EVALUATION AND CALIBRATION OF
FIELD TECHNIQUES TO
QUANTIFY CROP COVER

THIS THESIS HAS BEEN ACCEPTED FOR
THE DEGREE OF ...MSc...
AND A COPY MAY BE PLACED IN THE
UNIVERSITY LIBRARY.

BY

THE THESIS HAS BEEN ACCEPTED FOR
THE DEGREE OF ...MSc...
AND A COPY MAY BE PLACED IN THE
UNIVERSITY LIBRARY.

PETER WASWA FUCHARA

Thesis submitted in partial fulfilment for the degree of

MASTER OF SCIENCE in LAND AND WATER MANAGEMENT

Department of Agricultural Engineering

Faculty of Agriculture

University of Nairobi

September, 1993

UNIVERSITY OF NAIROBI
KABETE

Declaration

I hereby declare that this thesis is my original work and has not been presented in any other University.

All sources of information and literature cited have been acknowledged and referenced accordingly.

Signed.........................

Fuchaka, Peter Waswa

Date. 24/9/93

This thesis has been submitted for examination with my approval as the Principal University Supervisor.

Signed ....

Dr. M.A. Zobisch.

Date. 24/9/93

DEDICATION

To

my father,

Joel Waswa

and

my mother,

Helen Omina.

They gave themselves for my

excellence in life.

Table Of Contents

ACKNOWLEDGEMENTS

My deepest appreciation are extended to the Swedish Agency for research Cooperation with Developing Countries (SAREC) for their commitment to finance this research.

I would also like to record my sincere gratitude of the help provided by a number of people:

> Dr. M.A.Zobisch, Department of Agricultural Engineering, University of Nairobi, under whose supervision this work was done.
>
> Prof. D.B.Thomas, Department of Agricultural Engineering, University of Nairobi, for overseeing the ultimate completion of this work.
>
> The entire academic staff of the Soil and Water Group of the Department of Agricultural Engineering, University of Nairobi for its distinguished academic guidance.
>
> Mr. P. Klingspor, SAREC co-ordinator, Department of Agricultural Engineering, University of Nairobi, for his timely assistance with the procurement of research materials and unique ideas.

I am sincerely indebted to Mr. Odour for his assistance with technical drawings; Messrs. Maina, Mungai, Muliro, Kirwa, Owili, Kipsongok, Gathiru, Nganga, and Miss. Kihato, Sis. Martha, Ms. Wambui, Ms. Murugi; all of the SAREC research station for their assistance with field preparation and data collection.

Many thanks are extended to Wayetta, Webbo, Khatievi, Ayieko, Naututu, Maruti, Nambami, Nekesa, and Simiyu; my brothers and sisters. They were a constant source of encouragement to me.

All my friends for whichever help offered to me.

And to God, who gives us the ability to do all things, be all the glory forever and ever!

P.W. Fuchaka B.Sc.(Agric)

LIST OF FIGURES

Figure No. **Description** **Page**

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

A.C	Alternating current
ANOVA	Analysis of Variance
a.s.l	Above Sea level
Cal	Calculated
^{0}C	Degrees Centigrade
CI	Confidence Interval
cm	Centimetres
C_R	Percent residue cover
df	Degrees of freedom
EI	Erosivity Index
Est	Estimate
Fig	Figure
g	Grams
ha	Hectares
hr	Hour
I	Intensity (mm/hr)
J	Joules
KE	Kinetic Energy (J/m^2)
Kg	Kilogram
M	Metres
M/stick	Metre-stick
mm	Millimetres
MSF	Modified sighting-frame
nm	Nanometres
No.	Number
PLU	Prior Land Use
Q	Runoff Volume (m^3)
Q_p	Peak Runoff rate (m^3/s)
R^2	Co-efficient of determination
r	Correlation co-efficient
REI	Rainfall Energy Intercepted
SAREC	Swedish Agency for Research Co-operation with Developing Countries
%SC	Percent Surface cover
Sec	Seconds
S/Frame	Sighting frame
SF-8	Sunfleck Ceptometer
SQS	Spatial Quantum Sensor
SR	Surface roughness
Std Err	Standard Error
t	tonnes
TQS	Traversing Quantum Sensor
USDA	United States Department of Agriculture
VCDB	Vegetation Cover Data Bank

ABSTRACT

Reliable estimates of the percentage of the soil surface covered by crop residues and shaded by crop canopies are required for the management of soils to reduce erosion. The importance of ground cover is reflected in its role in erosion prediction models as the cover-management factor. Research has shown that detachment of soil particles by raindrops is the prerequisite to erosion, and that ground cover is the greatest deterrent to this process through raindrop interception and attenuation. There also occurs a critical cover value below which erosion is significant and above which it is insignificant.

Most techniques of estimating ground cover are not very precise. Consequently, conservation options derived from predictive models are likely to be erroneous due to inaccurate cover management factors. This research was therefore meant to evaluate and calibrate four different cover measurement techniques (i.e. the photographic method, the sighting-frame. the ceptometer, and the metre-stick method). These techniques were evaluated on maize, bean and maize-bean intercrop cover in agro-climatic zone III (semi-humid).

All pairs of technique comparisons gave very high correlation coefficients (r) in the range of 0.95 - 0.99. This suggested that any of the four methods could be used for routine ground cover estimation. Although all the techniques gave higher estimates of cover than the actual cover, calibration of the crop cover values against the physical plant models gave r-values of 0.921, 0.909, 0.689, and 0.467 for the camera, sighting frame, metre stick, and ceptometer respectively. The cover correction factors obtained from the regression equations were 0.88, 0.875, 0.799, and 0.752 respectively. Consequently, the accuracy of cover estimation was highest for the camera and lowest for the ceptometer. The sighting-frame gave better cover estimates than the metre- stick. Precision was highest for the camera and ceptometer. This was attributed to their high objectivity contrary to the sighting frame and metre-stick which are more exposed to subjective bias. Analysis of variance showed that all the techniques were independent and there was no interaction between any technique and the crop. The sighting frame was however recommended for routine field application for row crops due to its cost effectiveness, local availability, ease of use and reliable accuracy.

Two approaches in the use of the Sighting frame were also compared; the conventional 0-0.5-1 and the new 0-0.25-0.5-0.75-1 systems. Both approaches had r-values in the range of 0.95 - 0.99. Consequently any of the two systems could be adopted for routine cover evaluation. A preliminary rainfall energy interception model for the short rains 1992/93 at the research site was also suggested. Of importance were the effects of extreme rainfall events realised towards late 1992 and early 1993.

It was recommended that for all cover measurement techniques, evaluation procedures standardization and design improvements be made to increase the precision and accuracy of cover estimation and to facilitate ease of application in the field.

CHAPTER 1

INTRODUCTION

1.1 Background

Soil erosion albeit being a significant obstacle to agricultural development is also an environmental hazard which must be dealt with today. The alarmingly high increase in population growth rates, especially in developing countries, has resulted in extension of cultivation onto steep slopes, vulnerable land and even into forest reserves. The resulting high pressure on the land has been identified as a major cause of accelerated soil erosion (Young, 1989; Hudson, 1980). Accelerated soil erosion is caused by perturbations introduced in the soil - vegetation - climate equilibrium mostly by human intervention (Lal, 1990). It commences immediately the natural ground cover is destroyed.

Lo (1990) pointed out that the prime causes of soil erosion are deforestation and agriculture. He also argues that when land is intensively cultivated, the rate of soil erosion is atleast three times what it is when the land is under forest. Estimates from the Worldwatch Institute show that the world is now losing approximately 23 billion tons of soil each year from crop lands alone in excess of new soil formation. Animal production systems also suffer serious soil losses when poorly managed. Fuls and Bosch (1991) showed that semi-arid vegetation which has retrogressed beyond a threshold of drought resilience can not rest-recover. This may explain the high rate of gully development in overgrazed semi-arid lands of the tropics. Under such conditions only mechanical inputs which are affordable by few rich farmers will restore the land.

Kenya's economy like that of many developing countries depends on agriculture. Most of its land users are small scale farmers. They live in environments characterized by highly erosive storms. The subsequent damage to land where soil is exposed is serious. Research findings indicate that productivity from such land with less than optimum cover during rains is generally low. This is attributed to the removal and reduction of the top fertile soil. The rooting depth is also reduced resulting into reduced efficiency of water and fertilizer use by the crops (El-Swaify, 1990). To achieve the national goal of food security, destruction of vegetation cover for agricultural and infrastructural development is inevitable. However there is need to reconcile between resource exploitation, conservation and environmental protection. Essentially, this approach constitutes sustainable agriculture, that is achieving the maximum production possible, combined with the conservation of the resource on which the production depends (Young,1989; Walsh,1991). The Technical Advisory Committee of the Consultative Group on International Agricultural research (TAC/CGIAR ,1988) defined sustainability as the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources.

Traditional indicators of erosion comprised irreversible gullies, sedimentation of bottom lands, dust storms and reduction in soil depth. Erosion was seen as mainly having physical repercussions on the soil. Therefore early research emphasized the need to trap sediment as a conservation measure, without much success. Today, erosion is regarded as only one form of soil degradation, including deterioration of physical, chemical and biological properties, all of which require attention.

Research work has shown that detachment of soil particles by high energy raindrops is a prerequisite to accelerated soil erosion. This is especially true in the tropics where the susceptibility of tropical soil to erosion by water has been attributed to climatic erosivity, rather than to high soil erodibility (Lo, 1990). The starting point for successful erosion control should therefore be the effective interception of the erosive raindrops. Vegetation cover therefore becomes the most crucial factor in controlling soil erosion. Research on cover provided by different crop species and under different cropping systems is thus very important considering that permanent natural vegetation is increasingly being destroyed in favour of a temporary cover provided by crops. Through such research, appropriate and effective soil and water conservation measures can be developed such as modifying certain traditional cropping systems/patterns to ensure all year ground protection.

This calls for the need to develop simple, consistent and accurate pieces of equipment for cover evaluation. In Zimbabwe, the quadrat sighting frame was recommended as the best method for field evaluation of cover for countrywide application (Stocking, 1988). In Alaska, the metre stick was recommended for evaluating residue mulch (Pierson, et al, 1982), and the point quadrat technique was recommended for quantifying cover provided by mixed communities of grass and shrubs (Vogel, 1987).

The challenge is now to improve on the design of already developed tools and also to recommend cover evaluation technique(s) for effective research and monitoring in Kenya. To achieve these goals, this research had the following objectives:

1. To test and evaluate four different methods of cover estimation; namely sighting-frame, photographic technique, ceptometer, and the metre-stick.

2. To recommend cover evaluation field technique(s) for application in soil and water conservation research in Kenya.

3. To improve the design of the equipment recommended and to standardize measurement and evaluation procedures.

4. To develop a simple empirical cover/Rainfall energy interception model for the cropping system practised at the steep lands research site (SAREC).

