International Institute of Tropical Agriculture (IITA)

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Research Guide 55

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Physiology of cassava

Objectives. This guide is intended to enable you to:

- describe the growth pattern of a cassava plant
- describe canopy development
- analyze development of storage roots
- discuss environmental effects on cassava growth
- explain the implications of cyanogenic potential

Study materials

- Cassava plants of different growth habits, cuttings and seeds
- Microscopes
- Storage roots at different stages of development
- Equipment for measuring physiological parameters (leaf area meter, porometer, photosynthetic system ...)

Practicals

- Observe canopy and root development in the field
- Examine structure of a cassava leaf through the microscope
- Measure physiological parameters (photosynthesis, LAI, LAD, CGR ...)
- Analyze the development of storage roots

Questions

1 What type of plant is cassava?
2 What factors affect the growth of the cassava plant?
3 What factors influence canopy development?
4 How does the growth pattern of cassava differ from many other crops?
5 What are the growth phases of a crop harvested after 12 months?
6 At what growth phase do storage roots begin to compete for assimilates?
7 What are the conditions for optimum photosynthetic rates of cassava?
8 What is the main difference between C_3 and C_4 plants?
9 What are 2 parameters of leaf development?
10 How is LAI defined?
11 What factors determine LAI?
12 How is LAD calculated?
13 What can LAI and LAD be used for?
14 Why can cassava storage roots not be used as planting material?
15 What factors does the number of storage roots depend on?
16 How does photoperiod interact with temperature in storage root development of cassava?
17 How does partitioning of assimilates determine yield?
18 How do environmental factors affect development of cassava?
19 What does 'cyanogenic potential' mean?

Physiology of cassava

Abstract. Cassava is one of the most important food crops in Africa. Roots and leaves are both used as food. Its growth depends on several factors. Canopy development is influenced by genetic and environmental factors. Canopy and storage roots grow simultaneously, competing for assimilates. Two parameters of canopy development are leaf area index (LAI) and leaf area duration (LAD). Yield of storage roots is determined by crop growth rate and partitioning of assimilates between shoots and roots. Also, various environmental factors affect yield. Nevertheless, a modest root yield can be produced on soils that are too poor for other crops.

1 The cassava plant

Cassava is a perennial plant, but when cultivated, the storage roots are harvested during the first or second year. Cassava is one of the most important food crops in Africa. More than 50% of world cassava production is in Africa. Both roots and leaves of cassava are consumed.

Humans consume over two thirds of the total production of storage roots in various forms, and the remainder is used as animal feed. The starchy, thickened storage roots are a valuable source of inexpensive calories. Roots are consumed raw, boiled, or processed.

Cassava flour, made from cassava roots, is used in many industries. Table 1 gives sugar, starch, and protein contents for cassava flour made from different cassava cultivars.

Leaves are used as vegetables and can be harvested periodically throughout the growing season. Some food values of cassava leaves are compared with those of sweetpotato and cowpea leaves in Table 2.

Table 1. Sugar, starch, and protein contents of cassava flour from different cassava cultivars.

Cultivar	Soluble sugars %	Starch %	Protein %
TMS 91934	5.1	66.4	26.0
TMS 4(2)1425	2.4	64.5	36.6
TMS 50395	3.7	63.5	29.3
TME 1 (Antiota)	3.6	61.8	30.7
Mean	3.7	64.1	30.7

Farmers propagate cassava from stem cuttings. When planted in moist soil under favorable conditions, cuttings sprout and produce fibrous roots within a week.

Propagation by seed is common under natural conditions and in cassava breeding. Plants established from seed are smaller, weaker, and grow more slowly in the early growth phase than plants from stem cuttings.

Forking or reproductive branching and flowering begin about 6 weeks after planting, depending on genotype and agroecological zone.

Tuberization begins about 8 weeks after planting. Leaf area reaches a maximum in 4–5 months. The height of a cassava plant usually ranges from 1 to 2 m, although some cultivars may reach 4 m during the first year.

Table 2. Some food values of cassava leaves (per 100 g of edible leaves) compared with sweetpotato and cowpea leaves.

	Cassava	Sweetpotato	Cowpea
Dry matter (g)	19.0	13.3	11.6
Calories (kcal)	60.0	42.0	34.0
Protein (g)	6.9	3.2	4.2
Fiber (g)	2.1	1.6	1.7
Ca (mg)	145.0	85.0	110.0
Fe (mg)	2.8	4.5	4.7
Carotene (mg)	8.3	2.7	2.4
Ascorbic acid (mg)	80.0	20.0	35.0

The following factors affect the growth of the cassava plant:

- rate of photosynthesis
- respiratory activity
- light interception and canopy architecture
- water use efficiency
- size of leaf surface available for photosynthesis (source potential)
- dry matter partitioning (capacity to translocate assimilates from leaves to storage roots)
- capacity of storage roots to accept assimilates (sink capacity)

Cassava physiology is the study of physical and biochemical processes, such as photosynthesis, water relations, and mineral nutrition of the plant. It includes study of morphological features and their interaction with the microenvironment.

