

CASSAVA

Procedures for Growth Analysis



I.J. Ekanayake

A PROCEDURES MANUAL

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C A S S A V A
PROCEDURES FOR GROWTH ANALYSIS

Indira J. Ekanayake

Crop Improvement Division (CID)
International Institute of Tropical Agriculture, Ibadan

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P R E F A C E

This *procedures manual* of the Crop Improvement Division (CID) of the International Institute of Tropical Agriculture is intended to provide an avenue for the wide dissemination of information on the modifications to and adaptation of research procedures resulting from the collaborative work on genetic improvement and associated research in crop management and biodiversity. It is aimed at agricultural researchers, technicians, extension specialists, educators and students involved in research and training. *Cassava: Procedures for growth analysis* outlines some of the steps involved in destructive and non destructive growth analysis. It also provides guidelines for developing appropriate sampling protocols for the growth analysis of cassava. Cassava is a principal food crop and a major income earner in Africa.

Individuals and institutions in Africa may receive single copies (at cost and handling charges) by writing to:

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1. Introduction

Cassava (*Manihot esculenta* Crantz) was introduced to sub-Saharan Africa from South America in the 16th century and since then has become a major staple food, consumed by both rural and urban people. In the drier regions it serves as a household food security crop. Although cassava had been previously relegated as a subsistence crop, a recent study revealed that in Africa cassava provides more income than any other crop in cassava producing areas (COSCA 1992). Cassava leaves are eaten as a vegetable, and its tuberous roots can be processed into over one-hundred different foods; certain varieties are also grown principally for agro-industrial use. Cassava is also grown in many countries outside Africa. In 1992/93, world cassava production was 154 million metric tonnes, of which 75 million metric tonnes were grown in sub-Saharan Africa (FAO 1992-3).

As Africa continues to industrialize, cassava's potential as a cash crop will increase. Therefore, a better understanding of its response to the environment and the influence of the environment at different growth stages is required to improve the production potential of cassava cultivars. The growth and development of a cassava crop is determined by several factors: the initial size of planting material, the number and nature of initial sprouts, the functioning and growth of the individual plants during their ontogeny and the environment in which these plants are cultivated (Milthorpe and Moorby 1979). Growth, development and yield (roots and

leaves) of cassava can be monitored in the whole plant and in the component plant parts using the popularly known 'growth analysis' approach as introduced by F.G. Gregory in 1917, and modified thereafter by Evans (1975).

Growth analysis is an approach which analyzes the plant as a whole rather than through individual physiological processes (gas exchange, transpiration) and does not require sophisticated and costly instruments. It provides a quantitative framework which can be used to describe the following growth phenomena in the plant:

- a. dry matter production and allocation to different plant component parts
- b. variations in these processes in relation to the stage of growth and environmental factors

This document outlines some of the steps involved in destructive and non destructive growth analysis which describe the growth and development patterns (vegetative and reproductive) of cassava. Guidelines are provided for developing appropriate sampling protocols for the growth analysis of cassava which suit the objectives and requirements of various cassava research and training programs, and for different types of physiological and agronomic trials (glasshouse, field, experimental and on-farm). The protocols selected will vary according to the depth of analysis needed. In addition, destructive growth analysis data will provide baseline information for crop growth modeling purposes.

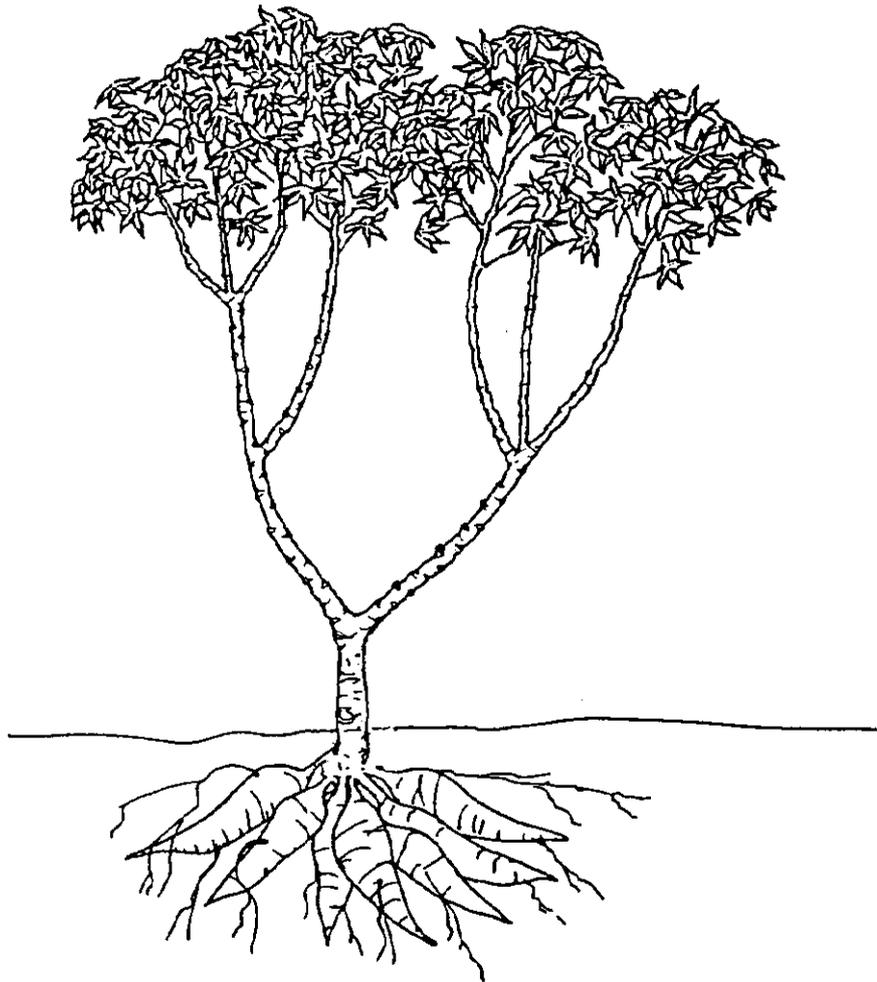


Figure 1. The morphology of a generalized early, low (reproductive) branching cassava plant (drawing by C. Onianwa, IITA; Osiru et al. 1996)

2. Non Destructive Growth Analyses

Non destructive growth analysis consists of the periodic evaluation of the growth and development of individual cassava plants, based on one or more growth characteristics, which are noted in-situ, without damaging the plants. Subsequent evaluation is carried out on the same plants. This type of growth analysis is used where there are not enough plants to enable destructive sampling or where there are time or other resource constraints. The ability to strike a balance between selecting appropriate sample numbers per replication to evaluate, which is practical; and at the same time being sufficiently sensitive to identify significant variations, depends on the objectives of an experiment, the genotypes used and the facilities available. Our experience with cassava shows that a desirable sample number for non destructive sampling would be between 4 and 8 plants per experimental unit.

2.1 Sprouting of stem cutting

The sprout emergence rate is influenced by the planting position of the stem cutting. The number of days to 50% sprouting and the number of days required for complete sprouting are important data for evaluating the early establishment of cassava stem cuttings and the genetic variability.

- Start sprouting observations one week after planting the stem cuttings (stakes) in the field or in pots.
- Count the number of stem cuttings which have sprouted at weekly or bi-weekly intervals. It is desirable to continue with these measurements until full or near 100% emergence (complete sprouting).

