AN AGROCLIMATIC ANALYSIS OF SELECTED HORTICULTI"KAL CROPS FOR COMMERCIAL AND DOMESTIC USE IN NIGERIA

by

Anthony A. Ochigbo

A THESIS

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Department of Horticulture

Under the Supervision of Dr. R. E. Neild

Lincoln, Nebraska

October, 1977

ACKNOWLEDGMENTS

The Author wishes to express his utmost appreciation to Dr. R.E. Neild for his advice, encouragement throughout the course of study, and for his suggestions and constructive criticisms in the planning, execution and presentation of this study.

The Author also wishes to thank Dr. J.O. Young and Dr. D.P. Coyne for serving in the committee that evaluated this thesis, and fellow graduate students for their assistance in conducting this study.

Finally the Author is greatful to the Federal Government of Nigeria and Ahmadu Bello University for making a study programme of this type possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Nigeria is the largest country along the coast of West Africa. It covers an area of 923,769 sq. km. and is situated between latitude 4° and 14° north of Equator. The population is over 60 million. Cocoa, (*Theobrama cacao*), oil palm, (*Elaeis guineensis*), ground-nut, (*Arachis hypogaea*), and cotton, (*Gossypium spp.*) for export and cassava, (*Manihot utilissima*), yam, (*Dioscora rotundata*), guinea-corn, (*Sorghum guineensis*), and millet, (Pennisetum spp.), are the principal food crops of the country. Horticultural crops have received less attention.

Nigeria produces about 394,000 tons of vegetables and 171,000 tons of fruit each year. The demand for fruits and vegetables for local consumption is increasing rapidly as incomes rise. This is particularly true in the northern states where consumption is very low. The demand for green vegetable and fruits is expected to be about 771,000 and 230,000 tons respectively by 1980 when the production will need to be doubled.

Nigeria is presently importing large quantities of processed vegetables and fruits from Europe, Japan and USA. In 1971, for example, Nigeria imported 5356 tons of tomato paste alone. This cannot be allowed indefinitely if hard earned foreign exchange resources are to be freed for import of capital goods. A greater proportion of the vegetable and fruit supply must come from domestic production. It would, therefore seem feasible to plan for increased local production of vegetables and fruits with a view to preserving these in-puts for out-of-season domestic consumption and to explore the possibility of processing those of wide commercial importance like tomatoes and pineapple. This is possible if use is made of Nigeria's wide range of environmental conditions and

and abundant good lands.

In assessing new agricultural potentialities one is often concerned with introducing crops or animals which, on the basis of their performance elsewhere, might be considered suitable for the particular climate pattern experienced in the area of development. A complete physical explanation of the meteorological factors which affect climate in Nigeria is not yet possible. Research in this area will provide an essential basis for future agricultural progress to keep pace with the rising population and the goal for a higher standard of living.

This study considers the horticultural crop potential in Nigeria in two broad groups: commercial-industrial production and for local consumption. Tomato and pineapple are two interesting cash crops for export, particularly within Africa.

Tomatoes have become an important item in the Nigerian diet and in Africa in general. In 1967, Italy alone exported over 18,000 tons of tomato paste to West Africa. The demand for processed tomatoes is increasing yearly in Nigeria. In 1971, 5356 tons of tomato paste were imported. This increasing demand is due in part to the growth of urban areas which depend on processed foods. Many small farmers are beginning to grow tomatoes on a commercial scale in the environs of metropolitan areas such as Kano state of Nigeria. Commercial companies notably the Cadbury concern, are beginning to process tomatoes to make a locally accepted tomato paste.

There is an increasing consumption of pineapple in the country. At present, production is mainly confined to the southern drier closed forests and thickets. Pineapples are cultivated not only for local consumption but also to supply a considerable export trade. Much of the fruit is exported in the canned form. The fresh fruit market in Nigeria is also important: the fruit is sold either for local consumption or for air freighting to Europe and other nations. The present supply of pineapple is short of demand both for export and for local consumption and has therefore created a need for increased production. With the use of agroclimatic analysis, we can locate those potential regions for the growing of pineapple.

Home garden vegetables add variety to the diet and are an important source of needed vitamins and minerals. The planting of a series of vegetables can be sequentially scheduled to provide fresh produce for the table for the maximum length of time. In this thesis, horticultural crops for local consumption will be limited to vegetables and will concern only the Northern States which are favorable for their production. Agroclimatic analysis will be used to develop a list of possible vegetable crops that could be grown. Planting and harvest times for some series of vegetables will be developed in three representative locations, Sudan, Northern Guinea and Southern Guinea Savannahs respectively.

The objectives of this study, therefore, were:

(1) To determine areas in Nigeria having climatic conditions most favorable for the commercial production of tomatoes and pineapple.

(2) To develop a sequence of planting and harvest schedules for a series of vegetables for local consumption.

Abstract

BRIEF DISCRIPTION OF CLIMATIC REGIONS OF NIGERIA

The study of climate deals with the analysis of seasonal levels of various meteorological factors which influence us chiefly through the aerial environment. Short-term deviations from the expected climate are described as weather. In agriculture, a knowledge of both climate and weather is an essential basis for the adoption of any farming system. Practical farmers all over the world have discovered by trial and error over long periods of time, patterns of farming suited to their respective climatic areas.

The climate of Nigeria is influenced by two trade winds. From April to September moist south-west trade winds predominate. The dry north-east trade winds, the harmattan, are experienced from October to March.

The mean maximum temperature is about 30^{o}C in the south and about 34^{o}C in the north with a decrease of about 2^{o}C per 30 meters of altitude. The highest temperatures occur between February and April in the south and between March and June in the north. The mean minimum temperature is about 22^{o}C in the south and falls to 19^{o}C in the north. The mean daily range of temperature is higher in the north than in the south. It averages 15^{o}C in the north and considerably more in the dry season. In the south, the range usually is not more than 8^{o}C.

Both the amount and distribution of rainfall show a distinct and fairly regular south-north gradient in which the annual rainfall decreases from the coast inland. The south has an annual precipitation of 3556 mm or more. The amount decreases to 762 mm or less in the extreme north. There are two major rain peaks in the south. In the north, the rainy season gradually changes into a single peak from June to September. The range of humidity varies greatly but is notably higher in the south than in the north. Towards the end of the dry season humidity may fall well below 10% in the afternoon (Buchanan and Pugh, 1955), but may rise as high as 95% at dawn in the rainy season.

In Nigeria, annual day-length varies from 11 hours 30 minutes to about 12 hours 40 minutes.

LITERATURE REVIEW

CROP-CLIMATE RELATIONSHIPS IN PINEAPPLE

The pineapple, *Ananas comosus* (L) Merr., is of tropical South American origin. It is beleived to have been domesticated by Indians in Southern Brazil. It has spread throughout tropical South America, Central America and the West Indies by the time of Columbus (Collins, 1960). The fruit is now commercially grown in over 17 major areas in an equatorial and subequatorial belt. Five nations, the United States (Hawaii), Philippines, Malaysia, Taiwan and Thailand produce 2/3 of the world's canned pineapple.

The following general climatic requirements for pineapple have been summarized from Sideris and Krause (1928), Nightengale (1942), van Overbeck (1946), Gowing (1958), Collins (1960), Py (1960), Black (1960), Green (1963), Mitchell (1963), Neild et al (1963), van Lelyveld (1964), Ekern (1965), Giacornelli (1967), Salter and Kwang (1967), Ramos (1968) and Figueroa et al (1970).

The pineapple is a perennial plant and will continue to grow and periodically bear fruit as long as adequate environmental conditions prevail. The number of months from planting to first harvest, a second harvest from the same plant (called first ratoon fruit) and the two-harvest-cycle length for different locations are summarized in Table 1. The cycle length varies from 21 months in the Philippines to 47 months in South Africa. This great difference in growing-cycle length is related to favorability of moisture condition important for initiating

Table 1. Lengths of pineapple growing cycle (months).

Location	Planting to Ist harvest	Ist harvest to Ist ratoon	Total
Philippines	13	8	21
Fiji, Sri Lanka, Malaysia	18	8	26
Martinique, Taiwan, Hawaii, Australia	20	13	33
South Africa	29	18	47

root growth on newly planted material and to temperature and moisture conditions for growth once roots have been initiated. Cycle length is also related to type of planting material. The pineapple crops is asexually propagated from 'suckers' or 'slips' arising from mature mother plants or with the crown of harvested fruit. Large suckers produce fruit in a shorter time than small slips. Crowns take longer and may be used only when moisture conditions are favorable.

Following planting, young pineapple plants grow vegetatively until they reach a certain size and then low temperature, moisture stress or hormone sprays induce differentiation of a floral tissue at the internal apex of the plant for subsequent fruiting. Fruit size is closely related to plant size at time of differentiation so timing of planting relative to precipitation and temperature patterns is critical. This is especially so in mechanized canning operations where processing equipment, container dimensions for whole fruit slices and the size and shape of fruit must be closely correlated. The optimum conditions for processing would be found in areas with uniform temperature and moisture regimes favorable for growing the Smooth Cayenne variety which is the standard of quality for processed fruit. Such conditions would enable planting to be made at any time of year and allow fruit initiation and harvest to be artificially controlled with hormone spray (Cutshall, 1951; Neild et al,1963)

Pineapples will grow in a temperature range between 20°C and 27°C, but 23°C to 24°C is considered optimum. Plant growth decreases rapidly at temperatures below 15°C or above 32°C. At air temperature above 32°C direct sunlight may cause sunburning and internal fruit temperature high enough to cause tissue collapse. Temperature during ripening has a pronounced effect on the influx of sugar from the vegetative organs to fruit. Air temperature of about 23°C is found to be most favorable for both acid and sugar. A diurnal range in temperature is important for growth and fruit quality. Daily maximum and minimum temperatures of 30°C and 20°C, respectively, are considered optimum for the entire growing cycle.

Pineapple is grown successfully under an extreme of moisture conditions ranging from less than 600 mm. annually on Molakai in the Hawaiian Islands to over 2,000 mm. on Mindanao in the Philippines. It has an amazing ability to endure moisture stress and arrests or renew growth in relation to moisture supply. Detached vegetative material has a remarkable ability to remain viable in the soil and to initiate roots to start a new crop when moisture conditions become favorable. These features enable pineapple to be grown over a wide range of moisture conditions. Areas receiving between 1,200 and 1,500 mm. per year of well distributed rainfall are most favorable.

Pest of pineapples are monkeys and rodents (grass-cutter and rats and termites (Macrotermes and Microtermes spp.). The monkeys and rats eat mature fruits while the grass-cutter destroys the young newly-planted slips and those meant for replacement. Termites are serious pests also. The control measures applied are shooting and scaring away the monkeys and trapping the rodents. There are no control measures yet against termites. Mealy-bugs, (Dysimicoccus brevipes) with their attendant black ants (Iridomyrmex humili) cause wilt and eventual death of the plants. Infested plants become discolored, bronze to red or pink with reflexed leaf margins and backward curling tips.

By-products can be made from the pineapple, namely:- pineapple bran for stock feed, alcohol for hospital use and vinegar-making, bromelain a meat tenderizing enzyme, made from pineapple stumps; bromelain is used also in the manufacture of medical drugs. Livestock feed in the form of hay, silage and pellets are made from the leaves of the plants. No attempt has been made in Nigeria to produce any of the by-products and it should be looked into if pineapple production in the country becomes abundant.

CROP-CLIMATE RELATIONSHIPS IN TOMATOES

Tomato, Lycopersicon esculentum, a member of the night shade family, is a native of tropical America. It is a warm-season plant and cultivated as an annual for its fruits. Tomatoes rank first in Naira (Nigerian money) value among all vegetables produced in Nigeria. In terms of per capita consumption tomatoes are the leading processed vegetables and are commonly grown in Nigeria under two cultural methods, ridged and flat rows. At present tomato cultivation is based generally on individual small-holdings in the country. The tomato plant requires 3 to 4 months from the time of seeding to produce the first ripe fruit. It thrives best when the weather is clear and rather dry and temperatures are uniformly moderate (20° to 29°C). Plants freeze at temperatures below 0°C. They do not increase in size at temperatures above 35°C. High temperatures accompanied by high humidity favor the development of foliage diseases. Hot dry winds cause the flowers to drop. If needed, the tomato field should be protected from the prevailing wind.

