International Institute of Tropical Agriculture (IITA)

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Research Guide 68

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September 1998

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IITA Research Guides

IITA Research Guides provide information and guidance to agricultural researchers, technicians, extension specialists, educators, and students involved in research and training. The Research Guides are periodically updated to meet advances in scientific knowledge.

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Printed in Nigeria by IITA

ISSN 1118-678X
ISBN 978-131-145-2

Ekanayake IJ. 1998. Screening for abiotic stress resistance in root and tuber crops. IITA Research Guide 68. Training Program, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. 46 pages.

Screening for abiotic stress resistance in root and tuber crops

Objectives. This guide is intended to enable you to:

- discuss environmental stress factors and plant responses
- describe the principles of breeding and screening
- screen for stresses caused by drought, waterlogging, temperature extremes, solar radiation extremes, and nutrient imbalances

Study materials

- Maps showing ecological zones
- Healthy and stressed cassava plants
- Examples of ideotypes
- Equipment for screening experiments in field, greenhouse, and laboratory
- Equipment for measuring stress responses

Practicals

- Identify stressed plants in the field
- Describe stress symptoms
- Evaluate stress responses

Questions

1. What types of factors influence the environment in which plants grow?
2. What are the 2 categories of environmental stress?
3. What are the major abiotic stress factors of cassava in the humid forest zone?
4. What are the altitude limits for growing cassava and yam?
5. On what factors does the crop response to adverse environments depend?
6. What is acclimation?
7. What are the 4 adaptational strategies for abiotic stress resistance?
8. What are the 4 types of breeding traits?
9. What is indirect selection?
10. What is the principle of the black box method?
11. What is an ideotype?
12. Why should breeders provide different levels of a stress factor, when screening for resistance?
13. What should you consider in selecting the most appropriate screening method?
14. What are common symptoms of drought stress?
15. How can you calculate WUE?
16. What is the main aim of plant adaptive mechanisms to waterlogging?
17. What are physiological adaptations to low temperature?
18. What are morphological adaptations to low radiation?
19. What are 4 ways of measuring nutrient use?

Screening for abiotic stress resistance in root and tuber crops

Abstract. The main abiotic stress factors affecting root and tuber crops in sub-Saharan Africa are drought, waterlogging, temperature extremes, solar radiation extremes, and nutrient imbalances. To reduce the effects of abiotic stress, researchers breed crops that have high levels of resistance to the relevant stress factors. Researchers identify traits that confer resistance to stress factors. Genotypes with desirable traits are selected by screening, and used to breed populations with improved resistance.

1 Environmental stress

Root and tuber crop productivity can be constrained by various environmental stresses. The environment in which plants grow consists of physical, chemical, and biological factors. An imbalance in any of these factors causes plant stress. Stress reduces the yield and the quality of a plant and its product.

Researchers divide environmental stress into 2 categories:

- biotic stress (biological factors)
- abiotic stress (physical and chemical factors)

Biotic stress factors include diseases, insects, nematodes, weeds, and plant competition. Figure 1 shows some abiotic stress factors that affect plants. Table 1 lists the major abiotic stress factors of cassava in the different agroecological zones of West and Central Africa.

Table 2 presents optimum environmental conditions, and tolerances and sensitivities, for cassava and yam cultivation. These conditions minimize stress and result in good yield.

The effect of 1 stress factor can be reduced or enhanced by another stress factor. For example, the combination of high temperature and drought during the dry season in West Africa increases dehydration stress of plants.