Information on cassava physiology can be used to:

- explain yield as a function of genotype x environmental interactions;
- describe crop performance as a function of age or phenology, abiotic and biotic stress factors, and various physiological processes;
- identify or develop suitable selection criteria for predicting crop performance;
- help define ideotypes suitable for different environments;
- formulate and validate crop growth models to predict performance and quality of various plant products;
- provide technical support to crop improvement, crop management scientists, and extension specialists.

2 Canopy development

Canopy development consists of leaf and stem growth, and is influenced by both genetic and environmental factors.

Genetic factors include:

- genotype
- hybrid vigor
- ploidy level

Environmental factors include:

- age of plant
- availability of nutrients
- availability of water
- light interception
- CO_2 level

The effects of each of these genetic factors on photosynthesis leaf growth and canopy development are described in the subsequent sections. Refer to chapter 4 on environmental effects on leaf growth. Effects of adverse environmental factors on cassava growth and developments are described in IITA Research Guide 68 (Ekanayake, 1998).

Components affecting the plant canopy include:

- size of stem cutting
- number and nature of buds on cuttings
- function and growth of plant during development
- growing environment

Healthy, fresh stem cuttings of 20–30 cm long cuttings with 5–7 nodes produce a fast growing canopy. For more details on planting materials, see IITA Research Guide

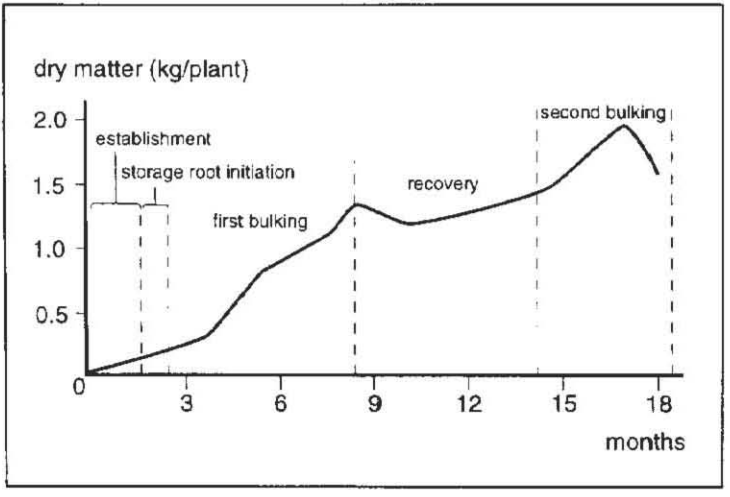
60 (Ekanayake *et al.* 1997). Rate of canopy development and its final size also depend on agronomic practices and therefore its growing environment. Agronomy of cassava is described in detail in IITA Research Guide 60 (Ekanayake *et al.* 1997).

Growth pattern. Unlike many other crops, foliage and storage roots of cassava grow simultaneously, resulting in competition for assimilates. A typical growth pattern of a cassava plant (Figure 1) shows two aspects:

- dry matter production
- phasic development

Dry matter production results in an increase of assimilates during the life cycle of the crop.

Figure 1. Growth pattern of a cassava plant.



Phasic development (vegetative plant growth) implies a sequence of 4 growth phases for a crop harvested after 12 months, and 5 growth phases for a crop harvested after 18 months in a location with a short dry season (2–3 months). The phases are as follows

1 Establishment phase. This commences when stem cuttings sprout, leaves form, and vegetative growth begins.
2 Storage root initiation phase begins with the initiation and formation of storage roots that start to compete for assimilates.
3 The first storage root bulking phase is the phase when storage roots enlarge while the leaf area reaches a maximum. When the crop is exposed to a dry period at the latter part of this phase, the leaf area reduces and crop growth slows down.
4 Recovery phase is the stage when cassava resprouts and produces a new canopy. Storage root growth and competition for assimilates continue.
5 Second storage root bulking phase is the phase following the recovery stage. The storage roots at this stage are the dominant sink.

Reproductive growth. In cassava, reproductive and vegetative growth occur simultaneously for most of the life cycle. Both growth stages compete for assimilates. Reproductive growth begins with the first reproductive branching or forking. Inflorescences are formed at the point of division of the main stem into 2 or 3 branches.