Satisfactory seed germination is achieved at temperatures around 20° to 21°C (Knott, 1962). Lower temperatures give slow, uncertain germination while at higher levels it is likely to be erratic. Excessive high temperature may even cause plant malformation resulting from damage to the growing point.

Research on temperature requirement of young tomato plant has shown that the rate of vegetative growth is highest when both day and night temperatures are approximately 25°C (Went et al, 1945). This is true even in poor light conditions. Higher night temperatures induce a large leaf area so that in the following light periods the plant can absorb more of the available light energy.

Among several factors which contribute to low yields, a critical one appears to be onset of conditions of unfavorably high temperature and light intensity. These conditions sharply curtail vegetative vigor and fruit set.

Four essential processes must be completed before a tomato fruit is formed. They are: the production of viable pollen in the anther, the release of pollen from the anthers on to the stigma, the germination and growth of pollen tubes down the style resulting in fertilization of the ovary. Adverse temperatures will cause these processes to fail with unfruitful results. Below 13°C and above 32°C pollen may be sterile but even if viable pollen is produced, germination and growth of pollen tubes down the style may be impaired (Kingham, 1973). Undoubtedly, temperature is a major factor influencing fruit-set and it is more than likely that many reported cases of poor fruit setting could be attributed to adverse temperatures. Most of the research carried out on this subject indicates that a high level of fruitfulness will be achieved at temperatures within the range of 18 to 20°C (Kingham, 1973).

Went (1950), has demonstrated that night temperature is more important than day temperature in tomato growth and fruit-set and that sugar translocation in the tomato occurs mainly in the night. Low temperatures (less than 12°C) reduce the rate of net CO_2 uptake and inhibit the germination and growth of pollen grains which bring about fertilization in th flower. High night temperatures (more than 22°C) are harmful to both vegetative growth and fruit-set because of depletion of stored carbohydrates by increased respiration. Temperatures between 12° and 20°C are therefore, considered to be an acceptable range with the optimum around 16°C (Neild et al, 1966 and Went, 1945).

Tomato is capable of producing flower buds in most natural day lengths and certainly over the range 8 to 16 hours. It is therefore, said to be a day-length insensitive or photoperiodically indifferent plant with respect to flowering habit (Kingham, 1973). Murneek (1948) lists it as the primary example of a day-neutral plants. Others have given it a similar classification.

Fruit quality is influenced by many factors, including nutrition, variety, light intensity, temperature, watering and occurence of serious diseases. Kattan et al (1957) found that climate during harvest and inherited varietal characteristics were the main factors affecting fruit quality. Moore et al (1958) found that close spacing of 45 cm. between plants and maintenance of high moisture levels materially improve fruit color; shading presumably increased lycopene content. When maximum temperatures ranged between 35° and 40°C during the day and 29°C at night, the tomato fruits developed little lycopene. When minimum temperature fell below 29°C, however, some lycopene developed, whether or not the fruits were attached to the vine. Although not likely to be a factor in the tropics, temperature below 10°C limits lycopene production (Sayre et al, 1953). Exposure of tomato fruit to direct sunlight in the field during ripening period causes poor color because it increases the fruit temperature thereby suppressing the development of lycopene (McCollum, 1954).

Lingle et al (1965) found that one or more irrigations during the 6 week period prior to harvest reduced both the percentage and the yield per acre of edible solids in the fruit. Huguet (1961), working in France, suggested that there were two developmental stages when soil moisture supply was particularly critical, the first during the period when the flowers were being formed from which fruit would subsequently mature, and the second when the fruits were rapidly enlarging. Similarly, Vittum et al (1963) in New York State found that early irrigation increased plant size and vigor, increased fruit set and reduced blossom-end rot, whereas later irrigation increased the fruit size and hence the yield. These workers stated that irrigation during the fruit ripening period appeared to be more effective than irrigation given before the fruit had set, and they found that it also reduced the incidence of fruit cracking.

Too much moisture delays maturity, decreases yield and decreases percentage of well colored fruits. Heavy rainfall delays field operations, which results in spoilage of fruits.

High relative humidity and too much rain during the growing season favor the rapid development of diseases within a tomato crop. Rainfed tomato crops are therefore subject to frequent spraying of chemicals in Nigeria. This is usually done either weekly or fortnightly depending on the severity of the raining season. Leaf mould, caused by Cladospoium fulvum, is a serious disease that limits successful tomato production in some parts of Nigeria especially in the western states of the country, having a high annual rainfall. Consistently warm temperatures and high relative humidity in these areas during the rainy season favor the development and spread of the disease. Leaf mould has been reported elsewhere along the Coast of West Africa (Boisson and Renard, 1967), but it has not been reported to be serious in the drier, Northern parts of Nigeria (Inyang, 1966).

INFLUENCE OF TROPICAL CLIMATE ON VEGETABLE PRODUCTION IN NIGERIA

The natural environment for vegetables in the tropics is profoundly different from that in most temperate regions of the world. In the tropics, radiation levels and temperatures are high throughout the year. The availability of water is often a limiting factor in vegetable growth.

As stated before, there are two distinct seasons in Nigeria; the dry season and the rainy season. In the dry season, the environmental conditions are very suitable for vegetable production due to cool dry conditions which dominate the season, specially in the Northern 2/3 of the country. However, in the dry season, there is a shortage of water and if the relation between the available and the required amount of water is unfavorable, the growing of vegetables is not possible. Unfortunately, at most villages in Nigeria, there is generally no water available (irrigation) for plants other than rain. As such, the favorable conditions established during the dry season is not fully utilized for growing vegetables. Vegetables are only grown towards the end of the rainy season, transplanted 3-4 weeks later so that by the beginning of the dry season, they should have rooted more deeply and commenced full production. During the remainder of the dry season, vegetables are grown scattered in the 'Fadamas' (flood plains) or near the stream and river banks.

In the rainy season, the environmental conditions are not suitable for vegetable production. The torrential rainstorms accompanied by violent winds are undesirable for vegetables; they damage seedbeds and growing crops by breaking lateral branches, tear foliage and cause fruits to drop prematurally (Quinn, 1974). Furthermore, the rainy season creates conditions which favor fruit and foilage diseases (notably fungus diseases) due to high humidity and thereby increase the cost of production by spraying chemicals for control and also result in reduction in yield.

In the tropical zone the difference between shorter and longer days does not exceed 2 hours (van Epenhiujsen, 1974). In Nigeria, there is an annual variation of day-length of one hour. However, photoperiodicity is still very important since a difference of 30 minutes can prevent or initiate a change in development in certain species and varieties. The day length has an effect on many vegetable crops and this must be considered in selecting the right varieties to be grown under tropical conditions eg. cowpea and onion. Most African vegetables are short-day plants (van Epenhuijsen, 1974).

In the tropics, temperature difference between the hot and cold seasons may only 2^{o} to $5^{o}C$, unlike in the temperate zone where it could be more than $10^{o}C$. However, variations of 2^{o} to $3^{o}C$ in mean temperature from one location to another have a marked effect on the success with which different kinds and varieties of vegetables can be grown in the tropics (Harold et al, 1967).

In West Africa nights are long and warm, which is a disadvantage, especially for cool season crops, such as cabbage and lettuce, and for locally grown crops, such as tomatoes. Long warm night temperature may be harmful, as plants do not photosynthesize during the night and respiration increases. Long warm nights, however, favor leaf and stem growth but at the expense of roots, tubers and fruits or heads (van Epenhuijsen, 1974). In general, therefore, cool months are best for most vegetable crops.

In practice the more exotic vegetables such as cauliflower, lettuce, carrot and potatoes are grown in higher areas with cool climate such as the Adamawa Highlands and Jos Plateau. Unfortunately many of these exotic vegetables do not produce seed in the tropics (cabbage, endive, beet, celery, radish etc.) and good quality seeds cannot be obtained from several others (lettuce, peas and carrots) (van Epenhuijsen, 1974).

An important element for success in growing vegetables is the sowing and planting of each crop at the best time and place. Since not all vegetables are the same, and show distinct seasonal preferences, attention must be paid to these preferences.

AGROCLIMATIC PROCEDURES

The great need to increase agricultural production in recent years has led to a succession of significant books and monographs in the field of agricultural meteorology and climatology (Wang, 1963, 1972; Waggoner (ed.), 1965; Chang, 1968 for example). These works on plant-climate relationships are based on the influence of different physical parameters such as radiation, moisture (rainfall), maximum-minimum temperatures, wind and humidity on plant growth and development rate. The plant-climate relationships are rather complex due to both the intensity and duration of these physical parameters. Various empirical methods and formulas have been proposed as a means of correlating the growth rate and development of crops with the meteorological elements. In temperate regions mathematical expressions of temperature summations of day-length duration appear to have yielded the best results. In the tropical regions, equations and numerical expressions of precipitation and precipitation-evaporation ratios seem to have had wider application. Other procedures described here are phenological, mapping and graphical.

PHENOLOGICAL METHODS: Studies have shown that plant development (progress toward maturity) is essentially uninfluenced by external environmental factors such as fertility, soil type, cultivation practice, or soil moisture content. As long as moisture and nutrients are sufficient to maintain the plant in a growing condition, its rate of development seems to be determined by climatic conditions and, more especially, by available energy. Thus it is the development rather than growth that must be used as an indicator of the effect of climate on the plant. Therefore, in the phenological methods, plants are used as indicators of climatic differences due to the fact that the time of occurence of phenological events is to a large degree controlled by the weather.

Nuttonson (1966) made use of phenological data of wheat varieties and of meteorological records to ascertain wheat-weather and wheat-climate relations. Dates of sowing, emergence, heading, and ripening of pure line varieties of wheat are the kinds of phenological data assembled and utilized in his study. Such data when properly organized and analyzed, appear to provide a means for a quantitative expression of the thermal requirements of wheat. Caprio (1967) who analyzed lilac bloom dates in the western United States, used phenological data to increase our knowledge and understanding of climate and its geographical patterns. His data were based on the date when the common purple lilac, Syringa vulgaris, bloomed through 5 consecutive years. He prepared maps showing the average date of occurence of phenological events in lilacs and related their different development stages to seasonal farm operations. For example, if the average date of lilac bloom in an area occurs at about the same time as the average date of last spring freeze, the farmer may plant tender crops if he is ready to take some protective measures. He also related the blooming date to change in latitude, longitude, elevation and mean temperature through isophene contor maps. Lindsay and Newman (1956) used a temperature summation technique to explain variation in flowering of species in Indiana, USA. It was not based on means, but on daily maximum and minimum temperatures in the assumption that growth was linear. Bassett et al (1960) used phenological data to estimate the first dates of anthesis of 10 early flowering woody plants at Ottawa.

Wang (1959) made use of phenological observations for 3 major commercial canning and vegetable crops for Wisconsin, USA. He divides the annual life cycle of cucumber, sweet corn and canning peas into underground, vegetative, flowering and fruiting stages. He further subdivides each of these major stages of growth and development, when attempting to correlate the influence of meteorological factors of less than one week duration.

Newman and Beard (1962), in their general discussion on some recording of phenological observations, mentioned morphological or physical change in the structure as one of the methods of approach; such as flowering, budding, leafing etc. The morphological phenological observation is that of recording events of growth and development of a single species or even a single plant in considerable detail. Observations are usally taken on a daily, bi-weekly, or weekly basis. An excellent example of detailed phenological observations can be made on almost any common crop plant of the grass family. The life cycle can be subdivided into several stages of growth and development. For example, the life cycle of corn may be subdivided into the dormant or seed stage, the germinating and seedling stage, the vegetative stage, the flowering and fruiting stage, and the maturing stage. In addition, each of these morphological stages may be divided into several phases of growth and development, thus greatly increasing the observable phenological events in the life cycle of a plant.