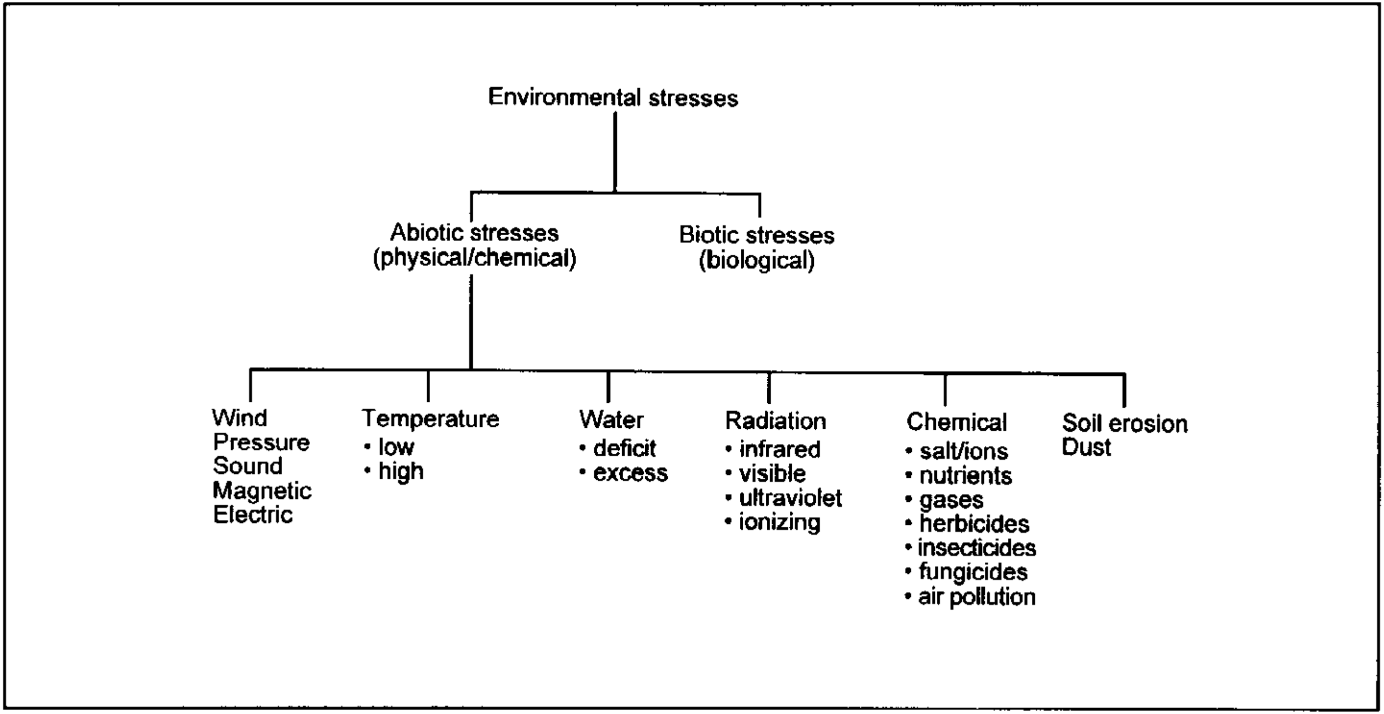


Figure 1. Environmental stress factors that can affect plants.

Table 1. Major abiotic stress factors of cassava.

Agroecological zone	Abiotic stress
Coastal savanna	Mild drought Salinity Alkalinity Low soil fertility
Humid forest	Low solar radiation Excess soil moisture Soil acidity
Forest–savanna transition	Mild drought
Moist savanna	Mild to moderate drought Low soil fertility
Dry savanna	Severe drought High temperature 'Harmattan' or dry season dust Low soil fertility
Midaltitudes	Low temperature Mild to moderate drought Moderate to low soil fertility
Inland valleys	Excess soil moisture Mild to moderate drought Mineral toxicity

Table 2. Optimum environmental conditions, and tolerances and sensitivities, for the cultivation of cassava and yams.

Environmental factors	Cassava	Yams
Climatic factors		
Adaptational range	Broad tropical (humid, subhumid and semi-arid)	Tropical (humid and subhumid)
Optimum temperature	>20°C; Andean zone:	25–30°C optimum
Mean annual rainfall	600–3000 mm	1150 mm; long rainy seasons, 7–9 months
Tolerance to drought	>6 months	2–3 months; from sett planting to sprouting
Sensitivity to light	Tolerance to extremes	Sensitive to low light; needs staking in low light
Altitude limit	1600–1700 m; Andean zone: up to 2300 m	1600 m
Soil factors		
Optimum soil temperature	25–29°C	25–28°C
Tolerances and sensitivities	Tolerates acidity (to pH 4.4)	Sensitive to extreme soil acidity
	Tolerates aluminum toxicity below pH 8	
	Sensitive to salinity/alkalinity	Sensitive to salinity/alkalinity
	Sensitive to waterlogging	Sensitive to waterlogging
Restrictions	Soil depth restrictions, high clay soils and calcareous soils unsuitable	Soils with gravel, hard pan and compacted soils unsuitable

Crop response to adverse environments depends on several factors, such as the genetic makeup of the crop, growth stage of the plant, and agronomic factors, for example crop density and companion crops. A genotype with a waxy cuticle, for example, assists the plant to survive during dry periods by reducing transpiration losses. A younger plant is more vulnerable to desiccation or tissue drying than an older plant.

The response of plants to different environmental conditions is the result of either acclimation or adaptation.

Acclimation. A plant can react to periodic or short-term (daily or seasonal) environmental changes, such as changes in air temperature, relative humidity of air, and rainfall. Such environmental changes induce phenotypic modifications. These modifications are not heritable.

Adaptation. Adaptation is the evolution of new characteristics through long-term selection of genotypes. These characteristics are heritable and pass along to new generations.

Plants have 4 adaptational strategies for abiotic stress resistance:

- temporal escape
- avoidance
- tolerance
- recovery

Temporal escape. Plants can avoid stress by growing when the stress factor is not present or is minimal. Farmers can also use temporal escape, for example, by manipulating planting date to avoid the stress factor, or by using early bulking genotypes.

Avoidance. Some plants have traits that prevent the stress factor from affecting the plant tissues. For example, a deep root system will help avoid drought stress, because soil moisture can be taken from deeper layers.

Tolerance. Some traits allow plants to grow or survive despite stress conditions. For example, osmotic adjustment allows plants to tolerate high salinity, or drought stress.

Recovery. Some plants have the ability to recover after the stress has passed, and to compensate for its effects. Cassava, for example, grows new shoots and leaves after a drought period has ended.

The main abiotic stress factors affecting root and tuber crops in sub-Saharan Africa are:

- drought
- waterlogging
- temperature extremes
- solar radiation extremes
- nutrient imbalances

To reduce the effects of abiotic stress in plants, researchers breed crops that have high levels of resistance to the relevant stress factors. In other words, the crops are adapted to prevailing climatic, soil, and other environmental factors. Farmers can then use these stress-resistant genotypes in areas where the stress factors are present.

Researchers identify traits that confer resistance to specific stress factors. These traits are bred into populations, to improve resistance to those stress factors.

Traits can be divided into 4 types:

- morphological
- anatomical/histological
- physiological
- biochemical

Traits are selected by screening. Screening involves subjecting different genotypes to an abiotic stress, to identify genotypes that perform well, and therefore have high levels of resistance to that stress factor.

Selection can be direct or indirect. In direct selection, the trait of interest is selected and monitored. In indirect selection, a trait that is highly correlated to the trait of interest is selected.

