A REVIEW OF SOME IMPORTANT SOIL STUDIES IN PAPUA NEW GUINEA

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ABSTRACT

This paper attempts to provide an appreciation of the variety of soil studies that have been undertaken in Papua New Guinea (PNG). The main themes considered and the reasons why they were investigated include: (i) land evaluation, in which considerable contribution has been made in assessing suitability of various cash crops at plantation and smallholder levels; (ii) land system mapping, where the results were built into a robust natural resource database and eventually linked to a GIS that covers the whole country on a scale of 1:0.5 M; (iii) soil erosion studies, where the results indicate low to modest soil loss rates despite high rainfall and high relief over much of the country; (iv) soil conservation, in which it was found that over much of the country the traditional conservation practices are based on the principal of removing water without causing erosion rather than retaining water; (v) soil fertility, especially the problems concerning the interpretation of data and highlighting the variety of approaches used to evaluate nutrient and yield decline and recovery on traditional garden plots; (vi) soils and human health, which though an unusual topic identify issues worthy of further research; and (vii) pedogenesis, in which latosols are used as the main example though references to other soil types. The problem of the difficult terminology especially with regards to soil classification is highlighted.

Key words: *soil erosion, soil conservation, land evaluation, land systems, soil fertility.*

INTRODUCTION

In this review the expression 'soil studies' is chosen deliberately so as to encompass traditional soil science, which is normally associated with agricultural and forestry pursuits, as well as themes within earth and environmental sciences. In this sense the review attempts to be broad ranging but it is somewhat restrictive in the material covered. This selectivity reflects more the authors' interests and experiences in working and conducting research in PNG rather than any profound rationalisation. Accordingly, any criticism that the review covers too many topics too briefly is valid. But the aim of this review is to provide an appreciation of the variety of soil studies already conducted in PNG, especially to new comers whether they are recent graduates or trained in different disciplines. Consequently the paper is organised on a topic basis rather than highlighting the achievements of particular individuals. A secondary aim is to provide a sense of historical background as to why and how particular research themes were selected. However, by its very nature it touches on potentially difficult grounds since most of what is published by researchers is technical and the behind-the-scenes reasons for the study in the first place are not always presented.

SOIL INVESTIGATORS AND THEIR LANGUAGE

Until the last fifteen years or so all published information on soils was provided by expatriates.[i] Of course national staff such as labourers and technicians contributed in various ways to this early expatriate input. The most visible has been the contribution by CSIRO (Australia) through their land systems mapping and policy to publish in international journals. In terms of sheer volume the Land Use officers of DAL have provided the greatest con-

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tribution but the vast majority of this is contained in reports accompanying reconnaissance mapping and much of it remains unpublished in departmental files. The last major source has been provided by university researchers and consultants and whilst the overall volume is not great the variety of subject matter must be acknowledged. It has really only been since Independence that PNG nationals have contributed directly to scientific knowledge of nation's soils. The contribution is dominated by Land Use Officers and other agricultural staff, and to a lesser extent by the university staff.

Papua New Guinea has a rich knowledge of soils especially in terms of fertility (the 'grease' factor in *Tok Pisin*), workability (ease of digging) or some other factor that identifies a special use or an undesirable quality (e.g. Sillitoe 1993 a). This knowledge and detailed language is to be expected given the reliance on root crops and the existence of agricultural systems that are noted for their high crop and cultivar diversity, complexity in cropping practices and in soil amelioration practices.[ii] Unfortunately, this knowledge remains largely untapped. The few published accounts are primarily investigations incidental to other interests and it is apparent to even the most casual inspection that considerable knowledge exists.[iii] For example, the Huli possess an extensive knowledge of how to deal with volcanic ash falls such as marking gardens to help locate harvestable produce and storing drinking water. They are aware also that high crop yields follow such events because of the added 'grease' (i.e. additional supply of soil nutrients) even though the last known ash fall occurred about 300 years ago (Blong 1982). There is considerable merit in attempting to understand why certain practices are pursued such as in the choice of fallow lengths and cropping cycles. The reasons given may be obscure but they deserve further investigation and one of the greatest challenges faced by government bureaucracies such as those in DAL is to incorporate this information into research programs.

Not surprisingly, most information obtained thus far is from the viewpoint of western knowledge. An interesting example of this is an attempt to assess the degree of sophistication of the local language in dealing with soil types. For example, Brookfield and Brown (1963) noted that the Kuman speakers of Simbu have no collective term for a soil profile and appeared to label the material and not the vertical sequence. Ollier *et al.* (1971), Lansberg and Gillieson (1980), and Wood (1984) reiterate this viewpoint from other language groups. In this context the absence of the equivalence of a soil profile was viewed as indicating a less than satisfactory approach i.e. it did not match prevailing scientific thought. It is interesting to note that in some circles in soil science there is a move to replace soil profiles with soil layers as the main unit of soil classification (e.g. Atkinson 1993; Paton *et al.* 1995). Soil layers correspond much more closely to the basic unit of organisation adopted in local languages in Papua New Guinea.

One of the main constraints to the dissemination of information to user groups such as other researchers, government agencies and land managers is closely tied to the language and classification systems adopted for this purpose. For the most part the classification of soils is very obtuse and remains largely unintelligible to others. One of the implications of this is that there are relatively few people who understand soil classifications and this is especially so in developing countries. In 1975 PNG adopted a soil classification system known as Soil Taxonomy (Soil Survey Staff 1975, 1992), a product of the United States Department of Agriculture. At least part of the rational stems from a desire to ensure PNG soil studies would be more accessible to an international audience (see Bleeker 1983) and to facilitate agrotechnology transfer which was a popular issue around this time.[iv] Unfortunately Soil Taxonomy is a complicated and expensive classification system relying on laboratory analyses of chemical, physical and sometimes mineralogical properties in order to fully classify a soil type even though the basic features can often be identified in the field using morphological attributes. Furthermore, this classification scheme is biased to soils commonly found in temperate areas of the northern hemisphere and many of the categories especially those based on moisture and temperature regimes have little meaning in PNG (Haantjens and Bleeker 1975; Humphreys 1991). To help overcome these difficulties a modified version of the forerunner to Soil Taxonomy, the 7th Approximation, was developed and used by CSIRO workers in PNG for several years (see Haantjens and Bleeker 1975). However, this modified version was abandoned in 1975. If it had been more widely used and developed PNG may well have had a more serviceable soil classification scheme. An alternate approach that overcomes the problems in using a hierarchical classification such as Soil Taxonomy is to adopt a nodal based classification i.e. a system that emphasises a core concept rather than concern itself with definitions at the boundaries between one node and another. This type of approach was used in PNG into the 1960's in which an assortment of terms based on great soil groups, mostly from USA and Australia, was employed. Modern developments in fuzzy logic and associated statistics has strengthened the robustness of the nodal approach. However, there are few soil types in PNG that have been sufficiently well studied that most workers would accept as a nodal soil. The one obvious exception is the "humic brown clay", a type of andisol, which is a widespread volcanic ash soil found mostly in the highlands.[v] The main reason for this nodal status is that the characteristics of this soil type are sufficiently distinctive that they are readily understood by various user groups, the extent of which may surprise some researchers.[vi]

