EFFECT OF SHIFTING CULTIVATION ON SOME SOIL PROPERTIES OF THE BISMARCK MOUNTAINS, TERRITORY OF PAPUA AND NEW GUINEA

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PREFACE

In 1967, as a research assistant to Dr. John M. Street, I spent nine months among the Maring-speaking people of Kompiai, Bismarck Mountains, Territory of Papua and New Guinea. Prof. Street and I were interested in the distribution and ecology of various grassland associations, the succession of vegetation from forest to grassland, and the effects of shifting cultivation and burning on soils and vegetation.

This paper is a preliminary report based on field research sponsored by the National Science Foundation (Grant GS 1464), titled, "The Influence of Savanna Vegetation on the Soil of Humid Montane New Guinea", J. M. Street the principal investigator.

I wish to thank the following members of the University of Hawaii faculty and staff for their assistance: Mr. Roger Watanabe of the Department of Agronomy and Soils; and Prof. A. Abbott of the Geology Department for identifications of rock specimens. I am also grateful to Mr. John Wormersley, Chief, Division of Botany, Department of Forests, Territory of Papua and New Guinea, for identification of plant specimens.

Finally, I would like to give special recognition to my wife, Beverly, for her help and encouragement.

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INTRODUCTION

In many areas of the humid tropics, shifting cultivation, or slash-and-burn agriculture, is the traditional form of native subsistence agriculture. In such a system the standing vegetation is cut, the litter and trash fired, and the land planted. During a cropping period of approximately two to three years decreasing soil fertility and increasing weediness and pest infestation interact to depress crop production. The garden is then abandoned and allowed to lie fallow for a number of years for the purpose of restoring soil fertility. Ideally the abandoned garden site reverts to secondary forest and in time the cycle of shifting cultivation on the same site is repeated. However, in many cases a large part of the land surface becomes covered by a graminoid vegetation, a result of repeated burning and cultivation. While these anthropogenic grasslands offer sites for gardening, shifting cultivators prefer to make their gardens in forested sites. If forested areas are lacking or scarce, gardens are made in the grassland employing laborious and time-consuming techniques. While conservation of labor and time may be some reasons for the preference of building gardens in forested sites, native gardeners have observed that crop yields are higher from gardens in forest than from gardens in the grassland. Other things being equal, the differences in crop yields suggest that the soil under a grassland is less fertile than the soil under a forest. However for many parts of the tropics, the effects of shifting cultivation or the effects of succession of old fields to grassland or secondary forest on soils have not been systematically investigated.

While a number of studies state that grassland soils are less fertile than forest soils, the comparisons of soil properties may be misleading as very often the soils examined are from sites of different rainfall, temperature or parent materials.

This research is an attempt to clarify some effects of shifting cultivation and burning on soils by means of comparisons between soils of adjacent vegetation formations and similar parent materials, climate and topography.

Literature Review

In the humid tropics, other factors being equal, the nutrient and physical status of soils under forest are better than those under a grassland. Kellogg (1963, p. 221) states that "soils under forest are generally more productive than those under savanna with other conditions comparable." Doyne (1935), Michelmore (1939), Satyanarayan (1960), and Nye and Greenland (1960) agree with Kellogg. Clarke and Street (1967) note similar results from the New Guinea Highlands. Soils under forest have higher organic carbon and nitrogen percentages, and higher amounts of exchangeable bases and pH than the soils from a grassland. Data from Doyne (1935) indicated that under comparable conditions of rainfall the exchangeable bases of the surface soil under a forest are at least three times higher than those under a grassland. Nye and Greenland (1960) note that under comparable conditions of rainfall and temperature, savanna ochrosols are less fertile than semi-deciduous forest soils. In addition, Nye and Bertheux (1957) note that forest soils have higher amounts of inorganic and total phosphorus than savanna soils. However the differences in phosphorus contents for their forest and savanna soils may not be due to the effects of cultivation and burning or differences in vegetation, as the rainfall conditions were dissimilar.

The lower base content and pH of a grassland soil may be partially attributed to the effects of burning and cultivation in reducing the amount of bases in the soil profile. Generally tropical soils are relatively infertile despite the luxuriant rainforest cover. This apparent contradiction is explained by the fact that there is a constant recycling of bases from the fallow and litter to the soil. Burning of litter and vegetation during garden building operations release bases to the soil and thus increases soil fertility. (Popenoe, 1957; Nye and Greenland, 1960; West, 1965). However, with continued burning and cultivation and the establishment of a grassland, bases in the top soil are diminished through deep leaching or runoff.

Under conditions of high rainfall the pH of grassland soils are low as bases are subject to loss in runoff and deep leaching. Doyne (1935), Morison et al (1948), Nye et al (1957, 1960), Misra (1958), and Clarke and Street (1967) state that the pH of grassland soils is lower than that of a forest soil. Furthermore, depending on the amount of rainfall, the pH of grassland and forest soils may either increase or decrease with depth. Under conditions of high rainfall, the surface soil under a forest may be more acid than the subsurface soil (Morison et al, 1948; Wycherley and Nair, 1958; Nye and Greenland, 1960; Kee, 1965). Under lower amounts of rainfall the acidity of the forest soils increases with depth as bases are accumulated on or near the surface (Doyne, 1935; Reed, 1951; Nye et al, 1957, 1960; Panton, 1960; Greenland and Kowal, 1960).

Similar trends of pH increase or decrease as a function of rainfall are noted for grassland soils. In grassland soils under low rainfall (and sometime drought) soils increase in acidity with depth (Doyne, 1935; Nye and Greenland, 1960). Under high rainfall, acidity decreases with depth as bases are leached from the surface horizons (Nye and Bertheux, 1957; Morison et al, 1948).

The effect of cultivation and burning on the organic carbon and nitrogen contents of soil seems to vary with the circumstances. For comparable situations of rainfall and temperatures, the organic matter and total nitrogen contents of soils under forests are higher than in savannas or cultivated land. These results have been noted by de Rosayro (1960), Lemee (1961), Nye et al (1957, 1960), and Jenny et al (1948, 1949, 1960). Reed's data (1951) indicates a higher amount of organic matter and nitrogen in a primary forest soil than in the secondary forest soil. Sly and Tinker (1962) found a slight decrease in the organic matter content of the soil after burning a felled forest. Thus as stated by Langdale-Brown (1968, p. 68):

> Fire has far-reaching effects on the soil; directly through heating the surface layers and reducing the moisture and humus content, . . .

However Nye and Greenland (1960, p. 73) state that for both the grassland and forest:

> . . . carbon, nitrogen, and sulphur in the fallow and litter are lost in the burn, but not the amounts in soil humus.

Baldanzi (1960), on the basis of three years of burning experiments in grassland soils found no significant decrease in the soil carbon or nitrogen. This is in agreement with Cook (1939) who noted on the basis of six years of experiments in grassland plots, no appreciable differences in the organic matter of burned and unburned plots.

The status of soil organic matter is further complicated by Abeywickrama (1961) and Budowski (1956) who note that the organic matter content of grassland soils may be higher than that of forest soils. Budowski (p. 26) states that the cause of lower organic matter and nutrient status for forest soils is due to the:

> . . . intensive circulation of organic compounds, further facilitated by the porous soil structure under the forest. . . . Under a savanna soil no such intensive circulation or organic compounds takes place.

However, Budowski's comments seem applicable to those grasslands which may have poor internal drainage as a consequence of an impermeable hardpan layer and a lack of slope. For most of the tropics it seems that grasslands, particularly old grasslands, subject to repeated burnings are poor in soil humus, a lack (Nye and Greenland, 1960, p. 104):

> . . . due primarily to the slow build-up of humus under the burnt grass fallow, so that the losses of humus in each period of cultivation are virtually additive.

Thus it can be readily seen that the status of organic matter and the effects of shifting cultivation and burning on soil organic matter are varied as they are also dependent on the climate, type of vegetation formation, frequency of burning, and topography. However under comparable environmental conditions the organic matter status of soils under forest is higher than that found in soils under grassland.

Usually C/N ratios of forest soils are lower than those of grassland soils. Under various temperature and rainfall regimes, low C/N ratios of primary and secondary forest soils have been noted by Birch and Friend (1956), Panton (1960), Arnott (1957), Hesse (1957), Greenland and Kowal (1960), and Reijnders (1964). Wycherley and Nair (1958) report a C/N ratio of approximately 18 for an abandoned rubber plantation. Nye and Greenland (1960) have reported a range of 10.0 to 18.0 for savanna ochrosols, 7.7 to 12.1 for forest ochrosols and a range of 11.7 to 17.9 for forest oxisols. The increase in C/N ratios as a function of increasing rainfall and decreasing temperatures have also been noted for various vegetation formations by Jenny, Bingham, and Padilla-Savaria (1948) and Birch and Friend (1956).

Physical differences in soils under forest and grassland vegetation have been noted by many authors. With a short cultivation and long fallow cycle Joachim and Kandiah (1948) report that adverse physical changes in the soil may not occur. However, it seems that a system of long cultivation and short fallow, with occasional burning of the vegetation has often been the rule as evidenced by the large extent of grassland.

Very often the soils under a grass cover are shallow, eroded and compacted. (See Street, 1966; Robbins, 1958 and 1960; Kellogg, 1963; Joachim, 1955; de Rosayro, 1960; Budowski, 1956; and Brookfield and Brown, 1963). Street (1966) notes that in the New Guinea Highlands the bulk density of the soil under grassland is 1.16 times higher than that of an adjacent forested soil. In addition to the sometimes eroded state of grassland soils, the sparse vegetation cover and often bare soil surface may encourage the formation of an indurated layer. Such formations are described by Budowski (1956), Vine (1968), Sherman *et al* (1954, 1953), de Rosayro (1960), and in New Guinea by Reijnders (1964).

Under grass, the soil is subject to high temperatures and subsequent dehydration which in turn lead to an increase in bulk density and particle density.[1]

In the preceeding summary, it has been noted that shifting cultivation and burning affect some chemical and physical properties of soils. However, some of these changes are due in part to changes in the temperature and moisture status of the soil that accompany the change in vegetation, e.g. from a primary forest to a grassland. Chang (1958) notes that temperatures of the soil are higher in the grassland than in the forest. In a forest situation, the denser shade reduces the insolation reaching the soil surface resulting in a lower soil temperature and lower rates of evaporation (Wilm, 1957). Buckman and Brady (1960), Ignatieff and Lemos (1963), and the studies by Jenny (1928, 1929, 1949) indicate that organic carbon and nitrogen increase as temperature decreases and moisture increases. Cunningham (1963) attributed a decrease in the organic carbon of an exposed forest soil to the increase in soil temperatures and the lack of litter renewal. Johnson and Jackson (1964) state that calcium increases with increasing temperatures and in Hawaii Ayres (1943) and Kanehiro and Chang (1956) have noted an increase in pH and base saturation with decreasing rainfall.