Selection and breeding for abiotic stress resistance is an important element in an integrated management approach that is sustainable and environmentally friendly. In addition to selecting and breeding resistant genotypes, appropriate agronomic and cultural practices can reduce abiotic stress.

Biotechnology provides molecular tools for genetic engineering of stress resistance. In the future, researchers will be able to incorporate stress resistance into crops using these methods.

The most common screening methods for improved resistance to abiotic stress are:

- black box
- ideotype

Black box. In the black box method, large numbers of genotypes are grown under stress. Researchers look for differences in plant structure or processes that might explain differences in yield. Large populations of plants have to be screened over several selection cycles to identify desirable genotypes, since most traits associated with stress resistance are controlled by many genes with small effects.

Ideotype. An ideotype is an optimum, high-performance genotype. The ideotype method is a method of selection by design. Based on a knowledge of the physiology, morphology, and anatomy of the crop, researchers identify a potential genotype adapted to the environmental stresses of an agroecology. High-performance genotypes corresponding to the potential genotype are then selected.

Researchers must ensure that certain conditions are met when screening genotypes for abiotic stress resistance and resource-use efficiency. Environmental conditions for testing should highlight differences among genotypes. Symptoms of a specific abiotic stress should be easy to identify.

Some factors to consider when screening for abiotic stress resistance are:

- select an appropriate and simple screening method
- select appropriate sites
- evaluate and define selection parameters carefully
- use controlled and uniform environmental conditions
- use uniform growth medium (for example, soil or solution culture)
- use genetically uniform planting material
- select genotypes for screening at the most appropriate (the most sensitive) growth stage
- evaluate large numbers of genotypes
- provide different levels of a stress factor, to demonstrate a variety of genotypic differences
- include susceptible, sensitive, or nonefficient genotypes as controls
- use methods that can be repeated over seasons and on different sites
- take a statistically significant number of samples for each parameter of interest. Researchers use the following equation to determine the number of samples required, within a specified limit or accuracy:

  $$n = t_a^2 \times S^2/D^2$$

  where:

  n = number of samples needed
  t_a = t-statistic for $n - 1$ degrees of freedom
  S = standard deviation
  D = specified limit (accuracy)

In selecting the most appropriate screening method, consider:

- available capital, labor and time
- available expertise in relevant disciplines
- ease of operation
- level of sensitivity required
- associations with other plant parameters
- the importance of a particular abiotic stress for a particular crop

3 Drought

Drought stress in plants falls into 2 broad categories:

- midday water deficit (daily deficit period)
- long-term water deficit or drought (seasonal deficit)

Most breeding programs attempt to overcome the seasonal (long-term) water deficit stress. Periods of drought vary in duration and intensity, depending on the agro-ecological zone.

Symptoms of drought stress. Stress symptoms from drought vary, depending on intensity and duration of drought, and growth stage of the crop. For root and tuber crops, the critical growth periods are initiation and development of storage organs (roots and tubers).

Common symptoms of drought stress are:

- postsprout wilting of young plants
- leaf wilting and rolling
- leaf yellowing
- leaf abscission
- reduced growth, short internodes, small leaves and plants
- reduced root or tuber bulking
- plant death

Drought resistance traits. Plants adopt various mechanisms to overcome drought stress. Researchers select plant traits associated with these mechanisms in order to screen for drought resistance.

Generally, 4 mechanisms of defence are incorporated in drought-resistant genotypes:

- escape
- avoidance
- tolerance
- recovery

The following plant traits assist these defence mechanisms.

Escape:

- rapid stand establishment
- early vegetative vigor
- early bulking (storage root development)

Avoidance:

- reduced leaf canopy or top growth
- high leaf water potential
- heliotropic leaf movement
- smaller leaf size
- pubescence, waxy cuticle
- stomatal closure/continued photosynthesis
- increased xylem vessel diameter
- deep fibrous root system
- rapid bulking

Tolerance:

- stay-green ability (leaf retention)
- osmotic adjustment
- proline and abscisic acid accumulation
- maintenance of turgor for growth processes
- desiccation survival

Recovery:

- remobilization of substrates for growth
- rapid resprouting/new shoot and leaf formation
- continued storage root bulking

Screening for drought resistance. Many plant parameters are measurable for evaluating root crops under drought conditions. Researchers generally look for the following indicators of drought resistance:

- stay-green ability
- stomatal response and photosynthetic rate
- rooting patterns
- water-use efficiency
- changes in leaf posture
- changes in leaf growth
- changes in plant architecture

Stay-green ability. When breeders evaluate a large plant population, a visual rating of the plants is the most practical way to evaluate drought resistance. For example, IITA has developed the following rating scale for cassava stay-green ability:

1 Normal plant with a full canopy: retains the majority of its leaves which are green, turgid, and photosynthetically active

3 30% of the leaves have dropped: less than 50% of the remaining leaves are droopy, partially wilted or dry; the young leaves have yellowing or reduced greenness

5 50% reduction in the number of leaves: 50% or more of the older leaves are droopy, wilted and partially dry; most young leaves have yellowing or reduced greenness

7 80% reduction in the number of leaves: more than 75% of the remaining leaves are wilted or brown; the young leaves have reduced greenness or are yellowing

9 Complete defoliation: stems have candlestick appearance; stem die-back occurs

(Even numbers are used for intermediate symptoms.)

Follow the 4 steps below to decide an appropriate cassava stay-green score (CSGS) for a given cassava plant.