5. To discuss crop cover development trends and the conservation implications for the research site.

CHAPTER 2

LITERATURE REVIEW

2.1 Ground Cover

Vogel (1987) defined ground cover as the horizontal cover by the combined aerial parts of the vegetation and the litter it produces naturally on site. Crop residue cover is a combination of standing stubble and straw remaining on the ground after harvest (Molloy and Moran, 1991). Plant canopy cover on the other hand is the percentage of the soil surface shaded by the plant (measurements done at solar noon) (Adams and Arkin, 1977). Therefore, ground cover encompasses both on ground and above ground living and non living matter. The definition of the same by Gardner, (1989) has some erosion control management implications where:

1. Ca is the fraction of the soil exposed to the splashing action of raindrops. It is related to the above ground protection. The percentage cover (C) can be given as;

$$C = [1-C_a]\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[2.1]$$

2. Cr is the fraction of soil exposed to the shear stress due to runoff. It is related to the on surface protection and on surface roughness. The percentage cover (C) becomes;

$$C = [1-C_r]\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[2.2]$$

2.1.1 Vegetation Cover, Rainfall and Erosion

Heavy rainfall has a bomb-like effect on bare soil surfaces, (Fig. 2.1), (Ghadiri and Payne, 1977; Ghadiri, 1978).

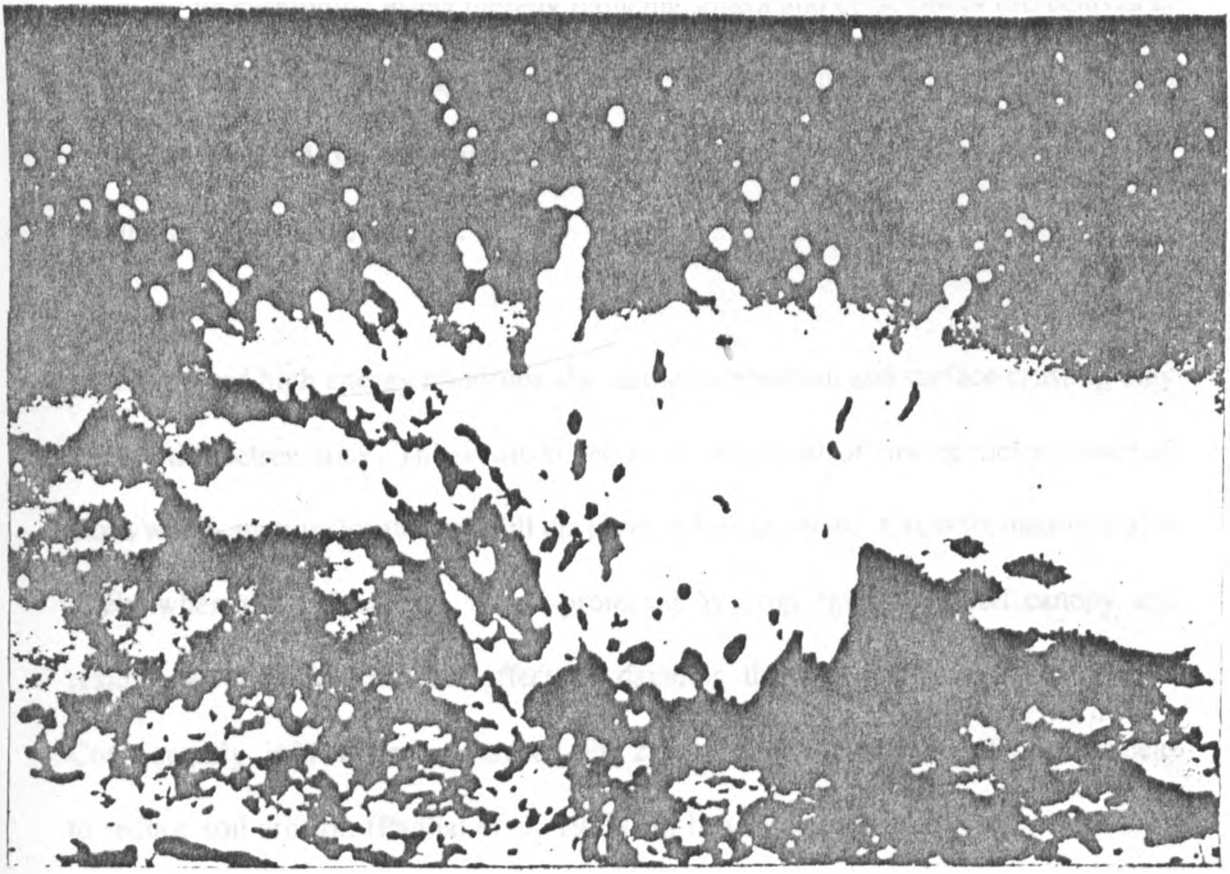


Fig. 2.1 Bomb-like effect of raindrops on bare soil surfaces. (source: Hudson,1986)

The single rain drop falling on unprotected soil has a momentum that produces a disruptive force on the soil particles (Morgan, 1986). Drop impacts break down soil aggregates and crumbs into smaller, more easily transported sizes. Impacting raindrops also detach soil particles from the soil mass and splash material in all directions especially downslope. They also break soil clods and release humus and clay materials which are carried into the soil profile with the effect of reduced soil permeability. Turbid water clogs the pores at the surface with the result of reduced infiltration (Meyer, 1981 and Jansson, 1982). Research work has shown that ground cover protects the soil against these disruptive forces of raindrops and high velocity winds by its cushioning effect thereby reducing splash and detachment (Screenivas et al, 1947; Elwell and Stocking, 1974; Holy, 1980 and Nair, 1984). The high Kinetic energy of the raindrops is dissipated by the canopy and the rain is thus released to the ground at non-erosive energy.

Unintercepted high energy raindrops also cause compaction and surface crusting only a few millimetres thick. This is attributed to the dispersal of fine particles from soil clods which are translocated to infill the pores (Morgan,1986). Crust formation is also likely when the soil surface is not protected by crop residue. Good canopy and residue cover minimize this effect by damping the energy of these raindrops. Consequently, infiltration is enhanced (Fig 2.2), and the reduced runoff volumes help to reduce soil erosion (Paglial et al, 1983). In Israel for example, measurements on sandy soils showed that crusting reduces infiltration capacity from 100 mm/hr to 8 mm/hr (Morin et al, 1981). Consequently splash and detachment are prevented while infiltration is facilitated.

Lal (1974) found out that the immediate soil loss when the structurally unstable tropical soils are exposed to the beating action of rain is alarmingly large. Hudson (1981) working at the Henderson research station in Zimbabwe, showed that the mean annual soil loss from bare ground was 4.63 kg/m^2 compared with 0.04 kg/m^2 from ground with a dense cover of Digitaria (Table 2.1). Hudson (1981) showed that the 10-year mean annual soil loss was 94 $tons/Km^2/yr$ and 12,657 $tons/Km^2/yr$ for soil covered with Mosquito netting a short distance above the soil surface and bare plots respectively. This observation indicates that ground cover splits the raindrops, alters their drop size distribution, impact velocity, and kinetic energy. The resulting decrease in splash and surface runoff is due to reduced drop momentum (Styczen and Hogh-Schmidt,1988).

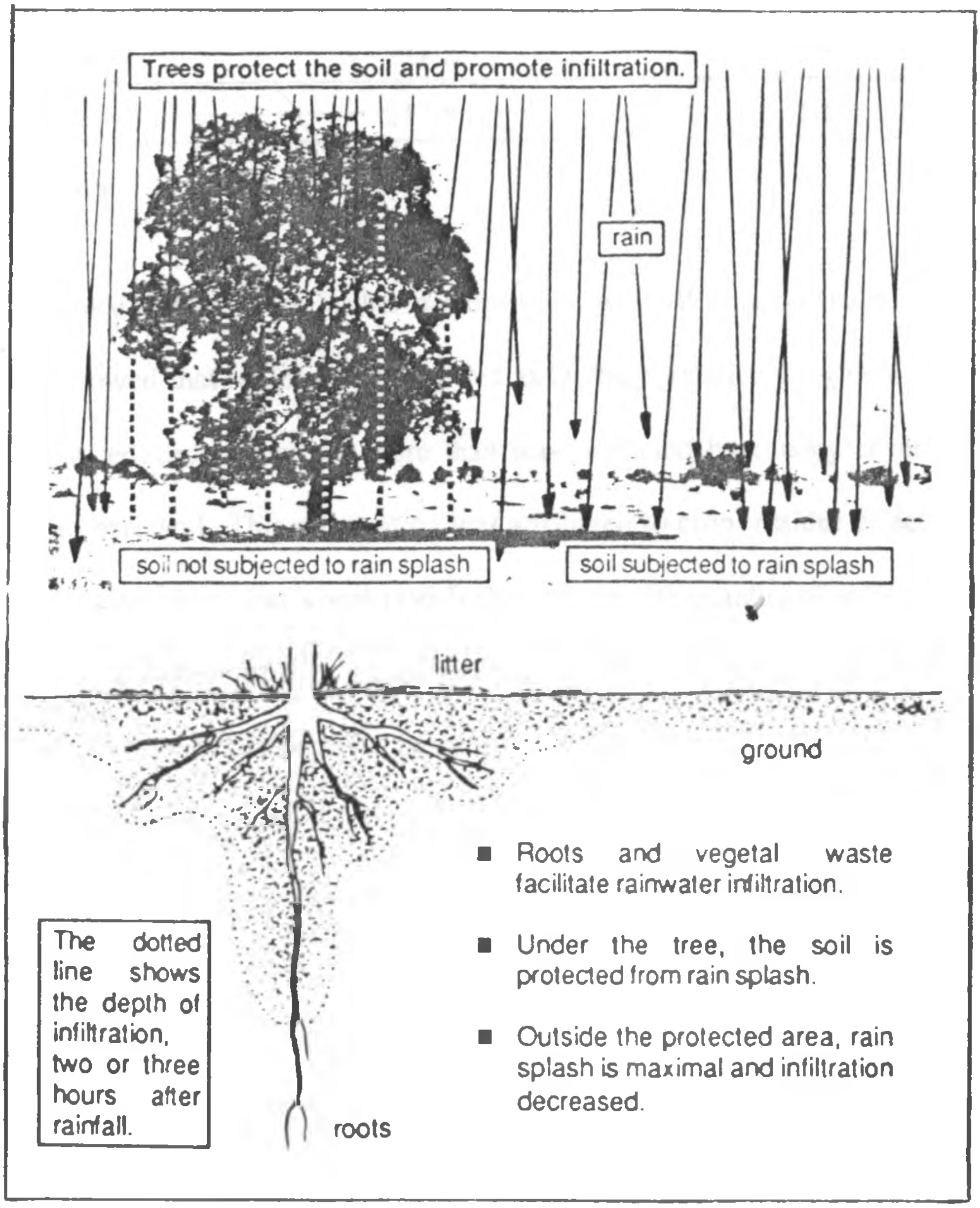


Fig 2.2 Effects of interception of raindrops by a plant canopy.
(Source: Chleg and Dupriez, 1988)

Table 2.1 Erosion from Bare and Grazed plots for a soil in southern Africa

Observation period	Bare plot (t/ha)	Grazed plot (t/ha)
1953-1954	156.2	0
1954-1955	573.5	2.3
1955-1956	153.7	5.1
1956-1957	139.7	0.3
1957-1958	56.1	0.3
1958-1959	222.8	2.8
Average	217.8	1.8

Source: Lal, 1990

The importance of cover was further demonstrated when Wilkinson (1975) working in Nigeria showed that Maize albeit regarded as having a relatively high erosion risk substantially reduced erosion by more than was predicted by canopy cover alone, compared to bare soil. This observation was attributed to crop residue effect on the surface. Hudson (1981) and Vogel (1987) showed that the quantity of splash erosion is related to the amount of bare ground exposed to the direct raindrop impact rather than the quantity of available cover per-se. The effectiveness of vegetation cover in controlling erosion is dependent on the evenness or distribution of cover over the entire space. As an energy intercepter, its effectiveness will depend on the factors explained below:

1. Height of Cover above the Ground Surface

Intercepted and attenuated raindrops can reform on the canopies and the through-fall can accelerate to erosive velocities if the canopy is very high. Water drops falling from 7m may attain over 90% of their terminal velocity (Morgan,1986). Tall growing vegetation also reduces ground cover and allows oblique raindrops to reach the surface at erosive velocities (Stocking, 1988). Although interception by canopies reduces the volume of rain reaching the ground surface, research has shown that the Kinetic energy is not significantly altered. It may even increase compared with that of open ground. This is because of the greater percentage of larger drops in the rainfall as a result of the coalescence of raindrops on the leaves (Mosley,1982; in. Morgan,1986). Wiersum (1985) recorded splash under Acacia and Beech canopies of 1.2 and 3.1 times above that in the open ground respectively. Similar results were obtained by Noble and Morgan (1986) and Finney (1984) when the canopy was found over a certain, but not excessive, often only 1m height. Lal (1990) noted that a complete cover within 50 cm of the soil surface is extremely effective in minimizing raindrop impact. Mati (1991) noted that generally splash detachment decreases exponentially with crop height. Natural vegetation at its climax provides the highest resistance to erosion. An area's susceptibility to erosion increases as soon as this natural cover is disturbed (Nair, 1984).

