2.2. *Soils of Papua*

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SOIL IS THE INTERFACE between the biosphere, atmosphere, hydrosphere, and lithosphere. It is a complex medium and has biological, chemical, and physical properties. Soils support plant growth by providing nutrients, water, and anchorage. Soils are also highly diverse ecosystems with a complex but little understood biota of fungi, bacteria, arthropods, and annelids that live below the surface but may contain more biomass than the above-ground organisms. The soil stores and respires large amounts of carbon and is an important source and sink of greenhouse gases.

There are five major soil-forming factors: climate, vegetation, relief, parent material, and time. Differences in the combination of these factors result in soils varying over relatively short distances. Most soils are derived from the weathering of the underlying rock (parent material). Such weathering is at its most rapid in the humid tropics and may result in very deep soils (>10 m). However, many soils owe part of their characteristics to continuing accessions of alluvium, windborne dust (loess), and organic matter (peat soils), colluvium, or volcanic debris. Thus parent material is often from multiple sources. Soils are always changing and will often not have reached a point of balance or maturity. Thus soil profiles (the description of a soil in cross-section) differ markedly between young and old soils. Soils are also significantly influenced by human activities, for example, by tillage, drainage, fertilization, mounding, or soil erosion.

Soils are dynamic, with changes due to influx of sediment and decayed rock and removal of material by leaching and erosion in a changing climate. Hence the imprint of one soil over an older one (a palaeosol) is not uncommon. The range of rock types, climate, and relief in Papua provides a wide range of soil types. This brief chapter gives an overview of the main soils of Papua and is based on surveys and older work such as a soil map of New Guinea by Haantjens et al. (1967) with extrapolations from more intensively studied agricultural soils of Papua New Guinea (Wood 1982; Bleekers 1983; Hanson et al. 2001). Detailed land system and soil mapping has been undertaken in connection with transmigration (*transmigrasi*) settlements in Papua but unfortunately those data are not available publicly.

Soils of Papua are somewhat similar to those occurring in western Papua New Guinea because of their shared geology. However, the soils of western New Guinea, including Papua, are less diverse than those of eastern New Guinea because Quaternary volcanic activity is not present.

Soil Classification

Knowledge on the distribution of soils and their properties is essential for managing agricultural production and other soil services. In Papua, most villagers have

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names for their soils and they are knowledgeable about soil properties. In textbooks and publications on soils in Papua New Guinea, the Soil Taxonomy classification scheme of the United States Department of Agriculture (USDA) is used (Hanson et al. 2001). Soil taxonomy uses measurable properties of a soil, including soil depth, color, texture (e.g., sand, sandy loam, loam, clay), structure (e.g., blocky, granular, crumb, columnar), consistency (e.g., sticky, porous), soil water and soil chemical properties such as pH (a measure of acidity), and the ability to retain nutrients. These properties are used to group soils into classes. A full classification, under the Soil Taxonomy, requires chemical and physical analyses (Soil Survey Staff 1998).

Papua New Guinea uses the Soil Taxonomy because of the close links to the development of a comprehensive Resource Information System (PNGRIS) in PNG. The Soil Taxonomy is internationally recognized and should be applied to Papua as it has advantages when exchanging information. Some problems occur when the Soil Taxonomy is used to classify New Guinea soils because that taxonomy relies heavily on laboratory analysis, which is expensive. Many descriptions and analyses of Papuan soils do not have sufficient analytical data to allow a full Soil Taxonomy classification. In addition, soil moisture and soil temperature information is needed in the Soil Taxonomy, but only limited data are available for Papuan soils.

In soil taxonomy, the highest level is the soil order, usually made up of several soil groups that reflect similar formational processes but different hydrological regimes or parent materials. The orders are usually arranged from least developed to most developed, as evidenced by horizonation, color (oxidation), and leaching. While there is a general correlation with time, some parent materials and topographic settings accelerate the development of weathering whereas cooler and drier conditions may hinder weathering. For example an iron-rich rock such as basalt on a mid-slope position where abundant water is running through the profile but which also has good aeration will weather to a bright red color. It may follow a path to a highly weathered soil more quickly than other rocks.

The following soil orders occur in Papua with the more important soil groups indicated in italics. The descriptions are based on Bleekers (1983). The common terminology applied in Southeast Asia is from the Food and Agricultural Organization (FAO). The FAO term (Dudal 2005) is given in parentheses after the following descriptions according to the Soil Taxonomy, but cross-categories are common, as are a plethora of earlier terms, many adopted from European usage.