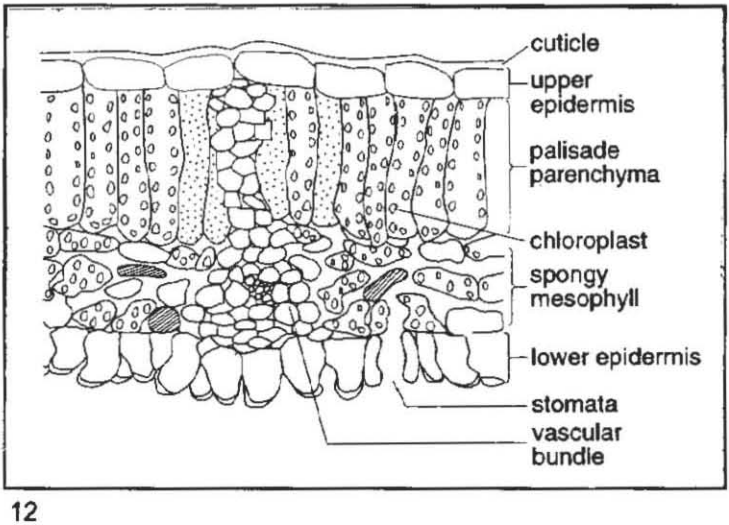
Depending on genotype, forking may occur from 6 weeks after planting, and ranges from sparsely branching to profusely branching types. Forking responds also to environmental stimuli, for example, temperature, and crop

management practices, such as spacing and planting dates. Branching and formation of inflorescences occur throughout the growth cycle, by the subsequent division of the primary branches.

Leaf anatomy. The leaf epidermis is either glaborous or hairy depending on the cultivar. A thin waxy cuticle provides additional protection.

Leaves have a single layer of palisade cells (palisade parenchyma) with an abundance of chloroplasts, located immediately below the upper epidermis (Figure 2). The palisade parenchyma also contains cells which store water and tannins. The spongy mesophyll, below the palisade parenchyma, contains 2–3 layers of loosely packed cells.

Figure 2. Internal structure of cassava leaf.



Vascular tissues occur in both the palisade parenchyma and spongy mesophyll. However, bundle sheets surrounding vascular tissues occur only in the mesophyll.

The lower surface of the leaf consists of a layer of epidermal cells interrupted by stomata. The stomata are small (50–150 μm^2). Leaves have stomata on both upper and lower surfaces, that is, cassava leaves are amphistomatous, but stomata occur more frequently on the lower than on the upper epidermal surface.

There are 50–800 stomata/mm^2 on the lower leaf surface, and 0–50 stomata/mm^2 on the upper surface. Rare exceptions may have up to 150/mm^2 on the upper surface. Stomatal frequency varies with cultivar, ploidy level, plant and leaf age, and upper versus lower leaf surfaces.

Photosynthesis. Cassava leaves are the main source of assimilates, through photosynthesis. Photosynthetic rates in cassava vary according to cultivar, ploidy level, soil-water status, and relative humidity of the air, as well as temperature and solar radiation. Typical photosynthetic rates under optimum growing conditions are 15–35 μmol $CO_2/m^2/s$ between 20 and 40 °C.

Optimum photosynthetic rates (20–35 μmol $CO_2/m^2/s$) are obtained at 30°C, with high light intensity, and high relative humidity. Large genotypic variations in photosynthetic rates (5–35 μmol $CO_2/m^2/s$) are obtained depending on the ploidy level. Generally, triploids have higher photosynthetic rates than diploids and tetraploids (Table 3).

Although its photosynthetic mechanisms are typical of a C_3 plant, some studies show that both C_3 and C_4 enzymatic systems function in cassava and the dominant

photosynthetic pathway varies between C_3 and C_4 depending on temperature.

At lower temperatures, photosynthesis follows a C_3 path, and at higher temperatures, a C_4 path. During photosynthesis, C_3 plants produce a 3-carbon compound (3-phosphoglyceraldehyde, 3-PGA). C_4 plants have the enzyme phosphoenolpyruvate (PEP) carboxylase and produce 4-carbon products (malate, aspartate, and oxaloacetate).

In the tropics, C_4 plants generally perform better than C_3 plants, producing more biomass and using water more efficiently. The C_4 enzyme system of cassava is not as active as that of a typical C_4 plant such as maize.

Table 3. Photosynthetic rates of cassava cultivars of varying ploidy levels (measured in Ibadan, Nigeria, 1994–1996).

Cultivar	Carbon exchange rate (μmol $CO_2/m^2/s$)
Diploid	
TMS 4(2)1425	19.3
TMS 30572	27.9
Triploid	
TMS 89/00003-10	27.8
TMS 89/00003-1	27.9
Tetraploid	
TMS 89/00003-4	22.7
TMS 87/00018-42	20.1

Leaf development. At high temperatures (24–30°C), leaf development takes 2 weeks; at lower temperatures (15–22°C), leaf development takes 3–5 weeks. Leaf size increases up to 4–5 months after planting, and then decreases. With optimum management, average leaf size between 3 and 5 months can reach 350 cm^2. Maximum leaf size in some varieties may reach 800 cm^2.

Adverse environmental conditions, such as low nutrient availability, water stress, and low temperatures, reduce leaf size. In suboptimal environments, average leaf size can range from 40 to 150 cm^2.

Cassava is a deciduous plant with a short leaf life and continuous leaf formation and abscission. Leaf production occurs at a constant rate in optimum environmental conditions, varying from 0.5 to 3.5 leaves per day, depending on cultivar and plant age.

