Short Title

THE CLIMATE OF THE RUPUNUNI SAVANNAS

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THE CLIMATE OF THE RUPUNUNI SAVANNAS - A STUDY IN ECOLOGICAL CLIMATOLOGY

Submitted in partial fulfilment of the requirements

for the degree of Master of Science

by

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August 17th 1966.

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ACKNOWLEDGEMENTS

I am particularly indebted to Professor T. L. Hills, the Chief Investigator of the McGill University Savanna Research Project, for the opportunity to join the Project, for my three field seasons in the Rupununi and for the assistance and advice which he has extended to me throughout the study.

My special thanks are extended to Professor B. J. Garnier, my thesis adviser, for his suggestions and helpful criticism during the preparation of the text.

Thanks also go to Mr. Peter Dettering and his assistants in the Meteorological Division of the Ministry of Agriculture, Georgetown, for their continuous support and ready assistance in times of difficulty.

I wish to thank my fellow workers on the Project, Mike Eden, Robert Goodland, Nawal Sinha and Dick Kesel for their invaluable suggestions in the field.

This study would obviously have been impossible were it not for the many observers both at St. Ignatius and at the other stations who insured that accurate records were kept. Especially I wish to thank Brian Westlake and John Melville at St. Ignatius and Mr. O. V. Gaskin at Moco-Moco.

To the many others in Canada, the Caribbean and Guyana who assisted by advice or material support, I acknowledge my gratitude. Lastly, I wish to thank my Mother for having typed this thesis.

NOTE

The former colony of British Guiana became independent in May 1966 under the name Guyana. In the text the spelling 'Guyana' will be used for that country, but all references to Guiana meaning the north east of South America will retain the original spelling.

CHAPTER I

SAVANNAS AND THE RUPUNUNI

PART A: GENERAL CONSIDERATIONS

The intent of this thesis is to set out new data relating to the climate of the savanna in the Rupununi district of Guyana, and to comment thereon with reference to the causes and continuing existence of that savanna. To indicate the significance of the data and the pertinence of the comments it will be necessary to review recent discussion of the nature and causes of savanna in general.

1. THE GEOGRAPHIC RELATIONSHIPS OF THE RUPUNUNI SAVANNAS

Within Guyana there are three distinct belts of savanna. About 30 miles from the coast and extending discontinuously from the Demerara River towards the east into Suriname are the White Sand Savannas, which have been described in that country by Heyligers (1963) among others. On the southern side of the Guiana Highlands at heights of up to 3,000 ft. are the mountain savannas which extend, again in discontinuous fashion, to the west and merge into the Gran Sabana of Venezuela. To the south of the highlands and in places connected to the mountain savannas are the Far Interior Savannas of the Rupununi.

The Rupununi Savannas are in fact a small western extension of the much larger Rio Branco Savannas in the Brazilian Territorio Federale do Roraima. The total area of the Rupununi - Rio Branco Savannas is approximately 21,000 sq. miles of which the Rupununi part constitutes roughly one

MAP I.


THE CARIBBEAN
AND
SOUTH AMERICA
0°
0°
STUDY AREA
see
MAP 2
SCALE
1:44,350,000
Miles
0
700
1050
Oblique Mercator

quarter. It is also the common meeting point of two great areas of South American Savanna; the one circumscribes the Amazon Basin, beginning on Ila de Marajo in the river mouth, circles around the head waters of its tributaries, through the Campos, along the foot of the Andes, skirts the Guiana Shield, thus including the Rupununi area, and returns to the coast again in Amapá. The other forms a great arc around the Gúiana Shield, and comprises the White Sand Savannas, the Mountain and Gran Sabanas, the Rupununi - Rio Branco Savannas and the Llanos of Venezuela.

2. THEORIES ON SAVANNA FORMATION

Savanna is strictly speaking a botanical term denoting a matrix of tropical vegetation composed of a lower herbaceous layer of grasses or sedges with trees or shrubs interspesed within it at varying densities. The term is as old as the 16th century in English, referring to the treeless plains of South America, and derives from the Spanish Zavana, Cavana, which itself is probably of Carib origin. Classifications and descriptions of savanna generally emphasize the arboreal layer either by referring to its density (as in the Brazilian system of Campo cerado, Campo sujo and Campo limpo) or by naming the savanna after the dominant tree species. These two view-points reflect a basic difference of approach and at a recent conference[1] it became apparent that they will not rapidly be reconciled.

To complicate the matter further, savanna is no longer limited

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1. IGU-UNESCO Conference on the Forest/Savanna Boundary (Caracas 1964) Committee on Delimitation and Classification.

to being only a botanical term but is now used in conjunction with other aspects of the physical and cultural environments of these areas, such as climate, soils, hydrological conditions and agriculture, conjuring up for those who introduce them special connotations reaching far beyond those of a plant matrix, in a manner which is frequently unjustified. Hills (1964) summarizing the literature on this point, has suggested that the following statement on vegetation is acceptable to the majority of researchers:

> "The savanna is a plant formation of tropical regions, comprising a virtually continuous ecologically dominant stratum of more or less xeromorphic plants, of which herbaceous plants, especially grasses and sedges, are frequently the principal, and occasionally, the only components, although woody plants often of the dimensions of trees or palms generally occur and are present in varying densities". (page 218)

He also tabulates several classifications of savanna types including that developed by the McGill University Savanna Research Project. It is this last classification which will be employed in this thesis.

TABLE 1

MUSRP Classification of Savanna Vegetation

Type	Woodland and/or Forest type	Parkland type	Grassland type	Shrub type
MUSRP designation	Savanna-woodland	Open savanna-woodland	Herbaceous savanna (a) grass dominant (b) sedge dominant	Shrub savanna

Physical, as opposed to cultural, theories on savanna formation may be divided into two groups, those that deal with some aspect of moisture relationships, and those that consider soil and geomorphology. The first group of theories has grown out of the early climatic theories presented by Bews (1929) and Myers (1936) and reiterated more recently by Bates (1948) and Miller (1961). These views note that a climate consisting of torrentially heavy rain for five months of the year and almost total dessication for the remainder, cannot be conducive to the growth of rain forest species. Thus the special xerophytes of the savanna have evolved to accommodate this climate. A later adjunct to this theory has taken particular note of the adverse edaphic conditions that prevail throughout most savanna lands. It does not seem possible for any soil to adapt satisfactorily to both the wet and dry seasons, for soils which are well drained in the wet phase are totally dessicated within a month of its termination, whereas soils which manage to remain moist throughout the dry phase, are waterlogged in the wet season. Waterlogging can be just as harmful for non-aquatic plants as drought can be for non-xerophytes, since it deprives them of oxygen and this induces physiological drought. In many areas this waterlogging results not so much from the inability of the soil to infiltrate all the moisture it receives, but from the flooding of neighbouring rivers and creeks which are quite unable to cope with the run-off they receive. Denevan (1964), for example, has proposed this theory with justification for parts of the Llanas, Pantanal and Mojos Savannas. Thus only those plants which are essentially xerophytic or resist physiological drought due to flooding can survive in these soils and this gives rise to the savanna-type grass and sedge vegetation.

The second group of theories is particularly concerned with soil characteristics and geomorphological conditions. It has been long recognized that the soil in savanna regions is seriously impoverished, and that in many cases this is not due to leaching alone, but also to senility. Thus as successive cycles of erosion renew the soil matrix, the geomorphic stage of a site becomes an extremely important factor, as Cole has demonstrated in Brazil. Puri (1964) has suggested that, due to the closed cycle of tropical vegetation and to the fact that tropical plants carry most of their energy above the ground, they can so denude the soil of all nutrients as to make it not only sterile, but also toxic by their excretion of trace elements. Fosburg commented at the Venezuelan conference (1964) that similar evidence is coming to light in Hawaii.

The cultural group of theories takes into primary account the results of human activities in these areas. Workers in all fields have noted the great influence that man can have in altering the natural vegetation and some have postulated this as an explanation for the existence of savannas. Slash and burn, or shifting agriculture in an area experiencing population pressure can gravely disturb the closed cycle of tropical vegetation to the point where the original forest species are no longer able to regenerate, and the area is colonized by the less demanding savanna grasses and trees. Besides practicing the subsistence agriculture along, or just within the forest edge, man in the savanna perennially burns the grass to improve its grazing quality for his livestock, to reduce the fire hazard around his dwelling, or just for the pleasure of watching it burn. In some cases these fires penetrate into the forest and may, over a period of many years, cause it to retreat, but as E. Foldats (personal communication 1964) observed, there is usually a narrow band of fire-resistant savanna tree species along the forest edge which prevents the fire from entering. If these fires do not advance the savanna into the forest they certainly preclude any extension of forest into the savanna by destroying the pyrophitically unadapted forest seedlings attempting to grow in the open. Man's cattle also perform a similar function, particularly if the range is overstocked, for they eat and trample seedlings from both forest and savanna trees and thus cause a degeneration in the quality of the vegetation.

It would be wrong to suggest either that any of these theories has no application or that any one of them points to the universal cause of the savanna phenomenon. The explanation of a problem such as the causes of the savannas can only be attempted by using a holistic approach which employs not only the findings of different disciplines but also uses the relationships between them. The concept of savanna as an ecosystem, that is, a view of these areas as an ecological whole and one which recognizes the relevance of all the theories outlined above, is such an approach and in this thesis its main ideas will be freely employed.

PART B: THE ECOLOGICAL VARIABLES

The foregoing discussion of possible origins and causes of savanna have emphasized certain ecological factors that are felt by most workers to be relevant to the savanna problem. In the following section each of these variables will be discussed in the Rupununi context, before presenting the thoughts of previous authors on the evolution of these savannas.

1. THE CLIMATIC SEASONS

Anyone, from the earliest investigators to those of the present day, who enquires into any relationship in the savannas, is immediately aware of the paramount importance of the climatic seasons. The climate of the Rupununi Savannas comprises a dry and a wet season, the former of seven months and the latter of the remaining five. During the wet season 124.36 cms. of rain falls over a period of between 90 and 120 days. This is 83% of a yearly average total of 161.80 cms. There are occasional groups of 3 to 5 days in the wet season when rain does not fall, but, as these tend to occur near the beginning or end of the period, the overall impression is of a 3 or 4 month period when rain falls daily. In a similar manner the dry season consists of long rainless spells divided by groups of 3 - 5 days on which rainfall occurs, but while these are more common at the beginning, they are not necessarily more prevalent towards the end of the season.

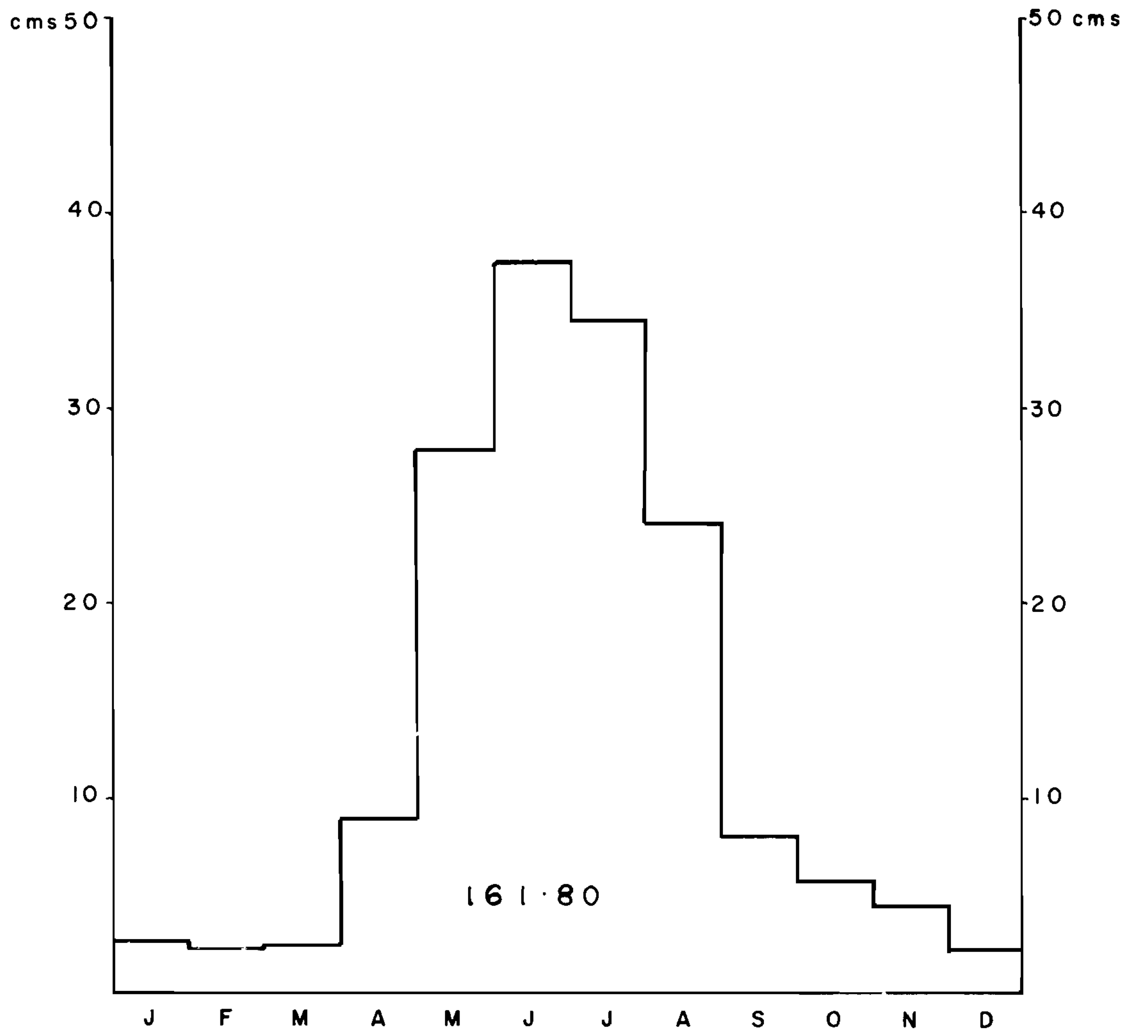
The exact manner in which this change of seasons is controlled by the movement of the Inter Tropical Convergence Zone (ITCZ) will be discussed at length later, but as this zone does not move north or south continuously in its seasonal migration, but rather, at any one time fluctuates north and south about its mean position for that period, it is obvious that an exact division of the seasons is difficult. For this reason it is equally difficult to recognize, on purely climatological grounds any definite intermediate seasons. Consideration of the average rainfall graph (Fig. 1) suggests that April and September are of such

FIG. I

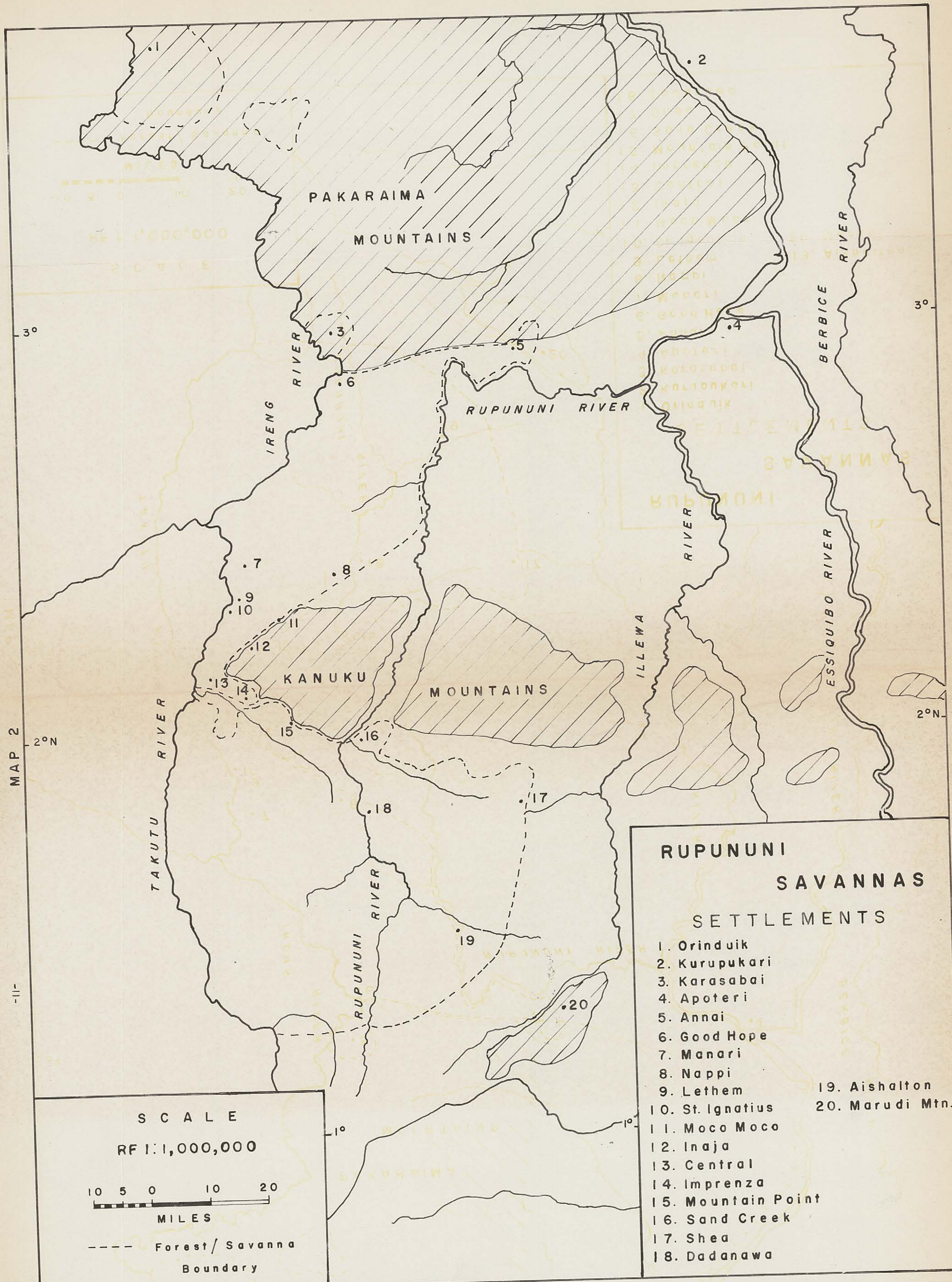
ST. IGNATIUS, RUPUNUNI

MEAN ANNUAL RAINFALL

(1930-1965)



MAP 2


PAKARAIMA
MOUNTAINS
KANUKU
MOUNTAINS
IRENG RIVER
RUPUNUNI RIVER
BERBICE RIVER
ESSIQUIBO RIVER
ILLEWA RIVER
TAKUTU RIVER
RUPUNUNI RIVER
3°
2°N
1°
RUPUNUNI
SAVANNAS
SETTLEMENTS
1. Orinduik
2. Kurupukari
3. Karasabai
4. Apoteri
5. Annai
6. Good Hope
7. Manari
8. Nappi
9. Lethem
10. St. Ignatius
11. Moco Moco
12. Inaja
13. Central
14. Imprenza
15. Mountain Point
16. Sand Creek
17. Shea
18. Dadanawa
19. Aishalton
20. Marudi Mtn.
SCALE
RF 1:1,000,000
10 5 0 10 20
MILES
Forest/ Savanna Boundary

an intermediate nature, but this is more a reflection of considerable variation in the opening and closing dates of the wet season than of the existence of a true intermediate season. Indeed it is probably more correct to regard December and January as a potentially intermediate season, for during these months the coast of the Guyanas and the interior of Suriname experience a second wet season that can just be recognized in the rainfall records at Annai on the edge of the savannas. If this second wet season is severe it can considerably affect the savannas, for St. Ignatius recorded over 9 ins. in December 1942.

Other climatological parameters, however, respond to the two-season division of the year in the expected manner, such as, for example, temperature which is 6°F. cooler in the wet season than in the dry. As, however, the diurnal variation is closer to 18°F. at all times of the year, this seasonal variation cannot be considered of very great importance.

2. PHYSIOGRAPHY AND DRAINAGE

The Rupununi - Rio Branco Savannas correspond with the widespread opinion that savannas are flat and low lying, being between 300 and 500 ft. and having low local relief. The surrounding areas are considerably higher by some 500 ft. to 3,000 ft. except in the north east and south south west, where the two main rivers leave the basin to join the Essequibo and Amazon systems respectively. To the north and west the Pakaraima Mountains, the southern edge of the Guiana Shield, form the boundary, rising abruptly 3,000 ft. from the savanna surface. The vegetation does not adhere rigidly to the demarcation line, but interdigitates forest and savanna up mountains or valleys in random fashion.

Elsewhere the boundary generally corresponds with the gentle escarpment of the 1,000 ft. level which can be identified generally throughout north-eastern South America.

The Rupununi Savannas are separated from the Rio Branco Savannas by the line of the Ireng and Takutu Rivers, which together with the Uraricuera form the Rio Branco itself. The savannas, are, however, virtually bisected by a disconnected portion of the Pakaraima Mountains, the Kanukus, which are roughly wedge shaped, intruding from the east with the major apex lying less than three miles from the Takutu River. They extend about 100 miles to the east towards the Ilewa and Essequibo Rivers where owing to lack of survey their exact end is not known. Between the Pakaraimas and the Kanukus lies the North Rupununi Graben, a deep trough, 50 miles wide and lying fractionally north of east in orientation. Dated by Sinha (1966) as mid-Mesozoic, it was originally filled by marine sediments. These now form the Takutu shales which, after uplift, were reduced to a surface at the 300 - 320 ft. level, which can be clearly seen in river channels at low water. Sinha has named this the Takutu Planation Surface and has proposed that a large west to east flowing river, the forerunner of the Proto-Berbice, was the major agent in its formation.

Subsequently the planation surface was covered by a layer of sand, clays and lateritic gravels, washed down from the 1,000 ft. surface, to depths of over 200 ft. At this time the major river in the area was the Proto-Berbice, rising in Brazil, flowing from west to east along the Pakaraima edge of the Northern Rupununi Graben, and entering the Atlantic either along the course of the present day Berbice or the courses of the

Essequibo or Courantyne Rivers. The Proto-Berbice actively eroded the deposits along the Pakaraima front, so that today the shales in these areas are close to the surface, but left undisturbed the deposits abutting on the Kanukus. Today these deposits are laterized to depths of 200 ft., far deeper than could possibly occur under present hydraulic conditions. Sinha has therefore proposed that it was the progressive lowering in regional base level by the Proto-Berbice that has caused the deep laterization and he has dated the initiation of this process at the close of the Pliocene. Once concreted, the sediments resisted erosion and today form a rolling landscape of alternating laterite ridges and sand-filled hollows that culminate in the remains of the original surface near Maracanata.

The present drainage network results from the capture of the head-waters of the Proto-Berbice by the Rio Branco in the mid-Pleistocene. The initial capture affected the Surumu River in Brazil but later the Takutu and most recently the Ireng joined the Amazon system. Today the process is still unfinished with the Rupununi savannas occupying the indistinct divide between the Rio Branco and Essequibo systems. Indeed during the wet season there is reason to doubt that a divide exists at all. The Rego Creek furnishes an example of the ill-adjusted nature of the tributaries for it rises within three miles of the Ireng but flows more than 50 miles to its confluence with the Rupununi River not far from Annai.

Although no study, comparable to Sinha's on the north savanna, has yet been undertaken, it is obvious that the south savanna is quite different in geomorphic character. There are similarities, however, for the south savanna is bounded in a similar fashion by the southern flank of the Kanukus to the north and by the edge of the 1,000 ft. surface to the east and south. It is also drained by the same rivers for both the Rupununi and Takutu Rivers have their head waters either within or just beyond the south savannas. The Takutu flows northward beside the western point of the Kanukus but the Rupununi lying further to the east traverses the mountains in a narrow valley emerging some 25 miles south of Yupukari. There is also a very small section, close to Shea Village which is drained by tributaries of the Ilewa River, another part of the Essequibo's extensive west bank system.

The country of the south is rolling but in a different fashion from that of the north, for the undulations are more gentle and further apart, with the ridges formed of granitic bedrock and frequently quartz cobbles occur. Throughout the south, bedrock is close to the surface suggesting that the orogeny which produced the North Rupununi Graben cannot have disturbed the south or else it produced different results. The landscape is totally dominated by inselbergs that rise, forest covered, directly out of the savannas to heights of over 1,000 ft. Most of them are congregated around the forest boundary but there are some, such as Shiriri, which rise to as high as 3,000 ft. in the open savanna. These can be seen stretching into Brazil as discontinuous extensions of the Kanuku Mountains and also into the forest to the east, rising in fantastic shapes (for example Bottle Mountain) to over 2,000 ft. These and other evidences suggest that a multi-cycle process has formed the landscape but it is not/yet possible to define its range or activities.

In both the north and south savannas it is apparent that a new cycle of erosion has commenced. The major streams are deeply incized, and this permits their level to rise and fall by 35 ft. without their directly overflowing their banks, as they did previously according to the terrace evidence. Nevertheless, the total drainage network is inadequate in the wet season for lakes and ponds develop in the hollows, and tributary streams which have not yet rejuvenated flood extensive areas.

3. SOIL AND SOIL MOISTURE

It is scarcely correct to refer to the laterite ridges of the north savanna as soil for they are over 80% lateritic gravels and cobbles. The remainder is a grey sand that turns to yellow at depth but the top 10 cms. of ridges with large gravels are devoid of any sand at all. Thus all the ridges are highly porous, with low field capacities, and never become waterlogged.

By contrast the flats between the ridges are filled with sandy clay that has been washed down from them. This material is far more compact, forming hard pans, and these can give rise to perched water tables. During the wet season it is common for the larger flats to become inundated, while the smaller ones remain waterlogged or slightly flooded for a few days after prolonged heavy rain. Although these soils have a greater field capacity than the laterite ridges, it is insufficient to carry unadapted plants through the dry season without moisture deficiency.

The soils of the Maracanata lowland are similar, being sandy silts and clays, pale in colour near the surface but yellowing with depth. The water table fluctuations and the flooding promote the lateritic process throughout all the savannas, but it is most marked in this area with iron and manganese concretions occurring at 1½ to 2 metres depth. Due to the inadequate drainage network these areas are flooded for two to three months during a normal wet season and the profile is waterlogged for still longer periods. Their field capacity is similar to that of the depressions between the ridges, and is insufficient to last throughout the dry season.

In the south savanna conditions in between the ridges and in the flatter, low-lying areas are very similar, with low infiltration rates and a poorly developed drainage system combining to cause prolonged waterlogging and flooding. The ridges are different from those in the north, however, as unlike them, they do not have better infiltration rates than the adjacent flats. Run-off is, therefore, more severe, aggravating the problems in the hollows and there is evidence that a layer of laterization two metres below the surface acts as a partial impedance layer[2]. Both in the hollows and in the ridges, field capacities are inadequate for the length and severity of the dry season.

In both savannas some of the higher ridges are still capped with lateritic material from the 500 and 1000 ft. surfaces. Due to its greater age, this material has developed a structure and has far better field capacity, permitting plants to withdraw sufficient water for the entire dry season.

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2. Field observations - Eden and Frost, September 1965.

4. VEGETATION

Man's activities within the forest close to the savanna boundary have reduced it from its original primary state to secondary and regrowth vegetation. It is, however, quite certain that in its original condition it was not the tropical rain forest associated with the Amazon, but was woodland of a more xeric nature due to the dessicatory effects of the dry season. Fanshawe (1952) has described the forest in the Pakaraima Mountains as Dry Evergreen and that of the Kanukus as Montane.

In the open savanna, bunch grasses such as *Tracypogon plumosis* and *Andropogon angustatus* cover between 40 and 60% of the surface, the rest being unvegetated. In regions having wetter moisture regimes, these grasses are replaced by sedges, *Bulbostylis* spp. and *Fimbristylis* spp. in the dryer areas, and *Rhynchospora* spp. and *Stinophyllis* spp. in the swamps, (Goodland 1964). The trees of the savanna are both xerophytic and pyrophitic with extensive root systems, thick leaves and rough deep bark. The most common species is *Curatella americana* but others such as *Byrsonima crassifolia*, *Bowdichia virgilioides* and *Plumeria inodora* are common, but more restricted in location. During the dry season the grasses wither and appear to die, but after a brief shower come to life and continue growing while water is available. It is far more difficult to determine whether the savanna trees continue to transpire during this period, but work by Vareschi in Venezuela suggests that they do, although his results have been questioned because the Piché evaporimeter he used is not well suited to the task.

Eden, among others, has suggested that Curatella is able to tap ground water at depths of 4 to 6 metres by means of a deep tap root, but excavation of two sample trees failed to produce any such roots below 1 metre[3].

The distribution of trees within the savanna can take several forms. One of the more common types so closely resembles an apple orchard, with sizable trees, 3 metres high and 4 - 5 metres in diameter, at a regular spacing, that some workers have named it orchard savanna although, in the classification adopted above (page 4) it is a form of open savanna woodland. The other common form within this same type has trees of all sizes irregularly scattered, but in places forming a small clump around one or two larger trees. Eden has suggested that they be called matas, the Venezuelan word for bush island, to distinguish them from the larger tree congregations discussed below.

Savanna woodland, where the trees are so close together and of such height and diameter that they cover more ground than does the herbaceous layer, is found in only one location, between the western tip of the Kanuku Mountains and the Takutu River. At the other end of the scale, herbaceous savanna and shrub savanna are very common, both in areas which are excessively well drained or which are seasonally flooded. In some cases the woody species are true shrubs, usually Psidium spp. or Randia, but just as frequently they are the common savanna trees suffering from excessive coppicing. Puri, discussing this problem in the field, suggested that repeated destruction of the young saplings by

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3. Observation by Eden and Frost, 1965. This result was confirmed by staff members of the St. Ignatius Livestock Station who had removed many such trees while clearing their paddocks.

fire is responsible, although others pointed out that under other circumstances trampling by cattle can have the same result.

Bush islands, varying in size from a few acres to several square miles, are composed of vegetation that is common to neither the surrounding savanna nor the nearby forest. Basically the trees are more adapted xerophytically than those of the forest but less so than savanna species, although Myers (1936) has identified Myrtaceae and Leguminosae in both forest and bush islands. In the Rupununi bush islands are found on top of the higher ridges or surfaces, and around the inselberg forms of the south. As Foldats has observed they are frequently ringed by fire-resistant savanna trees, which prevent savanna fires from penetrating into the islands on a regular basis. An explanation for the occurrence of these bush islands will be presented later.

