RAINFALL EVAPORATION AND SUGAR CANE YIELDS IN BARBADOS.

by

Julius S. Oguntoyinbo, B.A. (Dun.)

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the Degree of Master of Science.

Department of Geography,
McGill University,
Montreal.

April 1964.

ACKNOWLEDGEMENTS

The result of a summer's field work presented here has been made possible through the generosity and guidance of various organizations and persons to whom the writer would wish to express gratitude. The writer is very much indebted to Dean Hare and Professor Hills for their patient understanding of his problems and guidance both in the field and at McGill. Grateful thanks go to Mr. Colin Hudson of the Irrigation Board in Barbados both for his personal assistance and for placing his material resources at the writer's disposal; gratitude is also expressed to members of the Ministry of Agriculture and Fisheries and the plantation managers in Barbados for their co-operation in supplying most of the data used in the thesis. The writer also expresses deep appreciation to the External Aid Department, Canada, and the Canadian Commonwealth Scholarship and Fellowship Committee for making the funds available to carry out this project. Finally special gratitude goes to my wife for her constant encouragement.

TABLE OF CONTENTS.

TABLE OF CONTENTS.

MAPS AND DIAGRAMS

MAPS AND DIAGRAMS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Historical Background

Sugar cane has been the mainstay of the economy of Barbados since 1645 and it has, in spite of the vicissitudes of the sugar industry, maintained this unique position ever since; this can be realised from the fact that it contributes over 90 per cent of the annual income of the island (Macpherson, 1963, p. 75). The predominance of this crop has led to great interest being taken in measures by which a potential yield can be attained. The potential yield, according to Dillewijn (1952, p. xxii), is the maximum yield attainable given that the following five factors are fully satisfied: solar energy (heat and light), moisture (rainfall and irrigation), soil condition, availability of labour, and cultural methods. The potential yield, he states, is only of theoretical importance because the sugar industry is an economic enterprise, concerned with economic yield, which is generally lower than the potential yield.

However, the ultimate goal of the producer is to be able to make the economic yield equal to the potential yield at the lowest cost price. It has therefore always

Fig. 1. Location Map

been necessary in Barbados, to carry out research projects aimed at increasing yield while the initial outlay is kept at the minimum possible.

Until recently the knowledge about the soils of Barbados was not detailed enough; this has been rectified by a detailed soil survey of the whole island carried out between 1962 and 1963 under the auspices of the Soils Survey Department of the University of West Indies, Trinidad. The detailed analysis of this survey is not yet published but the drafts were made available to the writer and it is from this draft that the accompanying soils map is produced; the brief description is also based on the information supplied.

Much information on the effects of fertilizers on sugar cane has been obtained from experiments carried out from time to time at different sites in Barbados and is available in qualitative form. The responses of the crop to fertilizers in experiments conducted since 1928 have been summarized by Robinson (1951, 1952); and according to Bolton (1956) Hodnet's (1956) recommendations are not much different from those which Saint had made 20 years earlier. In other words, the fertilizer application has been close to the ideal for the island.

Since the turn of the century a great deal of research has been devoted to breeding varieties of cane suited to the conditions of the island; newer varieties are being produced from time to time to replace the older and less disease - resistant varieties. Up to 1940, the largest single variety was the B2935, which then accounted for over 40 per cent of the crop harvested; but by 1943 its share had dropped to 21 per cent of the crop harvested, and it was superseded by the B37161, which that year formed 27 per cent of the crop reaped. Thenceforth the B37161 variety increased in acreage until its maximum was attained in 1949 when it constituted over 90 per cent of the harvested crop. Its share has since been dropping until 1959, when its acreage was exceeded by B41211 and equalled by B4744, which in 1962 accounted for 28 per cent of the crop harvested.[1] Changes in variety are brought about by a decline in yield but, by and large, the B37161 seedling was a very successful variety both with respect to yields and to resistance to diseases; hence it dominated the other varieties for nearly two decades.

From the foregoing, it can be seen that the last three decades have had near optimum conditions with respect to fertilizer application and the breeding of a high-yielding and disease-resistant variety: labour

1 Annual Reports: The Yield of Sugar Cane in Barbados.

supply is usually not a major problem; consequently it is reasonable to assume that the yield will depend more on other factors such as evapotranspiration (which is a function of rainfall, solar radiation, wind, soil moisture conditions), plant physiology, especially its reaction to disease and drought, and cultural practices on the island. Such factors therefore deserve closer investigation.

The importance of rainfall, especally of its distribution and the dangers of drought in relation to the yield of sugar cane, are fully recognised in Barbados; this is all the more important since irrigation is not commonly practiced. The importance of evaporation was also noticed quite early in the development of the sugar industry in Barbados. Thus Rawson (1874) drew attention to the significant role of evaporation and rainfall by quoting figures for both, as recorded at two adjoining stations which he regarded as being comparable:

	1873		1874	
	Little Island		Birnfield	
	Rainfall	Evaporation	Rainfall	Evaporation
Jan.	6.31	3.73	5.91	1.50
Feb.	4.06	4.20	1.41	2.80
March	1.51	5.45	3.53	3.12
TOTAL	11.88	13.38	10.85	7.42

Table 1: Rainfall and Evaporation Jan - March 1873 and 1874 as recorded by Rawson.

From this he concluded as follows:

> "Thus while in the first 3 months of 1873 there was an excess of Evaporation amounting to 1.50 inches or 12½ per cent, there was during the same period in 1874 an excess of Rainfall, amounting to 3.43 inches or 46 per cent. Such a difference during the driest quarter of the year must have a most important and beneficial influence upon vegetation.".

Although the means by which the evaporation figures were derived was not stated, the low figures recorded may be assumed to be due to an altitudinal effect because Birnfield is located at an elevation of 1063 feet.

Rawson's deduction is, however, speculative; nevertheless it brings out clearly how much importance has been attached to the distribution of rainfall, especially during the dry season. Rainfall distribution is usually discussed in the annual "Bulletins of Sugar Cane yield" of the island but it was not until recently that keen interest was taken in the investigation of its effect on yields and of measures which may be taken to supply the deficit. On this score reference may be made to the works of G.W.Smith (1960), Rouse (1962) and I.Smith (1962). The present writer has chosen to investigate the distribution of drought and its influence on sugar cane yield. This project, the writer hopes, will clarify the statement of Rawson that has been quoted above.

Ideas about rainfall distribution, evaporation and their influences on growth rate, and ultimately, yield, have been topics of great controversy amongst scholars; the writer feels that it will be relevant to review some of the ideas being put forth insofar as they relate to the project under consideration. This will be the topic in the next chapter.

CHAPTER II

EVAPORATION AND WATER BALANCE

The study of energy balance has applications to a wide range of problems, such as the ecology of the plant community, agricultural planning, food control, water resources management and the like. In recent years both American and the Soviet geographers have devoted much effort to the study of energy budget and moisture balance. Gerasimov et al. (p. 66) consider Budyko's contributions to the understanding of this problem as unique. Budyko[1] concluded, among other things, that under conditions of a sufficiently humid or excessively humid climate, the radiation balance of the active surface represents a factor for determining the magnitude of evaporation. Among the American contributions, Thornthwaite's work is considered by James et al (1954, p.348) as outstanding. By using the factors of insolation and temperature, Thornthwaite developed a climatic classification by the balance, in the course of the year, between precipitation and "potential evapotrnaspiration".

Definition of Evapotranspiration

Evapotranspiration is the combined evaporation

---

1 Gerasimov: ibid

from the soil and plant surfaces, and transpiration. The rate of evapotranspiration is affected by the nature of the ground; when water supply is unlimited the concept of potential evapotranspiration applies. According to Penman (1956), potential transpiration (his own chosen term) is the amount of water transpired in unit time by a short green crop completely shading the ground. This definition has been criticized on two counts:
firstly, because the "short green crop" is not specified; Penman argued that when the crop cover is complete the potential evapotranspiration is determined primarily by weather and not affected by the plant species provided they have the same albedo. This has been found not to be true for all tropical crops and for lichen in the arctic; secondly, the effect of advective energy is being ignored. Pruitt (1960, p. 18) coined a term "potential maximum evapotranspiration" to designate the situation when advected energy is present. This would certainly remove a confusion. Thus, one should not expect an empirical formula for potential evapotranspiration derived in the humid climate to be adequate in estimating the potential maximum evapotranspiration in an arid area.

Methods of Determining potential Evapotranspiration.

Methods for determining or estimating potential evapotranspiration fall into four general categories:

(1) Direct measurements by lysimeters and evaporimeters.

(2) the aerodynamic approach, based on the physics of vapour transfer process,

(3) the energy budget approach, and

(4) empirical formulae using one or more of the common climatic factors.

These four categories can be divided into two classes according to the use to which they are put: the "research" tools for understanding of the physical processes, and the "operational" tools which can be applied to a large area for actual operation of regional planning. The literature is full of detailed description of both classes, and it is not necessary to discuss them in detail here except in cases where they are relevant to the present project.

The success of the "research" tools depends on careful and complicated observations and calculations which are often too laborious to undertake; furthermore the instrumentation is not yet reliable enough to make it available for ordinary users. The "operational" methods use either inexpensive field instruments or readily available climatic data. Since the use of mean monthly or daily values must depend upon a crude correlation between instantaneous and mean values, the empirical formulae cannot be as accurate as the elaborate "research" methods. Tanner (1960) maintains that for day-to-day operation, agriculturalists can tolerate an error of 10 per cent in estimating daily evaporation. Likewise, for regional analysis on a long term basis, geographers can use to advantage any method that provides monthly estimates within a 10 per cent error. The "research" methods may then be used as a check on the "operational" methods for practical application.

Empirical relationships between potential evapotranspiration and meteorological variables have been developed by Thornthwaite (1948), Penman (1948), Blaney and Criddle (1950) and others. The Thornthwaite formula is best known among geographers and it has been widely used for regional irrigation planning with some measure of success. The major limitation is that, of all climatic parameters, only air temperature is used. Air temperature is an inadequate measure of the availability of energy. The temperature method is satisfactory only because temperature and radiation are often highly correlated. There is an advective effect, which has been ignored; this may play a major role if there is strong horizontal advective heat transfer. When wind blows through small plots with little or no guard area like a clothes-line, a very strong horizontal advective heat transfer occurs; the "clothes-line effect" (Pelton et al.,1960) thus created, together with the vertical energy transfer from the air above the crop, constitute the "oasis effect" described by Lemon et al. (1957). Away from the border of the field the evapotranspiration caused by advective heating is usually smaller.

From the point of view of water use, Chang (1963b) considers that crops may be loosely divided into two groups: conventional and non-conventional. For the non-conventional crops the consumptive use is largely determined by its physiology, particularly the behaviour of the stomata. Rice and pine-apples are, according to Suzuki et al. (1958), good examples in this class. Most field crops, however belong to the conventional group and their potential evapotranspiration is dictated by the weather conditions.

According to Chang (1961), the consumptive use of a conventional crop increases with height. Thus the ratio between evapotranspiration and evaporation from the American Class A evaporating pan increases from 0.75 for short grass to 1.0 for sugar cane. The high water utilization by tall vegetation has been explained by Chang (1963b, p. 20) to be due to increased roughness and zero plane displacement at a given wind speed.

For most annual crops the evapotranspiration reaches the potential rate only for a short period when the crop is actively growing and the cover is complete. In both the early and late growth stages water needs fall short of the potential. Lemon et al (1957) and Stanhill (1962) have shown that during the ripening period the consumptive use is slightly reduced by senescence. In the early stage of the crop growth the low evapotranspiration rate is due more to a dry mulch surface developing on bare ground soon after soil is wetted.

As the soil dries out the actual evapotranspiration will at some stage fall below the potential rate. There is considerable controversy as to the effects of soil moisture tension on depletion rate. Veihmeyer and Hendrickson (1955) maintain that evaporation (E) proceeds at the potential rate (EP) up to the permanent wilting point and falls sharply thereafter; the contrary view, that the ratio E/EP is a decreasing function of the soil moisture tension, is summarized by Kramer (1955). This is still an open question; Pierce (1958) proposed a compromise between the two extremes. He showed that (for meadow crops) the depletion rate is maintained at 90 per cent or more of the potential rate until about two-thirds of the available moisture is exhausted from the top 30-36 inches of soil. Thereafter the rate increases rapidly until a value below 50 per cent is reached at a crop moisture deficit of 6 inches which is assumed to be the wilting point. Pierce's results, however, may not be valid in all cases.

The water balance equation of the plant-soil system down to the rooting depth can be expressed as follows: Rainfall-Evapotranspiration-Runoff-Percolation=Change in moisture storage. Once the evapotranspiration is known, it remains only to determine the soil moisture content to solve the equation. Thornthwaite and Mather (1955) adopted a storage capacity of 30cm as the average for the world.

In the water balance computation, run off and perco- are lumped together as surplus. Surplus occurs whenever accumulated rainfall exceeds the moisture storage capacity. The difference between rainfall and surplus is a measure of the effective rainfall. The effective rainfall is much less variable than the actual rainfall and can be precisely determined by the water balance technique. Chang (1963a) showed that the median rainfall for certain areas in Hawaii differs only slightly from the effective rainfall and thus for the purpose of long range water resource management the median rainfall may be taken as a good approximation of the effective rainfall.

Drought occurs whenever the soil moisture is fully depleted. The total amount of water deficiency throughout the year is a measure of aridity of the climate. The amount of this deficiency is, however, quite sensitive to a change of moisture storage.

Evapotranspiration And Sugarcane Culture

The application of the foregoing discussion to the sugar cane culture is the ultimate aim of the writer and for this purpose parallels can be drawn from other tropical areas where extensive research projects are being carried on. As temperature is not a limiting factor to the growth of sugar cane in the tropics it therefore means that there must be a relationship between water supply and the sugarcane yield. Physiologists have demonstrated that, for many crops, the accumulated dry matter is proportional to the amount of transpiration. That plants do not transpire for nothing has been proved to be true for sugar cane by McIntosh (1934) in Barbados and by Chang (1963) in Hawaii.

The close relationship between the dry matter production and transpiration has been shown by Chang (1963b) to have at least three practical implications: firstly, the maximum yield is obtained when the water application is exactly equal to the potential evapotranspiration; secondly the problem of estimating yield can be reduced to one of estimating transpiration, provided that the cultural practices and other factors are not limiting; and thirdly the effect of drought is not of sufficient severity to affect plant metabolism seriously, a long drought will have the same effect as several periods of short drought, provided that the total water deficiency of the long period is equal to that of the short periods.