Higgins (1952) makes use of this technique by subdividing major stages of growth and development for the garden pea. He divides the life cycle of the pea into four major phases; the seedling phase, the vegetative phase, the flowering phase, and the fruiting-maturing phase. Each of these major phases is subdivided into a number of observable events. For example, Higgins subdivides the vegetative phase into 8 to 10 sub-events based on the appearance of the leaves associated with each nodal development. He further subdivides each nodal development by recording the first appearance, growth, and final size of each pair of leaves associated with a particular node. With such refined observations, Higgins was able to follow the growth and development of the pea on a daily basis, during most of the vegetative, reproductive, and maturing stages.

MAPPING METHODS: Williams and Sharp (1972) used computer mapping methods and automated pen plotting to produce agroclimatic maps. They described in detail the equipment and the programs that were specially developed for the computer analysis and mapping of agroclimatic data. Agroclimatic maps are being prepared showing the spartial distribution of derived data such as soil water deficit, frost probabilities, soil temperatures, and photothermal resources for maturing and productivity levels for a number of economic crops.

GRAPHICAL APPLICATION: Climatologists have long been using diagrams that show mean temperatures and rainfall, month by month. However, Papadakis, (1966) proposed the use of 'Climodiagrams' which showed with 4 curves the most important characteristics of a climate: average daily maximum and minimum temperatures, frost-free seasons, potential evapotranspiration and rainfall surplus and deficit.

He developed the climodiagrams by replacing the mean temperature used in most climagraphs by 3 curves: average daily maximum, average daily minimum and average of lowest monthly temperatures.

RATING SYSTEMS: In his study on the effect of monthly maximum and minimum temperatures on pineapple production, Neild et al (1963) developed a rating system for classifying the different temperature ranges existing in a region as related to the crop's requirements.

MATERIALS AND METHODS

CLIMATIC DATA: The climatological data used in this paper were monthly maximum-minimum temperatures and precipitation from 30 meteorological stations in Nigeria where records have been maintained for 25 or more consecutive years. A list of these stations and their geographical coordinates and altitude are given in Table 2. Their location throughout the country is shown in Figure 1.

AGROCLIMATIC PROCEDURE FOR PINEAPPLE

The procedure for determining and rating of potential locations for growing pineapple in Nigeria was a numeric procedure developed by Neild and Boshell, (1976). It is explained as follows:-

Monthly means of daily maximum-minimum temperatures are evaluated relative to their effects on growth response, fruit quality and length of growing cycle. The system used to rate these temperatures is shown in Table 3. Months with maximum-minimum temperatures between 28-29.9°C and 19-19.9°C, respectively, the optimum temperature range for pineapple, received a score of 10. The score was decreased with temperature departures from this optimum. The largest value for a month would be 10 (5 + 5 when temperatures are between 28-29.9°C and 19-19.9°C, respectively, for maximum and minimum). The maximum score for a year would be 120.

Precipitation is evaluated as follows:-

(1) Sum the monthly precipitation excluding from the total any monthly

Table 2. Altitude and coordinates of the Meteorological Stations used in the analyses.

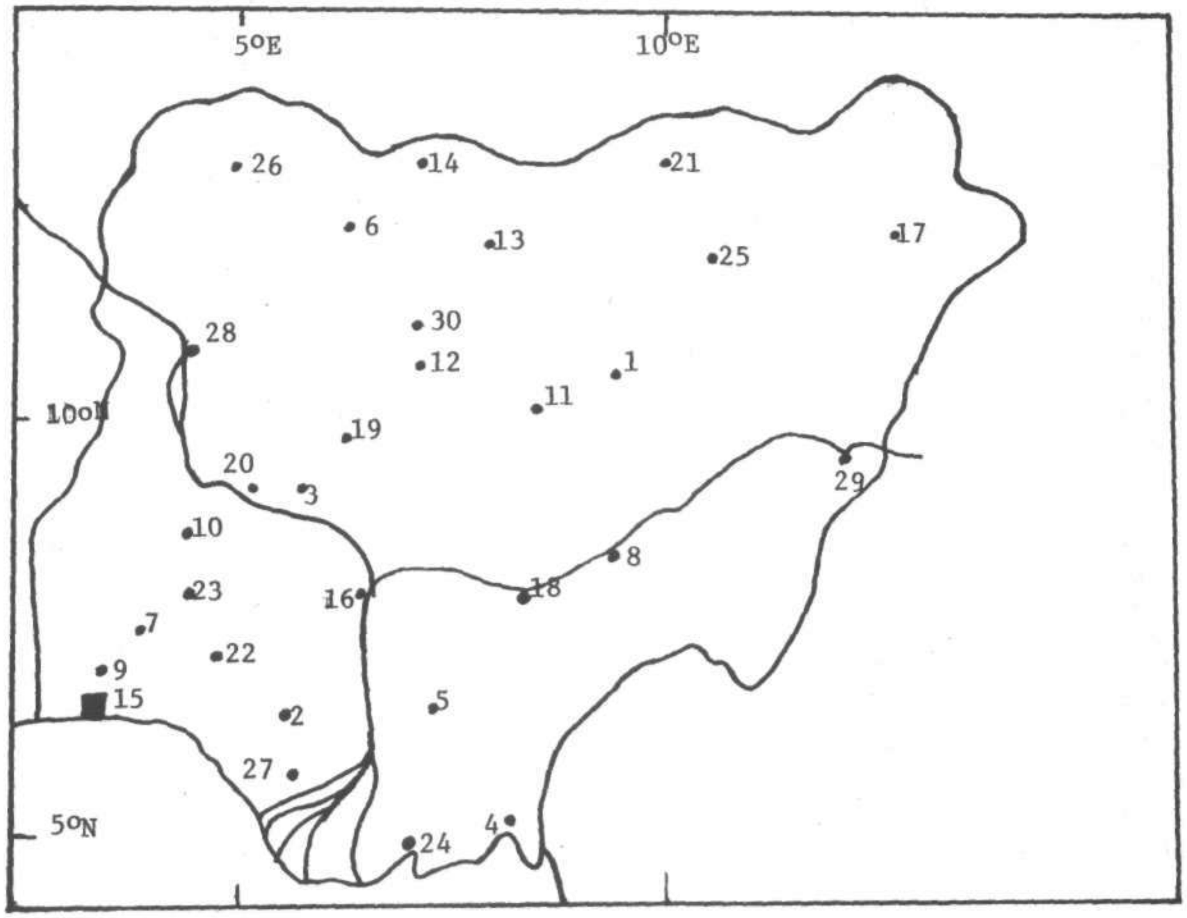
Number	Station	Latitude(N)	Longitude(E)	Elevation(M)
1	Bauchi	10° 17'	09° 49'	609
2	Benin	06 19	05 36	78
3	Bida	09 06	06 01	144
4	Calabar	04 58	08 21	62
5	Enugu	06 28	07 33	141
6	Gusau	12 10	06 40	464
7	Ibadan	07 26	03 54	227
8	Ibi	08 11	09 45	111
9	Ikeja	06 35	03 20	39
10	Ilorin	08 29	04 35	307
11	Jos	09 52	08 54	1285
12	Kaduna	10 36	07 27	645
13	Kano	12 03	08 32	472
14	Katsina	13 01	07 41	517
15	Lagos	06 27	03 24	3
16	Lokoja	07 48	06 44	41
17	Maiduguri	11 51	13 05	353
18	Makurdi	07 44	08 32	113
19	Minna	09 37	06 32	258
20	Mokwa	09 18	05 04	152
21	N'guru	12 53	10 28	343

Table 2 continued

Number	Station	Latitude(N)	Longitude(E)	Elevation(M)
22	Ondo	07° 06'	04° 50'	285
23	Oshogbo	07 47	04 29	274
24	Port Harcourt	04 51	07 01	19
25	Potiskum	11 42	11 02	414
26	Sokoto	13 01	05 15	350
27	Warri	05 31	05 44	6
28	Yelwa	10 53	04 45	244
29	Yola	09 14	12 28	186
30	Zaria	10 11	07 38	760

Figure 1

Location of the meteorological stations used in the analysis.



amounts in excess of 100 mm. Divide this sum by 10. The largest annual precipitation score would be 1,200 divided by 10 or 120.

(2) Areas with less than 500 mm average annual precipitation totaled in this manner are not suitable without irrigation.

(3) Areas with more than 3 consecutive months with less than 15 mm per month; 4 consecutive months with less than 25 mm per month or 5 consecutive months with less than 40 mm per month are also not suitable without irrigation.

(4) Harvesting difficulty should be expected in areas with heavy textured soils where annual precipitation exceeds 3,000 mm.

The highest possible combined temperature and precipitation score for an area would be 120 + 120 = 240. These temperature and precipitation criteria are specific to the Smooth Cayenne variety grown for processing. Conditions for other varieties and purposes might be less rigorous.

Table 3. Temperature (°C) ranges and score for pineapple.

Maximum	Score
> 38	0
36 - 37.9	1
34 - 35.9	2
32 - 33.9	3
30 - 31.9	4
28 - 29.9	5
26 - 27.9	4
24 - 25.9	3
21 - 23.9	2
18 - 20.9	1
< 18	0

Minimum	Score
> 24	0
23 - 23.9	1
22 - 22.9	2
21 - 21.9	3
20 - 20.9	4
19 - 19.9	5
18 - 18.9	4
17 - 17.9	3
16 - 16.9	2
14 - 15.9	1
< 14	0

AGROCLIMATIC METHOD USED FOR TOMATO

Climatological data from 30 weather recording stations were analysed and used to estimate tomato transplanting and fruit-set dates, harvest season length and fruit quality for different locations in Nigeria. The method used was a modification of both a graphical procedure developed by Neild et al, (1966) and a numerical procedure develpped by Boshell, (1974) for determining the time and length of harvest seasons for processing tomatoes.

The method was a 4-step procedure as follows:

(1) Average monthly maximum and minimum temperatures and monthly rainfall were plotted on graph paper for each of the 30 stations. Data were plotted for a two year period in order to show differences between rainy and dry periods and harvest seasons extending through the last months of the year and the first ones of the next. Stations with monthly average daily minimum temperatures continuously below 12°C or above 22°C, and/or monthly average daily maximum temperatures above 30°C were eliminated because these conditions are not conducive to plant growth, fruit set or fruit pigmentation. Locations with average monthly rainfall higher than 127 mm throughout the year were also eliminated because such high precipitation favors blight fungus development and adversely affects plant growth and harvesting.

All but 12 of the 30 stations originally considered were eliminated by this step.