- Assess the number of green leaves retained, as a ratio of the total number of leaves formed (count leaf scars on the stems).
- Grade the greenness of leaves.
- Calculate the ratio of green leaves to yellowing leaves, and dry leaves still attached to the stem.
- Estimate the turgidity of leaves; note leaf wilting, and complete or partial drying.

Researchers should be familiar with the normal external plant appearance of each cassava genotype in order to rate the plant successfully. Differences in the greenness of leaves across genotypes of different ploidy levels may distort the score. To validate the CSGS score of a large population of genotypes or plants, researchers require a baseline estimate of leaf chlorophyll content or leaf color to compare with the CSGS rating.

Stomatal response and photosynthetic rate. Leaf stomata respond to changes in water vapor pressure in the air and leaves. When external water vapor pressure is low, stomata close to reduce water loss through transpiration. Where the dry season is long, or where soils have a low water-holding capacity, plants with highly sensitive stomata are selected, as they conserve the small amounts of available soil moisture.

Physiological characteristics associated with stomatal response include:

- stomatal conductance
- transpiration rate
- leaf diffusive resistance
- intercellular CO_2 concentration
- CO_2 assimilation rate
- CO_2 compensation point

Measurement of these characteristics usually requires expensive equipment, and can be laborious when monitoring large populations. However, these measurements are routine for selecting parent lines in a breeding program.

Rooting patterns. Deep rooting gives plants access to water stored at deep soil layers. Plants with deep roots can, therefore, maintain higher photosynthetic rates during the dry season.

Rooting patterns can be observed *in situ* by soil core sampling and root extraction, soil pits, and profile walls of root distribution, but these methods are time consuming and difficult for routine screening.

Water-use efficiency. Water-use efficiency (WUE) is another important physiological characteristic of crop plants that reflects their ability to cope with drought stress. Researchers select water-use-efficient genotypes based on water extraction patterns during the dry season and at the end of the dry season.

Water extraction patterns are monitored by exposing genotypes to different depths of groundwater during the dry season.

WUE is the ratio of economic product (yield) to amount of water used by the plants:

WUE = yield/amount of water used

To calculate WUE, three different methods can be used:

- Divide the steady state CO_2 exchange rate by the transpiration rate.
- Divide dry matter accumulated by water lost through transpiration.
- Divide dry matter accumulated by water lost through evapotranspiration.

All factors that increase yield increase WUE. Similarly, cultural practices which reduce amount of water used increase WUE, for example:

- appropriate intercrop combinations
- addition of soil organic matter to increase water-holding capacity
- alleviation of poor drainage and high salinity
- deep ploughing to increase water infiltration rates and water availability

Changes in leaf posture. Leaf orientation changes in response to changes in the direction and amount of light. The leaf blade and petiole move to maximize light interception by the leaf during morning and late afternoon, when transpirational demands are low. Also, cassava leaves droop and roll during the hottest part of the day.

A combination of leaf orientation and leaf rolling during drought periods reduces transpiration and heat load, while maintaining photosynthesis. Leaf orientation and leaf rolling can be assessed visually.

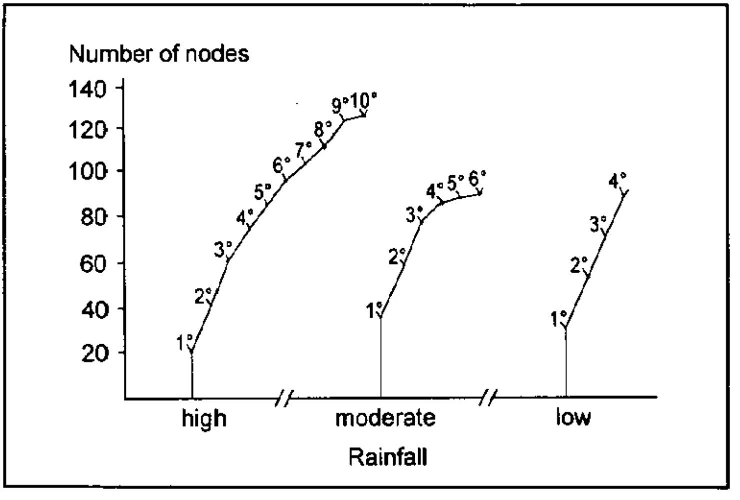
Changes in leaf growth. Several leaf growth parameters are affected by drought, and can be monitored to select for drought tolerance:

- rate of leaf area development
- rate of leaf expansion
- leaf area index
- leaf weight
- leaf abscision rate
- leaf life

Methods for measuring these parameters are described in Ekanayake (1996).

Changes in plant architecture. Plant architecture and branching habits of cassava, though primarily genetically controlled, are affected by drought. Figure 2 shows that water deficit reduces the number of branching levels and increases the number of nodes between branchings of the same cassava cultivar.

Figure 2. Cassava branching levels (1°, 2°,...) and number of nodes under different rainfall regimes.



Excess water in the root zone is called waterlogging. Waterlogging reduces the supply of oxygen to the root system. Excess water in the soil removes mineral nutrients and metabolites from the root zone by leaching. Waterlogging stress also increases susceptibility to pathogens, for example, those causing root rot.

Symptoms of waterlogging stress. Physiological and morphological symptoms of waterlogging include:

- delayed and reduced sprouting
- low plant vigor at early stages
- leaf chlorosis, epinasty, and premature leaf abscission
- decreased stem growth rate or stem hypertrophy
- adventitious root formation
- decreased root growth
- early death of fibrous roots
- decreased yield
- plant death

Biochemical symptoms of waterlogging are:

- a low yield of ATP (adenosine triphosphate), and an accumulation of toxins of anaerobic respiration, combined with rapid depletion of organic compounds
- reduced synthesis and translocation of gibberellins and cytokinins
- increased auxins in the stems
- increased CO_2 and ethylene in the stems
- reduced absorption rate in the fibrous roots
- reduced translocation of water and nutrients

Figure 3 shows physiological responses, including hormonal changes, of cassava plants to waterlogging.