Distinctive vegetation occurs in swamps and beside river courses in response to differing hydraulic conditions. In swamps the grasses die out and are replaced by sedges while the savanna trees give way to palms, mauritia minor being the major variety. If the watercourse is ill defined, being in fact little more than a linear swamp, the location of the stream will be marked by a line of palms on either bank, but, if the stream is in a well defined channel and remains flowing well into the dry season, extensive galerias form, sometimes more than 100 yards wide. Goodland (1964) describes these galerias as being composed of forest trees along with palms and bamboo, while Myers (1936) likened them to a monsoon forest. A similar situation is found beside the major entrenched rivers. In all cases in the Rupununi these galerias form in response to the moister conditions obtaining during the wet season, but in other savannas, such as the lower Llanos, they develop on levées where the seasonal flooding is less severe.

It has been mentioned previously that the edge of the savanna where it conforms with the foot of the Pakaraima Mountains does not adhere rigidly to that line. In most cases along the Pakaraima edge, savanna extends into the mountains in some places up valleys in others up the mountains themselves. In very few cases does the forest extend out into the lowlands. It is noticeable in the area of Lake Moreiru that the smaller ridges and peaks disconnected from the main mountain mass have savanna on their southern sides, but dry forest vegetation on their northern slopes. A similar intrusion of savanna from the lowlands into the mountains can be seen along the southern flanks of the Kanuku Mountains especially in the area around Mountain Point. The northern edge of the Kanukus presents a different picture, however, for savanna does not extend up onto the mountain slopes. Instead forest vegetation extends into the lowlands in several places, particularly where several sizable streams leave the mountains in close proximity to each other. In these cases the area between the galerias has been filled by tree species associated with the contiguous montane forests. An example of such an area can be seen in the left bank of the Moco-Moco Creek as it leaves the mountains. In most other areas it is noticeable that the forest extends some few hundred yards from the base of the mountains onto the level savanna surface.

5. MAN AND FIRE

Most of the savanna is held in grazing permissions by 10 to 15 relatively wealthy ranchers, for the soils are sterile agriculturally without large scale fertilization. The cattle affect the savanna directly as a result of selective grazing and of trampling, as noted by Waddell (1963), but far more damage results from man's habit of burning the savanna. Almost all of the ranchers deliberately burn their land at least once during the dry season to improve the grass by removing the dead material and allowing new shoots to spring up after the next rain shower. Theoretically this should gradually eliminate the more succulent grasses to the advantage of the pyrophitic bunch grasses. However, Hewson[4] was unable to find any evidence that this was so today, although he did not discount the possibility of such changes having been the effect of savanna burning in the past.

The savanna trees are also being rapidly changed by anthropic influences, for the leaves of the ité palm (_Mauritia minor_) are used to thatch houses and, although they are protected by law, Goodland reports that they are becoming noticeably more scarce. In addition, there are the effects of man's constant need of fuel. In the area of Lethem - St. Ignatius, for example, trees suitable for firewood, _byrsonemia_ particularly, have almost vanished for five or six miles around the town site over the last three years.

Subsistence, shifting agriculture is practiced along almost the entire length of the forest/savanna boundary and in the major bush

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4. R. H. Hewson, Agronomist, St. Ignatius Livestock Station (1964) Personal communication.

islands. The manner in which savanna may extend into the forest as a result of man's agricultural activities has been discussed previously[5] and, while there are several areas particularly along the southern flanks of the Kanuku Mountains where this encroachment appears to have taken place, in actual fact an examination of two series of aerial photography ten years apart has not in fact produced any evidence of a shift in the boundary (Hills, personal communication). There are, however, areas where the fallow period is being seriously shortened, notably in the Sororiwau Bush Islands, and there is a consensus of opinion among the more responsible inhabitants of the savannas that as a result of the farming methods employed the soil will soon become too infertile to support the present population. If the vegetation is at all unstable in such conditions there is potential for a change.

PART C: THEORIES ON THE RUPUNUNI

The most recent studies on the evolution of the Rupununi Savannas are contained in the four theses of the McGill University Savanna Research Project submitted by Waddell (1963), Eden (1964), Goodland (1965) and Sinha (1966). It is unfortunate that only Waddell's treats the South Savanna with anything approaching the detail devoted to the North.

Waddell investigated the anthropic factor and concluded that if the forest was in a state of potential imbalance pre-columbian man was present in sufficient numbers and with adequate tools to have caused the savanna to be established. In support of this hypothesis he cites the

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5. See page 6 above.

delicacy of the closed nutrient-cycle and the snowball-effect on adverse micro-climatic factors once a clearing has been established. He further claims to have evidence of the advance and retreat of the forest due to anthropic factors. He does not, however, claim that the forest was in fact in this state of potential imbalance and recommends further detailed study of the physical environment particularly in and around cultivated sites[6].

It is certainly true that in some areas man has pushed back the savanna-forect boundary by encroachment on the woodlands, but the area north of Shea Village where he suggests the forest is advancing due to lack of anthropic interference is more difficult to interpret. Eden and the author visited the area briefly in September 1965 and concluded that although the forest might indeed be advancing, it was more probably due to geomorphic changes. The area, being drained by tributaries of the Ilewa River, lies at a lower level and the vegetation shows signs of severe seasonal flooding.

Eden's work on soil moisture has presented an acceptable theory for the distribution of the savanna vegetation in response to the respective severities of dry season dessication and wet season physiological drought. The duration of these phases was directly identified with their location on the catena from ridge to sandy flat. He also pointed out that the savanna boundary closely approximates a break in relief for almost its entire length, suggesting that the particular stage in geomorphic evolution was the over-riding factor slightly modified

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6. See page 192.

in places by anthropic influences.

Goodland in his phytosociological study, while not disputing the work of Waddell and Eden, suggests that the savanna vegetation is well adapted to its moisture regime by the dual processes of xeromorphism for the dessicatory effects of the dry season, and oligatrophic scleramorphism (proposed by Arens 1958), for waterlogging and flooding during the rains. He further states that any adaptations either required or taking place in the vegetation are in response to fire. For these reasons he postulates that the savanna as it is presently constituted is a balanced ecosystem. He concludes by suggesting that the savannas are relics of much larger ones that existed during the last glacial period and that anthropic activity is the major element preventing regrowth of the forest.

Sinha (1966) discussing the geomorphic evolution of the Northern Rupununi has again emphasized the importance of the geomorphic stage and has presented a theory for the evolution of forest into savanna. He observes that the bush islands and the forest to the east of the Rupununi River are on top of the 500 feet surface. This surface is capped with laterite forming an aquifer that can sustain forest trees through the dry season. It is the destruction of the laterite massifs and the draining of the aquifers beneath that has permitted savanna species to colonize these areas and form small savannas in the forest to the east. Investigations by Eden accompanied by the author in the south savannas, suggest a similar system applies there also but with reference to the 1000 ft. surface.

All of the theses described above mention the overall importance of climate, although they may regard it as a predisposing, a causal or a maintaining factor in the savanna ecosystem. The present author favours a predisposing role for climate which, together with low soil moisture capacity, is the cause of the savannas. It is felt, however, that in certain areas there may be changes in climate such that either the effects of the adverse soil moisture capacity of the lowland surface are overcome or changes such that the increased capacity of the upland soils is nullified. In this case climate will directly influence the location of the forest savanna boundary. If this contention is to be investigated the moisture conditions of the savanna must be thoroughly understood and quantified. Chapter II is devoted to this end.

Chapter III compares the moisture conditions of the windward face of the Kanuku Mountains with that of the savannas because it is felt that the mountain area is wetter. Here the forest savanna boundary lies a little into the lowlands from the mountain front implying that moisture conditions are improved for at least a small distance. Furthermore the laterite required in Sinha's theory is not present and there is evidence that anthropic factors have pushed the forest closer to the mountains in the last hundred years[7]. These circumstances favour a climatic explanation for the boundary.

A second micro-situation is considered in Chapter IV but in this case a decrease in rainfall and available moisture is postulated. This situation is in the lee of the Pakaraima Mountains to the north of the

7. R. Kesel - Personal communication 1966.

North Savanna and possibly in the lee of the Kanuku Mountains in the South Savanna. In both cases savanna vegetation extends up onto the flanks of the mountains while forest vegetation does not extend onto the lowlands.

It is anticipated that these micro-studies will cast light on the influence of climate upon the savanna in general and the location of the forest savanna boundary in particular.

CHAPTER II

THE GENERAL CLIMATE OF THE SAVANNAS

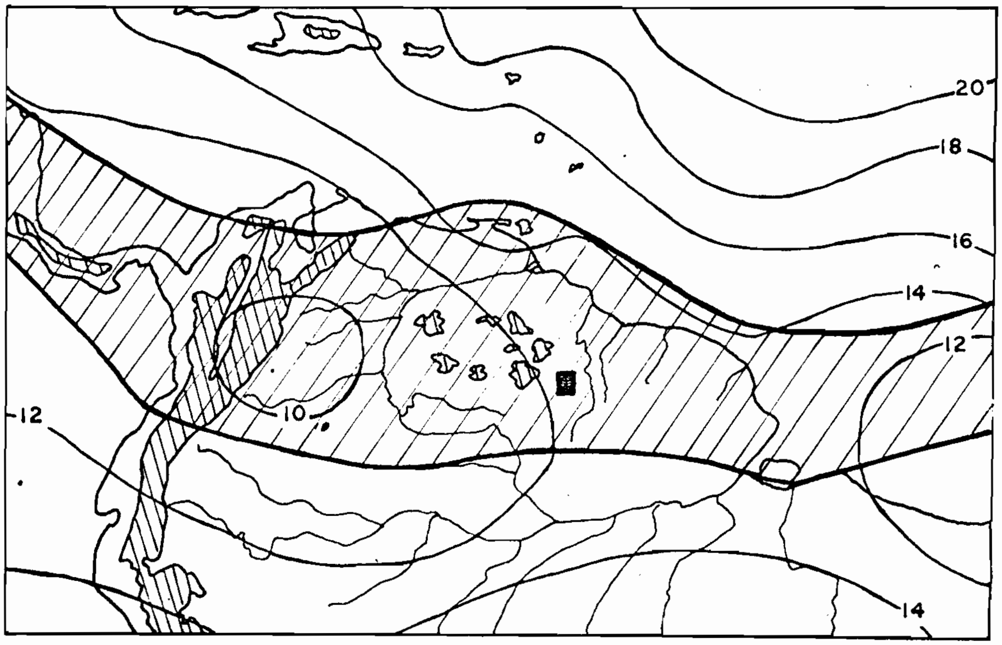
The preceding discussion has indicated that in the Rupununi Savannas an understanding of moisture conditions is of paramount importance for a study not only of the climate but indeed of any facet of the savanna ecosystem. Thus the discussion of the physical climate will examine all of the climatic perameters from the viewpoint of their influence on the hydrological cycle and then combine them into a water balance study which will permit an accurate assessment of moisture conditions. Before this can be undertaken, however, it is necessary to discuss the dynamic climatology of the region so that the rest, especially the differences between the two seasons of the year, can be seen in correct perspective.

THE DYNAMIC CLIMATE

It has been stated above (page 8) that the climatic seasons are caused by the annual migration north and south of the Inter Tropical Convergence Zone. Such a statement is a simplification of the situation. Rather it should be said that throughout the year the area is covered by moist air but that only at certain times of year are other conditions present to make the moisture precipitate. These conditions are present in a broad band of air some 300 miles wide which has been identified by the meteorologists in Trinidad as the ITCZ. It has been so named because it is the general area in which the NE and SE Trades meet and it has been suggested that it is this meeting which causes

MAP 3

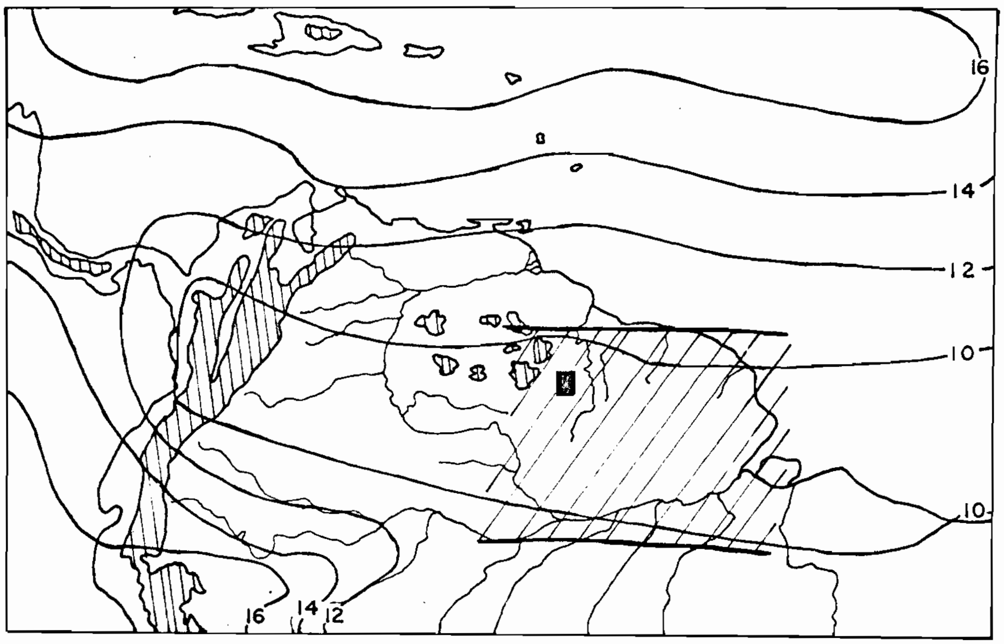
WET SEASON SITUATION



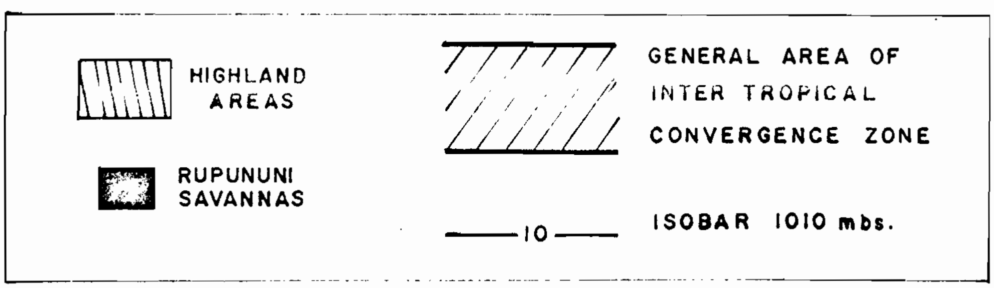
5/6/63

MAP 4

2 nd WET SEASON SITUATION



25/1/65



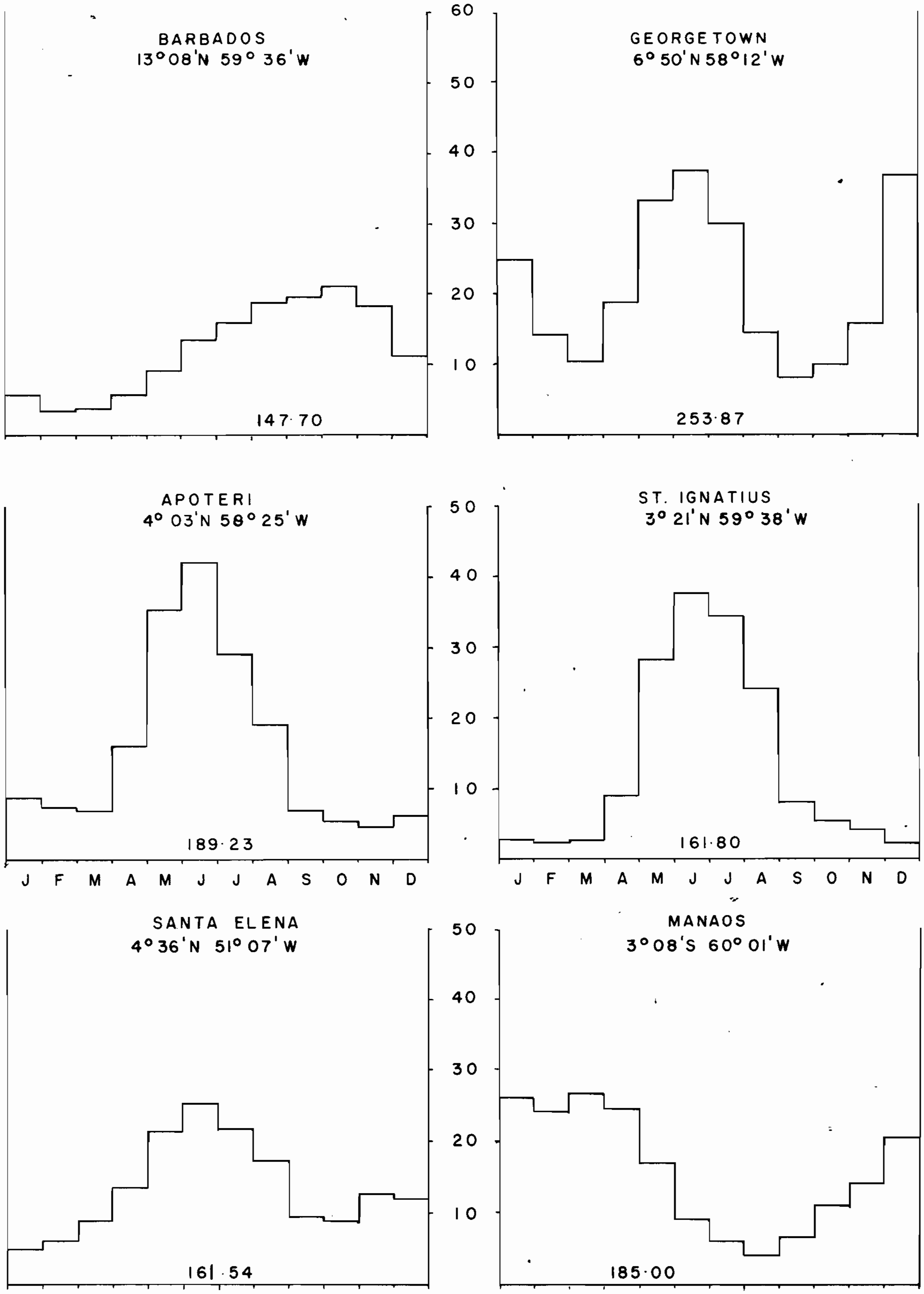
the special rain-making conditions. (See Flohn 1960 for a sophisticated presentation of this point of view). Thus the author wishes it to be realized that in the following discussion ITCZ will refer to this broad area in which precipitation occurs and will have no other connotations. The description of the movements of the ITCZ presented below is based on a study of synoptic charts prepared by the Trinidad Meteorological Office for NE South America.

The ITCZ moves once to the north of the equator and once to the south of it each year, following the movements of the sun and heat equator. Thus in April and May it moves to the north from its previous position south of the equator and it initiates the wet season in the Rupununi as it covers the area. It is recognized that the Zone does not merely move once north and once south but that rather it oscillates about its mean position. Thus the beginning of the wet season frequently lasts for a week or two with wet and dry days alternating. This impression is heightened by the fact that most of the rain falls at night during this period (see Fig. 8). By the beginning of June the ITCZ has extended north of the Guyana coast and the whole region is covered by rainy weather. During June and July, while the Rupununi is covered by the central portion of the ITCZ (see map 3) the oscillations of the Zone are not usually great enough to provide more than three or four clear days.

In August and September the ITCZ resumes or speeds up its movement to the north. The delay in doing so may be attributable to the more gradual warming of the Caribbean Sea. In the Rupununi dry days become increasingly interspersed among the wet days until suddenly the wet days

FIG. 2

RAINFALL AT SELECTED STATIONS



are up to 10 or 14 days apart. This is the end of the wet season. It is important to note that it is caused by the ITCZ moving to the north, not to the south as had previously been postulated[1]. The Rupununi remains within humid air (see section on humidity below) but the mechanism required to make it precipitate is no longer present.

In December and January the ITCZ returns to the south and again covers the region of NE South America with a wide belt of rains. During these months many stations receive monthly rainfalls that are comparable to those experienced in the major wet season (see Fig. 2, Georgetown). However, because it only lasts for two months this wet season is referred to as the 'Second Wet Season'. It is essentially similar in form to the main wet season and it closes in much the same way but as the ITCZ moves to the south. After the passage of the Zone the region is still covered by humid air although it is a little less moist than that on the south side of the ITCZ (see Fig. 15 below). Thus the full annual cycle of the climate has turned and the dry season will end in April and May as the ITCZ again moves to the north.

The Rupununi, however, does not fit precisely into this pattern, because, as is already apparent, it does not experience a second wet season in December and January. Fig. 2 has rainfall graphs for various stations around the Rupununi to illustrate the peculiarity of this omission. Nevertheless the vapour pressure at St. Ignatius (see page 55 below) remains high from the close of the wet season until January implying that by some means the ITCZ does cross the Rupununi but without giving any rain. Map 4 is included to emphasize that the synoptic

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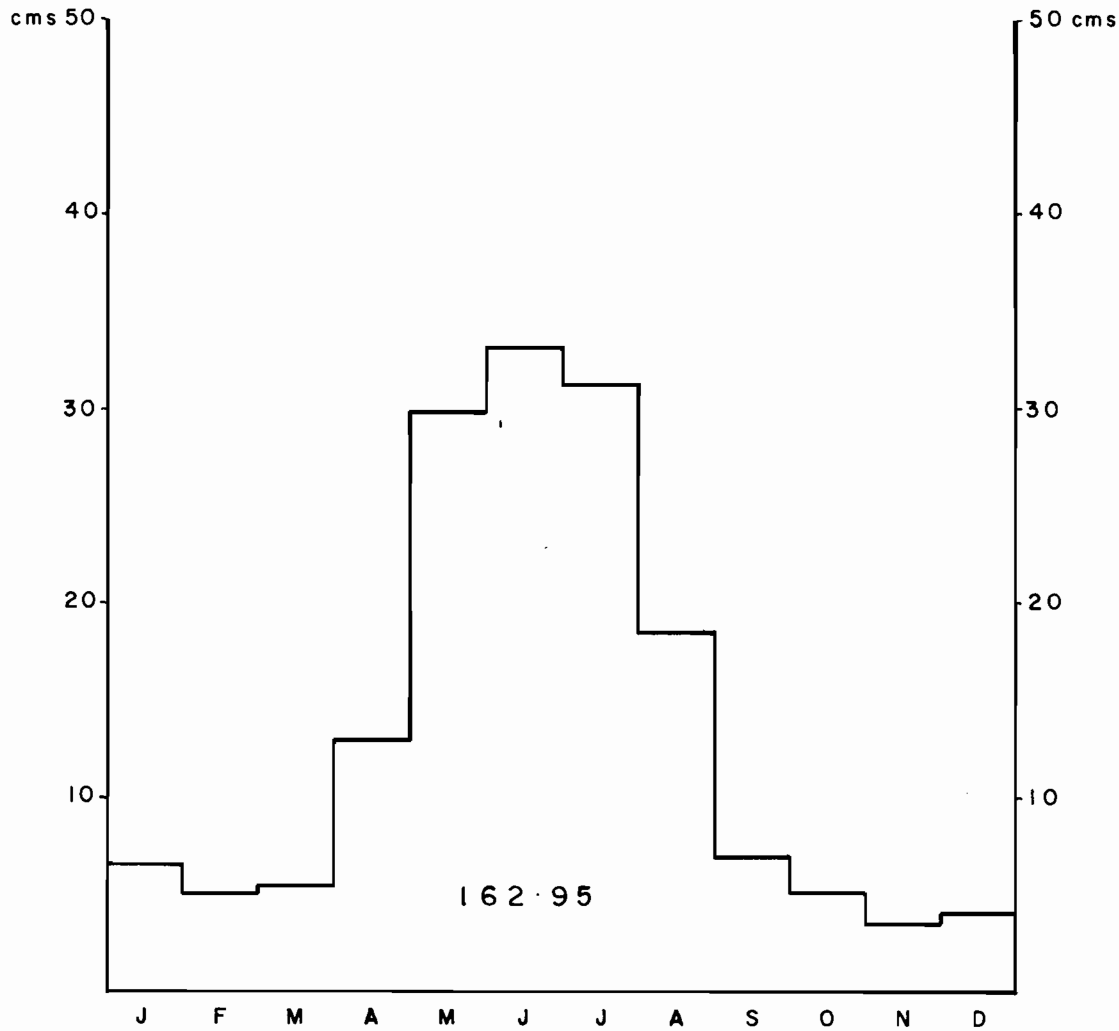
1. See both Eden (1964), and also Frost (1964) unpublished Undergraduate Thesis, McGill University entitled 'Climate and the Rupununi Savannas'.

FIG. 3

ANNAI, RUPUNUNI

MEAN ANNUAL RAINFALL

(1930-1965)



meteorologists believe the ITCZ to be present over the Rupununi but not causing rain in its usual fashion.

It goes virtually without saying that were the Rupununi to experience a second wet season plant moisture conditions would be so changed that different vegetation would almost certainly result. Therefore this peculiar circumstance must be explained; several possible causes exist. In other parts of the world the ITCZ is observed to split in two and such a development could possibly give rise to the observed pattern. Also Alaka (1964) mentions that there is evidence suggesting that the ITCZ may jump from one place to another without passing through intermediate locations. The present author does not favour either of these ideas because stations surrounding the Rupununi do receive the second wet season and also because the ITCZ as here defined is too large and amorphous. Instead a more simple solution is considered responsible.

If convergence is ultimately responsible for the rainy conditions within the ITCZ a mechanism must be proposed that would cancel it out to explain the lack of rainfall. The mass of the Guiana Highlands lying to the north of the Rupununi could provide sufficient directional divergence to do so and bearing in mind the rainfall regimes of Apoteri and Annai (see Figs. 2 and 3), where the effects of the second wet season are slightly visible, such a solution seems likely. Furthermore such an explanation has been proposed for a similar situation in Africa where directional divergence around the Abyssinian Highlands is thought to be responsible for the dry area of the Horn of Africa (Flohn 1963).

Obviously the preceding discussion is superficial, leaving almost untouched any description of day to day changes in the position of the ITCZ and their meteorological effects. Not only would such matters be generally irrelevant to the main arguments below but also meteorological data are so scanty that any discussion would be largely speculation. It is hoped that sufficient has been shown, however, to explain the climatic seasons and a satisfactory explanation has been postulated for the occurrence of only one wet season. Thus the discussion can now turn to an appreciation of the elements of the physical climate, culminating in a discussion of the water balance.

THE PHYSICAL CLIMATE

There is only one climatological station in the Rupununi, located on the St. Ignatius Livestock Station, and only one meteorological station at Lethem less than two miles away. Thus of necessity for the time being the climate at St. Ignatius will have to be considered as representative of the whole savanna, both north and south. Long term rain gauge records at two other stations in the Rupununi and one in Roraima confirm that no great error is involved in this assumption. Later, however, in Chapters III and IV, the possibility that St. Ignatius is not representative, due to the proximity of the Kanuku Mountains, will be examined in detail.

THE LOCATION AND HISTORY OF THE ST. IGNATIUS CLIMATOLOGICAL STATION

The St. Ignatius climatological station is located at 3° 21'N, 58° 37' W on the east bank of the Takutu River at an elevation of 355 ft. Half a mile down stream the Takutu is joined by the Moco-Moco Creek which flows from the Kanuku Mountains some 8 to 10 miles to the south.

There have been four settlements in the general area strung out along the river bank, the oldest, the St. Ignatius Mission, being just upstream of the Moco-Moco mouth. Half a mile further upstream is the St. Ignatius Livestock Station of the Department of Agriculture, on whose property the climatological station is located. Immediately downstream from the Moco-Moco is Lethem, the present day administrative centre for the Rupununi, with the remains of its predecessor, Bon Success, a mile further down.

Rainfall records have been kept at all of these sites at various times producing a virtually continuous record from 1930 to the present day. The missing records are those of 1952 - 1954 during which time the administration was moving from Bon Success to Lethem, and it is hoped that the missing figures may eventually come to light. The most satisfactory long-term record is obtained by treating the two St. Ignatius stations as one, producing a record broken only between 1951 and 1956. To partially fill this gap the figures for Lethem from 1954 - 1956 have been included in the long term total and averages. This assumption is validated by the small difference (less than 2%) recorded between the two stations over the succeeding nine years.

Maximum and minimum temperature observations were started at St. Ignatius Mission in 1936 and continued with occasional months missing until 1944. Although observations were taken in 1948 it was not until 1957 that these readings recommenced on a regular basis. Once again the Lethem figures will be included for the period 1952 - 1954 when calculating long term averages.