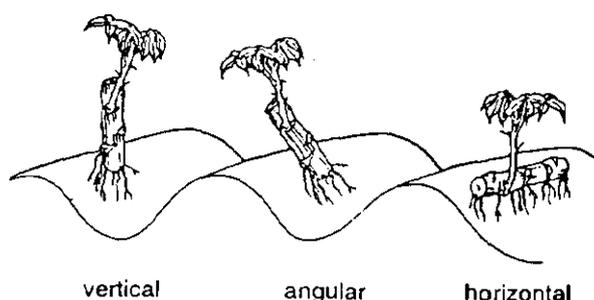


Figure 2. Three planting positions for cassava stem cuttings (Osiru et al. 1996)

- Score the planting position of the stem cutting as follows (CIAT 1983)
 - 1 = vertical
 - 2 = angular/inclined
 - 3 = horizontal
 - Calculate the sprouting percentage using the total number of stem cuttings per treatment and/or replication.
- Sprouting percentage is also used to determine the effects of treatment factors on the rate of establishment or on stand count.
- Do not monitor sprouting beyond 8-10 weeks after planting, unless the weather conditions are most unsuitable or the environment being tested is adverse for the test crop or genotypes, since delayed sprouts fall into a late sprouting category of genotypes or are non viable.

Sprouting data can be presented on the basis of the number of sprouts formed at a certain number of days after planting, or by counting the number of days after 50% or 90% (full) emergence or sprouting.

2.2 Vigor

- Rate the initial plant growth vigor visually (on a per plot basis) using the following scale (modified from CIAT 1983)
 - 1 = very poor vigor
 - 3 = poor vigor
 - 5 = intermediate vigor
 - 7 = vigorous
 - 9 = highly vigorous

2.3 Stem number

- Start counting the number of main stems or sprouts (potential main stems or shoots) per plant one week after planting. This can be done at the same time as the sprouting count.
- Monitor the stem number over the growth cycle at 2 to 3 month intervals up to about 6 months after planting.

This gives an indication of the degree of apical dominance of the stem cutting in response to prevalent biotic and abiotic stress conditions.

The number of stems formed per cutting is also influenced by the planting pattern (vertical, angular or horizontal, figure 1), number of nodes, carbohydrate reserves in the cutting, length and thickness of cutting, genotype and the environment.

2.4 Plant height

- Measure plant height from about 3 weeks after planting in field. Plant height is the distance between the base of the sprout to the topmost end of the sprout or the stem of the plant.
- Measure the plant height from the baseline at ground level in either field or pot experiments to the top of the plant or canopy as shown in figure 3.

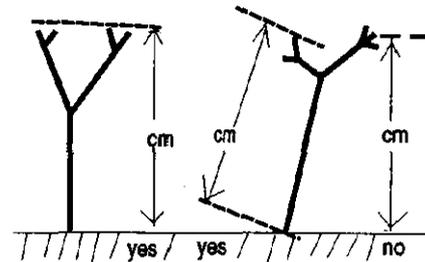


Figure 3. How to measure plant height (adapted from CIAT 1983)

- Measure plant height at weekly or bi-weekly intervals; this can be done when counting the sprouts and stem numbers, depending on the objectives of the experiment and labor availability.

Note that as the plant height of cassava increases (>2m height), it becomes difficult to obtain accurate measurements.

2.5 Leaf area development

- Monitor leaf area development non destructively using any one or more of the following measurements: leaf number, leaf age, leaf area and ground cover.

2.5.1 Leaf number

- Count the total number of fully open leaves per plant; count only those leaves with fully open leaflets since these are the leaves which contribute fully to the photosynthetic activity of the plant.
- Disregard the growing points, since these do not contribute significantly to the photosynthetic capacity of the plant.
- Count the number of leaves on a per stem per plant basis.

Since the number of stems are recorded wherever multiple stems are present on an individual stand (originating from a single stem cutting), the number of leaves on a randomly selected stem multiplied by the number of stems gives an estimated total number of leaves per plant.

2.5.2 Rate of leaf formation

- Calculate the rate of leaf formation on a per week basis or in terms of the number of leaves formed per unit of time per unit of area, based on the change in the number of leaves present between measurements.

The leaf formation rate monitored weekly and converted to the rate of leaves formed per day is a widely used unit of comparison.

This parameter could also be presented on a per plant, per branch (lateral or reproductive) or per stem basis where multiple stems are formed on an individual plant or in terms of the number of leaves formed per unit time per unit area. For comparative analytical purposes, per plant data is more desirable.

2.5.3 Leaf longevity or leaf age

Leaf longevity is the period (in days or weeks) between the first appearance of a fully open leaf and its senescence.

- Tag the youngest fully formed and expanded leaf closest to the growing point (the size depends on the genotype and other factors).
- Follow a single path from the growing point after the plant forks.
- Write the date and initial length of the leaf on the tag.
- Tag plants which are to be kept until maturity to record leaf longevity (so that they are not removed for destructive sampling, which could influence the period of active growth and function).
- Tag a minimum of two leaves, preferably three leaves per genotype per treatment per replication.

Leaf initiation is sensitive to environmental factors and genetic factors, such that the period between the appearance of new leaves may differ from plant to plant or from treatment to treatment.

The growth stage of the plant also has a strong influence on the leaf appearance rate, i.e., more leaves are formed during the vegetative phase and regrowth phase after a dry season, than during the tuberous root bulking phase or an abnormal/stress situation, such as the onset of a dry season (figure 4, Ekanayake 1993).

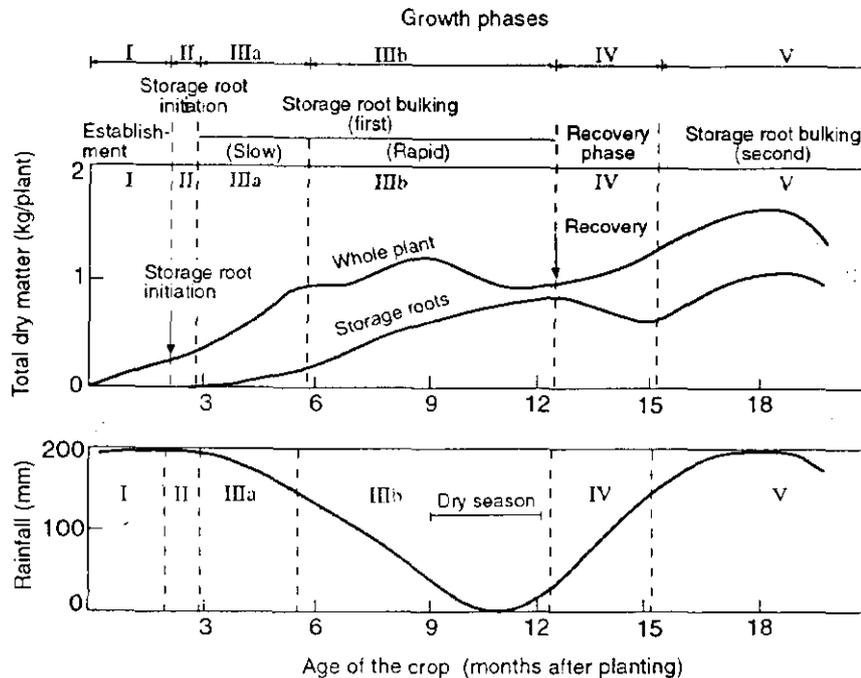


Figure 4. Schematic representation of phasic development (phenology) of cassava to a unimodal rainfall pattern: I. establishment phase, II. storage (tuberous) root initiation phase, IIIa. slow storage root bulking phase, IIIb. rapid storage root bulking phase, IV. recovery phase, and V. second storage root bulking phase (Ekanayake 1993)

- Record the number of tagged leaves that die at weekly intervals, starting from 4 to 6 weeks after planting. Record the approximate senescence date of the tagged leaves.

