

UNIVERSITY OF CAPE COAST

DEVELOPMENT OF A METHODOLOGY FOR ESTIMATION OF LEAF
AREA USING THE BETA MASS ABSORPTION COEFFICIENT OF THE
LEAF

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BY

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PHILOSOPHY DEGREE IN PHYSICS.

SEPTEMBER, 2010.

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this University or elsewhere.

.....

.....

Emmanuel Kofi Amewode

Date

Supervisors Declaration

“We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.”

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Prof. J. J. Fletcher

Date

(Principal Supervisor)

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Prof. J. P. Tetteh

Date

(Co-Supervisor)

ABSTRACT

Leaf area measurement can be a time consuming process and may require sophisticated electronic instruments. The objective of this research was to develop a simple, and less time consuming method for leaf area (LA) estimation of some leaves of cassava varieties. A method based on the beta mass absorption coefficient of the leaf has been developed and used for the estimation of leaf area of three varieties of cassava and the accuracy and precision of this method has been compared with that of a standard leaf area disk method. Leaf area estimates from both methods were highly correlated. In both methods, leaf area increased with stage of growth of the cassava plants. Comparisons of leaf area disk results for Bankye botan variety, Cape vars bankye and Adehye bankye varieties, showed that leaf area for these varieties could be measured with the same accuracy using the beta mass absorption coefficient method. This relatively simple method of estimating leaf area has advantages in certain experimental situations where many samples could be measured at the same time. The work permits the conclusion that using beta mass absorption coefficient of a leaf and the mass of the leaf estimation of the leaf area could be made fairly accurately thus allowing for example the estimation of yield of the cassava plantation.

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DEDICATION

I wholeheartedly dedicate this work to my dearest late father, Mr. Cletus Kodzo Amewode and my late mother, Madam Adzo Vemegah.

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CHAPTER ONE

INTRODUCTION

Background

Cassava (*Manihot esculenta* Crantz) is a tropical tuberous root crop, not a tuber, grown across a wide area of the world between 30 degrees north and south of the Equator, originally from Brazil. The Portuguese brought it to the west coast of Africa in the 16th century, but it is generally accepted that most of the spread of cassava occurred in the 20th century because of its resilience to locusts and drought. It is a crop with considerable potential with regard to Africa's alarming food insufficiency, because of Africa's fast increasing population. The crop has a comparatively high biological efficiency of food-energy production because of its prolonged crop growth. The crop is grown in all the regions in Ghana except Upper East (MOFA, 2001). It is important therefore to incorporate cassava into our food production. Incorporation of cassava in agricultural production systems depends upon a thorough knowledge of the plant and its agronomic potential (Ramesh *et al.* 2006). Leaves represent the main photo synthetically active surface of the plant and the development of leaf area are central to plant growth development. Studies on crop growth and development often require estimation of leaf area throughout the growth cycle of crop plants by non-

destructive methods. The knowledge of leaf area is essential to evaluate vegetative growth and to estimate crop production potential (Kozłowski *et al.*, 1991), and, therefore, leaf area (LA) has been a subject of interest in different physiological studies and plant genetics. Since leaf area is related to photosynthetic efficiency, appropriate leaf area is associated with good carbohydrate metabolism, dry matter accumulation, yield and quality (Williams, 1987; Centritto *et al.*, 1999) of plant growth. Leaf area must be determined for many physiological studies, such as growth analysis, photosynthesis and transpiration measurements. Reviews of the techniques normally used for the determination of leaf area (e.g. Květ & Marshall, 1971; Coombs *et al.*, 1985) cite the leaf area meter as the usual method, although planimeters, photo gravimetric methods and area-length regressions are also mentioned by some authors (Kvêt & Marshall, 1971; Coombs *et al.*, 1985).

Leaf area is also a valuable index in identifying plant growth and development. It is related to light interception, transpiration and photosynthesis and thus considered the most important single determination of dry matter and yield in plants (Sato *et al.*, 1978; Chen *et al.*, 1995, 1998). Plants with bigger leaf area have greater light interception surface that may result in higher photosynthetic rate (Taiz and Zeiger, 2002), however higher leaf transpiration may also occur with a bigger leaf area (Villa Nova *et al.*; 1997). Leaf area measurement is an important action in experimental procedure since it allows the researcher to estimate response to applied treatments and to handle a character closely related to the plant photosynthetic

and light interception capacity, soil covering and competition among plants. Frequently, leaf area is the most responsive characteristic to be evaluated in trials such as fertilization levels, soil acidity, water supply, salt stress resistance. It is needed for calculation of leaf area index (LAI), net assimilation rate (NAR), and leaf area ratio (LAR) and can also be used to measure plant efficiency by determining the amount of edible product like root weight per 100 cm² of leaf area. These facts, among others, show that leaf area measurement is important to help in evaluating plant physiological status.

There are two main procedures for leaf area measurements. These include the direct (destructive) methods (area meter, scanners, photogrameter, tracing, etc) and the indirect (non-destructive) methods using leaf linear measures (Tavares - Junior *et al.*, 2002; Bianco *et al.*, 2003; Monteiro *et al.*, 2005). The destructive method of determining leaf area through area meter, tracing, photographing, etc to measure the leaf area of leaves attached to shoots is time consuming, tedious and requires adequate, potentially expensive equipment (Manivel and Weaver, 1974). The non-destructive methods reduce some of the experimental variability associated to destructive sampling procedures (Ne Smith, 1992), they are user friendly, less expensive and can provide accurate leaf area estimates (Norman and Camphell, 1989). The leaf area estimation methods that aim to predict leaf area nondestructively can provide researchers with many advantages in the agricultural experiments. Moreover, these kinds of methods enable researchers to carry out leaf area measurements on the same plants over the course of the study (Gamiely *et al.*,

1991; NeSmith, 1991; NeSmith, 1992). To compare time saving measurement procedure, it was found out that, the non-destructive estimation of leaf area saves time better than the geometric measurements. For this reason, several leaf area prediction models have been produced for certain plant species in the previous studies (Odabas *et al.* 2005). However, taking leaf measurements, like width or length, and calculating the area by means of an equation is the most suitable method because it is fast, simple, do not dependent on any complex device and it allows to make non destructive analysis. Several authors have proposed similar method for others species (Bianco *et al.*, 2005; Monteiro *et al.*, 2005). The method for estimating leaf area through equations works better when the measurements to be taken can be easily and correctly identified and the equation is based on only one or few measurements. The equation should estimate an area as close as possible to the real leaf area and should be stable when measuring leaves of different shapes and sizes. As a result the development of mathematical models and equations from linear leaf measurement for predicting total or individual leaf-area has been shown to be very useful in studying plant growth and development (Gower and Norman, 1991). There is still the need to develop cheaper and technically easier but sound method. Therefore, the objective of this work is to develop a simple methodology to estimate the leaf area for different cassava cultivars based on beta mass absorption coefficient of the cassava leaf.

Relevance of Technique

The estimation of leaf area using the beta mass absorption coefficient technique will complement the other methods of leaf area estimation, when fully developed. The method has an advantage of being faster and cheaper. The use of instrument like Laser Induced 3100 Area meter, are expensive, laborious and takes time. The choice of strontium-90 beta source was primarily due to availability. The beta source does not need electricity to function.

Objective of work

Although, several methods have been used for estimation of leaf area of plants, the broad objective of this project is to develop the method of estimation of leaf area based on the expression $A = \frac{\mu M}{\rho}$ where **A** is the area of the leaf sample, **μ** is the linear absorption coefficient of beta rays in the leaf, **M** is the mass of the leaf sample and **ρ** is the density of the leaf sample at various stages of their growth.

Limitations

Due to time constrain the cassava leaf samples or varieties were taken from the University of Cape Coast Research Farm since the soil is maintained under certain conditions.

Scope of work

In this work, two main methods were used; beta mass absorption coefficient and leaf disk area for the estimation of leaf area in a variety of cassava leaves at various stages of their growth. Due to time and financial constraints, three different varieties were grown and studied on the University of Cape Coast Teaching and Research Farm over a period of one year (12months).

Organization of Work

Chapter One deals with introduction. Chapter Two presents the literature review. Chapter Three deals with the materials used for the experiment and the methods employed in the acquisition of data. Chapter Four deals with results, analysis and discussions of findings made. Chapter five provides conclusion drawn and the recommendations made for further work.

CHAPTER TWO

LITERATURE REVIEW

Beta particles

They are high - energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei such as potassium-40. Beta particles are much less massive and less charged than alpha particles and interact less intensely with atoms in the materials they pass through, which gives them a longer range than alpha particles. The beta particles emitted are a form of ionizing radiation also known as beta rays. Strontium-90 is the material most commonly used to produce beta particles. The production of beta particles is termed beta decay. Beta particles are emitted by the unstable nuclei of some radioactive atoms. They consist of electrons given out when a neutron in the nucleus converts to a proton plus an electron. The electron is too energetic to remain inside the nucleus and is ejected. It continues to move through these materials until they have completely used up all the energy that they had when they left the nucleus. The beta particles are particles that can ionize materials through which they pass.

Beta Rays Interaction with Matter

In passing through matter, beta (β) particles lose energy chiefly by interaction with electrons. This interaction may lead to the dissociation of molecules or to the excitation or ionization of atoms and molecules. A large part of the energy loss of beta particles and other ions is accounted for by the kinetic energy given to the electrons removed from atoms or molecules in close collisions. This energy loss mechanism is called “electronic stopping”.

Absorption of Beta Particles

When a beta ray passes through a material, there is an electric force between it and the electrons of the atoms it passes. With each "collision" the beta particle gives up a little of its energy, sometimes stripping an electron from an atom, ionizing it. Electrons which are emitted from nuclei in radioactive decay are known as beta-minus, or simply beta particles. Some of these particles upon striking matter are scattered out of the primary beam. They lose their initial energies by different means and come to a stop, and are absorbed, but others simply penetrate through the absorbing material as shown by Figure 1.

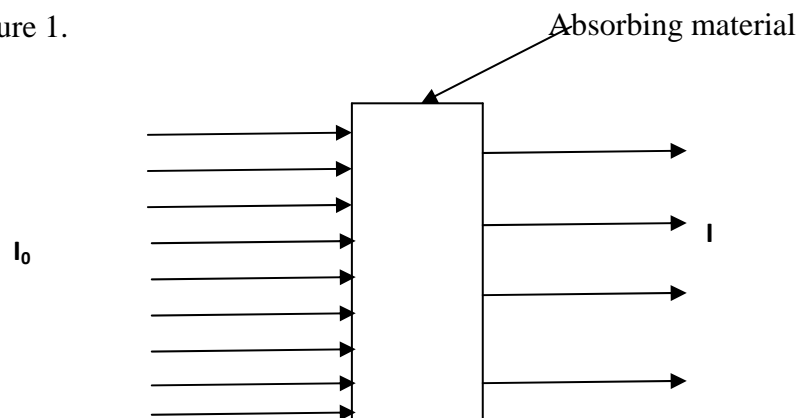


Figure 1. Absorption of electrons by target

where I_0 is the initial intensity, and I is the intensity after passing through the absorber. The electrons which come to rest generally become a part of the total electron population in the material. The absorption of electrons from a radioactive source in a material also allows in principle the extraction of the mass absorption coefficient from the measurements taken for different material thickness, using the (almost) linear part of the absorption profile (transmitted intensity versus thickness). The detailed shape of the absorption curve, however, is the result of the interplay between the continuous energy spectrum of the particular radioactive isotope being used and the straggling effects for each electron energy.

Continuous Beta Energy Spectrum

In the case of mono-energetic electrons, the capability of a material to absorb low-energy electrons is usually measured by its mass absorption coefficient μ/ρ , given by the ratio between the linear absorption coefficient μ (extracted from a fit of the data over a semi-log scale) and the density ρ of the material. For radioactive sources, which exhibit a continuous energy spectrum of the emitted electrons, no simple relation exists for the range, and only a parameterization of the results, expressed in terms of the end-point energy of the source, may be derived from the data (Ram *et al*, 1982). Even the evaluation of the linear absorption coefficient from a single set of data is questionable due to the complex nature of the absorption profile for a given material. For instance, in (Ram *et al*, 1982), such a fit was carried out on the linear part (in a semi-log scale) of the absorption profile, after excluding the

first part of the data set (small thickness values). However, there may be some ambiguity on how to define the relevant part of the data over which the fit has to be done. While the shape of the absorption curve may be represented in a crude approximation by an exponential, especially for large values of the absorber thickness, the detailed dependence of the count rate upon the absorber thickness is complicated by the interplay between the continuous electron energy spectrum (where two components, with different end-points, are present) and the absorption properties for mono-energetic electrons in a material. Additional effects arising from all possible interactions and scattering of the electrons in the traversed material may also contribute to determine the overall fraction of electrons which are able to reach the Geiger counter. Figure 2 shows the energy spectrum of the emitted electrons. As shown below, such a spectrum exhibits two components, one with an endpoint of 0.546 MeV, the other extending up to 2.25 MeV

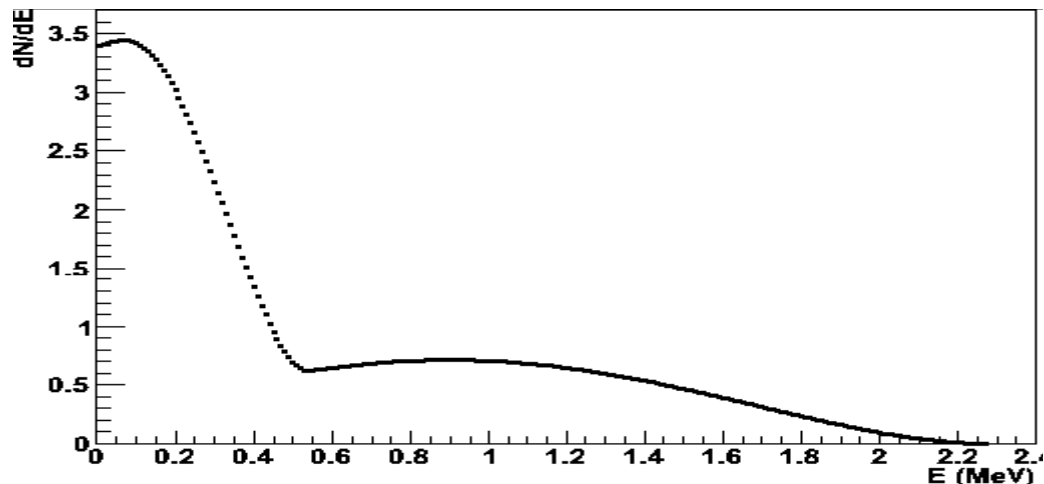


Figure 2. Energy spectrum of the electrons emitted from the $^{90}\text{Sr}/^{90}\text{Y}$ source (Burek and Chocyk, 1996)

Properties and Characteristics of beta ray

The exponential law of absorption holds approximately for nuclear beta-rays. Over a limited region the intensity of the beam is given by (Arya, 1966).

$$I = I_0 e^{-ux} = I = I_0 e^{-u(\rho t)/\rho} \quad [1]$$

$$I = I_0 e^{-zx} \quad [2]$$

where $x = \rho t$, and z which represent μ/ρ is an apparent mass absorption coefficient in cm^2/mg . Since zx is unit less, x is in the units of mg/cm^2 . The absorber “thickness,” x can be thought of as the number of grams of “thickness,” per square centimetre area of the material. That is, for one square centimetre of area, x is the number of grams of the substance that the beta particles travel through. Materials with a high density will have a large α (lots of electrons) for a small thickness (Lee, 1999). I_0 is the initial intensity, and I is the intensity after passing through a thickness α of the absorber.