Therefore it seems likely that the generally observed lower rates of soil loss under forests are due to the decrease in runoff volumes due to interception and the higher rates of infiltration associated with better aggregated soils and the opening up of macropores in the soil by roots. El-swaify, (1990) attributed this reduction in splash

KABETE LIBRARY

under forest canopies to the accumulated litter layers and the short vegetation in the understorey. These observations led to the concept that the amount of detachment is proportional to the sum of the momentum of each drop in a rain event (Styczen and Hogh-Schmidt, 1988). This is because momentum is a measure of the pressure exerted by rainfall on soil, and thus a better indicator of the potential detachment.

2. Density and canopy structure

Canopy that offers a high proportion of sunfleck is a poor intercepter since a significant proportion of raindrops can reach the ground, uninterfered with. Small gaps in the canopy also reduce raindrop sizes. Splash is thus reduced due to the low raindrop momentum. Multistorey canopies can buffer both vertical and oblique raindrops. The through fall that threatens to attain the erosive velocity can effectively be buffered by the underlying canopies.

Orientation of the Leaves will determine the rate of interception, raindrop coalescence and the through-fall. Perfectly horizontal leaves will achieve high interception but also encourage coalescence with subsequent increase in splash depending on the canopy height. Highly inclined leaves will effect minimum interception of erosive raindrops.

3. Continuity 0f canopy

Ground cover that is continuous over time will ensure protection of the soil through the production period.

In the hill evergreen forest on Doi Pui, Thailand, research showed that runoff and erosion increased with increasing quantity, duration and intensity of rain. However, they varied inversely with percentage crown cover, increasing rapidly when the cover was below 70% and remaining nearly constant at crown cover of more than 70 % (Ruangpanit,1983). Research at Gunnedah research centre showed that increasing amounts of ground cover resulted into a curvilinear decrease in the average number of erosion events and in the average rate of erosion from about 40 kg/plot/yr with 10-20 per cent ground cover to 0.1 kg/plot/yr with complete vegetative cover (Lang and McCaffrey, 1984). Similar results were obtained by Elwell and Stocking (1974); Elwell, (1980); Shaxson, (1980); Ruangpanit, (1983); and Mati (1991).

There also appears to be a critical cover value below which erosion is significant and above which it is insignificant. Elwell and Wendelaar (1977) working on grassland splash erosion found this value to be 40% over bare ground when splash was reduced by about 85% - 90%. Similar results were found for other crops by Elwell (1980) and Elwell and Stocking (1974). In the sub-humid to semi-arid zones of south-eastern Australia Lang and McCaffrey (1984) found the critical cover for pasture land to be around 70 %. Of the perennial crops grown in Kenya, Tea if managed well can achieve a percentage cover of close to 100 % and erosion is assumed to be zero. However work by Othieno and Laycock (1977) revealed that if canopy is less than 65 % , soil erosion is significant. Mati (1991) showed that the total splash detachment per unit of rainfall was constant when cover was less than 40% for Maize, Beans, and their intercrop. However at cover values above 40%, splash per unit of rainfall was highest under maize and lowest under the maize-bean intercrop. Different farming systems offer different ground protection. For instance, soil erosion risks are in the order A<B<C (Fig 2.3). The conservation implication here is to ensure an early ground cover which offers sufficient ground protection when erosion risk is highest. This goal is subject to the applied agronomic methods.

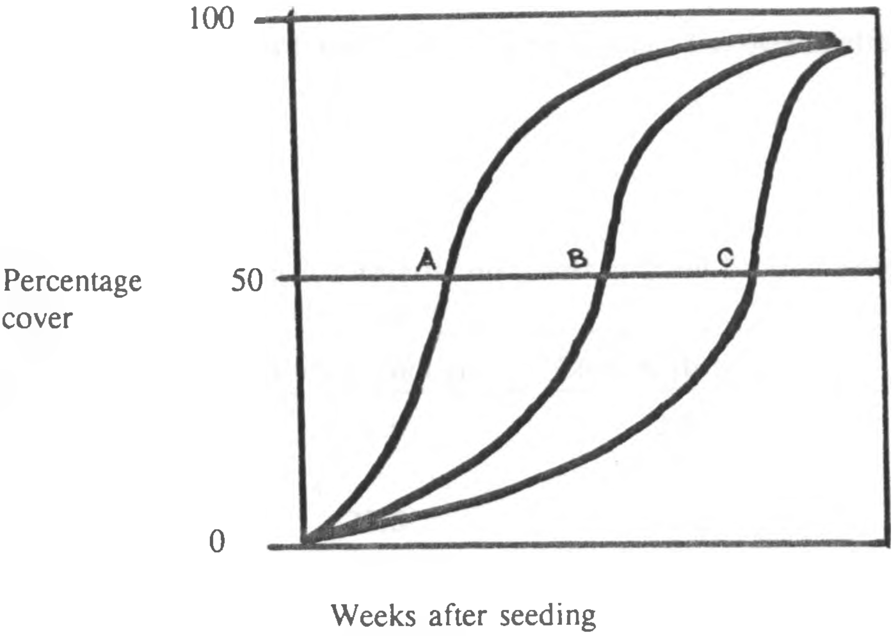


Fig 2.3 The relative effectiveness of different farming systems in erosion control (Adapted from Lal, 1990)

2.1.2 Vegetation Cover and Soil

The roots bind the soil particles together and also make the soil more permeable along the root channels. The shading effect of vegetation cover minimizes evaporation while transpiration increases the storage capacity of the soil Organic matter on the soil surface include mulch, leaf litter, decaying woody material and close growing vegetation. Besides interception, there is no remaining fall height to the ground for re-formed water drops. Hence the area on the ground exposed to erosion is reduced. The effectiveness of mulch as a soil cover for runoff control depends on its quantity, durability,and placement (Table 2.2). Surface roughness due to stalks and organic litter detain runoff and hence the scouring effect is minimized. Besides nutrient recycling, decomposing roots and litter add organic matter to the soil, and improve pores and soil structure (Noordwijk,1989). Water holding properties and enhanced biological activity are added benefits especially when Leguminous crops and trees constitute the cover. Mulch is quite important for water conservation during fallow periods, early crop growth stages and after harvesting. The overall effect is improved soil productivity.

Table 2.2 Effect of mulch material on runoff and soil Erosion under Maize for a Tropical Alfisol in Western Nigeria

Type of mulch	Runoff (mm/yr)	Erosion [t/(ha.yr)]
Unmulched control	52.9	2.5
Plastic sheet	23.6	0.65
Gravel	29.9	0.12
Grass straw	23.7	0.05
Leguminous straw	22.9	0.08

Source: unpublished data of R.Lal in Lal,1990.

These findings indicate that now that modern agriculture is quickly replacing forests with crops, farming systems and practices that maintain sufficient cover throughout the growing season can play leading roles in preventing soil compaction, detachment and erosion. Multiple cropping systems if properly practised offer multistorey canopies effective in protecting our soils from splash and detachment and hence erosion (Nair, 1984).

2.1.3 Spatial Variation in Vegetation Cover and Erosion

The spatial variation in vegetation cover and hence protection potential of the ground is caused by differences in climate, soils, topography and man's activities (Table 2.3). This makes erosion rates locality specific and they often follow a seasonal pattern. They however vary within a season based on the frequency and magnitude of specific storms. Vegetation cover growth rate follows a similar pattern but peaks up later in the season than the rainfall. Erosion risk is highest in the early part of the wet season when rainfall is high but cover has not grown sufficiently to protect the soil (Fig.2.4).

Table 2.3 Vegetation communities in order of decreasing protection against rain splash and erosion by overland flow

Temperate deciduous woodland
Temperate coniferous forest
Humid temperate grassland
Sub-tropical rainforest
Tropical semi-deciduous rainforest
Tropical evergreen rainforest
Mediterranean communities
Savanna woodland
Tree and shrub savanna
Steppe
Thorn shrub and other semi-arid communities
Tundra and montane communities
Extreme polar communities
Desert

(Source: Jansson,1982).

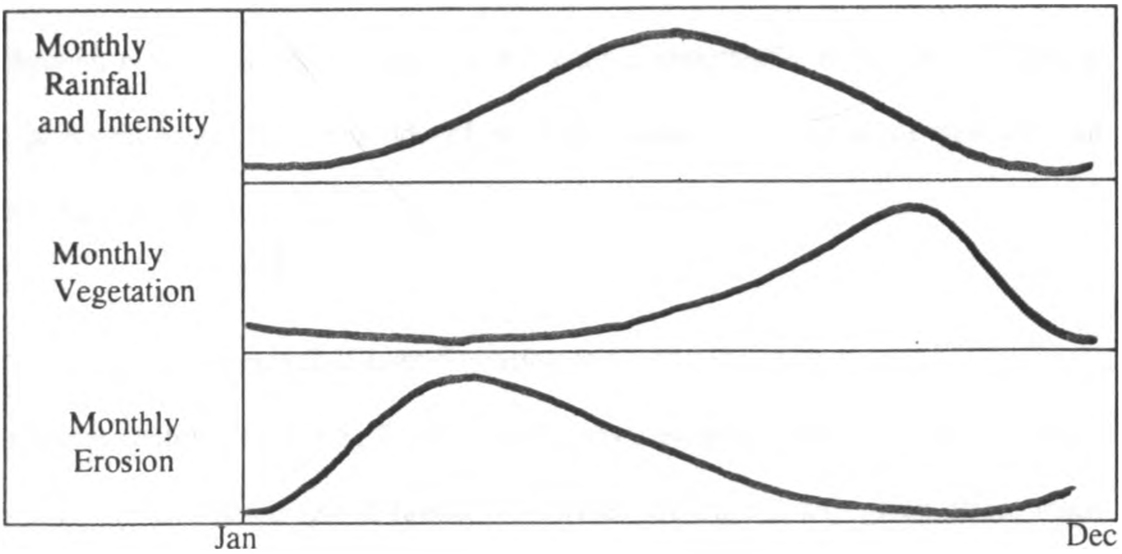


Fig 2.4 Seasonal cycles of rainfall, vegetation cover and Erosion in a semi-humid climate (Modified after Morgan, 1986)

2.2 Cropping Factors in Erosion Predictive Models

Through erosion prediction models, the relative importance of erosion influencing factors and processes can be identified. Appropriate soil loss control measures can thus be defined.