In summarizing, shifting cultivation reduces the organic matter, nitrogen and exchangeable base contents while increasing bulk density

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[1]The development of hardpans, lateritic layers and ferruginous layers is fully treated by Sherman (1949), Sherman et al (1953, 1954) and J. L. Walker (1964).

of soils and their susceptibility to erosion. Thus grasslands resulting from repeated cultivation and burning are poorer in nutrients and physical status than adjacent forest soils. However the status of organic matter as a function of burning or cultivation is still unclear and for the moment seems to be dependent on the particular set of environmental factors. In cases where grasslands exhibited a higher base, nitrogen or organic carbon content than the forest soil, it seems that the edaphic, topographic, and climatic conditions of the forested and grass sites were dissimilar.

While the effects of shifting cultivation and burning on soils and vegetation have been studied in other areas of the tropics, these effects have not been fully ascertained for montane areas of New Guinea. The effects of cultivation and burning on soils and vegetation have been only recently examined and briefly so by Street (1966, 1967), Clarke and Street (1967), Clarke (1966, 1968), and to a minor extent by Brookfield and Brown (1963). Generalized accounts by Anas (1960) and Robbins (1958, 1960) indicate that the soils of anthropogenic grasslands are physically and chemically poorer than soils of adjacent forests. Furthermore, Clarke and Street (1967, p. 11) have suggested that the grassland vegetation "may be an active agent of soil degradation rather than, as is often stated, only an indicator of degradation that has resulted from intensive gardening."

In 1967 I was able to conduct field research in the Bismarck Mountains of New Guinea on the question of the effects of slash-and-burn agriculture on soils and vegetation. Field observations--that the grasslands were not often used for gardens--and statements by native informants indicated that grassland soils were physically and chemically poorer for agriculture than the adjacent forest soils. In those few grassland areas used for crop production, soils were spaded and turned before planting. Nye and Greenland (1960) suggest that turning of the grassland soil increases aeration which in turn increases rates of humus mineralization and nitrification. Clarke and Street (1967) suggest that turning of the soil relieves toxic conditions that may be present in the grassland soils of the Bismarck Mountain area. In addition, some grassland sites intended for future gardening were planted with secondary forest trees and fallowed for approximately 10 to 15 years for the purpose of improving soil fertility and tilth.

But for the most part the effects of shifting cultivation and soil properties or the association of soils and vegetation in the Highlands have not been thoroughly investigated and very little data exists to support the contention that these anthropogenic grassland soils are poorer than forest soils. And since the effects of shifting cultivation and burning on soils and vegetation for the humid tropics in general have not been fully clarified, especially the status of organic matter, research was undertaken to investigate more thoroughly the effects of cultivation and burning on soils.

Purpose of Study

Thus the purpose of this thesis are:

1. To present the results and analyses of soil samples from primary forest, secondary forest and grasslands of the New Guinea Highlands whose soils may differ in some chemical and physical properties as a result of slash-and-burn agriculture, and,

2. To describe in greater detail the effects of slash-and-burn cultivation on humid montane tropical soil properties.

Major emphasis is placed on the analysis and discussion of surface soil samples.

Theoretical Approach

In order to assess the effects of shifting cultivation and burning on soil properties and vegetation a methodology proposed by Jenny (1941) is employed. Briefly stated, the soil is considered to be the result of a number of factors: namely, climate, biota, parent material, topography and time. Theoretically, a change in any one factor results in a different soil. If all factors but one are held constant, the resulting differences in a soil may be attributed to the varying factor. Since research was directed to the question of the effects of shifting cultivation on soil properties, these effects may be determined by holding constant the factors of climate, parent material, topography and time, and varying the vegetation which reflects man's use of land. Man, a biotic factor, through his agricultural and burning activities is the ultimate determinant of the present distribution and structure of vegetation: and, consequently, a factor affecting the soil system.

Location of the Study Area

Kompiai (5° 28'S, 144° 39'E) is located on the southern slopes of the Bismarck Mountains, Territory of Papua and New Guinea (Figures 1 and 2). Kompiai was chosen as the study site for a number of reasons:

1. At Kompiai and in the Bismarck Mountain area, traditional methods of shifting cultivation unchanged to any great extent by modern methods are still carried out on a large scale.

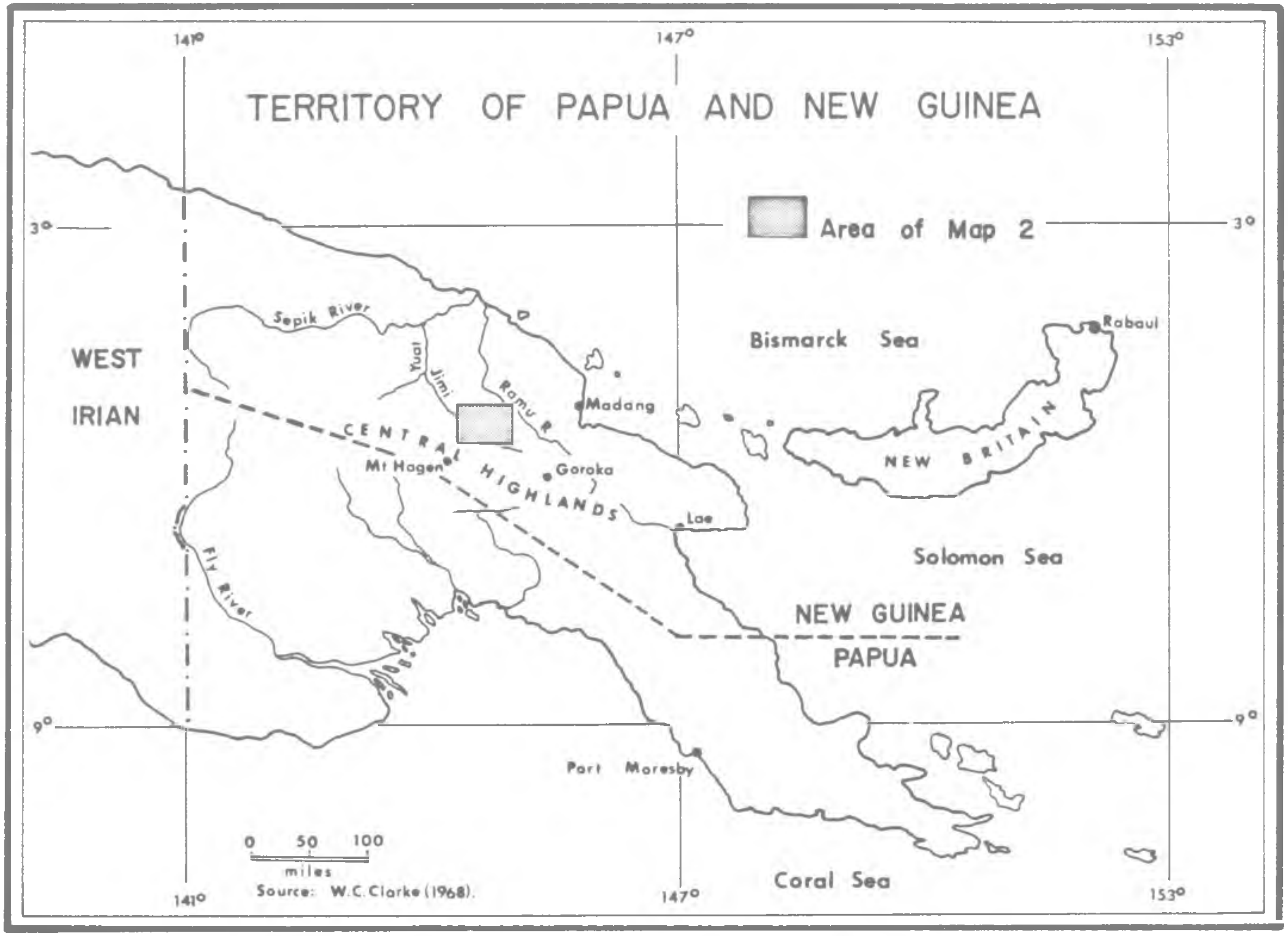

Figure 1. Location map of the territory of Papua and New Guinea and the Bismarck Mountain area (Map 2).

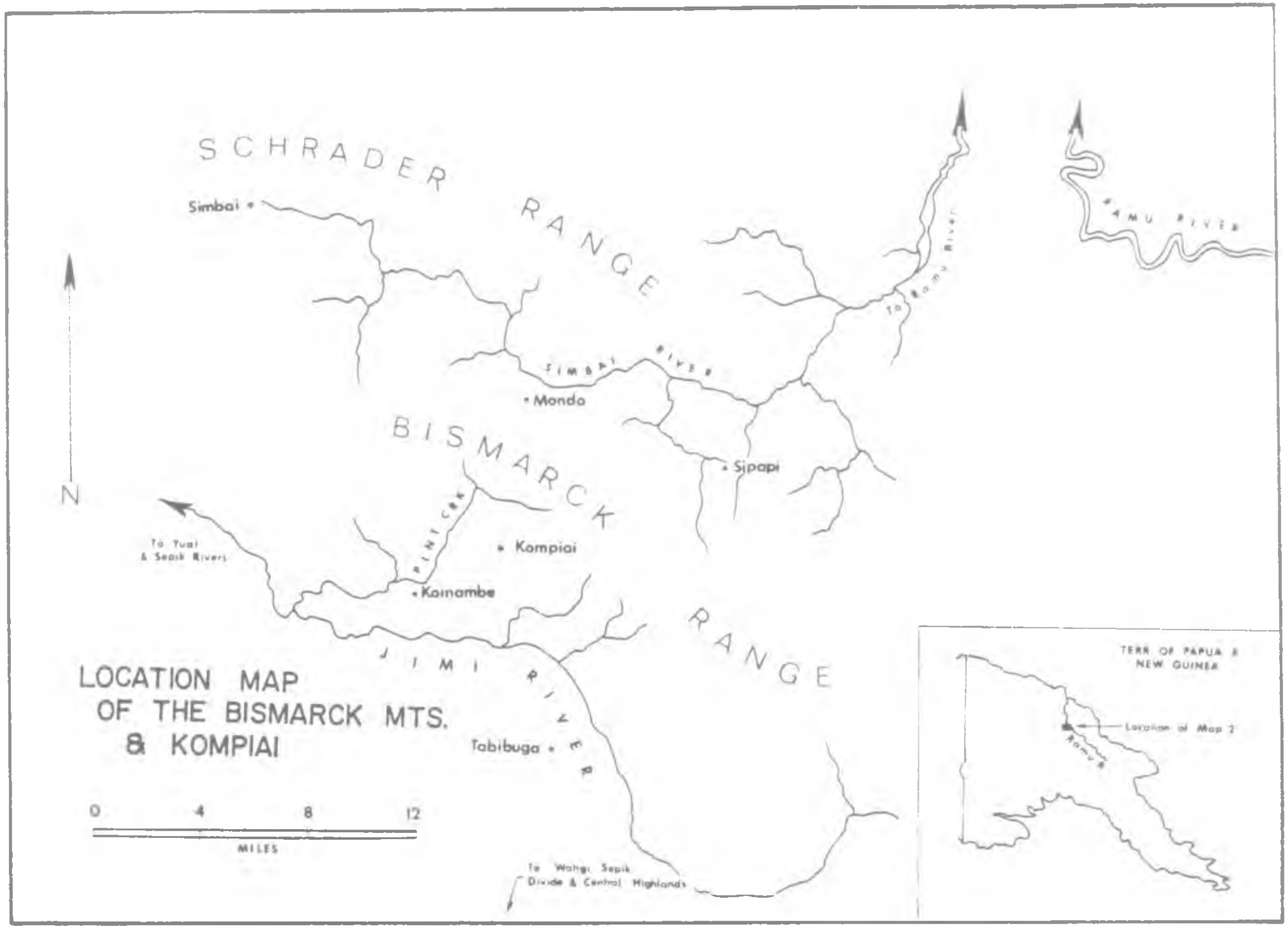

Figure 2. Area of Map 2. Location map of the Bismarck Mountain area and Kompiai.