The ratio of the absorption coefficient μ to the density is nearly independent of the nature of the absorber. More accurately it varies about as Z/A (Z = atomic number and A = atomic mass of absorber); that is the number of electrons per unit mass determines the stopping power of a substance for beta particles. The thickness required to reduce the activity to one- half of its initial value is called the half-thickness which is equal $0.693/\mu$ (Kennedy, 1956).

Range of beta particles

The thickness, at which the absorption intersects the background count caused by gamma rays accompanying the decay of the nucleus and cosmic rays, is called the range R_p , of the beta particles. There is a considerable difference in the shapes of the absorption curves for the case of nuclear beta particles (electrons that are produced by nuclear decay and have a continuous energy spectrum) and the homogeneous electron (that are produced artificially or by conversion). The nuclear beta particles do not have a linear region in the absorption curve, while the homogeneous electrons' absorption curves have a long straight portion and a long tail going into the background.

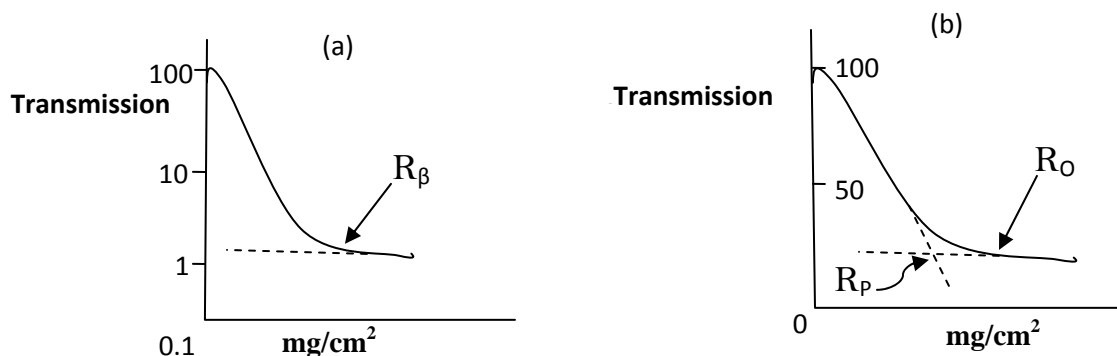


Figure 3. Ranges of (a) nuclear beta particle, and (b) homogeneous beta

In Fig. 3a, R_β is the range of the nuclear beta particles as defined above from fig. 3b, the range of the homogeneous beta particle is defined as the point where the extension of the straight portion meets the background and is called the practical range, R_p , the point where the curve itself meets the background is called the maximum range.

Electrons differ from alpha-particles and other heavy particles in that they are not characterized by straight-line paths and definite ranges. Rather, electron paths are quite fortuitous, and the ranges of monoenergetic electrons vary greatly. The crooked paths are due to the multiple scattering with atoms along the path. Electrons lose energy to the absorber, just as heavy particles do (Prince, 1964). However, for electrons there is another important mechanism for the loss of energy; this is through emission of electromagnetic radiation when the electron is decelerated. This radiation is often referred to as bremsstrahlung.

Range –Energy Relations

The range of beta particles in any medium is a function of the beta particle energy and of the density of the medium. Once the range of beta particles is known, a range-energy relation can be used to deduce the maximum energy. An empirical relation between the range (in g/cm^2 of aluminium) and energy (in MeV) of electrons of energies have been proposed. One given by Feather for energies above 0.6 MeV has been most widely used:

$$R = 0.54 \left(\frac{g}{cm^2} / MeV \right) E_{max} - 0.160 \left(\frac{g}{cm^2} \right) \quad [3]$$

for $0.01 \leq E \leq 2.5 MeV$

where E is the maximum beta energy in MeV and R is the range in aluminum in g/cm^2 . This equation holds for energies greater than 0.6 MeV with the

sample. We will assume the equation to be equally valid for leaves. Since the strontium -90 source has two energies.

$$I = I_0 e^{\frac{-0.693x}{x_{0.5}}} \quad [4]$$

Or

$$\log I = \log I_0 e^{\frac{-0.693x}{x_{0.5}}}$$

Where I_0 and I represent the net simple activity with no absorber and with absorber of thickness x , respectively and $x_{0.5}$ is the absorber “half-thickness” required to decrease the intensity by a factor of 2.

As already mentioned, scattering of electrons, both by nuclei and by electrons; is much more pronounced than scattering of heavy particles. A significant fraction of the number of electrons striking a piece of material may be reflected as a result of single and multiple scattering processes (America Society for Non-destructive Testing, 1988).

When a beta (β) particle has slowed to the point that its velocity is comparable to valence electron velocities of the medium in which it is travelling, another interaction mechanism, called “nuclear stopping” takes over. The particle starts making elastic collisions with the atoms rather than exciting the atomic electron (America Society for Non-destructive Testing, 1985).

Stopping Power

There are several ways of describing the net effects of charged-particle interactions, the rate of energy loss along the particle's path, $-\frac{dE}{dx}$, being most important. Here E is the particle's energy and x is the distance travelled. This rate of energy loss with distance travelled depends on the material and is called the linear stopping power, of the material (Niels Bohr, 1913):

$$S_l = -\frac{dE}{dx} \quad [5]$$

A common unit for linear stopping power is $\text{MeV}\cdot\text{m}^{-1}$. In general the stopping power will vary as the particle loses energy so it depends on the charged particle's energy. The linear stopping power of a material also depends on the density of electrons within the material (and hence on the atomic numbers of the atoms) as well as the energy of the particle. So a more fundamental way of describing the rate of energy loss is to specify the rate in terms of the density thickness, rather than the geometrical length of the path. Density thickness is expressed as $t_d = t_l \times \rho$

Mean free path

Mean free path is the average distance that a beta radiation can travel in an attenuator without having any kind of interaction. This is analogous to the 'mean life' in radioactive decay process. The mean free path is the reciprocal of the linear attenuation coefficient ($\mu^{-1}\text{cm}$). The attenuator thickness may be

expressed in units of mean free path. Here a thickness x may be expressed as μx which is dimensionless ($\mu x = \text{cm}^{-1} \times \text{cm}$)

Atomic Number (Z)

Atomic number is essentially a characteristic of the atom and has a value that is unique to each chemical element. Many materials, such as human tissue, are not a single chemical element, but a conglomerate of compound and mixtures.

Effective Atomic Number (Z_{eq})

Effective atomic number (Z_{eq}) is a term that is similar to atomic number but is used for compounds (H₂O, CaCO₃, C₆H₁₂O₆, etc.) and mixtures of different materials. The idea of the “effective” or average atomic number is to assume that a mixture or a compound can for special purposes be regarded as being built up of one kind of particle called “atoms” with atomic number (Z_{eq}).

The concept of effective atomic number (Z_{eq}) dependence of beta interaction has many applications in radiation studies and other fields involving radiation transport through materials. The effective atomic number has proved to be a convenient parameter for interpreting the beta-ray attenuation by a given medium. A compound or a mixture may be considered as a single element with an effective atomic number Z_{eq} given by

$$Z_{eq} = (\sum_i \sigma_i Z_i^{n-1})^{\frac{1}{n-1}} \quad [6]$$

where Z_i is the atomic number, index n depends on the particular interaction process being considered and σ_i is the fractional content by weight of the i th element in the absorber combination.

To characterize beta interactions, different effective atomic numbers have to be used for different individual processes over an extended energy range. The exponents need not only vary with energy, but also become different at a given energy as the elemental composition changes. In view of the extensive use of the radioactive sources in medicine, agriculture, industry etc., the study of beta (absorption coefficients) in different materials has gained importance in recent years. Since these interactions involve various compounds with different compositions, the effective atomic numbers (Z_{eq}) for the total beta-ray interactions in compounds are equally important. A number of investigations on effective atomic numbers for total beta interactions have been reported in the literature. These include both theoretical and experimental studies covering a range of beta energies from 0.02MeV up to 2.27MeV (Slack and Way, 1959).

Calculation of effective atomic number (Z_{eq}) of leaf

Living systems are open self-organizing systems that have the special characteristics of life and interact with their environment. This takes place by means of information and material-energy exchanges (Parent, 1996). Living

system contain “critical subsystems”, which are defined by their functions and visible in numerous systems, from simple cells to organisms (brain, heart, liver, root, leaf, etc.). Living systems are made of different major chemical compounds. The four major chemical compounds of living systems are carbohydrates ($C_6H_{12}O_6$), lipids ($CH_3(CH_2)_{10}COOH$), proteins ($C_2H_5NO_2$) and nucleic acids. Molecules of these compounds are composed mostly of atoms from the four major elements, which are carbon (C), hydrogen (H), oxygen (O) and nitrogen (N), plus some additional elements, such as phosphorus (P), sulfur (S), iron (Fe), magnesium (Mg), sodium (Na), chlorine (Cl), potassium (K), iodine (I) and calcium (Ca). Since we are concerned about plant leaves, the effective atomic number of the leaf is the effective atomic number derived from the compounds namely carbohydrates, lipids, proteins and some of the elements like phosphorus (P), sulfur (S), (manganese (Mn), chlorine (Cl), and potassium (K), that constitutes the leaf component. This value was based on the various structures which contributes as much as 95 percent of natural leaf. The formula for calculating the effective atomic number (Z_{eq}) of leaf by (Singh. *et al*, 2007)

$$Z_{eq} = \sqrt[n]{\sum_i a_i Z_i^n} \quad [7]$$

$$a_i = \frac{N}{\sum N}$$

and

$$N = N_A \frac{Z}{A} \quad [8]$$

or

$$N = N_A w_i \left(\frac{Z_i}{A_i} \right)$$

where w_i is the fraction by weight of the element, N_A is the Avogadro's number, Z_i is the atomic number of the element, a_i is the electron fraction of the i^{th} element and A_i is the atomic weight of, $n=3.5$. Below are the Tables for the Chemical compounds and the elements that constitute the leaf.

Table 1: Chemical compounds and effective atomic number of leaf

Compound	Chemical formula	Effective Atomic Number (Zeq)
Protein	$C_2H_5NO_2$	6.97
Lipids	$CH_3(CH_2)_{10}COOH$	6.06
Carbohydrate	$C_6H_{12}O_6$	6.97

Table 2: Major elements and their atomic numbers found in leaves

Element	Symbol	Atomic number (Z)
Potassium	K	19.0
Phosphorus	P	15.0
Sulphur	S	16.0
Chlorine	Cl	17.0
Manganese	Mn	25.0

To calculate the effective atomic number of the cassava leaf we used equations 11, 12, 13, and 14. See appendix A.

Compound Material

As the materials are composed of various elements, it is assumed that the contribution of each element of the compound to total electrons interaction is additive, yielding the well-known 'mixture rule' (Deslattes, 1969) that represents the mass attenuation coefficient (α/ρ) of any compound as the sum of the appropriately weighted proportions of the individual atoms. Thus,

$$(\alpha / \rho)_{compound} = \sum w_i (\alpha / \rho)_i \quad [9]$$

Where w_i is the weight fraction of element i , (α/ρ) is the mass attenuation coefficient for the compound, ρ is the density of the leaf and $(\alpha/\rho)_i$ is the

mass attenuation coefficient for the individual elements in the compound (Cullity, 1977).

The radiation intensity decreases exponentially, depending on linear absorption coefficient, as its penetration distance increases. The linear absorption coefficient also changes according to effective energy of radiation and chemical composition of test material (Cullity, 1977). For radiation incident on unit area of detector, the intensity decreases inversely as the square of the distance from the source. When the experiment is performed, the detector may record primary as well as some scattered beta ray. In conditions of good geometry a narrow beam was used. The factor by which the total value of the quantity being assessed at the point of interest exceeds the value associated with only primary radiation. The total value includes secondary radiations especially scattered radiation.

Mass Attenuation Coefficient

The mass attenuation coefficient is basic quantities required in determining the penetration of rays in matter and also to describe the total reduction of radiations at a detector due to both energy absorption and scattering. The intensity of radiations reaching a detector decreases as the mass attenuation coefficient increases for the same absorber thickness and beta energy. The mass attenuation coefficient tends to increase with increasing atomic number at the same beta energy, so materials with high atomic numbers (and, hence, high mass attenuation coefficients) are normally chosen to shield radiation.

Values of the mass attenuation coefficient as a function of energy are provided for a large number of elements and common shielding materials. The mass attenuation coefficients are also widely used in the calculation of photon penetration and energy deposition in biological, shielding and other dosimetric materials (Davisson and Evans, 1951). In Figure 4, an example of the mass attenuation coefficient for a number of materials is given. The trend of the different material is similar. The discontinuities in the attenuation curves reflect transitions in electron energy levels which are strongly element specific. At energies around 1 MeV the attenuation factors of different materials are more or less the same.