The availability of moisture for the sugar cane plant is therefore a major factor in determining the size of the yield to be expected. Chang's studies in Hawaii confirm this; when the ratio AE/PE is greater than 0.73 the potential yield is almost attainable but when this ratio is less than 0.73 a complicated situation occurs . The ratio AE/PE of 0.73 can then be regarded as a critical determining point whether drought exists or not. If the drought occurs during early growth (the first 12 to 14 months of a 24 - month-crop cycle), the actual yield will be below the expected yield but if the drought occurs late in the cycle the actual yield will be above the expected yield.

The writer feels that Chang's results are of such fundamental importance to the sugar cane culture that they can be tested on an island such as Barbados where sugar-cane is intensively cultivated, but where the rainfall is marginal to the crop requirements over a considerable portion of the whole island. The specific experiment in this project is therefore directed to an investigation of the last two of the three practical implications resulting from the relationship between yield and transpiration. Firstly, that is, to investigate the relationship between available moisture, evaporation and yield; secondly, to investigate the incidence of drought (both at the beginning and the end of the crop cycle), and thirdly, to investigate whether there is a significant correlation between yield and the occurrence of drought.

The factors which will be considered are the soils, rainfall, temperature and the sugar cane yield data. As the data lend themselves to the use of Thornthwaite's formula, the latter will be employed to estimate the evapotranspiration (potential and actual); then the relationship between both will indicate whether Chang's results are applicable or not. As a preliminary, the general sugar cane environment, including the physical features and the climatic conditions, will be discussed in the next chapter.

CHAPTER III

THE SUGAR CANE ENVIRONMENT IN BARBADOS

Physical Features:

The underlying basement rocks of Barbados consist mainly of shales, sands, clays and conglomerates of the Scotland Series. These were subjected to folding and uplift and later submerged beneath the sea where they were covered first by the Oceanic Series, and later by coral deposits which, after subsequent uplift, have today become the most important rocks on the island. They reach a maximum thickness of over 300feet in places and cover 6/7 of the island; the remaining 1/7 belongs to the Scotland Series in the north east where erosion has uncovered the basement Scotland and Oceanic Series.

The highest point on the island, Mt. Hillaby, (1115feet) is situated in the north centre (fig.1) of the island. From here the relief decreases in a series of coral terraces formed as the island was gradually uplifted in stages from beneath the sea, the sides of the terraces being old sea cliffs. They run generally parallel to the present shoreline and vary in altitude between 5feet and 100feet.

The situation on the north east coast is a major contrast. There is a sudden descent marked in places by sheer cliffs and deeply cut valleys of the Scotland District. On the south coast shows that the main highland mass also descends steeply into the broad St. George's valley. Beyond this valley is the Christ Church Ridge which reaches nearly 400feet and thenceforth descending into the sea. A most striking feature of the island is the general absence of surface drainage; this is due to the great depth of underlying porous coral limestone. The only exception is the Scotland District where valleys contain streams during the wet season. The steep gradient of the landscape in this area causes severe erosion, which is a major source of concern to the Soil Conservation Board of the island.

The Soils

The parent material of the coralline limestone soils extends over 6/7 of the island, and the remaining 1/7 consists of the exposed basement complex. Two major factors have contributed to the alteration of the soil texture. Firstly, there was the large quantity of volcanic ash transported from the 1902-1903 Soufriere eruptions from St. Vincent; this, according to Price (1962), deposited up to 3.9tons per acre of volcanic ash. The second factor is the application of fertilizers; this well established practice first started with the application of pen manure and was

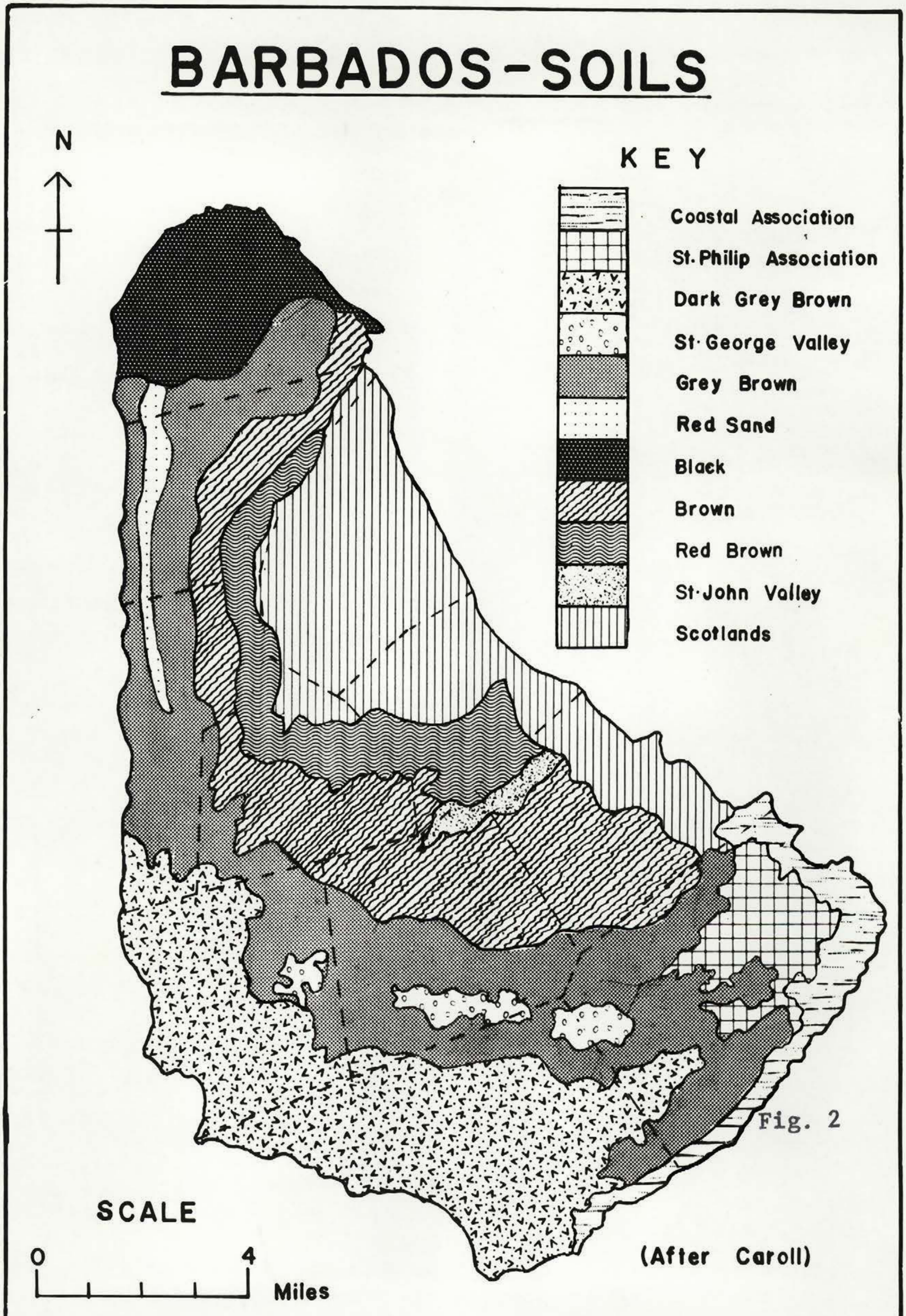

BARBADOS-SOILS
N
KEY
Coastal Association
St. Philip Association
Dark Grey Brown
St. George Valley
Grey Brown
Red Sand
Black
Brown
Red Brown
St. John Valley
Scotlands
SCALE
0
4
Miles
(After Caroll)

Fig. 2

later replaced by the application of phosphorus and nitrates as recommended by Saint (1931a,p.43)and others.

In spite of these factors, the major soil types are still recognisable. The first survey was by Saint (1931b,p.1); this has only recently been followed up by a more detailed survey by Caroll (1962-1963); the report of this survey is not yet available but as the writer was on the island towards the end of Caroll's survey, the latter's draft reports and map (fig. 2)were made available to the writer and it is on the information supplied that the following brief description is made.

The Red Brown Soils, found in areas over 500 feet elevation, contain a large percentage of clay, and only the top 12 inches give easy access to roots. This shallow soil depth, the writer believes, may be of great importance in the moisture supply to the crops especially during spells of drought.

The Grey-Brown Association, found generally between 200-400 feet elevation, consists mostly of the Montmorillonite clay which is characterized by swelling and shrinking during changes of water content. This may also be responsible for great damage to sugar cane roots, especially towards the end of the dry season when these cracks also allow more penetration of insolation into the soil. There is also a fairly easy root penetration to a depth of about 40 inches in this soil type.

The St. George's Valley Association consists of Old Lagoon material plus some colluvium. This soil is clayey; consequently the water table may be at about 24 inches during the wet season. This soil is marked by a very high water supplying capacity.

The Grey Brown, Coastal Association and St. Philip Association consist of colluvium from the higher slopes. Towards the northwest is the Red Sand group which has very low moisture storage capacity. The Coastal Association is marked by a dry zone with little rainfall, while the St. Philip Association, containing shale, marl and considerable oceanic debris, is generally impermeable and therefore creates some drainage problems; this is because the subsoil is poorly structured below 10 inches and thus root growth is impeded by such deteriorated structure in the subsoil. There is also a high salinity content.

The Scotland District soils consist of

(a) the Joes River Muds, which are sandy clays of mixed mineralogy, and which cover steeply eroded slopes; and

(b) the Oceanic formation, which includes a great diversity of geological meterials; one can recognise the brown, grey-brown and red-brown sub-groups in this series.

A common feature of all these soils is the severe leaching to which they are subjected. The colluvial soils are found generally on unstable slopes, where soil formation is mostly due to materials transported by gravity and wash rather than to the underlying rocks.

The foregoing discussion shows that there is a considerable variety in soil type and character of the soils of Barbados. Such variations will probably have far reaching effects on the moisture availability to plants, especially in relation to limited depth of roots.

Macroclimate

The climatic parameters which have been carefully measured in Barbados are rainfall and, to a less detailed extent, temperature. This has been attributed to Governor Rawson's keen interest in the collection of agro-climatological data (Anon.). Recently however, a more detailed observation of the micro-climatological observation-radiation, soil temperatures, relative humidity, evaporation and evapotranspiration has been embarked upon and these are giving illuminating results.

Temperature

The characteristic temperature uniformity of the tropics, as outlined by Thornthwaite (1951, p. 166), is found to be true in Barbados; the longest temperature record on the island, 1903 to date, is that of the Codrington

Agricultural Station. This 60 year-period shows a mean annual temperature of 78.4°F. . The lowest monthly average, 76.4°F., occurs in January, and the highest 80.4°F. in June. The extremes of mean monthly temperature recorded are 75.3°F. in Feb. 1917 and 81.5°F. in June 1926. Such uniformity in temperature can be used to give reliable estimates of the mean temperatures at other places on the island for which figures are not available if adjustment is made for altitudinal effects.

Recent soil temperature measurements at Waterford show that highest soil temperatures at depths of 2 inches, (81.5°F.) and 4 inches, (84.0°F.) occur in May and June respectively, roughly corresponding to the peak of the dry season. The highest temperature at the depth of 8 inches, 83°F., shows a lag of about two months. The minimum temperatures occur at the end of the rainy season (79.0°F. at 2 inches, 78.5°F. at 4 inches and 77.0°F. at 8 inches, in December in the first case and, between December and January in the last two). There is thus a lag between the upper and lower layers. The intense insolation of the dry season has been observed by McIntosh (1934) and Bolton (1956) to be responsible for marked temperature fluctuations in the upper 6 inches layer of the soil. This phenomenon has a twofold effect on plant growth; firstly, the upper root layers are more easily damaged by the fluctuating temperature;

secondly, the cracking of the dry clay soils accentuates the destruction of the surface roots (hence deep rooting systems tend to occur in the dry season) and more penetration of heat further encourages depletion of soil moisture. The dangers of **moisture depletion** have been minimized by the universal practice of mulching with cane trash; this practice can, however, be modified in light of Griffith's (1952,p.50) observations in Trinidad.

Wind

The prevailing winds on the island are the Trades, which blow with varying intensity between the NE and SE according to the season but with a most marked north-easterly component. The period from November to April is characterised by, ENE-E winds while May to June is marked by E-SE winds; July to October, the period of the hurricanes, is marked by a variable Easterly wind system. The wind reaches its maximum strength in June when mean windspeed may reach up to 13.5mph in Waterford; the minimum, about 3.5mph, is in November. The wind speed varies a great deal and Waterford cannot be taken as standard. A few examples will illustrate this:- Seawell, maximum 15.6mph, minimum 8.8mph.; Grove Agricultural Station, maximum 16.5mph, minimum 5.3mph. The highest part of the island certainly is exposed to much stronger wind force; this is borne out by the writer's observation during the month of June, when a Stevenson's Screen was completely blown down in Turner's Hall located at 700 feet elevation and facing the northeast coast, by a wind which was far less severe at the lower elevation. The most extreme, but rare, case is the hurricane in which the wind speed may exceed 100mph. The strength of the wind decreases from the east coast to the west coast; this can also be noticed by a decreasing number of windmills from east to west and also by the decreasing importance of windbreaks in the same direction. The windbreaks are used primarily to check damage done to the sugar cane by wind but the writer believes that a second factor, the reduction of advective effect of winds, is equally important. This latter advantage is not realised on the island.

Another effect of a constant easterly wind is the uneven distribution of salt load in the atmosphere. A recent salinity test conducted by Hudson (1963a p.6) showed that the wind freshly entering the east coast contains as much as 200mg of NaCl per square foot while on the west coast it contains only 10mg of NaCl per square foot. This has already been reflected in the high saline content of the soil on the east coast. Its other influence is the amount of damage done to sugar cane leaves by salt spray. This does an untold harm to the leaves on the east coast and will obviously affect the total yield in this part of the island.

Solar Radiation

The rate of evaporation depends to a great extent on the amount of net radiation; this in turn depends on the amount of insolation that the clouds let through. In Barbados the highest number of sunshine hours, (9.8 per day), 70per cent of possible on the island, occurs in April and the lowest, (7.7), 63 per cent of possible in September. Observations of cloud amount carried out by McIntosh (1934) at two isolated stations, Lion Castle (900feet) and Codrington (180feet), indicated that the number of sunshine hours at both stations are not significantly different; consequently he concluded that the number of sunshine hours is about the same all over the island. A more detailed observation carried out (with the assistance of McGill University students including the writer), by Hudson (1963b, p.7) at 15 stations located all over the island revealed that, in the southern and broadest part of the island, St. George's Valley, the cloud amount increases from the east coast to the west; whereas in the north centre, altitudinal effect rapidly aids cloud formation. From this it is possible to see how McIntosh derived his conclusions; Lion Castle is at high elevation, 900feet; and Codrington is on the western part of

St. George's Valley whereas there is an appreciable amount of variation from place to place. A lower amount of cloud cover further east would obviously increase evaporation in that region. The intensity of solar radiation varies with the season; the highest amount of incoming radiation, 661 g. cals/cm^2/day, occurs in May and the lowest, 433 cals/cm^2/day, is recorded in November; this shows a single peak, with insolation increasing to a maximum at the end of the dry season and decreasing to a minimum at the end of the wet season.