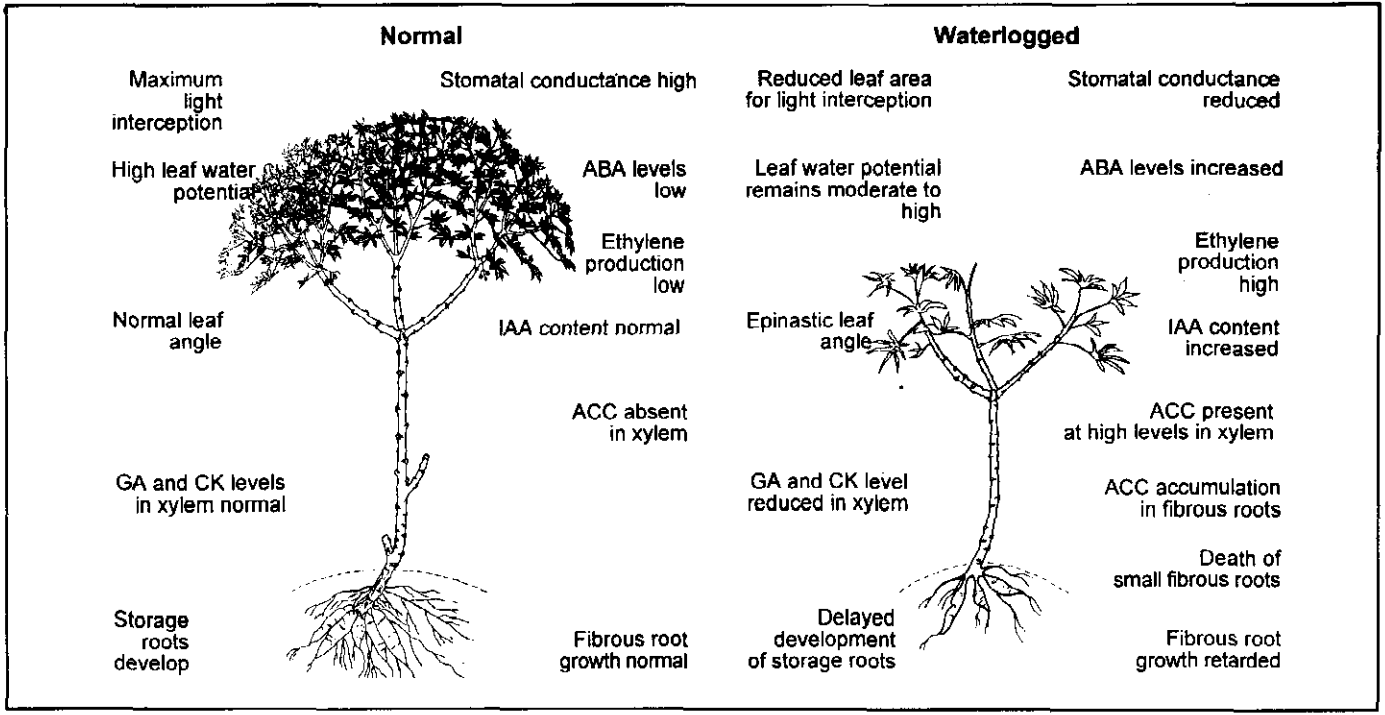


Figure 3. Physiological responses of cassava plants to waterlogging. ABA, abscisic acid; GA, gibberellic acid; CK, cytokinin; IAA, indoleacetic acid; ACC, aminocyclopropane-1-carboxylic acid (ethylene precursor).

Waterlogging resistance traits. Adaptive mechanisms to waterlogging stress mainly aim at increasing the oxygen supply of roots under waterlogged conditions.

Morphological traits indicating resistance to waterlogging include:

- development of adventitious roots
- reorientation of fibrous roots away from the wet zone of the soil
- longer and increased number of internodes

Anatomical traits include:

- intercellular space formation in the root cortex
- cell lysis to provide nutrients

Physiological traits are:

- efficient water use
- redistribution of nitrogen in leaves
- reduced growth
- leaf drop

Biochemical traits include:

- increased anaerobic respiration
- ethylene production
- lignification

Screening for resistance to waterlogging. Characteristics of waterlogging resistance are often difficult to distinguish from tolerance traits for other abiotic stress factors. For example, some areas, like inland valleys, are prone to both water excess and deficits at different times.

It is, therefore, difficult to screen for appropriate genotypes, because the plant requires mechanisms which resist both waterlogging and drought stress.

Researchers usually observe whole plant response, water relations, and photosynthetic traits, rather than specific anatomical and biochemical adaptational traits, for screening and breeding purposes.

The current screening method for waterlogging resistance of cassava at IITA is to expose genotypes to inland valley conditions in the field to determine which ones perform better, compared with sensitive genotypes (black box approach). An ideotype method of screening is being developed for screening for resistance to waterlogging.

Table 3 gives the main agronomic characteristics of some improved IITA cassava genotypes for inland valleys, and of a sensitive genotype for comparison.

Screening in the field, however, is time consuming and expensive. Also, it is affected by the varying environmental conditions from season to season and between different sites. Laboratory technology and controlled conditions reduce climatic changes, but field performance is the final test.