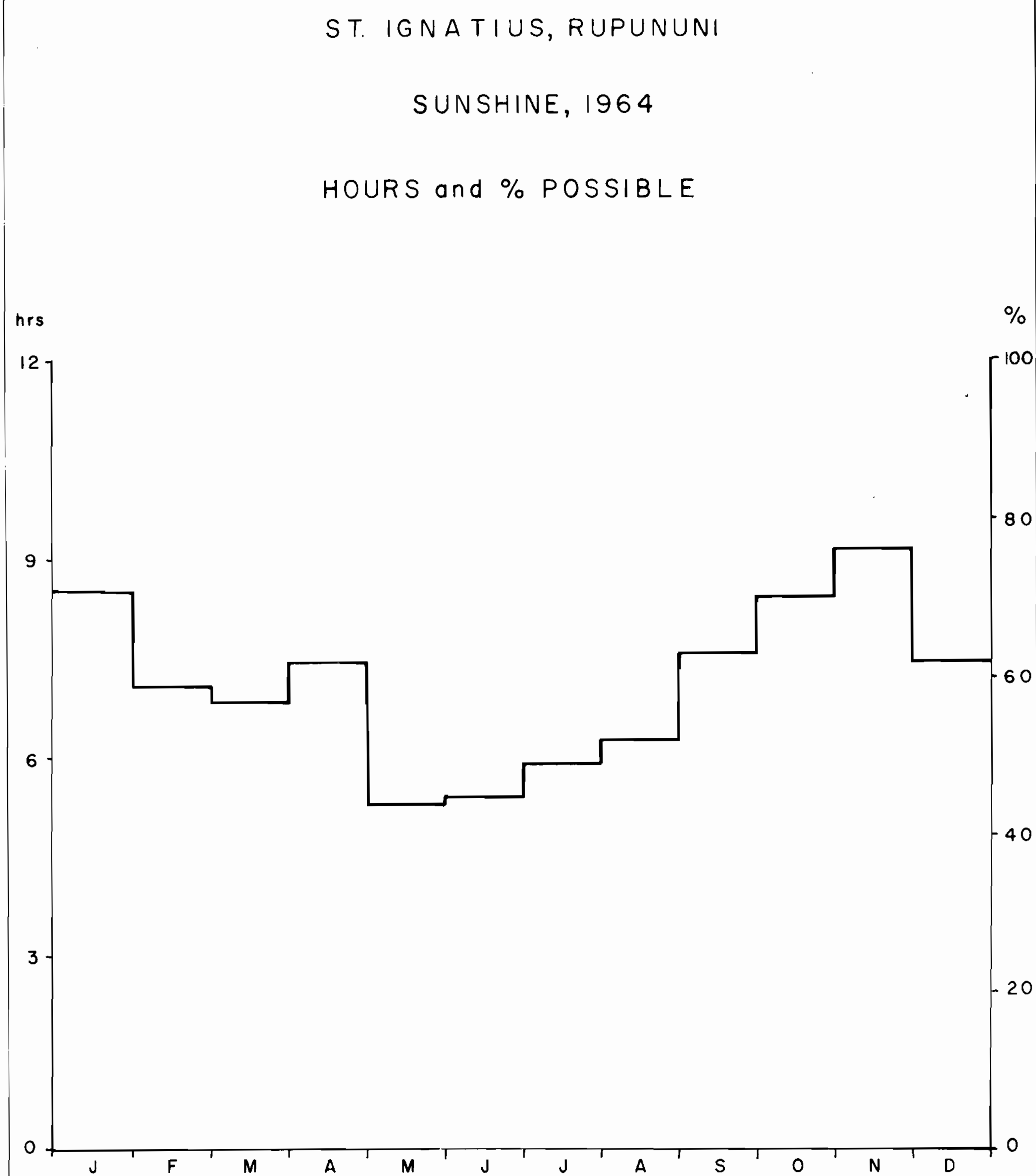
Since April 1963 the McGill University Savanna Research Project (MUSRP) has installed additional equipment to measure evaporation, sunshine, insolation, wind speed and direction and thermal conditions both close to and within the soil. Thus most of the data used in the following section will come from this recent period and its representivity will be judged on the basis of the rain gauge records. From them it can be seen that 1964 was quite close to the average, with 1963 a little wet and 1965 quite dry.

THE CLIMATE AT ST. IGNATIUS

1. RADIATION

The amount of solar radiation reaching the ground depends on the height of the sun, upon the amount of cloud that is present and on the transmissivity of the atmosphere. As St. Ignatius is within the tropics it has two periods when the sun at noon is directly overhead and two seasons when the sun's apparent daily path is relatively far from the vertical. On December 21st at noon it is 63° above the horizon and on June 21st it is at 70°. The most satisfactory way to measure cloudiness is to determine the amount of sunshine received as a percentage of the possible and to consider that the remainder is a measure of cloudiness. By this method it can be seen for 1964 (Fig. 4) that cloudiness varied from 29% in January and December and rose to over 50% in May, June and July, being much less at other times of the year. The transmissivity of the atmosphere will depend mainly on the height of the sun, since as the sun declines from the vertical there is an increase in optical depth and

FIG. 4


ST. IGNATIUS, RUPUNUNI
SUNSHINE, 1964
HOURS and % POSSIBLE
hrs
%
12
9
6
3
0
100
80
60
40
20
0
J
F
M
A
M
J
J
A
S
O
N
D

of Rayleigh scattering. Thus transmissivity will be least in December and June, although throughout the dry season there will be an increase in scattering and reflection by dust particles in the air.

The factors discussed above produce a four seasoned yearly cycle of insolation. It is composed of two maxima approximately equal in size, the one occurring during February, March, April and the other during September, October, November and these are separated by two minima, the lesser one occurring in December and January and the major one from May to August during the wet season. The record obtained from a Belfort Instrument Co. pyrheliometer from May 1963 to December 1965 confirms this distribution (Fig. 5) with minor fluctuations due to meteorological conditions. Calibration in June 1964 indicated that the values from the pyrheliometer charts were accurate to $\pm$ 10% so that the average daily values may be regarded as having at least that degree of accuracy and most probably better. They range from a low of 375 lys. day^{-1} in May 1963 to a high of 521 lys. day^{-1} in November 1964.

Calibration by a Silicon Cell instrument in June 1964 indicated that while individual values varied by $\pm$ 10% a 28 day average was high by 6.5%. Thus all monthly averages have been reduced by this amount and range from 351 lys. day^{-1} in May 1963 to 487 lys. day^{-1} in November 1964.

It is worthy of comment that in 1964, a year close to the average in other respects, there was a corrected total of 161 K cm.$^{-2}$ yr.$^{-1}$. Budyko (1956) has prepared maps of total incoming radiation for the entire earth and calculated that the Amazon Basin and parts of the Guiana

FIG. 5

ST. IGNATIUS, RUPUNUNI INSOLATION

mean lys per day

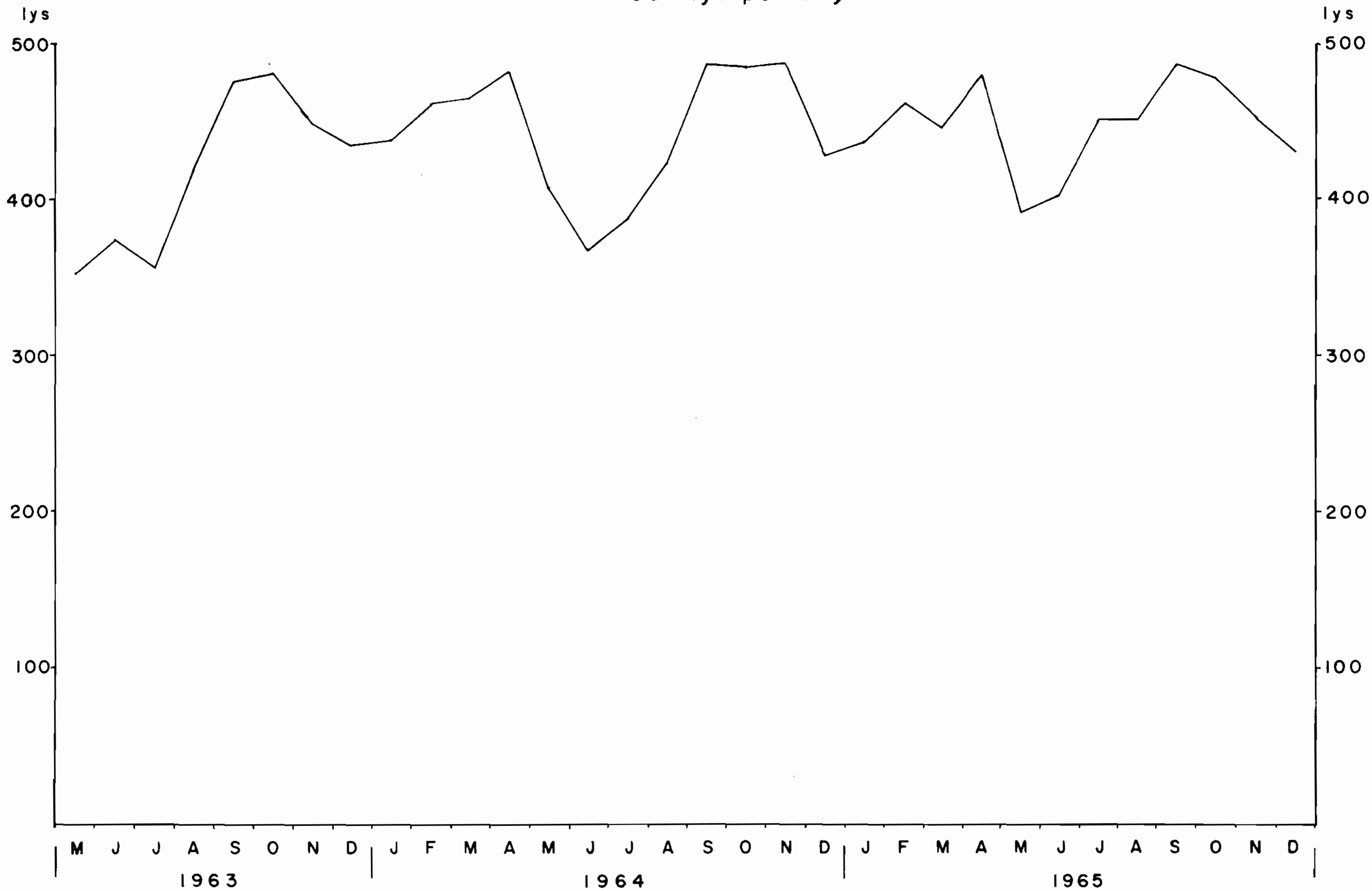


FIG. 5

Shield receive 140 K cm.$^{-2}$ yr.$^{-1}$ or 87% of that recorded at St.Ignatius. It is reasonable to attribute the difference to the reduced cloud cover over the savannas during the dry season, a feature not common to the rest of the Amazon Basin.

As no measurements of net radiation were available it was calculated by use of the method of Budyko (1956 page 42). Various suggestions have been offered with regard to savanna albedo, but pending actual measurements the value of 20% was employed. Budyko's formula is as follows:-

$$Ia = Io\,(1 - cn)$$

where

Ia - net radiation
Io - total incoming radiation
c - a constant (0.51 for St. Ignatius)
n - amount of cloud

The last term 'n' was assumed as indicated above to be the residual of the percentage of possible sunshine for the daytime. For the period of darkness it was assumed that there was no cloud during the dry season, but 20% in May and 10% in June and July. According to these calculations, monthly net radiation varied from 200 to 250 lys. per day, giving a yearly value slightly below that calculated by Budyko (90 K cal.cm.$^{-2}$yr.$^{-1}$) for his map of global net radiation. This discrepancy can also be attributed to the lack of cloud during the dry season, since thereby the greenhouse effect is minimised.

Before discussing the temperature regime it is appropriate to discuss the rainfall regime in greater depth than was appropriate in the introductory chapter (see page 8).

2. RAINFALL

Over the last 33 years the total annual rainfall has varied from 107.0 cms. in 1938 to 214.0 cms. in 1943. These values are approximately symmetric about the mean for that period of 161.8 cms. and the equivalent median of 163.0 cms. A portion of Fig.7 indicates the variability of the total rainfall by means of a histogram with the interoctile ranges indicated. Thus it can be seen for example that there is a 50% probability that any year's rainfall total will lie between 137.0 cms. and 185.0 cms.

The rain falls in one very distinct wet season that lasts for four to five months from May to September, with June and July receiving the heaviest monthly totals as can be seen in Fig. 6 (Mean Monthly Rainfall). The variability of monthly rainfall is considerable and is depicted in the major portion of Fig. 7 by the same method employed for the annual variability. May is the most variable month in terms of totals, closely followed by July; but December is the most variable in terms of exceeding its median value, as it does so by a factor of 27. Thus it is not possible to estimate with any certainty the amount of rainfall that will occur in any month of the year.

TABLE 2

Duration and Severity of the Wet Season St.Ignatius 1960-1965

Year	Duration	Length (days)	Rain (days)	Rainfall (cms)	%of total for year
1960	26 Apr. - 15 Aug.	112	100	130.8	77
1961	30 May - 22 Aug.	85	82	115.1	81
1962	2 May - 2 Sept.	124	105	155.9	84
1963	4 May - 21 Aug.	109	96	135.3	74
1964	18 May - 22 Sept.	128	98	138.8	87
1965	6 May - 4 Sept.	121	90	116.9	87
Av.	9 May - 30 Aug.	113	95 (84%)	132.1	81

FIG. 6

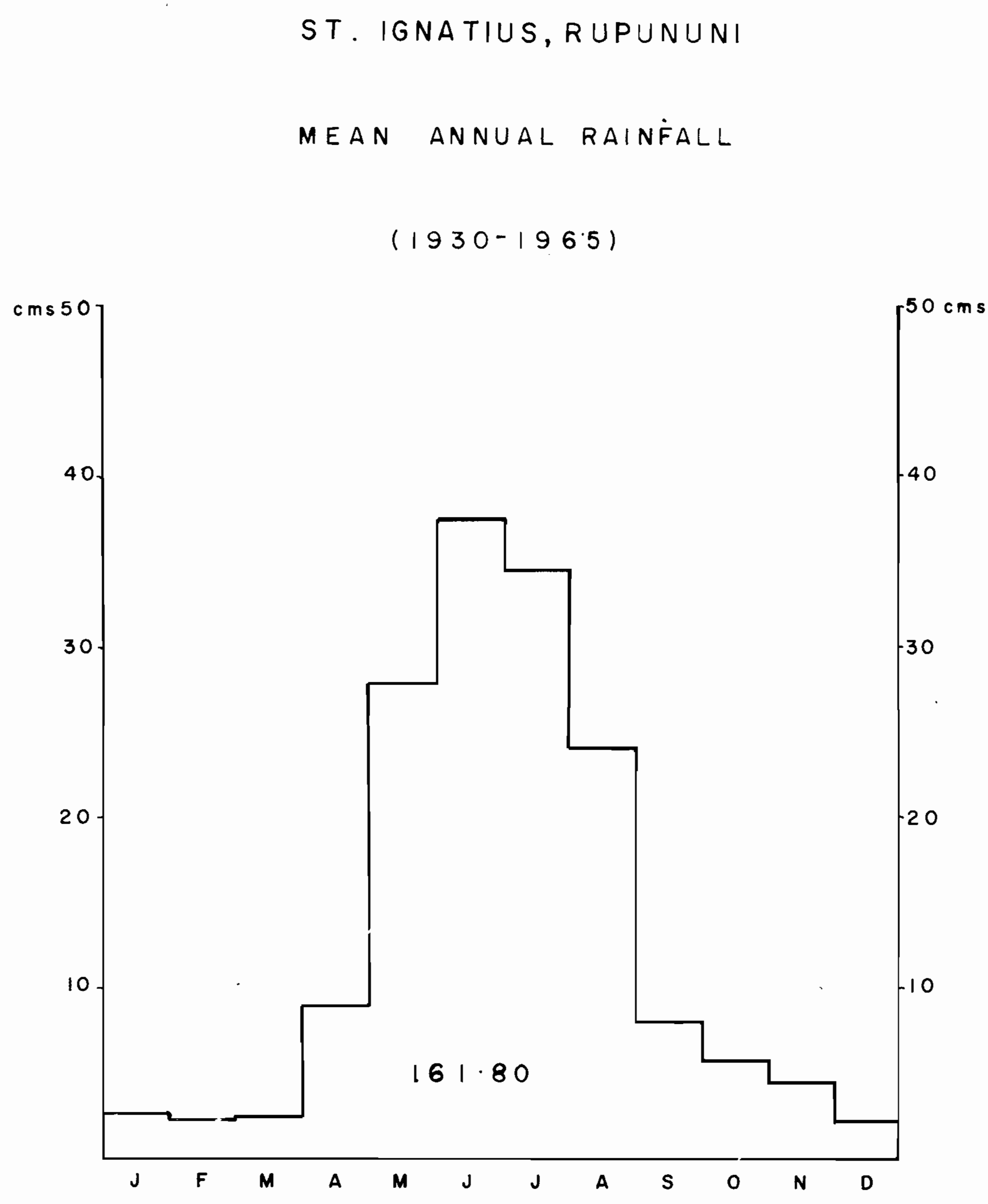

ST. IGNATIUS, RUPUNUNI
MEAN ANNUAL RAINFALL
(1930-1965)
cms 50
40
30
20
10
50 cms
40
30
20
10
161·80
J
F
M
A
M
J
J
A
S
O
N
D

FIG. 7

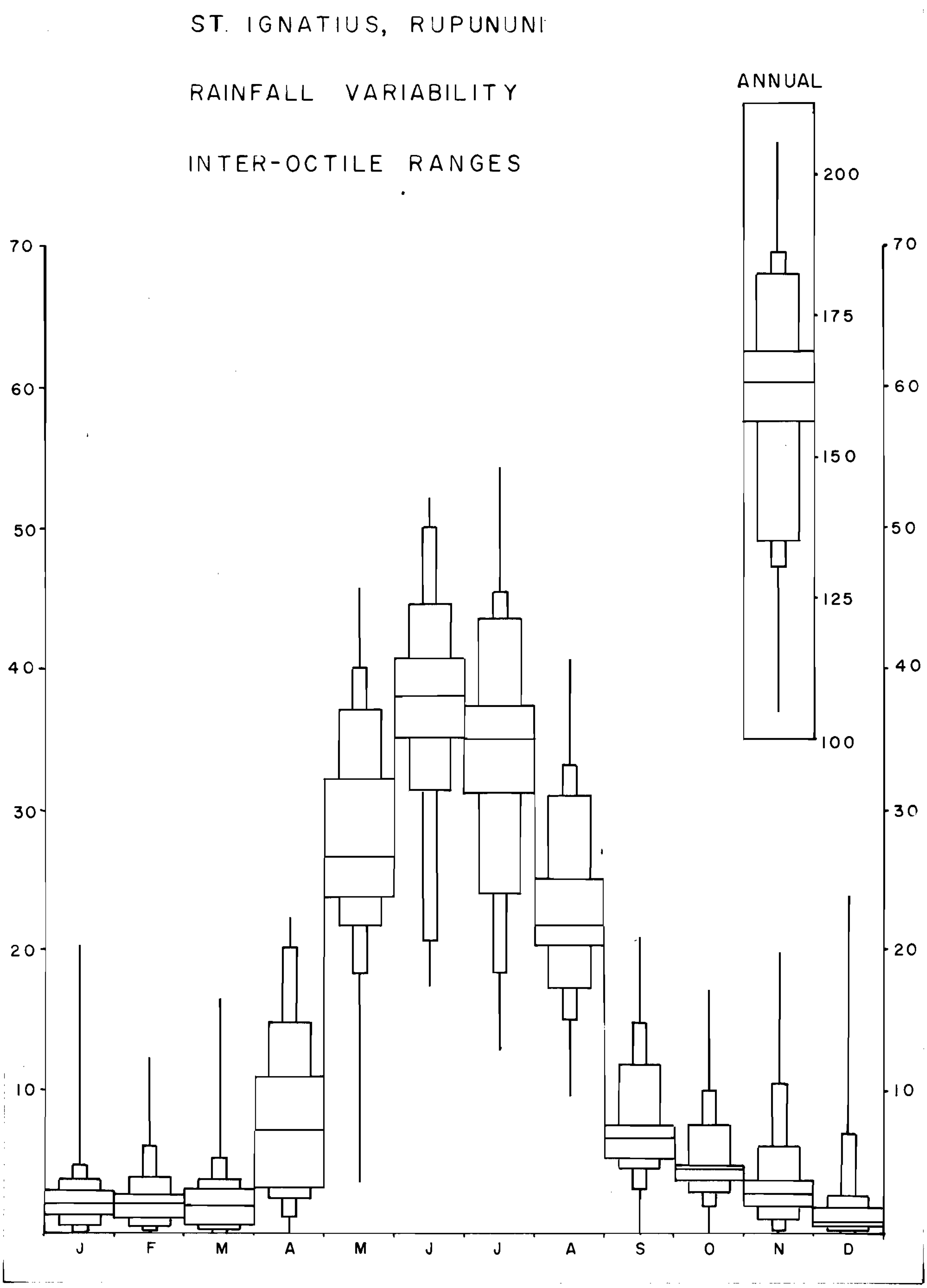

ST. IGNATIUS, RUPUNUNI
RAINFALL VARIABILITY
INTER-OCTILE RANGES
ANNUAL
200
175
150
125
100
70
60
50
40
30
20
10
J
F
M
A
M
J
J
A
S
O
N
D

Table 2 presents an analysis of the wet seasons from 1960 - 1965 emphasizing their variability in duration, length and amount of rainfall. The table also stresses that in spite of these vagaries, the season is always responsible for more than three quarters of the annual precipitation in less than one third of the year. It would be a mistake to believe that during this period it rained continuously, or even every day, for as the table indicates there are usually between 10 and 20 dry days.

Almost all rain falls from cumuliform clouds, either <u>cumulus congestus</u> (Cu^+) or <u>cumulonimbus</u> (Cb), during both seasons of the year. In the early morning, particularly in the middle of the wet season, layer clouds often occur and these sometimes acquire sufficient depth to produce precipitable droplets. Such falls are lengthy in duration but produce little rain. Most wet seasons experience at least two or three days when the sun scarcely shines and then <u>stratus</u> or <u>nimbo</u> <u>stratus</u> covers the sky. These appear to be the result of a penetration of cool air from Patagonia into the central Amazon basin, a phenomenon usually referred to as a <u>friagem</u>, its local Brazilian name.

However, most rain falls in short intense showers from the cumulus clouds. During the wet season of 1965, 66% by volume of the rain fell in showers of less than 1.27 cms. and 73% by volume of the season's rain had intensities of less than 2.54 cms. $hr.^{-1}$. Exceptional showers do occur, those of large volume usually at the beginning of the season, such as one of over 12.00 cms. on May 4th 1963. High intensities of up to 10.00 cms. $hr.^{-1}$ (1936) have also been reported[1], but each year experiences a few showers of over 5.00 cms. $hr.^{-1}$.

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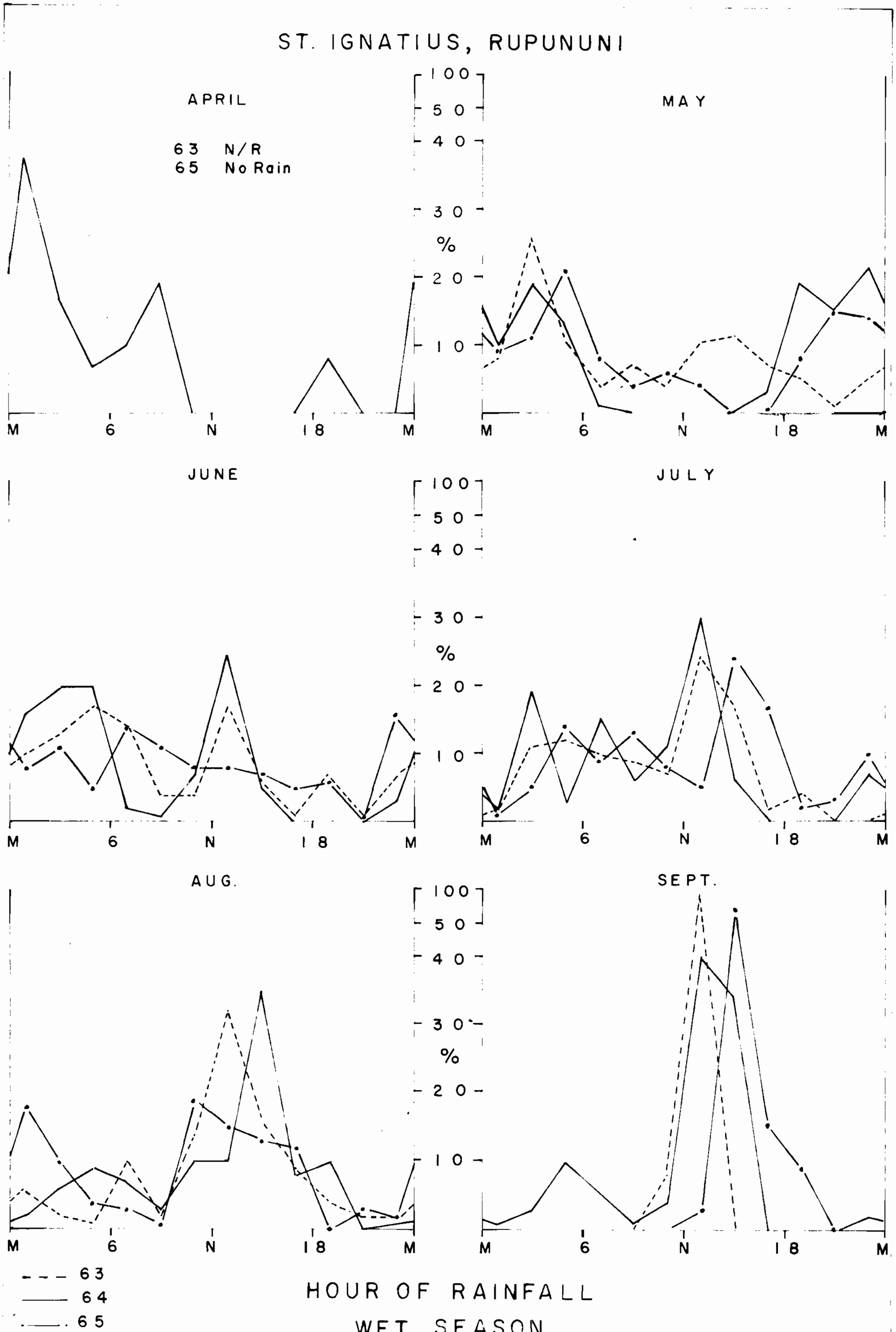
1. Records of Rainfall at St. Ignatius Mission 1930 - 1946.

Rain does not fall at the same time of day throughout the wet season, but rather the time of maximum precipitation, by volume, progresses in an orderly fashion from the early morning hours in April and May to the early afternoon exclusively in August and September. June and July are more even months, having maxima in both the early morning and the early afternoon, besides a fair amount of precipitation between 0800 - 1200 hrs. These points can be seen in Fig. 8 (Hourly Distribution of Wet Season Rainfall). An analysis of the rainfall record for intensity per shower indicated a similar diurnal variation as illustrated by Fig. 9 (Distribution of Heavy Showers, 1965). It was apparent, however, that a greater percentage of the rain falls in light showers during the main wet season months of June, July and August than during those at the beginning and the end, although no orderly progression of intensities was noticeable (see Fig. 10, Intensity of Rainfall May - September 1965).