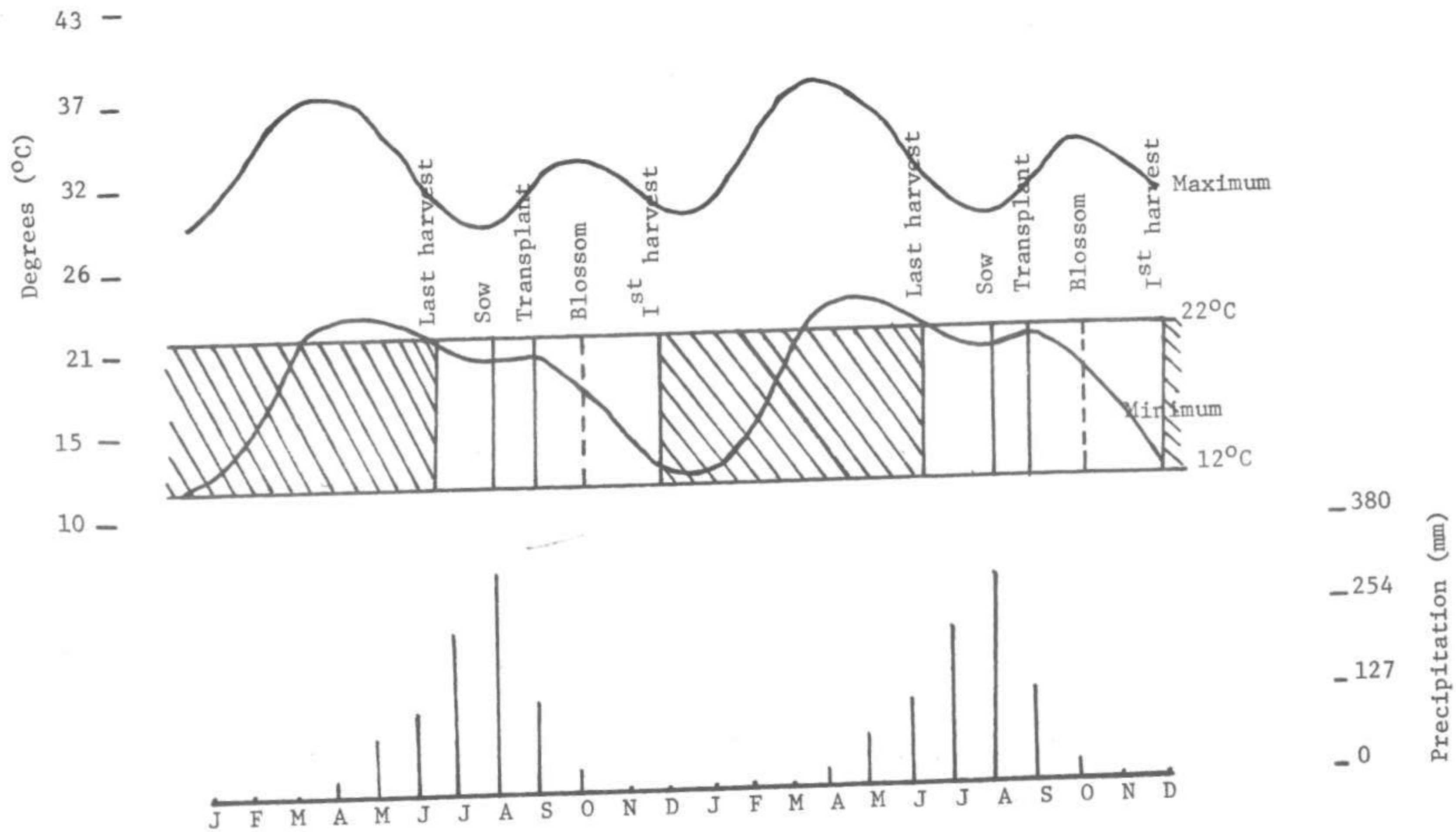
(2) For stations where temperature and precipitation were within the

criteria established for step 1, transplant date or dates were located near the end of the rainy period to ensure that harvesting would take place in the dry season. Figure 2 shows the distribution of temperature and precipitation in Kano in the Sudan Savannah of the northern region of the country. The transplant date in Kano was set in the beginning of September when the rainfall curves decline. The beginning of blossoming was then established as being 5 weeks after transplanting. Rainfall intensity usally drops below the critical point of 127 mm by this time and temperature conditions are conducive for fruit set and development.

Under tropical conditions fruit normally reaches maturity about 6 weeks after fruit set. This was used to determine the beginning of the harvest season, which continues as long as moisture conditions are favorable. Harvest is terminated by the middle of the first month when precipitation averages in excess of 127 mm.

(3) Fruit quality factor in tomato products, especially the color, is affected by temperature conditions during maturation. Development of lycopene, the red pigment in tomatoes, if limited by prolonged exposure to temperatures above 30^{o}C or below 10^{o}C. Fruit quality evaluation was therefore, based upon the analysis of the maximum and minimum temperature conditions during the harvest season. A rating method was thus developed which assigned values from 10 to 50 to different day and night temperature ranges. A value of 50 would correspond to excellent temperature conditions for obtaining optimum fruit quality and a value of 10 would indicate poor conditions. The largest value for a place would be 100,

Figure 2. Temperature and precipitation distribution in Kano.



i.e. 50 + 50 when temperatures are between 24°-26°C and 16°-18°C for a day and night respectively. The values assigned to different temperature ranges are given in Table 4.

(4) The percentage of rainy days and relative humidity conditions during the growing season were plotted in separate graphs to evaluate the need for protective sprays against blight fungus in the different stations under consideration.

The percentage of rainy days is defined as the number of days with precipitation of $\geq$2mm, expressed as a percentage of the total number of days in the growing season:

$$\text{\% Rainy Days:} \quad \frac{\text{\# of days with rain}}{\text{Total days in growing season}} \times 100$$

Stations with highest relative humidity and percentage of rainy days throughout the growing season would be expected to be more conducive to blight fungus attack and thus would require more frequent protective sprays.

Table 4. Tomato: Fruit Quality Evaluation.

Temperature ranges and their respective values.

MINIMUM TEMPERATURE (°C)

RANGE	VALUE
8 - 10	10
10 - 12	20
12 - 14	30
14 - 16	40
16 - 18	50
18 - 20	40
20 - 22	30

MAXIMUM TEMPERATURE (°C)

RANGE	VALUE
10 - 15	10
15 - 18	30
18 - 20	35
20 - 22	40
22 - 24	45
24 - 26	50
26 - 28	40
28 - 30	20
> 30	10

PROCEDURE USED FOR SELECTING SERIES OF LOCAL VEGETABLES AT 3 REPRESENTATIVE ECOLOGICAL ZONES IN NORTHERN STATES OF NIGERIA

An important approach to crop-climate relations is offered by the study of the basis of local adaptation, particularly of local varieties. Many of the vegetable varieties grown by peasant farmers in Nigeria seem to be very closely adapted to their home region. Furthermore, many of the vegetables that are commonly known in the temperate zones can be grown in Nigeria and in the tropics in general. This is not too surprising since many of the vegetable plants in the temperate zones actually had the tropical zones as their origin and in fact are found growing wild in many tropical countries. However, due to the intensive breeding and selection programs carried on in the temperate zone, many of the vegetables have become adapted to that zone and as a result are no longer well adapted to their native state. At any rate, the use of local varieties should never be over looked. Through natural selection some of the local varieties may be highly resistant to local pests and diseases.

The principal factor tending to localized vegetable production is climate; others are market, transportation and water supply in areas having deficit rainfall. If these are favorable, other problems generally can be overcome. For example, soils are not as restricting as for other crops because heavy fertilization is common in the vegetable growing areas.

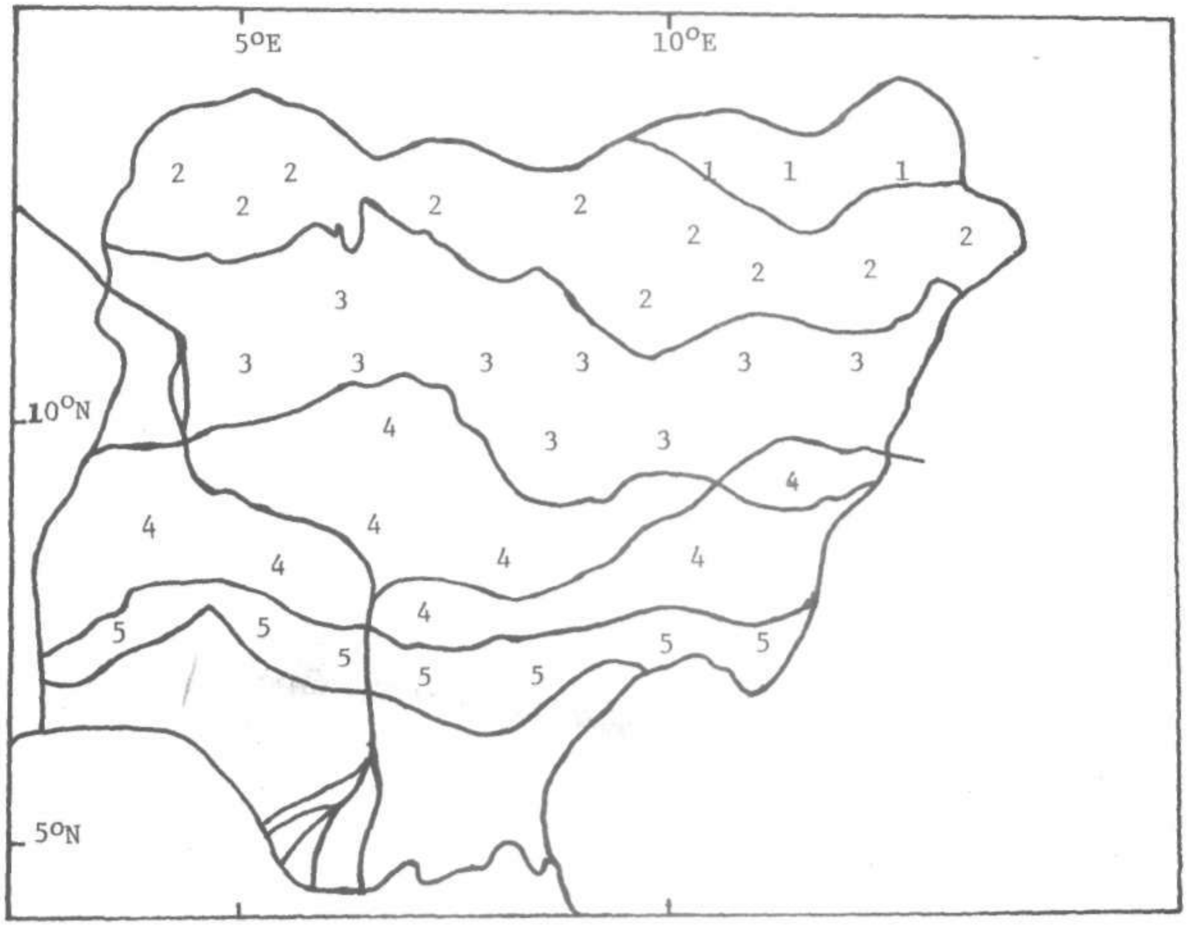
Nigeria has a tropical climate. There is little that can be done about the climate, but if one understands it, one can learn to adjust to it and thus learn to live with it. However, Nigeria is blessed with some climatological variations. Through agroclimatic analysis, an agriculturist can choose within its wide variations a place to live and the crops he will grow.

As stated in the introduction, this procedure will be limited to the ecological zones of the northern states of Nigeria. The northern states of Nigeria lies between 7^{o} and $13^{o}N$ and have a wide range of climatic conditions (Kowal and Knabe, 1972). Of all the climatic factors which influence vegetable production in northern Nigeria, availability of water is by far the most important.

In general, vegetables grown in northern Nigeria can be placed in two convenient categories:- (a) Cool zone vegetables that do well in cool temperature and low humidity. They will not tolerate too hot temperatures and are not adapted to high rainfall and water logged soils. (b) Hot zone vegetables which grow best in relatively high temperatures and a high monthly rainfall.

Northern states of Nigeria have been divided, in accordance with its vegetation types, into a number of ecological zones ranging from the dry Sudan Savannah in the north to the Sub-Sudan Savannah and the northern Guinea Savannah in the centre, and to the humid southern Guinea and derived Savannahs in the south (Figure 3). These regions lie in a series of east-west bands, across which rainy season duration and the amount decreases from over 1,500 to about 500 mm from south to north. In the south, the rain starts earlier and ends later than

Figure 3. The vegetation zones of Northern Nigeria.