Leaf death is said to have occurred when >75% of the leaf is yellow or dry or when the leaf falls off the plant.

- Tag the leaves at approximately two-week intervals to monitor leaf appearance and leaf longevity.

The tagging interval will depend on: genotype; the total duration of the experiment; the particular season (rainy season or dry season); full canopy duration; and time of harvest.

2.5.4 Leaf area

Leaf area is the total leaf area per plant and is a function of the rate of leaf formation, the size of individual leaves, and their longevity. A number of methods are used to estimate total leaf area.

- Visually rate the total photosynthetically active leaf area based on the leafiness of the plant, instead of measuring the actual leaf area. This gives an approximate estimation of leaf area.
- Estimate leaf area non destructively by counting the number of leaves per plant (C_1) and then estimate the area (C_2) as the sum of products of lamina length and maximum lamina width per leaf.

To obtain *actual* leaf area:

- Trace the leaf on a piece of paper, cut the shape out and run it through a leaf area meter.
- Calculate the relationship between actual and estimated leaf area of this sample using a regression equation (Akoroda 1993).

Another method for measuring total leaf area of a cassava plant in the field is to use a quadrat frame.

- Use a quadrat divided into equal small squares on tagged plants in each plot.
- Center the quadrat on top of the canopy of each plant and count all the squares covered by the plant's canopy (figure 5).
- Count only those squares occupied by more than half of a leaf/leaf portion.
- Compute the estimated leaf area (ground cover) as the ratio of the total number of squares occupied by the plant canopy (the shaded area in figure 5) and the total number of squares in the quadrat wooden frame used (figure 5).
- Use this method for cassava during the early developmental stages, i.e., up to about 4 to 5 months after planting, depending on the growth vigor of the crop:

The grid method measures an individual leaf area, which is summed up to give the total leaf area of the plant.

- Determine the leaf area by tracing its outline on graph paper (grid method, figure 6).
- Spread the leaves on a hand-held grid and count the number of squares covered by the leaf (figure 6).

- Compute the total leaf area as the product of the number of squares covered and the area of a single square.

Portable leaf area meters, for example, the Licor model 3000 are often used to measure leaf area.¹ The width of the running belt in most of the commercial and traditionally available instruments may constitute a limitation when taking non destructive readings for cassava leaves.

- Calculate the *leaf area index* (LAI) as the ratio of leaf area to land area per plant.

$$\begin{aligned} \text{LAI} &= \text{Leaf area index} \\ &= (\text{LA}) / (\text{land area}) \quad (1) \end{aligned}$$

where:

$$\text{LA} = \text{leaf area}$$

- Monitor leaf area development at weekly or at shorter (e.g., 2-day) intervals based on the objectives of the particular study.
- Calculate the *leaf area duration* (LAD = integral of leaf area over time; m² days) based on the leaf area data (Ekanayake 1994).

$$\begin{aligned} \text{LAD} &= \text{Leaf area duration} \\ &= \text{LA} \times t \quad (2) \end{aligned}$$

where:

$$t = \text{unit time}$$

2.5.5 Canopy development

- Evaluate cassava canopy development based on an individual plant or several plants within a plot.

¹ More information on using sophisticated leaf area meters is described in a companion paper (Ekanayake and Adeleke 1996).

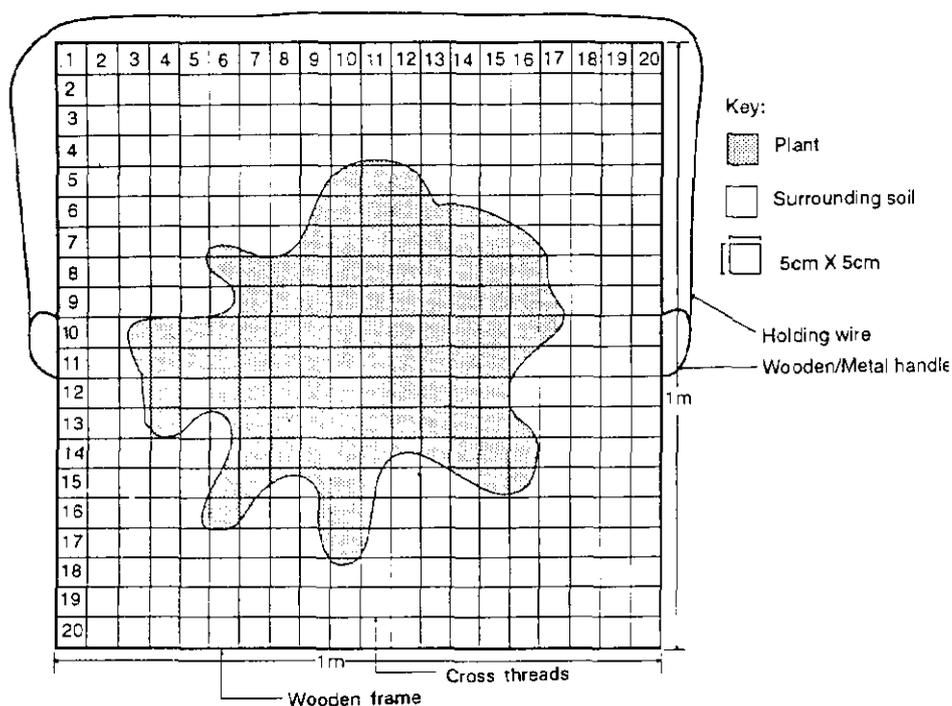


Figure 5. A schematic drawing showing a quadrat frame used to determine the area of a crop or ground cover (Kapinga 1994)

- Monitor full canopy development non destructively using a visual rating scale.

A rating scale² used for scoring cassava canopy development is as follows:

- 1 = <20% ground cover
- 3 = 20 - 40% ground cover
- 5 = 41 - 60% ground cover
- 7 = 61 - 80% ground cover
- 9 = 81 - 100% ground cover

This score is based on the percentage of ground cover (area per stand) at 7 to 8 weeks after planting. Rather than using time after

planting, a more appropriate time for scoring the leaf area development is to use specified crop growth stages. Ideally, the score should be made throughout the season at regular intervals. However, if resources do not permit monitoring over the full crop cycle, scoring can be done at specified intervals of 2 to 3 months.

- Standardize this scale across various genotypes and compare with measurements used by other researchers, to ensure greater accuracy across field trials, over various seasons and locations.

² F. Schulthess, IITA, personal communication.