Rainfall

Dove (1846 p.234) said, "In the tropical regions the mean temperature of any years differs but little from any other, but the quantity of rainfall differs largely. The result is that the yield of crops varies exceedingly.... Therefore in these climates the agriculturist cares less about temperature than about the rainfall...." This statement is still true of Barbados in this century; in 1903 there were over 200 raingauges on the Island but there was only one station recording temperature; in 1963 there were about 65 stations sending rainfall data to the central office but the number of stations sending temperature data is two; one may be able to collect data from about 8 other stations. The result is that Barbados has highly reliable rainfall data as far back as 1847.

Types of Rainfall

Three rainfall types have been recognised by Skeete (1931) on the island; the general or regional rains which are common to all the other islands; the surface heating type and the hurricanes. The first type is due to the general effect of the Trade winds; this rainfall is of great importance to the eastern parishes of Barbados as they receive very little of the other types. The surface heating type occurs between July and November due to high temperature and low wind velocities. The rarest, and the most devastating, is associated with tropical cyclones and, in the strongest form, the hurricanes.

Variability of Rainfall

There is a marked variation both in time and space. The year can generally be divided into two seasons: the wet and the dry. The wet season occurs mainly between July and November while the dry season occurs from December to June. The length of the dry season, however, varies roughly with altitudinal location; it is shorter in the the higher elevation than in the lower regions. The distribution of short dry spells which have far reaching effects also varies from region to region. According to

Rouse (1962,p.18), the island may be divided into three rainfall zones: the low rainfall area with 44-57 inches, the medium rainfall area, with 58-78 inches, and the high rainfall area, with over 79 inches. The average annual rainfall of the island is 60 inches of which about 45 inches falls between June and November. Saint (1953) has noted that there have been periods of successively dry years alternating with successively wet ones. Among the dry periods are the years between 1855-1875 and 1904-1949, when the mean annual rainfall was less than 50 inches; whereas 1874-1904 had a higher average than the other two periods. 1950-53 had a higher average than any other period since 1890-99.

There is also a marked variation in the monthly distribution. December to June are generally the dry months even in those years when the total amount is high. It is the usual case that the high rainfall is concentrated in the wet season. The 1938 annual rainfall for the whole island was exceptionally high (88.37 inches); and it was, according to Johnson (1942), the heaviest on record since 1901; but in that year the heaviest rainfall was not evenly distributed through the wet season but concentrated almost entirely in the month of November, when 28.09 inches, or approximately one-third of that years rainfall, was recorded in one month. In July 1963 over 10 inches of rainfall

GRAPH OF
MEDIAN MONTHLY RAINFALL

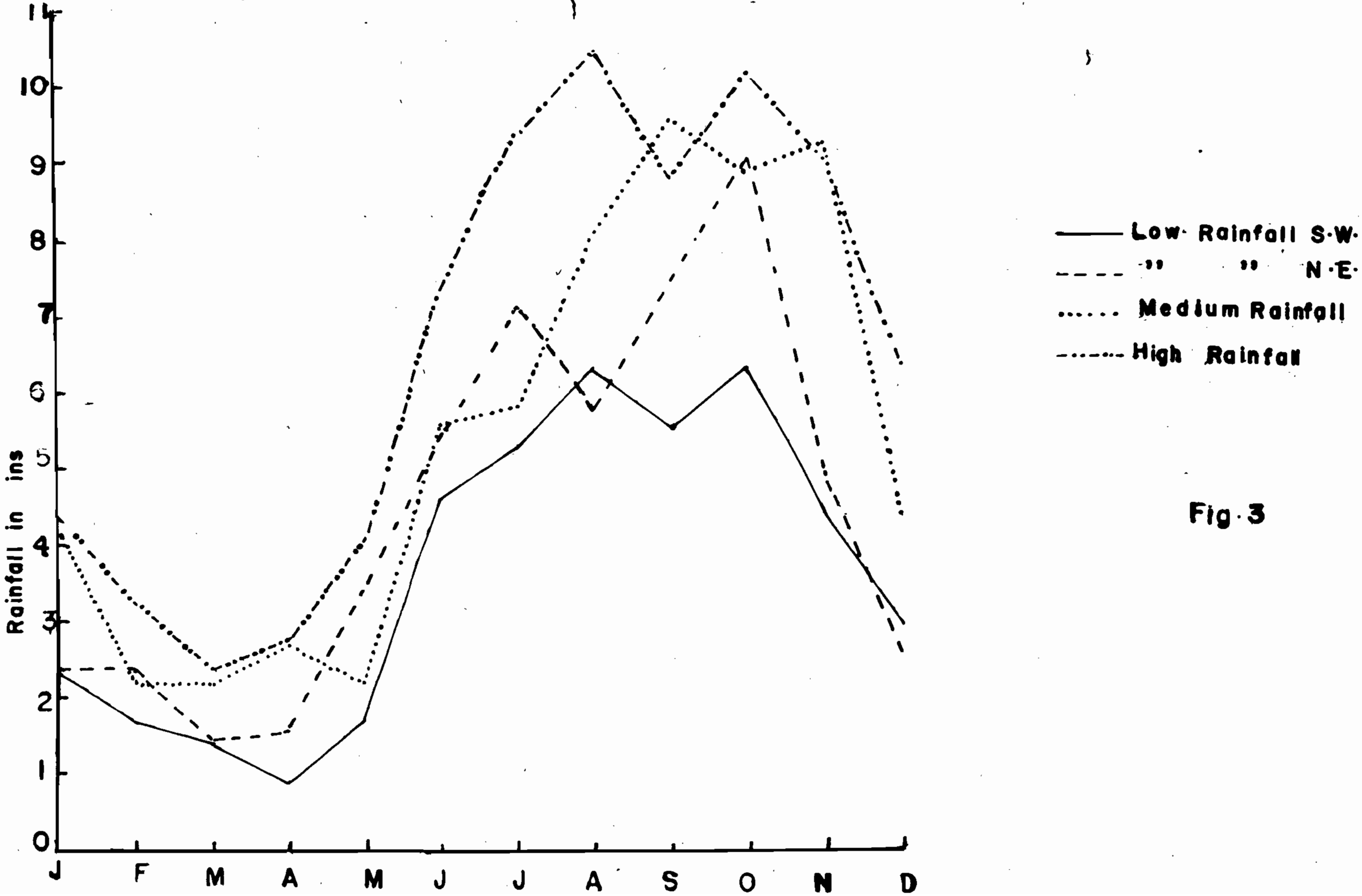


Fig. 3

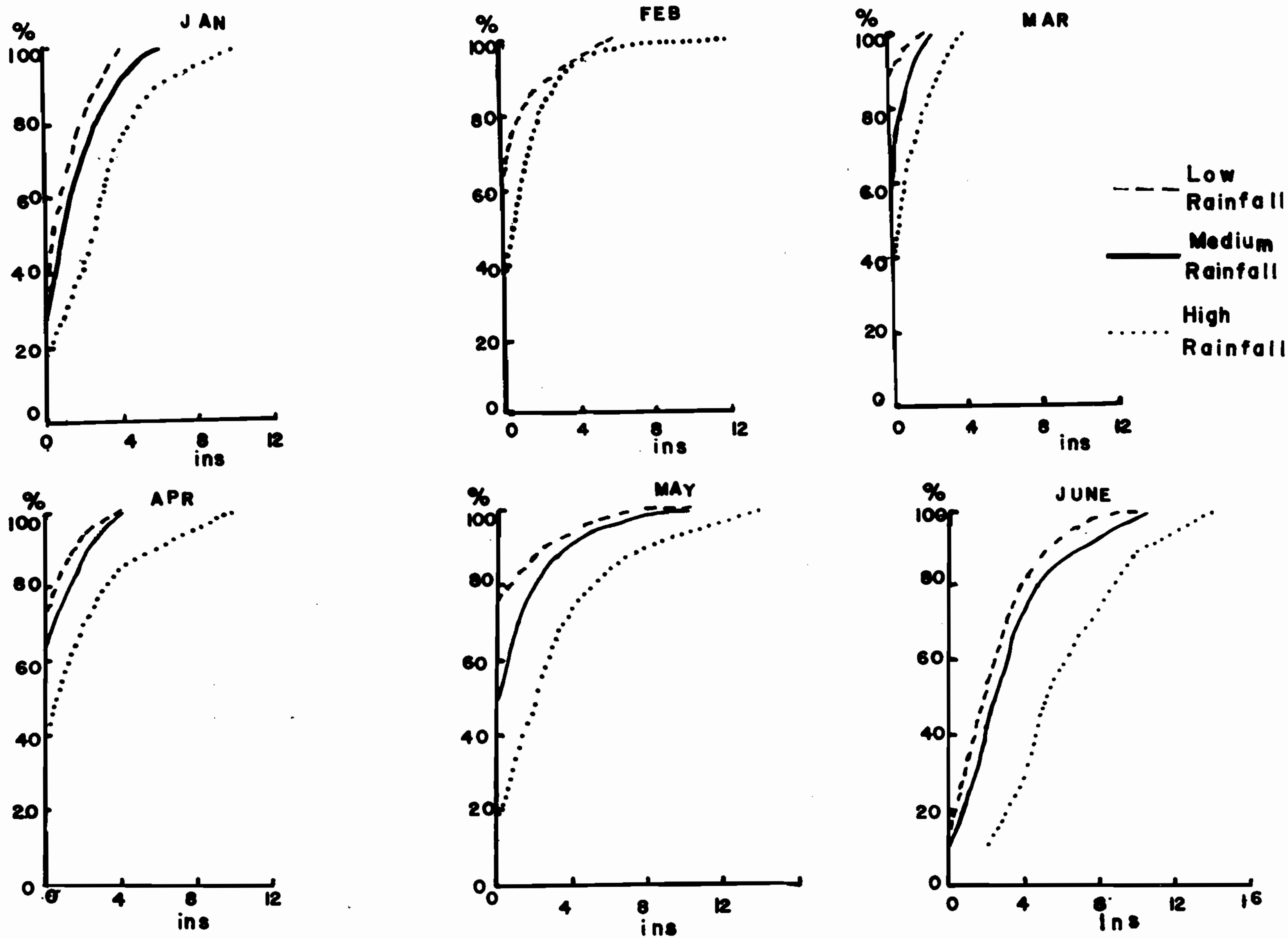
within 24hrs. was recorded in some of the driest parts of the island in St. Lucy; over the some period Waterford Observatory recorded 6.89 inches.[1] The total for the month was 12.98 inches and only three days had no rain during this month; thus over 50 per cent of the month's rain fell in twentyfour hours. On rare occasions, too, the driest part of the year receives an unusually heavy rainfall. Such was the situation in Jan. 1937, when a total of 9.7 inches was recorded, as compared with 3.43 inches, which is the average for that month.

The median rainfall has been shown by Chang (1963a,p.2) to be a better indicator of effective rainfall. In Barbados the median rainfall (fig. 3) portrays the pattern of rainfall distribution already described. The period between December and May is generally one of low rainfall and the heavy rainfall is concentrated between June and November. There is a tendency to have a period of lower rainfall during the height of the wet season, but the drop is not so significant as to indicate two marked wet seasons; the month of occurrence also varies from one region to the next. The cumulative frequency distribution of the median rainfall (fig. 4a and 4b) further helps to illustrate the general pattern of distribution in the rainfall between

---

1 Climatic Observations at Waterford May-Aug. 1963

RAINFALL CUMULATIVE FREQUENCY DISTRIBUTION (Jan — June)



FIG·4a

RAINFALL — CUMULATIVE FREQUENCY DISTRIBUTION (July – Dec)

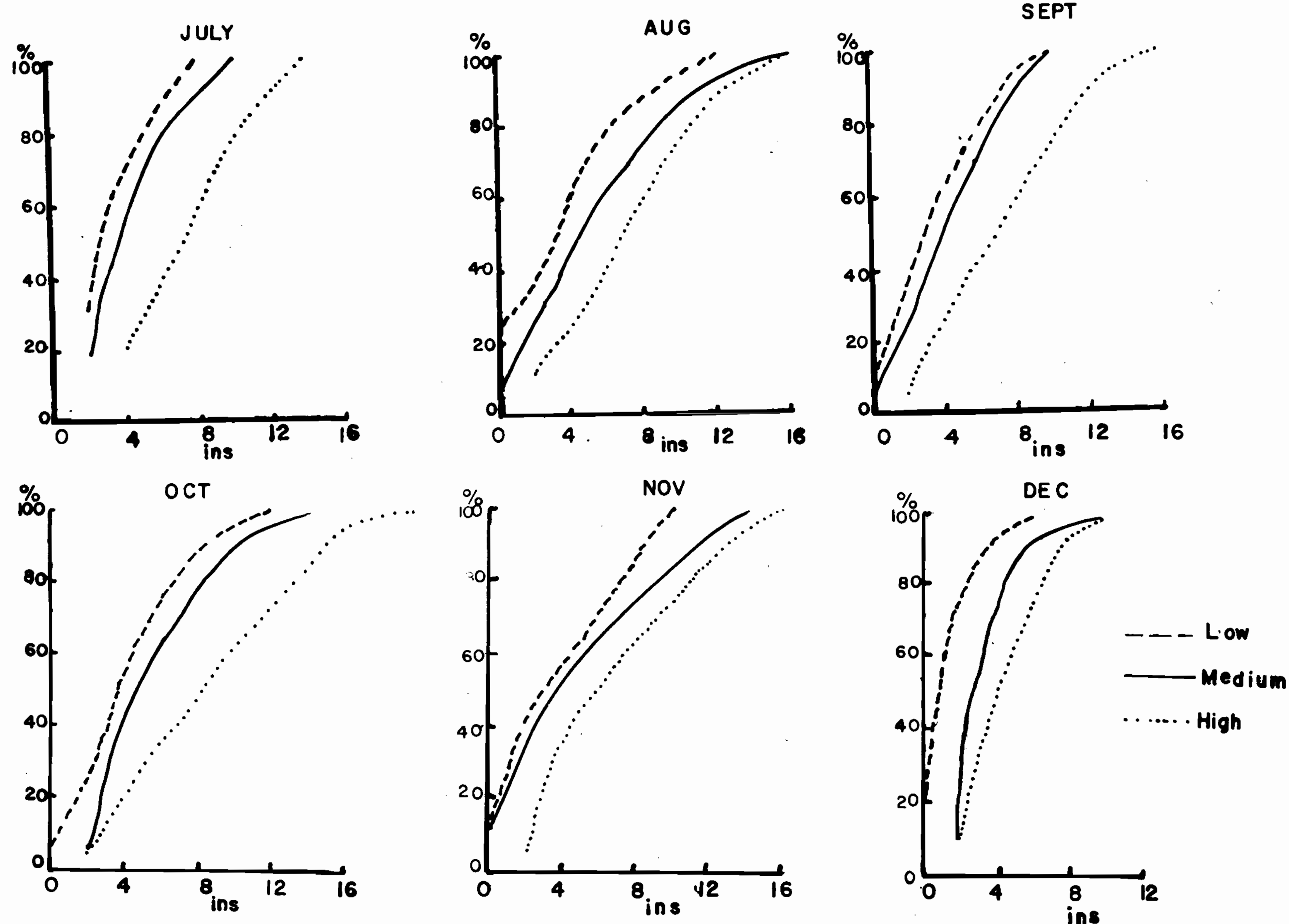


FIG. 4b

January and May is below 4 inches whereas June to November shows that over 50 per cent of the rainfall during this period lies between 4 inches and 12 inches. In the high rainfall area about 60 per cent is less than 4 inches between January and May whereas June to November indicates over 60 per cent lying between 6 inches and 18 inches. The medium rainfall area shows a peculiar distribution in that the dry season resembles that of the low rainfall area and the late wet season resembles the high rainfall type; it is only at the middle of the rainy season that it shows a clear-cut characteristic which is intermediate between the high and the low rainfall zones. The over all picture is one of heavy concentration of rainfall between June and November.