Other soil types with distinct morphologies or that appear to be important because they are widespread, and which could be developed as nodal soils include the following: cracking clays (vertisols), clayey colluvial mantles (some tropepts/orthents), texture-contrast soils (various alfisols/ultisols), pumiceous volcanic ash soils (andisol), certain organic rich materials and several others. The cracking clays form a distinctive group but are restricted mostly to valley fills in drier areas. Similarly, texture-contrast soils have a distinct morphology. They are known in Western Province (Bleeker 1983) and Irian Jaya (Schroo 1964). A gravelly texture-contrast variant occurs on lower hillslopes in the Port Morseby area (Scott 1965; Mabbutt and Scott 1966; Paton *et al.* 1995). Pumiceous volcanic ash soils are also distinctive and often have sandy to loamy textures (Bleeker and Parfitt 1974) with mineralogies conforming to a recent origin associated with the present day island arc. However, the relationship between well weathered varieties and the humic brown clay needs further investigation. Dark pedal clays or rendzinas (rendolls) are common on limestones and some very calcareous mudstones. However, in some locations deeper and redder alkaline clayey soils (rhodustalfs, rhodudalfs) occur on limestone. They may indicate a significant contribution of volcanic ash such as on the Pleistocene raised terraces of the Huon Peninsular (Bleeker 1983). In addition some limestone soils contain high levels of phosphorus. These were first reported in Irian Jaya by Schroo (1963) and Bleeker (1983) predicted that similar occurrences should be found in PNG. This was verified by Macfarlane *et al.* (1990) who reported high phosphate levels in some raised limestone reef areas in Milne Bay Province. Clayey, colluvial soils are widespread in PNG but those formed on calcareous marine mudstones such as the Chim Formation are particularly noteworthy since even the saprolite is quite fertile (e.g. Goodbody and Humphreys 1986). Other colluvial materials are poorly understood and a high degree of variability in fertility status renders evaluation at this time difficult. Various latosols (ultisols and oxisols) occur as well and this soil type is used as an example to explore some issue dealing with its identification and origin. Peats and other organic rich sediments (various histosols but also entisols and various aquic suborders) are widespread in PNG and some of these are highly valued for traditional crops and for growing tea. The high production potential of many of these soil variants requires further study to assist in promoting optimal usage.

In addition there are a variety of soil types which possibly occur but are very poorly known. Acid sulphate soils (sulfaquents/sulphaquepts) are expected in mangrove areas especially in estuarine settings (Bleeker 1983) but unless these are drained or otherwise aerated the very low pH condition and other associated properties may not develop. Podzols (spodosols) have not been positively identified in PNG though there is an unconfirmed report of a podzol at Kiunga on the Fly Platform (D. Freyne pers com.). Hardon (1938) reports a podzol in the Arfak Mountains in Irian Jaya but the description indicates a texture-contrast soil rather than the sandy podzols found elsewhere in the tropics such as in Malaysia (Richards 1941).

LAND EVALUATION

A full history of land evaluation in PNG has not been written but it would prove a worthwhile task as implied in several useful reviews (e.g. Bleeker 1983; Dearden *et al.* 1986; Brasher *et al.* 1995). In some respects it has closely followed international developments but it has also pioneered other approaches that would surprise many who are unfamiliar with local literature. Land evaluation involves the systematic assessment of land so as to ascertain the most suitable use of that land. Normally, it is used in the context of agricultural land use but it is also applies to forestry, water catchments, flora and fauna reserves and other purposes such as geomorphic hazard assessment (e.g. Hearn 1995). The basic information used in land evaluation is the soil and hence soil scientists have been very much involved. From the outset effort was placed into soil surveys by DAL's Land Use Section. The first land evaluation scheme used in PNG was developed by Haantjens (1963, updated 1969). His Agricultural Land Classification applied to commercial agriculture of arable crops, tree crops, improved pastures and irrigated rice. The scheme was based on the first widely accepted international land evaluation scheme, the Land Capability Classification (LCC) (Klingbiel and Montgomery 1961) but as the latter was devised for high input American farms it required extensive modification for possible plantation use in PNG. It is thought that Haantjens' scheme represented the first realistic application of LCC ideas to tropical conditions. It was also devised for smaller scale soil mapping and in particular the reconnaissance mapping involved in Land System Surveys which contrasted to the large scale soil mapping base used in LCC. Subsequently Haantjen's scheme was modified and applied across PNG at a map scale of 1:1 M (Bleeker 1975) as part of a series or resource maps produced at the same scale.

The LCC approach focussed on limitations to crop/pasture production in general. During the 1970's a new approach was devised based on the suitability of the land for a specific crop. Land Suitability Evaluation (LSE) as it is best known is the most widely applied outcome of the highly acclaimed Framework for Land Evaluation (FAO 1976). In some ways Haantjens' scheme anticipated aspects of LSE as did the scheme devised by Hartley *et al.* (1967) to rate land suitable for a variety of crops in West New Britain. LSE has been successfully applied in PNG to commercial cocoa (Bleeker and Freyne 1981 and Wayi 1987), plantation and small holder arabica coffee (Harding *et al.* 1986) and sweet potato (Radcliffe 1983). Subsequently, Venema and Daink (1992) extended LSE to encompass a variety of low input crops such as cardamom and higher input crops. Known as PNGLES (PNG Land Evaluation Scheme) it has become the standard means of land evaluation in PNG. In addition an ecophysiological approach for matching plants to land was developed within CSIRO for use in PNG and elsewhere (Hackett 1988). This approach represents a considerable advance in suitability assessment but depends on detailed information on the environment to be truly useful.