Leaf production is rapid in profuse branching types and in young plants. High temperatures hasten leaf production while water stress reduces and delays it.

The life span of leaves is dependent on the age, genotype, and environment, and is usually 40–120 days. Maximum leaf life is attained at about 3–4 months after planting. Leaf life span can be as long as 200 days, particularly at low temperatures. Shorter leaf life spans are noted under water deficit or flooded conditions, and under severe pest pressure. Shading also reduces leaf duration.

Two parameters of leaf development are:

- leaf area index (LAI)
- leaf area duration (LAD)

These parameters can be used to predict cassava root and leaf yield. Cassava genotypes with relatively high LAI and long LAD have high root yields. Continuous leaf harvest can reduce root yields.

Leaf area index. LAI is defined as the leaf area per unit of ground area, and is a measure of the leafiness of a crop.

LAI is determined by:

- genotype (Table 4)
- plant age
- environment
- management practices
- cropping system

Table 4. LAI of 5 cassava cultivars under monocropping at 3–4 months after planting (measured in Ibadan, Nigeria, 1993–1995).

Cultivar	LAI
TMS 1	4.2
TMS 4(2)1425	3.7
TMS 30572	2.4
TMS 91934	2.9
TMS 50395	2.1
S.E.	0.3

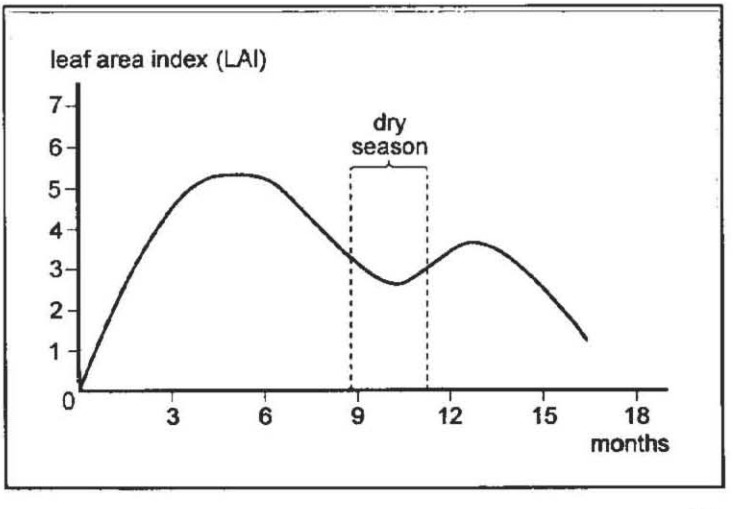
Periodic changes in LAI are determined by:

- rate of formation of leaves
- branching characteristics
- size of leaves
- life span of leaves
- area of falling leaves

LAI in cassava ranges from 1 to 7. Optimum LAI range for cassava in the tropics is from 3 to 4. Maximum LAI values above 7 are rare, except in the subtropics under long day conditions or with optimum management.

LAI increases as the number and size of leaves increase, reaching a peak 4–6 months after planting. Thereafter, leaf size and rate of leaf production decrease and some leaves die (Figure 3).

Figure 3. Leaf area development of cassava.



Dry periods also cause a decline in LAI. This decline is mainly due to increased leaf fall with a concurrent reduction in leaf age, and reduced production and size of new leaves. Following a second rainy season, leaf area may increase a second time, but may not be as high as in the first season.

Leaf area duration. LAD is the integral of LAI over time. LAD is calculated by multiplying LAI with the time (in days or weeks) during which the leaf area is photosynthetically functional. Good examples of long-LAD varieties developed at IITA are TMS 91934 and TMS 4(2)1425.

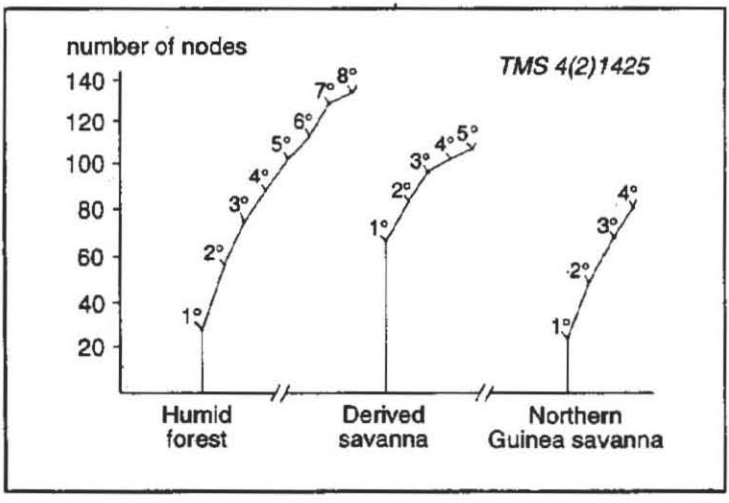
Canopy architecture. Cassava has an indeterminate branching habit and the branch numbers increase in a phasic manner. Cultivar differences and the environment affect branching habit (Figure 4).