2.2.1 The Universal Soil Loss Equation (USLE)

In the modelling of the USLE, detachment was seen as the most limiting process in erosion. It was noted that if rainfall erosivities are high at any given place, much improvement is possible by improving the quantity of cover thus diminishing the amount of ground exposed to rainfall impact (Holzhey and Mausbach, 1977; Elwell, 1978). The equation is given below:

$$A = R.K.L.S.C.P \quad \ldots\ldots\ldots\ldots [2.3]$$

where:
A = average annual soil loss (t/ha/yr.)
R = the rainfall erosivity index ($J/m^2.mm/h$)
K = soil erodibility index ($t/ha/EI_{30}$)
L = slope length factor (dimensionless)
S = slope gradient factor (dimensionless)
C = cropping management factor (dimensionless)
P = Erosion control practice factor

In the strict sense the crop and management factor (C) as used in (USLE) includes interrelated effects of cover, crop sequence, productivity levels, length of growing season, cultural practices and residue management (Young, 1989). However, for ease of calculation, researchers tend to lay emphasis on cover alone because it is easy to quantify.

The universal soil loss equation was modified by Williams (1975) to incorporate the effect of peak runoff on soil loss. The modified universal soil loss equation (MUSLE) predicts soil loss from an event rather than on an annual basis alone and is given as shown in equation 2.4.

$$\mathbf{E = 11.8\ (Q.Q_p)^{0.56}\ KLSCP/A\ \ldots\ldots\ldots[2.4]}$$

Where: E = event soil loss (t/ha)

Q = event runoff (m^3)

Q_p = Peak runoff rate (m^3/sec)

K = Soil erodibility factor (t/ha/EI_{30})

LS = Slope length and steepness factor

C = Cover management factor

P = Support practice factor

A = Catchment area (ha)

Revised Universal Soil Loss Equation (RUSLE) on the other hand is a computer package for the USLE to deal with more complex problems. This has been necessitated by the increase in data and computations required. Although it retains the six factors of USLE, some of the factors have been modified to include numerous sub-factors, whose most likely values at a particular location can be expressed numerically. Technology for evaluating the factors has been altered and new data added.

The cover management factor (C) for instance has been altered to a continuous function that is a product of four subfactors representing prior land use (PLU), surface cover (SC), crop canopy (CC), and surface roughness (SR). (Renard et al, 1992). RUSLE predicts the long term average annual soil losses (A) carried by runoff from specified fields in specified cropping and management systems as well as range.

2.2.2 The Wind Erosion Prediction Model

As an erosion prediction model, (Equation 2.5), maintenance of sufficient vegetation cover is the cardinal rule for controlling wind erosion (Skidmore, 1988).

$$E = f\ [I.K.C.L.V] \qquad [2.5]$$

where: E = predicted annual soil loss (mt/ha/yr)

I = soil erodibility (t/ha/yr)

C = climate factor (dimensionless)

L = width of field factor (m)

V = Quantity of vegetation cover expressed in kg/ha

K = a soil ridge roughness factor (dimensionless)

Unlike the USLE, the wind erosion prediction equation allows for factor interactions and so can not be solved by multiplying the parameter inputs. Instead predictions can only be obtained by use of complicated nomographs or specially developed equations in a set sequence (Morgan, 1986).

2.2.3 Soil Loss Estimation Model for Southern Africa (SLEMSA)

SLEMSA (Equation 2.6) was developed to suit tropical conditions in view of the site specificity of empirical soil loss estimation models (Elwell, 1984). The C-factor plays a vital role in the interception of high intensity tropical rains for a variety of cropping conditions.

$$Z = K.C.X \qquad [2.6]$$

where:

Z = predicted annual soil loss (t/ha/yr)

K = Combines the effects of rainfall energy and soil erodibility index from a conventionally tilled bare field (4.5% Slope and length 30 m. (t/ha/yr)

C = crop ratio factor (Is derived from the proportion of rainfall energy intercepted by crops and corrects the soil loss estimate for cropped land

X = topography ratio

2.2.4 Cover Erosion Response Model for Grazing Areas in Semi-arid Eastern Kenya

According to this model, soil loss from a grazed area is directly influenced by the area's susceptibility to erosion (Zobisch, 1986). An area's susceptibility to erosion (E_a) is given as:

$$Ea = \frac{K.L.S}{Veg} \qquad [2.7]$$

where: Veg = average seasonal fraction of cover

K = Soil erodibility index

L = Slope length (m)

S = Slope steepness

It is apparent from Equation 2.7 that an area's susceptibility to erosion increases with decreasing ground cover. The soil loss (A) per unit storm is given by:

$$A = \frac{E_a - 0.76}{0.15} \quad g/m^2/mm \ of \ r/f \qquad [2.8]$$

2.2.5 Modern Computer Based Process Models: PERFECT MODEL, GAMES MODEL, ANSWERS MODEL and WEPP MODEL

Productivity, Erosion, Runoff Functions to Evaluate Conservation Techniques (PERFECT) is a model that simulates the plant-soil-water management dynamics in an agricultural system (Littleboy et al, 1989). Management in agricultural systems are dominated by soil modifications and crop husbandry and hence the significance of ground cover. PERFECT calculates runoff as a function of daily rainfall, soil water deficit and surface residue and crop cover. As the name suggests, PERFECT can be used to investigate the management options in an agricultural system on the systems inherent properties and on outcomes.(e.g. effect of certain conservation measures on erosion and productivity). As a tool for extension work, PERFECT can therefore be used to select appropriate conservation techniques for sustainable agriculture.

The Guelph Model for Evaluating effects of Agricultural Management Systems on Erosion and Sedimentation (GAMES) was developed to identify erosion "hot-spots" within a watershed so as to develop remedial conservation systems. These erosion hot spots are identified based on set tolerance limits on both the soil loss and sediment yield. They are areas without cover and /or with high erodibility indices. The GAMES model can simulate soil loss within grids or cells in a catchment. Calculation of soil loss from each cell requires inputs of USLE parameters, which must be season specific and hence importance of ground cover. Output is a computer print out that details the rates and quantities of erosion and sediment delivery to the stream from each cell.

Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) was developed to simulate the behaviour of watersheds having agriculture as their primary land use, during and immediately following a rainfall event. The role of cover is reflected in the land use. Different agricultural systems will offer different quantities and qualities of cover for ground protection. ANSWERS has an inherent ability to simultaneously simulate conditions at all points within the watershed. This makes the model suitable for planing and evaluating various strategies for controlling nonpoint source pollution from intensively cropped areas .

The USDA-Water Erosion Prediction Project (WEPP) represents a departure from factor based erosion prediction technology to a new process-based technology. It is designed to be used for soil and water conservation and Environmental planning and assessment (Flanagan and Lane 1991). Although it can be run on a single - storm basis, WEPP is intended to be executed primarily as a continuous simulation model. That is it "mimics" the processes which are important to erosion prediction as a function of time, and as affected by management decisions and climatic environment. WEPP erosion model uses a plant growth model to estimate the quantity of crop residue present on the soil surface for each day through the year. It also adjusts surface cover as a function of processes that directly affect it such as tillage and leaf drop during senescence. WEPP's ability for continuous simulation should allow the model to evaluate an alternative management system within a minute (Laflen et al, 1991). The model is to be delivered in three versions; profile version, watershed version and grid version. It can thus predict soil loss and sediment yield from any unit space disturbed in one way or another.

As a guide to appropriate conservation planning, a conservation strategy is considered satisfactory when the average soil loss (A) is equal or less than the soil loss tolerance (T), (i.e the maximum rate of soil erosion that can occur and yet permit crop productivity to be sustained economically (Renard et al 1992). For example T can be substituted for (A) in the universal soil loss equation and the maximum allowable crop management (C_m) factor determined thus:

$$Cm = \frac{A}{R.K.L.S.P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots [2.9]$$

Cropping patterns and systems that give C_m values less than the computed Cm above should be considered as possible solutions to reduce soil loss.

As a strategy for soil conservation planning, the promotion of vegetation, or a biological approach to soil conservation is the single most important factor in soil erosion control in the tropics. However, to be fully effective, it requires continuous, sensitive and knowledgeable management of both the soil and the crop . Its cost effectiveness makes it a goal achievable by small or large, rich or poor farmers alike (Stocking, 1988).

2.3 Cover Evaluation Techniques

Since the management of residue and canopy cover has been identified as one of the most important tools for protecting cultivated fields from erosion, there has been an increasing need to establish suitable methods of estimating cover rates critical in soil conservation. Most of the techniques in use today are for quantifying residue cover. However with slight modifications, they can be used for evaluating canopy cover.

2.3.1 Overhead Photography

The photographic method has been used widely for estimating residue cover (Elwell and Gardner, 1975; Amphlett, 1986; Morrison et al, 1989 and Molloy and Moran, 1991). The procedure normally used involves attaching the camera to a pole and suspending it vertically over the area to be sampled, and a series of photographs taken (Plate. 3.2). Crop cover colour films (slides) are analyzed by projecting onto a standard dot grid. Percentage cover is estimated by counting the number of grid points intercepted by the crop and expressing this number as a percentage of the total number of grid points. The camera height of 4.3 m, necessitates that the shutter be activated by a self timer or an extension cord.

The photographic method has a tendency of over estimating the percentage cover especially due to crop height because the ground is viewed at an angle at the edges except at the photographic centre. Elwell and Gardner (1976); Williams (1979) noted that errors can be significant when estimating vegetative crop canopy cover due to changes in crop height. The relationship between the apparent (projected) area of cover (w_i^2) and the true area of cover (w^2) is given by:

$$w^2 = w_i^2 [\frac{(H - h)}{H}]^2 \quad . \; . \; . \; . \; . \; . \; . \qquad [2.10]$$

Where: H : height of Camera above the soil surface.

h : height of canopy above the soil surface.

It is apparent that viewing errors with the photographic technique increase with increasing canopy height (Appendix. 2). With crop residue cover which is flat on the ground, the error is negligible (Molloy and Moran, 1991). As an example, the correction factor for residue thickness of 30 mm and a camera height of 3 m from the ground surface is 0.98. For a canopy height of 1 m and the same camera height, the correction factor becomes 0.44. Note that 0.98 is closer to unit than 0.44 is.

Consequently the technique was found most suitable for residue cover estimation. However with correction factors, this method was successfully used for estimating crop canopy cover (Molloy and Moran, 1991).

The photographic technique is non destructive and is time efficient in the field (requiring only a single operator) once an appropriate boom and camera combination has been assembled. It can also be used in cloudy conditions and at all times of the day, although shadows may cause problems; in which case a flash is used to minimize shadow effects. It also provides permanent records of residue and canopy cover. However counting the dots on the overlay is tedious and the results are not readily available since processing of films takes time. Moreover results can be lost if processing is done carelessly. The method is also expensive and will require some fore knowledge.