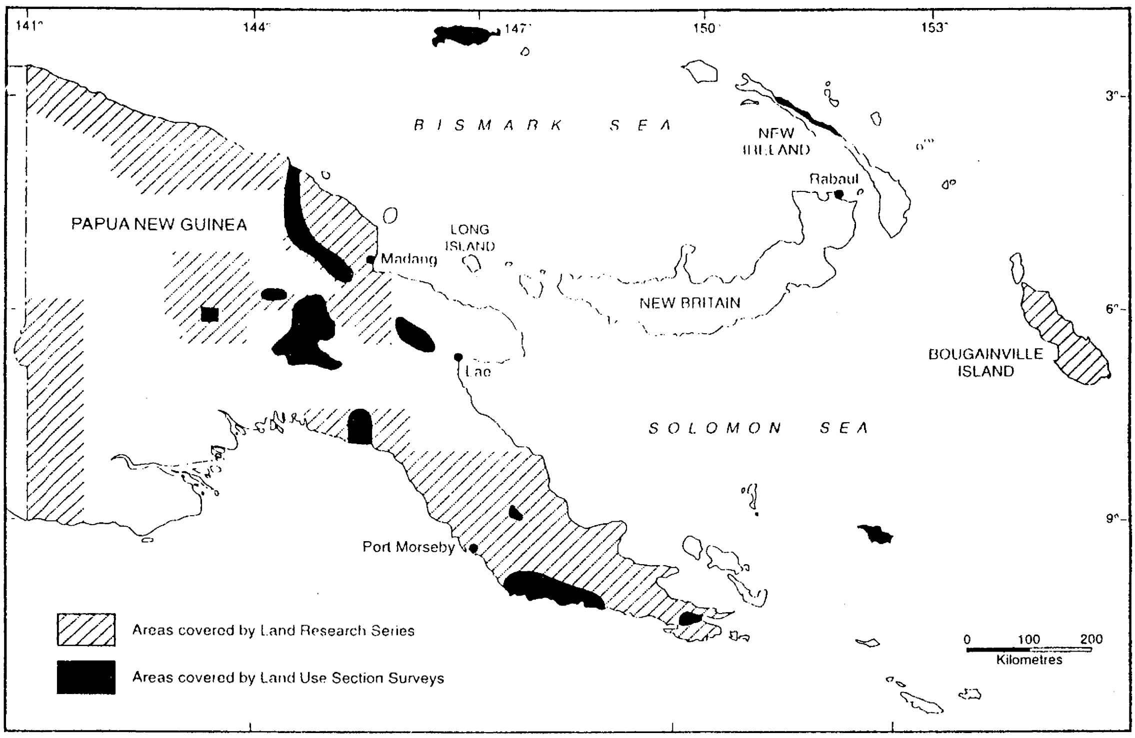
One of the major advances incorporated into PNGLES is the ability to use the PNG Resource Information System (PNGRIS). PNGRIS is a georeferenced data base of land resource information organised into spatial entities expressed at a scale of 1:0.5 M referred to as resource mapping units (RMU's) which are equivalent to polygons in GIS parlance (Bellamy 1986). PNGRIS is a development of CSIRO's land system mapping and PNG was possibly the first developing nation to have such a detailed data base that encompasses the whole country.[vii] Prior to this LSE could only be sensibly applied when detailed soil mapping was available. PNGRIS allowed the whole country or selected portions to be evaluated.

Built in to LCC and LSE are assumptions concerning the viability of particular land use practices mainly in terms of short term profitability. With a growing awareness of land degradation and the need to consider much more than short term profitability of farming practices the issue of sustainability has dominated the international land evaluation agenda during the 1990's. The Framework for Evaluating Sustainable Land Management (FESLM), which began appearing in draft form in 1991, is the latest land evaluation system designed to undertake this task at various management scales from individual fields to national level (Smythe and Dumanski 1993). The scheme is still being developed and trialed. FESLM and it is not without its critics. Brookfield and Humphreys (1994) noted that the structure was not particularly suited to complex multiple cropping systems widely used by subsistence farmers such as in PNG. They suggested that the agroecosystem scale was the appropriate lower level of FESLM-type investigation in these situations. Considerable work is required on this scheme and it is likely that investigations in PNG will assist this. In particular the main issue driving the Mapping of Agricultural Systems Project in PNG (MAPS) is the issue of the sustainability of these systems in the context of expected population growth, economic development, increased land degradation potential and global warming (Bourke *et al.* 1993). MAPS will use the FESLM approach to assist in this task and it is expected that this will also provide a means for scrutinising it (B.J. Allen pers comm).

LAND SYSTEMS MAPPING

No discussion on land evaluation would be complete without some comment on land systems mapping (LSM). Though much has been written about LSM in the international literature very little of it reflects the PNG experience. The process of undertaking a generalised assessment of the natural resources, including soil, over large tracts of little known terrain at a reconnaissance level was developed in Australia in the late 1940's. The land system approach aimed to delineate land that exhibited a recurring pattern in landform, soils and vegetation and was first applied to northern Australia by CSIRO (Christian and Stewart 1953). The same approach was soon applied to PNG with teams that included a pedologist, a geomorphologist, a plant ecologist/forester and others producing land system maps at scales of 1:0.25 to 1:0.5 M (Haantjens 1965; Blake and Paijmans 1973). Two important outcomes arose out of LSM in PNG. First, by the early 1970's about 40% of the country had been surveyed (Figure 1).[viii] This was a much higher proportion than the area mapped in Australia and more importantly it was reasonably representative though not all major agriculturally important areas were covered. This allowed the generation of separate 1:1 M maps on landforms, vegetation, soils, land use and forest types that covered the whole country. In turn these maps led to PNGRIS which forms the basic natural resource base for LSE as commented on above. The second point deals with the core concept of LSM. In Australia land systems could adequately represent large tracts of country and the concept of a recurring pattern between landform, soils and vegetation has held sacrosanct. This proved difficult to apply in PNG. Haantjens (1965) recognised three types of land system photo patterns in which mixtures of the last two are the most common: the truly 'recurring' pattern as noted above, the 'catenary' pattern, and an 'irregular' pattern. This change is not emphasised in the land system reports though it is apparent that a different concept is being applied if the reports and maps are carefully scrutinised. An outcome of this broadening of the land system concept was an even greater reliance on airphoto interpretation and the use of land-

***Figure 1.* Areas covered by CSIRO land system mapping and major surveys conducted by the PNG's Land Use Section and affiliates (modified from Humphreys 1991).**



forms or vegetation patterns depending on the terrain. Further difficulties emerged during a mapping exercise of Simbu Province in which the next level of detail in land system mapping was applied, *viz.* the land unit (Scott *et al.* 1985). They found it necessary to map on the basis of landform only when using a comparatively larger mapping scale of 1:0.1 M. The reason for these differences lies in the nature of the terrain: plate centre terrain of Australia compared to the much more tectonically active and higher relief plate margin terrain of humid PNG.

EROSION STUDIES

If published information is a guide, it is apparent that the first systematic treatment of soil erosion in PNG did not commence till the 1980's. At least this is what it must appear to outsiders. In reality the

***Table 1:* Summary of denudation estimates in Papua New Guinea (modified from Blong and Humphreys 1992).**

Location & category	Material	Rate (mm 1000 y^{-1})	Source
*Geological rates (with limited accelerated rates) in mountainous terrain**			
Hydrographers Range	volcanic	80-750	Ruxton & McDougall (1967)
Mt Giluwe	volcanic	590	Loffler (1977)
Kaugel Basin	volcanic & sedimentary	270	Pain (1973)
Mts Toricelli & Bewani	granites & mixed sedimentary	1000-1430	Simonett (1967)
northern Chimbu	volcanic ash	< 60	Humphreys (1984)
Mixed accelerated and geological rates in mountainous terrain			
Vulcan (Rabaul)	volcanic - pumice	18000	Ollier & Brown (1971)
Mixed accelerated and geological rates from large drainage catchments			
Purari River at Wabo	mixed geology	790	Pickup *et al.* (1977)
Fly River	mixed geology	260-350	Picup *et al.* (1981)
Largely geological rates from small to moderate catchments			
Aura River	mixed geology	4190	Pickup (1977)
Ok Ningi	mixed geology	2980-4050	Pickup *et al.* (1991)
Ei Creek (Sogeri)	agglomerate	90	Turvey (1974)
Kuk swamp	volcanic ash	1.5	Hughes *et al.* (1991)
Accelerated rates			
road batters in northern Chimbu	Chim mudstone	46000-91000	Blong & Humphreys (1982)
Kuk swmap	volcanic ash	340	Hughes *et al.* (1991)
Bare erosion plots (on 20-45° slope)	volcanic ash & clay	3500-7500	Humphreys (1984)