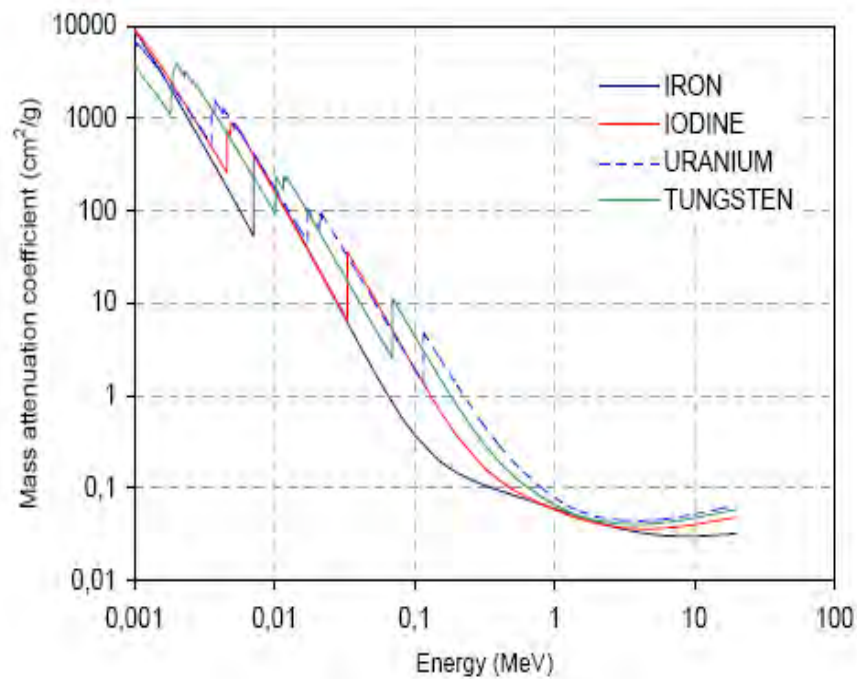


Figure 4. Mass attenuation coefficient μ/ρ of different materials as a function of energy

The figures show that for the different elements the energy dependence of mass attenuation coefficients (μ/ρ) is similar. Around 1MeV the value for mass attenuation coefficients (μ/ρ) is approximately 0.1 cm²/g. Mass attenuation coefficients are independent of the physical state of the attenuator. Because it is possible to express various interactions in terms of cross section per atom, we may obtain the mass attenuation coefficient by multiplying those quantities by the number of atoms per cm³ of the given substance.

Application of Mass Attenuation Coefficients

The measurement of mass attenuation coefficients of radiations in biological and other materials is of significant interest in industrial, biological, agricultural and medical applications. Accurate values of mass attenuation coefficients are needed to establish the region of validity of theory-based parameterization, in addition to providing essential data in such diverse fields such radiation biophysics.

Density

Density, an intrinsic physical property of matter, is the ratio of object's mass to its volume. When combined with other distinguishing characteristics (such as colour, melting point, boiling point, etc.) density is useful in identifying substances.

Mass and volume measurements are required to calculate density. Mass can be determined precisely using chemical and analytical balance. Volume can be measured by many different methods, each with its own

degree of precision. Density allows one to know the dimension of every substance be it a regular or irregular object.

Mass

Mass of a body is a physical quantity which measures body's inertia in translational motion. Inertia is a property of body to maintain its state of motion or rest if no external force acts on it or external forces compensate each other. Mass is one of basic properties, it depends on the size of the body and properties of matter, which the body consists of. Mass can characterize not only inert properties of matter but also its gravitational ability to attract other bodies. The magnitude of mass can be found using different manifestations of it (inertia, gravitational interaction), by comparison with mass of standard body, by convention taken as unit. In International System of units (SI) a kilogram is the unit of mass (1 kg). Mass of body, as a rule, is determined by weighing on scales. We calculate the mean value of mass by formula:

$$m = \frac{1}{n} \sum_{i=1}^n m_i \quad [10]$$

where m_i is the quantity of element i in the body and m is the mean value of mass.

Methods of Measuring Density

Mass and volume measurements are required to calculate density. Mass can be determined precisely using an analytical balance. Volume can be measured by many different methods, each with its own degree of precision. For irregular shapes, volume can be determined by water displacement. With this method volumes of liquids such as water can be readily measured in a graduated cylinder. To use the water displacement method, an object is inserted into a graduated cylinder partially filled with water. The object's volume occupies space, displacing liquid and raising the water level. The difference between the two volumes, before and after the object was inserted, is the object's volume.

$$V_{leaf} = V_{water+leaf} - V_{water} \quad [11]$$

Water displacement by a submerged solid can be used in a slightly different and potentially more precise way to find the solid's volume.

Geometry Method

A plastic tube of diameter 2.8 cm was used to cut equal portion of the detached middle leaflet of the fourth trifoliate leaf from cassava leaves of the three varieties of cassava. The mass of leaf samples weighed with Chyo JK-200 electronic was the accuracy of the balanced correct for the work. This was done according to the number of lobes each variety of leaf per plant had. The thickness of each leaf portion taken or cut was measured using a

micrometer screw gauge accurate to 0.01mm. Hence the relation below was used to calculate the density.

$$\text{Density}(\rho) = \frac{\text{mass}}{\text{volume}} = \frac{m}{v} = \frac{4m}{\pi d^2 t} \quad [12]$$

Where m= average masses, d= diameter of the tube t= average thickness and v= average volume

Water Displacement Method

The average mass of circular fresh leaves (2.8cm in diameter) was determined precisely using a digital Chyo, JK-200 chemical balance. A 500ml volumetric cylinder graduated in 5ml intervals was filled with distilled water up to 35ml mark. The piece of circular leaf which has been cut to a diameter of 2.8cm was then placed into the volumetric cylinder. The leaf's volume occupies space, displacing liquid and raising the water level. The difference between the two volumes before and after the leaf had been placed into the volumetric cylinder was the leaf volume.

The density was then calculated using the equation below;

$$\rho = \frac{m}{v} \quad [13]$$

where m is the average fresh mass of the circular leaf and v= the average volume of fresh leaf.

Pycnometry

Pycnometry is a technique that uses the density relationship between volume and mass, and the vessel used is called a pycnometer. To perform pycnometry measurements, the mass of the object and the mass of a flask filled with water to a mark is recorded. The object is then inserted into the flask. The volume of water displaced by the object's volume is removed by pipette; thereby restoring the water level to its original mark. The combined mass of flask, and remaining water, and objects is then measured.

$$Mass_A + Mass_o = Mass_B + Mass_{WD} \quad [14]$$

Where

$Mass_{WD}$ = the mass of water displaced

$Mass_A$ = the mass of water and flask

$Mass_B$ = the combined mass of flask, remaining water, and objects.

$Mass_O$ = the mass of object whose density is to be determined

With this, the mass of the displaced water could be determined using the above equation and the volume of displaced water using the density equation:

$$V = m/\rho. \quad [15]$$

The object's volume is equal to the displaced water's volume. From this the density of the object is determined.

Determination of Linear Absorption Coefficient

A plastic tube of diameter 2.8 cm was used to cut equal portion of the detached middle leaflet of the fourth trifoliate leaf from cassava leaves of the three varieties of cassava. The mass of each disc of leaf lamina was taken by using the Chyo JK-200 electronic balances accurate to 0.1 mg. Each fresh leaf weighed (disc of leaf lamina) was placed between a source of beta particle (strontium-90) and a detector which is connected to scaler. The intensities were measured by the amount of ionization which the beta rays produced after passing through the different thickness of absorbing sample. The data was represented on a semi-logarithmic graph with log of intensities against thickness. A straight line of slope is indicated as μ (linear absorption coefficient). The averaged of linear absorption coefficient was used as the result of the two energies emitted by the beta source (strontium-90) during the experiment.

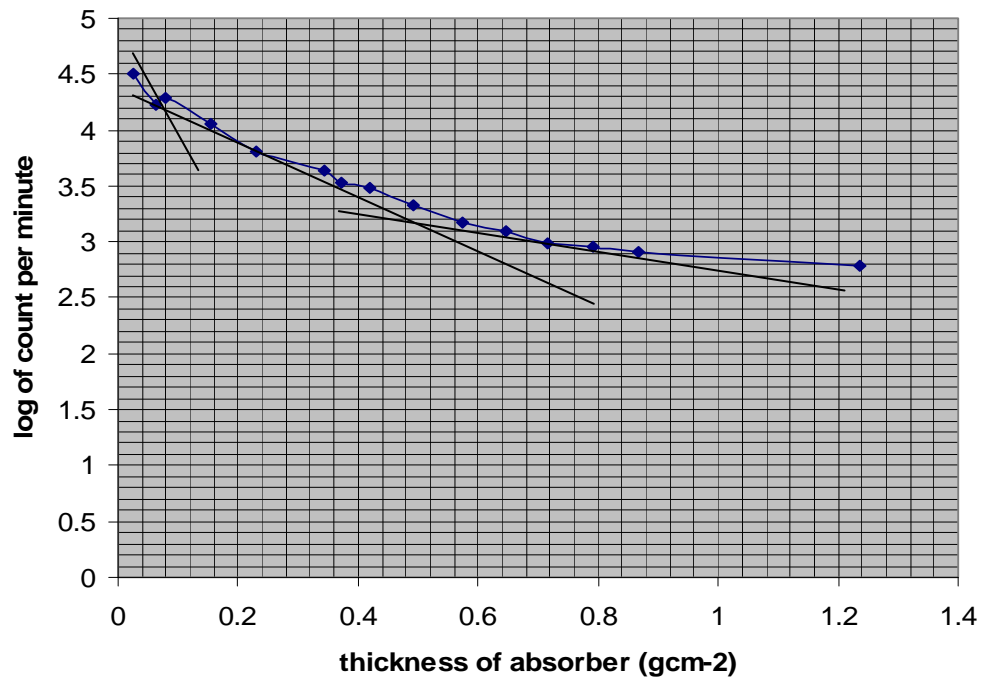


Figure 5. Characteristic curve for linear absorption coefficient of beta ray in thickness of cassava leaf

Geiger-Muller Tube

A Geiger counter (Geiger-Muller tube) is a device used for the detection and measurement of all types of radiation: alpha, beta and gamma radiation. Basically it consists of a pair of electrodes surrounded by a gas. The electrodes have a high voltage across them. The gas used is usually Helium or Argon. When radiation enters the tube, it can ionize the gas. The ions (and electrons) are attracted to the electrodes and an electric current is produced. A scaler counts the current pulses, and one obtains a "count" whenever radiation ionizes the gas. A Geiger counter (Geiger-Muller tube) consists of two parts, the tube and the (counter + power supply). The Geiger-Muller tube is usually

cylindrical, with a wire down the center. The (counter + power supply) have voltage controls and timer options. A high voltage is established across the cylinder and the wire. A Geiger counter is usually operated in the ‘plateau’ region, i.e. with an applied voltage which minimizes the variations in the output signal amplitude (hence in the number of registered counts) as a function of the voltage. The plateau curve was measured for the counter employed in registering the counts due to the presence of the radioactive source, placed at a fixed distance from the detector, for increasing values of the bias voltage. A value of 400 V was then chosen, roughly corresponding to the centre of the plateau curve. Figure 5 shows the Geiger count rate from the $^{90}\text{Sr}/^{90}\text{Y}$ source, as a function of the traversed thickness, for different materials.

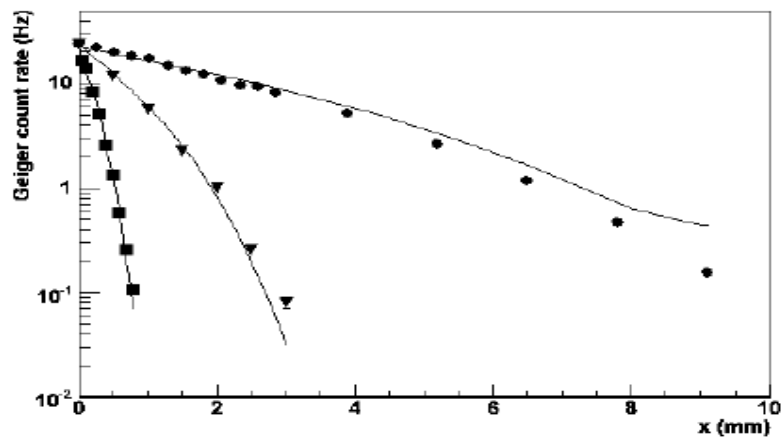


Figure 6. Geiger count rate from the $^{90}\text{Sr}/^{90}\text{Y}$ source, as a function of the traversed thickness, for different materials (from left to right: brass, squares; Al, triangles; cardboard, dots) (Burek and Chocyk, 1996)

Efficiency of the Geiger- Muller Counter

The efficiency of a detector is given by the ratio of the number of particles of radiation detected over the number of particles of radiation emitted. This definition for the efficiency of a detector is also used for our other detectors. If an efficiency of our Geiger counter system is found that it is quite small, then the reason is that the gas is used to absorb the energy. A gas is not very dense, so most of the radiation passes right through the tube. Unless alpha particles are very energetic, they will be absorbed in the cylinder that encloses the gas and never even make it into the Geiger Muller tube. If beta particles enter the tube they have the best chance to cause ionization. Gamma particles themselves have a very small chance of ionizing the gas in the tube. So although the Geiger counter can detect all three types of radiation, it is most efficient for beta particles and not very efficient for gamma particles.

Leaf thickness

The determination of leaf thickness is not straightforward due to the wide variation in leaf morphology (e.g., presence of specialized structure on leaf surface like hair and spine or protruding veins.). The difference in thickness within individual leaves and the fact that thickness is relatively a small dimension ($< 100\mu\text{m}$ in terrestrially plant) make it difficult and time consuming to measure accurately (Sims *et al*; 1998, Garnier *et al*; 1999). Hence it's therefore imperative to estimate leaf thickness from other leaf traits

which are relatively easy to measure: specific leaf area, leaf dry matter content and leaf density (Atkin *et al*; 1996, Wright and Westoby 2002).

The thickness of the sample was determined with the help of micrometer screw gauge up to a fraction of a millimeter. The measuring of the thickness was repeated a number of times to obtain consistent values of the thickness.

Mass of leaf disc

A leaf punch with a diameter of 2.8 cm was then used to collect a disc of leaf lamina. The mass of leaf disc was determined immediately using electronic balances accurate to 0.1 mg.