2.3.2 The Sighting-frame

The sighting-frame technique was based on the common point quadrat used in botanical analysis only that the wire droppers were discarded and measurements made by sighting through two vertically aligned holes (Fig. 2.5). Cackett (1964) working in Zimbabwe used such a tool with an accuracy of ±2 % based on 100 hole observations. On the contrary, Elwell and Gardner (1975) found that a total of 1000 sights would be needed to achieve a -+2 % accuracy for uniform cover conditions and 300 sights for a 5% accuracy where cover is variable.

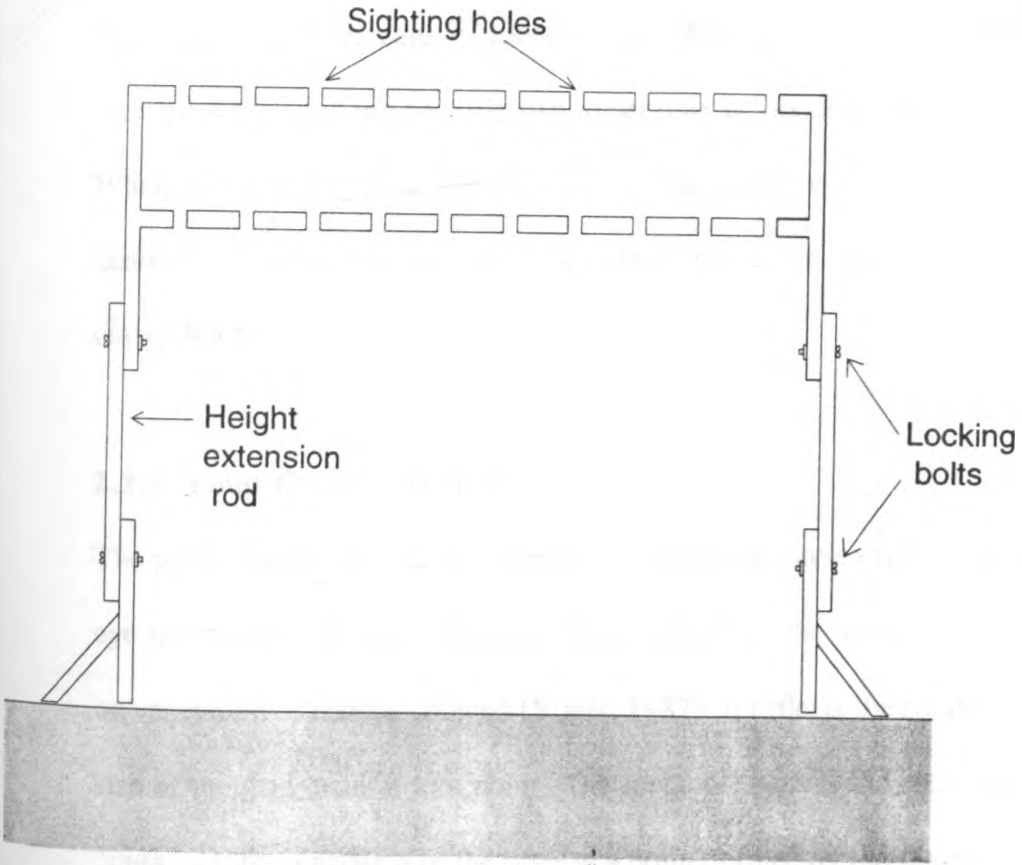


Fig. 2.5 Sighting frame set up (After Cackett, 1964)

The frame has a finite number of holes (10) and it is moved randomly to a finite number of placements per plot. The tool is placed perpendicular to the crop rows but position across the row was immaterial provided the holes are correctly spaced. The observer then peers in the holes to determine the presence of either zero cover, half cover, or full cover. For every frame placement, the percent cover was expressed as the fraction of holes that show a vegetation. The average of the replicates is taken as the field's representative cover. The 0-0.5-1 system of evaluation is subjective and erronous since any hole coverage between zero and full is taken as half cover.

Cackett (1964) recommended the tool for short growing crops and tall crops until the time the crop leaves start to interfere with the lower bar. With the use of extension legs, and a light Aluminium step ladder, it has been used satisfactorily on tall crops like Maize and Sugarcane (Cackett, 1964; Mati, 1991). The accuracy of ±2 % is seemingly high and can be attributed to parallax errors and also fewer sighting holes. When the crop height is limiting, the sighting frame can be converted into a point quadrat by introducing 'Hit pins' and adjusting cover values with the appropriate correction terms.

2.3.3 Point Quadrat Method

The point quadrat (Fig. 2.6) resembles the sighting frame except that the observation eye is replaced with pins which are dropped through the holes and the number of hits on vegetation or residue counted (Vogel, 1987). It reflects the concept of reducing the size of the grid quadrat to a point. The method involves the recording of a "hit" or "miss" on the vegetation or the litter at a point defined by the sharpest tip of the pins.

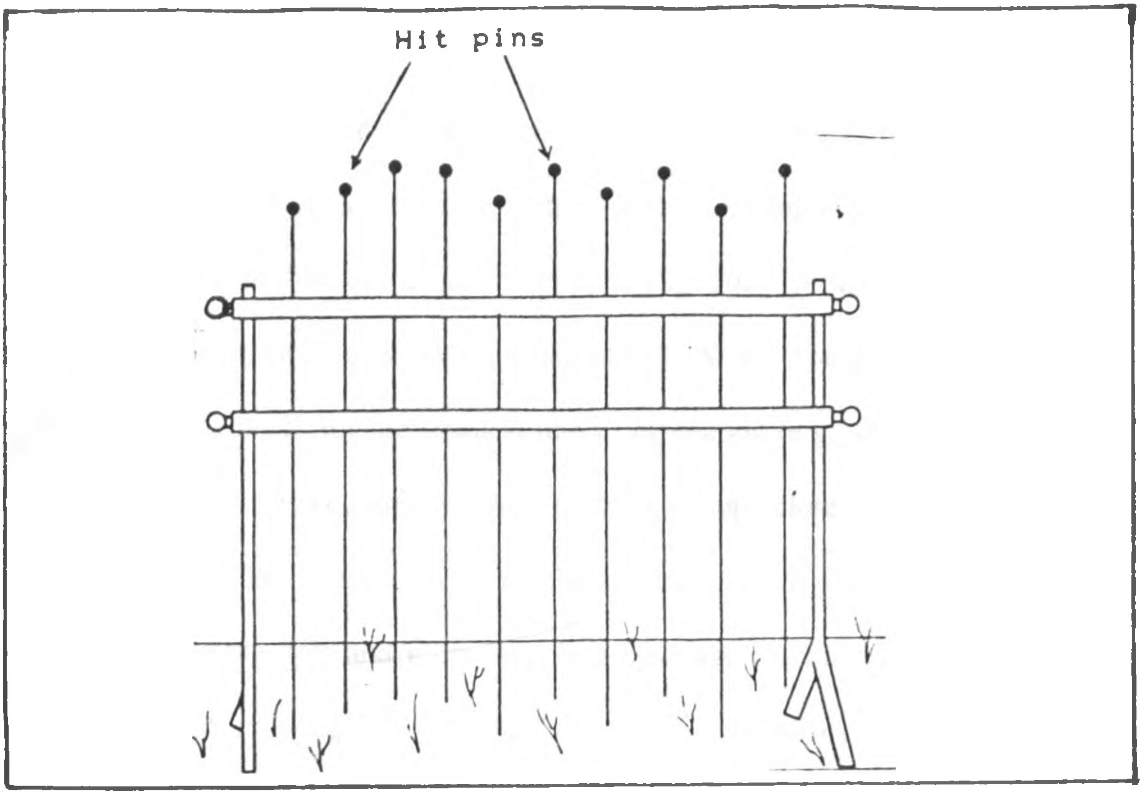


Fig 2.6 Point quadrat method (not to scale)
Source: Vogel, 1987.

The percentage cover (%C) is given by the equation:

$$\% C = \frac{Number\ of\ Hits}{Total\ Number\ of\ Points} . 100 \ldots [2.11]$$

With the eye replaced, the method is accurate, repeatable and reasonably objective. However as with the sigthing frame, maintenance of verticularity of the tool reference to the ground is imperative. The method is also limited to measuring relatively low growing herbaceous and dwarf-shrub vegetation. Vogel,1987 noted that 30 inches is about the maximum height that can be measured effectively or conveniently.

2.3.4 Grid Quadrat

The grid quadrat is a canopy measuring frame usually 1 m^2 However size and shape can be varied to suit the structure of the vegetation being evaluated. It can be made of wood or metal. Use of the quadrat improves accuracy because it is easy to estimate ground cover in small defined plots than in large areas. The grids within the canopy represent references for the smallest unit of estimation (e.g. 4% cover for each grid in figure. 2.7). The equipment is held over the canopy close to the crop manually or over a stand. The observer envisions the number of grids with canopy from above. Squares showing half and more than half coverage of canopy are counted as full cover. Those showing less than half are counted as zero cover. The equipment should be suitable for low, spreading crops with relatively large leaves. For tall crops, tripod ladders should be used to ease observations. Two researchers are needed for data collection. The human subjectiveness in assessing the grid coverage makes the technique very erroneous. However, accuracy can be improved by making the grids even finner although counting becomes tedious. An alternative approach is to fit hit pins at every grid line intersection so that the estimated cover is the fraction of pins that strike a score on a vegetation.

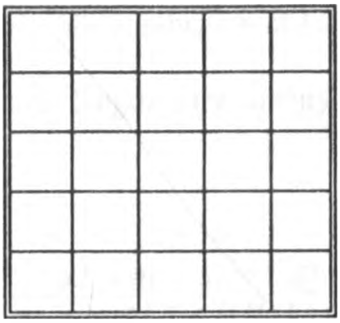
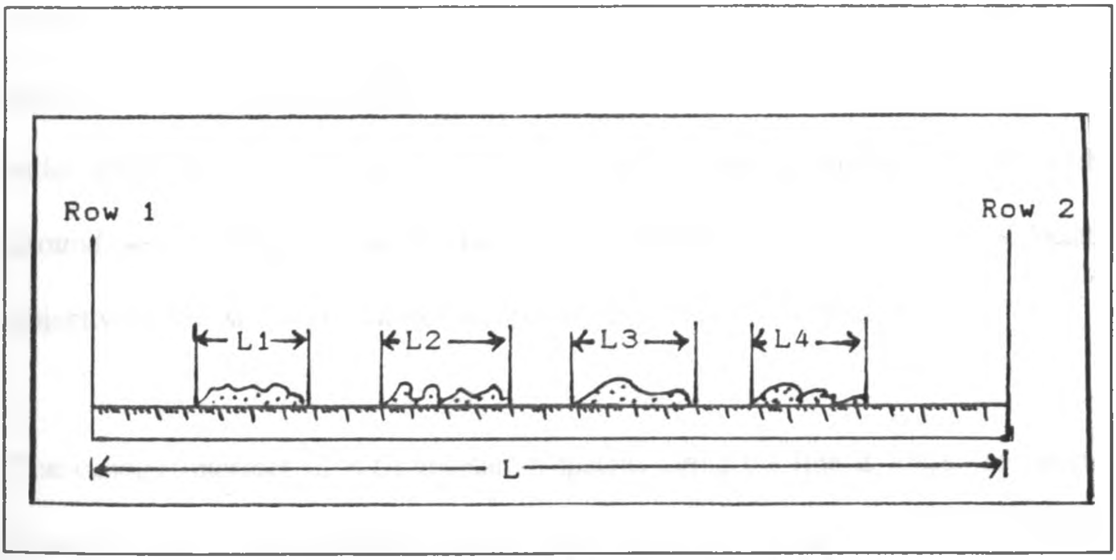


Fig.2.7 Grid quadrat technique (not to scale).