* Geological denudation means the natural rate of surface lowering that would occur in the absense of human impact. As the name suggests accelerated denudation refers to the impact of man which normally leads to an increase in erosion.

situation was some what different. To newly arrived researchers the mountainous, humid tropical setting of much of PNG is a recipe for high levels of erosion: intense tropical storms, raging freshets of the uplands and weakly protected soils is a formula for guaranteeing rapid erosion. Those with more experience recognised that the evidence did not appear to match expectation and adopted a much more conservative approach and directed research towards plant nutrition. This approach appears to have persisted throughout much of the colonial time. By the late 1970's a dichotomy of opinion was apparent. The more conservative approach was still pursued by the well established DAL. In contrast very different viewpoints were espoused from within the Department of the Environment and from others including academic staff from the universities. To a certain extent the recent arrival syndrome was evident but there was also a sense that erosion, if not an issue now, would surely become one, as agricultural systems were forced to intensify under the combined effects of population growth and the need for cash income. This lead to the establishment of erosion experiments by DAL in the highlands (Humphreys 1984) and the lowlands (Tyrie unpublished). At the same time other smaller scale studies were undertaken (Williams 1981; Wood 1984, 1985; Carman 1989). Perhaps not unexpectedly the results of this research showed that many of the various opinions had merit. An outline of some of the major findings is presented below:

(i) In a general sense the levels of erosion are not as high as might normally be expected. What is meant by 'normal' is crucial to this discussion. Normal is not defined in any statistical sense. It is used in the context of expectations based on previous experience, perception and the literature.[ix] In particular, it was the opinion of senior officers and key decision makers that if erosion was widespread it would manifest itself as extensive rilling and perhaps gullying. They were not. Furthermore, there were few agricultural areas that were badly affected by erosion. In addition geomorphologists were uncertain as to the efficacy of various erosional processes in the forested humid tropics. This issue was subsequently examined in two different ways in PNG. Ruxton (1967) established the reality of slope wash under mature primary rainforest and Simonett (1967) showed by elaborate statistical analysis the importance of landslides in denudation in earthquake prone areas. Nevertheless, overall erosion levels in PNG appear to be slight to moderate using FAO guidelines[x] with high to very high levels recorded under particular circumstances such as following a major earthquake (Simonett 1967), emergence of a volcano (Ollier and Brown 1971), and on road batters in very erodible mudstones (Blong and Humphreys 1982) (Table 1).

(ii) The reasons for lower than expected soil loss was attributed to the soil characteristics, rainfall intensity and vegetation cover (Humphreys 1984). Moderately fertile, loamy to clayey topsoils with high organic matter and good structure are not conducive to erosion. The rainfall, whilst substantial, is not particularly erosive. Most of PNG is outside of the cyclone belt and has a wet and less-wet seasons rather than distinct wet/dry seasons as occur around Port Moresby. As a consequence vegetation growth is prolific throughout much of the year. Hence, torrential downpours are likely to strike a well vegetated surface rather than bare ground. Existing data from micro plots and garden plots indicated that moderate soil loss (up to 50 $t\ ha^{-1}\ y^{-1}$) could be expected on totally bare ground on slopes up to 30° but reduces to low levels (<10 $t\ ha^{-1}\ y^{-1}$) as ground cover increased beyond about 50 % as occurs during most of the cropping cycle (Figure 2). Subsequently DAL initiated a much more rigorous set of erosion plot experiments at Aiyura and Kerevat as part of a network of trials conducted as part of the Pacificland project by the International Board of Soil Research and Management. Results to date appear to substantiate earlier findings (B.M. Wayi pers com; Humphreys 1994).

(iii) Major increases in soil loss have been determined from sedimentation rates in a few archaeological sites using enclosed swamp and lacustrine deposits (e.g. Golson 1982; Oldfield *et al.* 1985; Gillieson *et al.* 1987; and Hughes *et al.* 1991). The best studied site occurs at Kuk in the upper reaches of the Wahgi valley in WHP (Figure 3). Under apparently undisturbed forest prior to 9000 years ago annual denudation average only 0.012 tonnes ha^{-1} (1.5 mm 103 $years^{-1}$). This increased 8-14 fold to 0.1 - 0.17 $t\ ha^{-1}\ y^{-1}$ (12-21 mm 103 y^{-1}) with the onset of dryland cultivation Under present cultivation practices - a mixture of old and new techniques involving more intensive land use and metal tools (to support a higher population density), soil loss is about 2.7 $t\ ha^{-1}\ y^{-1}$ (340 mm 103 y^{-1}) (Hughes *et al.* 1991). Though this remains a very low rate of soil loss by global standards (FAO 1978), it is two

Figure 2. **Soil loss versus slope from microplots and garden plots on andisols and tropepts. All but Carman's study is from the central highlands. Modified from Humphreys and Wayi (1990).**

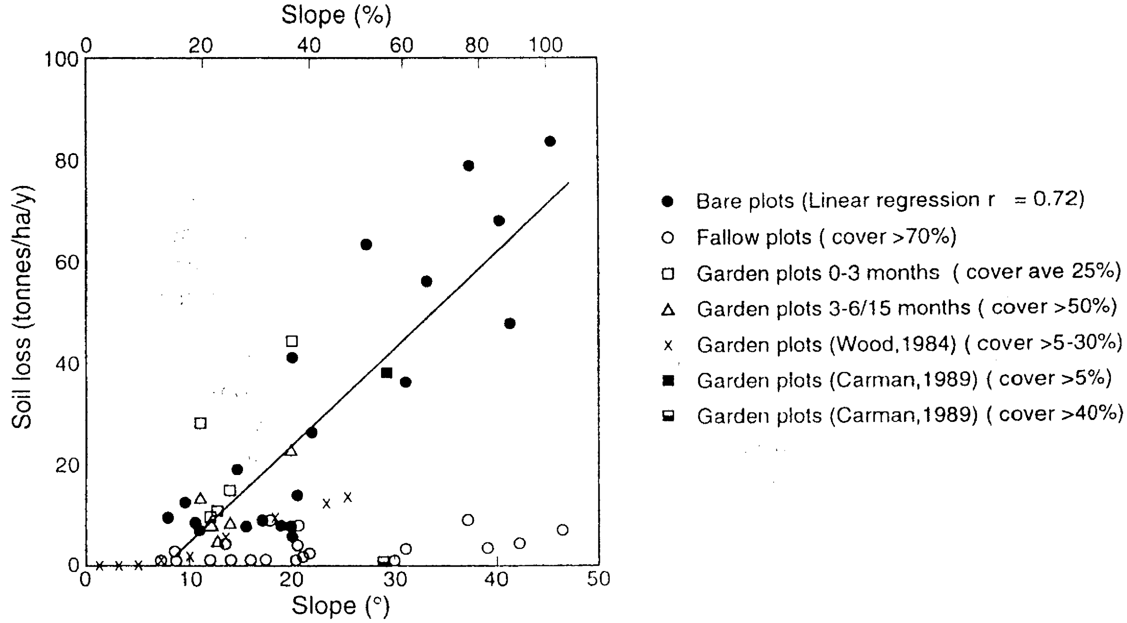
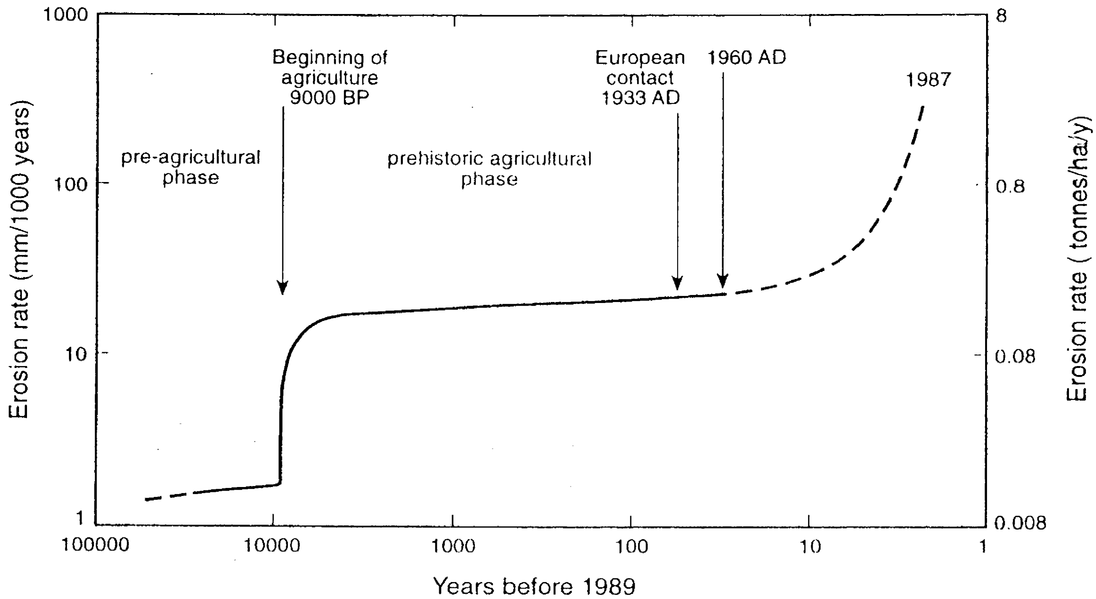