Evaporation

It is a usual practice to correlate rainfall directly with yield in Barbados; Thornthwaite (1951, p. 166) emphasized that it is not easy to assess the degree of wetness or drought in any region by knowing the precipitation alone. Mohr (1944) stressed the importance of evaporation from the soil; Hardy (1946) asserted that "the study of soil moisture relations comprises the most important part of ecological crop investigation." By adopting Mohr's methods Hardy made a study of the seasonal match of soil moisture and classified as "arid" the tropical climate having less than 6.0cm (2.4 inches) of rain and as "humid" the climate having more than 10.0cm (4.0 inches) a month. He found Mohr's values correct for Trinidad and also applied the same to produce an effective rainfall map of Barbados. Hardy however recognised that altitudinal effect will reduce temperature and thereby decrease evaporation.

Of recent more attention has been given to the measurement of potential evapotranspiration at the Waterford Observatory. It has been noticed that the Thornthwaite's monthly potential evapotranspiration values, derived from an empirical formula (1957) tend to be more rigid than are the measurements from instruments and do not show variations that month to month water elements should suggest. There is a measure of agreement between the open pan and the American Class A evaporating pans, but the American Class A pan usually shows a higher evaporation than the Thornthwaite formula. This discrepancy, the writer believes, is due to two reasons. First there is the advective effect, especially at the height of the dry season, when the wind speed reaches its maximum intensity. Secondly, the vegetation cover surrounding the weather station varies in height from season to season. This could vary the zero-plane displacement effect. An "oasis" effect is thus created around the pan and this is reflected in the amount of evaporation recorded.

There is a further problem in the application of the Thornthwaite's formula to the island. This concerns the release of moisture to plants when the storage is below field capacity. Although Thornthwaite's formula recognises that the amount of moisture available to the plant decreases as the soil moisture content decreases, Hudson (private correspondence) observed that in Barbados the character of the soil is such that the soil moisture is not easily available to the plant even when it is above the permanent wilting point; consequently growth may come to a standstill even when there is ample water supply in the soil.

The application of an empirical formula such as Thornthwaite's therefore has its limitations, some of which as mentioned earlier, are the advective effect and the peculiar behaviour of the soil. There is also the crop itself which has been noticed to lose its roots through decay in the latter part of its life cycle thereby further decreasing the moisture absorption which is already decreased by senescence. In spite of these limitations the Thornthwaite formula is good enough to show a relationship between the moisture supply and sugar cane yields on the island. The micro-effects of the limitations enumerated above could be investigated through some of the methods of measurement of evaporation prevously classified as "research" tools.

CHAPTER IV

MOISTURE DEFICIENCY AND SUGAR CANE YIELDS IN BARBADOS

The distribution of rainfall in Barbados is uneven both in time and space; the mean annual total is on the whole marginal to the cultivation of sugar cane. This means that the varying rainfall amounts will influence the amount of yields to be expected; also the yields will vary from one part of the island to the other.

Choice of Plantations and Data.

In order to investigate this varying effect of rainfall on yields, a survey representative of the sugar cane environment in Barbados was carried out. The criteria used to delineate this representation include the soil type, rainfall (distribution and reliability), temperature and the crop yield data.

The total number of plantations considered is thirteen and the choice of these plantations was made proportional to the area within each rainfall zone. The low rainfall area accounted for six out of the thirteen while the medium and high rainfall area, accounted for five and two respectively. The selection within each rainfall zone shown in fig. 5 is also governed by the

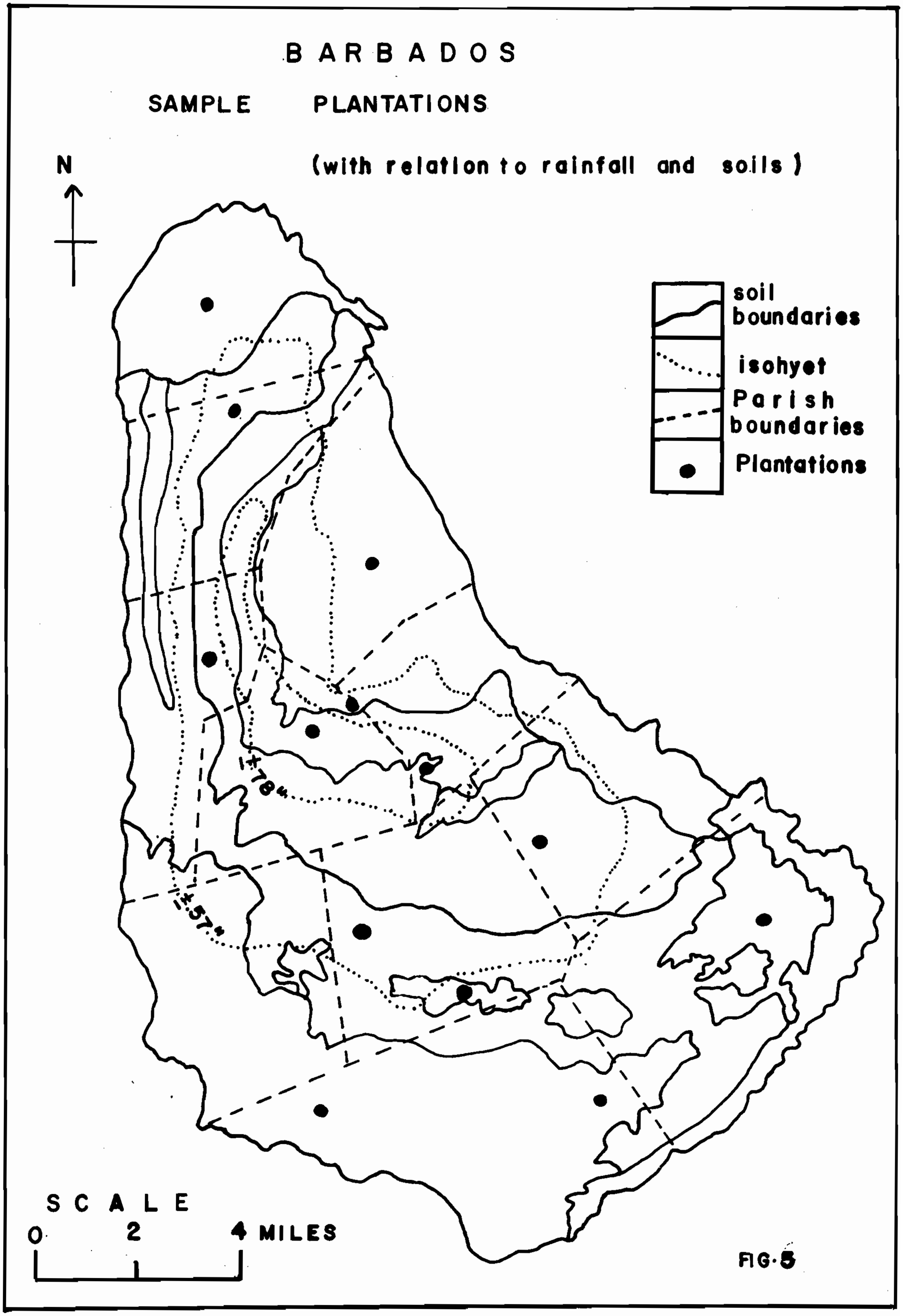

BARBADOS
SAMPLE PLANTATIONS
(with relation to rainfall and soils)
N
soil boundaries
isohyet
Parish boundaries
Plantations
78"
57"
SCALE
0 2 4 MILES

FIG. 5

soil type and the availability of data. The length of time for which data (especially of rainfall and crop yield) are available varies from plantation to plantation; while some plantations have records for nearly 40 years, others are able to supply only the previous season's records. Therefore most of the plantations chosen are those which had records extending over at least 10 years and in some cases beyond 25 years. This length of time corresponds roughly with the period when a successful variety of sugar cane (B37161) was thriving and also when manurial practices have been quite well understood.

Since the choice of data is wholly dependent on rainfall and temperature records, the writer is limited to a method of estimating the potential evapotranspiration which does not involve such parameters as the wind, height of crop and change in canopy (Penman, 1956); a consideration of such parameters, the writer believes, will require controlled field experiments extending through a crop cycle. The writer has therefore applied the Thornthwaite's formula which requires only temperature, rainfall and soil moisture conditions.

Temperature records extending over long periods have already been noted to be few in Barbados. However, the fact that the temperatures are uniformly high made it possible to estimate the monthly temperatures at the chosen stations by making an allowance of a decrease of 5°F. for every 1000 feet of ascent; this method was applied by Rouse (1962, p. 25). Recent soil moisture determination by Hudson in Barbados has shown that the soil moisture content at field capacity is of the order of 1¼-1½ inches (3.13-3.75cm.) per foot. This result the writer has assumed to mean that at field capacity the soil moisture content is of the order of 6 inches per month in the top 18 to 24 inches layer of the soil. This is generally uniform for most of the depth of soil, which depends on the depth at which the coral limestone of the sub-soil is located. In the deeper clayey areas such as the St. George's valley, a figure of 8 inches per month at field capacity may be acceptable. These estimates correspond to Thornthwaite's estimates of storage capacity of clay soils. They however, assume that the sugar cane roots are fully developed, whereas in fact the young crops have shallower root zones and less water need. As the vegetation cover increases, the amount of evapotranspiration increases until the maximum is attained with a fully developed canopy.

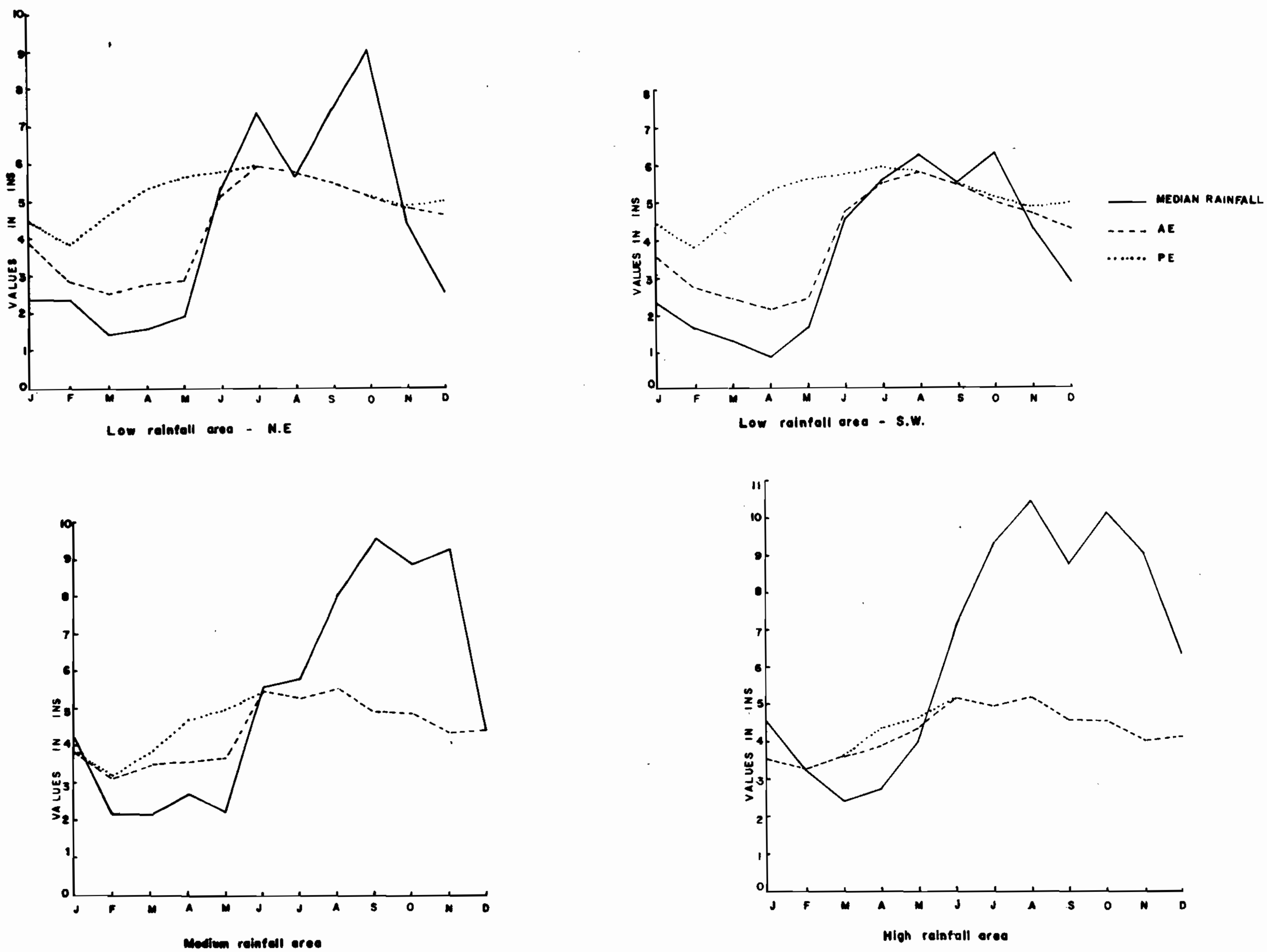
Calculation of PE and AE: Thornthwaite Formula

Thornthwaite and Mather's Instruction Tables (1957) were used in the calculation of the actual and potential evapotranspiration. The heat index value was obtained by the summation of the monthly value corresponding to the estimated mean monthly temperatures (^{o}F.), Then an unadjusted daily potential evapotranspiration, (corresponding to each monthly temperature and the calculated-heat index), was obtained from the table. These unadjusted daily potential evapotranspiration values were corrected for month and day length factor by multiplying each one with a latitudinal correction factor which, in the case of Barbados, is that for 13^{o}N.