2.3.5 Metre-stick

The metre-stick technique was designed to estimate residue cover (Fig. 2.8). It involves placing a metre stick or a graduated ruler on the ground (soil surface) perpendicular to the plant row. Beginning at one row and ending at an adjacent row, the total length of residue along one edge of the Metre Stick is measured. Crop residue coverage is the total length of residue divided by the total length of the metre-stick (Adams and Arkin, 1977 and Hartwig and Laflen, 1978).



$$\%\ Residue\ cover = \left(\frac{L1 + L2 + L3 + L4}{L}\right)100 \qquad [2.12]$$

Fig. 2.8 Metre stick method for measuring residue cover (not to scale).

For canopy cover, the summation of lengths of shadows projected on the metre stick divided by the total length is the canopy coverage. Percentage cover (C) is then given by:

$$C = \frac{Total\ Length\ of\ Shadow}{Total\ Length\ of\ Metre\ Stick}.100 \quad \ldots\ldots\ldots\ldots [2.13]$$

Adams and Arkin (1977) further showed that a single measurement of cover perpendicular to the rows was as accurate as the mean of 21 interrow measurements. parallel to the crop rows.

2.3.6 Line Intercept Method

The intercept technique was useful mainly for measuring aerial cover of plants and clumps of plants with well defined canopies and nearly solid crown cover and plants with relatively large basal areas (Vogel, 1987). The procedure involved stretching a tape or a line of predetermined length across the vegetation or beneath the canopy of taller shrub and tree vegetation. Some type of clumps or holder anchored in the ground was necessary to secure the tape on each end. The lines should be located objectively and stratified-random sampling design should be preferred.

The canopy intersect of each vegetation species along the line is measured directly from the tape or with a rule and the percentage cover expressed as the total length measured over the length of the tape. Sloneker and Moldenhauer (1977) adopted a different approach. They put a finite number of beads (100) at equidistant intervals (6 inches) on the tape (string). The tape was stretched across the crop rows, oriented such that each end of the string is over a row. The percentage cover (%C) was estimated dy the equation:

$$\%C = \left(\frac{No.\ beads\ that\ hit\ a\ vegetation}{Total\ No.\ of\ beads}\right)100 \qquad [2.14]$$

The results of this evaluation have been used in the United States to provide an indication of the least crop residue cover necessary for the protection of soil against wind erosion in various production areas (Miller, 1985). This method was recommended for crop residue cover evaluation where several hundreds of acre are to be sampled since its time saving. For tall crops, two tall people are needed, one to stretch the string over the canopy while another counts. Alternatively height extension legs attached at each end which can be pushed into the soil may be used.

2.3.7 Residue Dot Counter

A marked plexiglass plate is placed on the representative areas of the field and the number of dots that have residue in contact with them counted. The plexiglass plate usually has 100 dots. Hence if 42 dots are in contact with residue, the percentage residue cover (C_R) will be 42.

2.3.8 The Wheel Point Technique

A spoken wheel is pushed along a line transect. Cover is recorded if plants are struck by the spokes at the ground surface (Tidmarsh and Havenga, 1955). Percentage cover is expressed as number of spokes that strike residue over total number of spokes times 100. This method is only suitable for pasture assessment especially where species identification is needed and also residue assessment. It is also associated with mechanical disturbance and destruction of the vegetation. Hence its use should be restricted to residue cover and pastures.

2.3.9 Determination of Ground Cover Using Photosensitive Light Sensors

Measurements of ground cover by canopy foliage are used to evaluate the effectiveness of sunlight interception in photosynthesis and evaporation. Cover measurements could also indicate the ability of various row crops and cropping systems to intercept rainfall and reduce runoff and hence minimize erosion (Adams and Arkin, 1977). The study suggests that it is possible to come up with appropriate cropping systems and patterns that will offer sufficient cover throughout the year to control soil erosion and still attain admirable yields on a sustained basis. Some of the light sensors used include the Spatial Quantum Sensor (SQS), Traversing Quantum sensor (TQS) and the Sunfleck ceptometer (SF-80).

The SQS is a box like metal/bar with a light transmitting upper surface connected to a meter that records light intercepted by the upper surface of the bar. It instantaneously integrates irradiance along the 1 m long sensor. The ratio of light transmitted to the SQS on the soil surface to the light measured with SQS above the plant canopy is the proportion of light transmitted to the ground (T) (Adams and Arkin (1977). Consequently the per cent ground cover (%C) is given as:

$$\%C = 100 - T\% \qquad [2.15]$$

where T = Proportion of light transmitted to the ground

UNIVERSITY OF NAIROBI
KABETE LIBRARY

The SQS, although fastest (requiring about 10 sec to read the meter and record the data) , is not readily available commercially and thus its application is limited especially in less developed countries.

For the Traversing Quantum Sensor, voltage output of the overhead and traversing quantum cells are integrated separately and simultaneously during the traverse. Ground cover is computed from the light transmitted to the sensor (Adams and Arkin, 1977). Apart from being expensive (requires an A.C. power source that is not available under most field conditions).

The SF-80 (Plate 2.1) is an electronic device that provides adequate samples for accurate light measurements in plant canopies, important in biomass production experiments in plant communities. An added use is the measurement of sunflecks also called canopy gap fraction. Sunflecks measurements therefore provide indirect ways of estimating canopy cover. Model SF-80 has 80 light sensors placed at 1 cm interval along the probe. All these sensors are scanned by a microprocessor to determine how many are in sunfleck and thus what fraction is sunfleck for the canopy.

Plate 2.1 The Sunfleck ceptometer (SF - 80)

There occurs extreme spatial variation of irradiance in the canopy under normal conditions. For instance, in the photosynthetically active radiation (PAR) waveband, 400 - 700 nm, irradiance can vary from full sun to close to zero over a space of few centimetres. This necessitates a high number of samples in the canopy for accurate evaluation. The 80 sensors on the probe are equivalent to 80 point sensors at any given placement of the probe, apparently an important adaptation to reduce the number of samples.

Although the Ceptometer has several other advantages, (Appendix. 1), it is expensive, not readily available locally, it requires great care in handling, and if light along the probe is even, the SF reading will be 100% regardless of the strength of the light. Hence occurrence of shadows is imperative for reliable application. Changing light intensities also dictate the establishment of a new threshold when the manual threshold is used. The automatic threshold is most reliable under dynamic light intensities. Results obtained are also determined by placement positions; across, diagonal or along the row. It is important to restrict oneself to one placement pattern and always to ensure that the whole probe is under the canopy.

2.4 Comparison of Cover Evaluation Techniques

Most techniques of measuring ground cover are not accurate (Corak et al,1993). Morrison projected simulated residue cover values onto screens with 200 randomly positioned dots. Measured cover values exceeded actual cover values by 4 to 6 percent points. Corak et al (1993) compared cover values measured by computerized image analysis of tracings of residues on acetate film tapes, cover measured by dot screens, and image analysis of video-taped pictures. They concluded that although the tracing method was time consuming, it could be used as a bench mark for testing the accuracies of other methods.

Laflen and Hartwig (1978) compared the metre stick and the camera and found out that although the metre stick method gave slightly lower results than the camera, statistical evidence showed that at 95% CI the results were not significantly different. However due to variability in residue distribution, 10 trials were recommended as acceptable to estimate crop residue cover. In row crops, canopy variability is seldom high and thus 10 trials may not be required.

Laflen et al (1981) added the line transect method to this comparison and found out that the line transect method had higher precision compared to the metre stick and camera. They also recommended at least 5 observations per method to minimize errors.

Work by Adams and Arkin (1977) on grain sorghum showed that cover values with SQS were higher than those with TQS and there was a significant difference at 5% between Y-intercepts of the regression equation; however no significant difference occurred between the mean cover values. The metre stick and SQS also gave no significant difference in cover parameters.

Elwell and Gardner (1975) evaluated the photographic technique and the quadrat sighting frame, and concluded that the sighting-frame is the better method for routine field measurements of cover.

Such comparisons are necessary if specific pieces of equipment are to be recommended as appropriate technology for research and monitoring. A technique is said to be appropriate technology when it is technically feasible (High precision, portable and easy to handle), economically viable (locally available materials for construction and cost effectiveness), and socially acceptable (not complex but easy to be used by farmers).

2.5 Need for Standardization of Cover Evaluation Procedures

Cover estimation techniques that rely on visual assessment albeit the simplest and fastest, are also the least repeatable, least accurate and most subjective of any estimation method used (Vogel, 1987). Even among trained observers, estimates of cover on a given area may differ by as much as 25% and the accuracy by such methods is higher as cover approaches 0 or 100% (Vogel, 1987). Pierson et al (1988) showed that observations for cover assessment with a line transect method by experienced observers alone had no significant differences among individuals. However for inexperienced observers alone, observations had significant differences among individuals. Differences between experienced and inexperienced observers were apparent. They concluded that inexperienced observers can be used to measure crop residue cover when paired with experienced observers and trained prior to making residue measurements.

The number of observers was also shown to influence the time -effectiveness in the measurement of crop residue cover. Curran and Williamson (1985) concluded that a few accurate measurements could provide a better estimate than a great number of less accurate measurements. Laflen et al (1981) working on plots of 23m x 29m recommended 5 measurements per site for field use. Researchers however concur that the number of measurements should be increased as the field size and field variability increase.

The Metre-stick technique is even more difficult to use, being weather dependent. Few accurate measurements, apart from giving a better estimate of cover especially during unstable conditions of irradiance and cloud cover, also help the researcher to keep within solar noon limits.

2.6 The Rainfall Interception Model

The rainfall interception model, (Fig. 2.9) is the relationship between seasonal rainfall energy and cover through the growing season (Stocking, 1988). It is a basis for computing interception energy. Vulnerability of a given field to erosion can easily be assessed and hence appropriate soil conservation measures taken.