Table 3. Root yield, number of roots, and harvest index (root yield/total biomass) of some improved cassava genotypes, compared with a sensitive genotype, under inland valley flood conditions, 6 months after planting (Ibadan, Nigeria, 1992).

Genotype	Fresh root yield (t/ha)	No. roots/ plant	Harvest index (%)
M85/00025	15.9	5.8	50.3
63397	13.3	5.0	46.8
M84/00003	12.6	4.5	47.6
M85/00665	11.6	5.1	48.7
82/00661	11.5	4.5	58.4
M86/00080	10.7	4.1	60.4
50207	10.6	5.5	54.0
Bida local (sensitive)	9.2	4.1	50.3
LSD (0.05)	1.97	2.38	3.14

5 Temperature extremes

Temperature is a primary determinant of plant growth and yield. Temperature extremes adversely affect physiological processes and inhibit plant growth. High temperatures lead to increased transpiration and water loss, resulting in rapid wilting; low temperatures cause extrusion of intracellular water and tissue injury. Both air and soil temperature regimes are important in defining optimum growing conditions.

A tropical crop can tolerate higher temperatures than a temperate crop. Resistance to extreme temperatures is a heritable characteristic. Within a species, a wide genetic variation exists for temperature tolerance.

Low temperature stress. Low temperatures can affect crop growth at mid- and high altitudes and in the subtropics.

Morphological symptoms of low temperature stress that are easy to measure include:

- reduced germination and sprouting
- leaf wilting
- retarded shoot growth
- premature senescence
- chlorosis

Increased membrane permeability due to electrolyte leakage is a further, cytological, symptom.

Adaptational responses to low temperature stress can be morphological, physiological and biochemical.

Morphological adaptations:

- reduced leaf drying
- slow but continued growth

Physiological adaptations:

- increased calcium ion concentration in the cytosol of tolerant plants
- increased numbers of ion transporters
- increased potassium ion influx
- stomatal closure

Biochemical adaptations:

- changed composition and fluidity phase of cell membranes
- higher proportion of unsaturated fatty acids in the lipid phase
- shorter chain length, branching, sterol content, and polar head groups
- increased sugar and soluble protein (glycine, betaine, proline, and polyamines) content
- induction of cold stress proteins
- chlorophyll fluorescence maintained

In addition to direct field screening to monitor growth, development, and yield under low temperatures, there are several indirect screening methods. IITA uses 2 indirect screening methods for root crops:

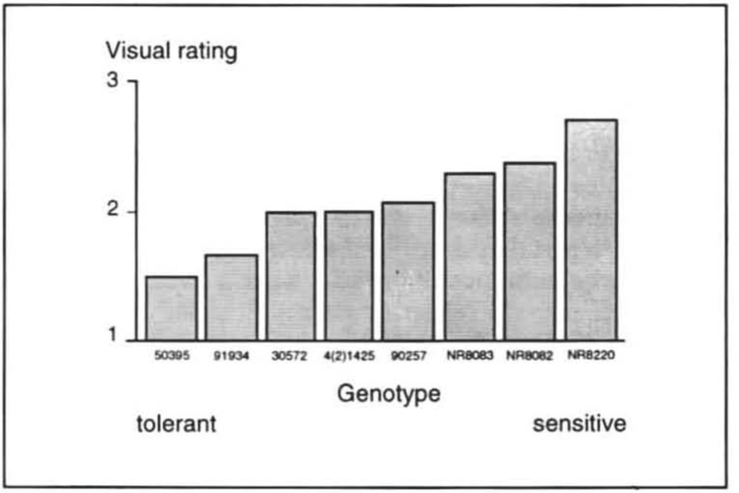
- visual scoring of leaf damage induced by low temperatures
- evaluation of membrane stability by electrolyte leakage levels

The visual rating scale used to evaluate low temperature stress in cassava leaves is as follows:

1 Normal and healthy dark green leaves
3 Leaflet edges browning, leaflet tips wilted; symptoms observed on young leaves
5 Partial leaflet (50% of the leaf area) browning; mature leaves also showing discoloration
7 Young leaves completely brownish grey; older leaves browning
9 All leaves completely dried and brownish grey; no photosynthetically active leaf area

Figure 4 shows genotypic variability for resistance to low temperatures in cassava, based on the visual rating scale for leaf damage.

Figure 4. Visual rating of leaf damage of different cassava genotypes, after exposure to low temperature (15 ± 3°C) for 4 weeks. Tolerant genotypes have lower scores.



High temperature stress. Acute exposure to high temperatures for short periods of time (minutes, hours), or chronic exposure over longer periods (days and weeks) causes stress.

Symptoms of high temperature stress can be morphological, cytological, physiological, and biochemical.

Morphological symptoms include

- chlorotic appearance of tissues
- reduction in growth
- accelerated senescence

Cytological symptoms are

- coagulation of protoplasm
- cytolysis
- nuclear changes
- altered mitosis
- inhibition of protoplasmic streaming
- increased protoplasmic viscosity (coagulation of plasma)

Physiological symptoms include

- reduction of photosynthesis and photosynthetic enzymes
- altered respiration
- depletion of respiratory substrates
- altered cytokinin activity

Biochemical symptoms include

- reduction and denaturing of proteins

- reduction in chlorophyll
- repression of normal protein and mRNA synthesis
- deficiency of chloroplast RNA
- accumulation of heat shock proteins

Adaptations to high temperatures include morphological, cytological/ biochemical, and physiological traits.