During the dry season the time of day when rain falls is more confused (see Fig. 11). October has a midday peak as might be expected and March has a tendency to night time rain. As, however, rain in the dry season is caused by sudden changes in atmospheric conditions, rather than by the gradual modification experienced within the wet period as the ITCZ moves northward, this confused picture is understandable. Perhaps a longer period of observation will permit a more general outline to be recognized. Nevertheless, December presents an interesting picture as the record for that month has several peaks stretching from early morning to late afternoon suggesting that the causal mechanism is present

FIG.8



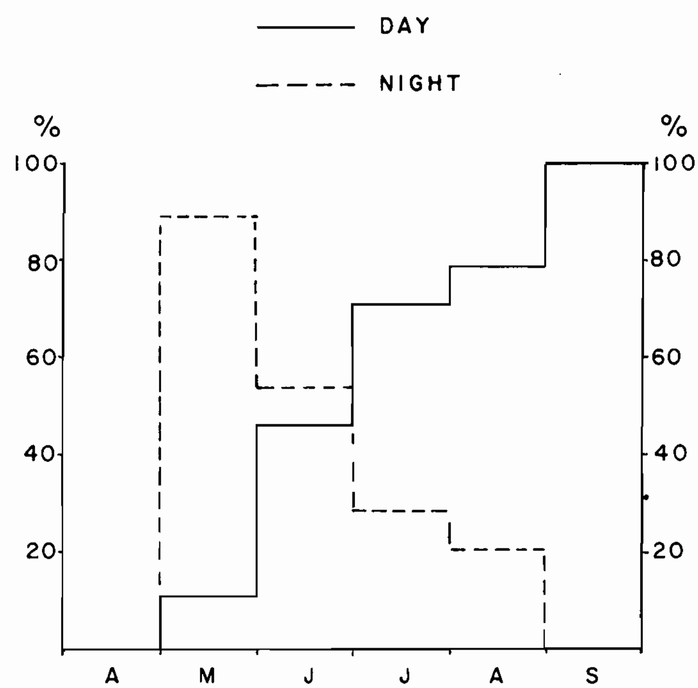
HOUR OF RAINFALL

WET SEASON

ST. IGNATIUS, RUPUNUNI

HEAVY SHOWERS

1965



HEAVY SHOWER > 2·54 cms per hour

FIG. 10

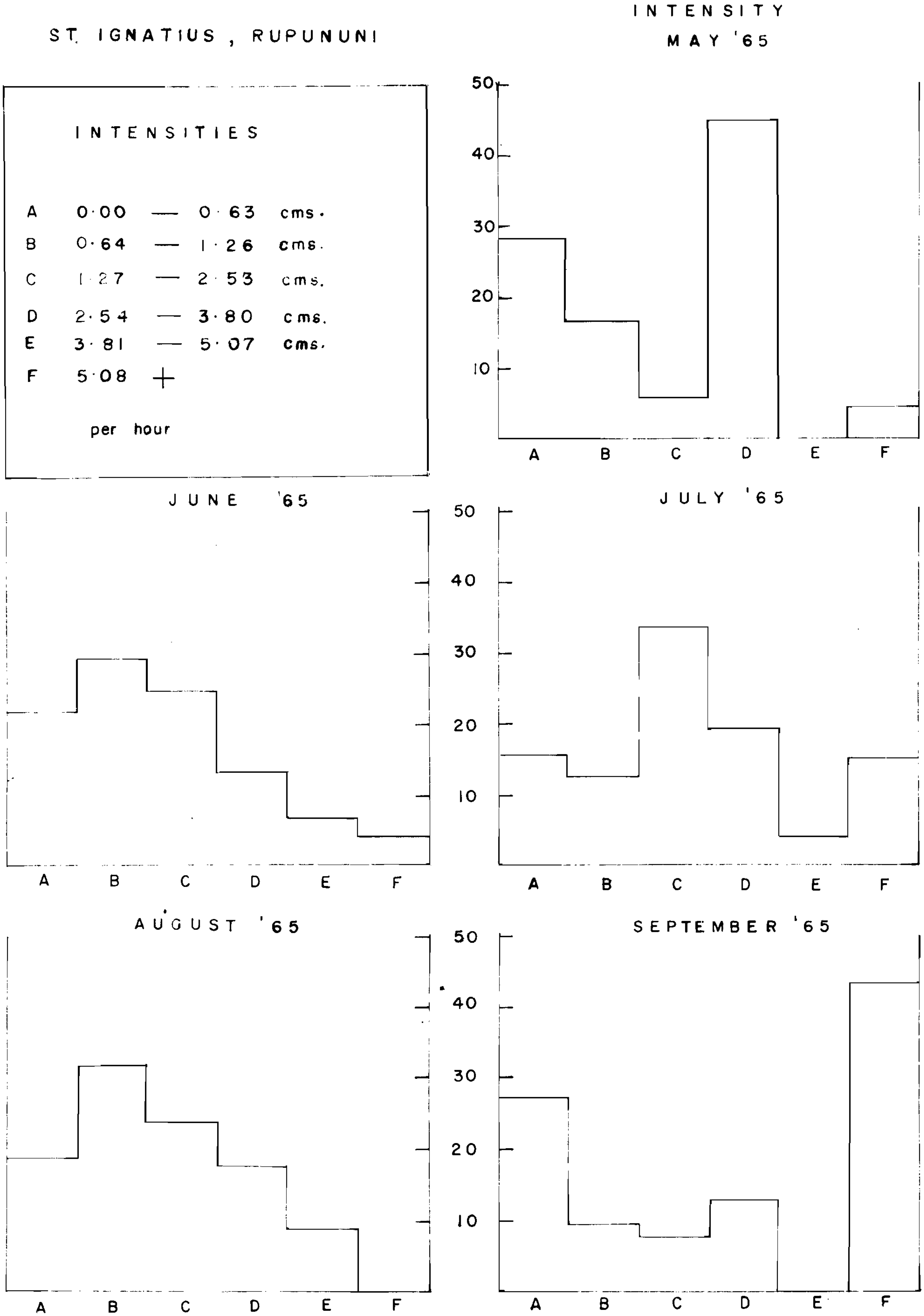
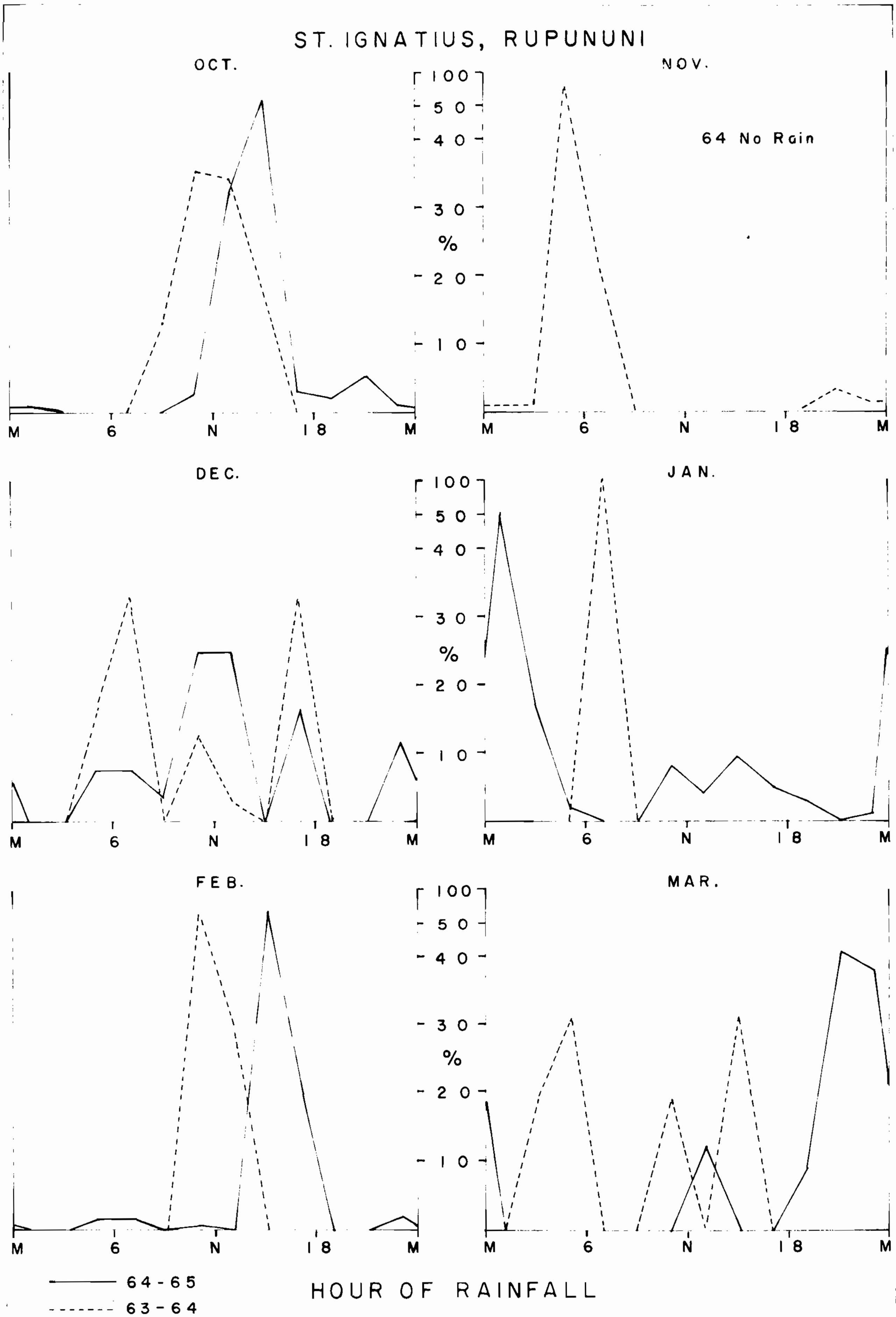

ST. IGNATIUS, RUPUNUNI
INTENSITIES
A 0·00 — 0·63 cms.
B 0·64 — 1·26 cms.
C 1·27 — 2·53 cms.
D 2·54 — 3·80 cms.
E 3·81 — 5·07 cms.
F 5·08 +
per hour
INTENSITY
MAY '65
JUNE '65
JULY '65
AUGUST '65
SEPTEMBER '65
50
40
30
20
10
A B C D E F

FIG. II



HOUR OF RAINFALL

DRY SEASON

more often during that month. In spite of these considerations, however, the most important feature of the dry season still remains its comparative lack of rainfall as indicated by the small number of rain days (Fig.12)

3. TEMPERATURE AND HUMIDITY

Temperature seasonality naturally follows the seasons of radiation and rainfall as discussed above. Thus the highest temperatures are recorded around the equinoxes, the lowest in June and July during the rains and a period somewhat cooler than the equinoxes occurs in December and January. The mean monthly maximum temperature varies in absolute values from 86.5°F to 92.0°F while the minimum ranges from 72.0°F to 76.5°F, giving a diurnal range of 14 - 16 F°. Dry bulb temperatures at 0800 hrs. and 1400 hrs. vary in the same way, although over slightly wider ranges. These distributions are presented in Fig.13. The all-time highs and lows recorded at St. Ignatius do not go far beyond the average values, 96.0°F for the maximum and 69.5°F for the minimum. Due to the slight range in overall high temperatures, it is presumed that seasonal variations in temperature in the Rupununi are not climatologically important. In the light of the comparatively high diurnal range this presumption is seen to be all the more reasonable.

Humidity, on the other hand, is a more interesting and important phenomenon, for it varies drastically with the seasons and has considerable effect. Relative humidities are much higher in the wet season than in the dry, at all hours of the day, as illustrated in Fig. 14. It can also be seen from that figure that at all times the relative humidity is lowest at 1400 hrs. and highest during the night.

FIG. 12

ST. IGNATIUS, RUPUNUNI

MEAN RAINFALL DAYS

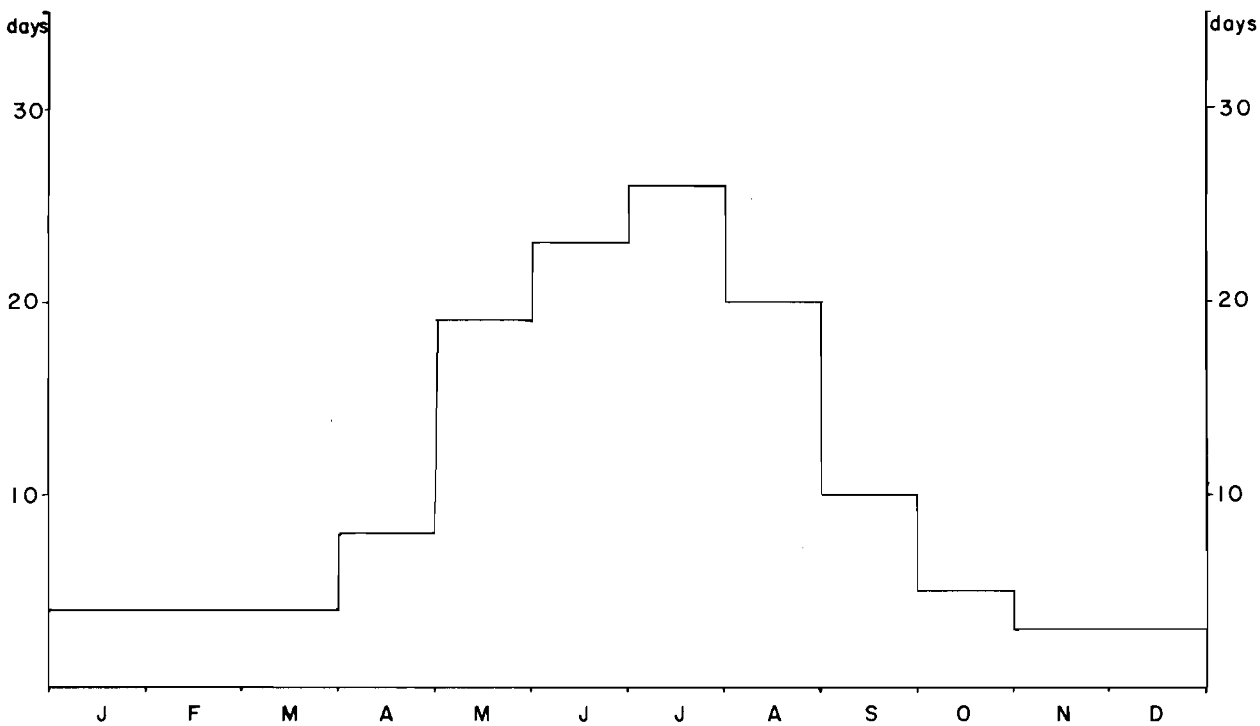
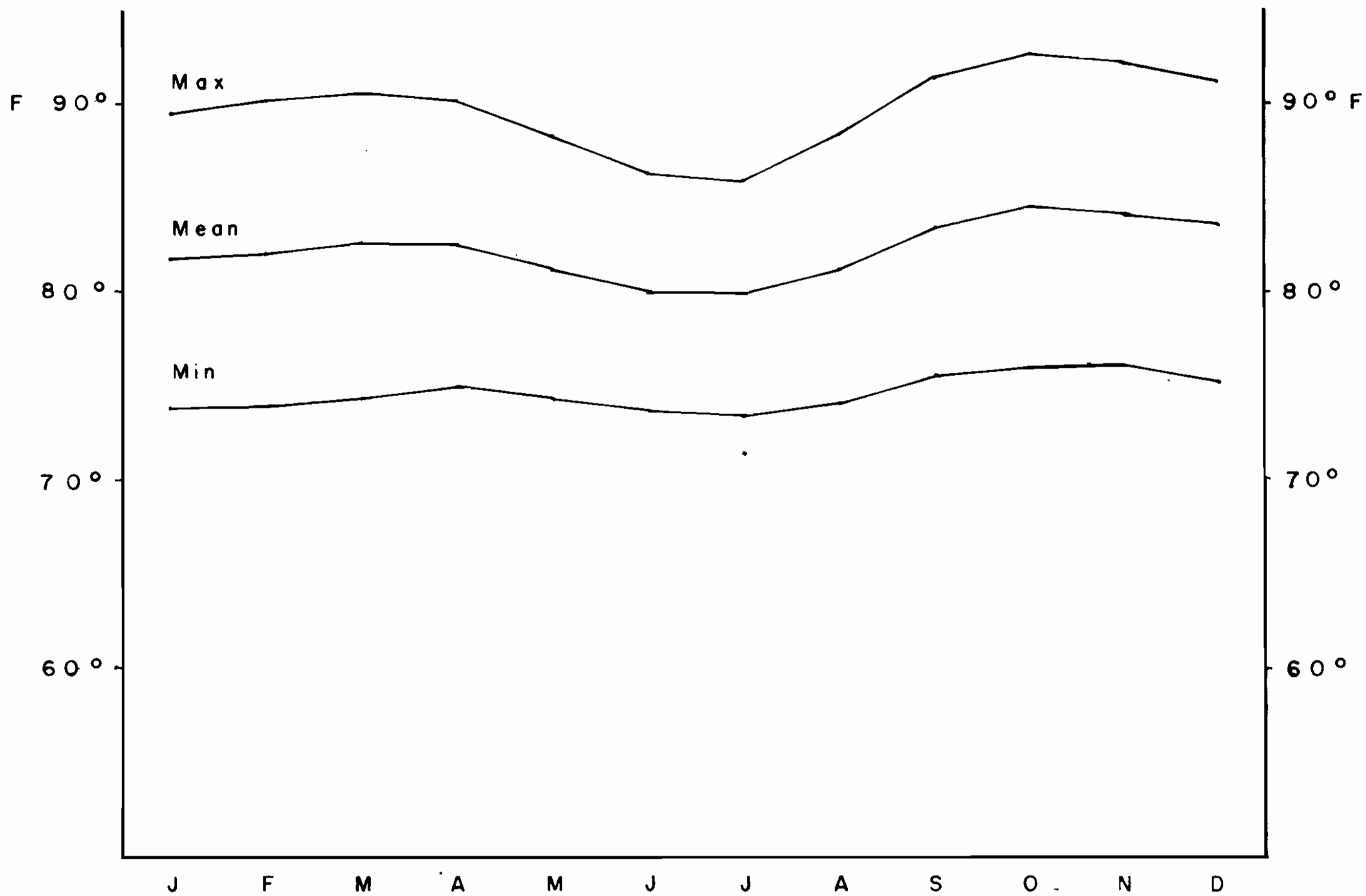


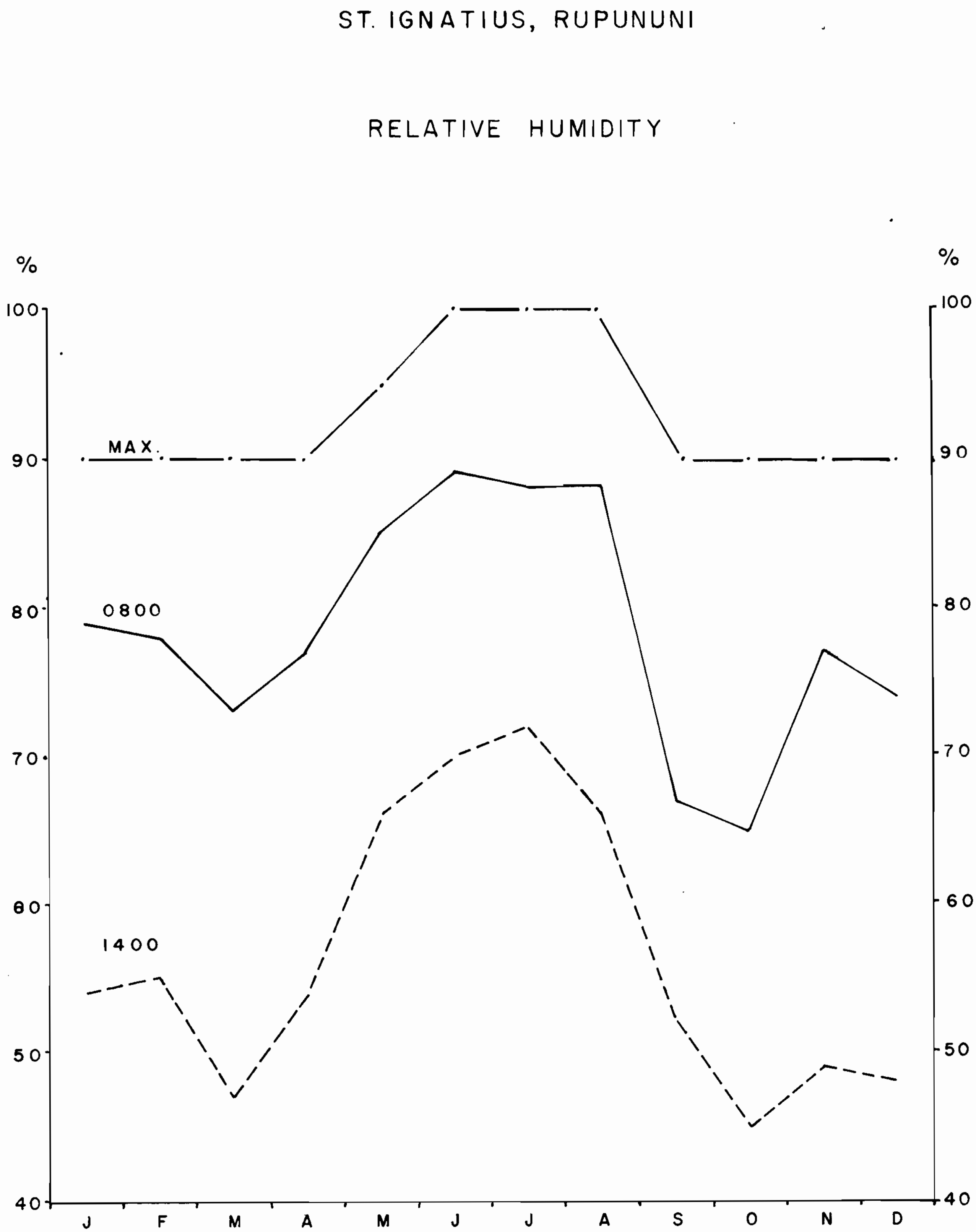
FIG. 13

MONTHLY TEMPERATURE: MAXIMUM, MEAN and MINIMUM



ST. IGNATIUS, RUPUNUNI

FIG. 14


ST. IGNATIUS, RUPUNUNI
RELATIVE HUMIDITY
%
100
90
80
70
60
50
40
MAX.
0800
1400
J
F
M
A
M
J
J
A
S
O
N
D

Vapour pressure is the measure used in studying the absolute humidity, as it can be conveniently calculated from psychrometric tables. Vapour pressures for 1965 have been calculated for 0800 hrs. and for 1400 hrs., and a further calculation has been made for the night hours by means of the following assumptions. The maximum relative humidity has been presented in Fig. 14, which is based on hygrograph charts. These indicate that during the wet season the air is saturated each night and that even during the dry season at least 90% relative humidity is reached nightly. It is assumed that these conditions pertain to the time of minimum temperature and the vapour pressures have thus been calculated for that time. An average of the partial pressure at these three diurnal times has produced a mean monthly value for atmospheric humidity.

Vapour pressure conditions are quite different in the dry season from those in the wet because not only are they lower, but the diurnal distribution is reversed. During the wet season the average vapour pressure is above 26.5 mbs., while in the dry season it is below 26.0 mbs. and falls to 22.8 mbs. in February. The diurnal variation from May to August has lowest values during the night and highest at 1400 hrs. but during the dry season this pattern is reversed. The rise in afternoon vapour pressure in the wet season reflects the availability of water for evaporation. Fig. 15 illustrates these points.

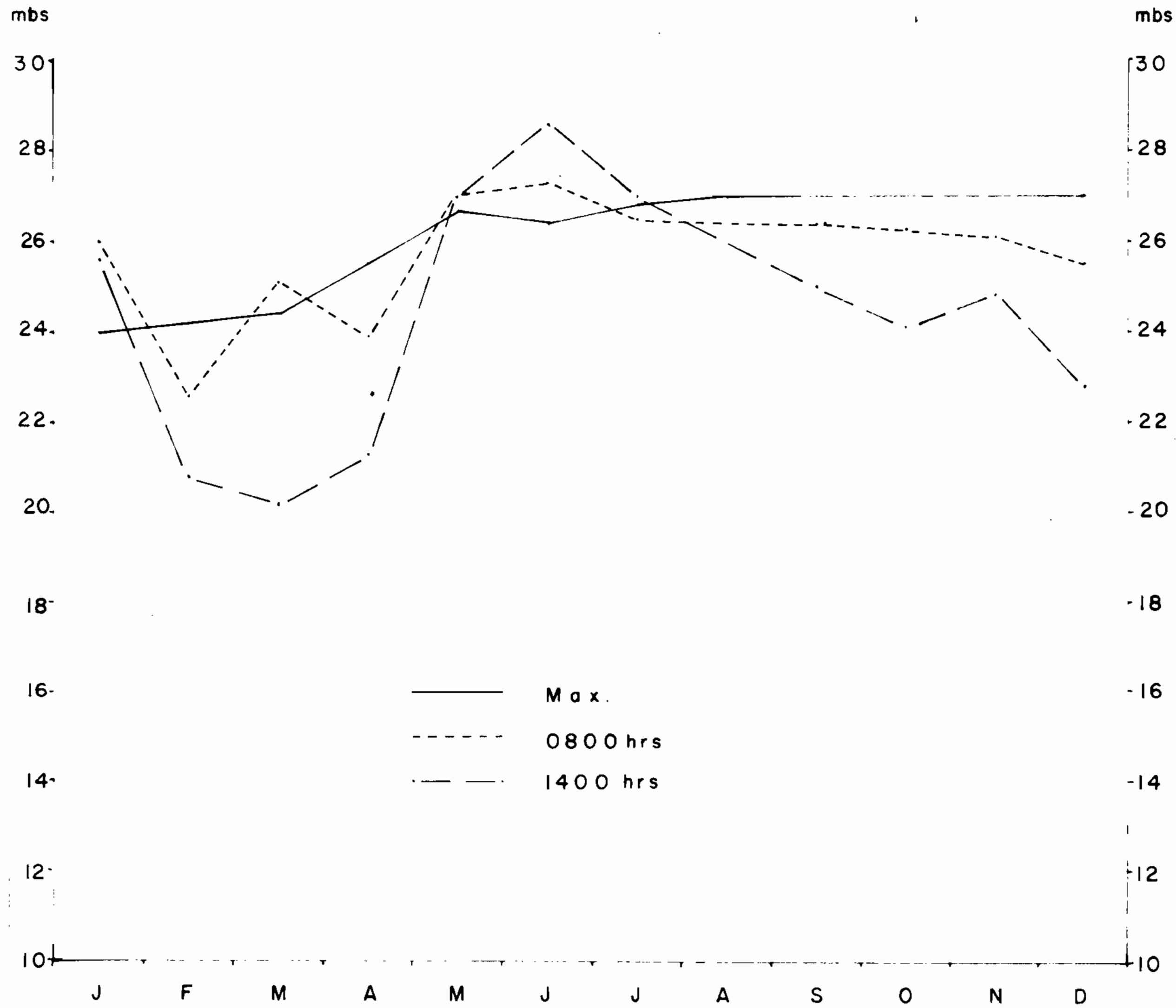
The vapour pressure conditions confirm that during the dry season there is not a lack of moisture but rather a lack of a mechanism to release it. Furthermore the high humidities which prevail until January

FIG. 15

ST. IGNATIUS, RUPUNUNI

VAPOUR PRESSURE

(1965)



indicate that it is not until that month that the ITCZ passes to the south covering the area with slightly dryer air.

4. WIND

As with the other climatic parameters, wind displays a marked difference in character depending on the season. In the dry period the wind blows strongly from midnight to sundown, virtually every day, and from the same direction, East to North East, but during the wet season it blows less strongly and only intermittently and its direction is less constant. Nevertheless the diurnal wind profile, on the average, is much the same as in the dry season (Fig. 16) and more than half of the observations record the wind as from the ENE octant. The monthly wind roses for 1964, as calculated by Sinha for the period January to October and by the author for the remainder, are presented in Fig. 17. Data for 1964 rather than 1965 was selected as observations made in the former years are available at 1100 and 1700 hrs. from May to October as well as at the normal 0800 and 1400 hrs. for the whole of the year. Monthly average wind speeds are presented in Fig. 18.

5. EVAPORATION

Evaporation pans, lysimeter tanks and a Black Bellani disc atmometer were installed at St. Ignatius during the wet season of 1963 and have been operating since then. The pans are of two sizes, one 22 ins. in diameter and 18 ins. deep, the other 48 ins. by 12 ins. Both are buried in the ground so that 5 cms. of rim protrudes and are surrounded by pangola grass, Digitens decumbens, cut to a height between 4 and 5 cms. The water level in the pans is maintained between 5 cms. and 8 cms. below

FIG. 16

ST. IGNATIUS, RUPUNUNI

ASSUMED WIND PROFILE

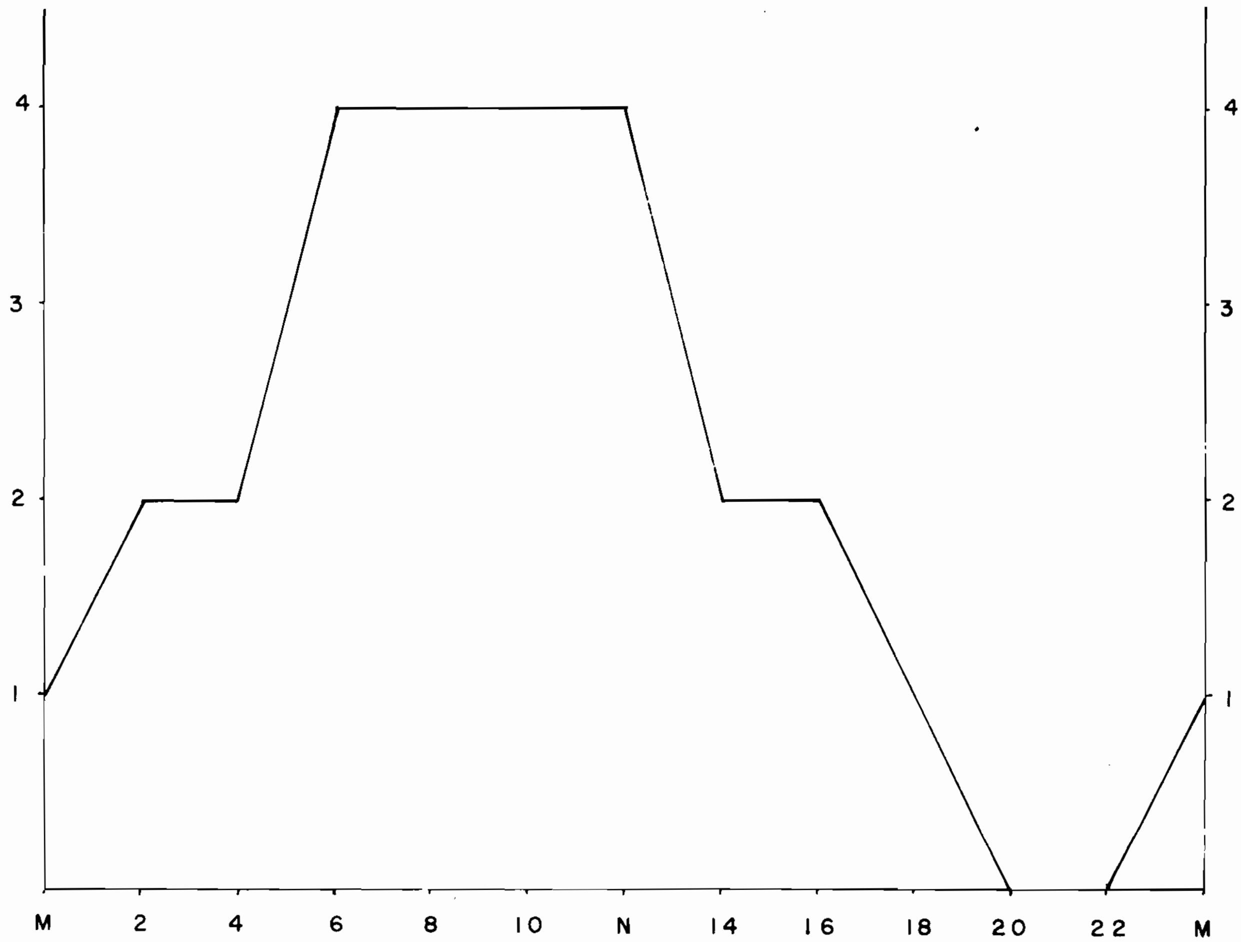
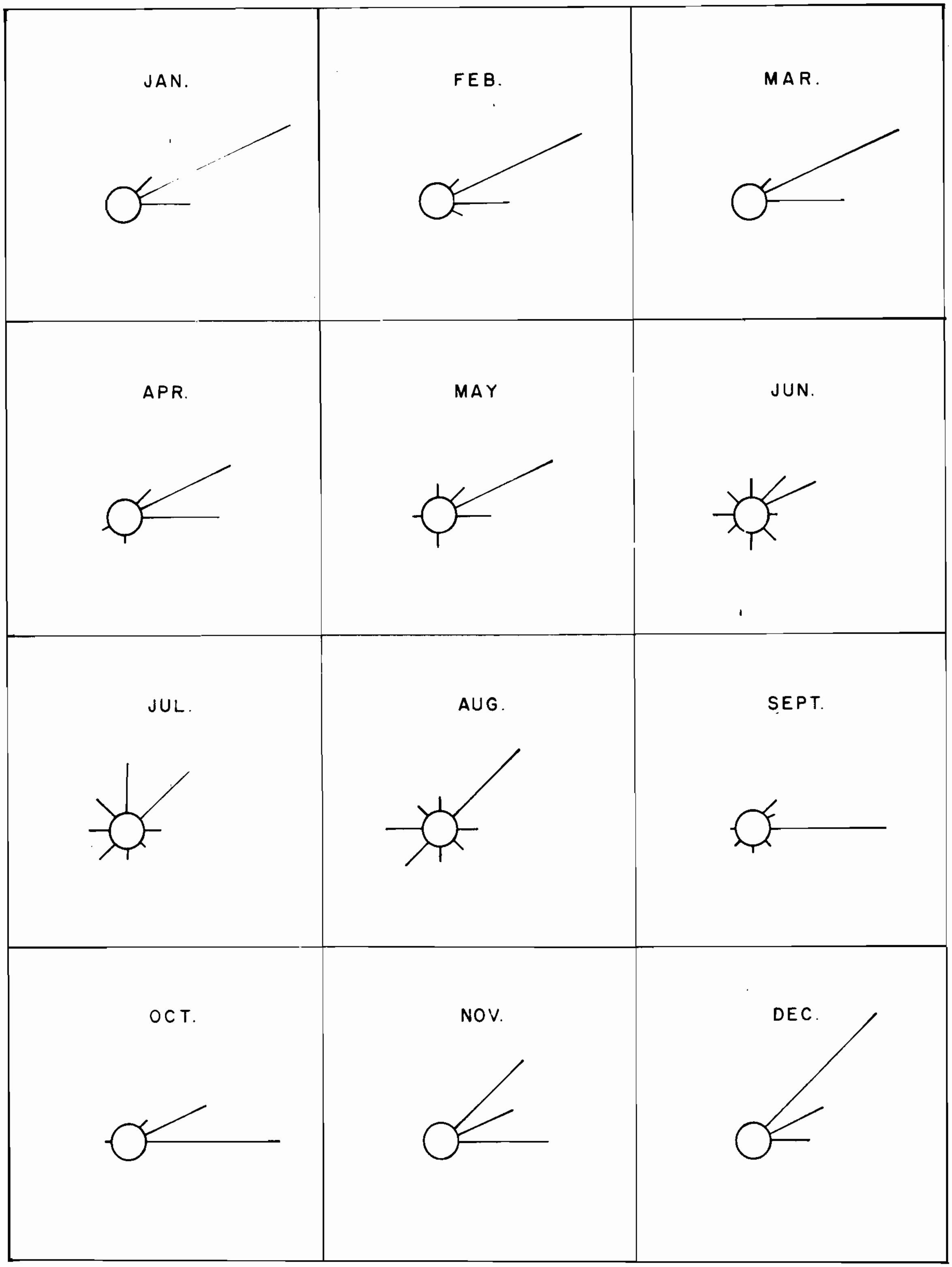