The number of active apices is affected by branching. The greater the number of apices, the higher the potential leaf formation rate per apex and leaf area.

The pattern of light penetration and interception depends on cassava canopy architecture. Branching pattern, leaf angle, and leaf area affect rate of light interception.

Vertical leaf orientation at the top of the canopy, changing to more horizontal leaf orientation in the middle of the canopy improves light penetration from the top to the bottom of the canopy. Individual leaf movement in cassava also enhances light interception during the day.

Figure 4. Branching levels (1°, 2°, ...) and number of nodes of a cassava genotype under different agroecological zones.



3 Development of storage roots

Due to cambium activity and deposition of starch grains in secondary xylem tissues, a few fibrous roots swell to produce storage roots. Cassava storage roots are physiologically inactive and cannot be used as planting material.

The number of storage roots is determined during the first 3 months after planting. Not all roots which show apparent root thickening form storage roots. Fibrous roots, which are triggered to deposit starch and enlarge, are anatomically indistinguishable from nonthickening roots. The number of thickened roots ranges from 5 to 20 per plant. Fewer storage roots are formed in drier environments.

The number of fibrous roots which form storage roots depends on several factors, including:

- genotype
- assimilate supply
- shading
- photoperiod and temperature

Genotype. The number and weight of storage roots differ between varieties. Four to 8 storage roots per plant are common, although under good management conditions, more than 20 storage roots are possible, for example, TMS 4(2)1425 produces large numbers of storage roots (10–28) in various agroecological zones and in upland or hydromorphic conditions.

Assimilate supply. Storage root development depends on assimilate supply, which depends on photosynthetic efficiency and effective leaf area. Storage root initiation requires a minimum level of assimilates. Any crop management or environmental factor that affects assimilate

supply also affects the weight and number of storage roots. Examples of environmental factors that may affect assimilate supply are moisture stress, low soil fertility, deficient soil aeration, and high soil temperature. Examples of agronomic factors are land preparation, plant spacing, shading, weed control, and cropping systems.

Shading. Shading or low light due to plant spacing, or companion crops in various cropping systems, may reduce the number of storage roots.

Photoperiod and temperature. Most cassava genotypes develop storage roots under short-day conditions. Long days encourage shoot growth but delay storage root development. For example, in higher latitudes, with longer days, storage root initiation occurs 5.5–13 weeks from planting, compared to 4–8 weeks in the tropics.

Photoperiod interacts with temperature to determine time of storage root initiation. Root initiation is delayed by low temperatures in the subtropics, and occurs 9–17 weeks from planting. In the tropics, high elevation-induced low temperatures, also delay storage root development.

Storage root initiation. Storage root initiation in cassava is not a distinct physiological event since it is not significantly controlled by environmental factors such as photoperiod.

Storage root initiation is however a critical physiological event for the determination of root yield. Time of occurrence in relation to plant age, number of roots initiated, and root enlargement rate (or bulking rate) are dependent on genotypic and environmental factors.

At initiation of storage root thickening, cambium differentiates, the secondary xylem is formed, and starch grains are deposited in storage cells. The cross section of a young root, before secondary thickening, shows outer to inner tissue layers, in the following sequence: an epidermal layer, cortical tissue layers, inner parenchyma with a pentarch of phloem and xylem tissues.

Root yield. Root yield components of a cassava plant are:

- number of storage roots per plant
- average root weight (fresh)
- root dry matter content

Cassava root yield is determined by:

- crop growth rate (CGR), related to leaf area index (LAI)
- radiation use efficiency
- partitioning of assimilates between shoots and roots

CGR and LAI. CGR is influenced by plant age, genotype, environment, and crop management practices. The rate of dry matter production follows a similar pattern to that shown by LAI, where CGR increases as LAI increases.

The optimum LAI for high yield is between 3 and 4. At a higher LAI, CGR declines due to mutual shading. Yield also declines when LAI exceeds 4, because less assimilates are available for growth of storage roots.

Cassava CGR values increase to a maximum of 10–12.5 g/plant/day after 5–6 months or 70–87.5 g/m^2/week. CGR may exceed 120 g/m^2/week, and values of up to 140 g/m^2/week have been obtained in some genotypes under high light intensities and long days.

Radiation use efficiency. Radiation use efficiency (RUE) is the slope of the linear relationship between biomass production and photosynthetically active radiation (PAR) intercepted by the canopy. RUE for cassava ranges from 1.3 to 4.2 g/MJ depending on genotype, season, and crop age.

Partitioning of assimilates. Yield is determined not only by the amount of dry matter produced, but also by the pattern of partitioning of dry matter to different parts of the plant. In cassava, foliage and storage roots develop simultaneously. Assimilate supply is thus divided between foliage and storage roots, leading to intense competition between these parts.

