

WORLD METEOROLOGICAL ORGANIZATION

AGRICULTURAL METEOROLOGY

CAGM REPORT No. 49

PART II

AGROMETEOROLOGY AND ECOPHYSIOLOGY OF CASSAVA

by

Prof. I.C. Onwueme

(CAGM-IX Rapporteur on the Agrometeorology
of the Cassava Crop)

WMO/TD-No. 507

Geneva, December 1992

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AGRO-METEOROLOGOLGY AND ECO-PHYSIOLOGY OF CASSAVA
(Manihot esculenta Crantz)

1.0 INTRODUCTION: WORLD CASSAVA PRODUCTION.

World production of cassava in 1991 has been estimated at 161.5 million tonnes. Most of this production comes from three distinct regions on three continents:

- a) West Africa and the adjoining Congo Basin;
- b) Tropical South America; and
- c) South-east Asia.

On a country basis, Nigeria (27 million tonnes/year), Brazil (25 million), Thailand (20.9 million), Zaire (18.2 million) and Indonesia (17.1 million) are the world's leading producers of cassava (Table 1).

The overall world wide production trend for cassava in the past decade (1981-1991) has been generally upward, although there have been years (such as 1990) when overall production has declined (see Table 2). The decline in 1990 was mainly attributable to a decline in Asian production, especially in Thailand. The other two producing regions have been able to record a steady increase over the past decade.

The most dramatic and consistent increase in cassava production over the past decade has been in Nigeria. During this period, Nigerian cassava output has more than doubled, catapulting the country from the fifth position in world production in 1981 to the first position in 1991. This turn of events has been made possible by much more modest increases in production in Brazil, Thailand, Zaire and Indonesia.

TABLE I

World production figures for cassava in 1990

	<u>Area</u> <u>(1000ha)</u>	<u>Yield</u> <u>(kg/ha)</u>	<u>Production</u> <u>(1000 tonnes)</u>
World	15635	10084	157656
Africa	8932	8207	73307
S. America	2517	12621	31766
Asia	3965	12974	51445
Nigeria	1700	15294	26000
Brazil	1953	12601	24611
Thailand	1488	13916	20701
Zaire	2280	7675	17500
Indonesia	1398	12206	17064

Source: FAO Production Yearbook Vol.44 (for 1990). 1991 FAO, ROME

TABLE 2 : Trend in cassava production (in millions of tonnes)
 from 1979 - 1991

	<u>1979-81</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>
World	124.0	148.7	159.1	157.7	161.5
Africa	48.8	67.0	72.9	73.3	74.8
S. America	29.8	28.3	30.4	31.8	33.4
Asia	44.4	52.3	54.6	51.4	53.2
Nigeria	10.8	20.0	25.0	26.0	27.0
Brazil	24.3	21.7	23.6	24.6	25.0
Thailand	15.1	22.3	24.3	20.7	20.9
Zaire	12.9	17.0	17.4	17.5	18.2
Indonesia	13.5	15.5	17.1	17.1	17.1

Sources: FAO Production Yearbook Vol.44 &
 Food Outlook December 1991, FAO, Rome.

2.0 CLIMATE OF THE CASSAVA-PRODUCING REGIONS.

The three major cassava-producing regions mentioned above are within the tropics, and for the most part, humid. For the South American region, Carter (1986) has attempted a climatic and edaphic classification of the cassava growing areas. Cassava production in this region is concentrated in about nine areas (see Figure 1):

1. Colombia: Andean valleys and the Departments of Santander and Norte de Santander.
2. Colombia: North Coast.
3. Brazil: Belem area of Para.
4. Brazil: Sao Luis area of Maranhao.
5. Brazil: Eastern Uplands of Rio Grande do Norte, Paraiba, Pernambuco.
6. Brazil: Bahia, particularly around Cruz das Almas. Alagoas and Sergipe, and extending south to Minas Gerais.
7. Brazil: Coastal plain in Santa Catalina and Rio Grande do Sul south to Porto Alegre.
8. The Parana Plateau and valley of the Rio Uruguay, and straddling the boarder of Brazil and Argentina.
9. Eastern Paraguay.

The climatic classification of these areas has been based on

- a) the mean growing temperature (over 22°C for low lands, 18-22°C for highlands),
- b) the duration of the dry season (months with less than 60mm precipitation), and
- c) whether or not the daily range of temperature during the growing season exceeds 10°C.