FIG. 17

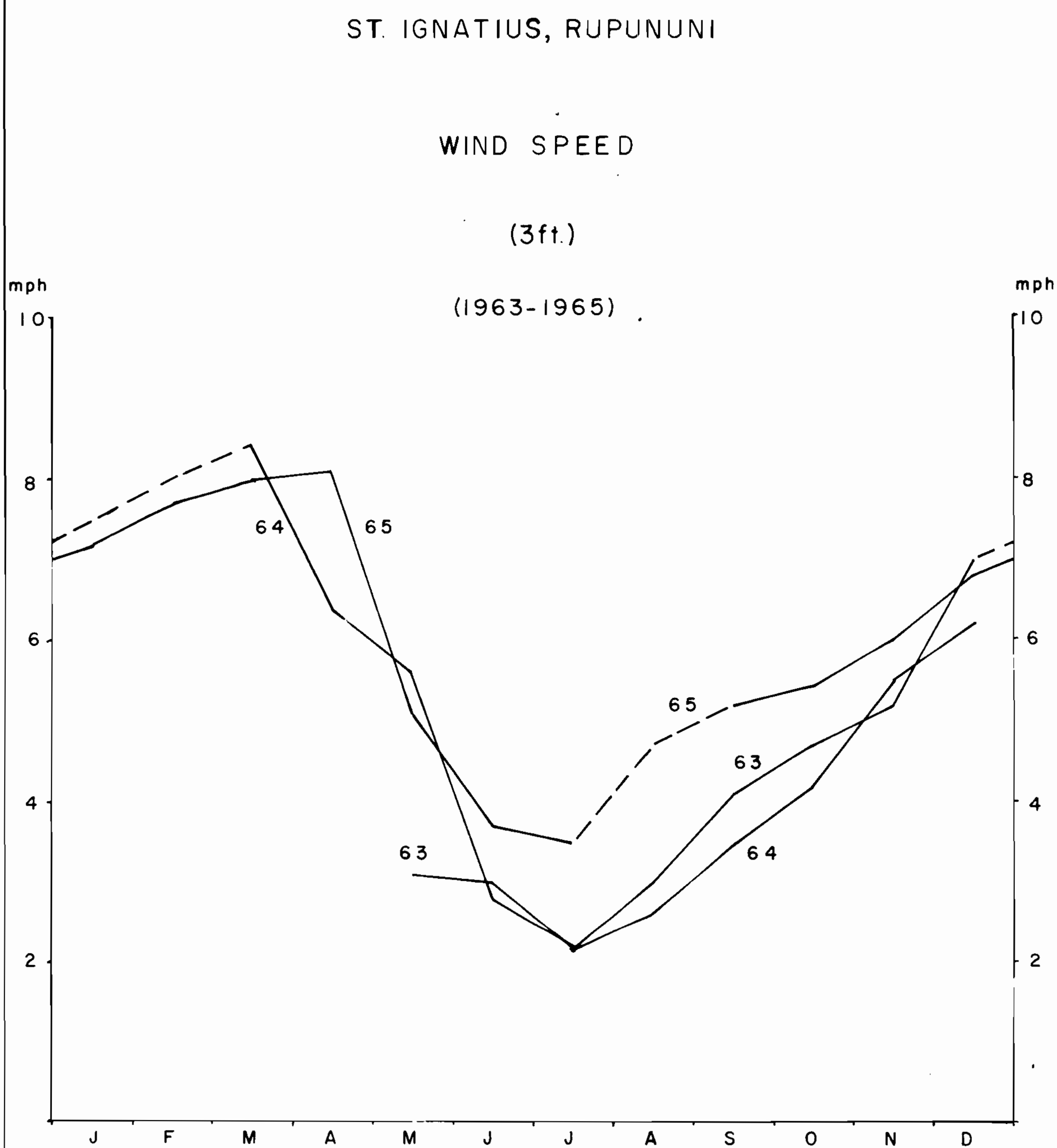
ST. IGNATIUS, RUPUNUNI

WIND DIRECTION (1964)



After SINHA

FIG. 18


ST. IGNATIUS, RUPUNUNI
WIND SPEED
(3ft.)
(1963-1965)
mph
mph
10
8
6
4
2
64
65
65
63
63
64
J
F
M
A
M
J
J
A
S
O
N
D

the pan rim and altered only when necessary, although it has been the practice to maintain a level closer to the lower than to the upper limit to inhibit splashing during heavy showers. This precaution has, however, not always been successful.

The three lysimeter tanks are 22 ins. in diameter and 36 ins. deep being filled with the soil that was excavated for their installation. Their rims protrude 3 cms. above the ground and the pangola grass is kept at the same height as that in the rest of the compound. The tanks drain to a pit 10 yards away where the water is collected and measured daily. Due to their slow infiltration rates these instruments are not accurate on a daily basis, but are reliable over the monthly period employed.

The Black Bellani disc atmometer has been described and discussed in numerous papers by Holmes and Robertson (see for example 1957 and 1964). This instrument measures latent evaporation, a function of the vapour deficit in the air, which has been closely correlated with computed evaporation (see 1954).

All these instruments by virtue of their construction measure different aspects of evaporation; the pans as from an open water surface, the lysimeters as from a vegetated surface and the atmometer the latent evaporation. None of these instruments ~~are~~ is perfectly reliable due to their construction and the way they are operated, and they all suffer from advective heating during the dry season. Wind is the major advective agent producing a strong correlation between the wind miles run and moisture evaporated. It has not been possible to combat this effect by irrigating even the meteorological site let alone the quarter square mile recommended by Thornthwaite and Mather (1955).

The evaporation pans of both sizes suffer from water being splashed and blown out of them by high intensity rainfalls and the strong winds that accompany severe showers. Even showers of only moderate intensity have been observed to splash water 15 cms. into the air, both from the pans and from the temporarily flooded ground surface, but usually the splashing on the ground is less marked. The net result is undoubtedly a loss of water from the pans. Occasionally, by this process, evaporation has appeared to rise to over 2.00 cms. and values exceeding 1.00 cms. are common. The results for such days have been corrected by correlation to windspeed, but it is not possible to do so on all occasions, especially when less than a millimeter is involved. Thus it is assumed that even during the wet season the pan values are too high. To reduce this difficulty only the values from the larger pan were employed for it has a rim area index less than half that of the smaller. Possible ameliorative proposals include using a Summerland pan or adding a 30 cm. wide (i.e. an additional 60 cm. of diameter) additional area of pan outside the one to be measured.

Many workers have reported difficulties in operating evaporation pans because birds, rodents and large animals drink from them. Stout fencing has effectively kept out larger animals and the presence nearby of watering facilities for cattle has prevented birds and rodents from becoming a serious problem. It is unfortunate that the same cannot be said for the evaporation sites elsewhere in the area.

The lysimeters read unduly high during the dry season not only on account of the advected heat but also because the quality of the vegetation in the tanks is far superior to that surrounding them. Even in the wet season the greater density of grass in the tanks compared with that without will increase the values obtained. Furthermore, due to good drainage the root systems will be better developed, since they are not inhibited by waterlogging or by high water tables during the wet season. Inflated values will also result from any omission to keep the grass at the specified level. Readings from lysimeters have therefore to be used with considerable caution.

The exact physical workings of atmometers are still in doubt for although Robertson has presented evidence[2] of their accuracy in measuring evaporation and in response to radiation, Mukamel ~~l~~ (1962) contends that they are mostly influenced by wind. In July 1965 both pans and atmometers were read at 0800 hrs. and also at 1700 hrs. with a view to investigating this difference of opinion. In terms of percentages of the monthly values, 94% of the daily solar radiation occurred between these hours, but the 48 in. pan only evaporated 56% of its total, while the atmometer at the standard height of 120 cms. evaporated 80% and that at 4 cms., 85%. There was, it is true, more wind during these daylight hours (53%) as suggested by the idealized profile (see Fig.16), but not so much that the atmometers could be regarded as responding more to wind than to radiation. Thus these observations uphold Robertson's position.

Because of these theoretical uncertainties connected with the atmometer, and the variable state of the lysimeters' vegetation, it was decided that the 48 in. evaporation pan was the most satisfactory of the

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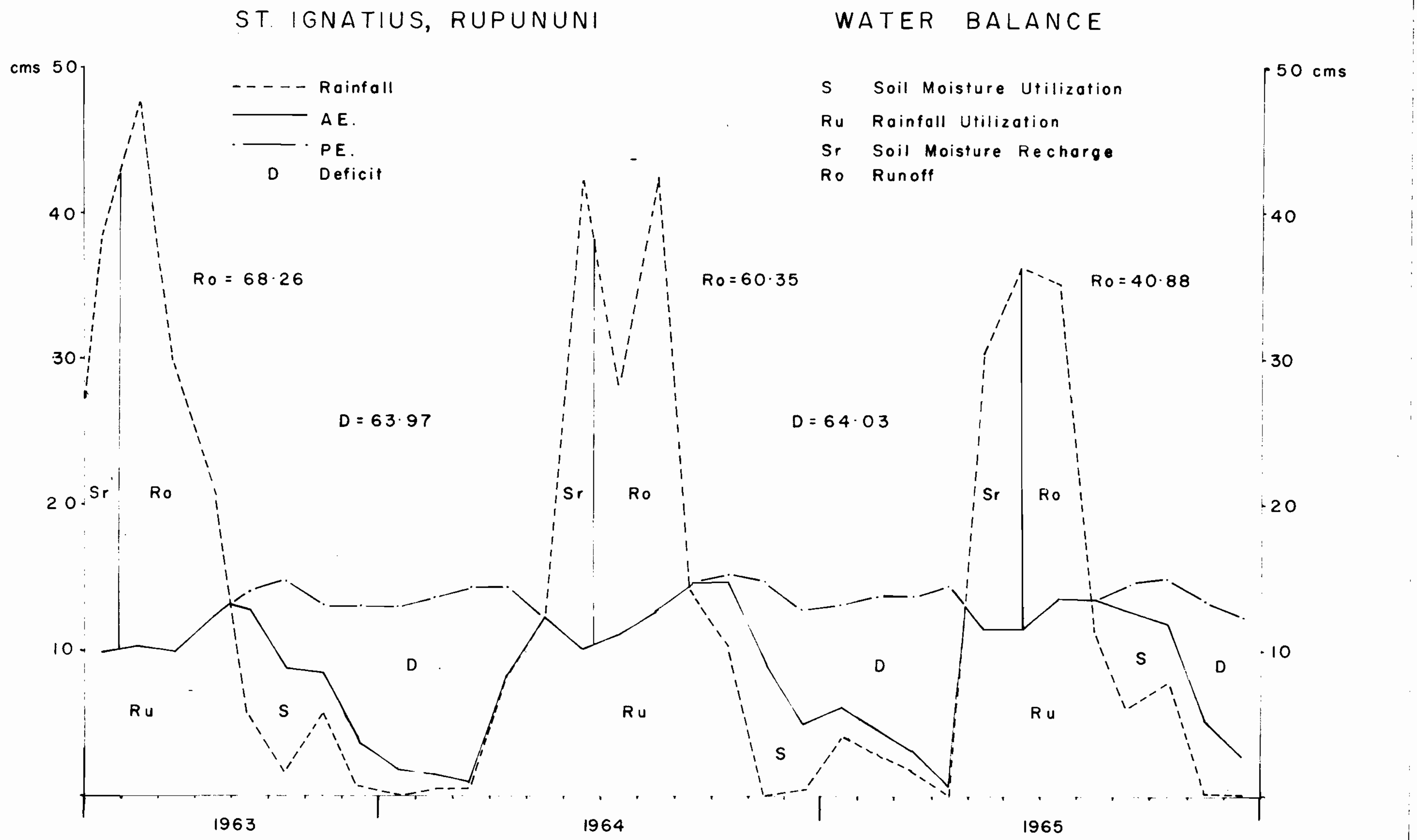
2. Robertson ~~1957~~. and Holmes (1957)

instruments available, since the choice of the 48 in. pan diminishes some of the worst splashing effects encountered in the 22 in. pan. To counter the effects of dry season advection, the evaporation during the wet season was correlated with the incoming solar radiation. Although only 12 monthly values were available a coefficient of regression $r = 0.938$ resulted, indicating a strong relationship. The evaporation pan values for the dry season were calculated from the radiation on the basis of this established relationship. Although this is the best estimate of pan evaporation that can be made at present, it is not suggested that this is the actual value for there may be advectional or splash effects during the wet season for which due compensation has not been made.

Potential evapotranspiration will take place at a lower rate than evaporation over an open water surface, not only because of the inability of the soil or plants to provide unlimited water, but because of the amount of energy they withdraw for heat and photosynthesis. Penman (1963), discussing his own evapotranspiration formula, has suggested values between 60% - 80% of that for an open water surface. Although he has suggested that 70% is adequate for all seasons, it was felt that sufficient energy existed for vegetation to flourish and transpire under the summer 80% conditions all year round. The latter assumption was adopted for the present study and the results entered as potential evapotranspiration in a regular Thornthwaite water balance computation, in which a soil moisture capacity of 25 cms. was employed. In this manner the water balance at St. Ignatius was computed from May 1963 to December 1965 (Fig. 19).

FIG. 19


ST. IGNATIUS, RUPUNUNI
WATER BALANCE
cms
50 cms
Rainfall
AE.
PE.
D Deficit
S Soil Moisture Utilization
Ru Rainfall Utilization
Sr Soil Moisture Recharge
Ro Runoff
Ro = 68·26
Ro=60·35
Ro=40·88
D = 63·97
D = 64·03
Sr
Ro
D
Ru
S
1963
1964
1965

There is little room for a discussion of the potential figures thus employed, since no superior method of calculation is possible at the present. The results of the Thornthwaite computation are presented in Table 3 together with the measured and computed pan evaporation to indicate the lack of response to seasonal changes which is inherent in his system when it is employed under tropical conditions.

TABLE 3

Evaporation 1964 - Measured, corrected and computed

cm/day

MONTH	Pan	ET from Pan	Thornthwaite	Garnier
Jan.	0.97	0.42	0.48	0.45
Feb.	1.00	0.45	0.49	0.45
Mar.	1.04	0.46	0.51	0.46
Apr.	0.95	0.47	0.56	0.45
May	0.87	0.38	0.52	0.43
June	0.48	0.34	0.47	0.36
July	0.40	0.36	0.46	0.34
Aug.	0.48	0.41	0.46	0.36
Sept.	0.57	0.49	0.49	0.39
Oct.	0.62	0.48	0.51	0.42
Nov.	0.80	0.49	0.45	0.45
Dec.	0.65	0.42	0.52	0.44

Garnier (1956), working in West Africa, has encountered the same difficulty and proposed a modification based on the saturation deficit of the air. His system was used to compute the potential evapotranspiration for 1964 for comparison with the Thornthwaite figures and those derived from the regression equation. The results are also presented in Table 3 above. Generally the results compared well in the first half of the year, but from August to October the Garnier system gave much lower values due to the relatively high vapour pressures prevailing in those months. The months used in the regression equation are those of the wet season and the first month or two in the dry season. Thus any lowering of the latter values, as suggested by Garnier's formula, would reduce values in the first four months of the year, destroying the close correlation that now exists. It is more likely that the existing wet season and early dry season correlation should be respected and that some system should be developed to increase the values for the remainder of the dry season. Until then, however, the radiation correlation method remains the best available.

The problem of soil field capacity is more difficult, for no measurements have been made in the Rupununi area. Thornthwaite's books of Water Balance Computations for the various continents employ a field capacity of 30.00 cms., which is far too high a value for either the normal sandy clay soil of the flats or the lateritic gravel ridges. The 25.00 cms., adopted in this study, is a maximum rather than a minimum figure, so that the water balance diagram must be regarded as presenting an optimistic picture of moisture deficits and surpluses.

The water balance has several implications. First it permits an assessment of the moisture deficits and surpluses from April 1963 - December 1965, the former being 63.97 cms. (1963-1964) and 64.03 cms. (1964-1965) and the surpluses, 68.26 cms. (1963), 60.35 cms. (1964) and 40.88 cms. (1965). Secondly it is now possible to recognize two intermediate seasons when evaporation proceeds at the potential rate in the absence of waterlogging in the soil profile. These seasons occur during the first two months of the wet season while the soil profile is being refilled and the first month or six weeks of the dry season when there is sufficient precipitation and soil moisture to maintain an actual evaporation rate close to the potential. Lastly, it is possible to determine the amount of strain imposed on the vegetation due to the lack of moisture in the dry season. Aubréville (1961) states that in tropical regions plants unadapted to drought will be unharmed as long as they receive 10 cms. of water per month. If they receive between 10 - 3 cms. they will not be irreparably harmed, but below 3 cms. lasting damage will result. By this criterion the dry season 1963 - 1964 was far more severe than that of 1964 - 1965, having three months below 3 cms. as opposed to one in the latter. It can be appreciated from the rainfall records that almost all years will present at least one month of serious drought and frequently two.

The water balance presently calculated does not take into account two phenomena. First, if rain falls when the soil is dried out it will not penetrate to the bottom of the profile and be evaporated at a low rate, but rather it will remain in the surface layers and be transpired at close to the potential rate. Robertson (1961) has demonstrated this process while proposing his 'Modulated Soil Moisture Budget'. A second factor will make this process even more rapid. Due to the showery and localized nature of dry season precipitation, it is incorrect to suggest that a potential rate of transpiration occurs, for around the edges of the rainfall area there will be severe advection effects that could increase daily transpiration rates to over 1.00 cms. This will almost certainly occur when any shower yields less than 0.50 cms. of rain.

Together these two phenomena produce a distinctive pattern of dry season evapotranspiration. Long periods of little transpiration and high plant moisture stress will be separated by periods, a few days in length, when transpiration will be exceedingly rapid. These conditions are obviously not suitable for unadapted plants.

6. RIVER LEVELS

The height of the Takutu River at St. Ignatius has been observed on a daily basis during the wet seasons and the first weeks of the dry season. In the dry season the river falls to a depth of only 8 ft. in its deepest place and a more general depth of 3 ft. In the wet season it has risen rapidly to a depth of 40 ft., as in June 1963, but reliable informants indicate that it has, in exceptional years, risen at least 5 ft. above this level. Unfortunately no rating curve has yet been produced for the staging point.

The water balance diagram discussed in the previous section indicates the amount of water that is lost either as runoff or as deep percolation. In the Rupununi situation the latter is not a significant factor as the Takutu Shale surface is almost impermeable and lies generally close to the surface. It is incorrect, however, to consider that runoff will not occur until soil moisture is totally recharged as infiltration rates are below rainfall intensities. Thornthwaite and Garnier have suggested various percentages of the unevaporated water to be attributed to runoff before the field capacity is reached, but these proposals have not been tested to date in the Rupununi. Nevertheless in 1964 the river commenced to rise in late May, but the increase did not reach significant proportions until June 14th by which date the river had gradually risen over 5 ft. In the following two weeks the river rose rapidly some 20 ft. anticipating the date determined from the simplified water balance by less than ten days. (The rainfall and river heights for the period are presented in Fig. 20). This gives grounds for a cautious confidence in the water balance data.

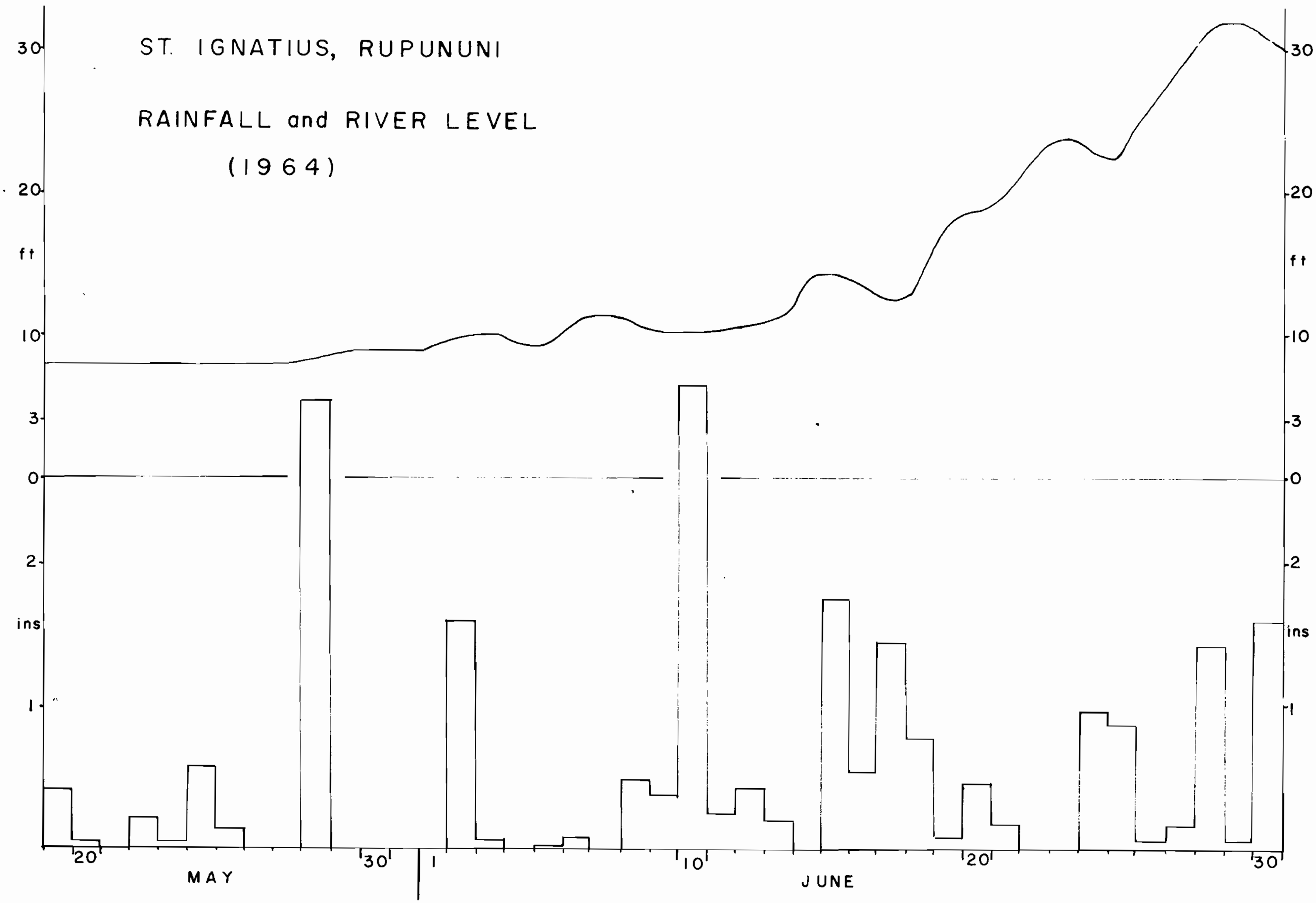
At the end of the wet season the river level falls rapidly initially but then declines very gradually as seepage flow into it declines. Occasional heavy showers cause slight rises in level but these rarely last for more than two or three days.

THE WATER BALANCE IN RETROSPECT

The foregoing sections have presented the major factors influencing the water balance and its major terms have been calculated. Thus it is now possible to assess the work of Eden in this connection, for he is the only author to present any conclusions or calculations on the matter (Eden 1964 pages 40 - 54 , particularly page 49 and following).

Eden was handicapped by having a shorter period of observations to utilize and by a lack of an energy calculation. He nevertheless neglected two important considerations, advection and the differing evaporation rates of water rather than soil. For these reasons his PE values are far too high throughout the dry season and slightly high in the wet season. He has not attempted to use this potential data to derive AE but has rather relied on measurements of soil moisture taken at a site about 6 miles from St. Ignatius that is fairly representative of a sandy loam flat. His measurements of AE are presented in Fig. 21 together with those ~~that~~ computed by the author's water balance system. Eden's values are lower for four reasons. First the author's system uses a soil moisture capacity that is high for such a situation and secondly his system has no

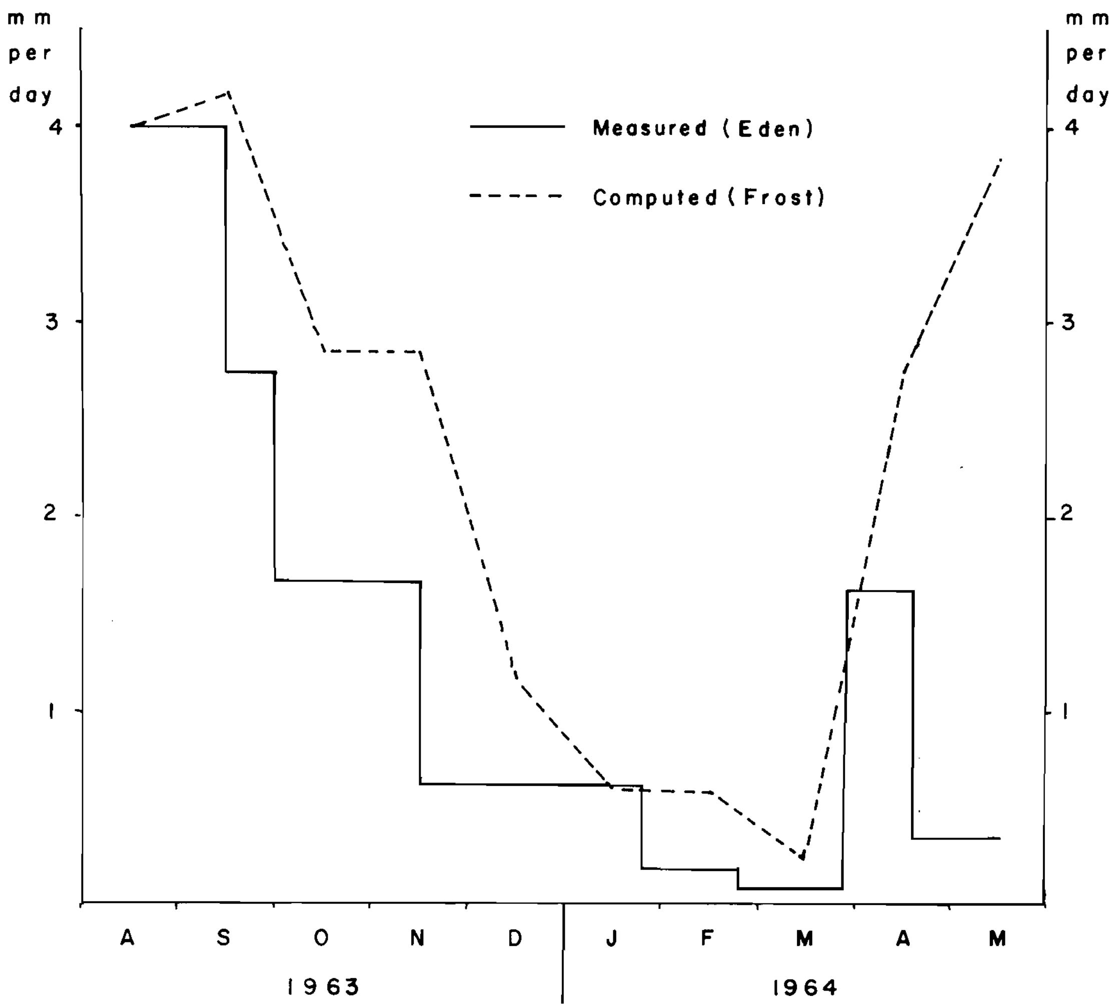
FIG. 20



ST. IGNATIUS, RUPUNUNI
RAINFALL and RIVER LEVEL
(1964)
30
20
ft
10
3
0
2
ins
1
20
30
1
10
20
30
MAY
JUNE

FIG. 21

ST. IGNATIUS, RUPUNUNI
ACTUAL
EVAPOTRANSPIRATION



NOTE- MAY 1964

Eden 1st - 15th

Frost 1st - 30th

runoff considerations built in. Thirdly Eden only measured soil moisture to a depth of 1.65 metres while the author believes that plant roots can and do extract moisture from greater depths. Lastly, Eden uses the St. Ignatius rainfall but the few rainfall values that are available for Manari Ranch, three miles away from his site suggest that the area may be somewhat dryer.

Thus it is felt that Eden's calculations are of comparable accuracy with the water balance results and that they may be regarded as confirming each other.

CHAPTER III

THE NORTHERN FACE OF THE KANUKU MOUNTAINS

In the discussion of the forms and patterns of the savanna and forest vegetation, it was stated that the forest savanna boundary corresponds closely with the front of the Kanuku Mountains. It was further noted that along their northern face the forest vegetation shows a tendency to extend into the flat surface which elsewhere is covered solely by savanna vegetation. It is generally recognized that forest vegetation requires moister conditions than does a grassland or savanna vegetation so that both theory and observation suggest that a change in climate is likely to be associated with the Kanuku Front, possibly of such a nature that it would be reflected in the differing vegetation of the two land-form units. It is the intention of this chapter to examine the nature of the climate within the mountain-forest area and in the strip of savanna adjacent to these discontinuities to find out if it differs sufficiently from the general savanna conditions recorded at St. Ignatius to have produced the change in vegetation.