1	Sahel
2	Sudan Savannah
3	Northern Guinea Savannah
4	Southern Guinea Savannah
5	Derived Savannah

in the north, where August is usally the wettest month. Variation in the amount of rainfall, length of rainy season and annual evaporation in the 3 recognized ecological zones are shown in Table 5. The incoming solar radiation in the harmattan (winter) season can be 25% less, when there is a thick harmattan dust layers, as compared with a no-dust day. This is a characteristic of the Savannah.

For each of these zones, there is a set of ecological conditions optimum for certain type of vegetables. Based on the agroclimatic analysis, some cryophilous (temperate) vegetables can be grown in these northern Savannah zones because nights are relatively cool during the dry season. This is particularly true in the Sudan zone and in the highland (plateau) zones which by reason of their altitude, are much cooler than the rest of the country. The best season is the dry season because climatic conditions are favorable for vegetables. At this time of the year crops are grown mostly in the 'Fadamas' (flood plains) where abundant irrigation is needed.

In employing the meagre and patchy knowledge available about these vegetation climaxes, the following vegetables could be planted in each of these ecological zones as the temperature and moisture (rainfall) approach the optimum range: tomatoes, pepper, eggplant, sweet corn, okra, cabbage, cauliflower, chard, lettuce, broccoli, mustard, spinach, beans, pea, beet, carrot, garlic, onions, Irish potatoes, radish, sweet potatoes, ginger, cucumber, muskmelon, pumpkin, watermelon, and squash. Many other tropical vegetables are grown but not much is known about their ecology. The tropical vegetables are numerous and only those important are included here.

Table 5. Rainfall and evaporation in the 3 principal ecological zones in northern Nigeria.

Ecological zone	Rainfall (mm)	Evaporation Eo (mm)	Length of Rainy season (days)
Sudan Savannah	500 - 1000	1900 - 2200	80 - 130
Northern Guinea Savannah	900 - 1400	1500 - 1900	130 - 190
Southern Guinea Savannah	1000 - 1600	1300 - 1600	190 - 250

PARAMETERS USED TO SHOW PLANTING AND HARVEST TIMES FOR SERIES OF VEGETABLES AT EACH LOCATION

The steps and/or criteria involved are as follows:-

(1) Many of the temperate zone vegetables grown in the tropics require special climatic conditions such as cool temperatures which can be obtained only during the dry (winter) months and at high altitude.

(2) Three locations are chosen; Kano, Jos and Ilorin as representative stations for Sudan, Northern Guinea and Southern Guinea Savannahs respectively as an example to show planting and harvest times for series of selected vegetables.

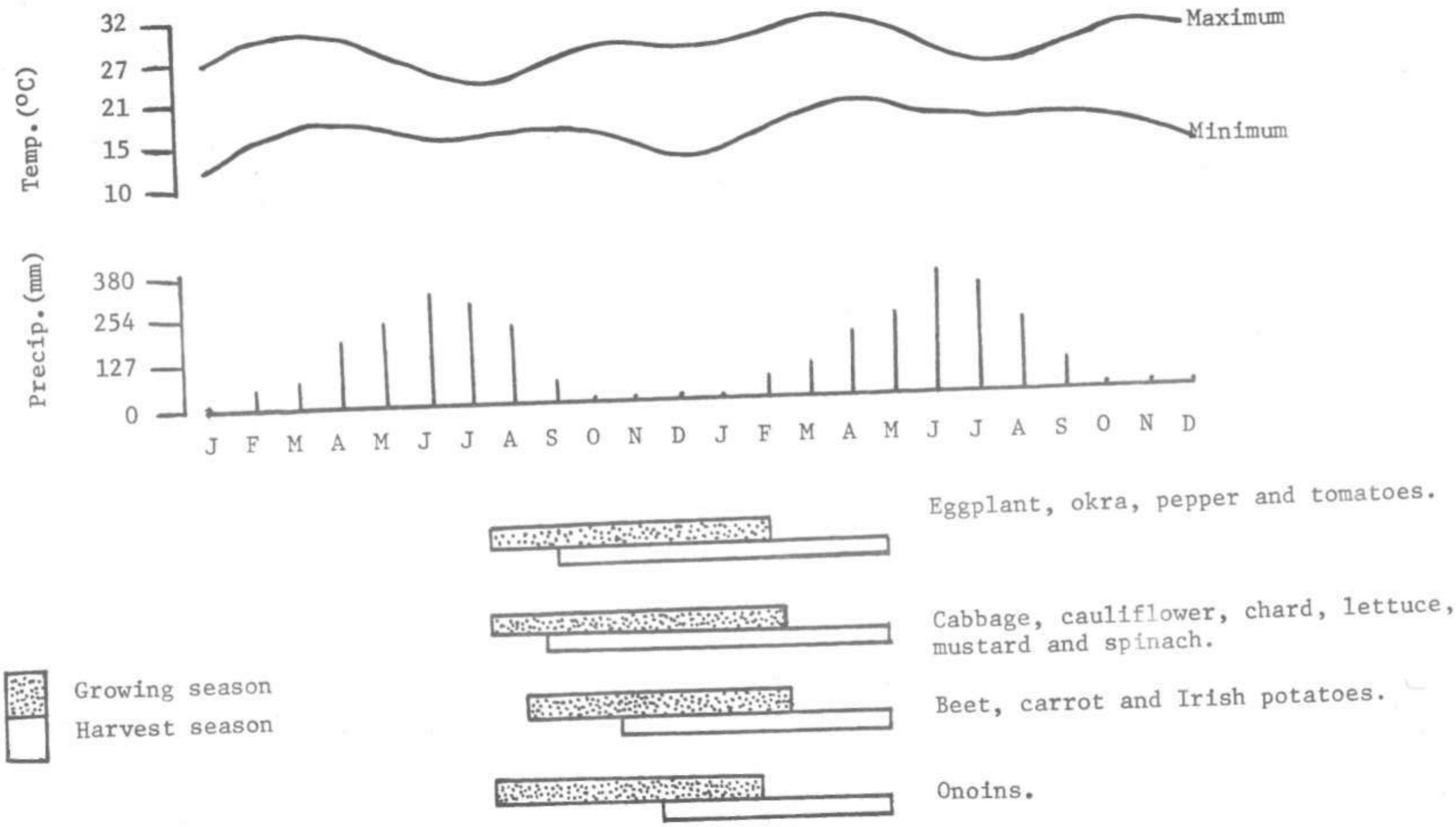
(3) Graphs for average monthly maximum and minimum temperatures and mean monthly rainfall for 67, 50 and 55 years respectively for Kano, Jos and Ilorin were plotted each to show the distribution of temperatures and precipitation. An example of data for Jos is shown in Figure 4. Data were plotted for two years inorder to show differences between rainy and dry periods and harvest season extending through the last months of the year and the first ones of the next.

(4) From step 3 we locate the beginning and the ends of the dry and rainy seasons and favorable temperatures of the year. Then sow seed towards the end of the rainy season; transplant where necessary, 3-4 weeks later. Transplant is limited to the first month after precipitation averages 127 mm or less. This is considered the earliest planting date and the beginning of growing season for the particular crop in question.

(5) The earliest harvest date is the date when the time requirement

Figure 4

Estimated growing and harvest seasons of some vegetables and climatic patterns for Jos.



from first planting is met. Knott (1962) has summerized data concerning days from planting to harvest for different vegetable species. The time for early maturing varieties was used for the earliest planting date. For tomatoes, time of first harvest was based upon the temperature requirement for fruit set and the time from fruit set to red-ripe maturity (Went and Cosper, 1945; Knott, 1962). The time parameters for series of vegetables are shown in Table 6.

(6) Last harvest is in the middle of the month when precipitation is above 127 mm.

(7) To determine the latest planting date, the time from planting to harvest was used. This requirement was subtracted from the end of the growth period so that the latest planting would provide enough time for crop development before yield or quality would be seriously affected. The time of first harvest is based on the time requirement of the early maturing variety of the vegetable group. The time for higher yielding, late maturing varieties, was used as the last planting date. Figure 4 shows climatic patterns for Jos and the estimated growing and harvest seasons for certain vegetables. The relationship between the rainfall pattern and growing and harvest seasons is quite evident in this graph.

Table 6

Time required to reach maturity in the Tropics.+

CROP	TIME REQUIRED TO MATURITY.* (DAYS)
Eggplant	89 - 132
Okra	55 - 60
Pepper	96 - 112
Sweet corn	90 - 120
Tomatoes	54 - 90
Cabbage	70 - 100
Cauliflower	56 - 118
Chard	60 - 75
Lettuce	47 - 70
Mustard	48 - 59
Spinach	63 - 76
Lima bean	60 - 80
Pea	57 - 78
Beet	65 - 100
Carrot	74 - 108
Onion	120
Potatoes	75 - 100
Radish	23 - 30
Cucumber	56 - 65
Pumpkin	112
Squash	47 - 89
Water melon	100

+ = After USDA Agric. Handbook No 323 1967. pp 26

* = Time is given as the approximate number of days to produce crop, from planting seed in the garden or from transplanting plants to the garden.

RESULTS AND DISCUSSION

1. Tomato; A) Estimated growing and harvest seasons for different locations in Nigeria:-

The graphical analysis of temperature and precipitation conditions of the 30 Nigerian stations showed that 12 of them have favorable conditions for growing tomatoes. Estimated sowing, transplanting, blossom, and harvest dates for each of the 12 locations are shown in Table 7. These locations represent a variety of temperature, relative humidity and precipitation regimes. Supplemental moisture from irrigation is assumed in areas having low seasonal precipitation.

The growing and harvest seasons in these 12 locations are terminated by high rainfall. High rainfall has a similar effect as frost in the temperate regions. The harvest seasons estimated for each of these locations are shown respectively in the Table 7. The harvest seasons are longer in the Northern States than in the Southern States. This is because the amount of rainfall decreases from the south to the northern parts of the country, favoring longer seasons in the north.

The capacities and cost of processing and storing tomatoes is inversely proportional to harvest season length at a given location. It would be expected that tomatoes produced near Ilorin, Lokoja, Makurdi, Minna and Mokwa would require more frequent spraying than at Kano, Zaria or Kaduna since the relative humidity and the percentage of rainy days are higher. A processing plant located at Kano could run for 221 days

Table 7. Estimated tomato sowing, transplanting, blossom, harvest dates and harvest season lengths for the 12 optimal stations.

TOWN	SOW SEED	TRANSPLANT	BLOSSOM	HARVEST Earliest	HARVEST Latest	HARVEST SEASON LENGTH (Days)
Bauchi	8/11	9/14	10/19	12/18	6/15	179
Gusau	8/7	9/10	10/15	12/14	6/15	183
Ibi	9/1	10/5	11/9	1/7	5/15	128
Ilorin	9/10	10/15	11/19	1/18	4/15	87
Jos	7/7	8/10	9/14	11/13	5/15	183
Kaduna	8/12	9/15	10/20	12/19	6/15	179
Kano	7/30	9/2	10/7	12/6	7/15	221
Lokoja	9/1	10/15	11/9	1/8	5/15	127
Makurdi	9/6	10/10	11/14	1/10	4/15	96
Minna	9/1	10/5	11/9	1/8	5/15	127
Mokwa	8/11	9/15	10/20	12/20	5/15	146
Zaria	8/14	9/17	10/22	12/21	6/15	176

as compared to Ilorin which is about 87 days. This would enable lower processing cost at Kano than at Ilorin. Processing cost at Ilorin, Makurdi, Minna and Mokwa would be expected to be much higher; the harvest season lengths at these locations are 87, 96, 127 and 146 days respectively. These are the shortest seasons among the 12 locations.

From this graphical analysis of temperature and precipitation, one could locate potential tomato growing areas in the country. Figure 5 shows potential commercial tomato growing areas in Nigeria.