FIG. 1:
CASSAVA DISTRIBUTION
SOUTH AMERICA

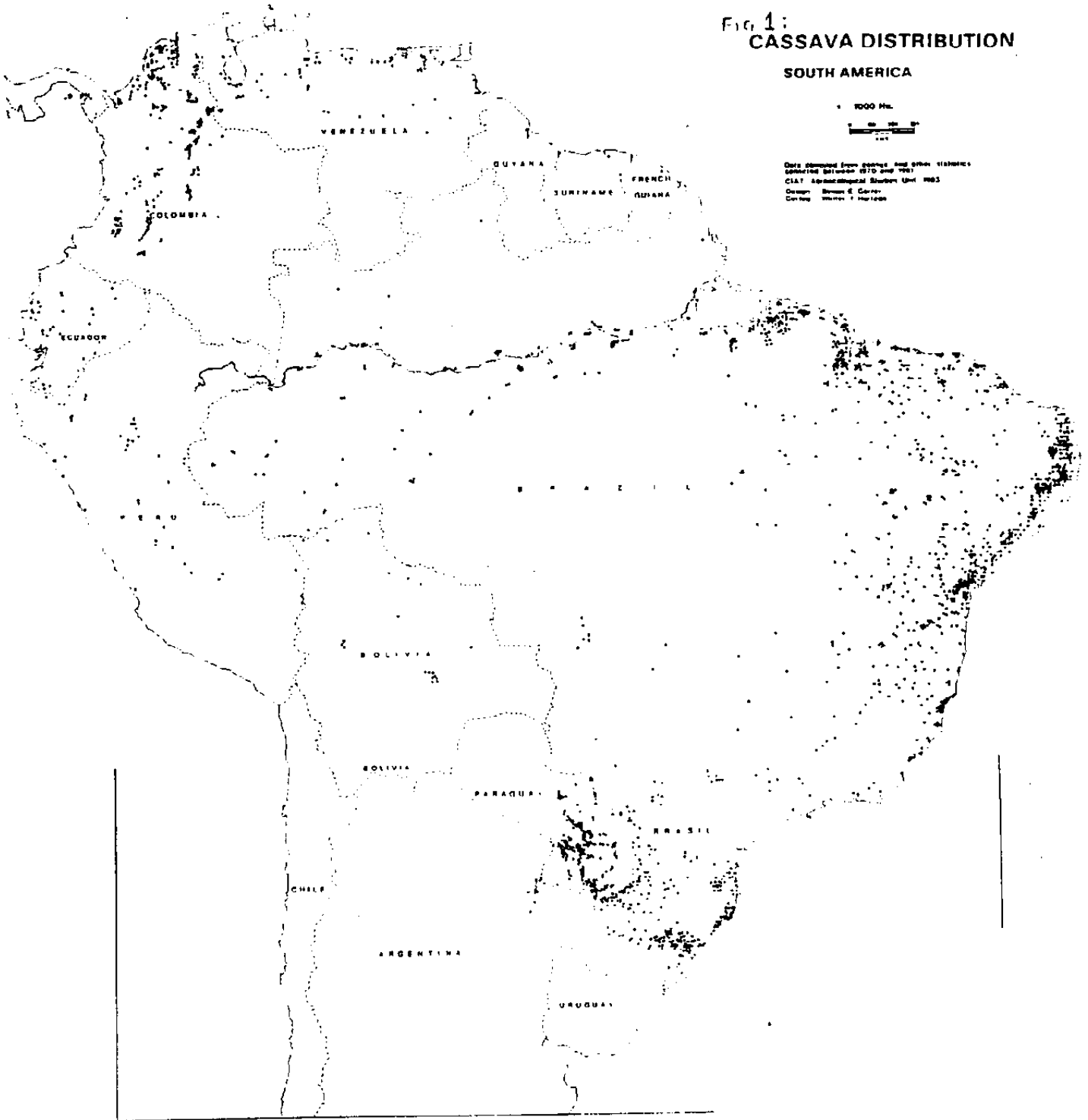


TABLE 3

Rainfall and temperature data for selected locations
in the cassava growing regions.