Figure 3. **Long term soil loss rates based on sedimentation in a swampy site at Kuk near Mt. Hagen. Modified from Hughes *et al.* (1991).**



orders of magnitude greater than the natural (pre 9000 years ago) rate. On this basis it becomes necessary to question the longer term sustainability of the current situation though Hughes *et al.* (1991) argue that it is a very robust system.

SOIL CONSERVATION

By the 1970s the most publicised account of soil erosion was based on research conducted in southern Africa, USA and to a lesser extent in Australia. This confirmed that increases in soil loss could be expected on unprotected soil. Furthermore, the only parameter that could be modified or even controlled by management practices was ground cover. In drier environments the basic soil conservation strategy to emerge was to retain water on hillslopes to encourage vegetation growth. This became the golden rule of soil conservation (e.g. Hudson 1971) and it remains so today. This notion was applied to the PNG highlands (Herman 1977; Gagne 1977) and advocated at least informally by many others. However, it was apparent to others that the main conservation strategy in humid areas of PNG was to remove water from hillslopes without causing erosion. Because of the high rainfall prolific vegetation growth occurred without the need to trap water on hillslopes. Furthermore, an examination of traditional soil conservation methods showed that controlled water shedding is widespread in PNG especially where heavy clay soils occur. In this situation a system of shallow drains (barets), aligned both down and across slope, are often employed to remove excess water, even on hillslopes up to 20° (Wood and Humphreys 1982; Humphreys and Wayi 1990). On steeper slopes a variety of barriers are sometimes placed across the slope. These act to trap soil and reduce velocity of runoff though it seems that the primary purpose is not related to conservation but to the mark out sections of the garden.

As noted above traditional soil conservation strategies are widespread in PNG. However, they remain poorly documented and understood. A review by Wood and Humphreys (1982) describes an array of techniques designed to overcome a common range of problems. For example the cultivation of sweet potato in poorly drained soils necessitates aerating the soil and this is achieved by drains and/or raised beds and/or mounds. Any combination of these three techniques may be found through out the highlands. A considerable amount of information has been gained in the study of agricultural practices especially by anthropologists and human ecologists but little of it has been seriously evaluated by researchers trained in agricultural science in general or soil science in particular.[xi]

SOIL FERTILITY STUDIES

Considerable effort has been expended in PNG by soil scientists and especially agronomists in examining crop response to major and trace elements so as to determine the most suitable fertiliser dose to rates. An extensive literature exists on this (see Bourke 1993) but this is not reviewed here. Despite this, however, only very generalised accounts exist on the fertility status of various soil types (see Bleeker 1983 for a useful treatment). One of the issues that needs to be confronted is that a particular chemical characteristic is not always restricted to a particular soil type and the converse that the same soil type may exhibit very different chemical properties. For example boron deficiencies appears to occur in several soil types including volcanic ash soils in the highlands but not all ash soils exhibit this problem. In other situations a clearer association exists. Phosphate fixation is widespread in highland ash soils (Parfitt and Mavo 1975; Moody and Radcliffe 1986) and a strong variable charge quality is expected (Radcliffe and Gilman 1985; Bleeker and Sageman 1990) though again neither property is restricted to the ash soils.

One issue that may hinder our understanding of the fertility status of soils reflects the practice of obtaining standard soil chemical tests on representative soil profiles during the course of a soil survey. These data are used to provide an overall assessment noting any apparent deficiencies and toxicities that might affect crop growth. For many years the guidelines developed by Metson (1956) in New Zealand have been applied. This appears to have worked reasonably well. It will be some time before a truly in house rating scheme can be devised given the large number of crops and cultivars grown in PNG even though useful advances in this direction have been achieved with crop suitability ratings noted above. Detail information is mostly limited to plantation crops such as cocoa, copra, oil palm, tea and coffee where suitable trials have been conducted. However, a major difficulty in assessing spot samples, as undertaken during normal surveys, is that the results relate to the time of sampling so that the relationship to site history remains obscure. Sampling sequentially so as to evaluate temporal effects is fairly common in plantation crops and during the course of agricultural field trials but only in a few cases has it been attempted in traditional cropping systems. Nevertheless, successional changes have been attempted in which the change in nutrient level is assessed during cropping, fallow and forest regrowth phases following the example set by Nye and Greenland (1960) in Africa (e.g. Clarke and Street 1967; Manner 1969,1976; Wood 1979, 1984; Humphreys 1984). These studies follow an ergodic approach (i.e. the substitution of space for time) and sample adjacent areas under different stages in the cultivation cycle simply because it is much too impractical to conduct a trial over 10-50 years or more. This approach indicates the most appropriate length of fallow (= recovery period) which remains essential information for assessing sustainability. A particularly interesting variation of this type of research was undertaken by Wood (1984). He utilised a very detailed oral history in the Tari Basin to date individual gardens to determine changes in nutrient levels and sweet potato yields under continuous cultivation.[xii] Yield decline on fertile soils adjacent to swamps and on floodplains (tropepts and fluvents) remained <20% after 100 years of cultivation whereas volcanic ash soils suffered a 50% decline in <50 years (Figure 4). Apart from general soil chemical attributes it is also appropriate to utilise other parameters such as soil microbial activity which is thought to provide a much more sensitive indicator of nutrient decline and recovery. Sparling and Humphreys, (1991) used microbial carbon values on garden, fallow and forest soils in the upper Chimbu valley at 2700 m a.s.l. and found that recovery period may exceed 50 years. Much more research of this type is required on a variety of soil types and cropping systems.