If partitioning of assimilates favors leaf growth, dry matter supply for root growth is reduced, giving low yields. If too little assimilate goes into leaf growth, the photosynthetic process is reduced and, again, root yield will be low.

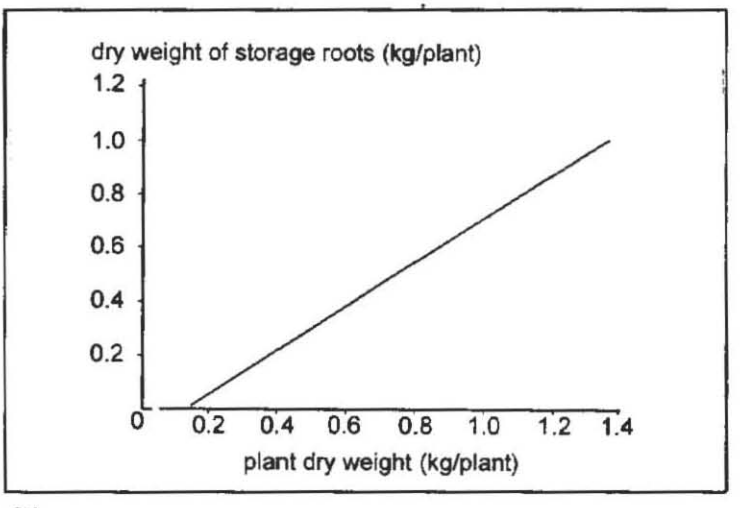
Other crops such as cereals show a 'determinate' phasic development of plant growth. In phasic development, the photosynthetic system (leaves—vegetative phase) develops first and the storage system (grains—reproductive phase) develops later. Thus, competition for assimilates between the two systems is minimized.

In cassava, partitioning of dry matter to different parts of the plant varies during the growth cycle. Allocation of

dry matter to the storage roots varies from almost zero during the early growth stages to nearly 80% of the daily dry matter production during the late growth stages.

The relationship between total dry weight of the plant and dry weight of the storage roots is linear (Figure 5), suggesting that the rate of root growth keeps pace with the rate of crop growth.

Figure 5. Relationship between total dry weight of the plant and dry weight of storage roots during the first 6 months of crop growth.



Environmental effects

The ideal environment for cassava is an annual rainfall of more than 1000 mm, annual temperatures higher than 18 °C, and mean solar radiation level higher than 16 MJ/m^2. Development of cassava is affected by:

- long days (greater than 12 hours) during the early growth period, which result in reduced yield
- low temperatures (less than 19 °C) as well as high temperatures (higher than 42 °C), which delay growth of storage roots
- drought, which hastens the declining phase of LAI

The adaptational range of cassava cultivars is wide. Cassava can be grown in areas where the annual rainfall is as low as 500 mm, and can survive in areas with dry seasons as long as 8 months. Because of such hardiness, farmers in semiarid areas rely on cassava as a 'famine crop'.

Cassava survives under such extreme conditions because the plant conserves water through several mechanisms. At the beginning of a dry season, the production of new leaves is reduced (Table 5) and excessive leaves are shed (Table 6). However, cassava has the ability to produce new leaves while more leaves are shed.

Apex mortality also contributes to a reduction in leaf area during the dry season. The decrease in leaf area reduces canopy transpiration.

Cassava stomata are highly sensitive to water vapor differential. High stomatal resistance reduces water loss during the dry season.

A clonal comparison of stomatal resistance to water loss during rainy and dry seasons is given in Table 7. The decreased leaf area and stomatal closure also reduce photosynthesis, CGR, and root yield.

Additional mechanisms ensure that drought does not seriously affect plant growth:

- A photosensitive mechanism allows cassava leaves to maximize interception of sunlight when transpiration is low. For example, in the morning and late afternoon, leaves turn to the direction of the sun by movement of petioles.

- A drooping mechanism causes the leaves to roll and droop when transpiration rates from leaves are too high. A rolled canopy conserves moisture in its microenvironment.

- Increased partitioning of dry matter to the fibrous root system during periods of drought improves access to soil moisture and absorption capacity of roots.

Table 5. Number of leaves formed (per day) during the dry season (Minjibir, Nigeria, 1992–1993).

Cultivar	Weeks after last rain					
	3	6	9	12	15	18
TMS 91934	0.5	0.4	0.7	0.7	2.0	1.2
TMS 4(2)1425	0.8	0.5	0.5	0.0	1.8	1.1
TMS 50395	0.4	0.4	0.5	0.7	2.0	1.4
TMS 30572	0	0.4	0.4	0.4	1.2	0.7

Table 6. Number of leaves shed (per week) during the dry season (Minjibir, Nigeria, 1992–1993).

Cultivar	Weeks after last rain					
	3	6	9	12	15	18
TMS 91934	0.21	1.19	2.24	2.17	5.32	7.14
TMS 4(2)1425	0.13	1.43	2.27	1.47	3.87	5.43
TMS 50395	0.50	1.60	1.77	1.43	2.37	5.37
TMS 30572	0.1	1.37	2.17	1.50	4.50	3.77

Table 7. Stomatal resistance (mol/m^2/s) of 5 elite cassava genotypes during rainy and dry seasons (Ibadan, Nigeria, 1993).