<u>Location</u>	<u>Mean Annual Rainfall (mm)</u>	<u>Mean Annual Temperature (°C)</u>
Belem, Brazil	2175	27
Bangkok, Thailand	1520	28
Ibadan, Nigeria	1150	26
Djakarta, Indonesia	1788	26
Khon Kaen, Thailand	1250	27

On this basis, much of the cassava producing area in north-east Brazil, the North Coast of Colombia, and Eastern Paraguay are classified as lowland tropical, of the humid or subhumid type. Here, the mean growing season temperatures exceed 22°C, and the dry season lasts less than half the year. These areas account for the bulk of the cassava production in South America. On the other hand, the Andean valleys of Colombia, the eastern uplands of Brazil and the Parana Plateau are cassava-producing areas with highland tropical climates. The mean growing season temperature ranges between 18-22°C, and the crop in the field occasionally experiences sub-optimal temperatures. The dry season in most of these areas also lasts for less than half the year.

The Amazon basin proper has a humid tropical climate, with growing season mean temperatures above 22°C, the dry season lasting less than 3 months, and the mean daily temperature range less than 10°C. This climate appears quite suitable for cassava production. However, present-day production in this basin is only at scattered locations. This is certainly an area that holds great promise for the future expansion of cassava production in South America.

Stoorvogel and Fresco (1991) have attempted an agro-ecological zonation for cassava-producing areas in Africa. The areas considered suitable for cassava cultivation are divided into

- a) Humid (tropical and subtropical),
- b) Savanna (tropical and subtropical), and
- c) Semi-arid (tropical and subtropical) climates.

The Mediterranean, Tropical highland, and Desert climates are considered unsuitable for cassava production. Annual average temperature below 20°C, or elevation above 1100m, or rainfall below 750-900mm per year, are considered unsuitable for cassava production.

Based on this classification, the greatest concentration of cassava production in Africa occurs in the areas with Humid Tropical and Savanna Tropical climates. This embraces most of the coastal and immediate hinterland areas of the Gulf of Guinea and the Congo basin. Further north in West Africa, the climate becomes progressively semi-arid and then arid, with corresponding diminution in the intensity of cassava cultivation. Further east and south from the Congo basin, the climate becomes too alpine or too dry, and the production and importance of cassava consequently decline.

The cassava-producing areas in Indonesia and Thailand are quite similar. In Thailand, most of the production occurs in the tropical savanna and tropical monsoon climatic regions in the north-east and eastern parts of the country (Duangpatra, 1988). In these regions, atmospheric temperature is isohyperthermic, with annual average temperature of 26-28°C. The mean humidity is 70-75%, while the mean potential evapotranspiration ranges from 1400-2000mm annually. There are usually two growing periods each year, with a total length of 180-225 days.

3.0 RAINFALL AND CASSAVA PRODUCTION.

In the major cassava-producing regions of the world, the water requirements of the crop are almost totally dependent on rainfall. Very little of the crop is grown under irrigation. The various dimensions of rainfall and water availability have profound effects on the growth, development, yield and storage of cassava.

3.1 Quantity of Rainfall

The total quantity of rainfall each year is quite important. Cock (1985) has suggested a lower limit of 750mm per year for cassava, while Stoorvogel and Fresco (1991) indicate that for optimum production, there should be at least 1000mm of well distributed rainfall. Mean annual rainfall in the major cassava producing regions of the world is indeed greater than 1000mm, but economic yields can still be obtained with as little as 500mm of rainfall. This depends very much on the drought-tolerant capabilities of cassava (discussed below).

3.2 Time distribution of Rainfall

Just as important as the total quantity of rainfall, is its distribution. While some of the cassava-producing regions experience one rainy season per year, others such as the savanna regions of West Africa, or north-east Thailand, experience two rainy seasons per year. The total number of months of dry season (months with less than 50-60mm of rainfall) is usually a critical determinant of whether or not large scale cassava production can be carried out. A total of more than 6 or 7 months of dry season in a year will usually make cassava production quite difficult or impossible.

The timing and duration of rainfall affect several aspects of the cassava production cycle. The time of planting is determined by the time of onset of the rains, since cuttings planted into dry soil will usually shrivel up and die. Sometimes, the time of cessation of the rains (i.e. onset of the dry season) may also influence the time of planting. This is because the farmer should always strive, within the constraints of other factors, to have the crop as

advanced as possible before the onset of the dry season. In this way, there is a reasonable assurance that the crop will survive the dry season in relatively good condition. Certain cassava pests (e.g. the cassava mealybug, or the cassava green mite) are more severe in the dry season, and where they are prevalent, the need to enter the dry season with a reasonably advanced crop is even more imperative.