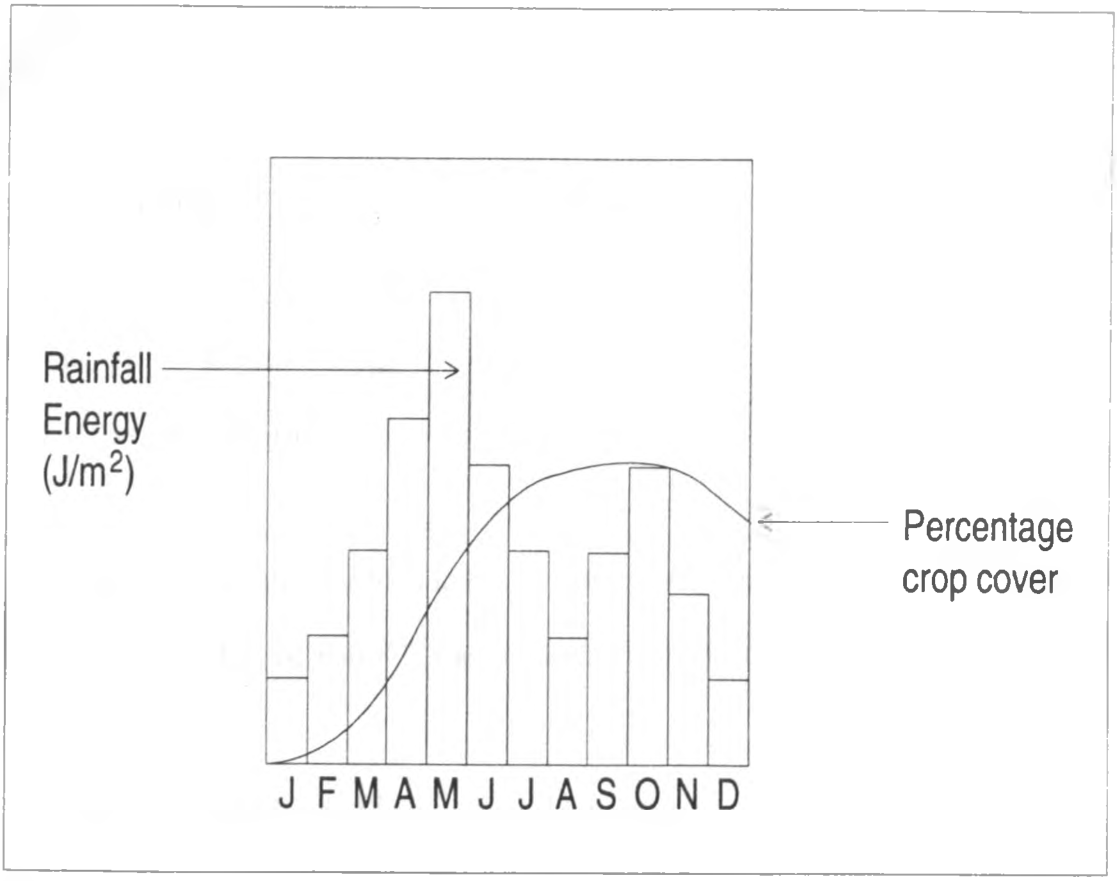


Fig. 2.9 Rainfall interception model (Hypothetical)

2.6.1 Rainfall Kinetic Energy

Rainfall erosivity is a function of the kinetic energy and rainfall intensity for a specified duration. Rainfall characteristics are locality specific. Consequently, relationships between Kinetic energy and rainfall intensity will vary for different places. Rainfall amounts that are required to induce significant erosion are important in conservation planning. Researchers concur that most erosion occurs in moderate events exemplified by rain storms yielding 30 mm/hr to 60 mm/hr (Morgan, 1986).

A 25 mm/hr intensity was found to be critical rainfall intensity for erosion in Zimbabwe. Consequently, the erosivity index was computed based on these intensity. For tropical storms, Elwell and stocking in: Hudson (1981) obtained the following equation for southern Africa:

$$\mathbf{KE = 29.8 - 127.5/I \ldots\ldots\ldots\ldots\ldots\ldots [2.16]}$$

Where; KE = Kinetic Energy (J/m^2)

I = Intensity (mm/h) .

This formula is suitable for high intensity storms only. In Nigeria, Lal (1981) quoted in Mati (1991) showed that KE was related to rainfall intensity as follows:

$$\mathbf{KE = 18.18\, I_{30} + 18.8 \ldots\ldots\ldots\ldots [2.17]}$$

where: KE = Kinetic energy (J/m^2 /mm).

I_{30} = Maximum 30 minute intensity (mm/hr).

Wischmeier and Smith (1958) quoted in Morgan (1986) obtained a general relationship between KE and rainfall intensity, thus:

KE (J/m^2 /mm) = 11.87 + 8.73 log I ....[2.18]

In Italy, Zanchi and Torri (1980) in: Morgan (1986) carried out similar research and obtained the ralationship below:

KE (J/m^2 /mm) = 9.81 + 11.25 log I ....[2.19]

2.6.2 Computation of Rainfall Kinetic Energy (KE)

To compute KE of a storm, a trace of the rainfall from an automatic recording rain gauge is analyzed and the storm divided into small time increments of uniform intensity. For each time period, knowing the intensity (I) of the storm, the KE is calculated by any of the equations above. This multiplied by the quantity of rain received gives the total KE for that time period. However to be valid as an index of potential erosion, an erosivity index based on critical rainfall intensities and correlated with soil loss must be developed (Morgan, 1986).

Seasonal interceptive efficiency of vegetation was shown to be one of the key parameters used in the soil loss estimation development and thus an important conservation planning guide in Zimbabwe (Elwell and Stocking, 1974). It was also on the basis of such research that Zimbabwe scientists established a vegetation cover data bank (V.C.D.B), with cover measurements and crop hazard ratings included for different crops. The V.C.D.B. is now an important tool in assigning the most effective erosion control cropping system on specific parcels of land in Zimbabwe.

Appropriate conservation measures should therefore entail the understanding of the complex interaction among vegetation, slope, soil type, rainfall and man's activities. Hence the need for integrated approaches to soil conservation.

CHAPTER 3

MATERIALS AND METHODS

3.1 The Research Site

The site occupies approximately 4 ha of land at Kabete Campus of the University of Nairobi. A detailed soil survey of the site was done by Gachene (1989). Based on the FAO-UNESCO classification system, the soils are humic Nitisols. They are well drained, very deep, dark red, friable clay soils. Mati (1991) found the soil texture to be 19% sand, 21% silt, and 60% clay. The textural triangle classifies such soils as clay soils (Hillel, 1982). The area is comprised of gently undulating to hilly topography with a slope range of 8% - 30%. The altitude range is 1850 - 2400 m a.s.l.

A mean annual rainfall of about 925 mm normally falls in two seasons: short rains (Oct - Dec) and the long rains (Mar - May).

Temperatures range from a maximum of 25.6°C in February to a minimum of 13°C in July -August; however the annual mean temperature is 19.4°C. Extensive cloud cover is common during the month of July - August accompanied often with a slight drizzle. These research site lies in agro-climatic zone III (semi-humid). It has a high potential for plant growth and supports a moist and dry forest kind of natural vegetation (Agro-climatic zone Map of Kenya, 1980).

3.2 Experimental Set Up

3.2.1 Treatments

Table.3.1 below shows the treatment combinations that were used. The four terraces A1-A4 (Fig. 3.2) at the research site represented the replicates. In total this experiment had 48 treatment combinations.

Table 3.1 Treatment combinations for evaluating cover measurement techniques

Crop type	Technique	Symbol
1. Maize	Photography	M 1
Maize	Ceptometer	M 2
Maize	Sighting-frame	M 3
Maize	Metre-stick	M 4
2. Beans	Photography	B 1
Beans	Ceptometer	B 2
Beans	Sighting-frame	B 3
Beans	Metre-stick	B 4
3. Intercrop	Photography	I 1
Intercrop	Ceptometer	I 2
Intercrop	Sighting-frame	I 3
Intercrop	Metre-stick	I 4

1: Photographic technique, 2: Ceptometer, 3: Sighting frame, 4: Metre stick.
I: Maize and Bean Intercrop.

3.2.2 Field Layout

The nature of this research necessitated the application of a split-plot experimental design (Fig 3.1).

BLOCK A1	MAIZE	INTERCROP	BEANS
BLOCK A2	INTERCROP	BEANS	MAIZE
BLOCK A3	INTERCROP	MAIZE	BEANS
BLOCK A4	BEANS	INTERCROP	MIAZE

(Where Block A1 was the highest terrace and A4 the lowest)

Fig 3.1 Field Layout and Randomization of Plots

As is conventional with split plot design, the crop factor, that is Maize, Beans, and intercrop were randomized to constitute the main plots. A random error occurs due to this main plot effect, designated error (a). The four techniques of cover measurement to be evaluated on these crops should give four subplots within each main plot. However in this research it was imperative that the same crops be monitored for height and cover by the four techniques. This was meant to eliminate errors that could occur due to possibilities of variation between subplots. Consequently, the modification introduced involved the superimposition of all the subplots on each other. Subplots within the main plots are associated with a random error effect designated error (b).

3.3 Crop Cover Component

The crops that were used for cover establishment were Maize (Zea mays), variety Hybrid 512 and beans (Phaseolus vulgaris), variety GLP2 Rose coco. This selection was based on the fact that these crops are popular in Kenya and constitute an important ground cover during the crop production seasons. Their maturity time is 16 weeks and 24 weeks for beans and Maize respectively. Maize variety Hybrid 512 is recommended for the coffee zone, characteristic of Central and Eastern provinces of Kenya (Major crops technical handbook, 1981). Beans usually do well where Maize thrives.

Seedbed preparation was done in the month of September and planting effected on 28/10/92, one week after the onset of the short rains at a spacing of 75cm x 25cm and 50 cm x 15cm for maize and beans respectively. Gapping was done accordingly to ensure sufficient crop density.

3.4 Equipment Used for Height and Cover Measurement

3.4.1 Crop Height Measurement

Within each subplot (sampling area), 5 plants of each crop type were selected randomly and labelled with metallic tags. Crop height was determined by a metallic metre rule in the early growth stages and later by a special "height-meter" from knee high to physiological maturity (Plate 3.1). Data were recorded in centimetres. Height measurements were restricted to the apical meristem for purposes of uniformity. Two people were required for this work, one to position and hold the equipment properly, then read the figure as the other person recorded.

Plate. 3.1 Measuring Maize Crop Height

3.4.2 Field Application of the Photographic Technique

The terrace (block) width was crucial in establishing the appropriate sampling area for all the treatment combinations. Based on the manufacturers specifications, for the lens, mathematical analysis indicated that to remain within the limits of the terrace width, a camera height of 1.5 m above the ground was required. With an angle of view of 100° , this camera height corresponded to an area of 3.76 m x 2.5 m on the ground. However, to ensure that the sampling area was sufficiently photographed, the camera was raised to 2 m above the ground and the sampling area reduced to enclose 4 rows of maize and 5 rows of beans. All the sampling areas were demarcated at the vertex by white topped wooden pegs. The camera set up was positioned at each sampling plot such that the camera was suspended at the centre of the plots. Crop height was compensated for to maintain a constant camera height of 2m above the canopy so as to minimise the errors associated with changes in camera height (Equation 2.10). The perpendicularity of the stand to ground was established by use of an air bubble attached to the camera stand (Plate. 3.2; Appendix. 7).

Plate. 3.2 Taking Vertical Photographs of Beans

Three exposures were taken per sampling plot , the shutter being released by an extension cord. Film adjustment was done manually.The order of taking shots was maintained for all the sampling plots throughout the research period. This was meant to avoid confusion during slide analysis. Slide film development was done the day after exposure to ensure that any repeat work due to spoilt film was not delayed. Cover estimation from the overhead photos was done by projecting each colour slide onto a standard dot grid using a 150 M cabin slide projector (Plate 3.3). The planimeter - Raster used had 25 dots evenly distributed within each grid, for ease of counting. Dots that intersected a piece of vegetation within the demarcated sampling area were counted and cover expressed as the proportion of the total number of dots pictured within the sampling area.

Plate 3.3 Slide film projector

The camera stand was used until the Maize was 1.9 m high above which it was impossible to compensate for crop height for the camera. However for Beans cover was taken until crop senescence.