Cultivar	Season	
	Rainy	Dry
TMS 4(2)1425	36	125
TMS 30572	31	154
TMS 91934	40	191
TMS 86/00080	20	80
TMS 85/00045	41	121

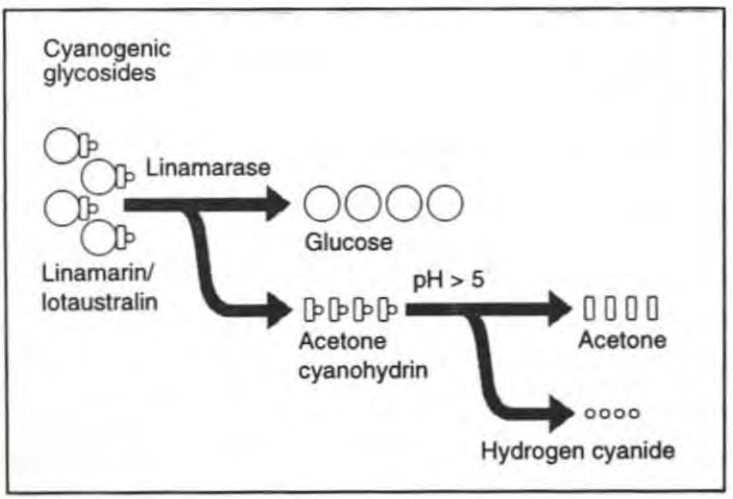
5 Cyanogenic potential

Cassava tissues contain natural nitrile (-CN) compounds called cyanogenic glycosides or cyanogens. These percursors upon breakdown release cyanide through an enzyme catalyzed process named cyanogenesis (Figure 6).

Cassava has a 'cyanogenic potential' (CNp) which means that, though not normally present in plant tissues, cyanide (hydrocyanic acid—HCN) can be produced through enzymatic processes, which occur when the plant cells are bruised, crushed, grated, or bitten, and when cyanogens and degradative enzymes come in contact with each other (Figure 7).

Most cassava root and leaf processing methods eliminate the toxic components.

Figure 6. Cyanogenesis in cassava.



Cassava genotypes are often classified according to their cyanogenic potential, expressed in mg HCN equivalent per 100 g fresh weight (Table 8).

CNp in leaves is usually 5–10 times higher than in storage roots (Table 9). CNp also depends on crop age (Table 9). In storage roots, CNp is higher in the peel.

Cyanogenic glycosides are bitter tasting in addition to their toxicity. Therefore, the term bitter versus sweet has traditionally been used to designate cultivars that contain a high amount of toxic and disagreable substances. An association between toxicity and degree of bitterness in cassava roots has been established.

Figure 7. Biochemical pathway of HCN formation in cassava.

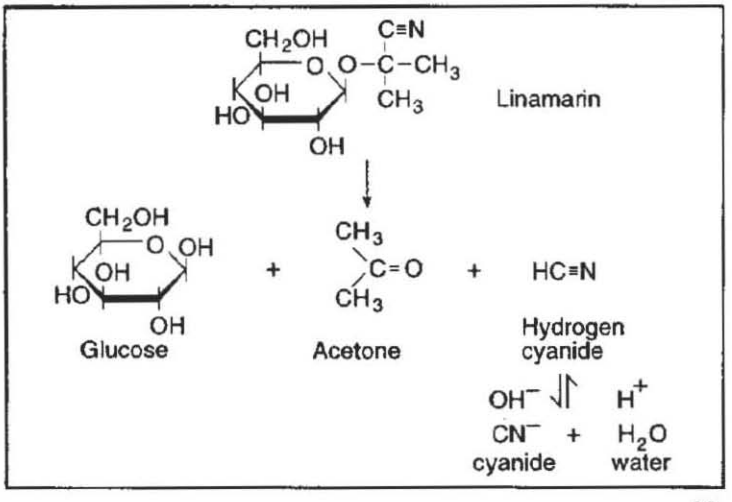


Table 8. Traditional classification of cyanogenic potential (CNp) of cassava cultivars.

CNp	HCN equivalent (mg/100 g)	Examples (IITA cultivars)
Low	< 5	TMS 30001, TMS 4(2)1425
Intermediate	5–10	TMS 30572, TMS 30555
High	> 10	TMS 50395

Table 9. Cyanogenic potential (mg HCN equivalent/100 g fresh weight) in storage roots and leaves of 6 cassava genotypes, 9 and 12 months after planting.