Entisols are very young soils, with little or no profile except for a thin humic surface horizon. These soils occur mainly on recent alluvium or on steep slopes where soil erosion takes place, or on coastal deposits. Examples include some acidic mangrove clay soils, *sulfaquents* (cat clays) that are continuously waterlogged, waterlogged fluvial silt-clays with reducing conditions (*aquents*), silt-clay alluvium (*fluvent*), and riverine or beach sands (*psamments*). (FAO: gleysols, fluvisols, arenosols)

Histosols are soils that contain very high levels of organic matter (peat soils). These soils are mostly dark brown to black in color, and occur in swampy areas. They are saturated with water for much of the year. Histosols are divided by the degree of breakdown of the plant material into *fibrist, hemist,* and *saprist* groups in waterlogged situations and *folist* on drained slopes. In some cases, these materials have been actively accumulating over thousands of years and can also be regarded as biogenic sediments. (FAO: Histosols, peats)

Inceptisols are moderately weathered soils, with slightly developed horizons. *Tropaquepts* form on rock and alluvium on ridge crests and slight hollows under grassland, and are acidic. *Humitropepts* are deep clay soils formed under cool humid conditions with a deep organic rich upper layer. *Eutropepts* and *dystropepts* have a humic horizon over reddish or mottled lower layer that may contain stones, and are found on slopes or alluvium up to an altitude of 1,500 m. In alpine conditions above 3,500 m, *cryochrepts* are shallow alpine humus or skeletal soils with black peaty layer over a brown clayey layer. (FAO: cambisols, cryosols). Inceptisols also include a sub-order, *andosols,* which are productive soils derived from volcanic ash. These are absent in Papua, though very common in Papua New Guinea (New Britain) and some Moluccan islands such as Halmahera and Ternate.

Vertisols are soils with high montmorillonite clay content that are sticky when wet and very hard when dry. These soils swell when wet and crack when dry but are generally of high fertility. They occur in seasonally wet depressions in drier regions near Merauke. (FAO: vertisols)

Mollisols are soils in which there is accumulation and decomposition of organic matter. Biological activity (worms, ants, termites, roots, etc.) is high in these soils and contributes to soil turnover and weak horizonation. These soils generally have a high base (e.g., calcium, magnesium) content. *Rendolls* are shallow black soils common on limestones. *Ustolls* are found on fine grained rocks in savanna areas with a pronounced dry season while *udolls* are found in humid areas up to 1,500 m. They have a thick grayish or brown top horizon grading into a clayey brown lower horizon of limited permeability. (FAO: phaeozems)

Alfisols are moderately weathered soils that have an argillic horizon (a layer within the soil profile with higher clay content due to movement of clay from the top to lower layers). These soils are sometimes very fertile. Variants (*aqualfs, ustalfs, udalfs*) occupy a range of waterlogged through seasonal to humid settings where the parent material has had a long time for horizonation to develop. Some contain plinthite, an iron-rich clay indicating poor drainage, which forms concretions if dried out. They include *rhodudalfs,* reddish clay soils formed on limestone, particularly raised reefs at low altitudes. The most common soil is the *tropudalf,* a deep brownish soil found on slopes on sedimentary rocks. (FAO: luvisols)

Ultisols are strongly weathered and acid soils with an argillic horizon found in wet climates up to 3,000 m. These soils have a low base saturation. *Plinthaquults* occur on flat terrain around Merauke and have gray sandy-clay upper horizon over deep gray or brown mottled plastic clays. They are infertile and, once dried, form concretions (Schroo 1964). *Tropohumults* have high organic content throughout the profile which is yellow to brown at the base and acid, and occur on rugged terrain on sedimentary and igneous rocks. *Tropudults* occur on gentle slopes below 1,000 m and have a red or yellow mottled horizon grading down to clay. They are acid and of low fertility. (FAO: acrisols, alisols, lixisols, plinthosols, podzols)

Oxisols are very strongly weathered soils, with low fertility, which are unusual in Papua. These soils reflect tropical weathering of very long duration so they occur on old land surfaces with profiles several meters in depth. The upper profile has lost much of the clay and other silicate minerals through leaching, retaining limonite and sometimes bauxite or kaolinite. On ultramafic rocks they are often enriched in nickel, iron, and cobalt oxides. (FAO: ferralsols)