Morphological adaptations:

- less leaf wilting and yellowing
- good stay-green ability
- reduced leaf senescence
- growth maintained

Physiological adaptations:

- ability to maintain photosynthesis rates
- normal fluorescence patterns
- tolerance to dehydration
- stomatal sensitivity

Cytological/biochemical adaptations:

- membrane thermostability
- reduced electrolyte leakage
- synthesis of heat shock proteins

Indirect screening methods are used to select plants tolerant to high temperatures. Photosynthesis is reduced in heat-sensitive plants, while tolerant genotypes maintain normal levels of photosynthesis. Change in photochemical efficiency (chlorophyll *a* fluorescence) is a photosynthetic trait that is easy to measure.

6 Solar radiation extremes

Crops are sensitive to both too high and too low radiation levels. Requirements vary between different crops (Table 4). The important factors for plant growth are light intensity, duration, and quality.

Low radiation stress. Plants are exposed to low radiation stress (shading) in various intercropping and alley cropping situations, and also in high rainfall areas.

Symptoms of low radiation stress in root and tuber crops are:

- elongated petioles
- delayed time to first flowering
- fewer flowers produced
- reduced growth rate
- reduced nutrient accumulation
- delayed storage root initiation
- reduced yield
- rapid leaf senescence and abscision

Plants show morphological and physiological adaptations to low radiation.

Table 4. Solar radiation requirement ($\mu mol/m^2/s$) of some root and tuber crops.

Cassava	1400–4050
Potato	1000–3950
Sweet potato	1450–4000
Yam	1250–3900

Morphological adaptations:

- larger leaf area
- higher leaf specific weight
- earlier branching
- prolonged leaf life

Physiological adaptations:

- ability to maintain photosynthetic efficiency
- ability to maintain transpiration rates
- leaf conductance maintained
- lowered leaf resistance
- early storage root initiation

IITA uses direct field evaluation to screen for resistance to low radiation in cassava (black box method). The performance of different genotypes is compared under different total seasonal radiation. The genotypes are grown at a variety of experimental sites that have different total radiation, but with controlled growing conditions. Leaf growth parameters are then compared.

Figure 5 shows genotypic differences in leaf conductance (rate of movement of water through the stomata) under different radiation levels.

Researchers also use an indirect method, to measure radiation-use efficiency (RUE). RUE is a measure of radiation intercepted and its transfer to dry matter.

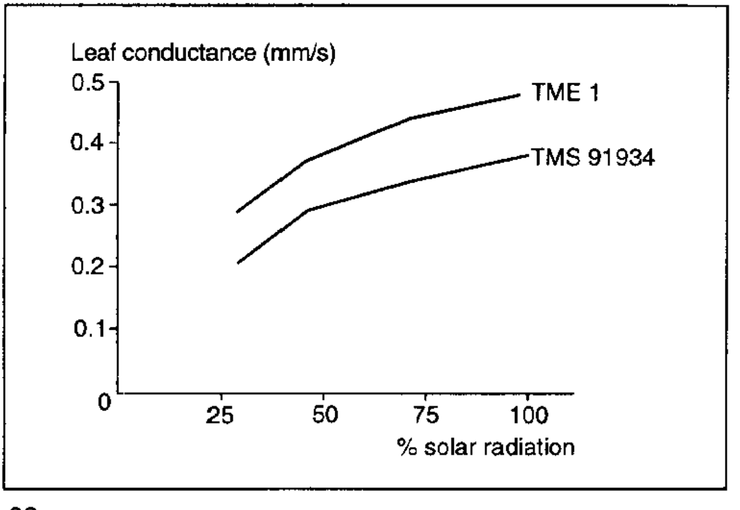
RUE = biomass production/solar radiation intercepted by the canopy

RUE values for cassava range from 1.3 to 4.2 g/MJ, depending on location, season, and genotype. More efficient transfer under low radiation (higher RUE) indicates a more resistant genotype. Compared to potato, cassava is less efficient at utilizing the available solar energy.

High radiation stress. The effects of high radiation stress on root and tuber crops have not been well investigated. Adaptational mechanisms associated with high temperature stress and drought stress are expected to assist the plants when they are exposed to short periods of high radiation.

High-intensity visible light and potentially ionizing shortwave radiation can generate superoxide radicals in the photosynthetic process, which can be damaging to the plant.

Figure 5. Effect of solar radiation level on leaf conductance of 2 cassava genotypes, 3 months after planting.



Physiological/biochemical adaptations to high radiation stress include:

- ability to remove toxic superoxide radicals
- biosynthesis of flavenoid pigments

Tolerance to high radiation stress is becoming more important as levels of ultraviolet light increase, because of atmospheric ozone depletion.

Nutrient stress results from a deficiency in the soil of an essential plant nutrient, or the presence or excess of a toxic element. Decline in total soil organic matter is often a cause of nutrient exhaustion in African farming systems, where there are few or no external inputs.

Cassava is well adapted to nutrient-poor soils. Most cassava grown in Africa is grown on Alfisols, Oxisols, and Ultisols. Oxisols are acid soils, often with high levels of exchangeable aluminum (Al), and cassava may suffer from Al toxicity.

Cassava root harvesting removes large amounts of potassium (K), so that continuous cassava cultivation, without replacement of K, can lead to K depletion in the soil and K deficiency in the cassava crop. Phosphorus (P) can be a limiting nutrient for cassava in acid soils, although fungal micorrhizal associations with the roots can improve P absorption from the soil. Nitrogen (N) can also be limiting in poor soils.