General Information on Strontium -90 Source

Radioactive Sr-90, like many other radio nuclides, was discovered in the 1940s in nuclear experiments connected to the development of the atomic bomb. Strontium-90 emits a beta particle with, no gamma radiation, as it decays, it releases radiation and forms yttrium-90 (also a beta-emitter), which in turn decays to stable zirconium. The half-life of Sr-90 is 29.1 years, and that of Yttrium-90 is 64 hours. Sr-90 emits moderate energy beta particles, of 0.546MeV and Yttrium-90 emits very strong (energetic) beta particles of 2.27MeV. Due to the half-lives of the two isotopes, a secular equilibrium between the two decay processes is reached, with a continuous beta spectrum, which extends up to 2.3 MeV and has two components associated with the

two isotopes. The range of strontium-90 and its daughter yttrium-90 in air is 185 cm and 1020 cm respectively. In water, the ranges are 1.8 mm and 11mm respectively. More also, the range of Sr-90 in cassava leaf is 6.9mm and that of yttrium is 9.1mm.

Leaf area Determination Techniques

After leaf collection, leaf area can be calculated by means of leaf area meter, tracing, planimetric, laser induced 3100 area meter, gravimetric and xeroxing, techniques (Daughtry, 1990).

Leaf Area meter Technique

The leaf area meter method utilizes an electronic method of rectangular approximation to measure leaf area on both detached and intact plants. The leaf area meter measure the leaf area by passing the scanning head over the leaf, and then logging the value by the readout console. Most leaf area meter systems use readout console with LI-3050 Transparent Belt Conveyer Accessory, or LI- 3100Area meter. The readout console in some cases, measure small objects and leaves that have been detached from the plant.

Principle of Leaf Area Meter

A new, portable, automatic apparatus for measuring leaf area is described. It is a digital, photoelectric type, with semi-automatic feeding mechanism. Its principle of operation is based on counting the number of

basic pulses passing through agate circuit whose operation, in turn, is controlled by other electric pulses derived from scanning of sample leaves by a flying light spot of unit area, as the leaves are conveyed on a transparent belt at a constant speed. Its performance is quite satisfactory, is it with an error of + 1.5 per cent of the measured value, with sensitivity of 0.04 square centimetre, and with a speed of more than 1.2 square meters per hour, being capable of handling very small pieces of material in succession.

Tracing Technique

The contour of a leaf is drawn on graph and its area measured by counting the square or dots within the leaf (Kvet and Marshall, 1971). Photocopies of leaves could also be used. Alternatively the leaf outline may be cut out, weighed, and area calculated based on an area to weight ratio for the paper. This is one of the earliest methods for determining leaf area and has been used extensively to calibrate all other methods. The efficiency of this method is low, that is much time is required to determine the area of each leaf. It is also poorly suited for crinkled or small compound leaves. Errors for measuring leaf area are typically less than 1%.

Planimetric Technique

The planimetric technique is based on the principle of the correlation between the individual leaf area and the number of area units covered by that leaf in a horizontal plane (Daughtry, 1990). To do so, a leaf can be

horizontally fixed to a flat surface, its perimeter can be measured with a planimeter, and its area can be computed from this perimeter assessment. There are different planimeter types for this purpose. A first type is the scanning planimeter (e.g. Li-3000, Licor, Nebraska) that uses an electronic method of rectangular approximation. The area of the leaf is measured as the leaf is drawn through the scanning head. The scanning head can be combined with a transparent belt conveyer with constant speed in order to measure large numbers of detached leaves. Other scanning planimeters (e.g. Li-3100, Licor, Nebraska) make use of a fluorescent light source and a solid-state scanning camera to sense the area of leaves as they move through the instrument. A portable scanning planimeter, CI-201 (Delta-T devices, Cambridge) uses a bar code reader to encode leaf length as the sensor moves along the leaf. Leaf width is measured by light reflected from the leaf to the detectors. The Ci-251 conveyer image analyser (Delta-T devices, Cambridge) has a very high spatial resolution and is able to store and transfer images to a computer for additional analyses. A second type of planimeter is the video image analysis system, consisting of a video camera, a frame digitiser, a monitor, and a computer with appropriate software to analyse the data. An example is the Decagon Ag Vision System (Decagon devices, Inc, Pullman, USA) that can provide areas, sizes, shapes, and number of leaves. An image of the flattened leaves is digitised, enhanced and analysed to discriminate the leaves from the background. The planimeter combines an easy to use, microprocessor controlled readout console with the proven scanning technology to measure

leaf area. The leaves are rapidly measured by placing the leaves on a transparent belt and allowing the leaves to roll over the belt. An adjustable press rolled flattens the leaves and feeds the leaves properly between the transparent belts, which in turn display the output on a screen as the area of the leaf.

Laser Induced 3100 Area meter

Laser Induced 3100 Leaf area meter precise measurements of both large and small objects, capability for 1mm^2 area resolutions is provided on the instrument. Samples are rapidly measured by placing them to pass through the instrument. An adjustable press roller flattens the curled leaves and feeds them properly between the transparent belts. The readout is then displaced and the value is recorded.

Gravimetric Technique

The gravimetric method correlates dry weight of leaves and leaf area using predetermined green-leaf-area-to-dry-weight ratios (leaf mass per area,). Leaf mass per area is determined from a sub sample extracted from the global field sample. After green leaf area determination using of one of the above-cited planimetric methods, the sub-sample is dried in an oven at a particular temperature until a constant weight is reached. The dry weight is subsequently determined using a precision balance and leaf mass per area is determined. Once the leaf mass per area is known, the entire field sample is oven-dried

and leaf area is calculated from its dry-weight and the subsample leaf mass per area.

Xeroxing

These were by taking leaf disk samples from the apex, middle and base of the leaves, and a method correlating leaf area with linear measurements, e.g. the square of the average length of the lobes, what is termed restricted leaf area and the square of the length of the central lobe. The last method, correlating the square of the length of the central lobe, was considered the most efficient due to its accuracy and ease of application.

Leaf Area Development

Leaf area development is an important factor in crop production because it affects the amount of radiation intercepted and, therefore, plant growth. The analyses of crop growth and yield are usually evaluated on the basis of three parameters; leaves area index (LAI), i.e. leaf area per unit ground area, and net assimilation rate (NAR), i.e. the rate of DM production per unit leaf area and leaf area ratio (LAR) and can also be used to measure plant efficiency by determining the amount of edible product, e.g. root weight per 100 cm² of leaf area.

In cassava a positive correlation between the leaf area or leaf area duration and yield of storage roots has been reported, indicating that leaf area

is crucial in determining crop growth rate and the storage bulking rate of cassava (Sinha and Nair, 1971; Cock *et al.*, 1979).

For cassava the leaf area per plant depends on the number of active apices (branching pattern), the number for leaves formed/apex, leaf size and leaf life. Given that there are significant varietal variations and influence of environmental conditions (Veltkamp, 1985 a), it is important to characterize the development of cassava leaf area and its components.

Here are some of parameters related to leaf growth that have been found in cassava. These parameters are discussed below.

After leaf emergence (folded, 1cm long) and under normal conditions, the cassava leaf reaches its full size on days 10 -12. Leaf life (from emergence to abscission) depends on cultivar, shade level, water deficit and temperature (Cock *et al.* 1979; Irikura *et al.*, 1979). It ranges from 40 to 120 days (Cock, 1984).

There are marked differences in leaf size among the different cultivars, and the size varies with the age of the plant. Maximum total leaf area is reached from 4 to 5 months after planting (MAP) (Cock *et al.*, 1979; Irikura *et al.*, 1979). Leaf size is influenced by changing the branching pattern.

Larger leaves are produced when the number of active apices is reduced (Tan and Cock, 1979). The rate of leaf formation decreases with plant age and is lower at low temperatures. (Irikura *et al.*, 1979).

Differences in mean LAI are closely related to the rate of root bulking. The optimal LAI for storage root bulking rate is 3 – 3.5 (Cock *et al.*, 1979) and exists over a wide range of temperature (Irikura *et al.*, 1979). Initial leaf area development is slow, taking 60 – 80 day after plants (DAP) before an LAI of 1.0 is reached. From 120 to 150 DAP the light interception by the canopy is around 90% with an LAI of 3 (Veltkamp, 1985). In order to obtain high storage root yields, the crop should reach an LAI of 3 -3.5 as quickly as possible (Cock *et al.*, 1979; Veltkamp, 1985) substantial leaf abscission began at LAI values of 5.0 – 6.0 (Keating *et al.*, 1982).

Importance of leaf area measurement

Leaf area is also an important parameter in plant research. It is needed for calculation of leaf area index (LAI), net assimilation rate (NAR), and leaf area ratio (LAR).

Leaf Area Index (LAI)

The concept of leaf area index (LAI) was first introduced by Watson (1947) and defined as the ratio of leaf area to a given unit of land area. Leaf area index (m^2/m^2) is the component of crop growth analysis that accounts for the ability of the crop to capture light energy and is critical to understanding the function of many crop management practices. Leaf area index can have importance in many areas of agronomy and crop production through its influence on: light interception, crop growth (Pearce *et al.*, 1982), weed control, crop-weed competition, crop water use, and soil erosion.

Although measurement of Leaf area index is straightforward (Evans, 1972; i.e., measure the total leaf area over a specific area of land surface), in the past it has been time consuming and usually destructive. To measure Leaf area index, scientists generally have cut a number of plants at the soil surface, separated leaves from the other plant parts, and measured the area of individual leaves to obtain the average leaf area per plant. The product of leaf area per plant and the plant population gives the Leaf area index. Alternatively, Leaf area index could be measured non-destructively with this procedure if area of individual leaves was determined by some combination of leaf length and width measurements (Hopkins, 1939; Lal and Subba Rao, 1950; Arkel van, 1978).

The leaf area index of a crop with adequate water supply at elevated carbon dioxide (CO₂) increases, especially early in the season, as a result of earlier and more rapid leaf production in the vegetative growth phase (Ackerly *et al.*, 1992; Grashoff *et al.*, 1995; Morison and Gifford, 1984). This applies especially for indeterminate growing species and under non-limiting supply of nutrients. Early development of the canopy will lead to an earlier full ground cover, and may thus limit water loss from direct soil evaporation. Depending on the local precipitation and available soil water reserves, such an early enhanced canopy development may also be favourable for the full utilization of water resources (Chaudhury *et al.*, 1990). The higher transpiration early in

the season may also lead to an earlier depletion of water reserves in the soil (Morison and Gifford, 1984).

Net Assimilation Rate (NAR)

This gives a measure of the rate of increase of dry matter per unit area of leaf surface and is also a measure of rate of photosynthesis and respiration. Net assimilation rate (NAR) increases linearly with the logarithm of the percentage full day light up to a maximum to the value corresponding to the full daylight have been reported for many species (Blackman and Wilson, 1951a, b; Mc Laren and Smith, 1978; Patterson, 1979; Regnier *et al.*, 1988). Net assimilation rate (NAR) depends more closely on the incoming radiation than on any other environmental factors (Kvet *et al.*, 1971). Watson (1952) found that Net assimilation rate (NAR) varies with the seasonal trend in climate factors, highest values being found in the long, hot, bright days of mid–summer.

Leaf Area Ratio (LAR)

This is the ratio of leaf area to total plant dry weight per unit of plant materials present. It is a useful measure of difference between plants resulting from genetic factors, environment or difference treatments. Several shade adapted species exhibit an increase in Leaf area ratio when grown at low irradiance (Alvim, 1960; Begonia *et al.*, 1988; Blackman and Wilson, 1951 a,

b; Huxley, 1971; Patterson, 1985; Venketaraman and Govindappa, 1987 and Whitehead, 1978). This response is found less frequent among sun adapted species (Blackman and Wilson, 1951 and Patterson *et al.*, 1978). This response compensates for reduced irradiance by increasing light interception in proportion total plant tissue. The increase in Leaf area ratio with shading represents an adaptation to low PAR because a greater leaf area results from greater allocation of plant material to the photosynthetic light harvesting structures (Patterson, 1979, 1980).

Photosynthate distribution efficiency has also been expressed by Leaf area ratio (Patterson, 1985). A decrease of Leaf area ratio with the increase in age of the plant is noted in coffee (Venketaramanan and Govindappa, 1987) and sweet pepper (Nilwik, 1981). In a low light environment it is obviously imperative that the photo synthetically active area per total plant mass be as high as possible and it can be achieved in several different ways.

Leaf Area Applications

Measuring the leaf area of plants spans many scientific disciplines. Monitoring the distribution and changes of leaf area is important for assessing growth and vigour of vegetation on the planet. It is fundamentally important as a parameter in land-surface processes and climate models. This variable represents the amount of leaf material in ecosystems and controls the links between biosphere and atmosphere through various processes such as

photosynthesis, respiration, transpiration and rain interception. A measurement that is seemingly so simple and fundamental is really the backbone that provides the framework for further research in areas like ecology, agronomy, entomology, carbon cycle research and plant pathology. These and many other disciplines rely on the measurement of leaf area in much of their work. For example, an ecologist may want to quantify total biomass in the environment he is working in and break that biomass to specific leaf area of all the species he or she is studying. Over time they would be interested in knowing how that total biomass changes from species to species.

An agronomist also interested in specific crop varieties might want to compare harvestable biomass using leaf area as the primary tool for looking at above ground biomass. Measuring leaf area changes is one way for entomologists to quantify insect damage on plants. They may be looking at different agronomic varieties of a specific crop to see if an insect pest prefers one over the other. In this case leaf area measurements become an important part of this study.

Carbon Cycle modelers have an interest in total biomass of a system as well as in understanding carbon uptake and storage in different environments.

A plant pathologist comparing the effect of different diseases on plant types may use leaf area as an indicator of treatment effectiveness.

Knowing the leaf area is essential for studies involving photosynthesis as well. The accuracy of a leaf-level photosynthesis measurement is dependent on the accuracy of the leaf area measurement. Leaf-level photosynthesis measurements are reported as the number of micromoles of carbon dioxide assimilated per unit time and leaf area. Therefore, errors in your leaf area measurement directly correspond to errors in your photosynthesis measurement.