2. There are extensive primary and secondary forests, gardens and grasslands under constant conditions of rainfall, temperature, and parent materials. There is conclusive evidence that these grasslands are anthropogenic in origin. Such evidence would include the presence of charcoal in the soil profile, the high frequency of fires, and the dark black color of soils (which is due to charring of the litter). The distribution of vegetation also indicates that the grasslands are anthropogenic in origin as the grasslands are virtually all found in the same altitudinal zone as agriculture, while above and below lie primary forests.
3. Previous researches by Clarke (1966, 1968), Clarke and Street (1967), Street (1966, 1967), Rappaport (1967), and Vayda and Cook (1964) were conducted in the immediate area. Thus the present research could build upon the investigations of these workers.

Selection of Study Sites

The study sites at Kompiai were carefully selected in an attempt to keep all factors constant except the vegetation. Soils were sampled from sites on north-facing slopes of five to twenty-five degrees underlain by a shale or greywacke parent material. The temperature range was limited by selection of sites between 4800 to 6200 feet. This altitudinal range would include a temperature range of four and one half degrees F assuming a normal lapse rate. Rainfall was considered constant as the study area was confined to an area approximately five miles square. A detailed description of the physical environment is presented in the following section.

ELEMENTS OF THE PHYSICAL ENVIRONMENT

Climate: Rainfall and Temperature

The basic circulation pattern of the New Guinea subcontinent is dominated by easterlies with perturbations occurring between fragmented parts of the Intertropical Convergence Zones (Fitzpatrick, Hart and Brookfield, 1966, p. 182-183; Thompson, 1951, p. 586). From December through April the low altitude and variable equatorial westerlies abut the Northeast and Southeast trades in two convergence zones (Chang, 1968; Curry and Armstrong, 1959). During May these equatorial westerlies are replaced by southeasterlies. However, these low-altitude perturbations, westerlies, and surface southeasterlies rarely penetrate into the Highlands. At 10,000 feet circulation is essentially a zonal easterly (Thompson, 1951, p. 586; Chang, 1968). Thus the circulation pattern at Kompiai is mainly locally induced with an easterly component at high altitudes. Observations on the local cloud and wind movements at Kompiai indicate that Defant's model of local slope and valley winds (1951) accounts for the pattern of rainfall.

Brookfield and Hart (1966, p. 8) state that:

> Over most of the region there is only a single maximum of mean rainfall. . . (occurring) between late-December and late-March--and most commonly in February. . . (with) the driest week between early May and August.

While the rainfall data for Kompiai are fragmentary and limited to ten months observation, they do indicate the seasonality of rainfall (Table I). During January, 1968 and June, 1967 totals of 21.95" and 2.91" respectively were recorded. Complete records for ten years at Tabibuga (Jimi River Station) located eight miles south are appropriate in

TABLE I

MEAN MONTHLY AND ANNUAL RAINFALL DATA
(IN INCHES) FOR SELECTED NEW GUINEA STATIONS

Station	J	F	M	A	M	J	J	A	S	O	N	D	Total
Tabibuga[a]	16.54	16.32	16.87	12.73	9.44	4.43	4.77	6.43	7.52	9.82	11.37	14.68	130.91
Tabibuga[b]	19.83	22.66	20.32	10.58	7.58	2.97	5.84	8.77	7.49	13.13	13.00	22.04	
Tabibuga[c]	26.60	14.70	16.49	9.90	6.78	1.85	3.58	9.35	4.56	9.10	19.67	14.99	
Kompiai[d]	21.95	17.46	N. A.	N. A.	5.11	2.91	4.90	5.46	8.24	11.74	13.47	17.64	108.88*
Simbai Air Strip[e]	12.71	13.07	11.28	14.13	6.89	4.71	5.92	7.77	10.67	9.72	10.00	11.90	118.14
Sipapi[f]	16	17	19	15	12	6	7	8	11	13	14	15	153

		Elevation	Years of Complete Record
[a]Station Records	5°33' S, 144°38' E	5000'	10
[b]Station Records for 1967	5°33' S, 144°38' E	5000'	1
[c]Station Records for 1968	5°33' S, 144°38' E	5000'	1
[d]Street and Manner	5°28' S. 144°39' E	5700'	0
[e]Brookfield and Hart (1966)	5°15' S, 144°42' E	5600'	5
[f]Clarke (1968) Estimated data		3300'	0

* January and February totals are for 1968; Data for February is from only 17 days of record

May through December totals are for 1967: Data for May is from only 9 days of record

N. A. Not available

describing the rainfall pattern at Kompiai. For the same period of record at Tabibuga there is a maximum of 26.60" in January, 1968 and a minimum of 2.97" in June, 1967. Mean annual rainfall at Tabibuga is 130.91". High amounts of rainfall are also recorded at Simbai by Brookfield and Hart (1966) and estimated by Clarke (1968) at Sipapi. Thus on the basis of rainfall records for Tabibuga and Kompiai for the period of record, assuming comparability of rainfall, the rainfall at Kompiai is about 130" per annum.

There is a marked variation in daily rainfall totals. During November there were 12 days without rain and one day with 3.35 inches. And while the 2.91 inches of rainfall registered in June may not be low enough to designate that month as "dry", of a total of 19 days without rainfall exceeding 0.1 inches, 14 days without rain occurred in succession at the end of which time the top soil under the primary forest felt dry.

Most of the rain falls in late afternoon and early night, the result of locally induced convective clouds and upslope winds. Most of the observed storms were of short duration and yielded less than 0.1 inches of rainfall. However, not infrequently, regional warm-cored disturbances and storms of long duration and high intensity bring more than one inch of rainfall within a 24 hour period. For the period of record there were 33 days during which the daily rainfall exceeded one inch.

Air temperatures at Kompiai (5700 feet) are mild and relatively constant. (See Table II). Days were warm, the maximum averaging 71.2°F, and nights cool, the minimum averaging 57.8°F. Frost is unknown in the area.

Soil temperatures varied with the nature of the vegetation cover. Average maximum temperatures of the soil at one inch depth were consistently higher in the grasslands than in the secondary or primary forest. Maximum temperatures in the grassland soils averaged 72.7°F, while in the secondary forest and primary forests they were 66.75°F and 65.0°F respectively. On bare ground, soil maximum temperatures were highest, averaging 84.03°F. The effects of soil temperatures on soil properties are discussed in later sections of this paper.

TABLE II

MEAN MAXIMUM AND MINIMUM AIR TEMPERATURES (IN DEGREES F) FOR KOMPIAI REST HOUSE

Month & Year	Av. Maximum	Av. Minimum
Jan 1968	70.77	58.94
Feb 1968 17 days	71.59	58.15
June 1967 24 days	70.98	57.38
July 1967	70.27	57.32
Aug 1967	70.31	56.90
Sept 1967	71.48	57.35
Oct 1967	71.07	57.84
Nov 1967	72.93	58.67
Dec 1967	71.52	58.66
Average for nine months	71.21	57.84
Average annual temperature	64.57°F	

Vegetation

The pattern of vegetation in the Bismarck Mountains is strongly influenced by man's gardening and burning activities. Generally, primary forests are located at high altitudes or on slopes considered marginal for agriculture. At Kompiai the lower limit of the continuous primary forest is found at 6000 feet (Figure 3). Gardens are seldom planted above that elevation because the high incidence of cloud cover, low insolation and temperatures would interact to depress crop yields.

The primary forests contain a large number of species and are complex in structure (Figure 4). The highest canopy of the forest is approximately 100 feet high with a few emergent species that reach 130 feet in height, notably Podocarpus amarus, Saurauia and Pasania species.[2] The most common trees of the high canopy are Castanopsis acuminatissima, Perrotetia grandifolia, Ficus bernaysii, Decaspermum fruticosum, and species of Eugenia, Andinandra and Lucinea. The coverage of this layer approaches 85 percent. Below the high canopy there is an intermediate canopy 80 to 100 feet high composed mainly of the Lauraceae (Endiandra and Cryptocarya sp.), Fagaceae and Sapindaceae (Harpullia sp.). Planchonella firma and Pandanus foveolatus often attain heights of 100 feet but are more commonly 85 feet high.

Between 40 to 80 feet high is found a lower canopy composed mainly of Eugenia, Aporosa and Macaranga. Smaller and younger trees are found

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[2]Description of the primary forest at Kompiai is based on a number of transects made in 1967. More complete descriptions of the primary forests of the Highlands are found in the articles by D. Walker (1966), and Robbins (1958 and 1960).

Figure 3. The distribution of vegetation at Kompiai. The primary forest is located near the ridge crest (altitude 6000 feet). Secondary forest and gardens occupy intermediate altitudes with grasslands in the foreground.

Figure 4. Interior view of the primary forest, elevation 6000 feet. Note the density of vegetation.

below 40 feet. Members of this layer include the Araliaceae and Myristicaceae and species of Urophyllum, Halfordia and Ficus. All of the taller trees support epiphytic growths of orchids, mosses, ferns and lichens. Freycinetia species and other lianas are also common in the primary forest.

The most numerous plants in the lower strata (5-10 feet high) are a number of Zingerberaceae, Monimiaceae and Rubiaceae. The forest floor is often matted by a dense surface root net and a heavy cover of leaf litter. Various ferns, mosses and small forbs, especially Pseuderanthemum species and various Urticaceae, occur in association with young tree seedlings.

Secondary forests are found in areas where the primary forest has been cleared for agriculture and the garden site later abandoned because of declining agricultural productivity and invasion by weedy species. Some secondary forests occupy what were once anthropogenic grasslands where succession by woody species had not been hindered. However such sites are rare and of small extent as fires are common occurrences in the grasslands. At Kompiai and in other areas of the tropics, the secondary forests are the results of succession and invasion of former garden sites by woody vegetation.