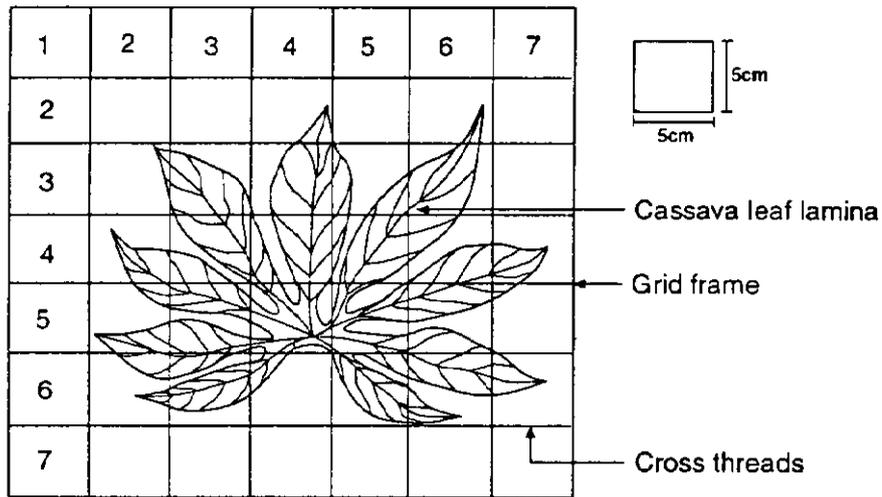


Figure 6. Grid method used for measuring leaf area (Kapinga 1994)

2.6 Forking and branching pattern

- Record the number of days to first forking or the formation of reproductive branches (Ekanayake 1995) and the plant height at which first forking occurs (figure 7).
- Count the number of nodes to first branching and to subsequent branching levels (figure 8).

The number of nodes is usually a better basis of comparison across genotypes and across environments than plant height (figure 9).

- Count twice during the season (before and after 12 months after planting) to take account of late branching genotypes.

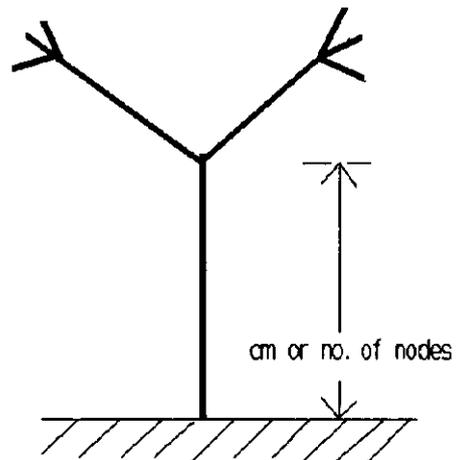


Figure 7. Plant height at which first forking occurs (adapted from CIAT 1983)

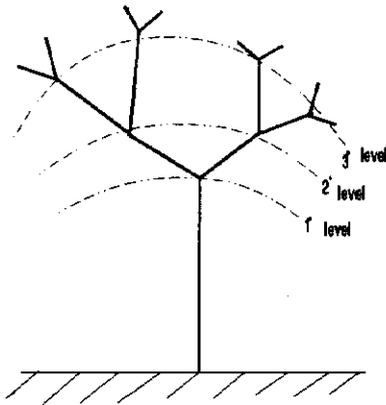


Figure 8. Branching or forking levels (adapted from CIAT 1983)

- Estimate the number of nodes visually, (instead of counting the number of nodes), wherever the typical genotypic growth habits of the test genotypes are known.

A clear understanding of the growth habits of individual genotypes is needed, however, since the branching habit (figure 10) can be influenced by environmental factors such as the climate and soil, cropping systems and associated abiotic and biotic stress.

- Count the number of branching levels and the number of nodes to branching at 12 months after planting or at the end of the cropping season, prior to harvesting (figure 8), instead of at other times during the season, e.g., 3, 6 or 9 months after planting.

2.7 Flowering

Flowers and fruits can be an important sink in characterizing and evaluating the growth habits of cassava, but this depends on their size in

relation to the biomass of the plant, (both above and below ground).

- Note the time to first flowering: days after planting (i.e., the emergence of the plant to inflorescence), days to first flower opening, the period required for 50% flowering (that is, when 50% of the plants in a given plot produce flowers).
- Record detailed flowering data, i.e., number of male flowers per inflorescence, number of female flowers per inflorescence, etc., depending on the objectives of the experiment.

2.8 Lateral shoot production

- Use the following measurements to record lateral shoot production. Monitor lateral shoot production simply by counting the number of lateral shoots formed along a single branching path in each plant instead of counting all branching paths (figure 10). Estimate the total number of lateral shoots produced per plant where the number of branches per branching level is known.
- Evaluate lateral branch formation immediately before the commencement of the second rainy season, for example, in bimodal or false bimodal rainfall zones such as in Ibadan, in the derived savanna zone of Nigeria. In monomodal rainfall zones, evaluate lateral branch formation at the end of the dry season (for a crop of >6 months of age).
- Count the number of lateral shoots at harvest, preferably along a single branching path, instead of at an early stage of growth.

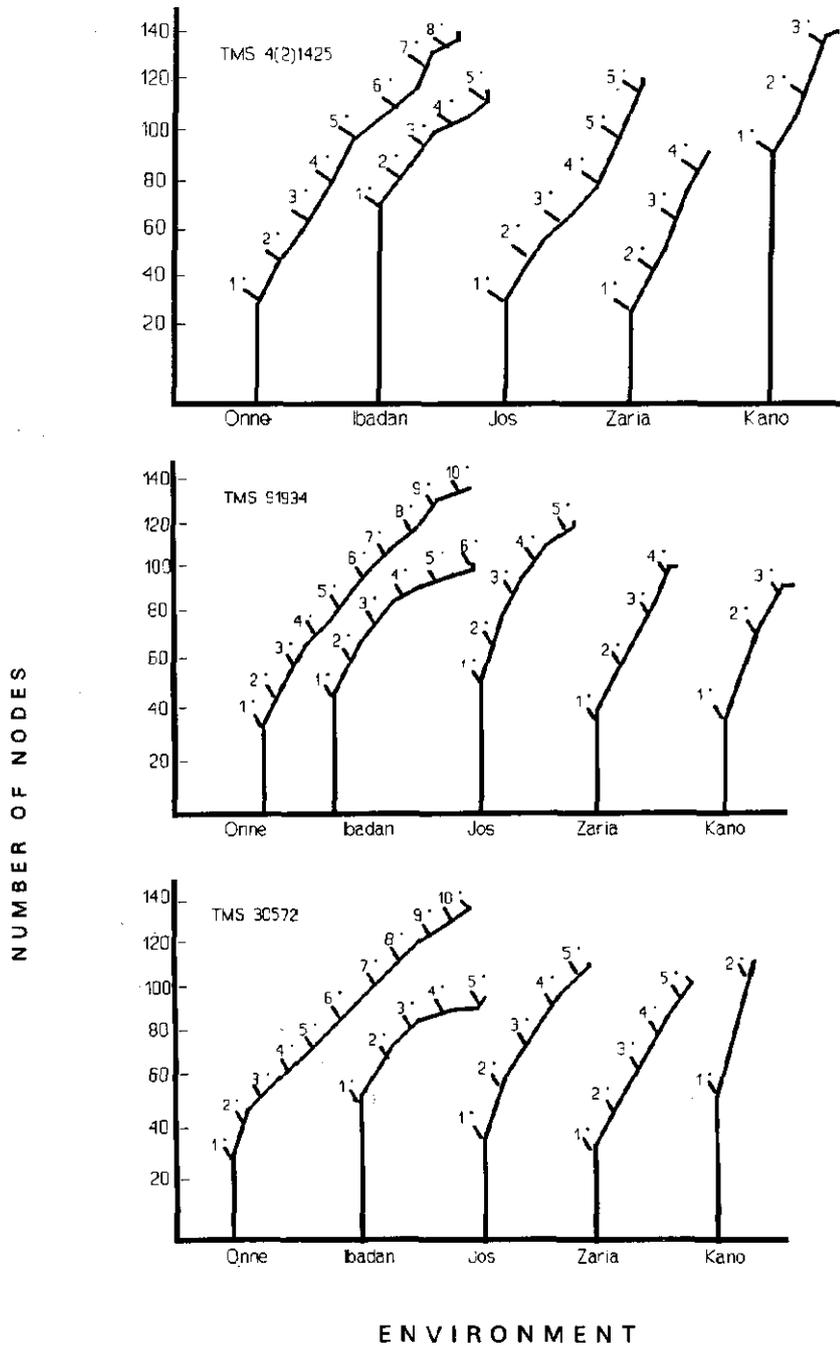


Figure 9. A schematic representation of the branching habits of three cassava genotypes (TMS 4(2)1425, TMS 91934, and TMS 30572) in five agroecozones in Nigeria: Onne (humid forest zone); Ibadan (forest savanna transition zone); Jos (mid-altitude savanna zone); Zaria (northern Guinea savanna zone); Kano (Sudan savanna zone)