A comparison of the calculated potential evapotranspiration (PE) with the corresponding monthly rainfall for each crop cycle-17 months (November to February) for plant cane and 12 months (March to February) for the ratoons revealed the trend of moisture supply to the sugar cane crop. Whenever the potential evapotranspiration (PE) is less than the actual rainfall, the actual evapotranspiration (AE) is equal to PE and the surplus goes to the soil either as run-off, if the soil is at field capacity or, increases the soil moisture storage if the field capacity is not yet attained. If, however, the potential evapotranspiration is greater than the actual rainfall, the accumulated potential water loss (which is the sum total of all the water losses suffered during the preceding months) helps to estimate an equivalent amount of moisture

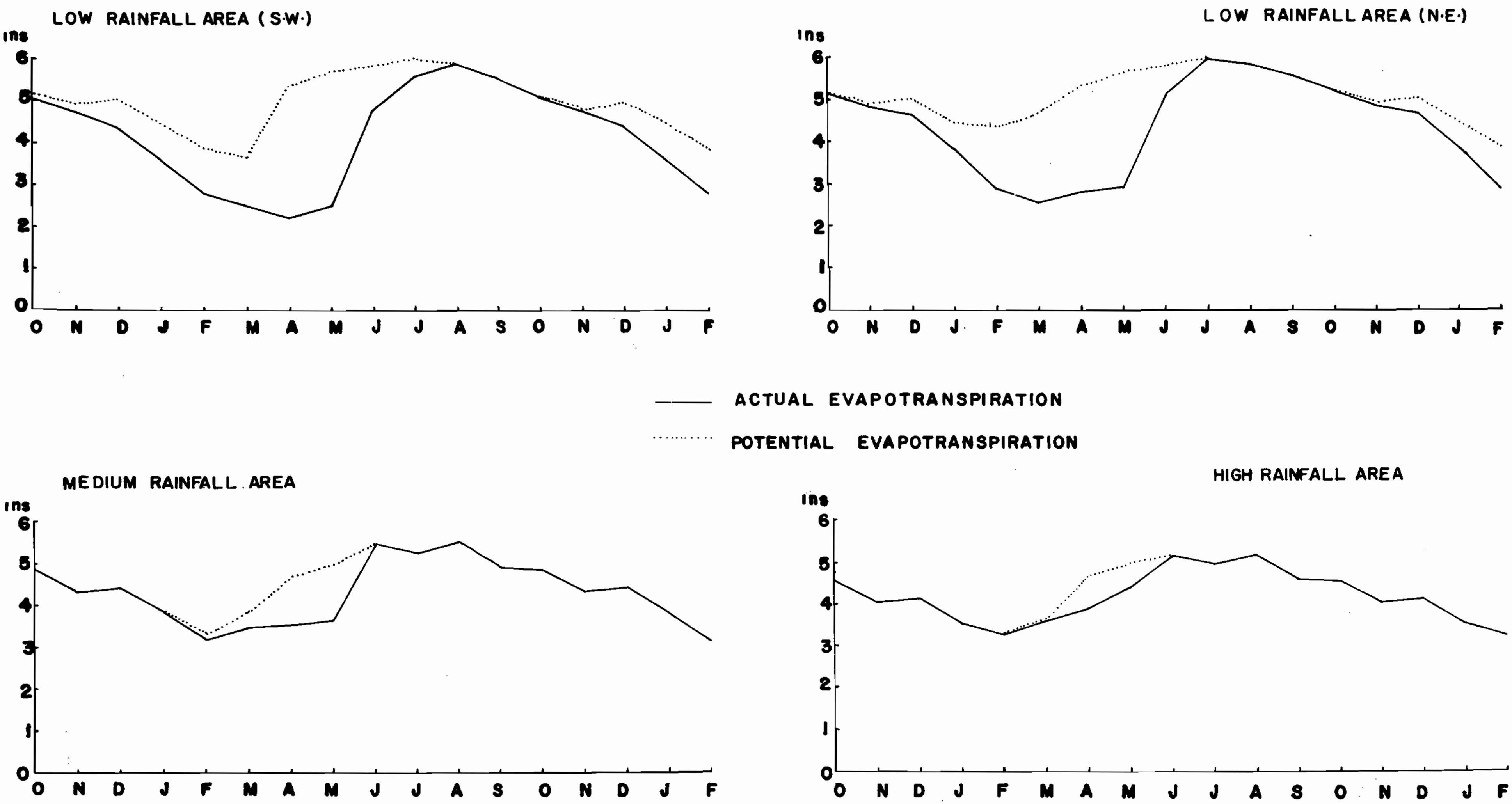
BARBADOS

Moisture Supply (Surplus & Deficiency)



FIG·6

A.E. and P.E. THROUGH A CROP CYCLE : PLANT CANE and RATOON



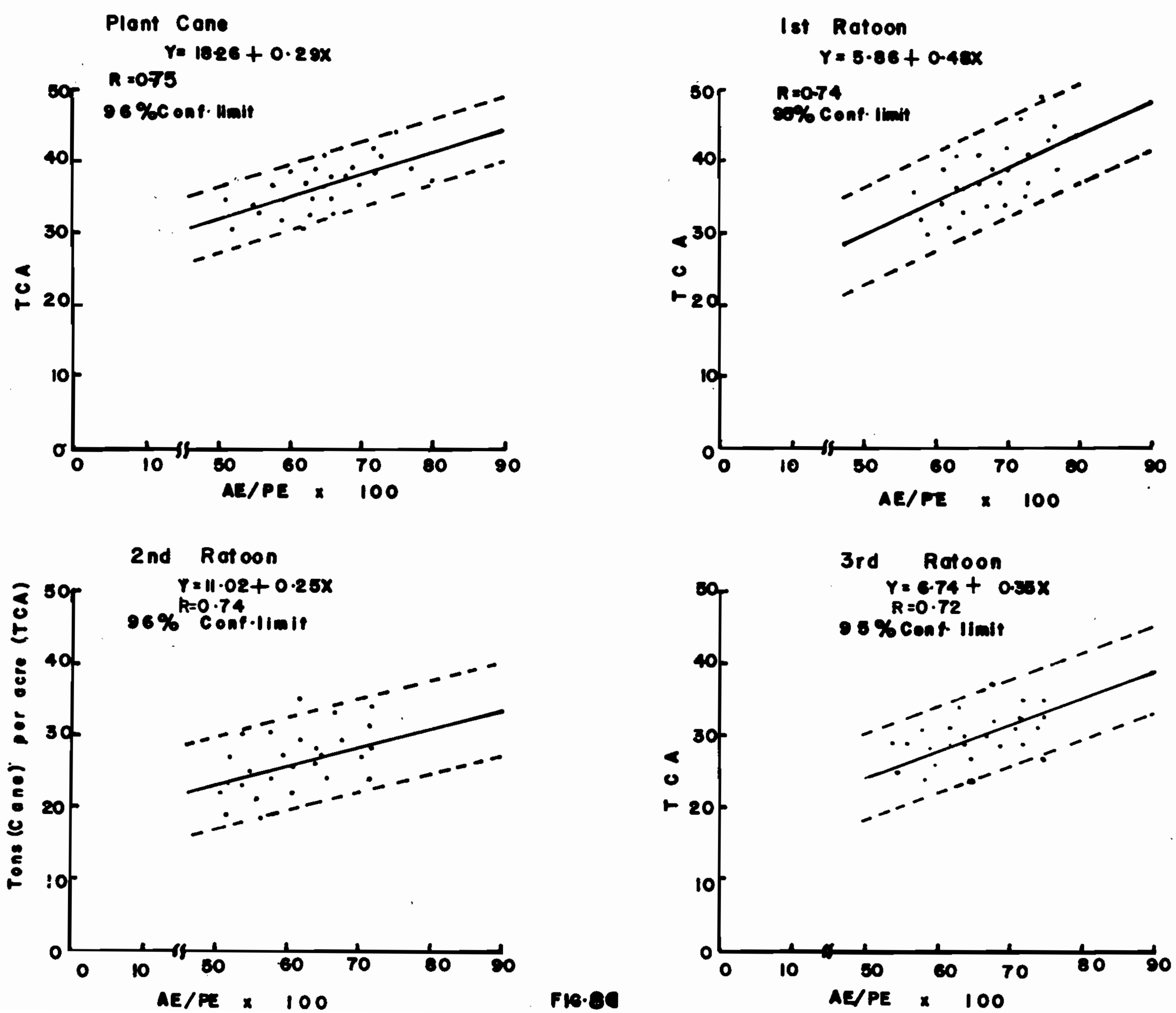
Fig·7

left in the soil with field capacity of 6 inches or 8 inches depending on the soil type. The loss in soil moisture content between two successive months represents the amount of moisture actually withdrawn from the soil to supplement the inadequate rainfall; thus the rainfall for the month plus the amount withdrawn from the soil represents the actual evapotranspiration (AE) and the deficiency is PE-AE.

The maximum potential evapotranspiration (5.83 inches in the low rainfall and 5.18 inches in the high rainfall area) is in August when the precipitation is generally able to satisfy the potential evapotranspiration; the lowest potential evapotranspiration (3.82 inches in the low rainfall area and 3.28 inches in the high rainfall area), occurs in February; the minimum actual evapotranspiration, however, occurs between February (3.28 inches in the high rainfall area) and April (2.18 inches in the low rainfall area). Figure 6 shows that the median rainfall is much less than the actual evapotranspiration for some part of the year; during such months the plants have to depend to a great extent on soil moisture storage; consequently the potential evapotranspiration could not be satisfied. As would be expected, the most adversely affected area is the low rainfall area. This area shows (fig. 7) that for a crop cycle of 17 months (plant cane) and 12 months (ratoon) there is adequate moisture supply for roughly 4 months between August and November, which means that there is a moisture shortage for 13 months and 7 months respectively. The most intensive drought occurs between February and May.

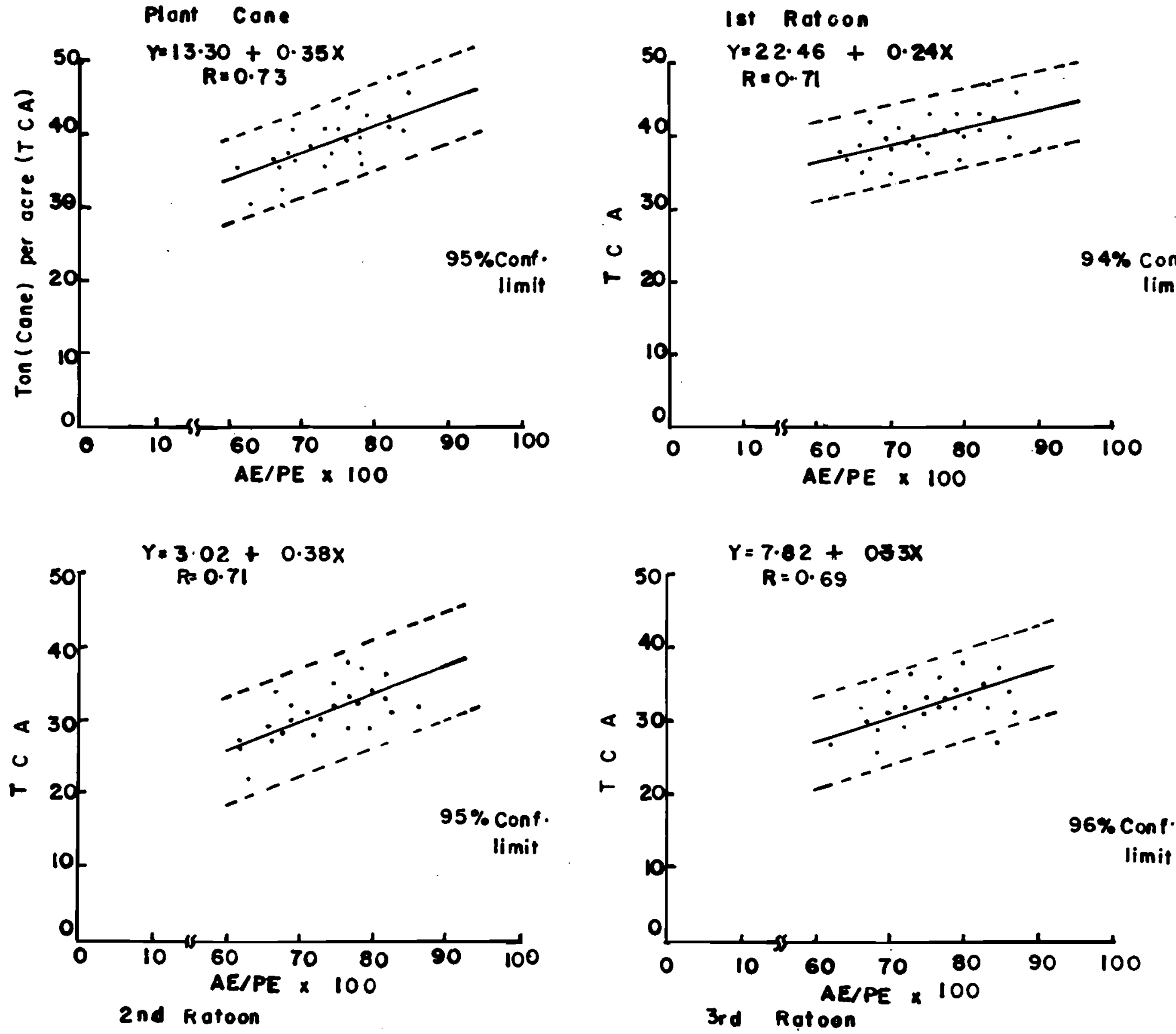
The degree of dryness becomes less and less as one moves to the higher rainfall zones for two reasons: Firstly, the potential evapotranspiration decreases with increase in altitude due to lower temperatures and lower energy for evaporation and higher cloud cover (a factor not reflected in the formula) and secondly, because the rainfall is higher, the actual evapotranspiration satisfies the potential evapotranspiration for a greater number of months; consequently the length of drought becomes progressively shorter and less severe than in the low rainfall zone. In the medium rainfall area the length of drought is about 8 to 12 months for plant cane and 5 to 7 months for the ratoons. The high rainfall area only shows a very weak, short dry spell occurring between March and June.