Another issue that has not been addressed is the biogeochemical link between the topsoil and deep subsoil. Often the whole soil (i.e. topsoil, subsoil and parent material) is treated as a discrete unit

***Figure 4.* Decline in sweet potato yields over time on various soil types in the Tari Basin (modified from Wood 1985)**

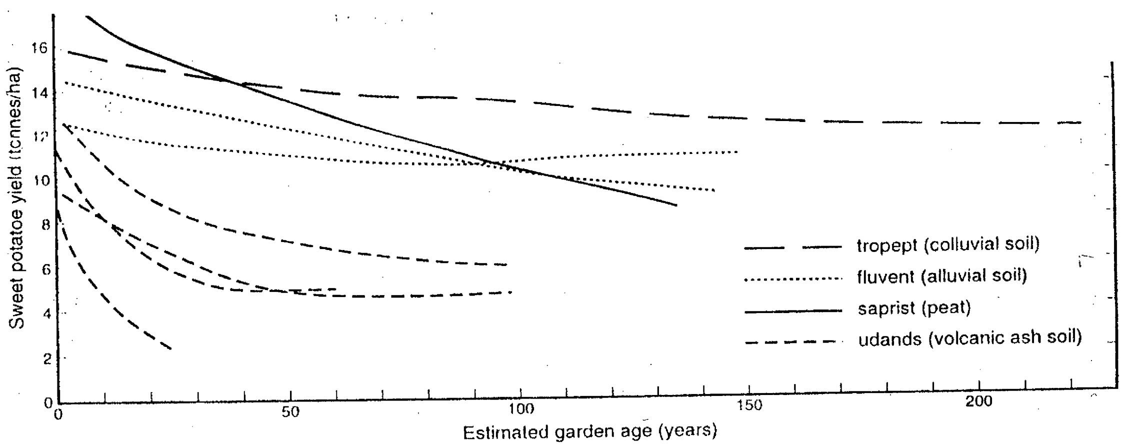
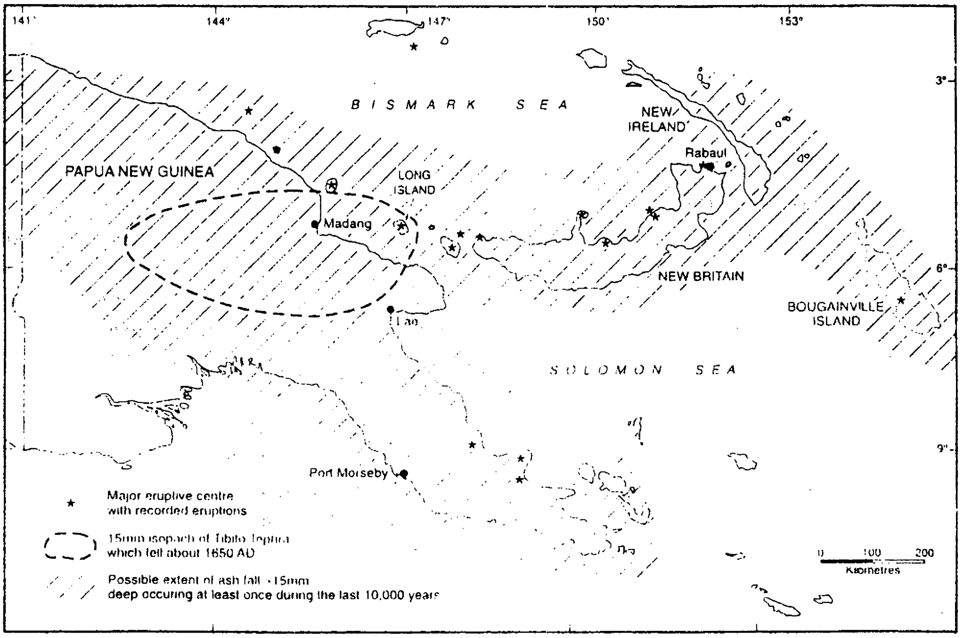


Figure 5. **Known extent of PNG where >15 mm of ash probably landed during the Holocene. The known extent of the well dated and mapped Tibito tephra is also indicated.**



and chemical changes are assessed on the implied assumption that the topsoil and subsoil is derived from the same parent material. It is apparent that this assumption does not always hold. Topsoil enrichment by volcanic ash has probably had a major effect and it is likely that about half of PNG soils, have received over 15 mm of ash during the last 10,000 years (Figure 5).[xiii] Similarly, extensive colluvial mantles occur, even on gentler slopes, and in various situations the overlying material is derived from a different lithology as is often recognised with mobile mantles (Paton *et al.* 1995; Ollier and Pain 1996) or other transported materials as has been speculated to occur in texture contrast soils in Irian Jaya (Schroo 1964) and on the Fly Platform (Bleeker 1983). In this situation chemical and mineralogical differences can be expected. However, downslope transport is not limited to mineral grains. Ruxton (1967) recognised the movement of litter and other organic fragments as part of slope wash under mature primary forest. Other well stratified deposits such as alluvium may also show chemical and mineralogical differences but where the source area is the same, any chemical variations may be related to particle size effects as would be expected if lithic sands were compared to clayey materials providing of course that allowance is made for the influence of organic matter. In thicker volcanic ash mantles trace element differences exist between successive ash layers even when they are derived from the same volcano and this feature provides the basis for fingerprinting individual layers.

It is possible that some of the mechanisms used to explain chemical trends such as the intensity of weathering and water table fluctuations may require reinterpretation though this task becomes difficult if the background information on the soil and the site is inadequate. For example, high ratios of exchangeable magnesium to exchangeable potassium are reported in soils in south-eastern PNG especially on the southern side of the Owen Stanley Range to the east of Port Moresby (Best 1977). This may be attributed in part to the ultramafic rocks in the hinterland which also have high magnesium. Just why magnesium accumulates here despite the high rainfall (high leaching rate) is not fully understood. The situation is somewhat confused since the same high ratios are not as common in soils on the north coast which also drains ultramafic areas though further west near Madang magnesium rich soil occurs with dunite (Holmes and Hall 1976). Perhaps the addition of volcanic materials on the north coast masks the high magnesium though it is also possible that a lack of knowledge of the real distribution of magnesium rich soils contributes to the problem. In addition to high magnesium levels the same ultrabasic rocks in eastern Papua reveal high and even toxic levels of manganese and cobalt which appear to concentrate in the topsoil above the seasonal high water table level (Bleeker and Austin 1970) though given the issues raised above other explanations should be evaluated.

The above discussion is from the viewpoint of seeking to understand soil fertility status and response on the basis of soil type. However, other vectors may be important too. For example during smaller ENSO droughts of 1972 and 1982 it appeared that there is a net build up in nutrient reserves so that the post drought period often produces a growth flux (R.M. Bourke pers com). The reasons for this have not been completely evaluated but nutrient release following fire, reduced rates of decomposition and reduction in weeds and pests are possible contributing factors. Similarly, it is not known whether a similar effect will occur after the pronounced 1997 drought. This is an area where soil scientists can and should make a significant contribution.