1. THE KANUKU MOUNTAINS

The geological and geomorphological significance of the Kanuku Mountains have been mentioned in Chapter I (page 12) and the distribution of vegetation along the northern face has been described on page 20. To facilitate appreciation of the study that follows, their formation within the study area, which stretches from 5 miles east of Moco-Moco to the point of the mountains near Central, is now described more exactly.

The mountains form the southern wall of the North Rupununi Graben, rising to over 3,000 ft. but having a general accordance of summit heights at that level. The front is a dominating feature of the landscape for the mountains rise at angles of 20° - 30° out of the level savanna surface without any noticeable foothills, although in places there are indications of step faulting that will produce foothills in time. In spite of the accordance in summit height there are no level areas on the mountain tops, a fact that indicates that erosion has reached the mature stage. Equally there are no flat bottomed valleys at the savanna level within the mountains, except for a few areas within a mile or two of the mountain front. Inside the mountain massif there is an extensive system of valleys at 800 - 1000 ft. reflecting a previous cycle of erosion. The major streams and creeks that rise in the mountains and flow out across the savanna to the Takutu River have extensive basins at this upper level. They leave the mountains through narrow gorges, plunging down rapids and falls to the savanna level before flowing placidly across the plain to the major stream. Examples of such a development can be seen in the basins of the Nappi, Moco-Moco, Kumu and Inaja Creeks.

The study area lies due south of St. Ignatius stretching 5 miles east and 15 miles west. Here the Guyanese Savannas are constricted between the mountains and the Takutu River and provide a relatively dense settlement pattern where rain gauges can be observed. The mountains are not a continuous wall but are rather parallel segments offset by half a mile to accommodate the triangularity of the mountain wedge. Each segment lies between east and east-north-east in orientation, virtually parallel to the direction of the prevailing wind of both seasons. Until upper air data ~~is~~ are available it is not certain whether this is a true wind direction or whether it results from channelling, but this is not of immediate importance to the arguments presented later. Because the wind is parallel to the mountains storms appear to move along the front following definite paths. The exact trace of these tracks, as they appear to the observer at St. Ignatius, will be presented below, but it seemed likely that more rain fell along the mountain edge. For this reason and in the light of the difference in vegetation distribution described in Chapter I, it was decided to investigate the moisture conditions along the mountains.

2. VISUAL EVIDENCE:- STORM TRACKS

An observer at St. Ignatius can distinguish several distinct storm tracks both along the mountains and out over the savannas which are regularly used throughout the wet season. The author has observed storm paths during the wet seasons of 1963, 1964 and 1965, spanning wet, average, and dry years and can report that the major paths are used with approximately similar intensity under all conditions. Local informants confirm this finding for even dryer and wetter years as well. Differences are, however, more noticeable with regard to the less frequently used paths, for they are more commonly used in wet years than in dry ones.

Of the 200 or so showers in a wet season less than 10 will come from any direction other than E to NE regardless of the surface wind. This suggests that the showers are propelled from the east by an upper easterly flow of air that extends down to about 3,000 ft. In addition there is evidence that the weak southerly winds of the wet season blow more strongly in the south savanna and may occasionally influence the showers in the north savanna by imparting an ESE direction to them.

Showers do not appear to generate over the open savanna but along or above either the Pakaraimas or Kanuku Mountains causing the major storm path to lie generally along the edge of the mountains. Storms that begin within the mountains tend to emerge through one of the offset gaps in the mountain front and join the major path. In similar fashion, showers tend to leave the main storm path at these gaps and travel out across the savanna. This is a frequent occurrence east of Moco-Moco toward Nappi, and seems to give most of the rain in the Lethem - St. Ignatius area.

The other very common situation is for a storm to generate within the mountains, to emerge at one of the jogs and then to continue directly out into the open savanna in a direction a little north of west until the ENE wind pushes it to the west and south over Brazil. This track is the second important source of rain for St. Ignatius with the showers emerging in the Moco-Moco area. There are a variety of tracks from the NE that have a few showers a year but they are only of interest as the storms appear to have developed far to the east over the forest or even along the Pakaraima front. Rare but interesting showers move up from the south during the few afternoons when light to moderate south westerly winds prevail. These storms seem to originate on the south side of the Kanukus, and to be blown north and east around the end of the mountains, but they rarely penetrate further than St. Ignatius, falling off either to the south along the mountains or to the west into Brazil.

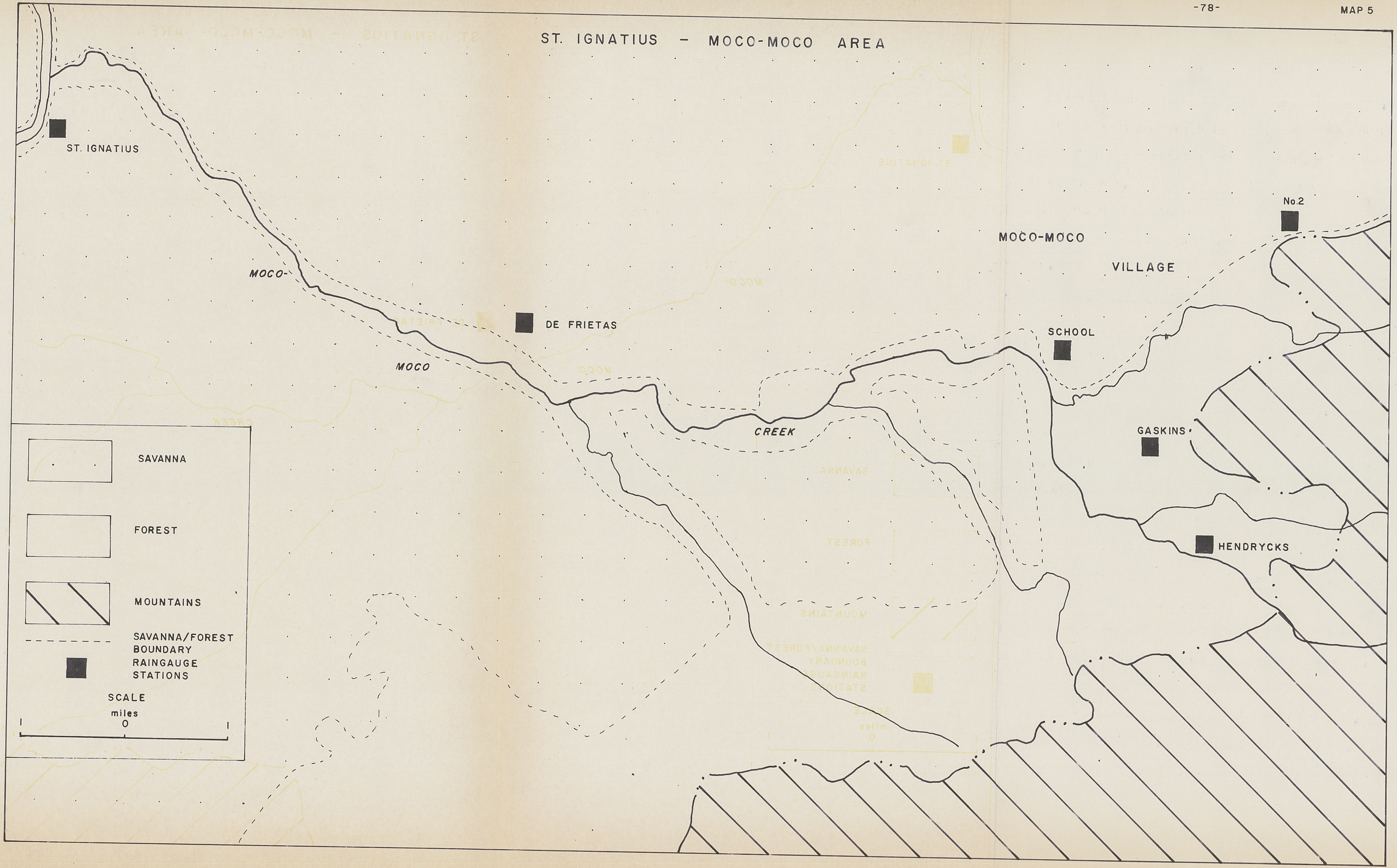
With these storm tracks in mind, the observers at St. Ignatius concluded that the mountains received more rain than the savannas at all times of year, a view with which the present author concurred. It was therefore decided to install rain gauges and other equipment to investigate this hypothesis. These stations are described in the following section.

3. STATIONS AND EQUIPMENT

The present writer was responsible for the planning and oversight of the stations described below during the summers of 1963, 1964 and 1965. During the winter the stations were supervised by other members of MUSRP. Observations were recorded by local personnel.

There is a sizable and fertile valley within the Kanukus at Moco-Moco formed by the exit of that creek from the mountains, and here a large village has grown up, with settlement both within and without the forest. As early as July 1963, it was decided to install a rain gauge in the section inside the bush, to determine if the rainfall regime differed appreciably from that at St. Ignatius, 10 miles away. The gauge has been operated by Mr. O. V. Gaskin and the station named after him. In July 1964 a pyrheliometer identical with that at St. Ignatius was installed and shortly afterwards a hygrothermograph. The latter instrument, however, has not operated satisfactorily.

A rain gauge was installed halfway between St. Ignatius and Moco-Moco on the ranch of Mr. de Freitas in April 1964, but this was read only during the wet season. These observations were resumed for the wet


ST. IGNATIUS - MOCO-MOCO AREA
ST. IGNATIUS
MOCO-
MOCO
CREEK
DE FRIETAS
MOCO-MOCO
VILLAGE
No.2
SCHOOL
GASKINS
HENDRYCKS
SAVANNA
FOREST
MOUNTAINS
SAVANNA/FOREST BOUNDARY
RAINGAUGE STATIONS
SCALE
miles
0

season of 1965.

In May 1965 additional rain gauges were installed in several locations in the Moco-Moco area and additional equipment placed at existing stations. 22 in. evaporation pans were set up at Gaskins and de Freitas and a rain gauge and pan installed at the Moco-Moco School, which is about half a mile outside the forest. In August 1965 further rain gauges were installed at site Moco-Moco 2, 2½ miles east of Moco-Moco School along the Kanuku front, and at Hendrycks, half a mile up the Moco-Moco valley from Gaskins. At the same time, additional gauges were installed in the forest at both Hendrycks and Gaskins to investigate direct arboreal interception under different canopies.

A rain gauge and pan were also installed on the property of Mr. G. Lomas in a clearing in the forest at Inaja Head. There are also rainfall records from September - December 1963 for this location, but they terminated when the observer moved to Lethem. Sporadic pan and evaporation measurements are available for several other locations around the end of the mountains, and these will be referred to when appropriate. Difficulty has been experienced, however, in finding personnel who are not only accurate and reliable but whose work does not inhibit regular daily observations.

The rain gauge at St. Ignatius is a standard 5 in. diameter bronze instrument, but for reasons of economy Marquis gauges were installed elsewhere. These are open topped, plastic wedge-shaped gauges with graduations stamped on the front for direct reading and are manufactured by the Commonwealth Plastic Moulding Pty. of Australia. They are designed to be installed at eye level for convenience in reading and in spite of theoretical considerations to the contrary their results compare very closely with those of the standard gauge. Similar results were obtained by Smith in Barbados[1].

In other places where only weekly readings were possible large capacity gauges of several types were employed. Before use they were all checked at St. Ignatius and certified as accurate.

The choice of an evaporation instrument was dictated by the availability of materials. The 22 in. pans were made by cutting standard 45 imp. gallon oil drums in half. It proved impossible to standardise the conditions under which they operated, such as the type and amount of grass surrounding them and their exposure. Furthermore small animals, frogs, snakes and lizards delighted to swim in them and unless sturdy fencing was installed cows, pigs, dogs and goats drank from them. (One observer unsuccessfully tried to prevent this last incursion by adding Javel Water, a substance whose evaporability is unknown, at least to the author). Splashing, both into and out of the pans, was experienced and much dirt entered the water. The effects of dirty water were investigated at St. Ignatius by operating a rusty pan filled with filthy water beside the standard. No difference in readings was apparent.

Advection was present but in varying amounts, for in clearings in the bush, wind is much reduced. Thus, although no measurements are available, it may be assumed that advection is far less at Gaskins and Inaja than out on the open savanna. If a comparative study were to be

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1. I. Smith - Unpublished report on Marquis Gauges. Prepared for Mannings Ltd. Barbados.

undertaken, the author would cut gas drums to class 'A' depth and install them in the usual manner of such pans, but the best instrument would be a small evaporimeter of the type developed by Tout in Barbados[2]. Briefly described, it consists of a large wooden box 6 feet from the ground with an upper surface some 30 ins. by 18 ins. covered by a bristle mat. Let into the top and flush with the mat are two 6 in. funnels, the one connected to a rain gauge, the other, filled with sand, acts as a drainage lysimeter. Provided that the lysimeter is irrigated every two days it can be read as frequently as desirable.

4. RAINFALL

We now turn to a study of the rainfall records. Unfortunately the only station in the mountains with records lasting for more than a year is at Gaskins. A comparison of the rainfall for 1964 and 1965 at Gaskins and St. Ignatius indicates that the yearly totals are almost identical in the latter year and differ by only 4.19 cms. in the former (1964 159.00 cms. and 154.81 cms., 1965 134.37 cms. and 134.21 cms.). The seasonal rainfall, however, does not correspond in the same way, in fact it is the reverse of what was expected by the author. During the dry season Gaskins receives slightly more rain than does St. Ignatius but during the wet season it receives less. Table 4 compares the dry season precipitation at the two stations for the three seasons between 1963 and 1966 illustrating the differences between them.

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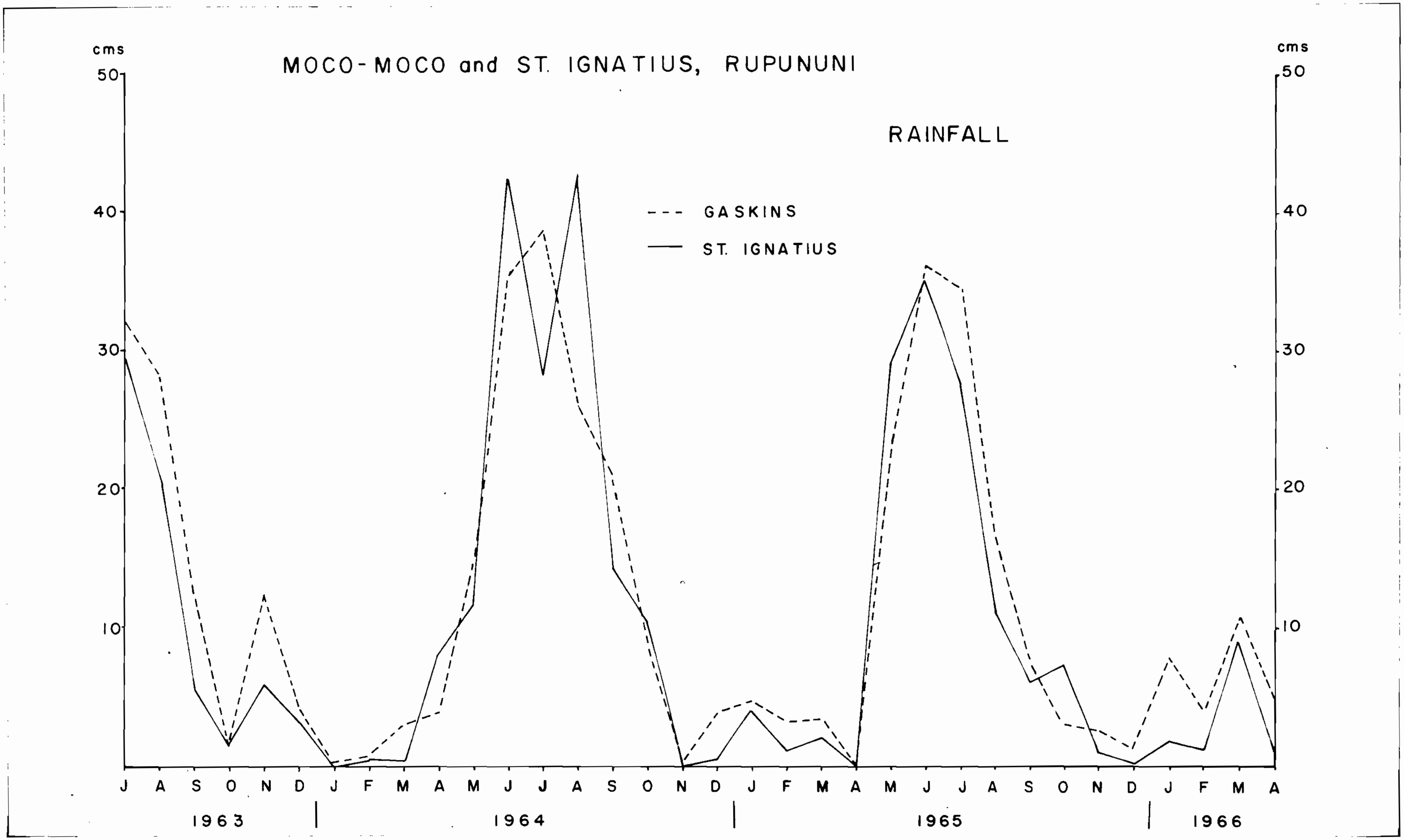
2. D. B. Tout. The evaporimeter is described in a Ph.D dissertation which he is currently preparing for McGill University, Geography Dept. under the direction of Professor B. J. Garnier.

FIG. 22

-82-



MOCO-MOCO and ST. IGNATIUS, RUPUNUNI
RAINFALL
GASKINS
ST. IGNATIUS
cms
50
40
30
20
10
cms
50
40
30
20
10
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
1963
1964
1965
1966

TABLE 4

Dry Season Rainfall at St. Ignatius and Gaskins 1963 - 1966 (cms)

Period	1963-64		1964-65		1965-66	
	Gaskins	St.Ignatius	Gaskins	St.Ignatius	Gaskins	St.Ignatius
Sept.	12.50	5.64	21.03	14.28	7.80	6.17
Oct.	1.55	1.57	8.74	10.41	3.18	7.77
Nov.	12.40	5.84	0.25	-	2.64	0.38
Dec.	3.15	0.76	3.86	0.61	1.32	0.08
Jan.	0.25	0.03	4.75	4.04	0.86	1.19
Feb.	0.76	0.43	3.28	2.90	7.98	0.84
Mar.	2.85	0.41	3.43	1.93	20.88	8.92
Apr.	3.79	8.00	-	-	5.03	0.66
Total	37.25	22.68	45.34	34.17	49.69	26.01
Diff.	+14.57		+11.17		+23.68	

The rainfall for the two intervening wet seasons, as presented in Table 5, suggests that during the wet season St. Ignatius receives more rain than does the mountain fringe. This indication cannot be stated more definitely because in July and August 1963 Gaskins precipitation exceeded that of St. Ignatius during both months. In the light of the storm paths previously mentioned and the orographic effects anticipated, it appeared doubtful if the Gaskins site was representative of the Moco-Moco area.

Accordingly, the rain gauge records for the other sites in the neighbourhood were examined to see if they indicated any great increase in rainfall (Table 6). The rain gauge at Moco-Moco School provided an important check as it receives rainfall from showers which proceed parallel to the mountain front but do not extend over it to any great extent and the instrument at Moco-Moco 2 performs a similar function. The gauge at Hendrycks will, in the future, perform a useful function recording conditions further into the mountains, but for the present work it was installed too late to provide other than an indication of conditions at the end of the wet season.

TABLE 5

Wet Season Rainfall at St. Ignatius & Gaskins 1964-1965 (cms.)

Period	1964		1965	
	Gaskins	St.Ignatius	Gaskins	St.Ignatius
May	14.45	11.91	22.76	30.10
June	34.01	42.32	36.28	36.27
July	38.61	27.94	34.61	35.23
Aug.	26.21	42.67	16.80	11.41
Total	113.28	124.84	110.46	113.01
Diff.		+11.56		+2.55

continued over

TABLE 6

Wet Season Rainfall at Moco-Moco Stations 1965 (cms.)

Period	2	School	Gaskins	Hendrycks	St. Ignatius
May 1-22			3.21		13.99
23-31		Installed	19.55		16.11
June 1-10		13.46	10.81		25.51
11-30		24.70	25.47		16.15
July 1-31		36.66	34.61		35.25
Aug. 1-5	Installed	2.95	3.26		2.44
6-13	1.83	3.71	3.40		0.84
14-19	7.11	7.96	7.29	Installed	2.34
20-27	0.89	Rg.U/S	2.40	3.35	0.91
28-31	1.07	1.08	0.45	0.69	1.80
Sept. 1-4	-	-	-	-	4.11
5-11	12.15	4.42	5.11	8.03	0.71
12-24	2.03	3.12	2.70	3.26	1.07

Totals:

June 1 - Sept. 24 X	N/A	98.06	93.10	N/A	91.13
Aug. 20 - Sept. 24	16.14	N/A	10.66	15.33	8.60
Aug. 6 - Sept. 24	25.08	N/A	21.35	N/A	11.78
May 1 - Sept. 24	N/A	N/A	118.27	N/A	121.23

X less August 20 - 27th.

The various totals provided in Table 6 indicate that throughout the wet season and into the dry, Gaskins site receives less rain than do the surrounding areas. This suggests that the edge of the mountains receives as much rain as St. Ignatius during the wet season and probably more during the dry season than the figures for Gaskins suggest. It is appreciated that in a mountainous area, such as the Kanukus, local rain shadows and orographic effects will be important but for the present ecological study a more generalized figure is better. For this reason the Moco-Moco Gaskin figures are to be regarded as the minimum rather than the average for the mountain front.

The orographic effects may also spread out from the mountain edge in a diminishing fashion towards St. Ignatius. To investigate this possibility the rainfall figures from the stations along the Moco-Moco Creek (St. Ignatius, de Freitas, School and Gaskins) were compared. While small differences do appear the agreement is remarkably good, implying that in this area the orographic effects, if present, extend further out beyond St. Ignatius into Brazil.

TABLE 7

Rainfall between St. Ignatius and Gaskins 1965 (cms.)

Period		St.Ignatius	de Freitas	School	Gaskins
May		20.10		Installed	22.76
June 1-10		26.51	Installed	13.46	10.81
11-30		16.15	34.09	24.70	25.47
July		35.25	31.88	36.66	34.61
Aug.1-19		5.62	8.36	14.62	13.95
20-27		0.91	1.50	Rg.U/S	2.40
28.31		1.80	1.83	1.08	0.45
Sept.1-11		4.88	2.92	4.42	5.11
12-24		1.07	N/A	3.12	2.70
Totals:					
May 1 - Sept.24		121.23	N/A	N/A	118.27
June 11 - Sept.11.		75.55	80.58	N/A	82.00
July 11 - Sept.11	X	74.64	79,08	84.60	79.60
July 1 - Sept.24		101.15	N/A	98.06	90.41

X omitting August 20 - 27th.

Information on conditions further north is lacking but the few records available at Manari Ranch indicate a slight dryness. It seems safe, however, to regard St. Ignatius as typical of a wide area about it.

Thus far it has been shown that a small increase in rainfall does exist between St. Ignatius and Moco-Moco and most significantly that this difference occurs during the dry season. Even though the increase is recorded at the time when it is most needed it is insufficient to account for the changes in vegetation which are observed. Therefore a more detailed investigation of moisture conditions is undertaken within the framework of the water balance beginning with a consideration of the theoretical reasons for a more favourable water balance at Moco-Moco.

5. THEORETICAL REASONS FOR A MORE FAVOURABLE WATER BALANCE

Three main theoretical reasons support the view that more rain is to be expected both along the mountain front and within the main body of the massif than on the open savanna. First the presence of a large mountain mass will produce orographic uplift. This does occur in the study area in striking form, for there are many days when little cloud passes over the savanna but a towering cloud street lies along the edge of the mountain, orientated down wind. A less common occurrence is for a cloud street to develop along the Pakaraimas also and for the two to meet far to the east and to the west, completely encircling the savannas. On most occasions, however, the orographic effect is less marked and it is only with care that the clouds over the mountain front can be recognized as either taller or larger in area than those over the savannas. The author has not observed any instances of heavy cloud or rain over the savannas unaccompanied by cloud along the mountain front, and this suggests that the orographic effect is always important.

Secondly, clouds will form over the mountains more rapidly than over the savanna for other reasons than simply the orographic uplift. Because the mountain sides are so steep, especially on the east and south east sides, these slopes will present a surface more nearly normal to the insolation than will the savanna surface during the early morning from sunrise to 0900 hrs. Thus these slopes will receive far more heat than will the level savannas. At 0800 hrs., for example, on the date when the sun is overhead at noon, a slope with an angle of 30°, facing the sun, will receive twice as much insolation per $cm.^2$ as does the savannas. Strong thermals will result and clouds form. This theoretical conclusion corresponds closely with actual observations made on clear mornings, when, between 0730 and 0830 hrs. the first small cumulus humilis develop over the Kanukus seemingly far to the east where the mountains are reportedly higher. The presence of many differently orientated facets of mountainside will thus produce strong up and down drafts as the day progresses. These are highly conducive to cloud formation and maintenance and help develop them to a size from which precipitation can take place.

Lastly, the fact that the vegetation on the mountains differs from that of the savannas should be considered. Conflicting evidence has been presented in the literature on the problem of transpiration rates of trees and grasses, but most workers agree that colour, season and size of plant make a considerable difference. The argument then progresses along the line that if some plants transpire more, the air above them will be more humid, thus increasing the likelihood of rain. Penman (1963) has, however, quoted various investigations in tropical Africa and the western U.S.A. which indicate that if such a closed cycle does exist within the rainfall budget, it is small, and that the relative differences are even smaller, so that any effect on annual totals is negligible. This matter is not introduced with the intention of making a positive statement as to whether vegetation does affect the rainfall, but rather to suggest that if it does, the effect must be to slightly augment the other two effects discussed previously.

All of the processes mentioned so far as potential methods whereby rainfall is increased, will obviously produce more cloud over the mountains than out over the savanna. The direct effect of such a cloud increase will be a reduction in the amount of incoming solar radiation because of reflection from the upper surfaces of the clouds, but due to the dispersal of such cloud at night there will be no proportional increase in net radiation. The difference in diurnal cloud amounts will presumably be marked most during the wet season and less towards the end of the dry. Shadow effects in narrow valleys will further decrease the amount of radiation received, as also will the angles of the slopes at midday. Under the same conditions as quoted previously but at 1200 hrs., the difference of receptivity between a flat surface and the slope will be 50% lower for the latter. Thus the amount of energy available for evaporation and transpiration will be sharply lower in the mountains than out on the savannas. Thus the mountains in comparison with the savanna may be expected to receive more rain and less radiation to produce a more favourable water balance, at least in the dry season.

6. RADIATION

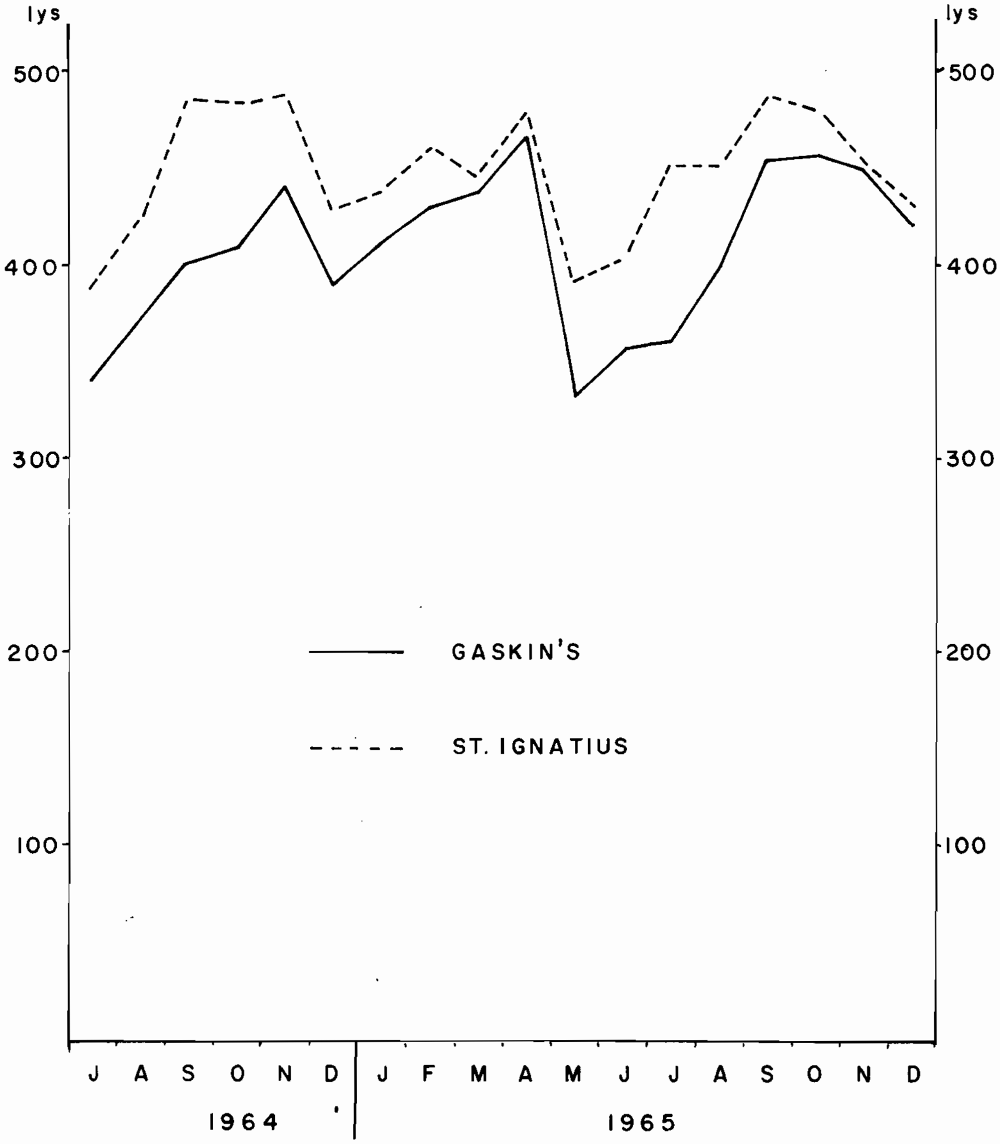
It was remarked above that due to increased cloudiness over the mountain front, this area receives less radiation than does the open savanna. The measurements of insolation at Gaskins confirm that it is indeed lower than at St. Ignatius at all times of year. The difference is least pronounced during the last month of the periods of maximum insolation, that is to say November and April and most noticeable in the period of minimum insolation. In December and January, when the sun is lowest in the sky, the resultant lack of insolation is of the same magnitude at both stations. However, after these months and after the period of low insolation during the rainy season, the amounts of insolation received at Moco-Moco increase less rapidly than those at St. Ignatius due to the greater prevalence of cloud. It is only at the end of the equinoctial periods when the atmosphere is dryest that the clouds disperse sufficiently to permit almost equal radiation readings.