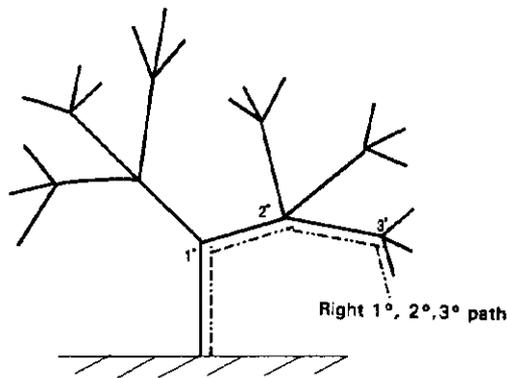


Figure 10. Branching path identification and nomenclature

1° = primary branching; 2° = secondary branching;
3° = tertiary branching

2.9 Canopy architecture

- Evaluate canopy architecture by noting the stem number, the production of lateral and reproductive branches, the angle of branching and the height at which branching occurs.

Canopy architecture is a compound characteristic which is influenced largely by both genetic and environmental factors.

2.9.1 Broad categories of canopy architecture for cassava³

Some of the broad categories of canopy architecture are as follows (see figure 11).

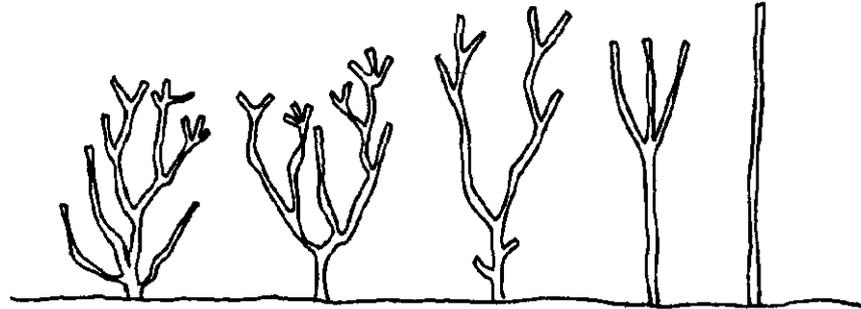
- a. *No branching type*, i.e., varieties without an upper ceiling for LAI, for example, a few landraces from the rain

³ Modified from F. Schulthess, IITA, personal communication.

forest zone of Nigeria and some Latin American clones

- b. *Non vegetative branching genotypes* have zero to few lateral shoots with a relatively dense canopy (plants with very strong apical dominance or late branching), for example, the traditional CIAT⁴ ideotype and popular Asian cassava cultivars
 - c. *Vegetative and late reproductive branching genotypes* display a stratified and relatively dense canopy as usually found in late branching varieties with a few lateral shoots. For example, Nigerian local cultivars such as Odongbo (TME2), Antiota (TME1) and Dakata Wariya
 - d. *Intermediate reproductive branching genotypes* have early to medium branching height cultivars with a regular dense canopy, the presence of apical dominance and few or no lateral shoots. For example, the IITA elite cassava clones bred and selected in the decades of 1980 and 1990.
 - e. *Early low, reproductive branching genotypes* display a broom-like dense canopy as a result of the formation of an excessive number of lateral shoots, for example the IITA elite cassava clones bred and selected in the 1970 and 1980 decades such as TMS 30572
- Score visually the full canopy appearance for clones using the scale of 1 to 9 (figure 11).

⁴ Centro Internacional de Agricultura Tropical, Cali, Colombia (CIAT 1976).



Canopy architectural type	e	d	c	b	a
Score	1	3	5	7	9

Figure 11. Various canopy architectural forms of cassava (Osiru et al. 1995). A description of each form is given in the text

2.10 Cassava stay-green score (CSGS)

The combined deleterious effects of leaf aging, cassava green mite damage, drought, large variations in day and night temperatures and dry and dusty harmattan winds and other biotic and abiotic factors are visually rated using the cassava stay-green score (CSGS) which is based on the general appearance of the leaves of the plant.

This score takes into account the visual appearance of the full canopy (figure 9) as described by the various canopy architectural forms and leaf distribution, number of leaves retained, leaf color, leaf turgidity or wilting, complete or partial drying, and greenness of the leaves to account for the proportion of the total leaf lamina area which is green and photosynthetically active.

The compound factor scale uses the following four plant parameters in a descending order of priority for rating. Other specific characteristics

mentioned earlier, may be added or used to modify the rating.

- the number of green leaves retained as a ratio of total number of leaves formed is rated based on the denseness of the canopy. This can also be evaluated by noting the leaf scars on the stem
- gradation of green color, i.e., light green, medium green, blue green, blue black green
- ratio of green leaves to yellowing leaves plus drying but retained leaves
- turgidity of the leaves

For the rating to be successful, it is necessary to be familiar with the normal external plant appearance of each genotype.

The greenness of the leaves may differ across genotypes of different ploidy levels and this may also have a confounding effect on the score rating with CSGS.

A one-time comparison of leaf chlorophyll content and leaf color can be used to assist in rating with CSGS. The visual rating scale used routinely for CSGS is described in table 1.

Rating of plants using CSG scores prior to the regrowth induction at the latter part of the dry season or due to any other adverse condition is more appropriate, since the visual separation of the old canopy versus the new growth later into the season is difficult.

A visual rating of a plant's green leaf retention is easier and more practical for breeders than either quantitative measurements of leaf age or branching, as described in the previous subsections or measuring the length of attached leaves which are also photosynthetically functional (figure 12); the latter measurements are more time consuming and require various instruments.

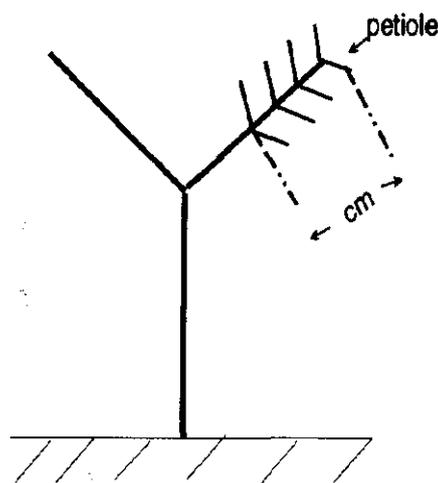


Figure 12. Length of stem retaining leaves (adapted from CIAT 1983)

Table 1. Cassava stay-green scoring system (CSGS)

Score	Description
1	A normal plant with a full canopy, retaining a majority of formed leaves. These leaves are green, turgid and photosynthetically active.
3	30% of the leaves have dropped; less than 50% of the remaining older leaves are droopy, partially wilted or dry; younger leaves have reduced greenness or yellowing.
5	50% reduction of the leaf number compared to a full canopy; most, or more than 50% of the older leaves are droopy, wilted and practically dry; most of the young leaves have reduced greenness or are yellowing.
7	80% reduction in the leaf number compared to a full canopy; more than 75% of the remaining old leaves are wilted or brown; young leaves have reduced greenness or are yellowing.
9	Complete defoliation of the stems, with a candlestick appearance. Some dieback of the stems is also evident.