Cultivar	Months after planting			
	Roots		Leaves	
	9	12	9	12
TME 1 (Antiota)	2.9	4.6	37.6	53.0
Isunikankiyan	3.1	5.4	16.4	42.5
TME 2 (Odongbo)	6.1	5.9	64.2	83.3
TMS 4(2)1425	3.7	6.3	59.0	74.0
TMS 30001	6.4	8.4	65.1	70.0
TMS 50395	15.8	22.6	79.9	108.0
LSD (0.05)	2.6	7.1	8.8	16.5

6 Bibliography

Bradbury JH, Bradbury MG, Egan SV. 1994. Comparison of analysis of cyanogens in cassava. Acta Horticulturae, Wageningen 375: 17–96.

Cock JH. 1979. Cassava research. Field Crops Research 2: 185-191.

Cock JH. 1985. Cassava: physiological basis. In: Cassava Research, Production and Utilization (Cock JH, Reyes JA, eds.), pages 33–62. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Ekanayake IJ. 1993. Growth and development of cassava—a simplified phasic approach. Tropical Root and Tuber Crops Bulletin 7: 4–5.

Ekanayake IJ. 1996. Cassava. Procedures for growth analysis. Procedures Manual. Crop Improvement Division, IITA, Ibadan, Nigeria. 25 pages.

Ekanayake IJ. 1998. Screening for abiotic stress resistance in root and tuber crops. IITA Research Guide 68. Training Program, IITA, Ibadan, Nigeria. 47 pages.

Ekanayake IJ, Bokanga M. 1995. Cassava. A review of production agronomy and cyanogenesis. In: The Cassava Biotechnology Network, pages 548–563. Working Document No. 150, CIAT, Cali, Colombia.

Ekanayake IJ, Osiru DSO, Porto MCM. 1997. Agronomy of cassava. IITA Research Guide 60. Training Program, IITA, Ibadan, Nigeria. 30 pages. First edition.

Ekanayake IJ, Osiru DSO, Porto MCM. 1997. Morphology of cassava. IITA Research Guide 61. Training Program, IITA, Ibadan, Nigeria. 30 pages. First edition.

El-Sharkawy MA, de Tafur SM, Cadavid LF. 1992. Potential photosynthesis of cassava as affected by growth conditions. Crop Science 32: 1336–1342.

Enyi BAC. 1972. Growth rates of three cassava varieties under varying population densities. Journal of Agricultural Science 81: 15–28.

Evans LT. 1993. Crop evolution, adaptation and yield. Cambridge University Press, Cambridge, UK. 500 pages.

Hunt LA, Wholey DW, Cock JH. 1977. Growth physiology of cassava (*Manihot esculenta* Crantz). Field Crop Abstracts 30: 77–91.

IITA. 1990. Cassava in tropical Africa. A reference manual. IITA, Ibadan, Nigeria. 176 pages.

Onwueme IC. 1978. The tropical tuber crops. John Wiley and Sons, Chichester, UK. 234 pages.

Silvestre P, Avraudeau M. 1983. Le manioc. Techniques agricoles et productions tropicales. N° 32. Agence de Cooperation Culturalle et Technique, Paris, France. 262 pages.

Veltcamp, HJ. 1986. Physiological causes of yield variation in cassava (*Manihot esculenta* Crantz). Agricultural University Waganingen Papers 85–6. Wageningen, The Netherlands.

7 Suggestions for trainers

If you use this Research Guide in training

Generally

- Distribute handouts (including this Research Guide) to trainees one or several days before your presentation, or distribute them at the end of the presentation.

- Do not distribute handouts at the beginning of a presentation, otherwise trainees will read instead of listen to you.

- Ask trainees not to take notes, but to pay full attention to the training activity. Assure them that your handouts (and this Research Guide) contain all relevant information.

- Keep your training activities practical. Reduce theory to the minimum that is necessary to understand the practical exercises.

- Use the questions on page 4 (or a selection of questions) for examinations (quizzes, periodical tests, and so on). Allow consultation of handouts and books during examinations.

- Promote interaction of trainees. Allow questions, but do not deviate from the subject.

- Respect the time allotted.

Specifically

- Ask trainees about their experiences with plant physiology, especially cassava physiology (10 minutes).

- Present the content of this document. Use and demonstrate the study materials listed on page 3 (45 minutes). Show color slides and overhead transparencies whenever appropriate (show the figures and tables included in this document).

- Conduct the practicals indicated on page 3. You may have to arrange the practicals in simultaneous group exercises. Make sure that each trainee has opportunity to practice.

International Institute of Tropical Agriculture (IITA)
Institut international d'agriculture tropicale (IITA)
Instituto Internacional de Agricultura Tropical (IITA)

The International Institute of Tropical Agriculture (IITA) is an international agricultural research center in the Consultative Group on International Agricultural Research (CGIAR), which is an association of about 50 countries, international and regional organizations, and private foundations. IITA seeks to increase agricultural production in a sustainable way, in order to improve the nutritional status and well-being of people in tropical sub-Saharan Africa. To achieve this goal, IITA conducts research and training, provides information, collects and exchanges germplasm, and encourages transfer of technology, in partnership with African national agricultural research and development programs.

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