The Distribution of Soils in Papua

The most common soils in Papua are entisols. These young soils cover more than a quarter of the total land area, reflecting the high geological and erosional activity. Entisols are common in the hills and foothills where alluvial deposits occur (Figure 2.2.1). In the highland basins, entisols occur on alluvial fans and are also found on sand sheets in sandstone country, such as north of Mt Trikora, and on alpine gravels (Figure 2.2.2). Inceptisols are common on more stable settings in montane areas and often have deep organic rich horizons overlaying clayey subsoils or shallow humic soils on limestone (Figure 2.2.3). Mollisols are deeper soils formed on limestone and are widespread in limestone terrains in the Central Range, Weyland, and Arfak mountains, as well as parts of Biak and Numfoor islands. Erosion occurs

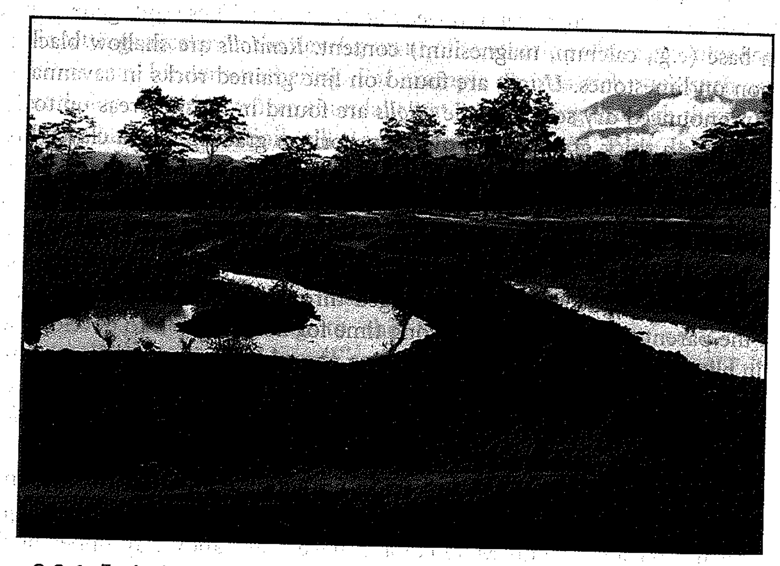

Figure 2.2.1. Entisols on riverine silts, Baliem Valley near Wamena. These are formed on overbank alluvium and slopewash.

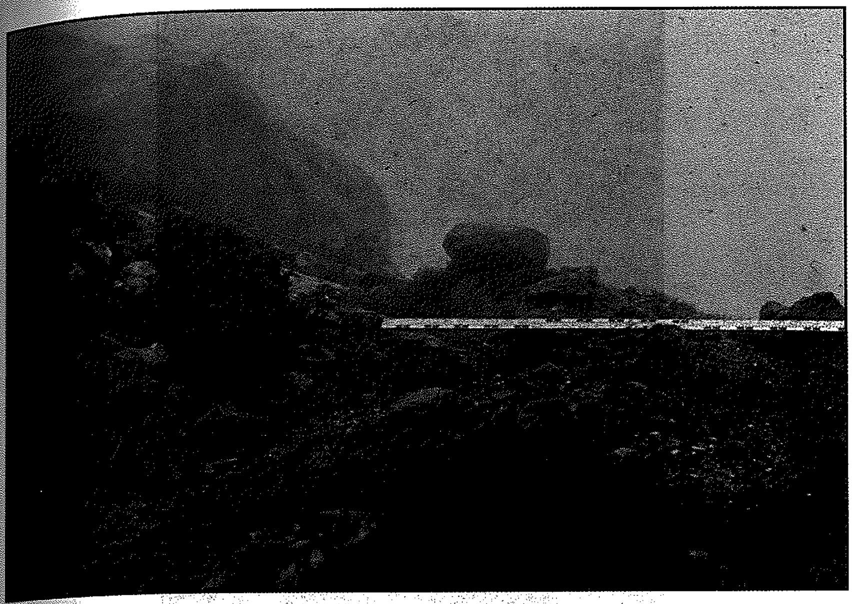

Figure 2.2.2. Entisols at 4,500 m on Mt Jaya. The vegetated area on left has acid peats on old moraine (a cryochrept) while a thin litter layer has built up on fresh limestone rubble left by a glacier about 1880 C.E.

in this area. Soil loss of a meter or more (Figure 2.2.4) can be readily seen on gardened limestone slopes because the boulders are etched up to the level of the soil that existed prior to clearance. This lowering may represent thousands of years of gardening.