3. Destructive Growth Analyses

Destructive growth analyses should be conducted at the end of a short-term experiment or at periodic intervals — sequentially — in a well-planned field trial, where plant populations in each plot are assigned to each destructive sampling date. Appropriate borders are excluded from sampling and remain to demarcate the sampling dates while providing requisite competition effects. In most pot experiments, destructive growth analysis is done at the end of the experiment, as the final sampling, unless arranged similar to the field trial design.

- Take a range of plant component measurements at each of the sampling times.

In addition to using such data to monitor growth in response to treatment factors, the data could be used as a base data set for modeling the growth habits and the ontogeny of the plant population concerned.

A standard field planting design used for destructive growth analysis is illustrated in figure 13 where alternate columns or rows are used for destructive sampling. In this example a minimum of 5 plants from alternate columns is selected for destructive measurement.

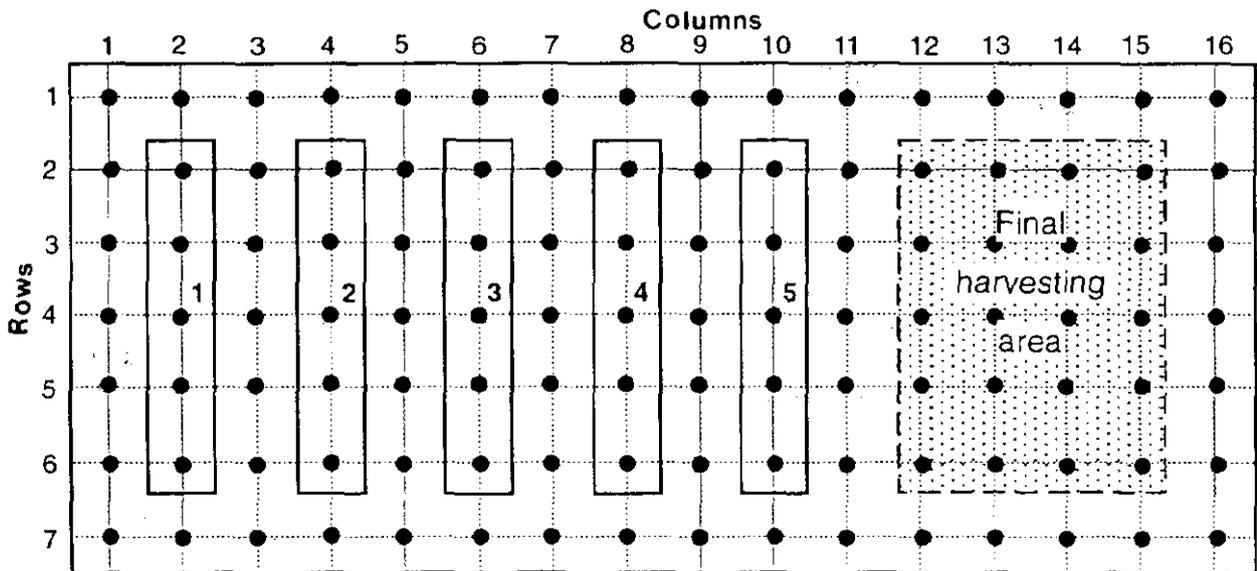


Figure 13. Arrangement of plants in a plot for periodic destructive growth analysis

1st sampling:

- Sample the plant positions at 2.2, 2.3, 2.4, 2.5 and 2.6.

Given the large variability among cassava plants in field trials, it is recommended that 5 or more plants be selected, provided other factors, such as land and labor, are not limiting.

2nd sampling:

- Sample the plants in positions 4.2, 4.3, 4.4, 4.5 and 4.6, leaving the borders between the consecutive sampling dates.

A minimum of a single destructive sampling is required to be able to monitor the growth pattern and the influence of the environment during each of the seasons of a single planting cycle.

- Adjust sampling intervals according to the changes in seasons (mainly based on the rainfall and perhaps minimum temperatures) or the age of the crop.

In cassava there is a large overlap of vegetative, reproductive and root bulking stages as shown in figure 5. Therefore, for most ecophysiological studies variations in seasons are used to demarcate sampling periods (table 2).

According to the plan proposed (table 2), if the plants are harvested after 12 months, four destructive samplings and a final harvest are carried out. For the final harvest, sample 12 to 16 plants at columns 12-15 (figure 13), a minimum of 12 plants per replication. In locations where the expected variability is high, sample more plants.

Table 2. Recommended sampling times for growth analyses based on a unimodal rainfall pattern, (>8 months) and planted early in the rainy season

Sampling date	Season	Months after planting
1	wet	2-3
2	wet / dry	5-6
3	dry	8-9
4	dry / wet	11-12
5	wet	14-15
6	harvest	17-18

- Adjust the sampling number and sampling schedule depending on the objective of the study.

An alternate plot arrangement is given in figure 14.

Various parameters which should be measured on plants sampled destructively are described below.

3.1 Plant height

- Measure the height for individual plants for each sampling date

3.2 Number of plants

- Count the number of plants sampled in a field plot.

Missing plants can either be accounted for during the analysis (statistical methods) or by pulling additional plants (if available).

- Count the number of stems, etc., as indicated in the non destructive sampling procedures.