A number of vegetation transects classified according to length of fallow and aspect are presented in Table III to indicate the structure and composition of the secondary forests at Kompiai. The following observations can be made. Secondary forests 10-15 years old on north facing slopes are dominated by Dodonea viscosa (35 feet high), with yikun, a Piper species, forming a secondary and fragmented

TABLE III

FREQUENCIES OF SOME SECONDARY FOREST SPECIES ACCORDING TO ASPECT AND AGE[a]

	NORTH ASPECT			SOUTH ASPECT		
Age of Forest (in years)	0–5	5–10	10–15	0–5	5–10	10–15
Paspalum conjugatum	.91	.27	.33	.83	.30	.19
Imperata cylindrica	.36	.46	.02	---	.04	.06
Microstegium spectabile	.50	.39	.31	.60	.36	.23
Cyclosorus unitus	.46	.64	.41	.45	.55	.27
Setaria palmifolia	.27	.07	.58	.24	.12	.09
Dodonea viscosa	.64	1.24	.20	.02	.38	.01
Phyllanthus sp.	.03	.08	.02	.33	.04	.13
Piper sp. "N"	.10	.08	.22	.54	.30	.37
Piper sp. "A"	---	.01	.05	.52	.19	.65
Homolanthus sp.	.07	---	.01	.02	---	.04
Macaranga pleiostamina	.06	.14	.11	.29	.07	.12
Alphitonia incana	.02	---	.15	.07	.04	.08
Saurauia sp.	.02	.06	.06	.34	.22	.28
Wendlandia paniculata	.01	.04	.13	.08	.18	---

[a] Frequency data based on vegetation transects.

canopy 10 to 15 feet high. The ground cover is composed of varying amounts of the fern Cyclosorus unitus, and the grasses Paspalum conjugatum, Microstegium spectabile, and Imperata cylindrica, with Setaria palmifolia and Ischaemum polystachyum occurring in lesser numbers. A succession in the ground cover according to age of the secondary may also be noted; generally the floor of a young secondary forest (0–5 years of age) is dominated by a graminoid cover. With an increase in the length of fallow time and the resulting increase in shade, the grass cover is replaced by a fern cover. (Compare Figure 5 with Figure 6).

In contrast to the secondary forests on north facing slopes, the secondary forests on south facing slopes have much less Dodonea viscosa and a heavier canopy of Piper species. Two species of Saurauia replace

Figure 5. A young secondary forest, approximately five years old on a north facing slope. The trees are mostly Dodonea viscosa. Tree heights are less than 15 feet. Miscanthus floridulus forms a thick but limited cover.

Dodonea viscosa as the most frequently occurring forest tree. Although not indicated by Table III, secondary forests on south facing slopes have a greater diversity in the number of woody species. The ground cover is essentially the same, the main difference being the lower incidence of Imperata cylindrica.

The high frequency of Dodonea viscosa on north facing slopes in contrast to the high frequencies of Piper and Saurauia on south facing slopes are in part a function of aspect. Aspect in turn determines the intensity of insolation received at the earth's surface, temperature and soil moisture. Kompiai, which is in the southern hemisphere, receives a higher amount of insolation on its north facing slopes than on its south facing slopes. Thus soil temperature is generally higher and soil moisture less on north facing slopes than on south facing slopes. The net effects are two dissimilar habitats, each with a somewhat different species composition. The data on Table III indicates that Dodonea viscosa is better adapted to a drier and warmer habitat while Piper and Saurauia are better adapted to a moister and cooler habitat.

Casuarina oligodon with heights up to 80 feet are common in some plots but uncommon in others. Some casuarinas attain heights of 120 feet. The variation in incidence of casuarinas seems to be dependent on the particular horticultural practices and preferences of the native gardeners. In some gardens, casuarina seedlings were planted with care, while in others such propagation was not carried out. Tall Casuarinas were often severely pollarded instead of cut down during garden clearing operations. In such cases, the incidence and regeneration of Casuarina oligodon would be higher.

Miscanthus floridulus and Gleichenia linearis formed thickets of limited extent. These thickets are less common in older secondary forests. In other parts of the highlands Miscanthus is often the dominant vegetation. This seems especially true in the large flat valley of the Wahgi where the water table is high.

Figure 6. An older secondary forest, 15 years of age, dominated by Casuarina oligodon. Tree heights approach 60 feet. Primary forest in background.

Other trees common to secondary forests on north and south facing slopes include Macaranga pleiostamina, Wendlandia paniculate, Alphitonia incana and a Maesa species.

In contrast to the primary forest where the effects of man on his environment are minimal, the grasslands represent a situation in which man has altered his environment drastically. The grasslands at Kompiai are mainly the consequences of repeated gardening and burning activities, especially burning of grasslands (Anas, 1960; McIntosh, 1960; Robbins, 1960; and Street, 1967) and subsequent soil nutrient or degradation (Street, 1966; Clarke and Street, 1967).[3]

On the basis of field work, the grasslands are provisionally divided according to species composition into two main types which represent opposite ends of a successional continuum. Young or incipient grasslands of small extent are found on recently fired garden or secondary forest areas (Figure 7). These grasslands are composed mainly of Imperata cylindrica, Cyclosorus unitus, Cyperus spp., Sorghum nitidum, and a few herbaceous annuals. Themeda australis is not present. Older grasslands (Figure 8) are associated with larger areas, which over time have been subjected to repeated burnings and soil nutrient depletion. These grasslands are dominated by Themeda australis and Capillipedium parviflorum. Other common species include Ophiuros tongcalingii, Coelorachis rottboellioides, Arundinella setosa, Eulalia leptostachys, and the fern Cyclosorus unitus. Imperata cylindrica is relatively less important in these older grasslands.

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[3]In Africa Clayton (1958) notes that firing is necessary for invasion of woody thickets by Imperata cylindrica var. Africana.

Figure 7. A young trailside grassland small extent dominated by Imperate cylindrica and bordered by secondary forests.

Figure 8. View of old grassland indicating the frequent occurrences of fires. The darkened areas were burned a few days earlier.

Grasslands protected from burning are eventually invaded by a few woody species, among them *Schuurmansia henningsii*, *Melastoma malabathricum*, and a tree fern *Cyathea angiensis* (Figure 9). Continued protection from firing will result in invasion by other woody species and the eventual formation of a secondary forest.

Physiography and Geology[4]

The Bismarck Mountains are a complex horst with steep knife edged ridges situated between deeply incised rivers and streams. The mountains run southeast to northwest for approximately 60 miles and are flanked by the Bundi Fault Trough and Schrader Ranges to the north and by the Jimi Fault and Wahgi-Jimi Divide to the south. The ranges are dominated by the Wilhelm Massif (15,400 feet) in the southeast and decrease in height and relief towards the northwest. At Kompiai the mountains reach a height of 7000 to 7500 feet. The Bismarcks are still tectonically active, as evidenced by frequent earth tremors.

Kompiai is located on the southern flanks of the Bismarcks and overlooks the Jimi Fault. Slopes are often steeper than 35 degrees and highly eroded in places, especially in the grasslands where large slump scars are in evidence.[5] Slopes less than five degrees are very rare.

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[4]This discussion on the geology and physiography of the Bismarck Mountains is based mainly on Dow and Dekker (1964).

[5]A discussion on the relationships between vegetation and slopes with reference to the Bismarck Mountains is found in a paper by Street (1968).

Figure 9. Invasion of a Themeda and fern grassland by woody vegetation primarily Schuurmansia henningsii.

The rocks at Kompiai are complexly folded fine grained sedimentaries of probable Middle and Upper Cretaceous period which Dow and Dekker have designated as Kompiai formation as the best exposures are found in this area. Commenting on these desimentaries, Dow and Dekker (1964, p. 17) further state that:

> The upper part of the formation consists of shales and siltstone, containing rare beds of fine-grained greywacke. The lower part is mainly siltstone and contains beds of light-colored feldspathic sandstone and greywacke.

In places, the Miocene epoch Oipo intrusives of gabbro and granodiorite intrude the Kompiai formation.

Soils

The soils at Kompiai fit Rutherford's (1962) description of yellow-brown Inceptisols formed from siltstones and greywackes. Soils developed from these sedimentaries on steep slopes are often subject to slumping. As a result, the soils tend to be shallow, usually not more than five feet deep and contain angular rock fragments throughout their profiles. Generally on slopes less than 30 degrees the soils under a primary forest are deeper, presumably the consequence of the heavy litter and canopy cover which protects the soil from erosion, and the mechanical support afforded the soil by the deep and extensive rooting system of primary forest trees. The dark brown and friable mineral A horizon may extend to a depth of 20 inches and intergrades into a compact and sticky brownish-yellow B horizon. Angular shards may be present in the profile. In the secondary forest the depth of the A horizon is less, often not more than 10 inches or so.

Under a grassland vegetation the depth of the A horizon is shallower (not more than 8 inches). The top soil is black from frequent firing, relatively compact, greasy to the touch and sparsely covered by a thin moss layer. The shallowness of the A horizon may be due to losses of the top soil through mass movements which expose the saprolite below. In places slumps which are common in grasslands (Figure 10) may result in the formation of a buried soil layer (Figure 11).

Figure 10. An incipient arcuate-shaped slump in the initial phase of down slope movement. This grassland has been repeatedly burned over time.

Figure 11. A buried soil in the <u>Themeda australis</u> grassland. The staff is four feet high.

MATERIALS AND METHODS

Soil Sampling Methods and Methods of Analysis

Soils were sampled from sites that exhibited constancy in all factors except vegetation. A number of surface soils from each site were composited and bagged in the field.[6] In many instances another set of soil samples was collected according to horizons, the analyses of which are also presented in this paper. The soils were fumigated with methyl bromide upon receipt at the USDA Plant Quarantine Station in Honolulu.

Preparatory to analysis, the soils were air dried for one to two weeks, then ground with mortar and pestle to pass through a 36 mesh sieve. Moisture factors were determined for each sample by calculating moisture lost in oven drying at 105°C for 24 hours.

Determinations of organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, pH, bulk density and color were made using standardized techniques. Organic carbon percentage was determined by the Walkley-Black method (Jackson, 1938, p. 219-21). Total nitrogen determinations were made using the Kjeldahl method, a wet digestion method where H_2SO_4 converts soil nitrogen to the NH_4 form, which is then distilled over into boric acid (Jackson, 1958, p. 183-190).

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[6] Surface soil is defined in this paper as a sample from the 0-4" depth. Major emphasis was placed on the analyses of this depth as this layer seemed most likely to be indicative of the effects of shifting cultivation on soils.

Cation exchange capacity was determined by saturating the soil sample with 1 N NH_4OAc (pH 7) and displacement of this ion by 4% KCl. For the analyses of Na, K, Mg, and Ca, the filtrate and washings of ammonium acetate from the CEC determinations were made up to a convenient volume (500 ml). Na and K readings were made by a Beckman DU flame spectrophotometer and compared to standard curves. Ca and Mg were determined on a Perkin Elmer atomic absorption spectrophotometer.