SOIL AND HEALTH

A direct association between soils and public health is often difficult to establish but it has been widely recognised throughout the world that land degradation is an important factor leading to population decline. The presence of extensive grasslands in Papua New Guinea, especially in areas where forest might normally be expected, is often ascribed an anthropogenic origin that involved a combination of clearance for cultivation and fire (e.g. Robins 1960). More detail on what may have transpired in the past has been obtained from various late Quaternary deposits especially those that show direct evidence of cultivation (e.g. Golson and Hughes 1980; Gillieson *et al.* 1987; Hughes *et al.* 1991). The deposits often show substantial increase in sedimentation in pre-historic times (mostly in the last 6000 years). Various lines of evidence have been employed to indicate that the sediment was derived from cultivated land in the contributing catchment and not from localised reworking of valley fills. The emerging scenario is that the lower productivity grasslands, especially on steeper slopes, were subjected to excessive soil erosion and hence the loss of an important soil nutrient store (i.e. the topsoil). A sequence of forest clearance for cultivation, over use of the soil, fertility decline and erosion would lower soil productivity and lead to extensive grasslands. The use of fire, possibly aided by ENSO driven droughts such as occurred over much of PNG in 1997, would assist in maintaining these grassland and also explain the low population densities that are common today.[xiv]

Other links to public health have been suggested also. A high incidence of motor neuron diseases such as Amyotrophic Lateral Sclerosis and Parkinson-Dementia have been found in communities using soils containing high levels of Al, Fe and Mn and low amounts of Ca, Mg and Zn (Standal 1988). This is a feature of the so called acid soils i.e. soils of moderately low pH (normally <5.5) with high levels of available aluminium and manganese that may be toxic to plants. A preliminary assessment of the distribution of acid soils in PNG indicated that about 11% of the country may contain acid soils but that these areas support only about 2% of the population (Humphreys and Freyne 1988). However, whether or not this relationship is due to the low fertility status of these soils or to various diseases is not known for certain even though it appears to be the case amongst certain groups in Irian Jaya. Soil, especially clay, is used as a medicine sometimes. The practice of eating clay, or geophagia, is reported in the East Sepik (Drover and Borrell 1980) but it is probably much more widespread in PNG. It appears that clay may provide an additional source of essential minerals such as in the smectite dominated Sepik samples which are favoured by pregnant women. Clays are also used for antidiarrhoeal and detoxification purposes (Reid 1992) in which case kaolinite is preferred.

LATOSOLS AND TROPICAL WEATHERING

One of the most enduring themes in soil science that emerged during the first half of this century was the belief that something different happens under tropical conditions. Intense or mature weathering and leaching under warm humid conditions was thought to lead to laterisation (= ferrallisation) i.e. the concentration of iron and aluminium oxides/hydroxides and kaolinite at the expense of silica. This theme was adopted by Humbert (1948) who used an example from near Oro Bay to promote a general theory of laterisation.[xv] In particular he advocated that laterites develop best under tropical wet and dry conditions and suggested that the lowland grassland environments would prove most conducive, thus implying that laterites (= latosols or oxisols) would be widespread in lowland PNG. Subsequent investigations indicated that the products of intense weathering, leaching and new mineral formation were fairly unusual in PNG (Haantjens and Bleeker 1970) and that latosolic soils (mostly oxisols) occupied only 5-10% of the country with occurrences confined mostly to a few areas such as near Safia (close to Humbert's site) and in Western Province (Bleeker 1972 1983; Bleeker and Sageman 1990) and also at some ore mineralisation sites of limited extent (e.g. Holmes and Hall 1976). It also became apparent that these soils occurred under rainforest in more humid settings (>2000 mm) than that suggested as being optimal by Humbert (1948). This finding meant either that the climatic conditions needed broadening to span the humid to wet/dry tropics or that some type of climatic change was required to account for those occurrences not conforming to the theory. Not withstanding the potential for circular argument Humbert (1948) opted for the latter. Of course, it is possible that other factors might be more important than climate but this option does not appear to have been considered in any serious manner.[xvi] Nevertheless, despite these misgivings it was widely accepted that laterite soils in PNG, especially deep varieties (i.e. more than a few metres thick) required a long time to form and hence would be preserved on remnants of old landscapes that had remained stable long enough for a latosol to form.

At face value this appeared to be plausible and conformed with ideas developed elsewhere that laterites take around 105 to 106 years to develop and that the tectonically active quality of the PNG landscape was not conducive to latosol development (e.g. Haantjens and Bleeker 1970; Bleeker 1972; Bleeker and Sageman 1990). However, the available information on age, though very limited, provides a very confusing picture. A carbon-14 age of 27,000 y BP was obtained from the upper few metres of the Lake Murray Beds on the Fly Platform (Blake and Ollier 1971) at a site that contains various latosols (oxisols) and associated soils. This very young age presents a dilemma: either the soil was missidentified (i.e. it is not really a latosol), or the date is erroneous (i.e. much too young), or that the implied great age requirement is not necessary. In contrast, other studies in PNG concerned with the alteration of volcanic ash, a highly reactive and easily weatherable medium, requires thousands of years to register a pronounced effect. Ruxtcn (1968) found only slight etching of hornblendes in tephras <20,000 years old and the transformation of allophane to halloysite can occur within a few thousand years (Bleeker and Parfitt 1974). It is possible that a simpler explanation may suffice to explain these soils: that they occur in localised situations conducive to the formation and preservation of deep weathering mantles such as thicker clay bands, oxidized metaliferous rocks, hydrothermal alteration zones, areas with a denser network of joints, and other easily weathered lithologies such as ultra-mafic rocks. The study by Bleeker and Sageman (1990) is instructive on this issue. They compared two deep latosols (acrorthox and eutrorthox) near Safia. The former had developed in serpentinite, an ultra basic rock low in silica with comparatively high magnesium, and it was shown to be composed mostly of goethite rather than clay minerals. The latter had formed in basalt and was dominated by 1:1 lattice clay minerals with greater variable charge properties. This implies that it is the rock type or the lithological material that retains a strong controls on soil mineralogy and hence soil type. A similar point was used to explain major differences in surface charge properties between nominally similar soils (Gilman and Sinclair 1987). In addition, it is now widely recognised that if there are any differences between temperate and tropical weathering regimes it is in the speed of alteration, especially the through-put of water, and not the type of mechanism involved.

CONCLUSIONS

This paper commenced with the fairly modest aim of revealing something of the variety of soil studies that have been undertaken in PNG and at the same time provide some background as to why various themes were addressed. The major limitation with this approach is that some important topics such as the investigations into soil nutrient deficiencies and toxicities were omitted or hardly addressed at all. Neverthless, some very real advances have been achieved and these are identified in the text.