Alfisols are common in the northern slopes of the Central Range (Figure 2.2.5). Ultisols (strongly weathered soils) cover approximately 25% of the land area of Papua, and are dominant in the Merauke Regency, where they occupy more than half of the lowland area. They also are found on ultramafic rocks such as in the Cyclops Mts (Figure 2.2.6). Histosols are most prevalent in the Taritatu (Idenberg)-Mamberamo basin (Figure 2.2.7), around McCluer Gulf and the southern plain, where they occur on a third of the land area. They are also common above 3,000 m in the mountains (Bleeker 1980).

Most areas are a mosaic of soil types often reflecting erosional history and gradients in slope processes, often giving rise to a soil succession (or catena). Palaeosols are also common (Figure 2.2.8). Thus soil mapping needs to be detailed. Table 2.2.1 estimates the importance of the Great Soil Groups in Papua and compares them to the figures derived from land system mapping in Papua New Guinea. Inceptisols are of less importance in Papua but histosols and oxisols, although still minor, occur more widely, reflecting the older landscapes and tectonic basins of the province.

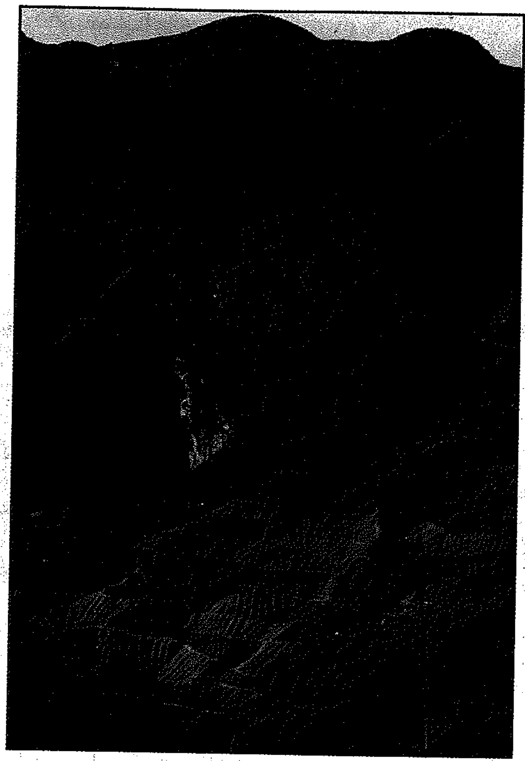

Figure 2.2.3. Inceptisol and rock slope in the Daelah Valley west of Wamena. The downslope drainage ditches are designed to reduce soil moisture and the soil is coherent enough not to gully.

Soil Moisture

The water balance (precipitation over evapotranspiration) of Papua is positive except in the Merauke Regency so that soil moisture rarely limits plant growth. Even in the driest stations soil moisture does not fall below 75 mm (50% of maximum storage) as was estimated from Western Province data from McAlpine and Keig (1983). In higher altitudes with more clouds, evaporation is low and soils are water-saturated during much of the year. These positive water balances result in reduced decomposition (and thus accumulation) of organic matter and possibly leaching of nutrients, together with landsliding, tunneling, and piping on steep sites and at-risk erodable soil types. However, drought occurs in both the highlands and lowlands with free drainage during long periods without rain, such as those experienced during the 1997–1998 El Niño (Ballard 2000).

Soil Fertility

In Papua, the highest density of settlement occurs in the highlands where entisols derived from alluvium are very important, together with alfisols and mollisols on

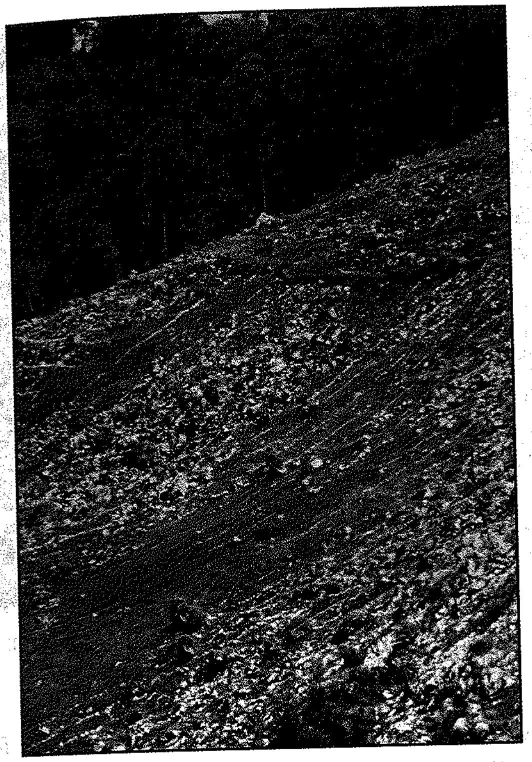

Figure 2.2.4. Mollisols eroding from gardened limestones, Baliem Valley near Tiom. Considerable soil loss has followed forest clearance here, and the area may soon be unusable.