Plant Growth

When leaves of certain plant species are exposed to light source, they absorb the light energy, since light plays an important role by controlling the process associated with dry matter accumulation (Viel la and Ravetta, 2000) and thus contributing to plant growth. The species adaptative plasticity to solar radiation depends on the adjustment of the photosynthetic apparatus, in order to render radiant energy conversion in carbohydrates highly efficient and, to promote higher growth (Villega and Ravetta, 2000). One key characteristic of leaf area is that it evaluates tolerance of shaded species. The increase of leaf area with shading is one of the ways used to increase photosynthetic surface, ensuring a more efficient yield in low light intensities, and consequently, compensating the low photosynthetic rates per leaf area (Jones and Mcleod, 1940).

Factor Influencing Plant Growth

Growth rate of plants is determined by both the genetic nature of the plant and the nurture given by the environment. Determination of the potential growth rate as a function of environmental variables is thus ecological understanding. In current practice, growth and development are measured in several different environments, a slow and costly practice. Plant growth can be associated with volume; length and mass, either fresh or dry are the commonly used measures. Alternatively, carbon or nitrogen content, protein or cellulose or lignin content can also be used for the same measures. Harvest yield, the amount of desired product, such as grain or wood is frequently used.

Crop yield', especially, from new breeds is a crucial factor in man's development. The success of a plant-breeding program depends on the ability of the breeder to select superior types out of the population to make up the next generation. The crop yield are different for different classification of the same crop as plant breeders have established various technique that have remarkably successful in producing seeds with increased yields, resistant to pests and diseases and tolerant to stress.

The yield of crop plants is controlled by the combined actions of genetic and environmental factors. These factors may differ from one plant to another, so that two or more plants that are genetically identical and are of the same age may not have the same yield due to the influence of the environment. In the same way, plants that are of the same age and under the same

environmental conditions may not have the same yield due to their genetic differences (Tetteh, 1998).

All things being equal, the harvested part over a given period of time may be a function of the overall photosynthetic efficiency of a crop. Fluorescence changes that occur in green leaves are correlated with photosynthetic assimilation. The more efficient the photosynthesis is, the less will be the fluorescence emission (Edner *et al*, 1994).

Direct measurement of growth rate, as a function of environmental variables is an inherently slow and complex process, because the plant or clones must be grown at many different sets of conditions. But, if the metabolic properties can be used to reliably predict growth rates, the process can be greatly accelerated. Because green plants are autotrophs, growth rate has often been assumed to be related to the rate of photosynthesis. Photosynthesis provides the necessary substrate and fuel to power the growth process, but the rate of growth is limited to the rate and efficiency with which photosynthesis is processed through respiration (Hansen, 2002)

In physics stress may be defined as a state of the plant under the influence of an applied force. This applied force may be due environmental factors, which potentially may or may not favour the living organism. Every organism experiences stress, although the way in which it is expressed differs according to its level of organization or tolerance.

Stress factors acting on a plant are either natural or anthropogenic. Some of the natural factors include high light intensities, heat, natural deficiency, long rain periods and water shortage. Some of anthropogenic factors may include herbicides, air pollutants, acid rain etc. In general, the stress conditions are not caused by a single factor alone but by several factors which come together to act jointly.

Leaf temperature, on the other hand is an intrinsic leaf factor that changes concomitantly to water stress development.

Plant Yield

Plants are the basic sources of all food and consequently the determining factor in life. The fundamental process of photosynthesis, by which the plant is able to combine water and carbon dioxide to form sugar, permit the synthesis of the more complex compounds by the plant and the use of these compounds by man and the lower animals to sustain their life processes.

The plant welfare is of particular interest to those most directly concerned with the growth of plants and the manufacture and distribution of plant products. More importantly, the welfare of plants should be of concern to every one of us cultivators of plants for food or pleasure. The growth and yield of plants depend on the availability of nutrients and water in the soil

where they grow and in the maintenance within certain ranges of such environmental factors as temperature and moisture.

Plant growth and yield depend also on protecting the plants from parasites. Anything that affect the health of plants is likely to affects their growth and yield and may seriously reduce their usefulness to themselves and to mankind. The yields are different for different classifications of the same vegetables or plants. A plant is healthy or normal when it can carry out its physiological functions to the best of its genetic potentials. Plant may be classified in many ways by similarities of parts, complexity of structure and means reproduction.

Cassava (*Manihot esculenta* Crant)

Cassava (*Manihot esculenta* Crant; Euphorbiaceous) is the only species in its genus that is cultivated as a food crop. In South America, where it originated, cassava was domesticated 2,000-4,000 years B.C., yet only recently has it become distributed worldwide. The Portuguese began importing cassava into the Gulf of Guinea in Africa in the 16th century. In the 18th century, they introduced it to the east coast of Africa and the Indian Oman islands of Madagascar, Rhnion, and Zanzibar. Portuguese ships probably carried cassava to India and Sri Lanka after the mid-18th century. Cassava at first was little appreciated, but since the 19th century it has extended rapidly across Africa and is now grown in 39 countries. Cassava is the third largest source of carbohydrates for human food in the world

(estimated annual yield is 136 million tons), and Africa is the largest center of production (57 million tons were grown on 7.5 million hectares in 1985). Cassava is produced for industrial purposes in Brazil and as an export crop in Thailand, but in Africa it is grown primarily for local food consumption. In fact, cassava is the most important food crop grown on the African continent, exceeding yam (*Dioscorea* spp.), 24 million tons; maize (*zea mais* L.), and pearl millet, 9 million tons. Production per hectare averages 5-10 tons, but on the basis of yields at research stations. The potential exceeds 80 tons. In most African countries, cassava is grown primarily by traditional farmers, but there are some industrial plantations in Liberia, Nigeria, and Togo. African farmers usually grow cassava in mono-culture or together with maize (*zea mais*), peanuts (*Arachis hypogea* L.), rice (*Oryza sativa* L.), beans (*Phaseolus vulgaris* L.), or other crops. Global production of cassava is estimated at 152 million tonnes per year (CIAT, 2001). Half (50%) of the 16 million hectares of cultivated cassava worldwide is grown by small-scale farmers in Africa, 30 percent in Asia and 20 percent in Latin America (CIAT, 2001). Small-scale farming is characterized by cultivation using traditional methods with little or no inputs and largely in intercropping practices.

It was introduced into Ghana in 1750 (Doku, 1969; and Carter *et al*, 1995). Ghana produces 7.2 million tonnes annually and is the third largest producer in Africa after Nigeria and the Congo (Alyanak, 1997). In Ghana, cassava is the most favoured among all the root crops and indeed all food crops by consumers. This is reflected by the per capita consumption (PCC)

index. The PCC for cassava is high (148kg/year) followed by that of plantain (83kg/year: Annor-Frempong, 1991). It is widely consumed in various forms in many parts of Ghana, therefore playing a role as the leading food security base.

It has smooth erect stems and resembles the cannabis plant in appearance. The large compound, dark green, reddish veined leaves are palmately divided into about seven leaflets. The stems contain soft white pith and have nodes from which new plants are obtained. The crop is grown in all regions in Ghana except Upper East (MOFA, 2001).

Cassava does well in areas with an annual rainfall of 1000 – 3000 mm. The distribution of the rainfall is an important factor affecting the productivity of cassava (Silvestre, 1989). Onwueme (1978) and Osiru *et al*, (1995), however, stated that the crop is well adapted to cultivation in areas where the annual rainfall is as low as 500mm. It can also survive in areas where the dry season is as long as eight months. According to Janssens (2001), despite the drought-tolerant nature of cassava, it must get a minimum amount of water of 500mm per year spread over six months to give an appreciable yield. He stated further that the optimum annual precipitation lies between 1000 and 1500mm per year. Kay (1987) and Silvestre (1989) also indicated that the amount of annual rainfall needed to grow a good cassava crop varies from 1000mm to more than 3000mm. Cassava is a typical tropical plant. The approximate boundaries for its culture may be accepted as from 30°N to 30°S

latitudes; however, most cassava growing is located between 20°N and 20°S. In general, the crop requires a warm humid climate. Temperature is important, as all growth stops at about 10°C. Typically, the crop is grown in areas that are frost free the year round. The highest root production can be expected in the tropical lowlands, below 150 m altitude, where temperatures average 25-27°C, but some varieties grow at altitudes of up to 1500m. A temperature range of 25-30°C has been given by Janssens (2001) and Kay (1987) as the mean annual temperatures for optimal growth of cassava. Furthermore, the optimum mean daily temperature is between 18 and 35°C, and the minimum temperature the plants can tolerate is 10°C. Kay (1987) and Purse glove (1988) reported that cassava does well on light sandy loams of medium fertility with a pH of 8-9. Kay (1987) stated further that cassava can be grown successfully on sands or loose laterites with a pH of 5-5.5. When grown on clay soils the cassava plant produces stem and leaf growth at the expense of the roots and many cultivars give poor yields.

Silvestre (1989) stated that short growth period harvest of 8-10 months, results in poor yields. Harvesting from 15-20 months onwards depending on varieties increases output. Kay (1987) and Onwueme (1978) reported that cassava reaches maturity in 9-24 months depending on cultivar, climate and soil conditions. Harvesting of cassava can be done throughout the year when the roots reach maturity. Maturity differs from one variety to another, but for food the tubers can be harvested at almost any age below 12 months. In regions with seasonal rains, like Madagascar, harvesting is usually

done in the dry season, during the dormant period of the plant; where rain prevails all year round, as in Malaysia, cassava is harvested throughout the year. When used as a vegetable, the tubers are normally harvested within 12 months, otherwise they become very fibrous. According to Doku (1969) and Kay (1967), it should not be left to stand in the field for more than 2 years.

In Ghana cassava and yams occupy an important position in the agricultural economy and contribute about 46% of the agricultural Gross Domestic Product (GDP). Cassava accounts for a daily calorie intake of 30% in Ghana and is grown by nearly every farming family. The importance of cassava in Ghana cannot be over-emphasized. The Ewe (a language spoken in Ghana, Togo and Benin) name for the crop is 'agbeli' meaning 'there is life'. The name, no doubt, portrays its importance to the whole country and the Ewes in particular who are found in almost every part of the country which stands supreme as cassava growers (Doku, 1969). The area cultivated in the country increased from 55,200 hectares in 1992 to 63,000 hectares in 1998. FAO (2002) has stated that cassava as 'women's crop' is becoming evident because women undertake most of the processing activities such as peeling, washing and transporting to grating and milling sites.

Nutritionally, cassava tubers have multiple uses. The chemical composition of the edible portions of fresh tubers varies. According to Purseglove (1988) the edible fresh tuber which comprises about 80% of whole tuber is made up of 62% of water, 35% carbohydrate; 1% protein, 0.3% fat and 1%

mineral matter. Kay (1987) and Onwueme (1978) have both observed that the edible portion of the tuber is composed of energy 607KJ/100g; water 62-65%, protein 0.7-2.6%, fat 0.2-0.5%; total carbohydrate, 32-35%, fibre 0.8-1.3%, ash 0.3-1.3%, calcium 33mg/100g; iron 0.7mg/100g. Fresh cassava leaves are a good source of protein (23 percent), vitamins, and minerals. The mature leaves have 5-7% protein contents.

Cassava is principally used as human food. It is eaten boiled, fried, baked or pounded or in numerous processed forms (Lancaster *et al*, 1982).

Some of the most common cassava based foods in Africa apart from those of Ghana are abacha, elubon, lafun ,eba,and kpokpo gari in Nigeria. Cassava's role as a traditional human food is changing to an efficient industrial crop in some parts of Africa, for instance in Nigeria (Nweke, 2004). It plays a prominent role in alleviating the food problem in the country because of its efficient productivity of food energy, tolerance of environmental stress conditions such as drought, year-round-availability and suitability for various farming systems (Hahn and Keyser, 1985).

In Cameroon, some of the dishes are baton du manioc and kumkum. Other dishes include attieke in Cote d'Ivoire, foofoo in Sierra Leone, njambo in Gambia and ugali in Tanzania (IITA, 1990).

The leaves can be pounded to fine chaff and cooked as a palaver sauce in Sierra Leone, usually with palm oil but vegetable oil can also be used. In DR Congo the leaves are used in a stew called Pondu (Frederick *et, al*, (2008).

Several researchers have reported that young cassava leaves, roots and tender shoots are used for human consumption in Africa; Owueme (1978), Kay (1987), Purseglove (1988). The leaves are chopped or crushed, boiled and then consumed or incorporated into stews. The number of tuberous roots and their dimensions vary greatly among the different varieties. The roots may reach a size of 30-120 cm long and 4-15 cm in diameter, and a weight of 1-8 kg or more. World production of cassava root was estimated to be 184 million tonnes in 2002, rising to 230 million tonnes in 2008 (FAO, 2008). Various varieties are usually differentiated from one another by their morphological characteristics such as colour of stems, petioles, leaves and tubers. The numerous varieties of cassava are usually grouped in two main categories: *Manihot palmata* and *Manihot aipi*, or bitter and sweet cassava.

Kay (1987) and the IITA (1990) have recorded the industrial purposes of cassava starch as used in the food industry. They stated further that it is also used as a jelly or thickening agent in the manufacture of adhesives, dextrins, pastes and as filler in the manufacture of paints. The paper industry uses various types of starches at different stages of the manufacturing process for different purposes. Currently, the most common starches used for paper manufacture are from maize, potato, and cassava. Cassava starch has very

good properties that are highly desirable for the paper manufacturer. Cassava starch, as a dominant source of starch in Nigeria, possesses a strong film, clear paste, good water holding properties, and stable viscosity. In the textile industry, cassava is used for wax sizing, cloth and felt finishing. Furthermore, in many countries, significant research has begun to evaluate the use of cassava as an ethanol biofuel (feedstock). Under the development plan for Renewable Energy in the 11th Five-Year Plan in China, cassava (tapioca) chips have gradually become a major source for ethanol production (Linley, *et, al.*, 2002).