Soil pH readings were made with a Beckman Zeromatic pH meter. The soil sample was moistened with distilled H_2O according to the "water-saturation percentage" method as described by Jackson (p. 45-46). Readings were made one half hour after wetting.

Bulk density was determined by the waxed clod method. An Ohaus balance was used for determining the weight of soil in water. Munsell soil color charts were used to determine moist soil colors.

Statistical Test of Significance

Due to the nature of the research design the number of soil samples collected and analyzed was small as sites that reflected constancy in all factors but vegetation were limited in number. Thus the Wald-Wolfowitz Runs Test as described by Blaylock (1960) was used as the test of significance. The means of soil properties when statistically significant at the .10 and .05 level are indicated along with the data on Table IV.

A larger sample size would probably increase the significance of differences in soil properties and permit the usage of more powerful tests of significance. Some differences, though real to the observer, were not statistically significant at the 0.10 or 0.05 level.

RESULTS OF SOIL ANALYSES

The results of soil analyses are presented in tabular form in Tables IV to XIV. Surface soil properties of the three vegetation formations are summarized in Table IV. Analyses of surface and subsurface horizons are also presented to indicate trends in soil properties as a function of depth (Tables V to XIV).

Determinations for cation exchange capacity, exchangeable and total bases, base saturation, organic carbon percentage, total nitrogen percentage and bulk density are expressed on the basis of oven dried soil weight. Cation exchange capacity and total and exchangeable bases are given in terms of m.e. per 100 grams of oven dried soil. Bulk density values are stated in terms of weight per unit volume (grams/cc^3). Color determinations were made on moistened soil samples.

TABLE IV

SUMMARY OF ANALYSES FOR SURFACE SOILS UNDER VARIOUS VEGETATION FORMATIONS[a]

Soil No.	pH	CEC	Ca	Mg	K	Na	Total Bases	Base Sat. %	O.C.%	Total N %	C/N	B.D.
		(milliequivalents per 100 grams)										
Primary forest soils												
580-2	5.40	65.35	1.96	1.14	.50	.96	4.65	6.97	17.28	.91	18.95	——
581-2	5.50	69.79	6.74	2.08	.76	.40	9.98	14.31	20.93	1.22	17.16	.968
582-2	5.45	61.80	1.17	.86	.40	.14	2.57	4.15	15.10	.67	22.38	.976
Average		65.65	3.29	1.36	.55	.50	5.70	8.48	17.77	.93	19.11	.972
Secondary forest soils												
161267T-1	5.62	47.81	14.23	3.92	.59	.27	19.01	39.31	11.65	.77	15.16	——
161267S-1	5.94	47.47	29.31	3.36	.82	.42	33.91	71.42	7.89	.79	10.01	——
31067-1	5.58	53.47	9.93	2.22	.40	.24	12.79	23.90	7.86	.83	9.46	1.000
Average		49.58-	17.28-	3.17-	.60	.31	21.90-	44.88	9.13-	.80	11.54-	1.000
Grassland soils												
121567-1	5.82	33.73	7.08	2.63	.68	.17	10.56	31.32	8.01	.51	15.71	——
121567-2	4.90	30.71	6.17	2.69	.79	.17	9.82	31.98	6.49	.47	13.74	1.10
Ming 31	5.75	45.77	7.64	2.42	.99	.18	11.33	24.76	7.78	.70	11.09	——
Ming 38	5.50	48.12	4.51	1.60	.70	.18	6.99	14.54	12.68	——	——	1.04
Ming 52	5.69	44.37	5.69	1.79	.71	.28	8.47	19.12	7.86	.73	10.80	——
Average		40.54--	6.24++	2.23	.77	.20+	9.43	24.34	8.56--	.60+	12.84-	1.07
Grassland-secondary forest soil												
29967B-1	5.90	42.84	10.54	4.14	.75	.29	15.72	36.68	6.87	.42	16.44	.96

Complete data for each soil sample may be found in Tables V to XIV.

Test of significance: Wald-Wolfowitz Runs Test

- \- Significantly different from primary forest soil at .10
- \-- Significantly different from primary forest soil at .05
- \+ Significantly different from secondary forest soil at .10
- ++ Significantly different from secondary forest soil at .05

TABLE V

ANALYSES OF PRIMARY FOREST SOIL, SITE #580

Soil Number:	580-2, -3	Location:	Arrupeng
Aspect:	355°	Slope:	15-20°
Altitude:	6000 feet	Substrate:	Shale
Vegetation:	Primary forest vegetation, slightly disturbed		
Comments:	Mineral soil is overlain by a thick (6") mat of roots and litter (mull). Number of composited samples--8 each		

Depth	0-3"	3-8"
pH	5.40	5.65
CEC	65.35	52.16
Ca	1.96	2.03
Mg	1.14	.77
K	.50	.23
Na	.96	.46
Base Saturation %	6.97	6.68
Organic Carbon %	17.28	9.18
Total Nitrogen %	.91	.76
C/N	18.95/1	12.04/1
Bulk Density	----	1.01
Color	5YR2/2	10YR3/4

TABLE VI

ANALYSES OF PRIMARY FOREST SOIL, SITE #581

Soil Number:	581-2, -3	Location:	Arrupeng
Aspect:	355°	Slope:	15-20°
Altitude:	6200 feet	Substrate:	Shale
Vegetation:	Primary forest vegetation. Number of composited samples--8 each		
Comments:	Litter and root mass is one inch thick. Number of composited samples--8 each		

Depth	0-5"	5-8"
pH	5.50	5.40
CEC	69.79	60.80
Ca	6.74	2.43
Mg	2.08	.86
K	.76	.57
Na	.40	.17
Base Saturation %	14.31	6.64
Organic Carbon %	20.93	13.84
Total Nitrogen %	1.22	.80
C/N	17.17/1	17.18/1
Bulk Density	.968	1.10
Color	10YR2/2	10YR2/2

TABLE VII

ANALYSES OF PRIMARY FOREST SOIL, SITE #582

Soil Number:	582-2, -3, -4, -5, -6	Location:	Arrupeng
Aspect:	10° N	Slope:	15-20°
Altitude:	6200 feet	Substrate:	Shale, Kompiai F.
Vegetation:	Primary forest		
Comments:	Relatively undisturbed site near ridge crest		

Depth	0-17"	17-23"	23-39"	39-69"	69-81"
pH	5.45	5.99		5.64	
CEC	61.80	34.94	14.68	17.82	20.26
Ca	1.17	.38	.56	1.55	1.45
Mg	.86	.15	.20	.62	.53
K	.40	.08	.01	.10	.00
Na	.14	.12	.09	.18	.23
Base Saturation %	4.15	2.10	5.87	13.79	10.90
Organic Carbon %	15.10	3.51	.96	.49	.38
Total Nitrogen %	.67	.24	.07	.02	.04
C/N	22.38	14.41	13.66	24.48	9.44
Bulk Density	.98	1.22	----	1.38	1.16
Color	5YR2/2	10YR3/4	5YR4/8	10YR3/4	10YR3.5/4

TABLE VIII

ANALYSES OF SECONDARY FOREST SOIL, SITE #161267T

Soil Number:	161267T-1, -2	Location:	Mandepant
Aspect:	10° N	Slope:	15-20°
Altitude:	5300 feet	Substrate:	Shale
Vegetation:	Mature secondary forest approximately 15 years old		
Comments:	Both samples consist of three composited samples		

Depth	0-4"	4-8"
pH	5.62	5.52
CEC	47.81	28.29
Ca	14.23	3.81
Mg	3.92	1.99
K	.59	.31
Na	.27	.24
Base Saturation %	39.31	22.45
Organic Carbon %	11.65	5.83
Total Nitrogen %	.77	.37
C/N	15.61	15.68
Bulk Density	-----	1.33
Color	10YR2/1.5	10YR3.5/2

TABLE IX

ANALYSES OF SECONDARY FOREST SOIL, SITE #161267S

Soil Number: 161267S-1, -2, -3, -4 Location: Mandepant

Aspect: 5° N Slope: 5-10°

Altitude: 5100 feet Substrate: Shale

Vegetation: Secondary forest approximately 10-15 years old

Comments: All samples consist of three composited samples

Depth	0-4"	4-8"	8-11"	14-19"
pH	5.94	5.40	5.70	5.70
CEC	47.47	35.17	19.05	18.87
Ca	29.31	9.31	6.49	3.81
Mg	3.36	2.63	1.80	1.67
K	.82	.20	-----	-----
Na	.42	.21	.33	.17
Base Saturation %	71.42	35.78	45.28	29.90
Organic Carbon %	7.89	7.10	2.28	.87
Total Nitrogen %	.79	.51	.19	.08
C/N	10.01/1	14.02/1	11.80/1	11.10/1
Bulk Density	-----	-----	1.08	-----
Color	10YR2/1	10YR2/2	10YR3/4	10YR5/6

TABLE X

ANALYSES OF SECONDARY FOREST SOIL, SITE #31067

Soil Number:	31067-1, -2, -3, -4, -5	Location:	Telapeh
Aspect:	350°	Slope:	15-20°
Altitude:	5500 feet	Substrate:	Shale
Vegetation:	Young secondary forest; 5 to 10 years old		
Comments:	One sample from each layer		

Depth	0-4"	4-8"	8-12"	12-16"	16-20"
pH	5.58	5.10	5.55	5.30	5.55
CEC	53.48	34.11	27.73	28.00	26.55
Ca	9.93	7.50	3.39	3.55	1.62
Mg	2.22	2.22	2.06	1.33	.50
K	.40	1.40	.87	.62	.18
Na	.24	.27	.23	.18	.18
Saturation Base %	23.90	33.45	23.62	20.28	9.31
Organic Carbon %	7.86	6.64	2.59	2.44	1.38
Total Nitrogen %	.83	.46	.26	.18	.14
C/N	9.46/1	14.35/1	10.12/1	13.29/1	9.85/1
Bulk Density	1.00	1.21	1.03	1.26	1.38
Color	5YR2.5/1	7.5YR3/4	5YR3/4	5YR3.5/4	7.5YR3/2

TABLE XI

ANALYSES OF A RECENTLY BURNED
GRASSLAND SOIL, SITE #121567-1

Soil Number:	121567-1	Location:	Melukpai
Aspect:	350°	Slope:	15°
Altitude:	4800 feet	Substrate:	Shale
Vegetation:	Grassland dominated by *Imperata cylindrica*		
Comments:	Relatively young grassland which shows signs of being recently burned. One sample		

Depth	0–4"
pH	5.82
CEC	33.73
Ca	7.08
Mg	2.63
K	.68
Na	.17
Base Saturation %	31.32
Organic Carbon %	8.01
Total Nitrogen %	.51
C/N	15.71/1
Bulk Density	----
Color	10YR2/1.5