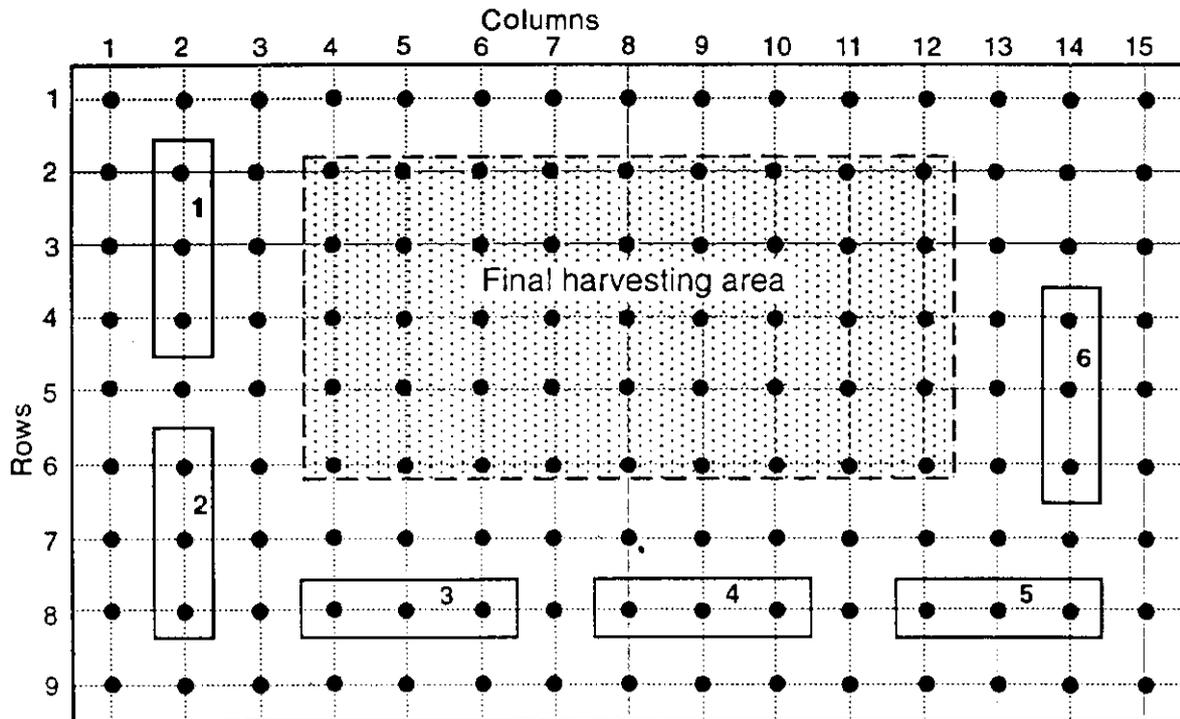


Figure 14. An alternative scheme for destructive and sequential growth analysis (Kapinga 1994)

3.3 Number of leaves

- Record the total number of leaves per plant (pot culture).
- Count all leaves if the plants are small and if the number sampled does not exceed 5; for bigger plants and large samples select a representative sample, i.e., 2 to 3 of all plants per treatment or plots.

For other procedures refer to the non destructive sampling protocol discussed in section 2.

3.4 Number of stems per plant

- Count the total number of stems per plant. In a plot of 5 representative plants, count stems of all plants if the expected variability is high.

3.5 Leaf area

- Remove a minimum of 5 (in young plants) and up to 20 representative leaves from each plant (in pots) or from field plots for the leaf area measurement.

- Run the leaves through a leaf area meter and record the area.

The total leaf area per plant or per plot can be calculated based on the total number of leaves per plant. Where a leaf area meter is not available, leaf area can be measured using a grid or by the length and breadth method (see section 2.5.4).

- Calculate the leaf area as the product of leaf lamina length and maximum width taken manually using some correction factors and taking into account the shape of the leaf of a given cultivar (see section 2.5.4).

The regression equations for estimating leaf area manually and procedures used are similar to those described in the non destructive growth analysis section (Akoroda 1993, section 2.5 of this study).

If the measurements cannot be done immediately, it is a good practice to transport detached leaves from the trial site to the laboratory in an insulated box with ice to reduce wilting. This is particularly important in dry environments.

An alternative method for finding leaf area is to multiply the total dry leaf weight by the leaf area to leaf weight ratio (leaf blades + petioles). If petiole weight is substantial however, leaf area values can be over estimated. For a more precise leaf area measurement, take only the lamina or blade area. Leaf weight may include both blades and petioles where the contribution of petioles is insignificant. The leaf area to leaf weight ratio may be determined by measuring the area of 20 young and 20 old leaves randomly sampled from each plant or plot, and oven drying them after measuring.

3.6 Crop growth rate

- Calculate *crop growth rate* (CGR) and *tuberous root growth rate* (TRGR) from the polynomial function of the 3rd order fitted to the log transformed dry matter data (Ekanayake 1994).

Crop growth rate ($\text{gm}^{-2} \text{day}^{-1}$), in general, includes all above ground plant parts and the tuberous and fibrous roots, while TRGR refers to tuberous roots only.

- Calculate daily growth rates as follows:

$$GR = (W_2 - W_1) / (T_2 - T_1), \quad (3)$$

where: W_2 and W_1 are the total for CGR or tuberous root dry weights TGR on two successive days, T_2 and T_1 .

3.7 Plant component analysis

- Separate the component parts of each sampled plant into stems, leaves, flowers, fibrous roots and tuberous roots on a per plant per pot or per plot basis.
- Separate the mother stem cutting if sampling is done very early in the plant life cycle.

Later on in the season, especially in field planting, the mother stem cutting becomes an integral part of the stem system and may not be easy to distinguish and separate.

Further analyses of these component parts are described in sub sections 3.7.3.7 and 3.7.3.8.

3.7.1 Counting fibrous and tuberous roots

- Separate and count the total number of individual primary fibrous roots, i.e., roots arising directly from the main stem.

The root branches arising from the primary roots are the secondary roots. In most instances, count only the primary roots, as the secondary roots are often small and difficult to separate.

Tuberous roots are those that are thicker than 0.5 to 1cm diameter; root thickness is dependent on plant age and genotype.

- Separate tuberous roots according to their diameter into small, medium, large and jumbo categories.
- Do a weight analysis on the basis of these individual classes.

The size classes are given in table 3.

Table 3. Tuberous root size classes based on root diameter (approximate sizes)

Class	diameter (cm)
Small	< 3.0
Intermediate	3 - 5.92
Large	6 - 9.0
Jumbo	> 9.0

- Count the total number of tuberous roots in each category.

3.7.2 Maximum fibrous root length

- Place the primary root system on a board and measure the length of the longest root.

This is a measure of the depth of the root system growth and its depth of water absorption. This approach is only used with plants which are grown in a pot or container.

- Use a root trench method or root length extractions at different soil layers (0-15

cm, 15-30 cm, etc.) for plants grown in the field.

- Calculate the root length density to explain the growth and development of the root system in vertical and horizontal directions within the soil profile.

Detailed root analysis information is given in a companion methodology paper (Ekanayake 1996).

3.7.3 Tuberous root weight, shape, peduncle length and skin color scoring

Various visual scoring systems can be used (IITA 1990, CIAT 1983) to describe the tuberous root characteristics of cassava. These descriptors are additional to that used for the tuberous root size score (see table 3), and are based on averages of all roots per plant or plot.

3.7.3.1 Tuberous root weight score

A modified IITA scoring system (1990) is as follows:

- 1 = very small (<0.49 kg)
- 3 = small (0.5 to 1 kg)
- 5 = medium (1.1 to 2 kg)
- 7 = large (2.1 to 5 kg)
- 9 = extra large (> 5 kg)

3.7.3.2 Tuberous root shape score

System 1: Tuberous root shape score (modified from IITA 1990)

- 1 = round
- 3 = oval
- 5 = medium, long
- 7 = fat, long
- 9 = thin, very long

System 2: Tuberous root shape score (CIAT 1983) (figure 15)

- 1 = conical
- 2 = conical-cylindrical
- 3 = cylindrical
- 4 = irregular

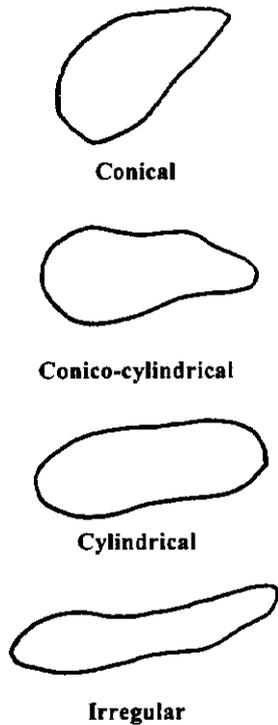


Figure 15. Tuberous root shapes

System 3: Misshapen tuberous roots score (CIAT 1983)

Constrictions and undulations of the roots are rated using this score (figure 16).