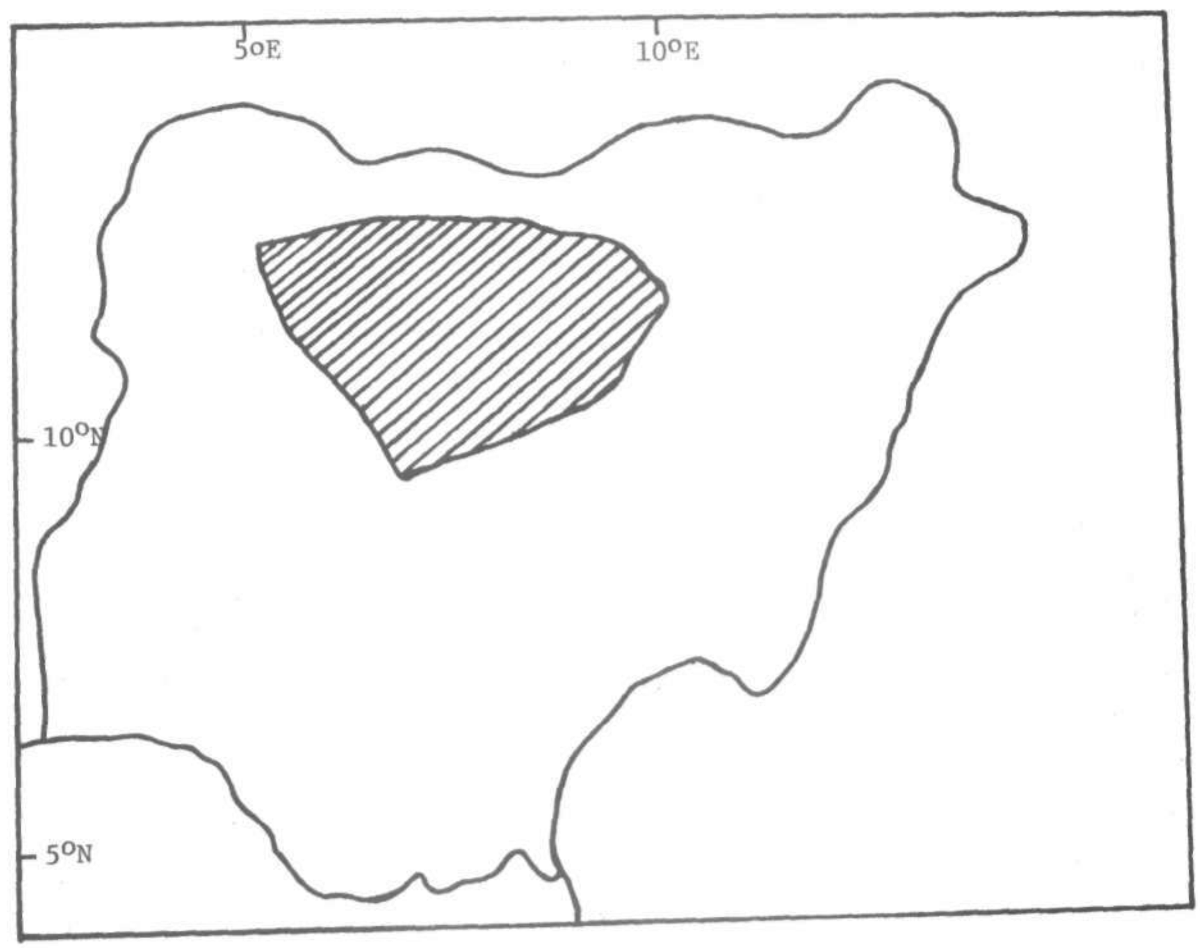
B) Evaluation of harvest season relative to fruit color development:

Fruit color and/or quality is directly related to maximum-minimum temperature conditions during the harvest season. The 12 stations were rated according to their day-night thermal characteristics as described in the procedure (see Table 4 pp 33).

Table 8 shows the calculated total scoring for each location. Jos has the highest rating because of favorable maximum-minimum temperature conditions throughout the harvest season. Development of lycopene and carotene are favored under these conditions and highly colored fruits would be obtained. In general, temperatures do not favor the development of good fruit color at most of the stations studied. However, in the months of December, January and February, all the stations have ratings higher than 80; highest quality fruit color could be harvested within these months. The rest of the harvesting months have high night temperatures that reduce lycopene content in the fruits.

Figure 5.

Areas most favorable for tomato production in Nigeria.



Potential tomato growing areas in Nigeria (commercially).

Table 8.

Day-night temperature scores used for evaluating tomato fruit quality and results.

Station	Day temp. (°C)	Score	Night temp. (°C)	Score	Total score
Bauchi	30	(20)	18	(40)	60
Gusau	33	(10)	18	(40)	50
Ibi	33	(10)	19	(40)	50
Ilorin	32	(10)	20	(40)	50
Jos	27	(40)	16	(50)	90
Kaduna	30	(20)	18	(40)	60
Kano	32	(10)	17	(50)	60
Lokoja	32	(10)	20	(40)	50
Makurdi	32	(10)	20	(40)	50
Minna	32	(10)	20	(40)	50
Mokwa	30	(20)	21	(30)	50
Zaria	30	(20)	17	(40)	60

2. PINEAPPLE: Determination of potential pineapple growing areas in Nigeria

The analyses of the data for 30 locations in Nigeria are listed in Table 9. The data showed that Port Harcourt has the highest score; with a score of 197 of a possible 240, it has a very favorable climate for pineapple. Other locations with very favorable climate for pineapple production are Oshogbo, Ondo, Benin, Calabar, Ibadan and Warri. Temperatures in these areas are within the optimum range during all months of the year. They favor a good influx of sugar from the vegetative organs to the fruit during maturation stage and produce an optimal sugar:acid ratio. Their precipitation scores also show that moisture conditions are favorable for rapid and continuous growth.

Locations having 5 or more consecutive months with less than 15 mm of precipitation per month were eliminated as potential producing areas because of their low and poor rainfall distribution. Locations having 3 consecutive months with less than 15 mm of precipitation or 4 consecutive months with less than 25 mm of precipitation were not suitable for pineapple production without irrigation. Locations having temperature scores of less than 60 were also eliminated because of their marginal temperature conditions; most areas here have temperatures which are not suitable for good quality pineapple production.

N'guru, Potiskum, Maiduguri, Sokoto and Katsina areas have the lowest total scores. These areas correspond to the extreme north of the country where rainfall is low and occurs within 5 or fewer months of the year.

Table 9.

Temperature and precipitation averages and agroclimatic scores for Nigerian locations to determined potential pineapple growing areas.

Location	Average annual daily temp.(^{o}C) Max.	Min.	Total precip. (mm)	Agroclimatic score Temp.	Precip.	Total
Port Harcourt	30	22	2436.9	95	102	197
Oshogbo	31	21	1258.5	103	89	192
Ondo	30	22	1599.6	96	94	190
Benin	31	22	2055.1	94	94	188
Calabar	30	22	3044.5	82	106	188
Ibadan	31	21	1239.7	95	87	182
Warri	31	22	2795.1	78	103	181
Enugu	32	22	1724.7	83	91	174
Ilorin	32	21	1286.5	87	83	170
Kaduna	31	18	1287.6	88	69	157
Lagos	30	24	1857.1	61	94	155
Makurdi	32	21	1331.7	75	76	151
Minna	33	21	1330.1	77	69	146
Ibi	32	21	1132.3	74	68	142
Jos	27	16	1408.8	72	67	139
Lokoja	33	22	1241.9	72	66	138
Zaria	31	18	1042.2	87	51	138
Bida	33	22	1227.2	71	60	131

Table 9 continues.

Location	Average annual daily temp.(^{o}C) Max.	Min.	Total precip. (mm)	Agroclimatic score Temp.	Precip.	Total
Bauchi	32	18	1090.8	82	48	130
Gusau	33	19	987.7	71	53	124
Yelwa	34	19	1069.8	53	70	123
Mokwa	33	21	1160.0	68	52	120
Kano	33	19	861.4	71	49	120
Yola	34	21	965.8	57	63	120
Katsina	33	18	704.2	68	45	113
Sokoto	34	21	723.4	62	47	109
Maiduguri	34	19	664.4	57	44	101
Potiskum	34	18	803.7	60	39	99
N'guru	34	19	540.2	50	44	94

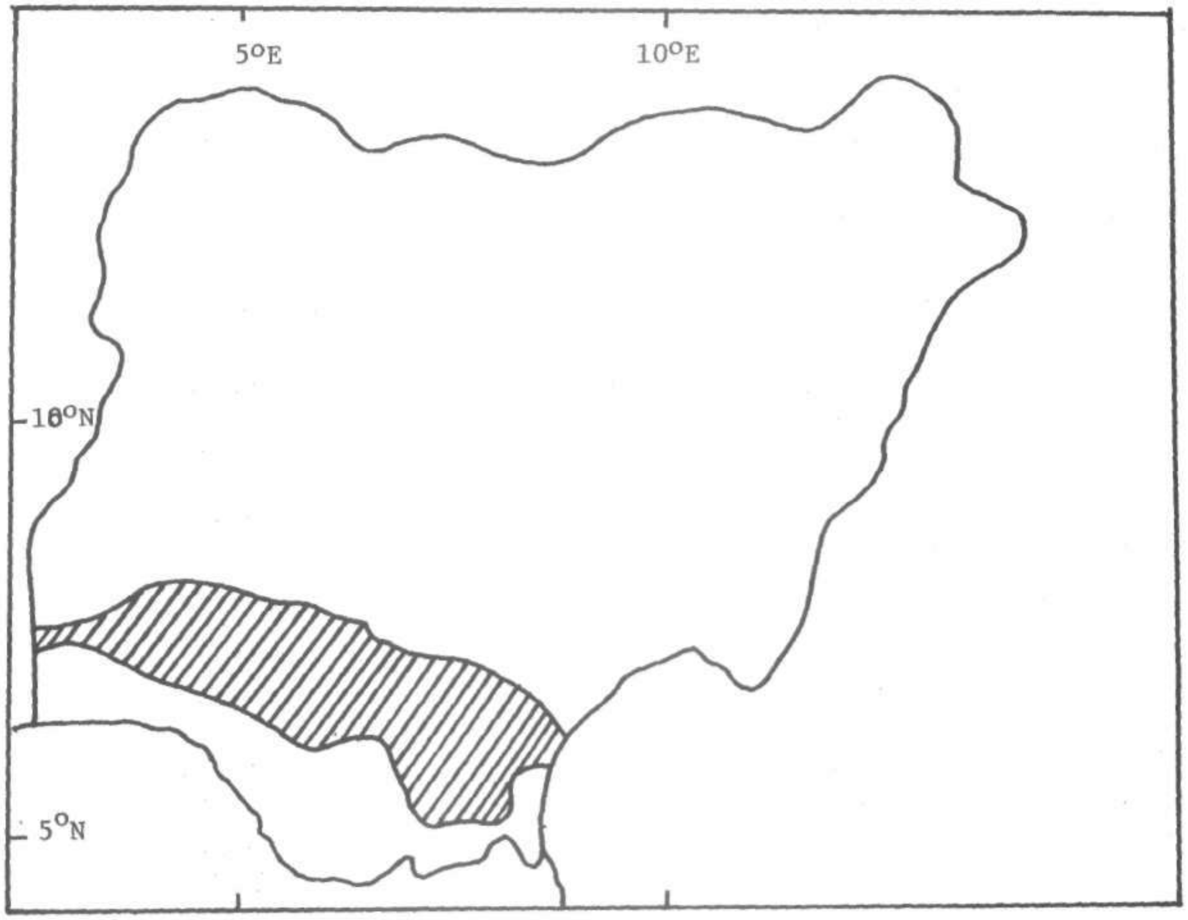
The temperatures are not in the optimum range; particularly the daily maxima. In the dry season, the minimum temperatures could be as low as around 12°C.