In absolute values insolation has varied from a high of 465 lys. day^{-1} after the equinoxes to a low of 332 lys. day^{-1} at the beginning of the wet season. The yearly total in 1965 was 150.3 Cal. $cm.^{-2}$ compared with 164.0 Cal. $cm.^{-2}$ at St. Ignatius, or a difference of about 8%. The radiation at Gaskins from July 1964 to December 1965 is presented in Fig. 23 and it is contrasted with the radiation at St. Ignatius for the same period.

MOCO-MOCO, RUPUNUNI

INCOMING SOLAR RADIATION

lys. per day



7. THE WATER BALANCE

Reliable evaporation measurements are available for three months (July - September 1965) during the period when AE may be presumed to equal PE. There is also a value for June, tabulated below but because there were difficulties with the instrument during that month the readings are not utilized. The three remaining averages cannot be considered to be completely accurate because of the general difficulties with the instrument discussed earlier. If, however, they cannot be regarded as providing an absolute figure, they do present a standard of comparison with the St. Ignatius figures sufficient to permit an assessment of the differences between savanna and forest. The evaporation is much lower at Moco-Moco, due not only to the reduced insolation, but also to the lower wind speeds within the mountains. A general confirmation of these points is provided by the readings available for Inaja in May, June and August.

The only parameter measured at Gaskins which will enable the evaporation to be calculated from it for any lengthy period is the radiation. It is not possible at Moco-Moco to produce a regression equation with measured evaporation because so few values are available for the latter. Nevertheless when graphed against radiation the three values available produce an astonishing straight line relationship. This has an intercept value (plotted by eye in Fig. 24) of 170 lys. which, in the light of lower wind speeds, compared with 103 lys. for St. Ignatius, seems to be high but not badly so.

FIG. 24

MOCO-MOCO, RUPUNUNI

RADIATION vs EVAPORATION

Intercept 170 lys

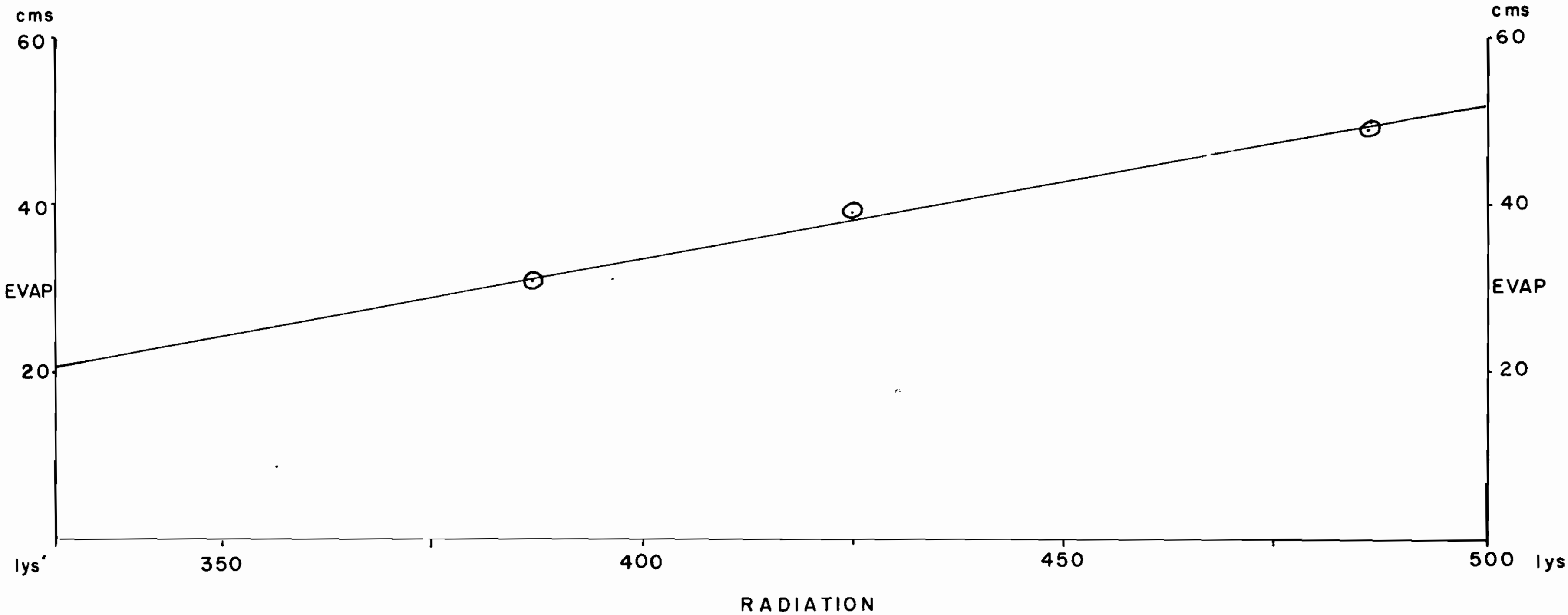


TABLE 8

Evaporation at Stations between St.Ignatius and Moco-Moco
(Wet Season 1965)

Month	St.Ignatius		de Freitas	School	Moco-Moco: Gaskins			Inaja
	Measd.	Compd.	Measd.	Measd.	Measd.	Compd.1	Compd.2	Measd.
May	0.56	0.46	-	-	-	0.36	0.26	0.13 X
June	0.52	0.48	-	-	(0.37)	0.40	0.30	0.30
July	0.57	0.55	0.49	0.45	0.31	0.41	0.31	
Aug.	N/A	0.55	0.55	(0.60)	0.39	0.47	0.38	0.43
Sept.	0.76	0.61			0.49	0.56	0.49	N/A

1 - St. Ignatius Regression
2 - Moco-Moco Regression
X 23 - 31 only.

Long term evaporation figures at Moco-Moco Gaskins have been computed using both the St. Ignatius and the Gaskins regression lines to provide both maximum and minimum figures. It is considered, however, that the latter figure is closer to the true values than the former. Table 8 above indicates the differing results that stem from using the two calculations and also the measured evaporation at the various places around Moco-Moco - St. Ignatius.

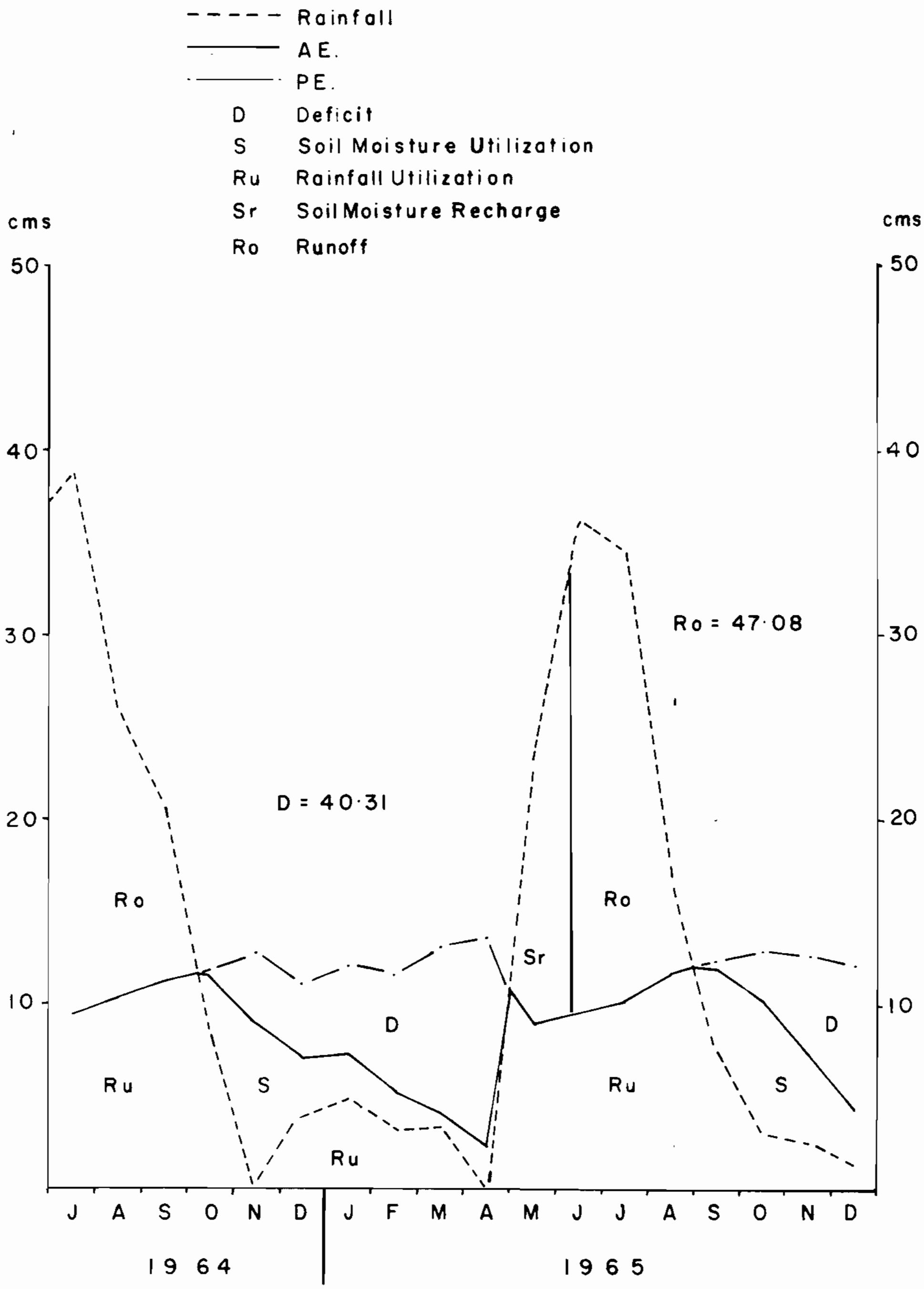
The water balance has been calculated using both evaporation figures and the calculation incorporates the same assumptions as the one for St. Ignatius, namely, that transpiration takes place at only 80% of the rate for open water evaporation and secondly that the soils have a field capacity of 25.00 cms. The latter assumption is satisfactory for the valley floors where deep sediments have collected but on the valley sides the depth of actual soil is slight compared to the amount of broken rock making an estimate of soil field capacity virtually impossible.

Both calculations (see Figs. 25 and 26) present significant differences from the St. Ignatius water balance for both seasons of the year. Runoffs are naturally much larger, being respectively 150% and 182% of those at St. Ignatius, but this increase is not harmful to plant growth as it does not remain within the mountains but rather flows out to aggravate the problem in the savannas. On the other hand the difference in dry season moisture deficits are equally marked, 74% and 52% of that at St. Ignatius, and this has a profound effect on the ecological conditions. Taking an average figure it can be said that during the 1964 - 1965 dry season the moisture deficit was at least 20 cms. less at Gaskins. It should be noted also that as Gaskins is thought to be in a rain shadow the difference from the savanna is probably in general even greater.

The admittedly scanty evaporation data presented in Table 8 suggests an additional use for the two calculations of the water balance at Gaskins. The data presented for Inaja, the other forest evaporation site, support the suggestion made earlier that the second calculation of evaporation is the more correct for Moco-Moco within the forest. In this case the other calculation could well apply to the Moco-Moco School site. Cloud observations from St. Ignatius suggest that the insolation would vary little from Gaskins to the School and if it did increase towards the latter, the increased rainfall would probably compensate for it. Furthermore the use of the St. Ignatius regression, with its higher wind speed and lower humidity factors built in, is eminently more appropriate at the School. Lastly, it should be noted that the

MOCO-MOCO, RUPUNUNI

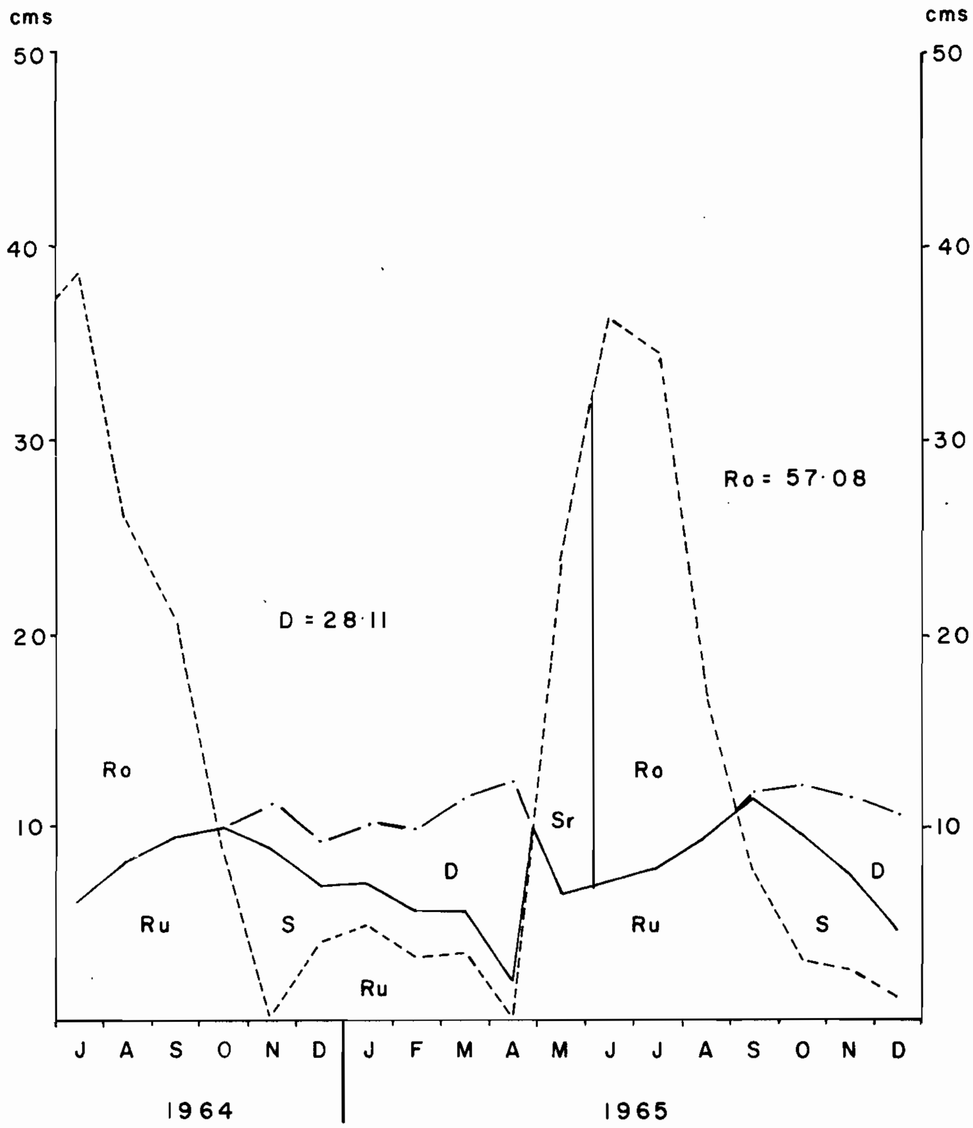
WATER BALANCE



ST. IGNATIUS REGRESSION

MOCO-MOCO, RUPUNUNI

WATER BALANCE



GASKIN'S REGRESSION

data for de Freitas is more akin to that at St. Ignatius, suggesting that the mountain effects do not extend that far into the savannas.

8. CONCLUSIONS

The work presented above is tentative in nature as it is based on only one year's records and any conclusions drawn from it must remain to an extent speculative. It is hoped that further work on evaporation and insolation at both Gaskins and the School will permit more definite conclusions in a few years time.

It has been shown, however, that during the dry season there is a significant decrease in the moisture deficit both within and along the edge of the Kanuku Mountains. The implications of this decrease cannot be assessed by Aubréville's method as they stem more from a decrease in PE than from an increase in available moisture. Holmes and Robertson (1963), among others, have pointed out that the amount of moisture deficiency correlates far better with the yield of agricultural crops than does the amount of moisture available. It is to be presumed that natural growth is similarly influenced.

Thus the author believes that the difference in moisture deficit is a major reason for the presence of forest growth in the mountains and not in the savannas. Bearing in mind the observations of Kesel at Nappi, cited earlier (page 25), that the forest appears to have retreated from the savanna surface, the author is of the opinion that forest should be present on the Moco-Moco flats adjacent to the mountain front. At this time it is not possible to do more than speculate on possible reasons for its absence, but the author suggests that adverse edaphic conditions or anthropic activity are the most likely.

CHAPTER IV

FURTHER OROGRAPHIC EFFECTS

In spite of the conclusions in the previous chapter the author believes that areas do exist where orographic effects produce markedly different rainfall regimes from those of the open savanna. Such areas lie in the lee of the Pakaraima and Kanuku Mountains, that is to say along their southern boundaries, and it is proposed that here the rainfall is sufficiently reduced to have ecological repercussions.

Evidence that such a phenomenon may be present has been referred to in Chapter I (see page 20), where the pattern of vegetation along the southern flanks of the Pakaraima and Kanuku Mountains was described. It was noted that in these areas savanna vegetation tends in places to extend up into the mountains from the plains in a seemingly inexplicable arrangement. Furthermore, in the area of Good Hope, where the Rio Ireng emerges from the Pakaraimas, there are several hills, detached from the main mountain mass, which have forest growth on their north sides but savanna on their southern flanks. Fanshawe's (1952) description of the vegetation of the Pakaraimas as Dry Evergreen adds weight to the supposition that rain shadow effects are in operation. Similar situations to those described at Good Hope are visible along the southern flanks of the Kanuku Mountains, near Mountain Point especially, suggesting that there too, similar causes are responsible.

The exact effects of the Guiana Shield on the climate of the area around it are not fully understood, but a probable effect, divergence of the second wet season, was discussed in Chapter II (page 33). There is, however, no doubt that it acts as a partial barrier to the further penetration of the North East Trades into the continent. The enforced rise of these winds to pass over the mountains produces high rainfalls all along the north and east faces of the Shield from Kanupukari where the effect is slight to stations far into the North West District. Potara is typical of stations along the mountain edge receiving some 325.00 cms. of rain, well distributed throughout the year but with both wet seasons showing clearly. Map 6, Preliminary Rainfall Map of Guyana, shows both the increased rain along the mountain front and also its decrease on top of the Highlands and towards the southwest.

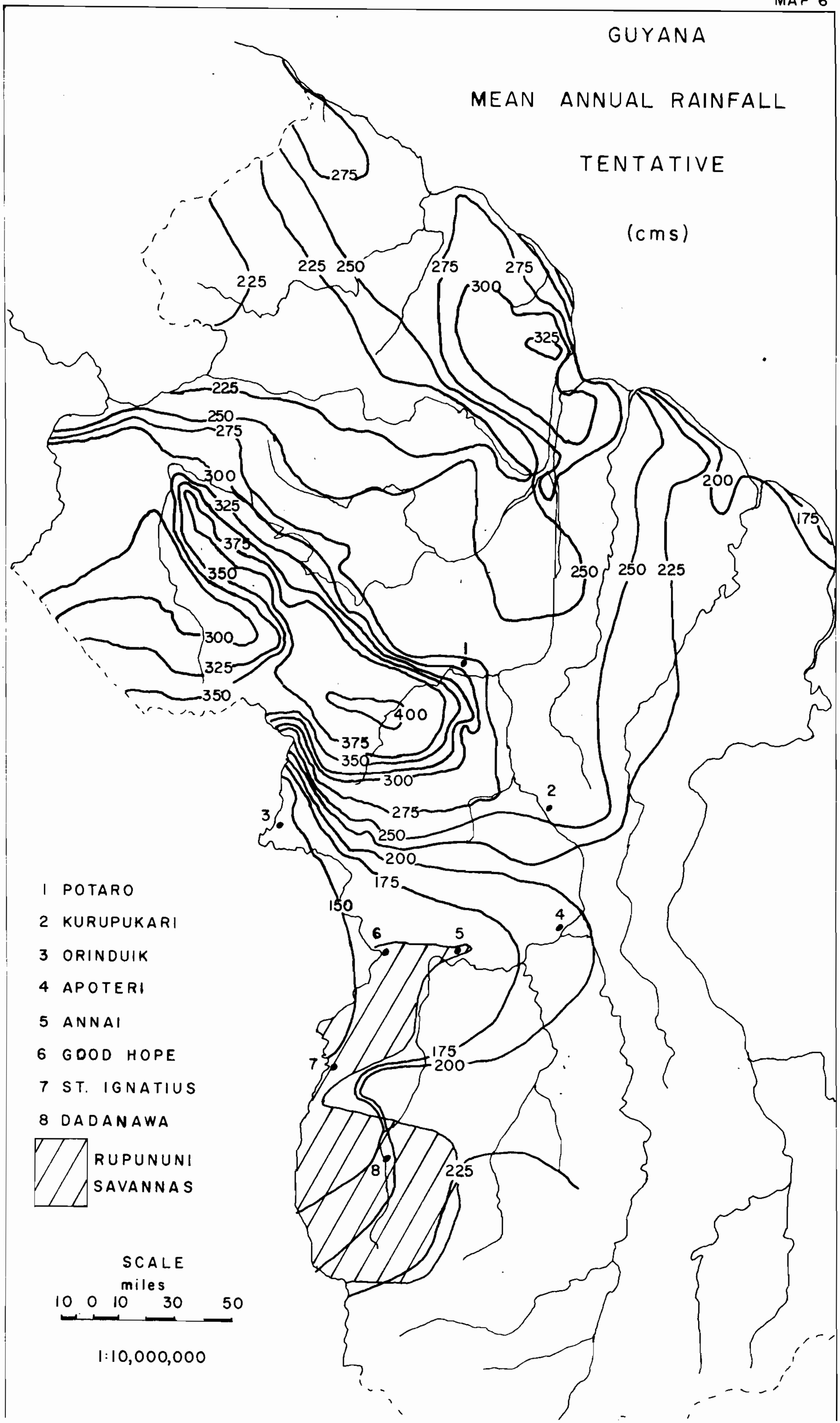
Although there is insufficient evidence definitely to identify a rain shadow in the lee of the Pakaraimas the orographic effects described above give evidence to such a belief. The author proposes, therefore, to study the long term rainfall records of the Rupununi for further indications of such a process.

1. ANNUAL DISTRIBUTION

There are only seven rainfall stations in the general area of the Rupununi - Rio Branco whose records extend for long enough periods that they can be considered as representative of the general climate. Although they all have observations for more than 10 years the periods are not coincidental.

Two of the stations, Kurupukari and Apoteri, are in the forest to the north and east of Annai on the Essequibo River. The former is at the crossing of the Essequibo by the disused cattle trail from Annai

MAP 6


GUYANA
MEAN ANNUAL RAINFALL
TENTATIVE
(cms)
275
225
225 250
275
275
300
325
225
250
275
300
325
375
350
300
325
350
400
375
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275
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1
2
3
4
5
6
7
8
175
200
225
1 POTARO
2 KURUPUKARI
3 ORINDUIK
4 APOTERI
5 ANNAI
6 GOOD HOPE
7 ST. IGNATIUS
8 DADANAWA
RUPUNUNI SAVANNAS
SCALE
miles
10 0 10 30 50
1:10,000,000

to the Berbice River while the latter is at the confluence of the Essequibo with the Rupununi River. Kurupukari is really in a different province from the savannas for it lies beyond the Guiana Highlands on the edge of the coastal lowlands. Even though it is over 100 miles from the coast, it receives a similar amount of rain to that received at Georgetown (Georgetown 253.87 cms., Kurupukari 261.77 cms.), the slight increase being due to orographic activity caused by the proximity of the edge of the Highlands. Even more importantly, the shape of its rainfall distribution is similar to that of Georgetown, having a permanent second wet season.

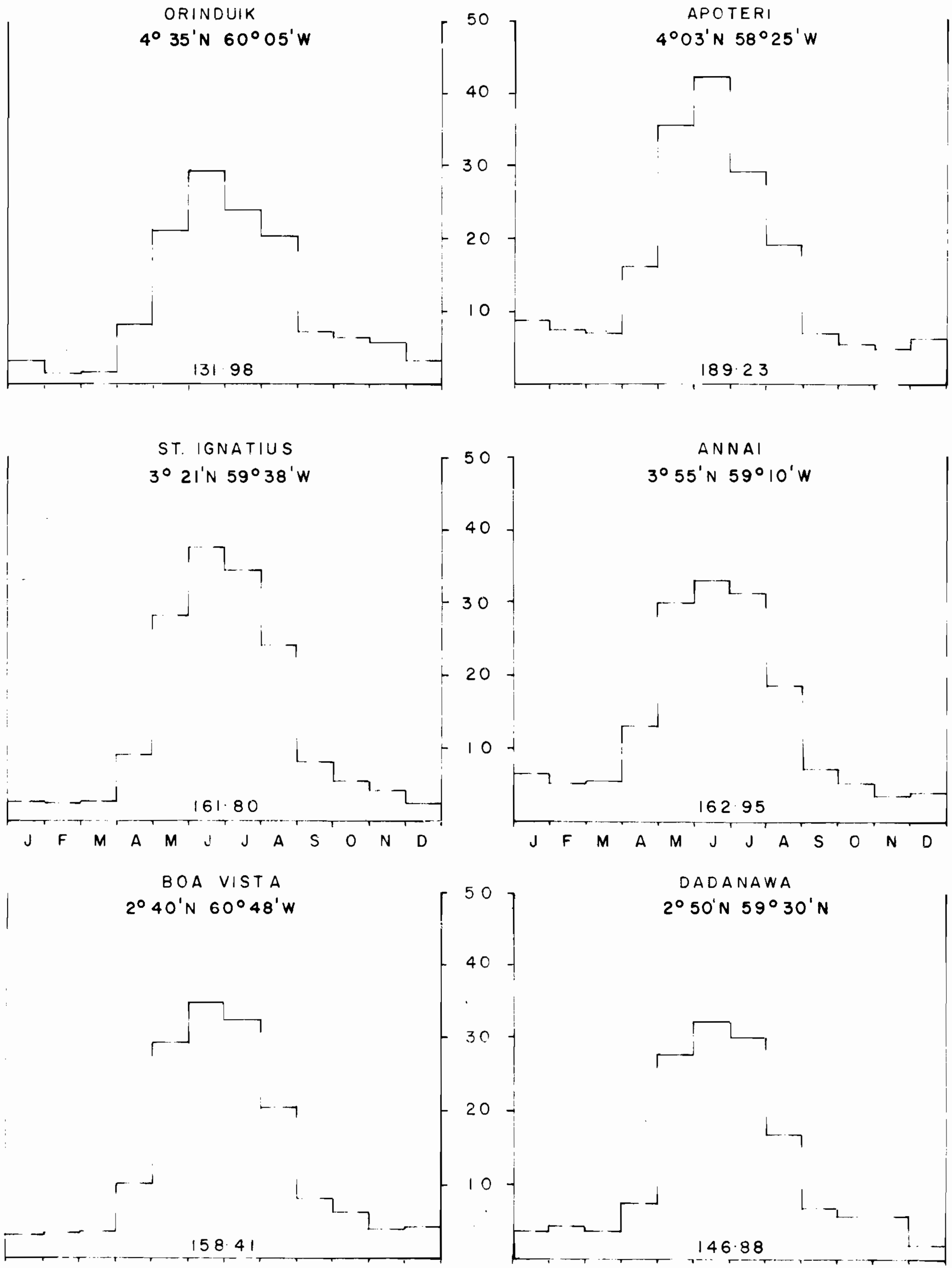
Apoteri lies far to the south of the mountain edge in a low area in which lay the former courses of the Proto-Berbice. It receives a lower annual rainfall (189.23 cms.) than Kurupukari due to its distance from the coast and the absence of the mountains, but it is more accessible for moisture moving inland and thus receives higher rainfall than the savannas. The second wet season can be recognized but it is by no means as significant as that at Kurupukari. (Unless otherwise noted it will be understood that in the following discussion the Wet season lasts from May to August and the Dry season from September to April).

	Wet Season	Dry Season	% Dry of Total
Kurupukari	142.48	119.29	42%
Apoteri	126.13	63.10	33%

Presumably the same mechanism that prevents the second wet season from occurring in the savannas is also operative over Apoteri but with slightly weaker strength.

FIG. 27

RUPUNUNI DISTRICT, LONG TERM RAINFALL STATIONS



The station at Orinduik lies north and west of the savannas within the Pakaraima Highlands on the Brazilian border. It lies at a height of approximately 3,000 ft. within one of the largest areas of mountain savanna and is for this reason of considerable interest. The whole area receives notably less rainfall than does the savannas and furthermore it has no traces of the second wet season apparent in its seasonal distribution. The area appears to be shaded by the higher table lands of Roraima Sandstone that lie to the north culminating in Mount Roraima at over 9,000 ft. The most revealing feature of the annual rainfall distribution is the dry season rainfall, for although the annual total (131.98 cms.) is far below that of St. Ignatius (161.80 cms.) the dry season rainfall at the two stations September - April is virtually identical (37.10 and 37.44 cms. respectively). The most probable explanation is that the higher areas generate rain in the dry season in a similar fashion to the Kanuku Mountains.

The other four stations, Annai, St. Ignatius, Boa Vista and Dadanawa are within the Savannas but are spread out over it to provide a reasonable coverage. The first three are almost in a straight line stretching from the north-eastern corner of the savanna well towards its south-western extremity. Thus, with the prevailing wind lying in the ENE octant for most of the year, they may be regarded as lying downwind from Annai to Boa Vista. In this respect perhaps it is unfortunate that they do so, for there will be a tendency for storms to move down the line from one to the other. This feature appears to be reflected in their annual rainfall totals, but a closer examination indicates that their seasonal distributions are slightly different (see Table 9).