TABLE XII

ANALYSES OF A RECENTLY BURNED GRASSLAND SOIL, SITE #121567-2

Soil Number:	121567-2	Location:	Melukpai
Aspect:	350°	Slope:	15°
Altitude:	4800 feet	Substrate:	Shale
Vegetation:	Grassland composed of *Imperata cylindrica*. and *Sorghum nitidum*. Number of composited samples, 3.		
Comments:	This grassland site shows signs of a recent burn		

Depth	0–4"
pH	4.90
CEC	30.71
Ca	6.17
Mg	2.69
K	.79
Na	.17
Base Saturation %	31.98
Organic Carbon %	6.49
Total Nitrogen %	.47
C/N	13.74/1
Bulk Density	1.10
Color	10YR2/2

TABLE XIII

ANALYSES OF GRASSLAND SOILS, MINGEUK SERIES

Soil Number:	Ming 31, 38, 52	Location:	Mingeuk
Aspect:	10° N	Slope:	15°
Altitude:	5400 feet	Substrate:	Shale, greywacke
Vegetation:	Mixed grassland dominated by _Themeda australis_		
Comments:	Older grassland that has not been burned for a long time. Slightly disturbed by pigs. Samples from various sections of 1 field. Number of composited samples--4 each		

Soil Number	31	38	52
Depth	0-4"	0-4"	0-4"
pH	5.75	5.30	5.69
CEC	45.77	48.12	44.37
Ca	7.74	4.51	5.69
Mg	2.42	1.60	1.79
K	.99	.70	.71
Na	.18	.18	.28
Base Saturation %	24.76	14.54	19.12
Organic Carbon %	7.78	12.68	7.86
Total Nitrogen %	.70	----	.73
C/N	11.09/1	----	10.80/1
Bulk Density	----	1.04	----
Color	10YR2/1	10YR1/1	10YR2/1

TABLE XIV

ANALYSES OF A GRASSLAND-SECONDARY FOREST TRANSITION ZONE SOIL

Soil Number: 29967B-1, -2, -3, -4, -5   Location: Mingeuk

Aspect: 5°   Slope: 15-20°

Altitude: 5200 feet   Substrate: Shale

Vegetation: Grassland next to secondary forest transitional zone, dominated by *Eulalia leptostachys*

Comments: Number of composited samples by depth; 5, 3, 2, 2, 2

Depth	0-4"	4-8"	8-12"	12-16"	16-20"
pH	5.90	5.40	5.42	5.32	6.20
CEC	42.84	31.20	36.97	31.55	30.10
Ca	10.54	8.09	9.32	8.27	10.97
Mg	4.14	3.05	3.10	3.09	4.28
K	.75	.56	.53	.47	.24
Na	.29	.36	.13	.30	.21
Base Saturation %	36.68	38.63	35.37	38.44	52.15
Organic Carbon %	6.87	5.61	6.54	5.63	3.61
Total Nitrogen %	.42	.39	.44	.36	.26
C/N	16.44/1	14.46/1	14.85/1	15.66/1	14.00/1
Bulk Density	.96	----	----	.93	----
Color	10YR1.5/1	10YR2/1	10YR2/2	10YR2/2	10YR3/3

DISCUSSION OF RESULTS

Analyses of soils from the three vegetation formations indicate that there are differences in soil properties as a consequence of shifting cultivation and repeated burning. These analyses are presented in Tables IV to XIV. The replacement of a primary forest site by a garden and the succession to a secondary forest vegetation is accompanied by an increase in soil pH, total exchangeable bases, and bulk density, and a decrease in the cation exchange capacity, organic carbon and total nitrogen percentages, and C/N ratios. Further burning of the vegetation or the replacement of a secondary forest or garden to a grassland results in an increase in bulk density and a decrease in the other soil properties. C/N ratios are not significantly affected.

Generally grassland soils are poorer in nutrients and physical status than the secondary forest soil, but higher in bases than primary forest soils. Secondary forest soils are better suited for cultivation on the basis of soil properties studied than the adjacent primary forest or grassland soils. The effects of shifting cultivation and burning on soil properties are discussed in the following sections. Emphasis is placed on the discussion of attendant processes that result in either an increase or decrease in soil properties as a function of the vegetation and shifting cultivation.

Cation Exchange Capacity

As a result of shifting cultivation, burning and the subsequent change in the vegetation, there is a decrease in the cation exchange capacities of soils. Cation exchange capacity is highest in the primary forest soil and lowest in the grassland soil. The cation exchange capacities of the secondary forest and grassland soils are significantly different from the cation exchange capacities of primary forest soils. The high CEC's of the primary forest soils, averaging 65.65 m.e./100 grams, are primarily due to the presence of high amounts of organic matter, which are able to adsorb a large number of cations. With a decrease in the organic matter content, a feature common in the secondary forest and grassland, CEC decreases to 49.58 and 40.54 m.e./100 grams respectively. Thus cultivation and burning, by reducing the organic matter content through litter removal and burning, reduce the cation exchange capacity. The relationship between CEC and organic carbon content of Kompiai surface soils is shown in Figure 12.

The decrease in organic matter content may not be the only reason for the decrease in cation exchange capacities. It is possible that the decrease in CEC is due to a decrease in the amount of amorphous colloids. Sherman *et al* (1964) have noted that on heating or drying of certain soils there is a decrease in CEC because there is a shift in the soil system from a colloidal to a cryptocrystalline or crystalline system. Such changes could occur in the secondary forest or grassland where the soil is sometimes heated by burning and an increase in insolation at the ground surface. However, the hypothesis of amorphous colloid loss in relation to Kompiai soils is yet untested as differential thermal analysis studies were not carried out.

While the range of cation exchange capacities in the primary and secondary forest soils is relatively small, in the grasslands the range is larger, from 30.71 to 48.12 m.e./100 grams. This range may be partly

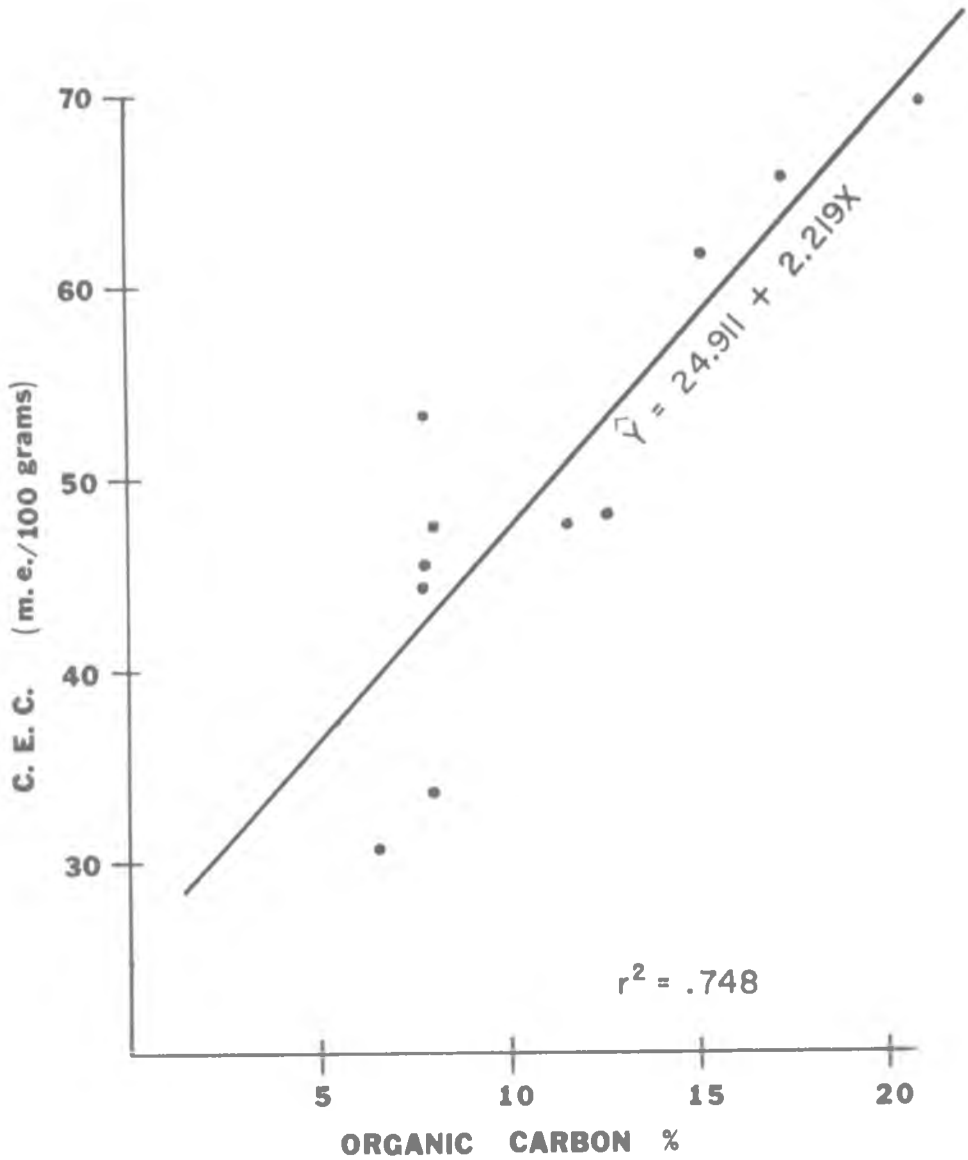

Figure 12. Relationship of cation exchange capacities and organic carbon contents of surface soils from primary and secondary forest and grassland. (Data in Table IV).

due to the effects of recent burning of the vegetation and the nature of the soil. Grassland soils that were protected from burning for approximately five years, as illustrated by the Ming 31-52 soil samples, had high cation exchange capacities. On the other hand grassland soils with low cation exchange capacities, as exemplified by 121567-1 and 121567-2 soil samples, were from sites showing signs of a recent burning. The lower cation exchange capacities of the 121567 series are also due to its slightly lower organic carbon content, the reduction of which is primarily due to the decreased litter supply and increased oxidation of organic carbon.

Burning or high soil temperatures resulting from removal of a vegetative cover, may also dehydrate and aggregate the soil. In turn soil dehydration and aggregation may result in the decrease in soil surface area and the amount and nature of colloidal material. The result would be a reduction in CEC. Finally one cannot discount the possibility that the soils of the recently burned grassland have a high sand fraction, the result of parent material conditions.

Total Bases

The total base content of primary forest soils is low, averaging 5.70 m.e./100 grams. With cultivation, burning and the succession of vegetation to a secondary forest fallow the base content increases to an average of 21.90 m.e./100 grams. Further burning, with subsequent establishment of a grass cover results in low average base content of 9.43 m.e./100 grams. The low base contents of grassland and primary forest soils are statistically significant in comparison to the higher base content of secondary forest soils. The low base status of the surface soil under a primary forest may be due to rapid leaching of bases and/or rapid uptake of bases by the standing vegetation. The uptake of bases by a secondary forest or grassland vegetation, in comparison, is less as the root network is limited. The acid conditions of the primary forest soil undoubtedly affect the base status of the soil. These effects are discussed more fully in a later section.