limestone. These soils are generally fertile. In contrast, 56% of the population of Papua New Guinea, almost three million people, live on inceptisols, many derived from volcanic ash, or mixed with volcanic ash from explosive eruptions that did not reach Papua. To compensate for the poor soil fertility, Papuans in the highlands have developed a system of returning organic matter to the soil to add nutrients and maintain favorable soil physical properties (Ploeg 2005; Chapter 6.3). Around 30% of the population in the seasonally dry region around Merauke cultivate ultisols. Attempts to develop these soils for rice agriculture have met great difficulties as large inputs of fertilizer and machinery are needed.

The availability of nutrients for plants depends on several factors. Low levels of available nutrients in the soil may be natural, caused by low amounts of nutrients in the parent material from which the soil is derived; by fixation and immobilization of nutrients; or by losses, for instance, when high rainfall leaches nutrients from the soil. Nutrient imbalances (e.g., high calcium, low potassium) in the soil may also cause limited availability of a particular nutrient. Low nutrient levels may also result from cultivation, when agricultural crops and repeated burning

Figure 2.2.5. Alfisol at Kwiyawagi, East Baliem Valley. The landforms are mature and more than 100,000 years old.

remove nutrients that are not replaced by manure or inorganic fertilizers (Yaku and Widyastuti 2005).

Nutrient deficiencies affect crop production in Papua. This problem is likely to increase in the future because of more intensive land use as the population rises, which results in reduced fallow periods in shifting cultivation system and higher land use intensities (Hartemink and Bourke 2000).

Soil nitrogen availability is determined in part by the length and type of fallow, the introduction of organic matter (plant materials) into the soil, and climate (temperature and rainfall). Most plant-available nitrogen in Papuan soils is derived from organic matter. Soil nitrogen tends to be higher in soils of the highlands, where temperatures are lower and organic matter decomposes more slowly.

In New Guinea soils the availability of phosphorus is dependent mostly on the organic matter content. A small part comes from the weathering of parent material or secondary minerals. Phosphorus is usually found in combination with calcium, magnesium, iron, and aluminum. Although relatively large amounts of total phosphorus may be present in the soil, little may be available to plants because phosphorus is held very tightly in the soil in organo-clay complexes. Phosphorus fixation can be severe in ultisols and oxisols and in soils derived from volcanic ejecta.

The availability of soil potassium is related to rock type and the mineralogy and the stage of weathering of the soil. Potassium-deficient soils are usually highly

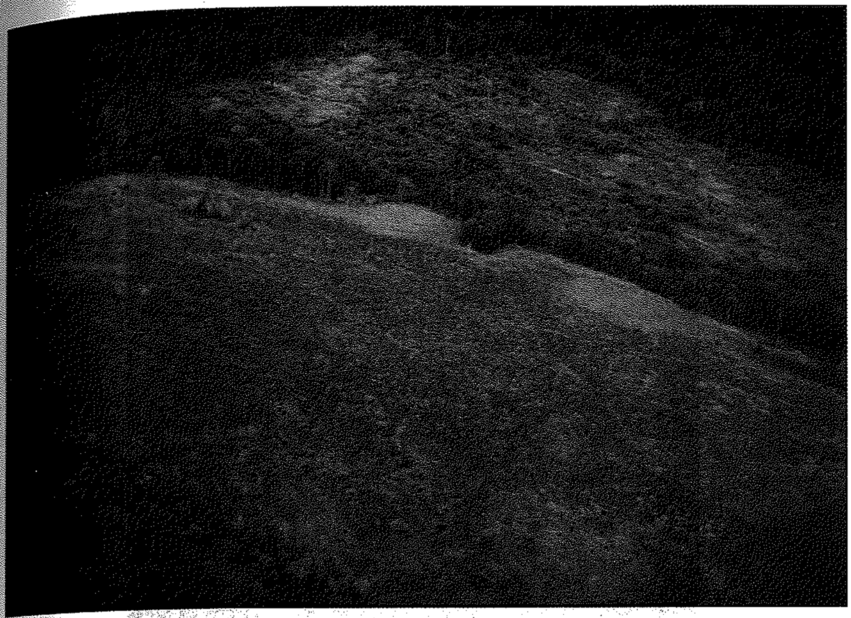

Figure 2.2.6. Ultisol or oxisols on the Cyclops Mts west of Sentani, developed on ultramafic rocks. The clearing is very infertile and forest does not readily re-invade. In some places internal drainage has developed by solution of the rocks.