Agronomically, cassava is frequently cultivated as a temporary shade plant in young plantations of cocoa, coffee, rubber or oil palm. In Thailand, however, it is grown mostly as a sole crop and the farmer may for ten years or more grow cassava on the same land (Purseglove, 1988). This practice is also carried out in almost all cocoa growing regions in Ghana (Mossu, 1992). Cassava hay is used worldwide for animal feed as well. Cassava hay is produced at a young growth stage, 3–4 months, harvested about 30–45 cm above ground, and sun-dried for 1–2 days until it has final dry matter of at least 85%. The cassava hay contains high protein content (20-27% Crude Protein) and condensed tannins (1.5-4% Crude Protein). It is used as a good roughage source for dairy, beef, buffalo, goats, and sheep by either direct feeding or as a protein source in the concentrate mixtures. In the medical field, according to Kay (1987) cassava is used to prepare drugs and chemicals or

pharmaceuticals. IITA (1990) and Carter *et al.*, (1995) reported that cassava was used as a medicine in the 18th century as a cure for tuberculosis. The bitter variety of cassava root and leaves are used to treat diarrhea, malaria, hypertension, headache, and pain (Frederick *et al.*, 2008).

Arnon (1972), indicated that when production is not limited by moisture and nutrients supply, and maximum interception of available light is achieved by an optimum plant population, the only means of increasing productivity further is to use genotypes with a greater adaptations to high plant densities. Under optimal conditions, annual harvest up to 80 tonnes per hectare of cassava can be reached (CIAT, 1979), but currently the annual yields rarely exceed 10 tonnes per hectare (FAO, 1995). Cassava is expected to become even more important as human populations and pressure on the available land continue to increase and soil fertility declines (Cockcroft, 2004). However, the productivity of cassava in sub-Saharan Africa is generally low, in part due to the deleterious effects of pest and diseases.

Most workers agree that any increase in plant density is accompanied by a slight increase in grain up to an optimum which is determined by variety, location and fertility status of the area. Further plant density inputs might not influence grain yield (Black, 1965), might lead to slight increases in yield (Kirby, 1967; Jones and Hayes, 1967) or might reduce yield (Guitard *et al.*, 1961; Pelton, 1969). When cassava is grown by traditional tropical methods, yields lie between 5 and 20 tons per hectare, varying with the region, the

variety, the soil and other factors. However, when the crop is given more attention, yields of between 30 and 40 tons per hectare are obtained. It has been reported that it is normal for some varieties, under appropriate cultivation methods, to yield over 60 tons per hectare (FAO Yearbook of Food and Agricultural Statistics, 1955). The high yields frequently achieved at agricultural experiment stations and occasionally by some active farmers show what might be accomplished with improved varieties and better cultural practices.

Arnon (1972), listed the following planting patterns as having influence on yield: square arrangements, rectangular arrangements, very elongated rectangles (wide-row-interval with very small intervals within rows), irregular spacing in the row (pockets or hills within the rows), and the direction of the rows. Arnon (1972), suggested that square arrangements of plants is more efficient in the utilization of the light, water and nutrients available to the individual plant, than would be a rectangular arrangement, as square arrangements would reduce to a minimum the competitive effect of neighbouring plants on one another. He however, also expressed that extremely narrow rows would be necessary to achieve square spatial arrangements with the plant density required for maximum yields of many crops, and this would entail considerable technical difficulties in most crops.

Environmental Effects on Cassava

Cassava is found over a wide range of edaphic and climatic conditions between 30⁰N and 30⁰S latitude, growing in regions from sea level to 2300m altitude, mostly in areas considered marginal for other crops: low-fertility soil, annual rainfall from < 600mm in the semiarid tropic to >1500mm in the sub humid and humid tropics. Given the wide ecological diversity, cassava is subjected to highly varying temperatures, solar radiation and photosynthesis and temperature.

Temperature affects sprouting leaf size, leaf formation, storage root formation and consequently, general plant growth. The behaviour of cassava under the temperature variations that usually occur where cassava is normally cultivated indicates that its growth is favourable under annual mean temperatures ranging from 25 to 29⁰C (Conceicao, 1979), but it can tolerate from 16 to 38⁰C (Cock, 1984)

At low temperature (16⁰C) sprouting of the stem cutting is delayed, and rate of leaf production, total and storage root are decreased (Cock and Rosas, 1975). Sprouting is hastened when the temperature increases up to 30⁰C but is inhibited with temperatures > 37⁰C (Keating and Evenson, 1979). As temperature decreases, leaf area development becomes slower because the maximum size of individual leaves is smaller, and fewer leaves are produced at each apex although leaf life is increased (Irikura *et al.*, 1979). At a temperature of 15 – 24⁰C, the leaves remain on the plant for up to 200 days

(Irikura *et al.*, 1979), while at higher temperatures leaf life is 120 days (Splittstoesser and Tunya, 1992).

There is a genotype by temperature interaction for yield ability, (Irijura *et al.*, 1979) evaluated four cultivars under different temperatures and found that higher yields were obtained at different temperatures according to the cultivar, indicating that the effect of natural selection is highly significant on varietal adaptation.

The main effect of temperature is on biological production, as DM partitioning does not change much when cassava is cultivated under different temperatures (Cock and Rosas, 1975). Higher temperatures are associated with a greater crop growth rate (CGR) and high photosynthetic rate. El-sharkawy *et al.* (1992) evaluated the potential photosynthesis of three cultivars from contrasting habits under different growing environments and verified that photosynthetic rate increased with increasing temperature, reaching its maximum at 30-40°C. In all cultivars photosynthesis was substantially lower in leaves that had developed in the cool climate than in those from the warm climate. The high sensitivity of photosynthesis to temperature points to the need for genotype more tolerant to low temperature, which could be used in the highland tropics and subtropics.

Solar Radiation

The commonest cassava production system is intercropping with other staple crops. In Latin America and Africa cassava is usually associated with an earlier maturing grain crop such as maize , rice or grain legumes (beans, cowpeas or groundnuts, Mutsaers *et al.*, 1993).cassava is also intercropped with perennial vegetation (Ramanujam *et al.*,1984). Cassava is usually planted after the intercropped spears. Even when it is planted at the same time, the associated crop such as maize is established faster than cassava. Thus in an associated cropping system cassava is always subjected to different degrees of shading and low light intensity in the early stages of development considering that cassava is a crop that requires high solar radiation to perform photosynthesis more efficiently (El-Sharkawy *et al.*, 1992 b). It is very important to know the effect of shade on cassava development and production. Ramanujam *et al.*, (1984) evaluated 12 cassava cultivars under the shade in coconut garden (85 – 90 %) shading. Under shading, the root bulking process started about 3 weeks after that in plants grown without shading, and the number of storage roots per plant and Net assimilation rate NAR was reduced under shading. Okoli and Wilson (1986) submitted cassava to six shade regimes and observed that all levels of shade delayed storage root bulking and at 20, 40, 50, 60 and 70% shade reduced cassava yield by 43, 56, 59, 69 and 80% respectively.

In relation to shoots, under field conditions, shading increases plant height and the leaves tend to become adapted to low light conditions by

increasing leaf area per unit weight (Fulai *et al.*, 1984; Okoli and Wilson, 1986; Ramanujam *et al.*, 1984) and shortening leaf life only under severe shading. Under ideal growing conditions, cassava leaves have a life of up to 125 days (Splittstoesser and Tunja, 199). Levels of shade up to about 75% have very little effect on leaf life, but under 95 – 100% shade, leaves abscise within 10 days (Cock *et al.*, 1979).

Areta and Fukai (1984) observed that only 22% shade decreased both fibrous root elongation rate (53%) and storage root growth rate (36%) without altering shoot growth rate, which was significantly decreased (32%) only under 68% shade. Thus under limited photosynthesis caused by low solar radiation, most of the photosynthates are utilized for shoot growth, affecting storage root development significantly, showing that the shoots are a strong sink than roots.

CHAPTER THREE

MATERIALS AND METHODOLOGY

Experimental Sites

Experiments were carried out during the 2007 minor season (May to December) and during 2008 (January to April). The plants were grown in the open space for sunlight throughout the day at the Teaching and Research Farm of University of Cape Coast, Ghana. Beta Mass absorption coefficients measurement and the leaf disk area measurement were carried out in the Teaching and Research Farm of University of Cape Coast, Ghana. The experimental site has a typical climate of the coastal savannah lowland characterized by the mean annual rainfall ranged between “800 mm” to 1000 mm”. The area has a bimodal pattern, the major season (April to July) with maximum rainfall in June and the minor season (September to November) with maximum in October. The mean monthly temperature is about 26.5°C. The soils of the experimental site belong to the Benya series which is a member of the Edina-Benya-Udu compound association developed over *sekondian* material. The soil is medium to fine textured and moderately well drained (Asamoah, 1973).

Experimental Design

Three varieties of cassava, namely “Adehye Bankye”, “Botan Bankye”, “Capevars Bankye”, are new, high yielding varieties from University of Cape Coast, Ghana were grown at the Teaching and Research Farm of University of Cape Coast. In all 120 plants were planted. Thus, 60 plants out of the 120 plants were selected and 20 plants from each variety were used for the measurements. All the plants were treated under the same environmental conditions.

Experimental Procedures

Measurements were taken on the detached leaflet of the fourth fully expanded leaf starting from the top of the plant at the second, fourth, six, eight, ten, and twelve months after planting. This was done to ensure that all the leaves chosen for the analysis had almost the same ages. The plants were later allowed to grow to maturity. Two methods were used for the area measurement of leaf area. They were the beta mass absorption coefficient method, which involves the use of linear absorption coefficient, density and masses of leaves and leaf disk which served as standard. A table was taken to the field and set up under shade close to the cassava plant so that the leaves could be picked and cut out to a standard diameter of size 2.8cm before taking the leaf areas measurement with the beta mass absorption coefficients and the standard method. The results obtained from both beta mass absorption

coefficient method and standard methods were compared. Statistical analysis was used to analyze the data.

Beta Mass Absorption Coefficient measurements

The radioactive source, Sr-90 was used in the present investigation. The beta-ray of energy 0.544 MeV and 2.271 MeV emitted by the above radioactive isotope was collimated and detected with Geiger-Muller tube detector.

In the beta mass absorption coefficient experiment, the intensities were recorded by placing the samples in between the source and the detector (see figure 5). This procedure was repeated at least ten times for each sample. The intensities of the incident and transmitted electrons were determined by choosing the counting time for one minute intervals. The intensities were measured by the amount of ionization which the beta rays produced after passing through the different thickness of absorbing sample. The data was represented on a semi-logarithmic graph with log of intensities against thickness. A straight line of slope is indicated as μ (linear absorption coefficient). From the measured values of unattenuated intensity I_0 (without any sample) and attenuated intensity I (with sample), the mass attenuation coefficients (μ/ρ) of all samples were calculated by using the relation

$$\frac{\mu}{\rho} = \frac{\ln (I_0/I)}{\rho t} \quad [16]$$

where ρt = mass per unit area in g/cm^2 , ρ is the density and t is the sample thickness.

The samples under investigation were weighed in a digital balance capable of weighing up to a fraction of a milligram. The weighing was repeated a six times to obtain consistent values of the mass. The mean of this set of values was taken to be the mass of the sample. The estimated leaf area was obtained by multiplying the mass absorption coefficient (MAC) (μ/ρ) of the leaf with the mass (g) of the leaf.

Leaf Area Meter Measurements

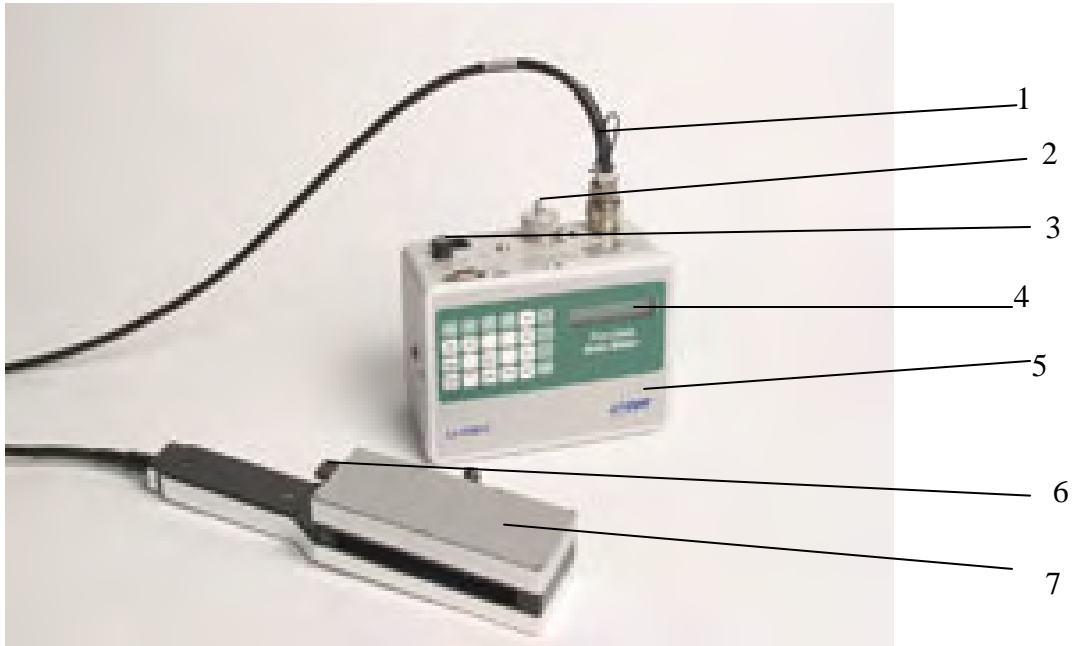
The power source of the machines was switched on. The scanning Head was opened and positioned over the disc sample of leaf lamina from the leaf which was detached from leaflet of the fourth fully expanded leaf starting from the top of the plants. It was then closed over the disc of leaf lamina of the leaf to allow the leaf to remain in the scanning head. Then the encoding cord length was drawn to keep it steady and at the same time the closed scanning Head was also drawn over the leaf to register the data in the digital display portion of the read-out console system.

Description of the Equipment used

Laser Induced (LI) -3000 Area meter System

The leaf area meter used was of types LI-COR machine; model LI-3000A which operates 12V, 12W at frequency of 50 - 60Hz. It has two major components: the scanning Head which is passed over the leaf and the Readout Console where area data is logged. The scanning head consist of the scanning head button. The scanning head button on the LI-3000A scanning head allows one to clear the area data register when pressed once and add area data when pressed twice. The readout console also provides additional data on leaf length, average width, and maximum width and accumulated area for single leaves or groups of leaves. The reading can be summed or subtracted in a secondary summing register where area data's are registered (see plates 1). The reading can also be stored in the console, and later output to a computer or printer.