Sprouting or emergence of the planted cassava cutting is, of course, dependent on sustained moisture supply after planting. There must therefore be some assurance that the rainfall which precedes planting will soon be followed by other rains which permit sprouting and crop establishment to occur. Indeed, the ideal production situation is one where steady rainfall is available from planting to harvesting, so that the various phenological events in the life of the plant (sprouting, shoot growth, tuber initiation, tuber bulking, maturity) can succeed one another without delay or interruption.

When cassava sprouts, the leaves produced are small, but the size of leaves produced increases progressively until 4-6 months after planting. Thereafter, leaf size declines (Cock and El-Sharkawy, 1988). Leaf production initially occurs at the rate of about 5 per week at each apex, declining as the plant gets older and the number of apices increases. Correspondingly, the leaf area index (LAI) rises steadily for the first 4-6 months, then declines slightly and finally steadies at about 4-5. By the eighth week after planting, tuber initiation has occurred (Onwueme, 1978). Tuber bulking follows immediately, and continues for virtually the rest of the life of the plant. During this time, tuber growth, shoot growth and even reproductive growth (flowering and seed production) are all occurring simultaneously and competing with one another for the available photosynthate.

3.3 Drought

The absence of rainfall for more than a few weeks during the life of the crop imposes droughty conditions on the crop, with the resulting moisture stress on the plants. The effects of drought on sprouting and crop establishment have already been mentioned.

The absorbing roots of the established cassava occur mainly in the top 1-1.5m of the soil (Cours 1951, Cock and El-Sharkawy, 1988). Thus the ability of the plant to source water from great depths is quite limited. Moreover, the crop only reduces soil water potential to the range of -10 to -15 bars (Cock and El-Sharkawy, 1988). The ability of cassava to survive drought must therefore depend on the conservation and efficient use of available water.

When exposed to water stress, the cassava plant decreases the rate of leaf production, and decreases the size of individual leaves produced (Connor and Cock, 1981). If the drought is prolonged, the shedding of older leaves may also occur. The net effect of all these reactions is to drastically reduce the LAI, which in turn reduces the amount of transpiration and water loss. When water stress is relieved by the provision of water, leaf area again increases and the plant recovers. Apparently, stress occurring later in the season is most detrimental to yield, because older plants have a reduced ability to recover leaf area after stress is relieved (Baker, Fukai and Wilson, 1989).

In the addition to the morphological reaction of reducing LAI (and therefore transpiration) under water stress, cassava has a unique physiological mechanism for conserving water in times of drought. The stomata of cassava appear to be sensitive to the water vapour pressure difference (VPD) between the leaf and the surrounding air. The stomata close once this difference reaches a threshold value, even if water stress has not yet developed within the plant. This

contrasts with other plants which keep their stomata open and continue to lose water until water stress has developed within the plant; then they close the stomata. For cassava, conditions of high transpirative demand (with high VPD) automatically result in stomatal closure, thereby forestalling the build-up of water stress within the plant. This feature, combined with the reduced LAI, makes for high water use efficiency by the cassava crop.

The fact that most cassava cultivars have their stomata only on the lower side of each leaf, is an additional adaptation that helps the crop to conserve water under droughty conditions.

As with most other crop plants, water deficits result in a reduced growth of most parts of the cassava plant, including the shoot and roots. Tuber bulking rate is also diminished. However, experiments (Connor, Cock and Parra, 1981; Cock and El-Sharkawy, 1988) have shown that the adverse effect of stress on the root tuber is less severe than its effect on the shoot. The net result, therefore, is that assimilates that are produced under stress conditions are preferentially translocated to the roots. This leads to an increased harvest index under moisture stress conditions, even though there might be a decrease in the absolute weight of harvested tuber and in the total biomass produced.

3.4 Rainfall and Cassava Diseases and Pests

Rainfall and drought very often exert indirect effects on cassava production through their influence on the severity of diseases and pests. In many instances, the effect of rainfall in this regard is mediated through its effect on atmospheric relative humidity (see

below). However, in the case of the cassava green mite, rainfall causes significant mortality of the mites, thereby keeping the population low during the rainy season (Yaninek and Animashaun, 1987). A similar phenomenon also probably operates with respect to the cassava mealybug. It is mainly during the dry season, when rainfall is minimal, that these pests are able to build up their populations to devastating levels. In contrast, the cassava bacterial blight (disease) is mainly dependent on rain-splash for the spread of infection from plant to plant within the field. Its severity and rate of spread are therefore greatest during the rainy season.