Seven out of the 30 Nigerian locations listed in the table have total scores of 180 or higher. Most of these locations have temperature and precipitation conditions that compare favorably with the world's leading pineapple producing areas like Naha (Okinawa), Port au Prince (Haiti), Wahiawa (Hawaiian Island), Singapore (Malaysia), and Colombo (Sri Lanka) which have total scores of 181, 181, 183, 185, and 187 respectively. In these locations, temperature and precipitation tend to compensate for each other; if the score for one factor tended to be low, its effect was offset by a higher score for the other.

Figure 6 shows the areas most favorable for pineapple production in Nigeria from this analysis.

Figure 6.

Areas most favorable for pineapple production in Nigeria.



Potential pineapple growing areas in Nigeria (Commercially).

3. LOCAL VEGETABLES: Estimation of planting and harvest dates, days, and comparism of length of dry season, growth and harvest seasons for leafy vegetables at Kano, Jos and Ilorin.

Estimated start of planting and harvest dates and the estimated number of days for planting and harvest seasons for Kano, Jos and Ilorin are shown respectively in Tables 10 and 11. Figure 7 shows the comparism of length of dry season, growth and harvest seasons for leafy vegetables at Kano, Jos and Ilorin.

Table 10 shows that planting and harvesting start earlier at Kano in the extreme north than at Ilorin in the extreme southern part of the study area. From Table 11 we see that both planting and harvest seasons are longer at Kano, where the period of the rainy season is relatively shorter than at Ilorin. Planting and harvest seasons start late at Ilorin but end earlier than at Kano. These differences are due to south-north trends in the length and amount of rainfall which decreases progressively northwards.

Jos has unique climatic features and therefore, does not conform with this regular south-north pattern. Jos Plateau has much higher precipitation because of its altitude. Jos has a shorter growing and harvest season than Kano although planting and harvest seasons start earlier at Jos.

The extent of the dry season depends on both the duration of the south-west (trade) winds and the distance from the sea. The effects of increasing distance from the sea on moisture depletion of the

Table 10

Estimated start of planting and harvest dates for Kano, Jos and Ilorin

CROP	KANO Pl. Date	KANO Har. Date	JOS Pl. Date	JOS Har. Date	ILORIN Pl. Date	ILORIN Har. Date
Eggplant	7/30	10/27	7/7	10/4	9/10	12/8
Okra	9/2	10/27	8/10	10/4	10/15	12/9
Pepper	7/30	10/28	7/7	10/11	9/10	12/15
Sweet corn	9/2	12/1	8/10	11/8	10/15	1/13
Tomatoes	7/30	9/22	7/7	8/30	9/10	11/3
Cabbage	7/30	10/8	7/7	9/15	9/10	11/19
Cauliflower	7/30	9/24	7/7	9/1	9/10	11/15
Chard	7/30	9/28	7/7	9/5	9/10	11/9
Lettuce	7/30	9/15	7/7	8/23	9/10	10/27
Mustard	9/2	10/20	8/10	9/27	10/15	12/2
Spinach	7/30	10/1	7/7	9/8	9/10	11/12
Lima bean	9/2	11/1	8/10	10/9	10/15	12/14
Pea	9/2	10/29	8/10	10/6	10/15	12/11
Beet	9/2	11/6	8/10	10/14	10/15	12/19
Carrot	9/2	11/15	8/10	10/23	10/15	12/28
Onion	7/30	11/27	7/7	11/4	9/10	1/8
Potatoes	9/2	11/16	8/10	10/24	10/15	12/29
Radish	9/2	9/25	8/10	9/2	10/15	11/7
Cucumber	9/2	10/28	8/10	10/15	10/15	12/10
Pumpkin	9/2	12/23	8/10	11/30	10/15	2/4
Squash	9/2	10/19	8/10	9/26	10/15	12/1
Water melon	9/2	12/11	8/10	11/18	10/15	1/23

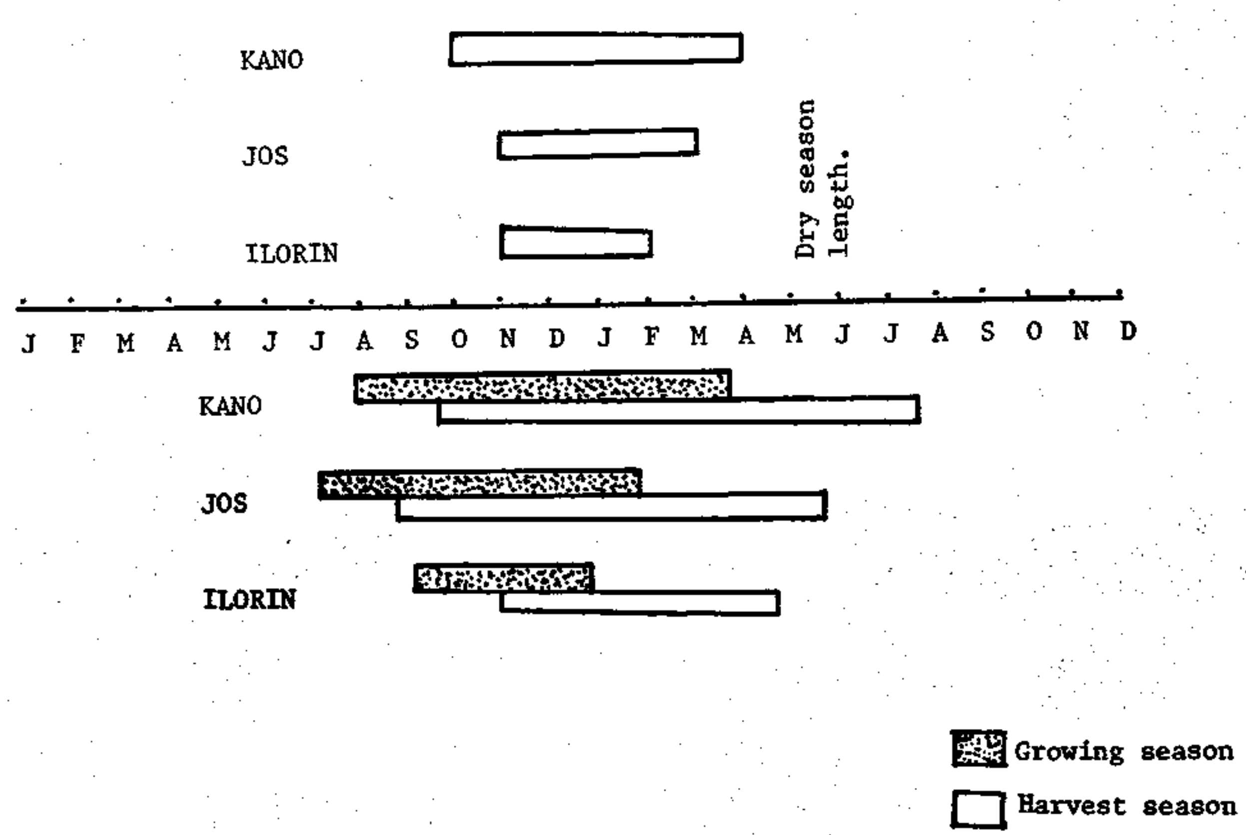
Table 11

Estimated number of days for planting and harvest season at Kano, Jos and Ilorin.

CROP	KANO No. of Days Pl.	KANO Har.	JOS No. of Days Pl.	JOS Har.	Ilorin No. of Days Pl	Ilorin Har.
Eggplant	218	261	180	223	86	129
Okra	256	261	218	223	122	127
Pepper	238	260	200	216	106	122
Sweet corn	196	226	158	188	63	93
Tomatoes	260	296	222	258	127	168
Cabbage	250	280	212	242	117	147
Cauliflower	232	294	194	256	100	162
Chard	275	290	237	252	142	157
Lettuce	280	303	242	265	147	170
Mustard	257	268	219	230	123	134
Spinach	274	287	236	249	141	154
Lima bean	236	256	198	218	102	122
Pea	238	259	200	221	104	125
Beet	216	251	178	213	82	117
Carrot	208	242	170	204	75	109
Onion	230	230	192	192	98	98
Potatoes	216	241	178	203	82	107
Radish	286	293	248	255	152	159
Cucumber	251	260	213	222	117	126
Pumpkin	204	204	166	166	73	73
Squash	227	269	189	231	93	135
Water melon	216	216	178	178	82	82

Figure 7

Comparism of length of dry season; growth and harvest seasons for leafy vegetables at Kano, Jos and Ilorin



prevailing winds and increasing activity of the dry overland winds normally reach their peak in January. Therefore as one moves progressively northwards, the dry season increases in length; for example, the dry season length at Ilorin is 4 months (November-February) as compared to 7 months (October-April) at Kano which is located further north of the country. Unlike other field crops, the growing and harvest seasons for vegetables are directly proportional to the length of the dry season and this relationship is quite evident in Figure 7.

SUMMARY AND CONCLUSIONS

Agroclimatic analysis were conducted to show the relationships between Nigerian climatic conditions and crop growth as it affects certain horticultural crops in the country. Nigeria has a tropical climate, and since we have no absolute control over it, we are compelled to study its components and their interaction so that we can, through appropriate cultural and varietal improvement efforts, exploit the diversified nature of our climate to increase horticultural production. In this direction Nigeria could improve vitality and higher standard of living for her people and save its hard-earned foreign exchange from importing processed vegetables and fruits from other countries.

Numerical and graphical procedures were used for the agroclimatic analysis; pineapple and tomatoes were studied in detail, some selected local vegetables were also studied to estimate their growing and harvest seasons. The numerical procedure for pineapple showed that the southern lowlands of the forest zones have the most favorable climatic conditions for the crop development. Locations in the southern Guinea Savannah, the Middle Belt, have 3 to 4 consecutive months with less than 15 mm of rain. Irrigation is necessary if pineapple is to be produced in these regions. It is not advisable to grow pineapple in the northern Guinea Savannah nor in the Sudan Savannah zones. Locations in these two ecological areas show 3 to 5 consecutive months without rain and relative humidity at this time of the year is between 0 to 10%. Temperature scores in these zones are also poor for any good pineapple production.

The graphical procedure for tomatoes showed that high precipitation limits the harvest season in the tropical regions similar to the effect of frost in temperate regions. The analysis shows considerable variation in suitability of climate for tomato production in Nigeria. There is considerable variation in the length of harvest seasons. The analysis indicates that year round production is possible with irrigation in Kano, N'guru, Potiskum, and Maiduguri areas of the Sudan Savannah zone. Bauchi, Kaduna, Zaria and Gusau in the northern Guinea Savannah are also favorable areas for tomato production. The number of protective sprays against fungus diseases in these areas is expected to be low. However, good tomato fruit-color is obtained only in the months of November, December and January. The analysis further shows that commercial tomato production is uneconomical in the southern parts of the country because of too much rain and high humidity and unfavorable temperature throughout the year.

Estimated growing and harvest seasons for local vegetables are longest at Kano followed by Jos and Ilorin respectively. This is due to an increase in length and amount of rainfall during the rainy season as one moves from extreme north of the country to the south.

Finally I will conclude that there are diverse crop-growth conditions in Nigeria and these can better be exploited for improved and increase production of horticultural crops in two broad ways:-

(a) Better understanding of the weather for efficient cultural management and

(b) Development of weather-adapted varieties and practices.

Based on the agroclimatic analysis, research on pineapple should be located in the southern lowlands of the forest zones. Research on tomatoes and other local vegetables in the country should be located in Sudan and northern Guinea Savannah zones.

LITERATURE CITED

Azzi, G. 1956. Agricultural ecology. Constable and Co. Ltd. 10-12, Orange street, London W.C. 2 242pp.

Baier, W., Sharp, W.R., and Robert, J.G, 1973. Recent development in preparing colored agroclimatic maps by computer. Can. J. Soil Sci. 53:133-134

Bassett, I.J., Holmes, R.M. and MacKay. 1960. Phenology of several plant species at Ottawa, Ontario, and an examination of the influence of air temperatures. Can. J. Plant Sci. 41:643-652

Bliss, F.A. and Arny, D.C. 1971. Breeding tomatoes for resistance to leaf mould (Cladosporium Fulvum) in Western Nigeri. Exper. Agric. 7:177-181

Boshell, F. 1974. Agroclimatological analysis and temperature estimates for Columbia. Unpublished Master thesis, University of Nebraska, Lincoln, U.S.A.

