow periods are commonly between 15 and 20 years before the site is recultivated.

Similar systems of shifting cultivation are practised on many types of soil over much of Papua New Guinea. The soils at Karimui and Bomai are in the author's opinion probably more fertile than most soils because they are derived from volcanic ash parent materials. Although the ash is fairly old, highly weathered and consists mainly of clay sized particles, it contains a small reserve of weatherable, sand sized minerals. Plant nutrients are being constantly released as the weathering of primary minerals proceeds in the soil, although much of this weathering is taking place well below the soil surface and it is doubtful whether many of the nutrients released can be utilised by growing plants. Those nutrients that cannot be held in the soil by the exchange complex are likely to be leached out, and since cation exchange capacity values in the subsoil are low, most of the nutrients released by weathering are probably removed by leaching.

THE EFFECTS OF INTENSIVE CULTIVATION

The Karimui and Bomai Plateaux have been considered as a possible resettlement area for up to 40,000 people from the more densely populated northern part of Simbu Province (Simpson 1975). The present system of shifting cultivation with long fallow periods provides satisfactory subsistence crop yeilds for the relatively small resident population. However, a large increase in the population density could place the agricultural system under stress, and would result in a reduction in the length of fallow periods and an overall decline in soil fertility.

It is possible to make an estimate of the number of people that can be resettled on the plateau areas from the results of the garden survey. Families subsist from an average of 2 gardens, and the average garden size is 0.65 ha. If gardens are cultivated for 2 years and fallowed for 15 years, each settler family would require at least 11 ha of land if present fallow periods are to be maintained. This gives a population carrying capacity of 9 families per km^2 or about 45 persons per km^2, given an average family size of 5 persons.

Although the plateaux contain the largest area of flat land in Simbu Province, the total area of suitable land for cultivation is limited to about 300 km^2. There are already about 8000 people living in the area, and so there is only room for a further 5500 people to settle on the plateaux. If the plans for resettling 40,000 people in the area go ahead, shifting cultivation in its present form could not be practised, and a more sedentary form of agriculture based on the intensive use of a small area of land would need to be developed.

Newton (1960) has considered

various alternative agricultural systems to shifting cultivation which involve rotations combining food crops with leguminous cover crops and green manures. In high rainfall tropical rain-forest areas he concludes that shifting cultivation will maintain soil fertility as effectively as any other system of agriculture, and that rotation trials have failed to maintain yields. Where land shortage exists, the use of commercial inorganic fertilisers and cover crops is recommended.

Charles (1976) also saw shifting cultivation as an efficient method of subsistence agriculture for Papua New Guinea conditions, and considered that problems were only likely to occur when land pressure resulted in shortened fallow periods. He listed various alternatives and modifications to shifting cultivation including the use of fertilisers, but stressed that many of these techniques are alien to subsistence cultivators, who would be slow to adopt them.

Any attempts to intensify the present agricultural system in order to support a large influx of people would face difficulties. The proponents of resettlement argue that in the higher, northern part of Simbu Province there is a more intensive cultivation system with only short fallow periods, supporting population densities of up to 200 persons per km^2, and that incoming settlers from the north would already have a knowledge of these intensive techniques. However, the environmental conditions in the north are quite different from those at Karimui. The risks of soil deterioration and environmental degradation are much greater in the south of the province, and intensive cultivation associated with widespread forest clearance would result in a more rapid decline in soil organic matter content, due to the warmer temperatures and higher rainfall. This would also result in accelerated leaching and nutrient loss, and a high risk of soil erosion, particularly on steeper slopes.

The development potential and limitations to cultivation in the Karimui and Bomai Plateaux are quite different from those in the northern part of Simbu Province. It is not known fully what the effect of an intensification of cultivation techniques would be on the soils of the area. However, it seems likely in view of the soil and climatic differences between the north and south of the province that intensification of agriculture could not take place to the same extent in the south without severe soil deterioration occurring.

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