LINEAR REGRESSION : AE/PE Vs YIELD (Low rainfall area)



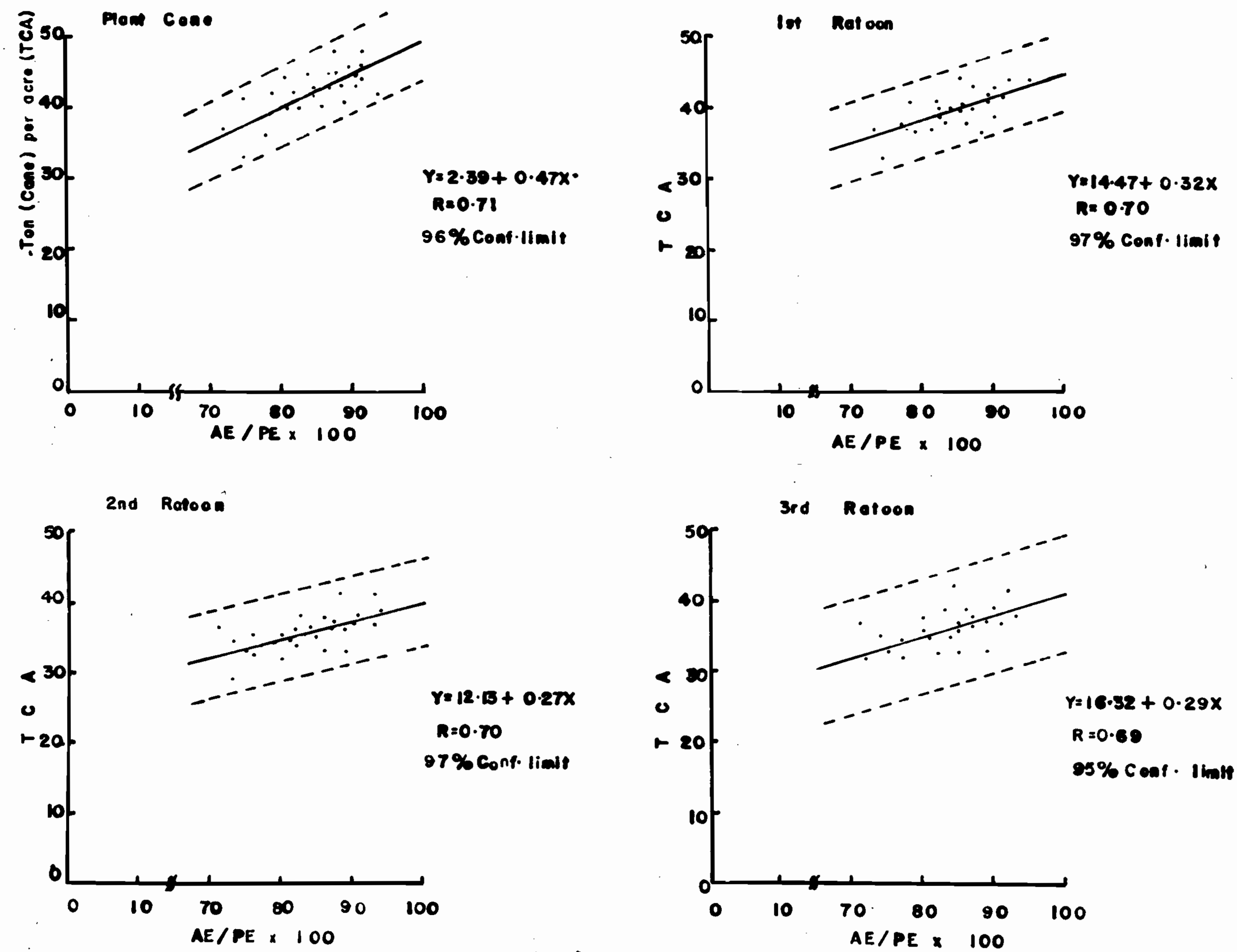
FIG·8C

LINEAR REGRESSION : AE/PE Vs YIELD (Medium rainfall area)



FIG· 8b

LINEAR REGRESSION : AE/PE Vs YIELD (High Rainfall Area)



Fig·8e

Linear Regression between Moisture Supply and Yield

A linear regression established between sugar cane yield and the ratio AE/PE for plant cane and ratoons (figures 8a-8c), shows a positive trend as shown in table 2 below:

Table 2 : Equations of Linear Regression between Yields and AE/PE x 100

	Rainfall Areas		
	Low	Medium	High
Plant Cane	Y=18.26+0. 29x r= 0.75	Y=13.30+0. 35x r= 0.73	Y=2.39+0.47x r=0.71
1st Ratoon	Y= 5.86+0.48x r= 0.74	Y=22.46+0.24x r=0.71	Y=14.47+0.32x r=0.70
2nd Ratoon	Y=11.02+0.25x r= 0.74	Y=3.02+0.38x r=0.71	Y=12.13+0.27x r= 0.70
3rd Ratoon	Y= 6.74+0.35x r= 0.72	Y=7.82+0.33x r=0.69	Y=11.32+0.29x r=0.69

where AE=Actual Evapotranspiration
PE=Potential Evapotranspiration
Y=Actual Yield
X=AE/PE x 100
and r=correlation coefficient.

The correlation coefficient varies from 0.71 to 0.75 (mean of 0.73) for plant cane and between 0.69 and 0.74 (mean of 0.72) for the ratoons. Although these correlation coefficients are a little lower than those obtained by Rouse (1962, p 49), probably because

Rouse applied a correction factor to the Thornthwaite formula, the results are generally similar.

The AE/PE ratio is found to be lowest in the low rainfall areas. It was less than 0.73 for 60 per cent of the crop cycles investigated in this area; in the medium rainfall area about 46 per cent, and in the high rainfall area 15 per cent of the cases investigated indicated an AE/PE less than Chang's estimate of 73 per cent which may be regarded as modest because Smith (1962,p.129) reckoned this minimum AE/PE ratio as 0.79. This therefore means that a significant portion of Barbados, over 50 per cent of the total surface area, will be critically affected by moisture deficiency. The size of the yield therefore will be to a large extent determined by the amount of moisture deficiency during a crop cycle.

Effect of Moisture Deficiency

In order to establish the periods of moisture deficiency on the island, the writer made certain assumptions: firstly, a month in which the actual evapotranspiration is unable to satisfy the potential evapotranspiration can be regarded as a month of deficiency. There is a fundamental difference between this definition and Mohr's (1944) definition of an "arid" month; whereas Mohr considered a month when the rainfall is below the requirement at wilting point (2.4 inches) the writer is considering the months when actual evapotranspiration (rainfall and storage change) does not afford the sugar cane plant an opportunity for its maximum growth; secondly, the maximum growth rate for a 17-month crop cycle has been known to occur in Barbados between July and August (McIntosh, 1934; Bolton, 1956); the writer has therefore assumed that the first 8 months of a plant cane cycle and the first 5 months of a ratoon crop cycle can be regarded as the early growth stage for sugar cane in Barbados; thirdly, in any crop cycle when over 60 per cent of the deficiency occurs under the conditions stated above, such a crop harvest may be regarded as having most of its deficiency in early growth.

On these assumptions, it is revealed that most of the moisture deficiency occurs during the early growth stage in Barbados. A linear regression between the ratios Y/Av. Y and D/Av. R (figs. (9a-9d) shows a negative trend as stated in table 3 below:

Table 3: Equations of Linear Regression between Y/Av.Y (=Y*) and D/Av.R (=X*).

	Rainfall Areas		
Crop	Low	Medium	High
Plant cane	Y*=1.31-1.10X* r=-0.74	Y*=1.46-2.24X* r=-0.71	Y*=1.29-2.93X* r=-0.71
1st Ratoon	Y*=1.57-1.09X* r =-0.74	Y*=1.28-1.96X* r =-0.69	Y*=1.36-2.06X* r =-0.68
2nd Ratoon	Y*=1.77-1.60X* r =-0.75	Y*=1.35-2.68X* r =-0.70	Y*=1.26-2.06X* r =-0.68
3rd Ratoon	Y*=1.87-1.96X* r =-0.75	Y*=1.32-1.86X* r =-0.70	Y*=1.26-1.79X* r =-0.69

where Y= Actual Yield

Av.Y= Average Yield

D= Moisture Deficiency (PE—AE)

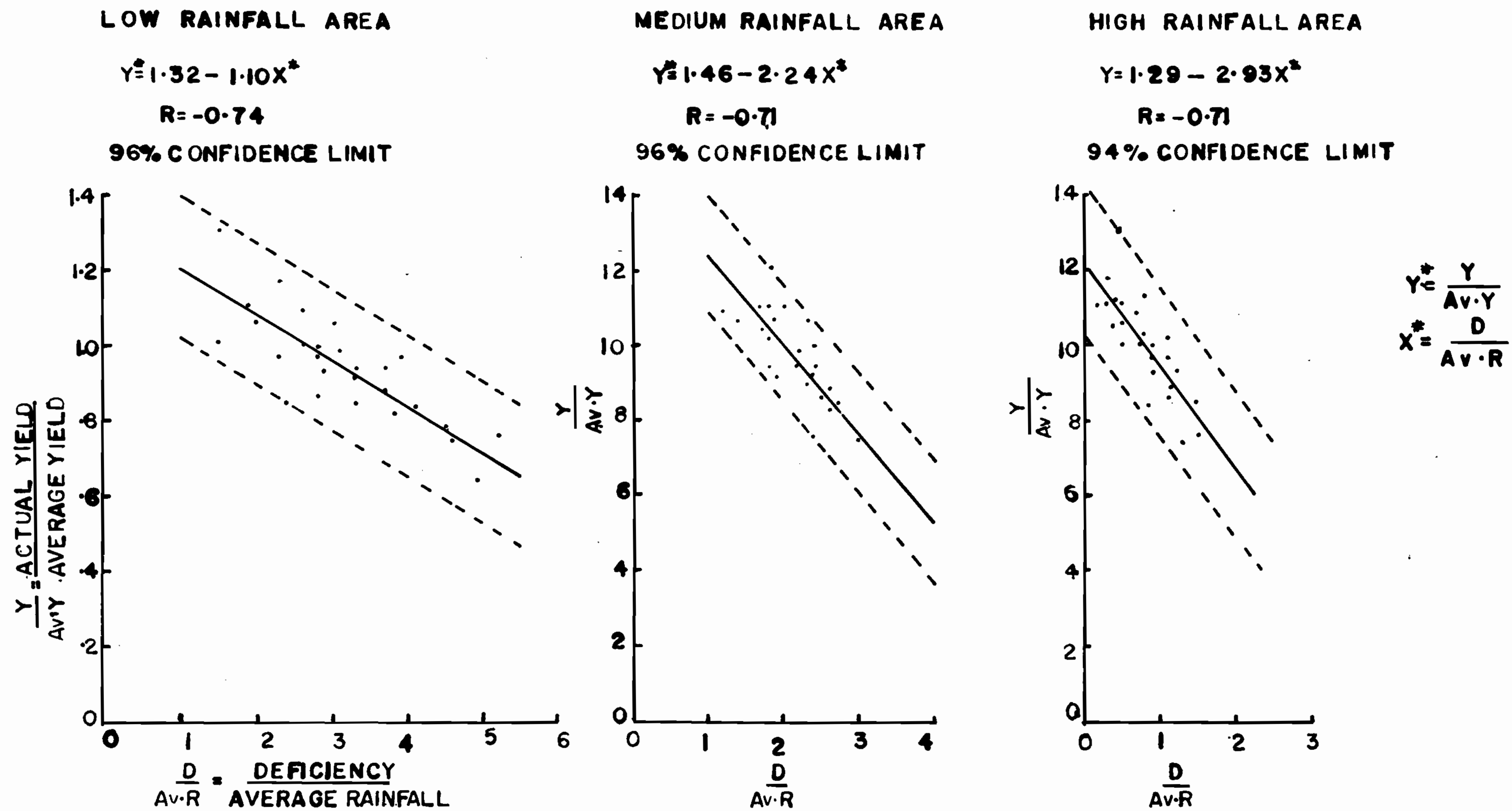
Y*= Y/Av.Y

X*= D/Av.R

and r = correlation coefficient.