3.5 Rainfall and field Operations

Rainfall, or the lack of it (drought) also influences various operations in the cassava production system. Land preparation for planting is particularly difficult under droughty conditions. The same is true of harvesting. This factor makes lifting the crop extremely expensive during the dry season. On the other hand, the rainless conditions of the dry season are favourable for the low-technology (village level) processing and storage of cassava products. Sun-drying is much easier in the dry season, and the dried products are less prone to deterioration in storage during this period.

3.6 Excessive Rainfall

Excessive rainfall can pose a problem in cassava production. Heavy rains on heavy and poorly-drained soils can lead to waterlogging and poor soil aeration. Cassava performs very poorly on such soils. Root and shoot growth are retarded, leaf shedding occurs, late tuber bulking is severely impeded, and yield is poor. Moreover, tuber rots are prevalent under such conditions.

Excessive rainfall can also lead to soil erosion, with consequent adverse effects on cassava production. Cadavid and Howeler (1987) have reported soil losses of 52-106 tonnes/ha over 14 months in some cassava-producing regions in Colombia. Similar erosion problems occur in the cassava-producing parts of Thailand and south-eastern Nigeria.

4.0 HUMIDITY AND EVAPOTRANSPIRATION

The reaction of cassava stomata to the water vapour pressure difference between the atmosphere and the leaf has already been described. This implies that conditions of low relative humidity will result in stomatal closure, even if water supply to the roots is ample. Since the stomata are also conduits for photosynthetic gaseous exchange, their prolonged closure under conditions of low relative humidity can lead to reduced yields. This factor may prove quite important in dry areas where attempts may be made to grow cassava under irrigation. Despite ample irrigation water supply, the low relative humidity of the atmosphere may cause prolonged stomatal closure, with adverse effects on yield. The ideal production situation for cassava, therefore, requires that the atmospheric relative humidity be high enough to prevent protracted stomatal closure.

Similarly, a high relative humidity between planting and sprouting is ideal in situations where the cutting is planted partially exposed. This prevents undue desiccation of the cutting and permits rapid sprouting. Where cassava cuttings have to be stored for long periods before being planted, high relative humidity is also desirable.

Evapotranspiration in various cassava growing regions in the world is in the range of 600-1500mm per year (Fukai, 1985), while the transpiration ratio for cassava is of the order of 300g water/g plant material.

Relative humidity influences the severity and spread of various cassava diseases and pests. The population of whitefly, which is a vector of the African cassava mosaic disease, is influenced by relative humidity (Yao, 1987). Similarly, the severity and spread of the cassava bacterial blight and the cassava anthracnose disease are increased at high relative humidity.

5.0 LIGHT AND SUNSHINE

5.1 The Photosynthetic Pathway in Cassava

The photosynthetic pathway for cassava has over the years (e.g. Fukai, 1985) been regarded as C_3 , with CO_2 first reacting with ribulose diphosphate in the Calvin-Benson cycle. However, more recent evidence seems to suggest that the pathway is somewhere between the typical C_3 and the typical C_4 pathways (El-Sharkawy, Cock and Porto, 1989; Indira 1989). Among the reported peculiarities of photosynthesis in cassava, are the following:

- a) Leaf extracts contain significant amounts of PEP carboxylase, a key enzyme in the C_4 pathway. However the levels of the enzyme are only 15-35% those of a typical C_4 plant such as maize.
- b) The CO_2 compensation point of cassava is very low, of the order of $23cm^3 CO_2/m^3$. Such low CO_2 compensation points are quite typical of C_4 plants.

c) The release of CO_2 into CO_2 -free air is lower in intense light than in the dark, suggesting that in light, the plant is able to recycle large portions of its respiratory CO_2 for use in photosynthesis.

d) Photorespiration in the leaves is much lower than that of typical C_3 plants.

e) The cassava leaf does not possess the typical Kranz anatomy characteristic of C_4 plants. The cells surrounding the vascular bundles indeed contain abundant chloroplast, but they are not thick-walled.

The indications, therefore, are that cassava possesses the required enzymes for C_4 photosynthesis, but has not developed the appropriate anatomy for its full expression. El-Sharkawy, Cock and Porto (1989) conjecture that cassava is intermediate between C_3 and C_4 , or a hybrid between C_3 and C_4 progenitors. Various experiments (CIAT, 1988) have led to the suggestion that at lower temperature, the C_3 cycle dominates; as temperature increases, the activity of PEP carboxylase and other C_4 enzymes becomes more pronounced, and the C_4 pathway dominates.