The console is used with either the LI-3050A transparent belt conveyer accessory or the LI-3100 area meter. A rechargeable sealed lead acid battery provides power for operation and its life is approximately 15 hours



Plates 1. Photograph of the Laser Induced 3000 Area meter

1. LENGTH ENCODING CORD-it supports the scanning head when measuring the leaf sample.

2. BATTERY KNOB-used to control the battery.

3. POWER SOURCE-allows one to switch on or off the machine.

4. DIGITAL DISPLAY-is a portion where the data's are display.

5. READOUT CONSOLE-is where the digital display can be located.

6. SCANNING HEAD BUTTON-it controls the digital display in the Read out Console.

7. SCANNING HEAD-is where the leaf sample is placed

Beta Mass Absorption Coefficient System

The figure 7 shows the essential features of the mass absorption system. The radioisotope, strontium -90 was used as a radiation source, from which the radiation emanates in straight lines onto the samples with collimators, directing the beams into the detector, which is connected to the scaler. As beta radiation passes through the samples, some of the radiations are absorbed and others are transmitted. The amount of the beta radiation transmitted depends on the thicknesses of the sample. Heavy samples will absorb more of the beta radiation and fewer samples will transmit more of the beta radiation. This figure shows the essential features of the beta mass absorption coefficient system.

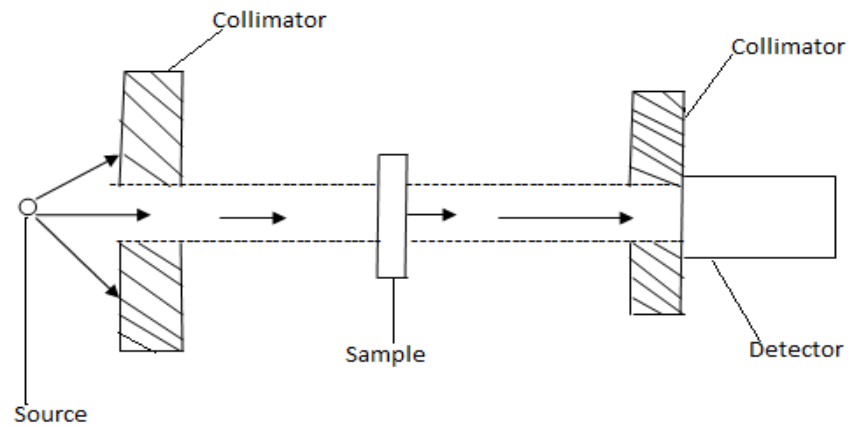


Figure 7. Experimental set up for the determination of Beta Mass Absorption Coefficient

Determination of areas of regular geometrical figures using $A = \frac{\mu}{\rho} x m$

A test was carried out on the following materials: aluminium absorber, cocoa leaf, A-4 paper, cardboard and brass using a geometrical figure in the shapes of square, rectangle, equilateral triangle, ellipse, and trapezium of different known areas as shown in the diagrams below. The precision and accuracy of the method were validated by comparing the experimental value with the geometrical values as shown in the tables below

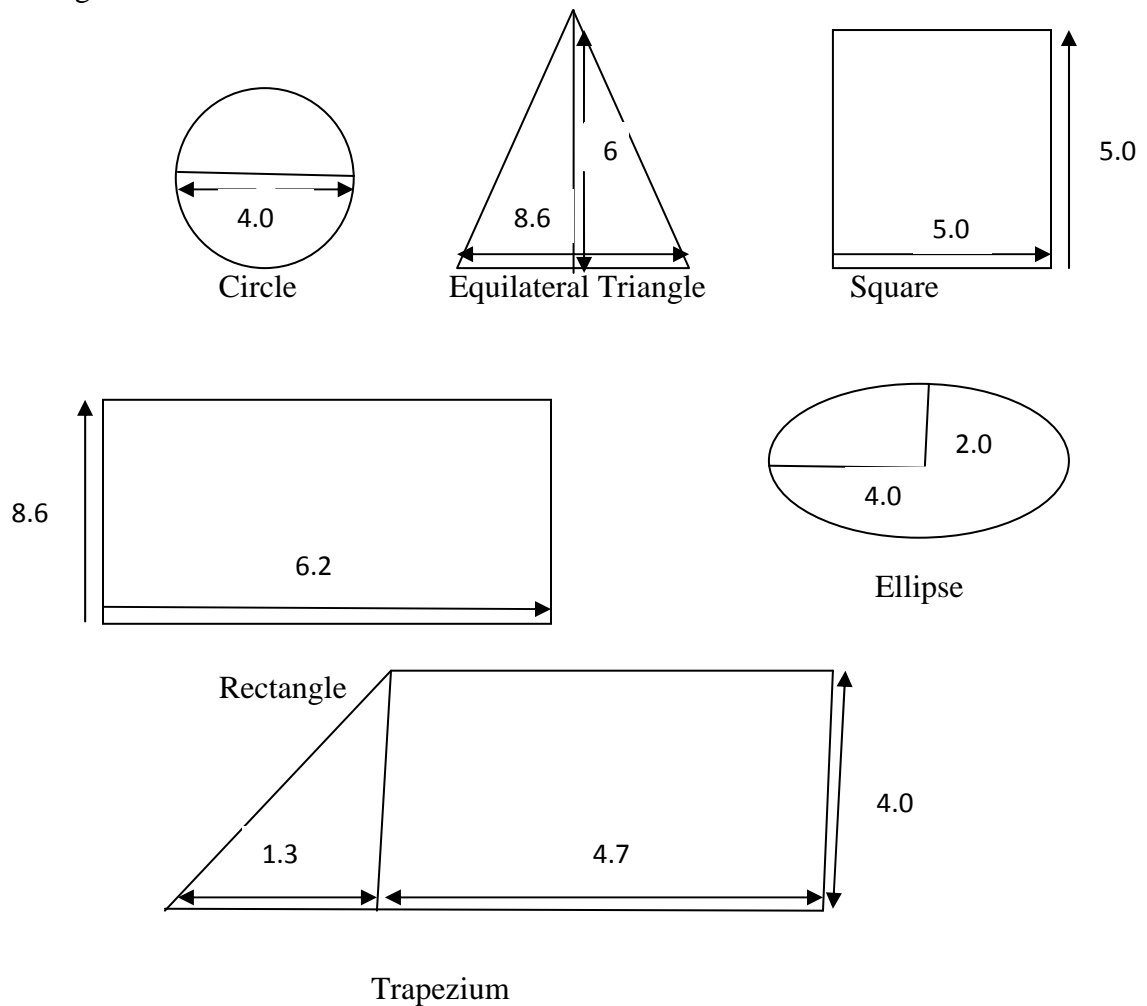


Table 3: Circle geometrical measurement used for validation

Materials (cm ² /ρ)	Geometrical figure	Area estimated by calculation (πr^2) (cm ²)	Area estimated by Leaf area meter(cm ²)	Area estimated by beta mass absorption coefficient(cm ²)
Al-absorber (7.0±0.4)	Circle	12.6±0.1	13.2±0.1	14.5±0.3
A-4 Paper (10.4±0.3)	Circle	12.6±0.1	12.9±0.4	14.8±0.4
Cocoa leaf (10.2±0.2)	Circle	12.6±0.1	13.6±0.3	15.1±0.5
Brass (7.8±0.3)	Circle	12.6±0.1	11.8±0.5	11.2±1.2
Cardboard (7.4±0.3)	Circle	12.6±0.1	13.3±0.2	14.1±0.2

Table 4: Ellipse geometrical measurement used for validation

Materials (cm ² /ρ)	Geometrical figure	Area estimated by calculation (πab) (cm ²)	Area estimated by Leaf area meter(cm ²)	Area estimated by beta mass absorption coefficient(cm ²)
Al-absorber (7.0±0.4)	Ellipse	18.8±0.1	17.5±0.7	16.5±1.3
A-4 Paper (10.4±0.3)	Ellipse	18.8±0.1	19.6±0.2	21.4±0.9
Cocoa leaf (10.2±0.2)	Ellipse	18.8±0.1	17.5±0.7	20.9±0.7
Brass (7.8±0.3)	Ellipse	18.8±0.1	20.3±0.5	17.2±0.9
Cardboard (7.4±0.3)	Ellipse	18.8±0.1	20.5±0.6	21.1±0.6

Table 5. Square geometrical measurement used for validation

Materials (cm ² /ρ)	Geometrical figure	Area estimated by calculation axa (cm ²)	Area estimated by Leaf area meter(cm ²)	Area estimated by beta mass absorption coefficient(cm ²)
Al-absorber (7.0±0.4)	Square	25.0±0.2	24.6±0.5	23.1±0.9
A-4 Paper (10.4±0.3)	Square	25.0±0.2	25.4±0.4	27.3±1.0
Cocoa leaf (10.2±0.2)	Square	25.0±0.2	26.3±0.5	23.5±0.7
Brass (7.8±0.3)	Square	25.0±0.2	25.6±0.1	28.6±1.6
Cardboard (7.4±0.3)	Square	25.0±0.2	25.5±0.1	22.8±1.0

Table 6: Trapezium geometrical measurement used for validations

Materials (cm ² /ρ)	Geometrical figure	Area estimated by calculation $\frac{1}{2}(u_1+u_2)b$ (cm ²)	Area estimated by Leaf area meter(cm ²)	Area estimated by beta mass absorption coefficient(cm ²)
Al-absorber (7.0±0.4)	Trapezium	21.4±0.2	20.2±0.5	19.39±1.3
A-4 Paper (10.4±0.3)	Trapezium	21.4±0.2	20.5±0.6	24.1±0.8
Cocoa leaf (10.2±0.2)	Trapezium	21.4±0.2	22.3±0.4	18.9±1.5
Brass (7.8±0.3)	Trapezium	21.4±0.2	23.6±0.9	23.5±0.5
Cardboard (7.4±0.3)	Trapezium	21.4±0.2	20.3±0.3	24.8±1.1

Table 7: Rectangle geometrical measurement used for validation

Materials (cm^2/ρ)	Geometrical figure	Area estimated by calculation axb (cm^2)	Area estimated by Leaf area meter(cm^2)	Area estimated by beta mass absorption coefficient(cm^2)
Al-absorber (7.0 ± 0.4)	Rectangle	31.0 ± 0.3	30.8 ± 0.3	27.9 ± 0.7
A-4 Paper (10.4 ± 0.3)	Rectangle	31.0 ± 0.3	31.1 ± 0.6	33.6 ± 1.5
Cocoa leaf (10.2 ± 0.2)	Rectangle	31.0 ± 0.3	28.2 ± 0.9	31.5 ± 0.5
Brass (7.8 ± 0.3)	Rectangle	31.0 ± 0.3	32.1 ± 0.6	27.4 ± 1.3
Cardboard (7.4 ± 0.3)	Rectangle	31.0 ± 0.3	31.5 ± 0.5	31.1 ± 0.4

Table 8. Triangle geometrical measurement used for validation

Materials (cm ² /ρ)	Geometrical figure	Area estimated by calculation ½bh(cm ²)	Area estimated by Leaf area meter(cm ²)	Area estimated by beta mass absorption coefficient(cm ²)
Al-absorber (7.0±0.4)	Triangle	24.3±0.1	25.3±0.5	21.8±1.2
A-4 Paper (10.4±0.3)	Triangle	24.3±0.1	23.1±0.5	27.2±1.2
Cocoa leaf (10.2±0.2)	Triangle	24.3±0.1	25.2±0.3	26.7±0.9
Brass (7.8±0.3)	Triangle	24.3±0.1	23.1±0.5	25.1±0.2
Cardboard (7.4±0.3)	Triangle	24.3±0.1	24.3±0.2	22.1±0.6

CHAPTER FOUR

RESULTS AND DISCUSSION

The methodology employed in the present research made possible the measurement of the leaf area of three varieties of cassava at different stages of the plant's growth. The method was based on manipulation of the dimension of beta mass absorption coefficient and the standard method. Hence, the data presented below were the averaged values of all the three varieties of cassava leaves estimated by the beta mass absorption coefficient method and the standard method at various plant growth stages.

Results of beta mass absorption coefficient method and the standard method (Leaf disk) measurement.