The cycling of bases is also evidenced by the analysis of a litter layer six inches thick shown below in Table XV.

TABLE XV

EXCHANGEABLE BASE CONTENT OF A PRIMARY FOREST LITTER LAYER (IN m.e./100 GRAMS)

CEC	Ca	Mg	K	Na	Total Bases
123.98	94.38	6.62	1.14	0.64	102.76

Although the base status of the litter layer is high, especially in exchangeable calcium, the surface soil is low in bases because under moderately acid conditions, bases released by the decomposing litter are rapidly leached into the subsurface soils and then recycled into the standing vegetation. Undoubtedly the litter contains some presently non-exchangeable bases, which upon mineralization of the litter would increase even further the base content of the soil. However, these effects are only transitory.

Since the primary forest litter and fallow contain a high amount of bases, burning of this litter and fallow would result in an increase in the base content of the soil as shown by the analyses of secondary forest soils. Some of these bases are taken up by the succeeding vegetation and some are adsorbed by either the clay or humus micelles. Some bases may be lost to the soil and vegetation by sheetwash, deep leaching or shallow seepage. However, for the secondary forest soil there is a net increase in bases.

Further burning of the secondary forest or severe nutrient depletion due to repeated cultivation results in the formation of a grassland and a decrease in the base status of the soil. Bases may be leached deep into the profile and because of the limited rooting depth of the grass, they may be eventually lost. Bases not leached into the soil column may be lost via sheet wash as the grass cover does not fully protect the soil from such losses. Protection of the grassland from fire may result in the re-establishment of a woody vegetation accompanied by an increase in the total base content of the soil. Such a situation is reflected by the analysis of a soil from a grass-land-secondary forest transition zone (Soil Number 29967B-1 in Tables IV and XIV). This site, which shows indication of invasion of a grass and by woody vegetation, lies 75 yards southeast of the Mingeuk grassland soil samples, Sample Number 29967B-1 was taken from an areas dominated by the grass Eulalia leptostachys. The base content (15.67 m.e./100 grams) of this soil is higher than that of the grassland soil but lower than that of the secondary forest soil. It is probable that over time, the base content of this soil will increase and approach that of the secondary forest soil. The high base content of this soil is probably due to the deeper rooting system of trees which is able to recycle a higher amount of bases from subsurface horizons than that amount possible by a grass vegetation.

The higher amount of bases in the secondary forest or grassland soils are also due to the higher temperature and decreased moisture content found under such situations. Increases in various bases due to an increase in solubility as a function of temperature have been noted by Johnson and Jackson (1964) and Tisdale and Nelson (1966).

Soil pH

Soil pH values are lowest in the primary forest and highest in the secondary forest, ranging from 5.40 to 5.50 and 5.58 to 5.94 respectively. In the grasslands, the soil pH varied from 4.90 to 5.82. The pH values of these soils are similar to those described by Rutherford (1962), and in comparable situations to those described by Reijnders (1964).

The pH of these soils may be associated with two factors which (themselves) are the consequences of the lack or presence of shifting cultivation and burning. The two factors are the organic matter content of the soil and the amount of bases in the soil or vegetation.

The low pH of primary forest soils is due to the high amounts of organic acids, a consequence of the slow decomposition of large amounts of organic matter under cool and moist conditions. Under such conditions bases are leached from the surface horizons and eventually taken up by the standing vegetation. Upon decomposition of the litter bases are returned to the soil and the cycle repeats itself. While the humus affords numerous sites for base adsorption and accounts for the high cation exchange capacity, the slow rates of decomposition result in a low rate of base accumulation in the soil.

Thus the highly acid primary forest soils at Kompiai are similar in some respects to the temperate moist podzols where low organic matter decomposition and high soil acidity are to be found.

Burning of the vegetation and litter results in the release of bases from the fallow and litter to the soil and a reduction in the organic matter content and cation exchange capacity of the soil. With an increase in base saturation and a decrease in cation exchange capacity, the soil pH rises. Furthermore, the increase in soil pH may be due to the increasing solubility of bases as a function of increasing soil temperature. However this increase is probably slight as the secondary forest soils are only slightly warmer than those under primary forest.

Further burning of the vegetation or the conversion of the secondary forest to a grassland may be accompanied by a decrease in pH. Burning of the vegetation and litter releases bases which are then subject to leaching and sheetwash loss. If repeated over time, bases are progressively diminished from the soil surface until equilibrium is is reached at low pH.

If the grassland is protected from fire, a colonization by woody species occurs; subsequently pH would increase as the woody vegetation with its deeper rooting system is able to pump bases from the subsurface horizons to the surface soil. This sequence is exhibited by Soil Sample 29967B-1, a soil from a grassland-secondary forest transition zone. The pH of 5.90 is higher than the pH values from a nearby grassland (Ming 31-52 series). However, because of the small sample size, not much confidence can be placed on this particular sequence.

Organic Carbon and Total Nitrogen

The organic carbon contents of surface soils under primary forest are high, averaging 17.77 percent, and are almost twice as great as the amounts found under secondary forest or grassland soils. Under the secondary forest the organic carbon content of the surface soil averages 9.13 percent. Grassland soils have slightly less organic carbon than the secondary forest soils. The amounts of organic carbon in primary forest soils when compared to the amounts found in the secondary forest soils were found to be significantly different at the 0.10 level. When comparing the organic carbon contents of primary forest soils to grassland soils, these differences were statistically significant at the 0.05 level.

Similarly the nitrogen contents of primary forest soils are higher than those found in the secondary forest and grassland soils. Total nitrogen averaged 0.93 percent in the primary forest soil compared to the 0.60 percent of grassland soils. In the secondary forest, the amount of total nitrogen averaged 0.80 percent. The nitrogen contents of secondary forest compared to grassland soils were found to be significantly different at the 0.10 level.

The differences in organic carbon and total nitrogen levels for soils under primary and secondary forests and grassland are due to differences in rates of humus mineralization and the amount of litter available for humus mineralization. In turn, litter supply and humus mineralization rates are associated with disturbance of the vegetation by either fire or cultivation. In the primary forest where disturbances due to fire or cultivation are minimal, the standing vegetation and litter represent a large source of organic material. Since soil temperatures are low (averaging 66.75°F at Kompiai), a consequence of the decreased amount of insolation reaching the soil surface, rates of humus mineralization are also low. Thus organic carbon and total nitrogen contents remain high.

Clearing and burning of the primary forest vegetation and litter result in the decrease in organic carbon and total nitrogen contents and an increase in rates of humus mineralization. Fire volatilizes carbon, nitrogen and hydrogen and in addition reduces the litter supply for humus production. The displacement of the primary forest by a garden or secondary forest regrowth also results in a decreased litter supply as there is a reduction in the annual litter fall. Thus the amount of humus in the soil is less in secondary forest or grasslands. Furthermore the secondary forest and grassland are subject to repeated (cyclic in case of the secondary forest) burnings which tend to keep soil organic matter and nitrogen levels far below those of the primary forest soil.

Generally soil temperatures are higher in the secondary forest and grassland as the less dense vegetation permits a greater amount of insolation to strike the soil surface. As a consequence, the organic carbon and total nitrogen contents of secondary forest and grassland soils may be diminished by higher rates of organic matter oxidation.

The grasslands which are more frequently burned than the secondary forests reflect a situation where rates of organic carbon and total nitrogen losses through combustion and possibly by increased organic matter decomposition are high. This is indicated in Table IV by the low organic carbon and total nitrogen contents of grassland soils. Protection of the grassland from fire can increase the organic matter and nitrogen content of soils. This increase becomes evident when comparing the data from the Ming 31-52 soil samples with the data from the 121567-1 and -2 soil samples. (See Table IV) The organic carbon and nitrogen contents of soils from the Ming 31-52 series are slightly higher than those of the 121567 series. The Kompiai Marings said that the soils of the Mingeuk series had been protected from fire for a long time. The 121567 series showed evidence of a recent fire. The lower altitude of the 121567 series may also help to account for the lower amounts of organic carbon and total nitrogen.

Thus for Kompiai, clearing and burning of the primary forest for gardening and the succession of old fields to grassland, result in a decrease in the organic carbon and total nitrogen contents of soils.

C/N Ratio

Shifting cultivation and burning of the vegetation generally reduce the C/N ratio mainly by a decrease of the organic carbon content of the soil (through increased oxidation and decreased litter supply). The percent decrease of organic carbon from the primary forest to grassland is much greater than the decrease in total nitrogen. The organic carbon contents of soils under secondary forest and grassland are significantly different from those of the soils under the primary forest; and, as mentioned previously, significant differences in nitrogen were found between the secondary forest and grassland soils only.

In the primary forest the C/N ratio of the surface soil averages 19.11 while under the secondary forest and grassland soils the ratio averages are 11.41 and 12.84 respectively. The C/N ratio of the primary forest soils was significantly different from the C/N ratios of the secondary forest and grassland soils at the .10 level.

In other areas of the tropics, the C/N ratio of primary forest soils is less than that found in grassland soils. However, this is not the case at Kompiai where a high ratio is noted in the primary forest. This high ratio seems primarily due to the very high amounts of organic matter, a result of the high rainfall and low soil temperature. This high ratio is in agreement with Jenny and Raychaudhuri (1960) who note that C/N ratios increase as temperatures decrease.

In the secondary forest soil the amounts of organic carbon, total nitrogen and C/N ratios are lower than in the primary forest soil. Shifting cultivation and burning reduce the C/N ratio mainly by increasing the rate of organic matter decomposition and decreasing the supply of litter for the production of humus. With an increase in fallow length, the C/N ratios may approach the high ratios found in primary forest soils. However, the likelihood of such an occurrence seems remote at this moment as the need for agricultural land is increasing.

In grassland soils the C/N ratio ranges from 15.71 to 10.80 with the difference in ratios correlated with the amount of nitrogen in the soil. Nitrogen contents are very low in the grassland areas that were recently burned, as exemplified by the 121567 series. In grassland soils that were protected from fire the amount of nitrogen is almost twice as high. Only slight differences in organic carbon are noted between the fire protected and recently burned grassland. With protection from fire, total nitrogen increases resulting in a decrease in C/N ratios. Thus it would seem that burning, by affecting rates of nitrogen fixation, uptake by plants and micro-organisms, and the reduction of nitrogen to the gaseous state, is probably a major determinant of soil nitrogen content and C/N ratio.

Bulk Density

Although soil bulk density values were not significantly different, a number of replicated analyses do indicate that soils under secondary forest and grassland have a higher weight per unit volume than soils under a primary forest vegetation. Shifting cultivation and burning increase soil bulk density by decreasing the organic matter content of soils. Thus the primary forest soil with its high organic matter content has the lowest bulk density. In the secondary forest and grasslands where organic matter contents of soils are lower, bulk densities are higher.