In preparing this review it became evident that it is not so much the variety of soil themes investigated that is of major interest but rather the diverse backgrounds of the investigators in terms of both nationalities and disciplines. Even so, no attempt was made to link opinions and approaches or even paradigms to cultural or disciplinary roots. A natural consequence of this is the divergence of opinion, and aspects of this are evident in the paper. This healthy effect is also enhanced by the policy to send most PNG soil scientists overseas for postgraduate studies. In this respect it is apparent that many of the investigated themes benefited from the contribution of two major approaches: present day dynamics and environmental history. Thus an understanding of erosion comes from process studies and the depositional records, sometimes spanning thousands of years. Likewise an understanding of nutrient decline and recovery was obtained from experimental plots and utilising old gardens dated by oral history. In a similar way it is necessary to understand local land use history and the source of soil materials to adequately interpret soil chemical trends and other issues such as sustainability.

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In composing this paper I have relied on conversations and tit-bits of information gleaned from various sources in an attempt to mould it into something more than just a straight review. Accordingly, I acknowledge the assistance of various PNG workers who have contributed in some way to this retelling of an incomplete history. For convenience they are named here on an alphabetical first name basis: Andrew Wood, Balthasar Wayi, Bryant Allen, David Freyne, Grahme Tyrie, John McAlpine, Michael Bourke, Paul Harding, Pieter Bleeker, Ralph Scott, Robin Hide, Russell Blong and many others. Of course any inaccuracies must rest with me.

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i Though this paper does not attempt to provide an historical account of the development of soil studies in PNG, it is pertinent to recall some of the early contributors who helped to lay the foundations for what followed. F.P. Aland, G.K. Graham, A.C. Hartley and P.G.E. Searle, who were Land Use Officers, are mentioned here as they have not been afforded the same recognition as achieved by the CSIRO soil scientists of P. Bleeker, H.A. Haantjens, G.K. Rutherford and R.M. Scott.

ii Within the Kuman speakers in Simbu the women, especially older women, appear to employ a very much more detailed terminology that is largely beyond the full comprehension of males. I became aware of this during soil investigations in 1979-81 but could not establish the full extent of this other than that there was another level beyond the common soil words such as magan kama (very good soil for cultivation).

iii There are about 150-200 PhD theses by anthropologist and geographers dealing with traditional agriculture in PNG and of these about a third contain considerable detail (R. Hide pers com).

iv An agrotechnology transfer workshop was held in PNG in 1983 (Anon 1983). Part of the widespread adoption of Soil Taxonomy in developing countries appears to stem from the policy of USAid to insist that this classification be used in agriculture based programs though, this did not occur in PNG.

v This soil type achieved a degree of infamy following the suggestion that it was the zonal soil (meaning that climatic influences overshadowed all others) of the humid tropical mountains (Haantjens and Rutherford 1964) when it was established that the parent material was the same *viz.* volcanic ash [See review by Wood (1987) and comment by Humphreys (1991).]

vi For example there is, as might be expected, considerable detailed information on chemical, physical, mineralogical and morphological properties of this soil especially those influencing plant growth (e.g Rutherford and Wantabe 1966; Parfitt and Mavo 1975; Bleeker 1983, Wood 1984; Humphreys 1984; Radcliffe and Gillman 1985; Moody & Radcliffe, 1986; D'Souza and Bourke 1986; Allbrook and Radcliffe 1987; Wood, 1987 and Kanua 1995). However, there are also studies on engineering properties (Wallace 1973; Blong & Pain 1978), pedogenesis (e.g. Haantjens and Rutherford 1964; Rutherford 1964a,b; Chartres *et al.* 1983; Chartres and Pain 1984) and soil loss on cultivated lands (Humphreys 1984; Wood 1984; Humphreys and Wayi 1991; Sillitoe 1993 b). Volcanic ash beds (or tephra), have also been used to unravel landscape evolution during the Quaternary at a regional scale (Pain and Blong 1979) and they provide useful marker beds in lacustrine, swampy and footslope deposits (e.g. Blong and Pain 1976; Oldfield *et al.* 1980).

vii This was not the first attempt at establishing a major data base on soil and landscape data of PNG. Haantjens *et al.* (1975), Haantjens and Bleeker (1975) and Haantjens (1975) describe a computer data base system but it appears to have received little use. By the early 1980's it was impossible to retrieve any information from the data base - such was the rapid growth in computer software systems. In order to obtain soil information it was necessary to manually decode up to six fortran code sheets per soil profile which proved necessary in the land unit mapping exercise undertaken by Scott *et al.* (1985). The whole exercise can be best summed up as an expensive lesson.

x Together with the more detailed surveys conducted by the Land Use Section and affiliates, about half of PNG has been mapped.

ix There appears to be little firm evidence to go on but it might be surmised that some information on erosion was known, though not directly quoted. Brune (1949) considered that about 75% of erosion was due to sheet wash in some coastal areas of PNG but that because of high vegetation cover total soil loss amounted to < 2 tonnes ha^{-1} y^{-1} for catchments < 270 km^2. However, it was also known that considerable sediment loads were produced by large catchments. Fournier (1960) used a limited but widespread data set to predict global rates of denudation based on an index that emphasises seasonality. A small scale map indicated a denudation rate of 10-20 t ha^{-1} y^{-1} over PNG. An update using a more complete rainfall data would imply rates between about 10 and 100 t ha^{-1} y^{-1} with a country wide average of about 23 t ha^{-1} y^{-1} .

x According to FAO (1978) <10 t ha^{-1} y^{-1} amounts to slight erosion, 10-50 is moderate, 50-200 is high and >200 t ha^{-1} y^{-1} is very high.

xi op cit (iii)

xii The study showed that the rate of nutrient decline varied between soil types in an expected and predictable way. The beauty of the study is in dating the gardens and establishing the history of each sampled garden plot which was possible by the very detailed oral records retained by the local farmers. The oral history was subsequently confirmed by Chris Ballard (pers com) who has cross checked fifteen generations of information across several Huli sub-clans and independently confirmed key events by utilising dated archaeological sites. See also Wood (1985) for a summary and Blaikie and Brookfield (1987) for an even briefer treatment.

xiii The extent of Tibito tephra, as shown in Figure 5, is fairly well dated and mapped (Blong 1982; Pain and Blong 1979). The possible extent of ash fall during the Holocene is based on the position of volcanic centres that have been active in historical times together with seasonal wind patterns. However, the distribution pattern of Tibito Tephra and an older ash fall, Olgaboli Tephra, do not conform with major seasonal wind directions which implies that the extent of ash is somewhat greater than mapped here.

xiv During 1997, PNG experienced the biggest drought in living memory and possibly greater than any thing in the last 120 years or more (Allen and Bourke 1997). It is now well known that these droughts are a part of the periodic El Nino - Southern Oscillation (ENSO) phenomenon.

xv There is no indication in Humbert's paper as to how much time was spent in the field in PNG for this study nor of any other areas that may have been visited. Furthermore, I know of no other paper by this author on PNG soils. It is possible that he/she was with the armed forces, presumably American, during the Pacific campaign of WWII. For example, Brune (1949) records that his observations on soils and erosion in the SW Pacfic were made during WWII.

xvi Climatic determinism still dominates pedological thinking today. Soil Taxonomy (an influential soil classification system) retains a very strong implicit link to climatic determinism. Yet the questionable utility in calling a soil a tropical soil in a tropical settings (e.g. tropepts) does not appear to have registered. See Haantjens and Bleeker (1975) and Humphreys (1991) for further comment.