TABLE 9

Seasonal Rainfall in the Savannas

	Orinduik	Annai	St. Ignatius	Boa Vista	Dadanawa
Wet	94.88	113.13	124.36	115.56	106.59
Dry	37.10	49.82	37.44	42.85	40.24
Total	113.98	162.95	161.80	158.41	146.83

It will be immediately appreciated that St. Ignatius has a more severe climate than the other two stations because it receives more rain during the wet season and less in the dry. The much larger amount of dry season rainfall received at Annai has been previously explained by the partial occurrence of the second wet season. The explanation in terms of the orographic effect of the Kanuku Mountains for the larger wet season rainfall at St. Ignatius is satisfactory to account for the way in which St. Ignatius differs from both Annai and Boa Vista which display a recognizable similarity. The difference between St. Ignatius and Boa Vista during the dry season cannot be so definitely explained. A possible reason is that the strong dry season winds prevent some of the showers generated along the Kanuku front from penetrating into the savanna in the direction of St. Ignatius. They are rather blown down wind in the direction of Boa Vista, a few of them reaching that area before dissolving.

The final long term rainfall station is located on the Dadanawa Ranch, near the Rupununi River, some ten miles before it enters the Kanuku

Mountains. The station is of particular interest as it is the only one in the south savanna, for although Boa Vista is on a latitude suitable for inclusion it does not have the Kanuku Mountains to the north. Dadanawa is significantly dryer than any of the other three savanna stations in its yearly total, but during the dry season it receives rainfall comparable to that of Boa Vista. The problem is then to explain its lower wet season rainfall. A further difference that will be of assistance in finding an answer to the problem is the lower number of rainfall days during the wet season at Dadenawa compared with St. Ignatius, 52 as against 88. This suggests, and the author's observations confirm, that light, small showers are almost unknown at Dadanawa and only large and violent storms are experienced. Thus the conditions suitable for the generation of large storms are almost equally present between the two stations, but there is no range of mountains to the east of Dadanawa to generate smaller showers that would provide the other 10 - 12 cms. of precipitation.

These investigations have not contributed any proof either for or against the hypothesis that orographic effects are causing less rain in the lee of either the Pakaraima or Kanuku Mountains. To provide additional evidence the recent rainfall record at Good Hope must be employed. This station has only operated during 1965 so that no mean figure for the rainfall at that location can be presented at present. It is possible, however, that an examination of the correspondence in rainfall records between nearby stations may provide a method of assessing the likely mean rainfall at Good Hope. Because 1965 was a dry year, this problem will be dealt with under the heading of Wet and Dry Years.

2. WET AND DRY YEARS

It was noted in chapter II that the rainfall at St. Ignatius is highly variable in character and this has been graphically presented in Fig. 5. The other long term stations have equally unreliable rainfall amounts as seen in Table 10.

TABLE 10

Rainfall Variations:- Savanna Stations

	St. Ignatius		Annai		Orinduik		Boa Vista		Dadanawa	
Av.	161.80		162.95		131.98		158.41		146.83	
High	214.0	113%	212.37	130%	169.93	129%	235.91	149%	227.56	155%
Low	107	66%	104.67	64%	71.07	56%	109.94	69%	98.45	67%

It can be seen that, with the exception of Orinduik in the Pakaraima Highlands, the savanna stations all have similar ranges and any discrepancies can be ascribed to the differing lengths of record and the years embraced by the records. Orinduik, on the other hand, has a lower bottom range even though it does not embrace any years of particularly hard drought, such as 1939 - 1941. It is presumed that with an adequate length of record ~~that~~ this station would prove to have even dryer years. Without being proved statistically, it appears that the savanna stations have equal variability as well as equal range. Eden (page 46) has computed the deviations for St. Ignatius and Annai as 17% and 15% respectively.

In this case the obvious line of investigation is to discover if all the stations experience high and low years together or whether there is in fact any relationship at all between their variations. To study this point the annual rainfall totals of each station were examined from 1935 to 1965 to see if they were high, average or low. The results of this investigation are presented in Table 11.

TABLE 11

High and Low Annual Rainfall. Long Term Stations of the Rupununi 1935 - 1965

Year	Forest		Mtn.Savanna	Rupununi Savannas			Rio Branco	Result
	1	2	3	4	5	6	7	
1965		L	L	L	L			L
1964		L	L	L	L			
1963		N/R	H	H	H	L		Av
1962		L	H	L	H	Av		
1961		L	Av	L	L	L	L	L
1960		H	Av	H	H	H	H	H
1959		L	H	L	L	L	N/R	
1958		L	L	L	L	L	H	L
1957		L	L	L	L	L	N/R	
1956		Av	Av	L	Av	H	N/R	Av
1955		H	H	L	Av	H	N/R	
1954		H		H	H	H	H	
1953	H	N/R		H	N/R	L	N/R	
1952	H	N/R		Av	N/R	N/R	N/R	H
1951	H	L		H	H	H	H	
1950	L	L		L	H	H	H	
1949	H	H		H	H	H	N/R	
1948	L			Av	Av	N/R	N/R	
1947	H			L	N/R	N/R	N/R	
1946	L			N/R	L	N/R	N/R	Doubtful
1945	L			N/R	H	H	N/R	
1944	H			N/R	Av	H	N/R	
1943	H			Av	H	H	H	
1942	L			H	H	H	H	H
1941	L			Av	L	L	L	
1940	L			L	L	L	L	L
1939	L			L	L	N/R	L	
1938	H			H	H	L	H	
1937	H			H	H	H	H	H
1936	L			H	H	L	L	
1935	L			H	L	H	Av	Av

1 - Kurupukari 2 - Apoteri 3 - Orinduik 4 - Annai
5 - St. Ignatius 6 - Dadanawa 7 - Boa Vista

This table indicates that there are high and low years generally throughout the savannas, although there are also confused periods when no pattern can be easily recognized.

As there seem to be years when all the stations differ from the average in the same way it is reasonable to attempt a correlation of these differences. Such a correlation was attempted initially between Annai and St. Ignatius because their means are so close.

TABLE 12

Annual Rainfall as a Percentage of the Mean for Orinduik, Annai and St. Ignatius 1954 - 1965

Year		Annai	St. Ignatius	Orinduik
1965		74	83	86
1964		86	98	54
1963	X	128	112	116
1962		96	115	109
1961		82	88	102
1960	X	124	105	103
1959	X	102	83	120
1958		67	82	83
1957		68	86	90
1956		83	103	98
1955		82	99	128
1954	X	126	115	

X Unusual years at Annai

Only readings subsequent to 1954 were used in the scattergrams to avoid any breaks in the records and also because before that date there are occasional discrepancies between the records at Lethem and those in Georgetown. The scattergram was drawn using these data (Fig. 28). A clear relationship was apparent as applying to the majority of years and a second was also visible as applying to approximately one third of the

NORTHERN RUPUNUNI

RAINFALL CORRELATION

ANNAI and ST. IGNATIUS

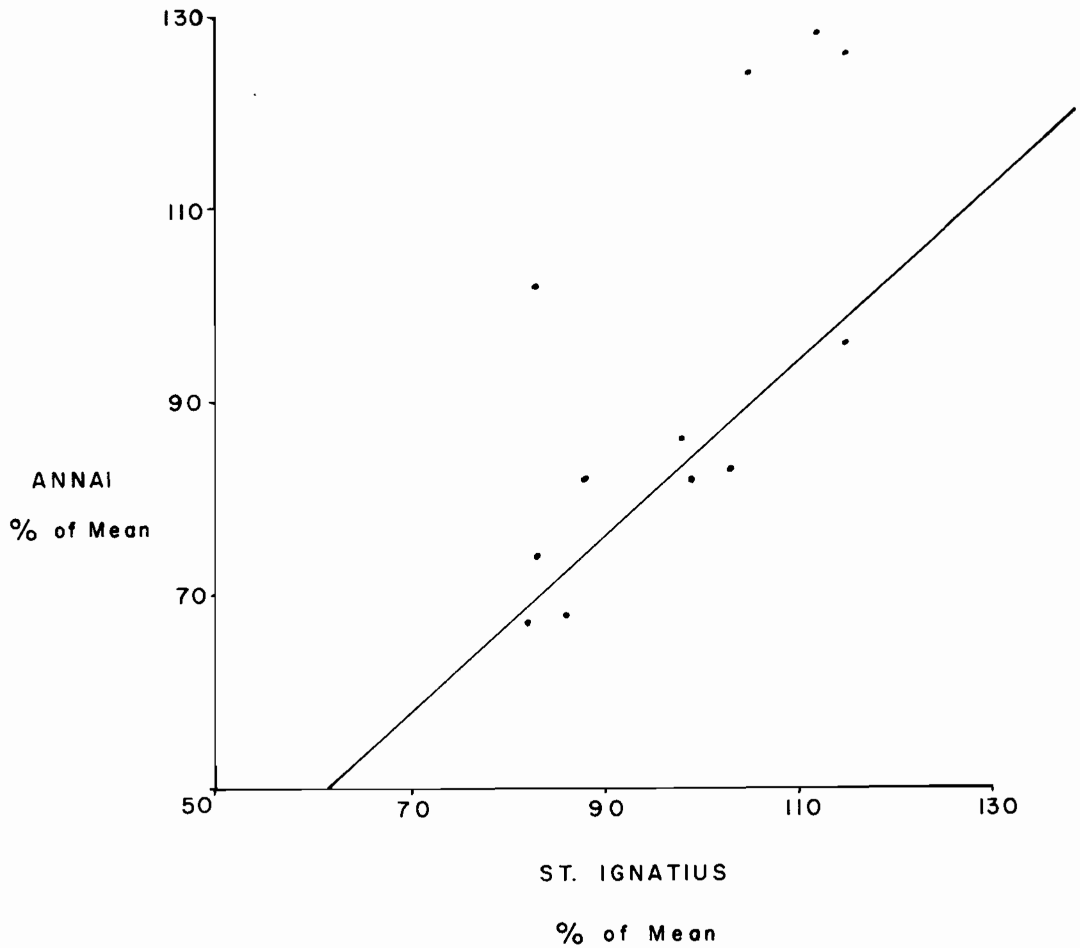


FIG. 28

years. During the latter years the Annai total is uncharacteristically far above that of St. Ignatius. Thus in most years Annai receives less rainfall than does St. Ignatius as a result of two processes. The first, orographically induced rainfall from the Kanukus at St. Ignatius, has already been discussed but the other, a rain shadow effect at Annai has not yet been introduced. It is not possible at present to assign values to either effect, but it is reasonable to assume that both are operative.

The reasons for the years when Annai rainfall is far above that at St. Ignatius are not easily understood. An examination of the two rainfall records shows that the difference is wholly attributable to the wet season. In two cases the wet season commenced earlier at Annai, in another case it ended markedly later and in the last instance there was much higher rain in June and July. It is assumed that the reasons for these differences are due to oscillations of the convergence zone for meteorological rather than climatological reasons and are thus beyond the scope of the present discussion.

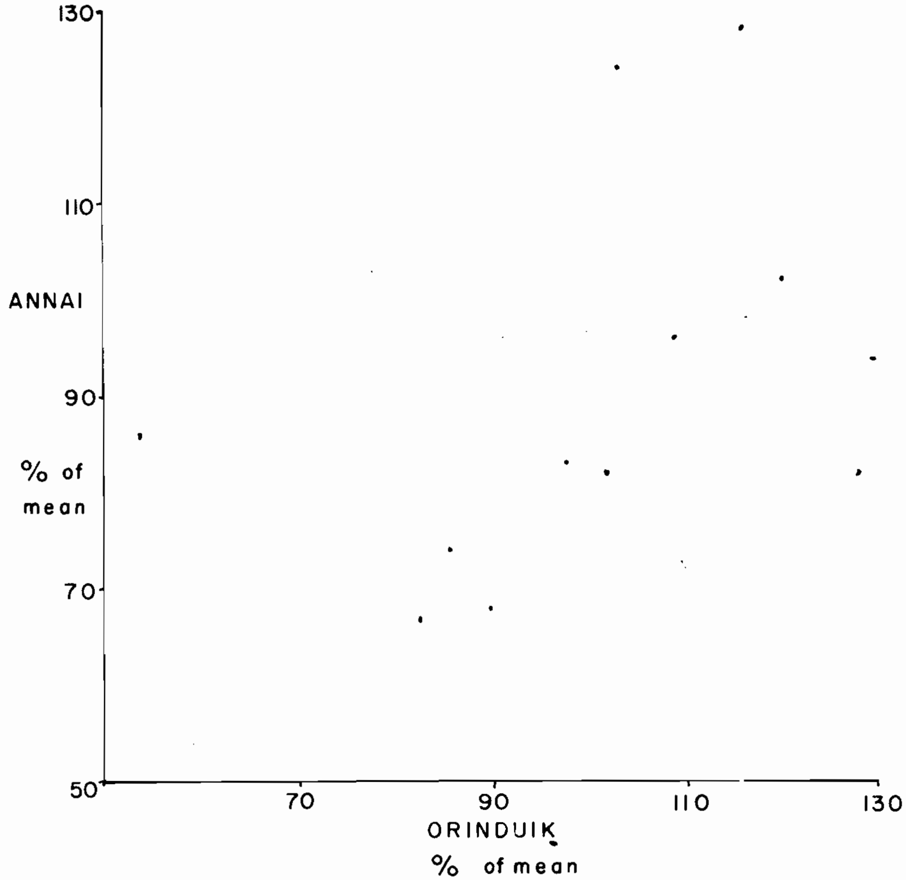
A similar scattergram for Annai versus Orinduik (1955 - 1965) produced essentially similar results but when St. Ignatius was substituted the relationship was less distinct (see Fig. 29). Nevertheless it was apparent that Orinduik and St. Ignatius tend to have each year approximately the same proportion of their average annual rainfall.

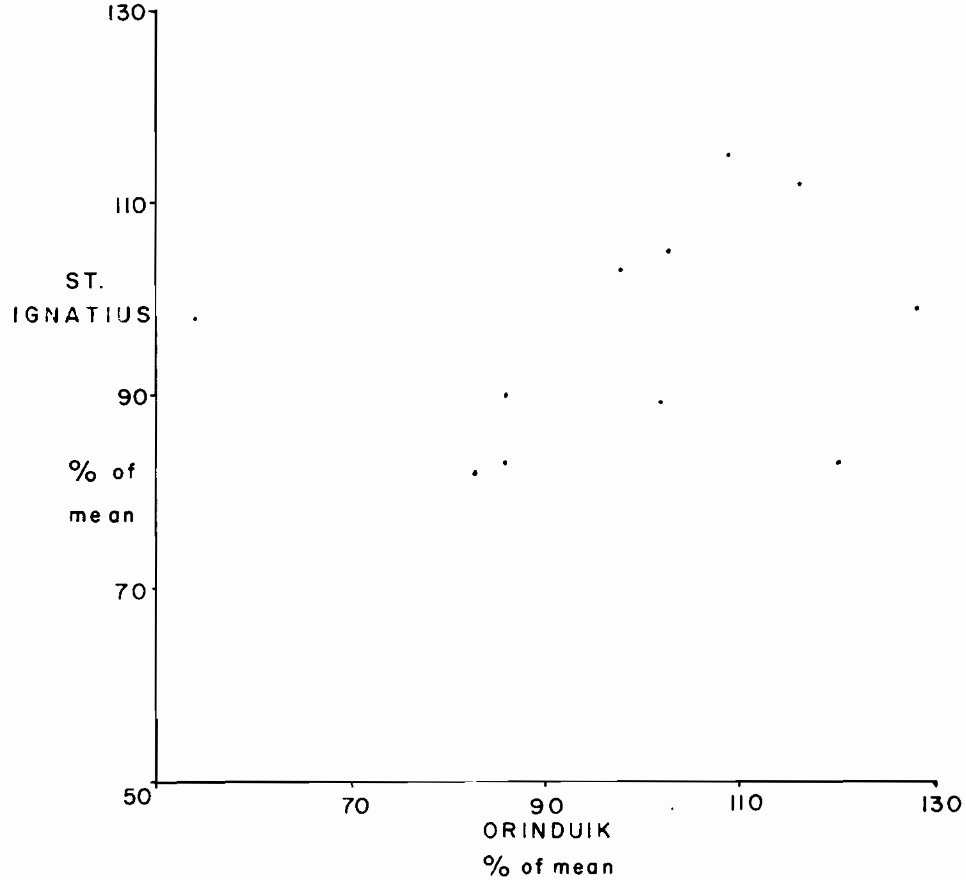
The result of investigations outlined above is to show that in most years the three long term rain gauge stations of the Northern Rupununi have amounts of rainfall that can be predicted from the amounts of the other stations. It is assumed that this conclusion also holds for the

NORTH RUPUNUNI

RAINFALL CORRELATION

ORINDUIK, ANNAI, ST. IGNATIUS





areas between them. 1965 was one of these normative years.

3. RAINFALL AT GOOD HOPE AND ITS EFFECTS

It has been shown above that in 1965 the relationship in annual rainfall between the three long term stations was maintained. It is therefore postulated that whatever relationship exists between the rainfall of Good Hope and that of these neighbouring stations was also maintained in that year. Good Hope lies almost in the middle of the triangle formed by the three main stations. To estimate the percentage of the mean rainfall at Good Hope that fell in 1965, it was felt that an average of the values of St. Ignatius and Orinduik would provide the more realistic criterion, for although Annai is not so far away, it is in a special location. Thus it is suggested that in 1965 Good Hope received 85% of its mean annual rainfall. Seeing that the actual amount was 76.00 cms., the mean annual figure is to be taken as 89.50 cms. or more likely somewhere in the range between 85.00 cms. and 95.00 cms. This is a difference of some 70.00 cms. from the mean rainfall at St. Ignatius.

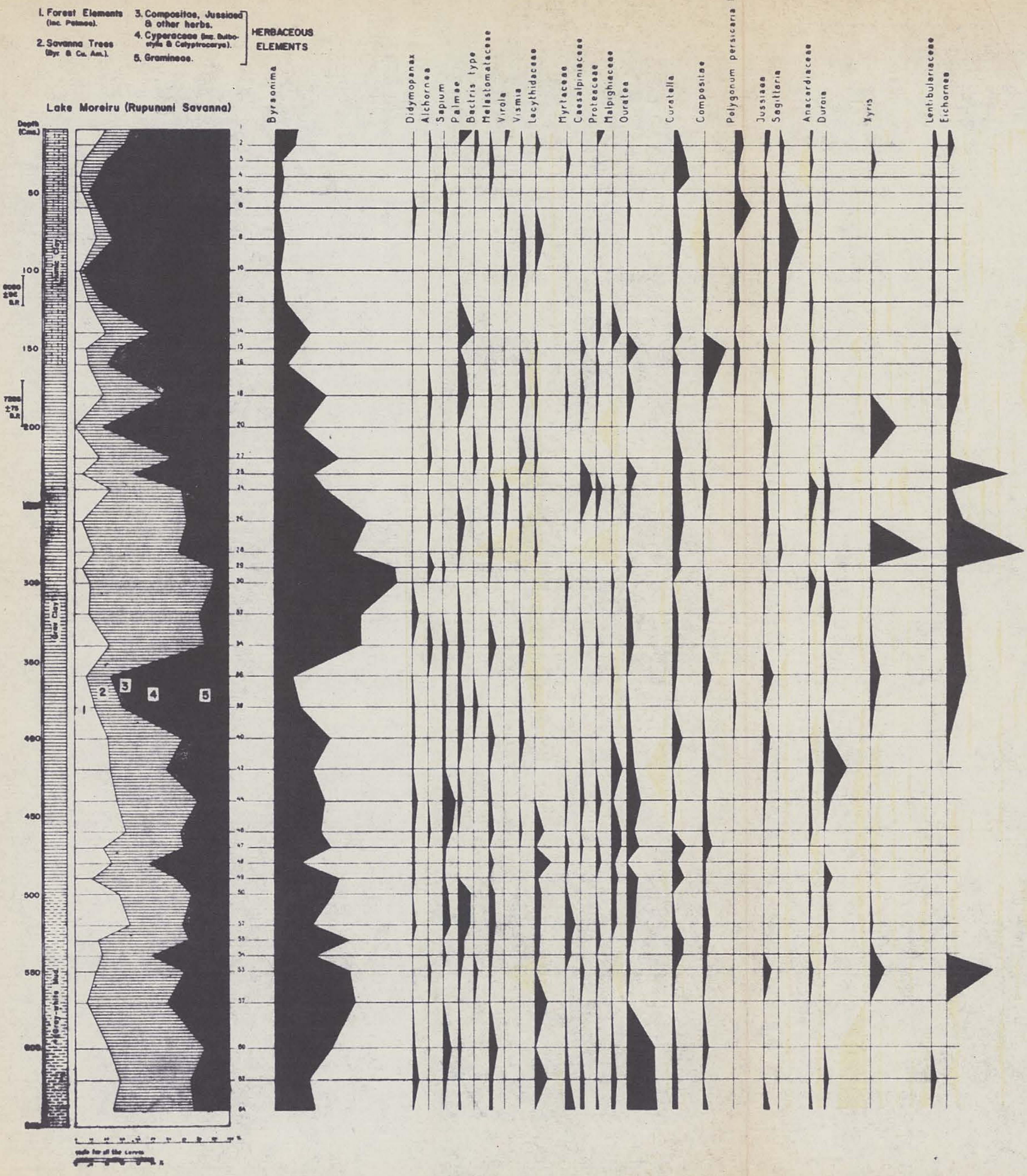
It is not possible at the present time to be sure how much of this difference should be ascribed to the wet season and how much to the dry. In the light of the relationship in dry season rainfall between Orinduik and St. Ignatius it is likely that Good Hope receives a similar amount, that is 37 - 38 cms. This gives a very low wet season value of only 52.00 cms.

Furthermore the investigations at Gaskins showed that a small change in incoming solar radiation can have a significant effect on evaporation. Under the orographic conditions that appear to be operative at Good Hope the descending air will cause less cloud, more radiation and hence more evaporation. Rather than attempt to assign a value to this effect it is sufficient to note that St. Ignatius during the wet seasons of 1964 and 1965, had respectively 48.00 cms. and 53.00 cms. of evaporation. Thus it seems likely that little soil moisture recharge takes place except in wet years.

The lack of soil moisture will have two effects. First there will be little savanna caused by the physiological drought that results from flooding. This is an important consideration on the flat savanna surface but is not of great significance on the mountain slopes for there runoff will be sufficiently improved that flooding is never a problem. The second effect will be greatly increased dry season dessication. This will not only totally prohibit the growth of rain forest species but also inhibits the growth of even savanna trees. On the mountain slopes the lack of moisture may even prohibit the growth of Dry Evergreen vegetation or at least make it so unstable ecologically that anthropic activity could easily remove it.

This general information on the water balance conditions at Good Hope has an additional use. Van der Hammen and Wijmstra (1964) have analysed pollen core from Lake Moreiru, less than four miles from Good Hope. The sequence of vegetation that results from their diagram (see Fig. 30) has been interpreted by them to show that savanna has been the dominant form of vegetation during the last 15,000 years. Because, however, of the more severe water conditions at Good Hope the author would like to sound a note of caution to any who consider extending Van der Hammen's findings to more than the immediate area. Especial care should be exercised near the limit of the diagram, where the increased occurrence

FIG. 30. POLLEN DIAGRAM
(Wijmstra & Hammen, 1965).



of woody pollen might reflect more arboreal conditions elsewhere.

4. SOUTH OF THE KANUKU MOUNTAINS

Investigations south of the Kanukus are hampered by a lack of data because several stations have not yet reported their 1965 data. Nevertheless certain conclusions can be drawn. It will be recalled from section 1 above that Dadanawa, the lone long term station in the south savannas, has a lower average than either Annai or St. Ignatius, 146.83 cms. Three other stations have been installed to investigate the distribution of rainfall around the boundary of the south savanna. These gauges are at Aishalton, in the extreme south east, Sand Creek in the extreme north east and at Imprenza on the Saurab Creek at the junction between the north and south savannas.

In 1964 there seems to have been a regional total rainfall in the vicinity of 130 cms. as shown by the records of Aishalton and Imprenza. Such figures as are available for Dadanawa indicate that a similar total was also recorded there. Sand Creek, however, was much lower, by as much as 25.00 cms., and, on the basis of the following January - April (1965), appears to be much dryer during the dry season rather than the wet.

TABLE 13

Rainfall - South Savanna 1964

Period	St.Ignatius	Imprenza	Sand Creek	Aishalton
Jan.-Apr.	8.98	6.65	N/A	7.01
May - Aug.	124.81	106.27	91.82	99.19
Sept.-Dec.	25.33	37.03	11.35	22.25
Dec.-Apr.	8.96	N/A	0.00	N/A

With only these skimpy data available the author can do no more than suggest that Sand Creek is in a rain shadow and that this will doubtless be demonstrated as more data becomes available. It seems that the dry season is harder at Sand Creek and thus there is a reasonable chance that the forest nearby is not in equilibrium and could be removed by other agencies to produce the grassy mountain slopes seen along the southern flanks of the mountains.

It has been mentioned previously that there is a sizable bush island near Imprenza and that it has been suggested by Rutherford that this is caused by increased rainfall. The first point to observe is that the island is not on the savanna surface but rather on a sizable inselberg which is disconnected from the Kanukus by the Sororiwau Gap. Because of this it is most unlikely that a simple difference in climate has produced the island but rather it is probable that a complete rearrangement of the ecological variables has been effected. At the moment, there is no indication that rainfall is in fact greater in this area than on the surrounding savanna, but to be certain a gauge would have to be installed on top of the mountain.

5. CONCLUSION

This chapter has tried to examine the climate in the lee of the Pakaraima and Kanuku Mountains to determine if a rain shadow exists. It has been shown in the north savanna that such an effect is certainly present at Good Hope and probably to a much smaller extent at Annai. The effects of the reduced rainfall have been presented and it has been pointed out that the resulting dessication has serious effects on plants and is likely to be a major cause of the unusual vegetation distributions seen in the area.

South of the Kanukus the problem was more difficult as no means existed to tie in the observations of the recent stations to the long term mean of Dadanawa. Nevertheless it was shown that at Sand Creek the rainfall was less than in the open savanna and if subsequent investigations show that this difference is usual then a second area of rain shadow will have been shown to exist. In this latter case it is worth noting that the dryness is felt more in the dry season than in the wet season, as it is at Good Hope.

Thus the author feels he had identified a second situation where climate is a major, if not the major, factor determining the location of the forest savanna boundary.

CHAPTER V

CONCLUSIONS

In Chapter I the 'Savanna Problem' was posed not only in its world-wide application but also with specific reference to the Rupununi Savannas. Recent work in the savannas was discussed particularly in cases where it offered some suggestions on the causes for the origin or maintenance of the savanna. In this respect the work of Waddell and Sinha was stressed. Careful note was also made of any theories relating to the location of the forest savanna boundary. It was then stressed that all of these suggestions only considered the climate as a constant overriding factor rather than as an ecological variable that changed from place to place just as much as did the other variables. It was therefore decided to investigate two areas of forest-savanna boundary where large and possibly significant changes in plant moisture might have occurred for climatological reasons. One area was the windward or northern face of the Kanuku Mountains where it was anticipated that rainfall would be greater than over the savannas and the other area was the lee sides of the Kanuku and Pakaraima Mountains where less rainfall was anticipated.

To permit accurate contrasts between these chosen areas and the main savanna area the climate at St. Ignatius was closely studied. This culminated in a water balance study which gave an accurate assessment of moisture deficit during the dry season. It is particularly to be noted that a high soil moisture capacity was used in order that the moisture deficit of the savannas should be as low as possible.

Initial thoughts and observations suggested that the Moco-Moco area of the northern Kanukus should be much wetter than St. Ignatius. Observations of rainfall, however, showed only a slight increase in dry season moisture and roughly equal amounts in the wet season. It was therefore concluded that if moister conditions prevailed in the forest at Moco-Moco it must be due to a lessening of evaporation. This was demonstrated to be correct and when the dual effects of increased rainfall and lower evaporation were combined in a water balance it was shown that the forest had only half of the moisture deficit compared with that at St. Ignatius. Care was taken to select a low soil moisture capacity in this case. Use of the same soil moisture capacity at both locations ensured the wettest conditions for the savannas and the dryest for the forest, preventing any possibility of explaining away the differences by changes in soil moisture. It was also postulated that the moisture deficit was less than at St. Ignatius for a mile or two into the savannas. Thus it was shown that a potentially significant climatic difference existed on either side of the forest savanna boundary.

In the other special situation it was shown that the northern side of the Guiana Shield is far wetter than is the southern side. To provide a more exact measure of this the rainfall of the three long term rainfall stations nearby was analysed and it was shown that in most years a definite correlation existed between their rainfall totals. From this conclusion it was deduced that in 1965 the Northern Rupununi received 86% of its mean rainfall. Thus the station at Good Hope, in the lee of the Pakaraima Mountains, could be shown to have a mean annual rainfall that was only 56% of that at St. Ignatius. It was further demonstrated that in such a situation soil moisture is only rarely recharged during the wet season. Thus an area was recognized where climate was much dryer than at St. Ignatius.

The ecological effects of these findings can only be appreciated in the light of current postulation concerning the reasons for the existence of the Rupununi Savannas. Initially it was suggested that man and fire played highly significant roles. Further work, however, showed that soil moisture was of great importance while at the same time other studies tended to reduce the likelihood that man and fire were responsible for more than very local areas of savanna. If soil moisture is indeed the key then changes in rainfall can have profound effects. It will be remembered that in the two areas chosen for special study the vegetation appeared to be occupying inappropriate areas. That is to say at Moco-Moco forest vegetation was found on the level savanna surface while at Good Hope savanna extended into the mountains.

The author believes that he has found one of the major reasons for these abnormalities. At Moco-Moco the reduced aridity permits forest vegetation to exist on the savanna surface while in the mountains forest vegetation regenerates too rapidly for savanna to intrude into any clearings. At Good Hope the reverse is true. Here aridity prevents forest from occupying the lowlands and it also inhibits its regeneration on the mountain slopes. A similar situation has been suggested in the South Savanna for Sand Creek but not proved. It is felt that at Moco-Moco human activity has confused the picture by removing forest from the lowland, an achievement possibly made easier by edaphic conditions adverse to forest regrowth. At Good Hope and Sand Creek it is felt that human activity has rather increased the extent to which savanna would naturally encroach on the mountain forest areas.

Thus it has been demonstrated that climate does vary significantly within the Rupununi and that these changes do have ecological repercussions in the exact location of the forest savanna boundary.

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