5.2 Cloud Cover and Shading

Cassava thrives well under the full intensity of sunshine. However, the relatively high rainfall requirements in the producing regions invariably entails cloud cover for several hours each day during the growing season. In the cassava-producing areas of Thailand, the cumulative light receipt during the year is about 2700 sunshine hours (Fukai, 1985). Furthermore, a significant proportion of cassava planted around the world is intercropped, causing the crop to be shaded to varying degrees for all or part of its field life.

Whether shading is caused by cloud cover, or by the interference of other intercrops, it is not a positive factor for cassava productivity. Deliberate shading experiments (Okoli and Wilson, 1986) have shown that shading resulted in increased plant height, decreased LAI, decreased dry weight of stems and leaves, delayed tuber bulking, and decreased yield. Fukai, Alcoy, Llamelo and Patterson (1984) have shown that reduced solar radiation depressed tuber production more than shoot growth. The implication for cassava production is that shading should be avoided as much as possible at all stages of the cropping cycle.

5.3 Photoperiodism

Some aspects of development of the cassava plant are influenced by daylength (photoperiodism). Flowering is promoted by long-day conditions, while the partitioning of carbohydrates preferentially to the tuber is promoted by short-day conditions (Fukai, 1985). In each case, the photoperiodic requirement is not absolute, and the process can go on reasonably well in the absence of the appropriate inductive daylength cycle. Keating (1981) has reported that flowering at low temperature was day-neutral, but at high temperature, it was promoted by long days. Otoo (1983) on the other hand suggests the existence of two photoperiodic classes with respect to flowering: a short-day early flowering class, and a long-day intermediate-to-late flowering class. The situation with respect to tuber initiation is slightly less clear. While Bolhuis (1966) and Mogilner *et al.* (1967) suggest that tuber initiation is induced by short day lengths, Fukai (1985) suggests that the process is day-neutral.

5.4 Heliotropism

Under normal conditions, cassava leaves exhibit heliotropism, moving with the sun so that maximum light interception is achieved at all hours of the day. When stomatal closure occurs as a result of a high vapour pressure difference, the heliotropic response is over-ridden by a drooping of the leaves. Solar interception is reduced, and this avoids the unnecessary heat build-up that would otherwise occur as a result of the closed stomata.

6.0 TEMPERATURE

Cassava is basically a tropical crop. The mean monthly temperatures experienced in the producing regions world-wide range from 15-29°C (Fukai, 1985). The lowest monthly minima range from 10-20°C while the highest monthly maxima range from 30-36°C.

The sprouting or emergence of the planted cutting has a minimum temperature of 16°C, an optimum of 28.5-30°C and a maximum of 34-38°C (Keating and Evenson, 1979, Fukai, 1985). The optimum soil temperature for cassava growth is about 30°C (IITA, 1982) while the optimum air temperature for the season as a whole is in the range of 24-28°C. Experiments on the effects of supra-optimal temperatures have been reported for cassava growing next to gas flares in the Niger delta region of Nigeria (Lawanson, Imevbore, and Fanimokun, 1984). The closer the distance to the flares, (and presumably the higher the temperature), the lower the tuber yield, the lower the starch and ascorbic acid contents, and the higher the amino acid and total sugar contents of the tubers. This suggested a reduced synthesis or increased degradation of root proteins and insoluble carbohydrates.

Sub-optimal (low) temperature can cause cassava plants to shed their leaves. This is quite common in the colder producing locations such as southern Brazil or the Andean valleys of Colombia. Low temperature also results in an almost complete cessation of growth and development, resulting in a prolongation of the time from planting to crop maturity. Cassava production in the Northern and Luapula Provinces of Zambia suffers from this handicap, so that it sometimes requires up to 3 years before the crop is mature enough to be harvested.

The photosynthetic rate of cassava is virtually unaffected by temperature within the range of 25-40°C (El-Sharkawy, Cock and Held, 1984). Above this range, the rate declines to essentially zero at 50°C, while below the range, it declines to about 40% (of maximum) at 12°C. As has already been mentioned, there are suggestions that the C₃ pathway predominates at lower temperatures while the C₄ predominates at higher temperatures (CIAT, 1988).