Cultivation practices can also increase soil bulk density. During clearing and planting operations the soil may be unintentionally compacted. Puddling by rainfall impact can also occur. As a result, the soil bulk density is increased. However, the slight increase in bulk density values due to Maring cultivation practices does not seem to be serious as the secondary forest soils are still friable and easily worked.

Repeated burning of the vegetation will lead to the establishment of a grassland and a soil that is heavier and harder to garden in.

However the grassland soil (average bulk density 1.07) is only slightly denser than the secondary forest soil (average bulk density 1.00). The difficulty in working with these grassland soils seems to be largely the result of the fibrous and extensive rooting system of the grasses, a system that binds the soil into a very compact and cohesive surface. But whatever the processes involved, shifting cultivation and burning increase soil bulk density and resistance to penetration of dibble sticks.

The ironstone gravels and lateritic hardpans common to tropical areas where shifting cultivation has exposed the soil to high temperatures are not found in the Kompiai Maring area. Bulk densities above 1.9 (Sherman et al, 1953) indicative of indurated layers were not found for grassland or secondary forest soils. The lack of indurated or lateritic layers for Kompiai soils may be due to the high monthly rainfall, low temperatures, comparative youth, and the relatively high amounts of organic matter found in grassland and secondary forest soils.

Soil Properties as a Function of Depth

A small number of soil samples from primary and secondary forests and the grassland-secondary forest transition zone were analyzed with respect to depth. Generally cation exchange capacity, total bases, organic carbon and total nitrogen decreased with depth while bulk density increased with depth. Soil pH and C/N ratios present some interesting trends, no doubt the results of shifting cultivation and burning effects on soils. The discussion in this section is primarily concerned with the differences in soils from the primary and secondary forest. Conclusions drawn in this section are tenuous because of the small sample size and are subject to modifications as further research is completed.

Organic carbon contents of primary forest soils show a marked decrease with depth, the reduction of organic carbon in the subsurface soil often approaching 40 percent or more. For the primary forest, while additions of organic matter to the surface soil are high, the incorporation of humus in the subsurface layers is low (see Tables V, VI, and VII).

The decrease of organic carbon with depth in the secondary forest soils is not consistent and seems correlated with age of fallow. Under 10-year-old secondary the differences in organic carbon contents of the 0-4 and 4-8 inch layers are relatively small. (See Tables IX and X). The low differences in organic carbon contents may be due to high rates of organic matter oxidation and decreased litter supply. Turning and digging of the soil during harvesting may mix the soil and organic matter resulting in the low differences in organic matter contents for the top 8 inches of soil. With an increase in fallow length the differences in organic matter between the 0-4 and 4-8 inch layers approach 50 percent as additions of organic matter to the surface soil are higher than those to the subsurface soil. Also, the effects of digging and soil turning in minimizing differences in organic matter contents for the top 8 inches of a secondary forest soil are lessened with increasing fallow length. However, it may be noted that the secondary forest soil is very friable and, therefore, permits rapid root penetration by crops. Thus turning of the secondary forest soil during planting is usually unnecessary.

As noted in the preceeding section, total nitrogen is highest in the primary forest soil and lowest in the grassland soil. With respect to soil depth, total nitrogen is highest in the surface horizon and decreases with depth. The decrease in total nitrogen with depth is striking for the secondary forest soil, the average decrease between the 0-4 and 4-8 inch layers being 44 percent. In the primary forest the average decrease in total nitrogen for the soil immediately below the surface horizon is 33 percent. The higher decrease in total nitrogen for subsurface soils under secondary forest is due to the decreased litter supply, the result of clearing and burning operations during garden building. With the decrease in litter supply the amount of nitrogen added to the soil would be low. In the primary forest no such interruption occurs. Thus the decrease of nitrogen with depth is less. Losses of nitrogen by crop removal or burning could also account for the higher decrease in nitrogen for secondary forest subsoils. Since the subject of soil nitrogen is complex and not fully understood further study is necessary before any definite conclusions can be made.

The different rates of organic carbon and total nitrogen decrease with depth for primary and secondary forest soils present some contrasting trends in their C/N ratios. For primary forest soils, C/N ratios decrease with depth as the addition of litter to the surface soil is high. Furthermore, the rate of organic carbon decrease with depth is higher than the corresponding rate of total nitrogen decrease. In the secondary forest C/N ratios increase from 11.54 (average) at the surface to 14.68 (average) in the 4-8 inch layer. This increasing ratio at a lower depth indicates that the additions of nitrogen to the already nitrogen poor subsurface soil layers are low as there is a high amount of nitrogen uptake by plants and soil micro-organisms, possible low rates of nitrification and leaching.

The decrease in organic matter with depth is accompanied by a decrease in cation exchange capacity and total exchangeable bases. The decrease in CEC and total bases with depth is rapid between surface and subsurface soils. The decrease in CEC with depth is attributed to the lower amounts of organic matter and amorphous colloids and higher amounts of saprolite found in subsurface soils.

While bases and CEC decrease with depth for most soils, Soil Sample 582 (Table VII) shows an increase in CEC, bases, and base saturation below a depth of 39 inches and may be indicative of either podzolization, a parent material other than shale or greywacke, slumping, or an unleached parent material.

An examination of the data on Tables V and VII indicates a decrease in acidity with depth for primary forest soils. However, unlike other areas of the humid tropics under high rainfall, the pH of secondary forest (and probably grassland soils) increases in acidity to a depth of 8 inches before decreasing with increasing depth. These trends in pH with depth are associated with the effects of cultivation and burning on soil organic matter and base content.

The acid surface soil of the primary forest soil at Kompiai is undoubtedly due to the high organic matter content (which results in a high amount of organic acids) and its low base content. The effect of high amounts of organic matter on soil pH seems especially evident in Soil Samples 58C and 582 (Tables V and VII) where the amounts of organic carbon of the surface soil are two to three times greater than in the subsurface soil. Soil Sample 581 (Table VI) reflects a situation where the more acid subsurface soil is due to a lower base saturation. With a decrease in organic matter, soil pH increases. Thus soils at greater depths have higher pH than the surface soils.

The trend of decreasing acidity with depth is reversed for secondary forest soils as the surface samples are less acid than the subsurface soil. The high pH of surface soils in the secondary forest are due to the higher amounts of exchangeable bases and decreased amounts of organic matter. Burning of fallow and litter releases bases from the fallow and litter and in turn decreases the litter supply necessary for humus production.

At a depth of 4-8 inches, the pH of the secondary forest soil decreases sharply before increasing again as cation exchange capacities and total bases, especially calcium and magnesium are decreased. (See Tables IX and X). At depths below 8 inches pH rises slightly.

Soil bulk densities increase with depth as organic matter decreases. For corresponding soil depths, bulk densities are higher in the secondary forest (and grasslands) than in the primary forest. At a depth of 16-20 inches the bulk density of the secondary forest soil is 1.38 (Table X). This same bulk density is found in the primary forest soil at an average depth of 55 inches (Table VII). The higher bulk density for the secondary forest soil is most probably due to the reduction of organic matter or to soil compaction, results of cultivation and burning. It is also possible that some of the secondary forest top soil has been eroded away, resulting in a total decrease of soil depth and the presence of high bulk densities at rather shallow depths. In the primary forest where the incidence of erosion is less, correspondingly high bulk densities are found at deeper depths.

CONCLUSION

In the New Guinea Highlands, shifting cultivation and burning of the vegetation affect some chemical and physical properties of soils. Soils from three adjacent vegetation formations--primary forest, secondary forest, and grasslands were sampled for pH, cation exchange capacity, total bases, organic carbon, total nitrogen and bulk density. Assuming that the soils sampled are representative of the Kompiai Maring territory and are formed under similar conditions of parent material, climate, and topography, we may conclude on the bases of soil analyses that:

1. The pH of the soil is lowest in the primary forest and highest in the secondary forest. All soils are moderately acid. Cultivation and burning release bases and decreases the organic matter content of soils which changes in turn the pH in secondary forest and grassland soils.
2. Cation exchange capacities are highest for primary forest soils and lowest in grassland soils. The high organic matter content and a probable high amorphous colloid content are reasons for the high CEC in primary forest soils. Shifting cultivation and burning decrease the CEC by decreasing the amount of organic matter and litter supply.
3. Total exchangeable bases are lowest in the primary forest soil and highest in the secondary forest soils. Burning of the primary forest litter and vegetation releases bases to the soil. Part of the increase in bases of the secondary forest and grassland soils may be due to the decrease in soil

moisture and an increase in soil temperature.

4. Organic carbon and total nitrogen percentages are highest in the primary forest and lowest in the grasslands. The high organic carbon content of primary forest soils is attributed to the lower temperature of such soils as well as abundant litter. Increases in soil temperature and burning of the litter and vegetation lead to a reduction of the organic carbon and total nitrogen contents in secondary forest and grassland soils.
5. C/N ratios decrease with cultivation and burning as a consequence of higher oxidation rates of organic matter and reduced litter supply. C/N ratios are highest in the primary forest soils as there are high amounts of organic matter and lower rates of decomposition. Grassland soils have high to moderate C/N ratios. In grasslands that are recently burned C/N ratios are high as losses of nitrogen are high or inputs of nitrogen are low. In grasslands protected from fire, C/N ratios are moderate as nitrogen contents are twice as high.
6. Bulk densities increase with cultivation and burning. Grassland soils have the highest bulk densities as the amounts of organic matter are least and the chances for soil compaction are high. However the extensive rooting system of grasses may be a factor in increasing the difficulty of working these soils.

7. Analyses of soils with respect to depth indicate that the primary forest soils decrease in acidity, total bases, cation exchange capacity, organic carbon, total nitrogen and C/N ratio with depth. Secondary forest soils are less acid at the surface and decrease in organic carbon, total nitrogen, cation exchange capacity and total bases with depth. C/N ratios of secondary forest soils increase to a depth of eight inches before decreasing again. Bulk densities for primary and secondary forest soils increase with depth. A larger sample size is necessary for conclusive results.

Thus on the basis of limited soil analyses, I have found that shifting cultivation in the Bismarck Mountains of New Guinea affects some chemical and physical properties of soils. Clearing and burning of the primary forest vegetation during garden building operations and secondary forest succession on abandoned garden sites is accompanied by an increase in base saturation, total bases, and pH and a decrease in organic carbon and total nitrogen. However conversion of the secondary forest to grassland and the perpetuation of the grassland through repeated burnings are accompanied by a decrease in exchangeable bases, organic carbon, total nitrogen, and pH. Protection of the grassland from fire may result in a succession by a woody vegetation and an increase in soil fertility.

While the old *Themeda australis* is an indicator of the relatively compact and nutrient-poor grassland soils, Clarke and Street's suggestion (1967, p. 11) that the grassland vegetation may be an active agent of degradation, remains unresolved. However, there is very little doubt that fire is an important factor in the creation and maintenance of the physically and nutriently-poor anthropogenic grassland soils.

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