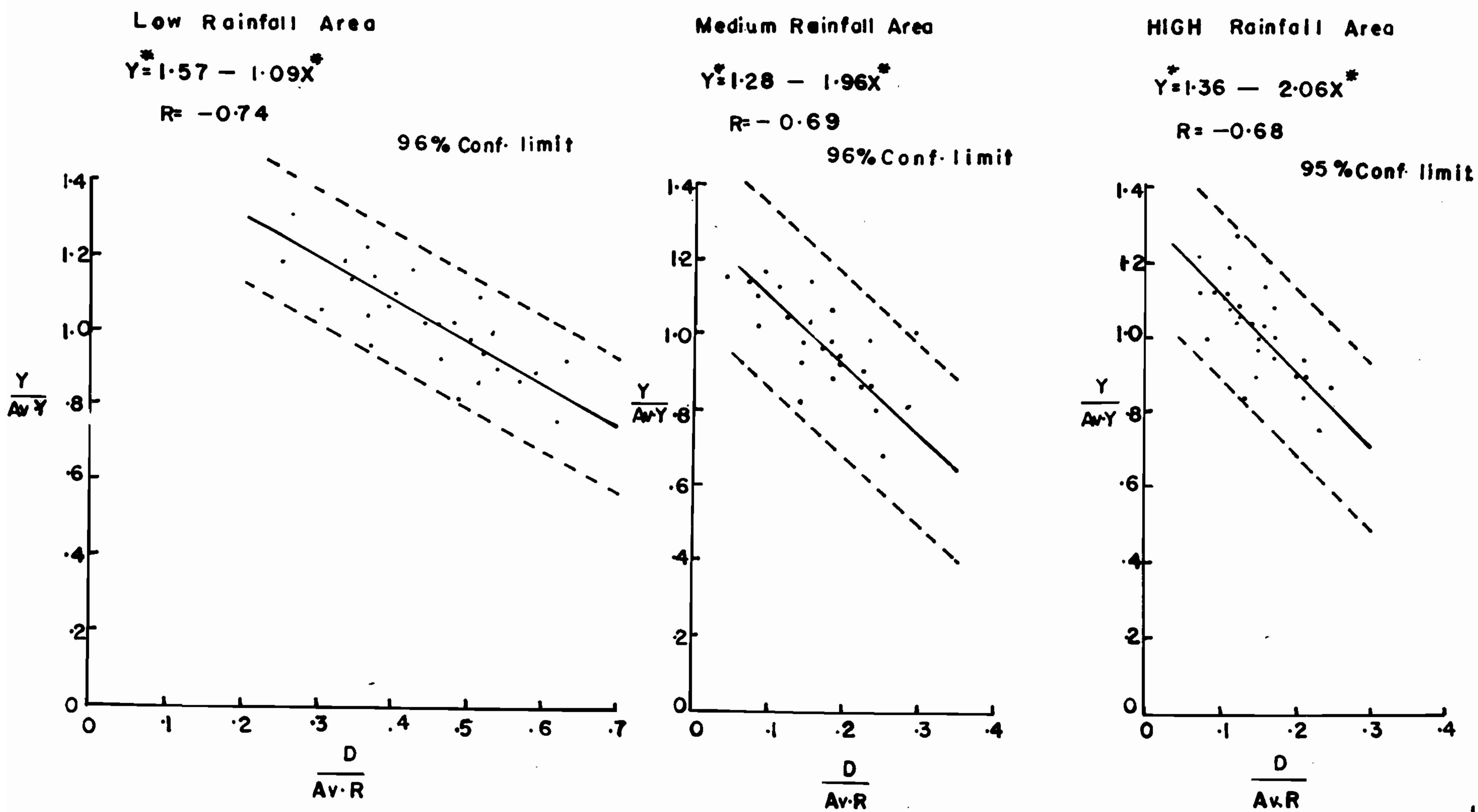
The above results show that there is a negative correlation between yield and moisture deficiency (between 0.71 and 0.74 for plant cane and 0.69 to 0.75 for

LINEAR REGRESSION : MOISTURE DEFICIENCY Vs YIELD (Plant Cane)



Fig·9a

LINEAR REGRESSION : MOISTURE DEFICIENCY Vs YIELD (Ist Ratoon)



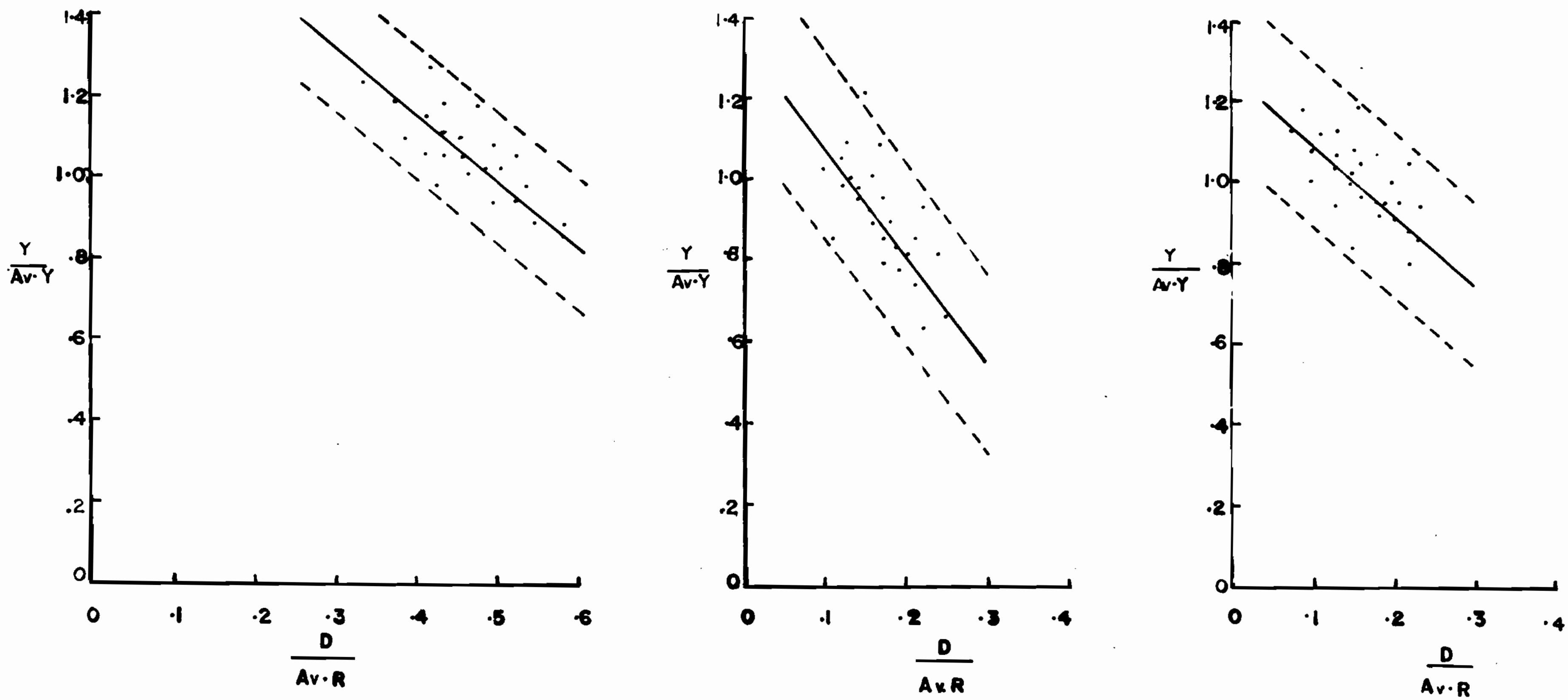
Fig·9·b

LINEAR REGRESSION : MOISTURE DEFICIENCY Vs YIELD (2nd Ratoon)

Low Rainfall Area
$Y^{*} = 1{\cdot}77 - 1{\cdot}60X^{*}$
$R = -0{\cdot}75$
97% Conf· limit

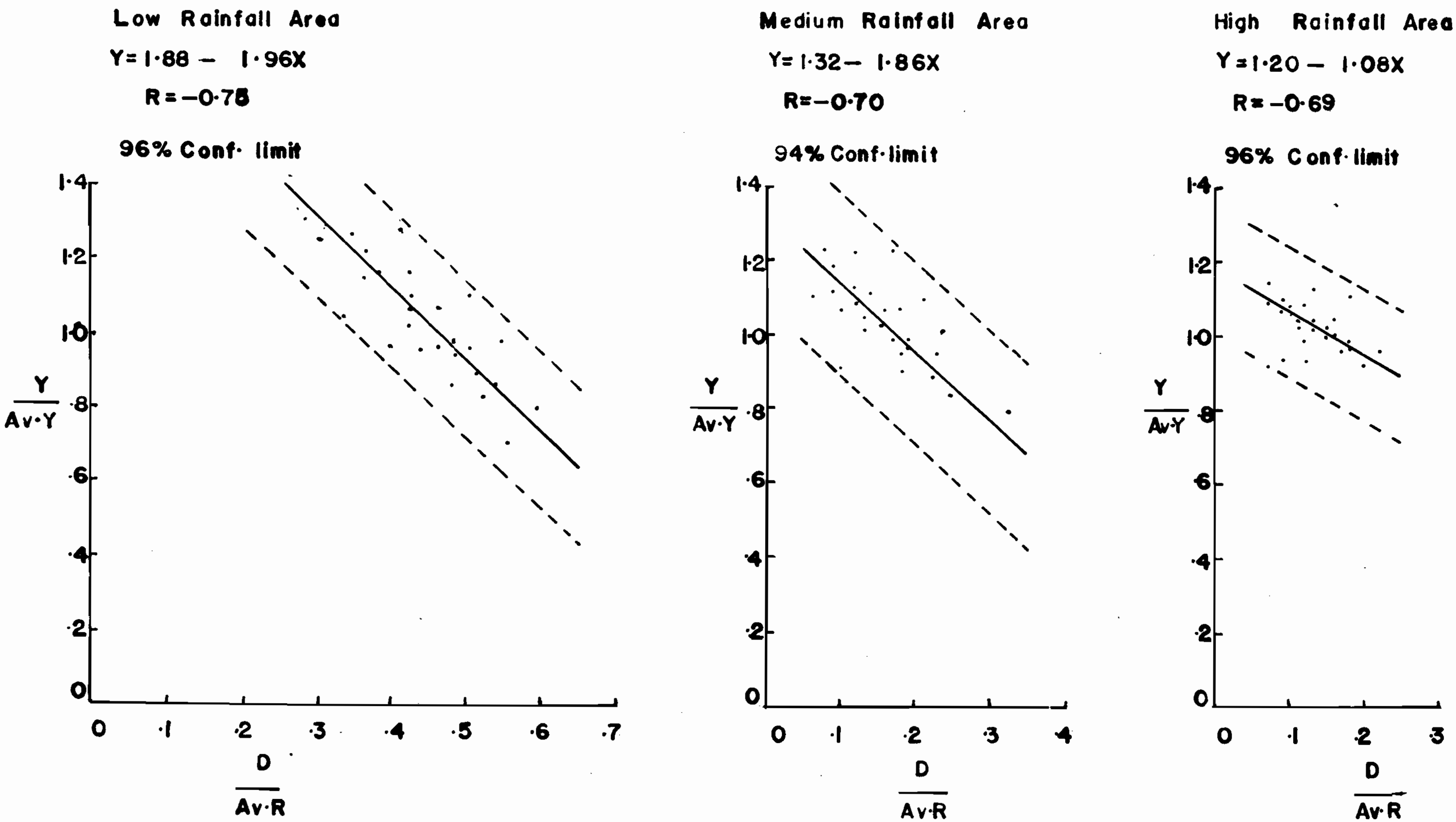
Medium Rainfall Area
$Y^{*} = 1{\cdot}35 - 2{\cdot}68X^{*}$
$R = -0{\cdot}70$
94% Conf· limit

High Rainfall Area
$Y = 1{\cdot}26 - 1{\cdot}79X^{*}$
$R = -0{\cdot}68$
95% Conf· limit



Fig·9c

LINEAR REGRESSION : MOISTURE DEFICIENCY Vs YIELD (3rd Ratoon)



Fig· 9d

ratoons). In other words the yield decreases linearly with an increase in moisture deficiency. Since the greater proportion of this deficiency occurs in the early growth, it can be inferred that the actual yield will fall below the anticipated yield in most years. The decrease in regression coefficient from the low rainfall to the high rainfall area may be due to the increasing influence of other factors because the moisture deficiency becomes progressively lower at higher altitudes.

Influence of other Factors

A consideration of the correlation coefficients shows that in the low rainfall area yield and moisture deficiency are closely correlated. The correlation coefficient tends to increase with the age of the sugar cane and this probably indicated that the plant progressively becomes less resistant to drought conditions. The plant cane and the ratoon crop respond differently to drought conditions in the medium and high rainfall areas. The plant cane generally shows a high correlation between yield and moisture deficiency while the ratoon crop shows a low one.

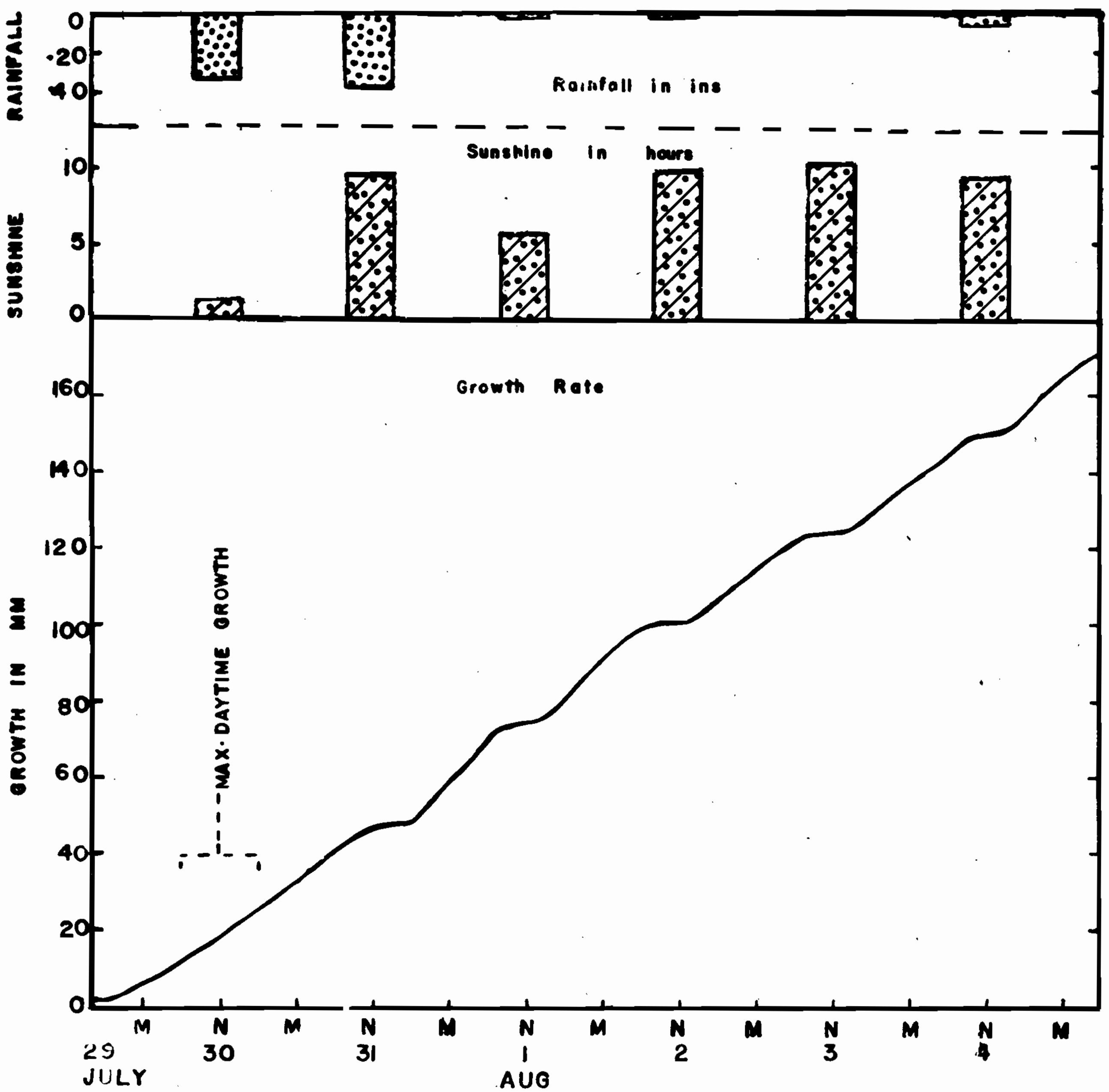
One could conclude that on the whole the yield and moisture deficiency in the low rainfall area show a higher correlation (75 per cent) than in the medium and high rainfall areas (70 per cent). The exception to this is the plant cane which shows no significant difference in the three rainfall areas. The variation in cane growth within these rainfall areas is therefore not adequately explained by the moisture deficiency alone and it is likely that some other factors should be taken into consideration.