Table 9: Comparison of leaf area values between the standard method and beta mass absorption coefficient method of Capevars Bankye variety

Age of plants (month)	Leaf disk area per ten leaf disk(cm ²)	MAC of leaf sample (cm ² /g)	Mass of leaf sample(g)	Estimated leaf area by BMAC (cm ²)
Two	61.6	125.1	0.5	62.7±0.4
Four	61.6	121.9	0.5	60.9±0.3
Six	61.6	148.7	0.5	59.5±0.8
Eight	61.6	197.0	0.3	59.1±1.0
Ten	61.6	196.4	0.3	59.0±1.1
Twelve	61.6	194.7	0.3	58.4±1.4

* *BMAC=Beta Mass Absorption Coefficient., MAC=Mass absorption coefficient*

Table 10: Comparison of leaf area values between the standard method and beta mass absorption coefficient method of Bankye Botan variety

Age of plants (month)	Leaf disk area per ten leaf disk(cm ²)	MAC of leaf sample (cm ² /g)	Mass of leaf sample(g)	Estimated leaf area by BMAC (cm ²)
Two	61.6	119.7	0.5	59.8±0.7
Four	61.6	101.4	0.6	60.8±0.3
Six	61.6	200.2	0.3	60.1±0.6
Eight	61.6	299.9	0.2	59.9±0.7
Ten	61.6	291.3	0.3	58.5±1.3
Twelve	61.6	200.3	0.3	60.0±0.6

* *BMAC=Beta Mass Absorption Coefficient., MAC=Mass absorption coefficient*

Table 11: Comparison of leaf area values between the standard method and beta mass absorption coefficient method of Adehye Bankye variety

Age of plants (month)	Leaf disk area per ten leaf disk(cm ²)	MAC of leaf sample (cm ² /g)	Mass of leaf sample(g)	Estimated leaf area by BMAC (cm ²)
Two	61.6	151.7	0.4	60.7±0.4
Four	61.6	126.8	0.5	63.3±0.7
Six	61.6	210.4	0.3	63.1±0.5
Eight	61.6	295.4	0.3	60.1±0.6
Ten	61.6	212.6	0.3	63.7±0.8
Twelve	61.6	207.7	0.3	62.3±0.2

* *BMAC=Beta Mass Absorption Coefficient., MAC=Mass absorption coefficient*

Table 12: Comparison of average leaf area values between the standard method and beta mass absorption coefficient method of all the three cassava varieties

Age of plants (month)	Leaf disc area per ten leaf disk(cm ²)	MAC of leaf sample (cm ² /g)	Mass of leaf sample(g)	Estimated leaf area by BMAC (cm ²)
Two	61.6	132.1	0.5	61.1±0.5
Four	61.6	116.7	0.5	61.6±0.4
Six	61.6	186.4	0.4	60.9±0.6
Eight	61.6	264.1	0.3	59.7±0.8
Ten	61.6	233.4	0.3	60.4±1.1
Twelve	61.6	200.9	0.3	60.2±0.7

* *BMAC=Beta Mass Absorption Coefficient., MAC=Mass absorption coefficient*



Figure 8. Relationship between Mass absorption coefficient versus age of plants (months) for Cape vars bankye

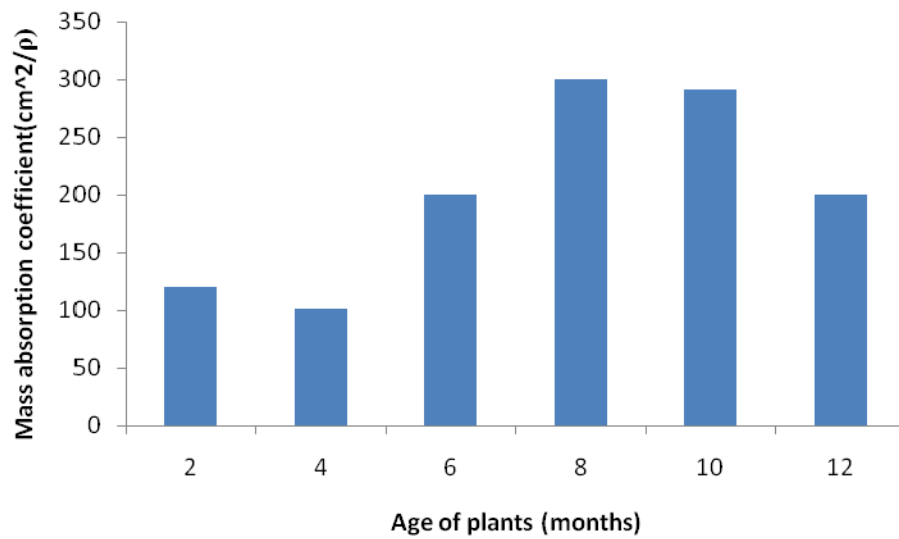


Figure 9. Relationship between Mass absorption coefficient versus age of plants (months) for Botan bankye



Figure 10. Relationship between Mass absorption coefficient versus age of plants (months) for Adehye bankye



Figure 11. Relationship between averaged mass absorption coefficient versus age of plants (months) for all the three varieties

From (Tables 9, 10, & 11) above, it was noticed that there was an increase and decrease in the leaf area values with age of the plants for all the three varieties throughout the measurement with beta mass absorption coefficient method. The mean leaf discs area estimated by the beta mass absorption coefficient method was not significantly different from the standard (leaf disk). The beta mass absorption coefficient slightly overestimated the disk area. Statistical analysis (using 95% confidence interval) found out that, throughout the measuring period the average leaf area of the entire three varieties estimated using beta mass absorption coefficient method was not significantly different from the standard method as shown in the appendix B.

The beta mass absorption coefficient method varied significantly with the standard method at 95% confidence interval. The mean of the error was estimated to be -1.377% and standard deviation of the error was 4.00, for beta mass absorption coefficient method. In finding the correlation between the standard method and the beta mass absorption coefficient method, the analysis of data indicated insignificant difference between them for any of the three varieties. Through statistical analysis no significant differences existed among the leaf area for all the three cassava varieties.

The estimation of leaf area by the beta mass absorption coefficient method was done to predict the photosynthetic capacity of varieties of cassava at various stages of growth. Detailed discussion of the results is presented in the following paragraphs.

Generally, both standard method and beta mass absorption coefficient method corresponded well throughout the measurements with the age of the plants. It was noticed that there was increase in the mass absorption coefficient values up to the 8th month and decrease in the mass absorption coefficient values was also observed especially during the 4th month which could be attributed to weather conditions when data was taken in comparison with the age of the plants for all the three varieties.

The increase in leaf area with age of the plants for all the three varieties could be attributed to the fact that there was an increase in mass, thickness and the density of the leaves due to the rainy season that is abundant rains leads to increased growth rates. The more surface area a plant has the more sunlight it can absorb. As leaf area increases, the proportion of incoming radiation which is intercepted increases, resulting in higher crop growth rate. The decrease in leaf area value during the measurement for all the three varieties could be due to the reduction in weight (mass), thickness and density due to the harmattan seasons that is there is loss of water by the leaves (dehydration).

Additionally, the slight variations in the leaf area measurements using beta mass absorption coefficient techniques could be attributed to the instrumental errors.

Another influential factor affecting beta mass absorption coefficient techniques is sunshine (weather conditions) since the cassava leaves withered

in a few minutes when exposed to sun shine after taken from the main plant. This tends to reduce the weight of the leaves and the thickness resulting in decrease in density. It is worth stating that, all measurements were taken under standard conditions.

From the results obtained above (see tables), it was observed that the beta mass absorption coefficient method could measured approximately the same standard (leaf disk) leaf area for all the three cassava varieties. This information is in accordance with the statistical analysis made between standard method and beta mass absorption coefficient method for each variety during the measuring period, which indicates a highly positive correlation. Experimental errors could result from the nature/state of the leaves (varying thickness). This is because the cassava leaves dehydrate (loss in water) within some few minutes, especially when exposed to sun after taking it from the stem. This also reduces the weight of the leaves as well as the thickness; resulting in decrease in density. Leaf diseases also can affect the results.

It is worth stating that from literature (<http://www.ctahr.hawaii.edu/fb/cassava>), cultivars and climatic conditions influence maturity of cassava. The early types mature at about 6 month after planting (MAP). The greatest yields are achieved at about 9-12 month after planting (MAP). Prolonged maturity periods, however, turn the tubers fibrous and poor in quality. This is consistent with our observations using the mass absorption coefficient values, which could help in the estimation of leaf area

to determine the well-being and yield in the crop (see plots or figures 8, 9, 10, &11).

Through the data analysis, it was found that there was significant difference between the leaf area measured by means of beta mass absorption coefficient method and standard method for all the cassava varieties during the measuring period. Since mass absorption coefficient and mass of leaf sample determine the area of leaf, it may be possible that the beta mass absorption coefficient method may be used to determine the well-being and potential yield of plant. The above observations give a justification that the beta mass absorption coefficient method could be used to approximate the leaf area of plants.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Conclusion

The main objective of this study had been to develop a methodology for the estimation of leaf area using the beta mass absorption coefficient technique of the leaf. The study which has been conducted using the two techniques in measuring the leaf areas of three cassava varieties over a period of 12 months indicated that the beta mass absorption coefficient method showed high and effective performance in terms of mass absorption coefficient values (μ/ρ) and leaf area estimations (see relevant plots and Tables) especially during the sixth and eighth months after planting which is consistent with the maturity age of most cassava varieties. An advantage of the proposed technique (methodology) is that, it lends itself to the measurement of areas of both regular and irregular shaped objects: a property that can be extended to virtually all small area measurements. Furthermore, this method is cheaper, and possibly easier to use than the leaf area meter since the beta source used does not need electricity or any cells to function.

Comparing our observation and that from the survey conducted in Hawaii (different climatic conditions), early type of cassava mature within 6

months after planting which is consistent with our observations during the same month of measurement using both methods. Leaf area, plant population and climatic conditions have been observed as critical in plant growth which influences crop yield although crop variety may also gives influential results.

The results arising from this thesis work draws conclusions that the estimation of a leaf area could be approximately measured and used to estimate the well-being and yield of the cassava plantation when accurate determinations of the leaf mass absorption coefficient and the mass of the leaf are made. This work could be extended to other plant varieties.

Recommendations

It will be ideal that further research be carried out in other parts of the country on different soils and varieties in order to generalise and validate the study. Work could also be extended to the determination of relative area and thickness of both regular and irregular shaped materials utilizing the beta radiation method as proposed in this thesis work.

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APPENDICES

APPENDIX A

Protein (C₂H₅N₀₂)

Carbon(C)

$$N_C = N_A (24/75) (6/12) ;$$

$$= 144/900$$

$$= 0.160N_A$$

Hydrogen (H)

$$N_H = (5/25) (1)$$

$$= 0.067N_A$$

Nitrogen (N)

$$N_N = (14/75) (14/28) ;$$

$$= 196/2100$$

$$= 0.093N_A$$

Oxygen (O)

$$N_O = N_A (32/75) (8/16)$$

$$= 256/1200$$

$$= 0.213N_A$$

$$\sum a_i = 0.093 + 0.160 + 0.213 + 0.067$$

$$= 0.533$$

$$a_C = 0.16/0.533; \quad a_H = 0.0667/0.533; \quad a_N = 0.093/0.533; \quad a_O = 0.213/0.600$$

$$= 0.300$$

$$= 0.126$$

$$= 0.174$$

$$= 0.399$$

$$Z_{eq} = 3.5 \sqrt{0.300(6)^{3.5} + 0.126(1)^{3.5} + 0.174(7)^{3.5} + 0.399(8)^{3.5}}$$

$$= 3.5 \sqrt{158 + 0.126 + 157.9 + 577.8}$$

$$= 3.5\sqrt{894.5}$$

$$= 6.97$$

Lipids (CH₃(CH₂)₁₀COOH),

Carbon(C)

Hydrogen (H)

$$N_c = N_A (144/200) (6/12) \quad ; \quad N_H = N_A (24/200) (1)$$

$$= 864/2400$$

$$= 0.12N_A$$

$$= 0.36N_A$$

Oxygen (O)

$$N_o = N_A (32/200) (8/16)$$

$$= 256/3200$$

$$= 0.08N_A$$

$$\sum a_i = 0.36+0.12+0.08$$

$$= 0.56$$

$$a_c = 0.36/0.56 \quad ; \quad a_H = 0.12/0.56 \quad ; \quad a_o = 0.08/0.56$$

$$= 0.643$$

$$= 0.214$$

$$= 0.143$$

$$Z_{eq} = 3.5\sqrt{0.643(6)^{3.5} + 0.214(1)^{3.5} + 0.143(8)^3}$$

$$= 3.5\sqrt{340.2 + 0.214 + 207.1}$$

$$= 3.5 \sqrt{547.5}$$

$$= 6.06$$

Carbohydrate (C₆H₁₂O₆)

Carbon(C)

$$N_C = N_A (72/180) (6/12)$$

$$= 432/2160$$

$$= 0.2N_A$$

Hydrogen (H)

$$N_H = N_A (12/180) (1)$$

$$= 0.067N_A$$

Oxygen (O)

$$N_O = N_A (96/180) (8/16)$$

$$= 768/2880$$

$$= 0.267N_A$$

$$\sum a_i = 0.200 + 0.267 + 0.067$$

$$= 0.533$$

$$a_C = 0.200/0.533 ; a_H = 0.067/0.533 \quad a_O = 0.267/0.533$$

$$= 0.375$$

$$= 0.126$$

$$= 0.501$$

$$Z_{eq} = 3.5 \sqrt{(0.375) (6)^{3.5} + 0.126 (1)^{3.5} + 0.501 (8)^{3.5}}$$

$$= 3.5 \sqrt{198.4 + 0.126 + 725.5}$$

$$= 3.5 \sqrt{924.0}$$

$$= 7.04$$

$$\sum Z_{eq} = \text{Carbohydrates} + \text{Lipids} + \text{Proteins} + \text{Potassium} + \text{Phosphorus} + \\ \text{Sulphur} + \text{Oxygen} + \text{Chlorine} + \text{Manganese}$$

$$= 6.97 + 6.06 + 7.04 + 17 + 19 + 15 + 16 + 25$$

$$= 67 + \underline{6.97 + 6.06 + 7.04 + 17 + 19 + 15 + 16 + 25}$$

8

$$= 12.01$$

APPENDIX B

Result of statistical analysis using Confidence Level (95.0%) for Cape Vars Bankye variety

Statistics	Value
Mean	59.9333
Standard Error	0.6505
Median	59.3000
Mode	#N/A
Standard Deviation	1.5933
Sample Variance	2.5387
Kurtosis	0.9476
Skewness	1.2610
Range	4.3000
Minimum	58.4000
Maximum	62.7000
Sum	359.6000
Count	6.0000
Confidence Level (95 %)	1.6721

#N/A=Not at all

Result of statistical analysis using Confidence Level (95.0%) for Bankye

Botan variety

Statistics	Value
Mean	59.8500
Standard Error	0.3063
Median	59.9500
Mode	#N/A
Standard Deviation	0.7503
Sample Variance	0.5630
Kurtosis	2.8938
Skewness	-1.1249
Range	2.3000
Minimum	58.5000
Maximum	60.8000
Sum	359.1000
Count	6.0000
Confidence Level (95%)	0.7874

#N/A=Not at all

**Result of statistical analysis using Confidence Level (95.0%) for Adehye
Bankye variety**

Statistics	Value
Mean	62.2000
Standard Error	0.6039
Median	62.7000
Mode	#N/A
Standard Deviation	1.4792
Sample Variance	2.1880
Kurtosis	-1.6158
Skewness	-0.6674
Range	3.6000
Minimum	60.1000
Maximum	63.7000
Sum	373.2000
Count	6.0000
Confidence Level (95%)	1.5523

#N/A=Not at all

Result of statistical analysis using Confidence Level (95.0%) for all the three varieties

Statistics	Value
Mean	60.6500
Standard Error	0.2790
Median	60.6500
Mode	#N/A
Standard Deviation	0.6834
Sample Variance	0.4670
Kurtosis	-0.7330
Skewness	0.0000
Range	1.9000
Minimum	59.7000
Maximum	61.6000
Sum	363.9000
Count	6.0000
Confidence Level (95%)	0.7172

#N/A=Not at all