Bunting, A.H. and Curtis, D.L. 1968. Local adaptation of sorghum varieties in Northern Nigeria. Agroclimatological methods. Natural resources research, V11. (UNESCO). pp 101.

Calvert, A. 1972. Effect of day and night temperatures and CO_2 enrichment on yield of glasshouse tomatoes. Journ. Hort. Sci. 47(2):231-247.

Caprio, J.M. 1966. Pattern of plant development in western United States. Mont. Agric. Exp. Station Bull. 607.

Caprio, J.M. 1967. Phenological patterns and their use as climatic indicators; p 17-43 in Shaw, Robert, H., ed., Ground level climatology. Publ. No. 86, Amer. Ass. Advance Sci. Wash. D.C.

Chang, Jen-Hu. 1971. Climate and Agriculture. An ecological survey. Aldine Publishing Co. Chicago, U.S.A.

Chang, Jen-Hu. 1968. Agricultural potential of the humid Tropics. The Geogr. Rev. 58(3):333-361.

Chapman, T. and Acland, J.D. 1965. Investigations on out of season tomato production in Trinidad. Trop. Agric. 42:157-162.

Charles, W.B. and Harris, R.E. 1972. Tomato fruit-set at high and low temperatures. Can. J. Pl. Sci. 52:497-506.

Collins, J.L. 1960. The pineapple. London Hill Book Ltd. Interscience Publ. Inc. New York. pp 74-75.

Cutshell, A. 1951. A pineapple landscape in Mindanao. The Scient. Month. 73:130-133

Denisen, E.L. 1948. Tomato color as influence by variety and environment. Proc. Amer. Soc. Hort. Sci. 51:349-356

Donald, P.G. 1958. The induction of flowering in pineapples by exposure to short-day length. Pl. Physiology 33(Supl.):19-20

Donald, P.G. 1961. Experiments on the photoperiodic response in pineapple. Amer. J. Bot. 48:16-21

Donald, S.H. 1965. Tropical Agriculture, An Abridged Field Guide. Howard W. Sams. International Corp. U.S.A. pp 1-2 & 180

Food and Agricultural Organization of the U.N. Agricultural Development in Nigeria. 1965-1980. (F.A.O. Rome).

Frederick, L.W. 1977. World climatic Data. Climatic Data Press.

Godfrey-Sam-Aggrey, W. 1969. Pineapple culture in Ghana. World Crops. 21:33-36

Green, G.C. 1963. The effect of weather and climate upon the keeping quality of fruit. Part 111: The pineapple plant. WHO, Tech. Note. No. 53. 180 pp.

Harold, F.W. and George, W.M. 1967. Vegetable Gardening in the Carribbean Area. Agric. Handbook No.323. U.S.A.I.D. Publ. 114 pp.

Higgins, J.J. 1952. Instructions for making phenological observations of garden peas. John Hopkins. Univ. Lab. of Climatology, Seabrook, N.J.

Johnson, S.P. and Wayne, C.H. 1955. Further studies on vegetative and fruiting responses of tomatoes to high temperatures and light intensity. Bot. Gaz. 117:100-113

Kingham, H.G. 1973. The U.K. Tomato mannual. Grower Books, 49 Doughty Street, London. pp 23-29.

Knott, J.E. 1962. Handbook for Vegetable Growers. John Wiley & Sons, Inc. Publication. 245 pp.

Koskitalo, L.W. and Ormrod, D.P. 1972. Effect of sub-optimal ripening temperatures on tomato fruit quality. Journ. Amer. Soc. Hort. Sci. 97(1):13-16

Kowal, J.M. and Knabe, D.T. 1972. An agroclimatological Atlas of Northern States of Nigeria. Ahmadu Bello University Press.

Kowal, J.M. and Andrews, D.J. 1973. The pattern of water availability and water requirement for grain sorghum production at Samaru-Nigeria. Trop. Agric. (Trinidad) 50:89-100

Lacoevilhe, J.J. and Giequiaux, Y. 1971. The cation nutrition of pineapple in Martinique, V-V1. Fruits 26(9):581-597.

Livingstone, B.E. 1916. Physiological temperature indices for the study of plant growth in relation to climatic conditions. Physiology Res. 1:399-420.

Mather, R.J. 1974. Climatology: Foundmentals and Applications. Publ. by McGraw-Hill, Inc. pp 157-160.

Mac-Gillivray, J.H. 1934. The variation in temperature of tomatoes and their color development. Proc. Amer. Soc. Hort. Sci. 32:529-531

McCollum, J.P. 1954. Effects of light on the formation of carotenoids in tomato fruits. Food Res. 19:182-189

McCollum, J.P. 1956. Sampling tomato fruits for composition studies. Proc. Amer. Soc. Hort. Sci. 68:587-595

Miller, J.R. and O'Brien, M.J. 1952. Plant disease forcasting. Bot. Rev. 18:547-601

Monthly Bulletin of Agricultural Economics and Statistics. 1972. 22 (12) 40 pp.

Mortensen, E. and Bullard, E.T. 1964. Handbook of Tropical and Subtropical Horticulture. USAID. Publ. & Technical Services Branch, Washington D.C. 260 pp.

Neild, R.E. and Young, J.O. 1965. Comperative climatology as an approach for defining the approximate growing season for vegetables in Nebraska. Res. Bull. U.N. College of Agric. & Home Economic.

Neild, R.E. and Young, J.O. 1966. An agroclimatological procedure for determining and evaluating time and length of harvest season for processed tomatoes. Proc. Amer. Soc. Hort. Sci. 89:549-558

Neild, R.E., Rosenberg, N.J. and Myers, R.E. 1967. Temperature patterns and some relations to agriculture in Nebraska. Neb. Agric. Exp. Stat. Misc. Publ. 16.

Neild, R.E. and Graig, J.K. 1972. An agroclimatic procedures to determine growing seasons for vegetables. Agric. Meteorol. 9:225-240

Neild, R.E. and Boshell, F. 1976. An agroclimatic procedure and survey of the pineapple production potential of Colombia. Agric. Meteorol. 17:81-92

Newman, J.E. and Beard, J.B. 1962. Phenological observations: The dependent variable in Bioclimatic and Agrometeorological studies. Agron. Journ. 54:399-403

Nightengale, G.T. 1942. Nitrate and carbohydrate reserves in relation to nutrition of pineapple. Bot. Gaz. 103:409-456.

Nuttinson, M.Y. 1966. Phenological temperature requirements of some winter wheat varieties grown in the southern Atlantic region of the U.S. and several of its latitudinally analogous areas of the eastern and southern hemispheres of seasonally similar thermal conditions. Amer. Inst. of Crop Ecology, Washington, D.C.

Omer, W.H. 1968. Consortum for the study of Nigerian rutal Development. (C.S.N.R.D.-22) pp 49-58.

Oyenuga, V.A. 1967. Agriculture in Nigeria. Food and Agricultural Organization of the U.N. Publ. pp 45-48.

Papadakis, J. 1966. Climate of the world and their agricultural potentialities. J. Papadakis. Cordoba 4564, Buenos Aires, Argentina. 170 pp.

Peter, A.H. 1965. Climate and agricultural production in Ugandaᵤ Expl. Agric. 1:81-97

Quinn, J.G. 1974. Nigeria: prospects for a tomato paste industry. Samaru Res. Bull. 209, IAR/ABU, Zaria-Nigeria. 3 pp.

Salter, P.J. and Goode, J.E. 1967. Crop response to water at different stages of growth. Research Rev. No.2. Commonwealth Agric. Bureaux.

Sayre, C.B., Robinson, W.B. and Wishmitsky, W.T. 1953. Effect of temperature on the color, hycopene and carotine content of detached and of fine-ripened tomatoes. Proc. Amer. Soc. Hort. Sci. 61:381-387.

Selina, B., and Went, F.W. 1956. Some effects of temperature and photoperiod on the growth of tomato seedlings. Bot. Gaz. 117:326-335.

Sideris, C.P. and Krauss, B.H. 1928 Water relations of pineapple plants. Soil Sci. 26:305-315.

Sideris, C.P. and Krauss, B.H. 1956. Transpiration and translocation phenomenon in pineapples. Amer, J. Bot. 42:707-709.

Smith, A.P. 1940. A discussion of the climatological diagram, the huthegraph, to the distribution of natural vegetation types. Ecology 21(2):184-191

Tables of temperature, relative humidity and precipitation for the world. 1961. Meteorological Office, Air Ministry, Her Majesty Stationery Office, London.

Tan, K.M. and Wee, Y.C. 1973. Influence of size of pineapple slips on plant growth, fruit weight and quality in graded and mixed planting. Trop. Agric. (W/Indes) 50 No. 2 pp 139-142.

Temperatures and humidities (averages and extremes). 1951-1965. The Nigerian Meteorological Service, Lagos-Nigeria.

Thompson, H.C. and Kelly, W.C. 1957. Vegetable crops. Fifth edition, McGraw-Hill Book Co., Inc., New York-London. 609 pp.

Ticho, R.J. 1969. Climatic adaptability of fruit and plantation crops. World Crops 21:300-302.

van Epenhuijsen, C.W. 1974. Growing native vegetables in Nigeria. F.A.O., Rome. pp 8-9.

van Lelyveld. 1964. In the eastern Cape we produce pineapples by the ton. Farm Sci. Afr. 40(7):17-60.

van Overbeck, J. 1946. Control of flower formation and fruit size of the pineapple. Bot, Gaz. 108:64-73.

Visher, S.S. 1955. Comperative agricultural potentials of the world regions. Econ. Geog. 31(1):82-86.

Waithaka, J.H.G. and Puri, D.K. 1971. Resent research on pineapple in Kenya. World Crops 23:190-192.

Wallen, C.C. 1968. Agroclimatological studies in the Levant. Agroclimatological Methods. Natural Resources Research. V11. UNESCO. pp 225.

Wang, J.Y. 1963. A graphical solution on temperature moisture responses of tomatoes. Proc. Am. Soc. Hort. Sci. 82:429-445.

Wang, J.Y. 1972. Agricultural meteorology. Third ed. Milieu Inform. Service. 357 pp.

Went, F.W. 1950. The response of plants to climate. Science 112:489-494.

Went, F.W. and Cosper, L. 1945. Plant growth under controlled conditions. 1V. Comparism between field and air conditioned green house culture of tomatoes. Am. J. Bot. 32:643-654.

Williams, C.N. and Joseph, K.T. 1970. Climate, soil and crop production in the humid Tropics. Oxford Univ. Press, Singapore. pp 32-33 & 103-104.

Williams, G.D.V. and Sharp, W.R. 1972. Computer mapping in agrometeorology. Tech. Bull. 80, Agrometeorology Sect. Plant Res. Inst., Can. Dept. Agric., Ottawa-Ontario. 40 pp.

Wittwer, S.H. 1963. Photoperiod and flowering in the tomato. Am. Soc. Hort. Sci. Proc. 83:688-694.

Wittwer, S.H. and Reath, A.N. 1952. Early tomato production in Michigan. Mich. Exp. Stat. Bot. 220

Wright, J.R., Lingle, J.C., Floker, W.J. and Leonard, J.J. 1962. The effects of irrigation and nitrogen fertilization treatments on the yield, maturation and quality of canning tomatoes. Proc. Am. Soc. Hort. Sci. 81:451-457.

Yamaguchi, M., Howard, F.D., Luh, B.S. and Leonard, S.J. 1960. Effect of ripeness and harvest dates on the quality and composition of fresh canning tomatoes. Am. Soc. Hort. Sci. Proc. 76:560-567.