Temperature influences the occurrence, intensity, and spread of several diseases and pests of cassava. The African cassava mosaic disease (ACMD) is influenced by temperature at two levels: the direct effects on the virus or its symptoms, and the indirect effect on the vector, the whitefly (*Bemisia tabaci*). Robinson *et al.* (1984) have reported that the virus replicated in cassava plants better at 23°C than at 30°C. Similarly, Kaiser and Louie (1982) used prolonged thermotherapy at 37°C to obtain a remission of the symptoms of the ACMD. The effect of temperature on the activity of the whitefly vector has been reported by Yao (1987).

The influence of temperature on the cassava mealybug has been studied by Lema and Herren (1985). The intrinsic rate of natural multiplication of the mealybug increased, while the longevity of individuals decreased, with increase in temperature from 20 to 30.5°C.

Temperature, especially soil temperature, appears to influence the efficiency of formation of beneficial mycorrhizae on the roots of the cassava plant. Sieverding (1988) reported that many fungal isolates which were able to form mycorrhizae at 30°C were unable to do the same at 20°C. Thus, lower temperature, while causing retarded growth in cassava, may additionally be depriving the plant of the benefits of mycorrhizal associations.

7.0 ALTITUDE AND ATMOSPHERIC PRESSURE

The upper altitudinal limit for cassava cultivation is about 2000m for the tropics such as Colombia (Cock, 1985), but is as low as 1000m for subtropical regions such as southern Brazil. For Papua New Guinea, Bourke, Evenson and Keating (1984) reported an upper limit of 1800m. They showed that this upper altitudinal limit corresponded to a mean soil temperature of about 18°C which was shown to be the lowest temperature for satisfactory cassava establishment. Thus the major effect of altitude was due to its moderating effect on temperature.

Atmospheric pressure, one major climatic factor which varies with altitude, has so far not been shown to influence cassava growth and development.

8.0 WIND

Wind as a climatic factor is only occasionally significant in cassava production. Mild winds do not generally affect the crop, but severe gusts and gales may cause lodging of the plants. In addition, Yao (1987) has reported that wind speed and direction were very important factors influencing the spread of the African cassava mosaic disease. The effect of the wind in this case was due

to its effect on the accumulation and movement of the whitefly which is a vector for the virus.

Appreciable wind pollination may also take place in cassava fields, but insect pollination is regarded as being more prevalent.

9.0 AREAS FOR FURTHER RESEARCH

The foregoing review readily reveals definite information gaps with respect to the agrometeorology of cassava, and its interaction with the environment generally.

Firstly, the unfolding picture with respect to the photosynthetic pathway of cassava needs to be further clarified. Is the cassava plant a C_3 plant, a C_4 plant, or both, or even neither? The answer is critical for developing appropriate agronomic strategies for producing the crop, especially under conditions of environmental stress. If, as present evidence suggests, the crop has both C_3 and C_4 pathways, then under what condition does the one pathway prevail over the other, and is it possible to switch from one pathway to the other through agronomic manipulation?

In various parts of the world, cassava has (correctly or incorrectly) gained a reputation as a crop for harsh climatic conditions and poor soils. In East Africa, for example, where drought in the late 1980's to the early 1990's has palyed havoc with other crops, cassava is being promoted as a crop that should be able to weather the rather difficult conditions. Such efforts must be backed up by concrete research to ascertain the actual limits of tolerance of cassava to various climatological extremes, especially in the presence of other pressures such as poor soils or disease and pest incidence. Indeed there is a feeling that the geographical limits of cassava production on the various continents could easily be extended beyond their present confines. In this effort, it will be necessary to develop ecophysiological models

which in turn will assist in producing several specialized cassava ideotypes, each optimally suited to a different environment. For example, cultivars to be grown under irrigation in dry (low humidity) locations must be able to keep thier stomata open for photosynthesis, despite the existing large water vapour pressure deficits which would normally have caused stomatal closure. The ultimate objective of the scheme, therefore, would be to create a wide array of ecologically-adapted cassava cultivars. Apart from highland, lowland, dryland, or wetland types, shade-tolerant types should also be developed for use in intercropping or in locations of incessant cloud cover.

Finally, it should be noted that very little research has been done on the effects of atmospheric pollutants on cassava and its production. With increasing industrialization and environmental degradation in the producing countries, it should be useful to know how the various atmospheric pollutants affect the performance and yield of cassava.

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