- 1 = very few or no constrictions, smooth shape
- 2 = intermediate number of constrictions
- 3 = many constrictions



Smooth shape



Intermediate amounts of irregularities



Highly irregular shape

Figure 16. Misshapen tuberous root shapes (CIAT 1983)

3.7.3.3 Peduncle length score

System 1: (modified from IITA 1990)

- 1 = short or no neck (short)
- 3 = about 5 to 7 cm
- 5 = about 7 to 10 cm (intermediate)
- 7 = about 10 to 15 cm
- 9 = over 15 cm long (long)

System 2: (IITA 1990)

- 1 = short
- 2 = intermediate
- 3 = long

3.7.3.4 *Tuberous root skin color score (outer skin)*

System 1: Tuberous root skin color score (outer skin surface) (CIAT 1983)

- 1 = white
- 2 = light brown
- 3 = dark brown

System 2: Tuberous root skin color score—inner skin surface (CIAT 1983, 1990)

- 1 = white
- 2 = cream
- 3 = yellow

3.7.3.5 *Tuberous root flesh color score* (CIAT 1983, IITA 1990)

- 1 = white
- 2 = cream
- 3 = yellow

3.7.3.6 *Root cortex pigmentation score* (CIAT 1983)

- 0 = no pigmentation
- 1 = lightly pigmented
- 2 = intermediate pigmentation
- 3 = intensely pigmented

3.7.3.7 *Ratio of peel to flesh of tuberous roots*

The fresh weight ratio of tuberous root peel and flesh of the harvested plants can be taken.

3.7.3.8 *Fresh weight*

- Take the fresh weight measurement of each component part of the plant.

When the sample is very small (<50g), measure to two decimal places for greater precision, otherwise to one decimal place, particularly where large amounts per

component plant part are available under field conditions. Round off these values to the next significant digit (IITA 1979).

- Take a representative sample of the component part, which should weigh approximately 250 to 350g for each plot (consisting of the 5 or 6 plants sampled) and the total plant fresh weight if the fresh weight analysis is done on a per field plot basis.

3.7.3.9 *Dry weight*

- Place each component part in a paper bag and dry in an oven set at 65 - 70°C for a period of 48 hours.
- Dry the tuberous root samples at a higher temperature (100°C) for 24h to 36h.

If comparisons are required across cultivars, treatments or sampling dates, dry all the samples at the same temperature and follow the same protocol.

- Take the dry weight of each plant component after drying.

Care should be taken to reduce reabsorption of moisture after drying, by the immediate weighing of the sample in its own container.

- To obtain the dry weight, calculate the total dry weight per plant component as the product of the ratio of fresh to dry weight of the sample and total fresh weight of the plant component.

3.7.3.10 *Dry-matter content*

- Calculate the dry-matter content (%) as the ratio between fresh weight and dry weight:

$$DM (\%) = (DW/FW) \times 100 \quad (4)$$

- Calculate total dry-matter production as the product of dry-matter content (%) and total plant component weight.

3.7.3.11 Yield and total biomass

Cassava tuberous root yield is the fresh or dry weight of that component. Total plant biomass is the sum total weight (fresh or dry) of the individual component parts.

- Carry out a general evaluation of roots and foliage, based on plant appearance at harvest as follows (modified from CIAT 1983).

- 1 = very good
- 3 = good
- 5 = regular
- 7 = bad
- 9 = very bad

- Calculate the harvest index (HI) of the plants using the following formulae, where the economic harvested plant part is the root (Ekanayake 1994). Use the formula:

$$HI(\text{root}) = \frac{(\text{root yield})}{(\text{total biomass})} \quad (5)$$

where the economic harvested plant part consists of leaves the formula is modified as:

$$HI(\text{leaf}) = \frac{(\text{leaf yield})}{(\text{total biomass})} \quad (6)$$

Where the economic harvested plant parts include both leaves and roots the formula is modified as:

$$HI(\text{rl}) = \frac{(\text{leaf yield} + \text{root yield})}{(\text{total biomass})} \quad (7)$$

To present the HI as a percentage, multiply the formulae in equations 5-7 by 100.

- Construct growth curves throughout the ontogeny of the crop, using component plant part data at each sampling period. Use such data also for crop growth model testing (figure 4).

3.8 Chemical analyses

- Use plant component parts arising from the above described growth analyses, after drying at 65-70°C, for further analyses of major and micro nutrients and/or proximate analysis of moisture, carbohydrates (starch and sugars), lipids, proteins, crude fibre and ash (IITA 1979; 1982). Draw out cause and effect relationships to estimate the influence of any of the treatment factors on these different elements or products, i.e., morphological changes versus biochemical changes.

The cyanogenic potential of cassava roots and leaves is an important characteristic, which should also be routinely analyzed (Cooke 1979, Almazan 1988).

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GLOSSARY

Apical dominance: The condition whereby the shoot apex regulates the growth and development of the lateral buds and branches. Hormonal regulation, i.e., auxin, on apical dominance has been noted.

Axillary bud: A bud formed in the axil of a leaf.

Branching: Stems produce two types of branches; lateral branches and reproductive branches. Reproductive branching is a more stable genotypic characteristic.

Cambium: A layer, usually 1 or 2 cells thick of persistently meristematic tissue that divides to give rise to secondary tissues, resulting in growth in diameter.

Cultivar/variety: A uniform group of cultivated plants obtained by breeding or selection.

Fibrous root: An extended, thin root similar to a fibre.

Flesh of tuberous root: The solid mass of flesh formed as secondary tissue of the xylem, derived from the cambium that surrounds the flesh and contains starch granules.

Forking: A common term used to describe reproductive branching.

Growth: An increase in the dry weight of an organ or plant.

Harvest index: The economically important part of the dry weight, as a proportion of the total dry biomass

Inflorescence: The entire reproductive structure arising from the branches on the upper part of the plant or occasionally formed in the leaf axils. It includes a group of racemes consisting of male and female flowers.

Internode: The section of the stem between two successive nodes.

Lateral branch: These are branches or suckers arising from the axillary buds of the leaves of the stem. These branches are generally thinner than the main stem, with longer internodes and small leaves also termed lateral shoots.

Net assimilation rate: The increase in weight per unit time per unit leaf area present.

Node: The insertion point of the leaf in the stem, with one or more axillary buds in the axil of the leaf.

Peduncle: The cylindrical plant part that connects the neck of the tuberous root to the stem.

Peel: The skin of tuberous roots.

Plant density: The total number of plants per unit area.

Propagation: Methods of raising or establishing crop plants.

Relative growth rate: The rate of increase in weight per unit weight present.

Reproductive branch: Induction of flowering mode is indicated by terminal branching where the main stem or lateral branches divide to form 2 to 4 side (secondary) branches, then tertiary branches and so on.

Secondary thickening: Formation of additional, secondary vascular tissue by the activity of cambium, with accompanying increase in diameter of stems and roots of plants; providing additional conducting and supporting tissue for the growing point.

Skin of tuberous root: The skin is formed by the periderm and the cortex, also termed peel.

Stem cutting: Used for asexual propagation; serves as *seed* in cassava cultivation.

Tuberous root: A thickened, fleshy underground tuber-like root.

Cassava: Procedures for growth analysis is a manual on physiological research methods prepared by the Crop Improvement Division of IITA. This manual provides step by step procedures for the destructive and non destructive analyses of important growth characteristics of the cassava plant.

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