Visual symptoms of nutritional disorders in root and tuber crops, especially deficiency symptoms, are not easily recognized. Diagnosis of disorders associated with nutrient imbalances requires soil and plant tissue analyses.

Table 5 shows maximum and minimum soil nutrient levels for growing cassava, that is, levels that will prevent nutrient stress. These values can be used as a general guide to interpret soil analysis data.

The capacity of a soil to provide plant nutrients can be supplemented by the use of chemical fertilizers. However, smallholder farmers in Africa rarely use fertilizers, because of the cost.

Cultural methods for improving nutrient recycling are:

- application of organic residues
- use of live mulches
- lower tillage systems
- avoiding burning

Table 5. Soil nutrient, pH, and conductivity levels for growing cassava.

Nutrient	Minimum	Maximum	Method of analysis
Al (mEq/100 g)	2.5	–	1 N KCl
Al (sat %)	80	–	Al (Al+Ca+Mg+K)
P (ppm)	7	8	Bray 1
K (mEq/100 g)	0.09	0.15	NH_4-acetate
Ca (mEq/100 g)	0.25	–	NH_4-acetate
Na (sat %)	2.5	–	NH_4-acetate
Zn (ppm)	1.0	–	North Carolina method
Mn (ppm)	5	9	North Carolina method
SO_4^{2-} (ppm)	8	–	–
pH	4.6	7.8	1:1 soil/water
Conductivity (mmhos/cm)	0.5	0.7	Saturation Extract

Resistant genotypes (efficient nutrient users) can also help to maintain yield on nutrient-poor soils. Screening and breeding for resistance to specific soil nutrient stresses are not common for root and tuber crops. Exceptions are resistance to salinity and aluminum in sweet potatoes and cassava.

Measuring plant nutrient use. Genotypes that use nutrients efficiently grow better in nutrient-poor soils. Nutrient use, and particularly chemical fertilizer use efficiency, can be measured in 4 ways:

- agronomic efficiency
- physiological efficiency
- apparent recovery efficiency
- nutrient-use efficiency

Agronomic efficiency. Agronomic efficiency (*AE*) is the total biomass produced per unit of nutrient applied:

$$AE = \frac{Y(f) - Y(uf)}{F}$$

where $Y(f)$ = total dry matter yield of fertilized crop, $Y(uf)$ = total dry matter yield of unfertilized crop, and F = quantity of fertilizer applied.

Physiological efficiency. Physiological efficiency (*PE*) is the biological production per unit of nutrient absorbed. *PE* reflects the biological efficiency of nutrient use:

$$PE = \frac{Y(f) - Y(uf)}{U(f) - U(uf)}$$

where $U(f)$ = nutrient uptake by fertilized crop, $U(uf)$ = nutrient uptake by unfertilized crop, and $Y(f)$ and $Y(uf)$ are as defined above.

Apparent recovery efficiency. Apparent recovery efficiency (ARE) is the quantity of nutrient absorbed per unit of nutrient applied:

$$ARE = \frac{U(f) - U(uf)}{F}$$

Nutrient-use efficiency. Nutrient-use efficiency (NUE) is a combination of physiological efficiency and recovery efficiency:

$$NUE = PE \times ARE$$

Salinity stress. Soil salinity is a stress factor for root and tuber crops grown in the coastal savanna and semi-arid zones of Africa. Cassava is generally sensitive to high pH, and the associated problems of salinity, alkalinity, micronutrient deficiencies, and poor drainage. Selected saline-tolerant genotypes grow better under conditions of high salinity.

Symptoms of salinity stress in cassava include

- reduced sprouting
- retarded growth and reduced leaf area
- leaf yellowing, beginning at the top of the canopy and moving down
- necrosis of lower leaves
- reduced root-to-shoot ratio
- plant death

Adaptational responses to salinity stress can be morphological or physiological/biochemical.

Morphological adaptations:

- sprouting maintained
- slow but continued growth

Physiological/biochemical adaptations:

- decreasing tissue water content through osmotic adjustment
- salt exclusion by synthesis of organic solutes (sugars and amino acids)
- salt exclusion by increased uptake of K^+, Ca^{2+}, or NO_3^-
- salt exclusion from leaves

Screening for resistance to salinity is usually carried out in the laboratory, using hydroponic culture media or *in vitro* tissue culture media. Physiological response parameters, such as ion exclusion and leakage, are monitored, using instruments such as ion-selective electrodes and conductivity meters. Relative performance is compared in a range of saline concentrations, and the best performers at higher saline concentrations are selected.

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9 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

- Discuss with trainees about experiences and problems of abiotic stress in root and tuber crops (10 minutes).

- Introduce the content of this Research Guide, using the study materials listed on page 3 (40 minutes).

- You may photocopy the illustrations and tables of the Research Guide on transparencies for projection with an overhead projector.

- Combine presentation and discussions with the practicals suggested on page 3 (1/2 day). Have samples of normal and stressed plants and sample protocol sheets available for each trainee.

  Conduct the practicals in groups of 3–4 trainees per group. Make sure that each trainee has the opportunity to practice. Have resource persons available for each group and practical.

  Organize your practicals and demonstrations well. Keep trainees busy. Prevent trainees from scattering around field, greenhouse, or laboratory.

- Conduct an informal survey of the stress situation at farmers' fields in your area (1/2 day). Ask groups of 3–4 trainees per group to learn from farmers about their perceptions of abiotic stress. Summarize and discuss the conclusions of the groups (1 hour). See Rhoades (1996).

International Institute of Tropical Agriculture (IITA)
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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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Cover design: Chuks A. Onianwa