These factors may included soil depth, resistance to drought (depending on cane species), and the amount of cloud cover. The third factor is considered by the writer to be of most significance in influencing growth rate.

Hudson's (1963b, p. 7).observation in Barbados shows that cloudiness increases with altitude and it is closely associated with rainfall. This means that the high rainfall areas will probably receive more diffuse radiation than direct radiation as a result of the cloudiness. The response of sugar cane, in Natal, to direct and diffuse radiation has been shown by Smith (1962, p. 50) to vary with the type of radiation which is available; under more direct radiation the sucrose content manufactured was greater than under diffuse. However, with a higher diffuse radiation, spindle elongation was found to be higher.

The writer's growth experiment carried out between July 29th and August 4th, 1963, also illustrates that sugar cane growth is probably influenced by diffuse radiation. The result of the experiment shown in fig. 10, reveals that there is a higher growth rate recorded on a wet day with a large amount of cloud cover than on a dry sunny and cloudless day. The plant used for this experiment was a second ratoon of the B37161 variety, and it was located at about 200 yards from the Waterford Experimental Observatory. On July 30th, the Observatory recorded only 3 hours of sunshine and 0.34 inches of rainfall, the growth recorder showed that between 6.00 a.m. and 6.00 p.m. on that date, the spindle of the plant had increased in length by 14mm.; this rather high growth rate is typical of a wet and cloudy day (Hudson, private discussion). Usually the growth rate is retarded or at a standstill at noon with brilliant sunshine; such a retarded growth rate is noticeable in fig. 10. On August 1st and 3rd, plant growth was at a minimum in the afternoon when the sunshine hours amounted to 6.3 and 10.4 with a rainfall of 0.18 inches and nil respectively.

The result of this experiment agrees with the effect of diffuse radiation on sugar cane growth in Natal. It may be of interest to investigate the sucrose content of the sugar cane under different weather conditions in the island. It seems therefore that in the high



EFFECT OF DIRECT AND DIFFUSE RADIATION ON GROWTH

N= NOON

M= MIDNIGHT

FIG·10

rainfall areas, yield will probably depend not only on the rainfall but also on the amount of cloud cover. It can also be suggested that the difference between the correlation coefficients in the various rainfall zones is due in part to the varying amount of cloud cover.

CHAPTER V

CONCLUSIONS AND SPECULATIONS.

The dependence of Barbados on sugar cane production demands a great deal of constant research to find ways and means of improving the island's output without necessarily increasing the production costs or of finding means by which the increase in output resulting thereby will more than offset the increased production cost.

The writer feels that the ability to supply sufficient moisture to offset the deficiency during the months of low rainfall is of utmost importance if the industry is to continue to prosper. The high correlation coefficients, (0.69 to 0.75 between AE and yield and 0.69 to 0.75 between moisture deficiency and yield), demonstrate that the ability to supply the moisture deficiency will be a great asset to the sugar cane cultivation, especially as most of the deficiency occurs during the early stage when drought causes the actual yields to fall below the expected. The influence of drought seems most pronounced in the low rainfall area; other factors reduce its influence in the other regions.

The writer appreciates the limitations of a formula such as the Thornthwaite's to assess accurately the potential evapotranspiration on an island like Barbados;

some of these limitations include the rigidity of the formula in the use of a single parameter; the temperature. It therefore excludes the influence of other climatic parameters such as the cloud cover and wind advection which can be equally important in determining the water needs of sugar cane. There is also the fact that the water needs of the crop vary with its age; the early and late growth stages require less moisture for different reasons. In the early stage the plant cover is small and in the late stage the moisture requirement is reduced by senescence.

There are other local factors which impose limitation on the attainment of optimum yields in Barbados. The shallowness of the top soil does not allow for an easy root penetration; furthermore it has been established by Hudson 1963a that the soil does not release its moisture quite easily to the plant even when its moisture content is above the permanent wilting point but below the field capacity. Such peculiarities accentuate the effects of short spells of drought. The sugar cane itself has been known to adjust to climatic conditions and efforts have been made in the past to breed varieties best suited to each locality. The effect of diseases has been known to cause severe damage to roots especially in the late growth state, consequently some of the stems are lost at harvest. There is the cultural efficiency which varies from individual to individual and finally, occasional fires, carelessly set burning causes severe damage not only to the immediate harvest but also to the succeeding ratoons to be harvested from the burnt crops. Such factors, the writer believes, are responsible for the unexplained variance in regression results already discussed. Some of these factors will open an avenue for further research.

In spite of these limitations the significant correlation between sugar yield and moisture deficiency indicates that Barbados can still increase her output if the moisture deficiency can be supplied. (The low rainfall area will benefit a great deal from such a project.) An encouraging step in this direction is the recent effort of the government to establish an Irrigation Board; the preliminary report of this board has been published. If the irrigation project comes into fruition, there will be the need for detailed research employing some of the elaborate methods already mentioned in order to work out a more accurate formula for calculating potential evapotranspiration under Barbados conditions. It will be necessary to estimate the varying potential evapotranspiration according to the stage of growth; such a formula will have to take cognisance not only of the temperature but also of the more embracing parameters such as the solar radiation (direct and diffuse), the wind and the characteristic behaviour of the soils.

Such a detailed calculation will reduce irrigation costs to a minimum while the yields will be increased to near optimum which is an ideal that every investor on the island is aspiring to achieve.

BIBLIOGRAPHY

Annual Reports: "The Yield of Sugar Cane in Barbados." Dept. of Sc. and Agric.,Barbados. 1940-1963.

Annonymous : "Some Notes on Reliable Observations made at Barbadian and other Carribean Meteorological Stations." Unpub.

Blaney,H.F. and Criddle,W.D. (1950): "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data." U.S.Soil Conservation Service, Tech. Paper. 96pp.

Bolton,J.(1956): "Record of Investigations 1955-1956." Dept. of Sc. and Agric., Barbados, Bull. No. 25.

Caroll,D.(1963): "Soil Survey of Barbados." In prepation.

Chang,J.H.(1961): "Microclimate of Sugar Cane." Hawaiian Planters' Record, Honolulu, Vol. 56, pp.195-225.

Chang, J.H.(1963a): "Basic Climatic, Yield and Agronomic Information." Journal Series, Hawaiian Planters' Ass. Unpub.

Chang, J.H.(1963b): "On the Study of Evaporation and Water Balance." Jour. Series, Exp. Sta. Hawaiian Planters' Ass. Unpub.

Climatic Observations at Waterford, Barbados. Bellairs' Res. Inst. of McGill Univ. 1959-1963.

Dillewijn, C.N.(1952): "Botany of Sugar Cane." The Chronica Botanica Book Co. p.xxii.

Dove, H. (1846): "A First Report on the Relations between Climates and Crops." Trans. by Cleveland Abbe. U.S. Weather Bureau. Bull. No. 36, 1905, pp. 234 - 235.

Gerasimov, I.P. "Soviet Geography: Accomplishments and Tasks." Trans. by L. Ecker, American Geog. Soc., 1962, p. 66.

Griffith, G. (1952): "The Interception of Rain Water by a Vegetation Mulch." Trop. Agric. Vol. XXIX, pp. 50 - 53.

Hardy, F. (1946): "Seasonal Fluctuations of Soil Moisture and Nitrate in a Humid Tropical Climate (Trinidad, B.W.I)." Trop. Agric. Vol. 23, pp. 40 - 49.

Hudson, J.C. (1963a): "An Interim Report on the work carried out by the Research Student to the Irrigation Board from Aug. 1961-Jan. 1963." Unpub.

Hudson, J.C. (1963b): "Some Meteorological Observations in Barbados." Dept. of Sc. and Agric., Barbados. Bull. No. 33.

James, P.E. and Jones, C.F. (1954): "American Geography Inventory and Prospect." Syracuse Univ. Press, p. 348.

Johnson, B. (1942): "Barbados Rainfall." Dept. of Sc. and Agric. Barbados, Bull. No. 16

Kramer, P.J. (1955): "Contributions to discussion of F.J. Veihmeyer and A.H. Hendrickson's paper. Transactions: American Geog. Union, Vol. 36, pp. 425 - 448.

Lemon, E.R., Glazer, A.H. and Saitherwhite, L.E. (1957): "Some aspects of the relationship of Soil, Plant and Meteorological Factors to Evapotranspiration." Proc. Soil Sc. Soc. of America. Vol. 12, pp. 404-468.

Macpherson, J. (1963): "Carribean Lands: A Geography of the West Indies." Longmans, pp.70-80.

McIntosh, A.E.I.(1934): "Sugar Cane Growth Measurements in Barbados." Barbados Agric. Jour. Vol. 3, No. 1.pp.9 - 19

Mohr, E.C. Jul. (1944): "The Soils of Equatorial Region with Special reference to Netherlands East Indies." Trans. from the Nederlandsch by R.L. Pendleton and J.W. Edwards. Ann. Arbor.

Pasquill, F. (1950): "Some further Considerations of the Measurement & Indirect evaluation of Natural Evaporation." Q.J. Roy. Met. Soc. Vol. 76 pp. 287 -301.

Pelton, W.L., King, K. M. & Tanner, C.B. (1960): "An Evaluation of the Thornwaite and Mean Temperature Methods for Determining Potential Evapotranspiration." Agron. Jour. Vol. 52, pp. 387 - 395.

Penman, H.L. (1948): "Natural Evaporation from Open Water, Bare Soil and Grass." Proc. Roy. Soc. Ser. A. Vol. 193, pp.120 - 145.

Penman, H.L. (1949): "The Dependence of Transpiration on Weather Conditions." Jour. of Soil Sc. 1, pp. 74 - 89.

Penman H.L. (1956): "Evaporation, an Introductory Survey." Neth. Jour. of Agric. Vol. 4, pp. 9 - 29.

Pierce, L.T. (1958): "Estimating the Seasonal and Short term fluctuations in Evapotranspiration from Meadow Crops." Bull. Amer. Met. Soc. Vol. 39, pp. 73 - 78.

Price, E.T. (1962): "Notes on the Geography of Barbados." Fieldwork Report Univ. of California 1938. Barbados Jour. of Hist. Mus. Soc. Vol. 29, No. 4, p. 139.

Pruitt, W.O. (1960): "Correlation of Climatological Data with Water Requirement of Crops." Dept. of Irrigation, Univ. of Calif., p. 18.

Rawson, W.R. (1874): "Rainfall and Meteorological Observations in Barbados." Official Gazette of Barbados.

Robinson, J.B.D. (1951a): "A brief Review of Sugar Cane Manuring in Barbados." Proc. B.W.I. Sugar Ass. P. 73.

Robinson, J.B.D. (1951b): "Manurial Trials with Sugar Cane in Barbados." Dept. of Agric. Barbados. Bull. No. 18.

Rouse, W. (1962): "Moisture Balance of Barbados and Its Influence on Sugar Cane Yields." Unpub. McGill Univ. M.Sc. thesis, pp. 25 - 49

Saint, J. (1931a): "Manuring of Sugar Cane in Barbados." Agric. Notes: Reprints From Articles published from Jan. - June 1930, Pamphlet No. 6, pp. 43 - 49.

Saint, J. (1931b): "Preliminary Report on the Coral Limestone Soils of Barbados." Agric. Notes: Reprints From Articles Published from Jan. - June 1930, Pamphlet No, 6, pp. 1 - 6.

Saint, J. (1953): "Sugar Production in Barbados during the past 100 years." Presidential address 8th Congr. Int. Soc. of Sugar Cane Tech. B.W.I.

Skeete, C.C. (1931):"Barbados Rainfall." Dept. of Sc. and Agric. Bull. No, 9.

Smith, G.W. (1960):"Irrigation Needs of Barbados, W.I." Soils Research & Survey Dept., Imperial College of Trop. Agric., Trinidad. Unpub.

Smith, I. (1962):"Climatic Control of Distribution and Cultivation of Sugar Cane." Unpub. McGill Univ. Ph.D. thesis, pp.50 - 129.

Stanhill, G. (1962):"The Control of Field Irrigation Practices from Measurement of Evaporation." Israel Jour. of Agric. Research, Vol. 12, pp. 51 - 62.

Suzuki, S. and Fukuda, H. (1958):"A method of Calculating Potential Evapotranspiration from Pan Evaporation Data." Jour. of Agric. Met., Vol. 13, pp. 81 - 85

Tanner, C.B. (1960):"A Simple Aero-heat Budget Method for Determining Daily Evapotranspiration." Trans. 7th. Inter. Congress of Soil Sc. pp. 203 - 209.

Thornthwaite, C.W.(1948):"An Approach toward a Rational Classification of World Climate." Geog. Rev. Vol. 38, pp. 55 - 94.

Thornthwaite,C.W. (1951):"The Water Balance in Tropical Climates." Bull. Amer. Met. Sco. Vol. 32, No. 5, pp. 166 - 173.

Thornthwaite, C.W. & Mather, J.R. (1955):"The Water Balance." Lab. of Climatology Pub. Centerton, N.J., 86pp.

Thornthwaite, C.W. & Mather, J.R. (1957):"Instructions and Tables for Computing Potential Evapotranspiration and Water Balance." Lab. of Climatology Vol. X, No. 3, 311pp.

Veihmeyer, F.J. & Hendrickson, A.H. (1955): "Does Transpiration decrease as the Soil Moisture decreases?" Trans. Amer. Geog. Union, Vol. 36, pp. 425 - 448.