Figure 2.2.7. The Mamberamo Lakeplain, a tectonic basin crossed by the Tariku and Taritatu Rivers, is a complex of alluvial entisols and widespread histosols under swamp forest and floodplain grassland.

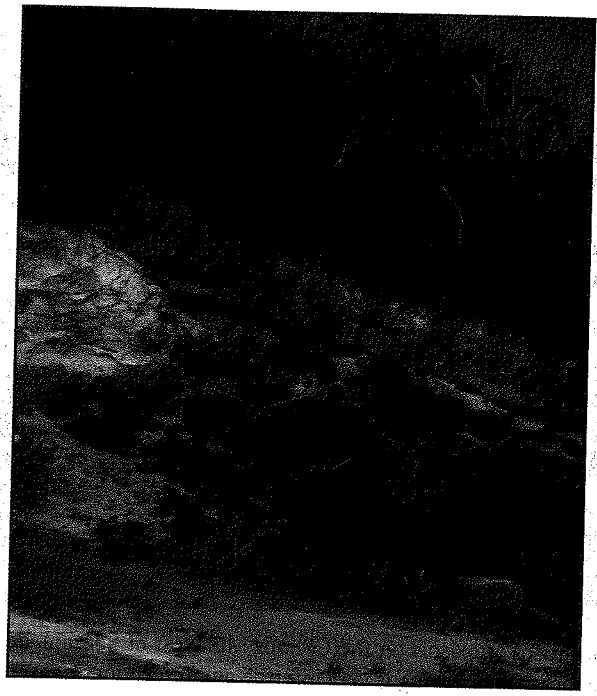

Figure 2.2.8. Slope profile of an inceptisol over a palaeosol at Supulah Hill, a sandstone hill north of Wamena. The humic layer has built up on sands that eroded and covered an earlier humic horizon about 30,000 years ago.

weathered and leached with limited amounts of mineral reserves. Soils that develop on limestone and that have high levels of calcium and magnesium may have a potassium deficiency (nutrient imbalances). This is common, for example, on soils developed on Pleistocene coral terraces on Biak Island.

Research on nutrient deficiencies of agricultural crops started in the 1950s, but only limited research is currently being carried out on soil nutrient deficiencies or on soil fertility management strategies in Papua (Yaku and Widyastuti 2005). Soil fertility problems exist in parts of the island. Further intensification of land use affects soil fertility, and nutrient deficiencies are therefore likely to increase, particularly in food crops where inorganic fertilizers are not being used. There is a need to monitor the development of nutrient deficiencies as well as to properly identify the deficiencies through trials and soil and foliar analysis. Papua differs from much of the rest of Indonesia in having low-fertility soils. This may be part of the reason why there seems to be more marked patterning in the forests (greater species diversity per unit area) compared to the monodominant stands of west Malesia. The soils may thus be fragile and prove difficult to return to forest once logged. Thus specific research into soil structure and nutrition within the province remains essential, as do active efforts to retain the soils already there.

Table 2.2.1. Major soil orders distribution by physiographic area of Papua, compared with PNG

Region	Entisols	Histosols	Inceptisols	Vertisols	Mollisols	Alfisols	Ultisols	Oxisols
Merauke	A	D	B	D	D	X	A	X
Southern Lowlands	A	B	B	X	C	B	A	X
Southern Slopes	A	D	B	X	B	B	B	X
Highland Valleys	B	B	B	X	B	B	B	D
Alpine and Subalpine	C	A	D	X	X	D	X	X
Northern Trough	A	B	C	X	C	B	B	X
Northern Ranges	B	D	C	X	C	C	A	D
Coastal	A	C	A	X	C	D	C	C
Vogelkop and Islands	A	C	A	D	C	X	B	C
PNG km^2x 1000	120	8.6	219	0.2	34	13.3	63	0.007
PNG % of area	26	2	48	<0.1	7	3	14	<0.1

Note: A: >25%; B: 10–25%; C: 2–10%; D: <2%; X: absent. The two PNG values for soil orders give the estimated area in thousands of km^2 and the percentage land cover in PNG. B. J. Allen provided these unpublished data.