3.4.3 Field Application of the Modified Sighting-Frame (MSF)

Since the sampling plots were small, 2.25 m x 2.25 m, it was assumed that there was no significant variation among the crops within each sampling plot. At every placement, the sighting-frame was anchored in the ground by stepping on the frame stabilizers. The sighting frame was moved up and down the cylindrical stands and fixed at a height above the canopy that had the lowest viewing errors. This point was the observers responsibility. The whole set up was moved to three random positions within each subplot and sighting done through the holes for a vegetation score. For every Sighting frame placement, a single line of Maize was accomodated for the pure maize stand, two lines of the Bean crop for the pure bean stand, and either two lines of beans and a line of Maize or two lines of Maize and a single line of beans for the intercrop. Zero score was given to any hole observation without a vegetation, half score was given to any hole observation between zero and full coverage with a vegetation, and full where the entire hole was covered with the vegetation in question. For every frame placement the Percentage cover (C) was given as:

$$C = \frac{TotalVegetationScore}{TotalNumberofHoles} x100 \ldots\ldots\ldots\ldots\ldots\ldots [3.1]$$

The estimated canopy cover for the crop under consideration at that specific time was the average of the three frame placements. The instrument was designed to adjust its height as the crops grew taller. However it was only possible to achieve an effective height of 1.5 m, above which height of stand and researcher were limiting.

Compared with the design described by Cackett (1964), the sighting frame used in this research was modified to reduce viewing errors, reduce the total weight and increase the portability (Plate. 3.4; Fig. 3.2).

Plate. 3.4 The Modified Sighting-frame

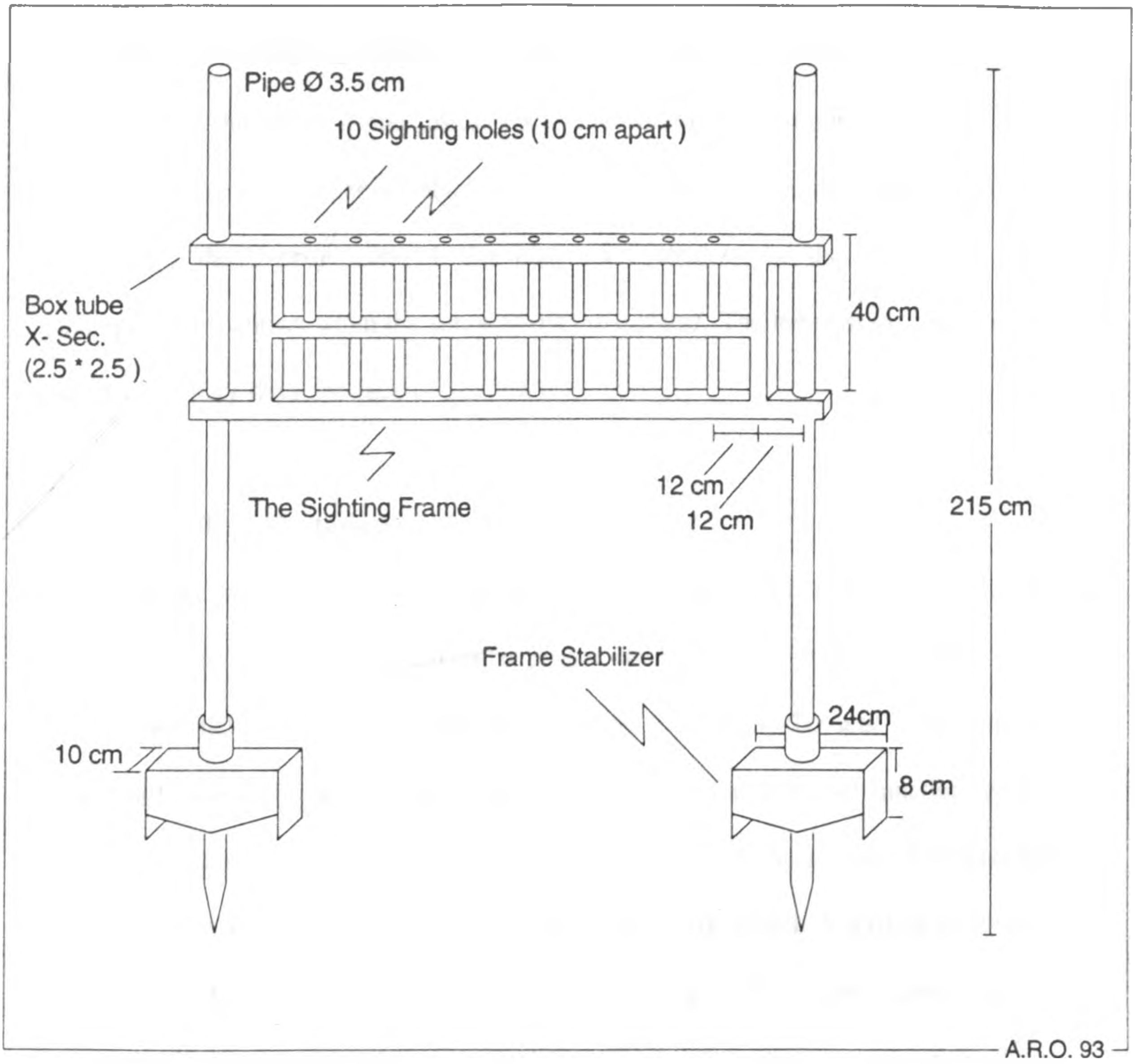


Fig. 3.2 Design Specification of the Modified Sighting-frame

3.4.4 The Metre-stick

A graduated metre-stick was placed on the ground perpendicular to the rows within each sampling plot and the lengths of the shadows projected on it by the canopy summed up. Three trials were carried out within each sampling plot and the percentage crop cover, (%C) computed as shown in equation 2.11. The average of the three placements was taken as the estimated coverage of the field.

Albeit being the simplest and fastest cover measurement technique, errors could be introduced due to; exaggerated shadows before and after solar noon, unstable shadows on windy days, projection of the observer's shadow on the metre-stick and exaggerated shadows when the sun was off the equator. The metre stick could not be used on cloudy days for lack of shadows.

3.4.5 Sunfleck Ceptometer (SF-80)

The display was turned on by pressing any of the buttons A or B (Plate 2.1). Before sunfleck measurements were taken, a proper threshold level was established. The probe was held in direct sunlight and function 7 selected. To sets the automatic threshold, button B was pushed. Pressing Button A in the threshold function set the threshold manually. These were displayed accordingly on the screen. The function indicator was changed to 2 (sunfleck measurement) and button A pushed to sample for sunfleck fraction at each placement under the canopy. The sample number and the sunfleck fraction were displayed on the left and right of the screen respectively. Two people were required for this work, one to sample and read values as the other recorded. within every sampling plot, 10 probe placements were done. Percentage canopy cover (C) per placement was estimated as:

C = (100 - Sunfleck value)....................[3.2]

For every crop therefore, a total of 40 C - values were averaged to give the mean crop cover.

3.5 Calibration of the Cover Evaluation Techniques

A Bean crop was simulated using physical plant models made from thin metal sheets. Only the upper most leaves important in interception were used. Each model bean plant had two leaves with a total average area of 64 cm^2. 200 plants all of approximately the same leaf sizes and height were modelled. The leaves were painted green (Plates 3.5 and 3.6).

A field of dimensions 100cm by 100cm was properly ploughed, levelled and firmed. To simulate a bean field, the bean plant models were pinned within the selected plot at the standard spacing of 50cm by 15cm. Reference crop cover values of 0, 5%, 13%, 20%, 21%, 35%, 51, 60% and 100% were analysed. An increase in the percent coverage was achieved by increasing the number of plant models in the sampling plot within and between the rows. Crop height was maintained constant to limit errors in modelling that would arise due to changing crop height (Plates 3.5, 3.6).

Plate. 3.5 Physical plant model (Low % cover)

Plate 3.6 Physical plant model (High % cover)

At each reference crop cover, cover estimates were done using each of the four techniques under investigation. At least five replicates were used for each evaluation.

3.6 Standardization of Cover Evaluation Procedures for the Sighting Frame

The conventional system. 0-0.5-1 was compared to the proposed system 0-0.25-0.5-0.75-1 at the following reference crop covers; 0, 13, 17, 20, 21, 35, 36, 48, 58, and 71%. In the new system. a crosshair was fitted at the bottom of each sighting hole to divide the hole into four equal quarters. Peering through the hole was done to determine presence of either zero cover, a quarter cover, half cover, three quarter cover, or full cover. The conventional approach entailed observation of zero cover, half cover, or full cover. At each reference crop cover, both systems were used each replicated three times.

3.7 Rainfall Interception Model

Rainfall records (quantity per storm, duration, and intensity) were obtained from an automatic rainfall recorder situated about 100m from the research fields. For every storm recieved, the kinetic energy was calculated using equation 2.18. This equation was chosen because even for a storm of intensity 1mm/hr significant in splash erosion (Bolline, 1977), it gives an energy value of 11.87 J/m^2 /mm of rainfall. Contrary to this is the output by equation 2.16 which though recommended for tropical storms, gives negative energies for low rainfall intensities. For example an intensity of 1mm/h gives an energy value of -98.6 J/m^2 /mm of rainfall. This would suggest that no amount of splash is possible.

The kinetic energy per unit of rainfall was multiplied by the total amount of rain recieved to give the total Kinetic energy (J/m^2) per storm recieved. The daily total kinetic energy was obtained by summing the specific storms Kinetic energies in that day. The weekly total kinetic energies were obtained in a similar manner.

3.7.1 Calculation of the Energy Interception

Computation of the intercepted energy is point (time) specific and assumes a linear relationship between cover and the kinetic energy of the raindrops (Stocking, 1988). An example is illustrated below.

Assumption: 100% cover will intercept 100% rainfall energy.

If at time X percent cover was 30 and Kinetic energy of storm was 800 J/m^2 , rainfall energy intercepted (R.E.I) at that specific time is given as:

$$REI = \frac{30 \ X \ 800}{100} = 240 \ J/m^2 \ . \ . \ . \ . \ . \quad [3.3]$$

It follows that rainfall energy that reaches the ground under such conditions will be 560 J/m^2 Percentage cover of 80 would intercept 640 J/m^2 of the rainfall energy and allow 160 J/m^2 to strike the ground. The higher the percentage cover, the higher is the interception. The rainfall energy intercepted at specific crop percent cover throughout the short rains season was calculated similarly.

3.8 Duration of the Study

A complete set of data was collected from the experimental plots during the short rains season of October 1992 - February 1993. The long rains which were expected as from mid March delayed until May. Futhermore the distribution was skewed and the duration about a month. Consequently the second seasons data was generally a failure. Crop establishment was very poor and very variable especially for the pure Maize stand. The season was also characterized by chilly and cloudy weather which limited the use of the Ceptometer and the Metre-stick. The second rains season was therefore not considered for this study.

3.9 Statistical Data Analysis

The performance of the four cover evaluation techniques was compared using the following computer programmes Quotro Pro and Cohort 2 (Costat) for regressions and correlations respectively. Analysis of variance was done manually following standard procedures (Zar, 1984, and Steel and Torrie, 1988). Cover trends were obtained by use of the Crickett Curves programme and Havard graphics.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Crop Cover Time Series

All the techniques gave similar crop development curves, sigmoid in shape. However, the ceptometer gave generally higher cover values than all the other techniques (Fig. 4.1). Non linear correlation of crop cover against time, gave high r-values of 0.996, 0.981, 0.965, and 0.95 for the ceptometer, camera, sighting frame, and metre stick respectively.

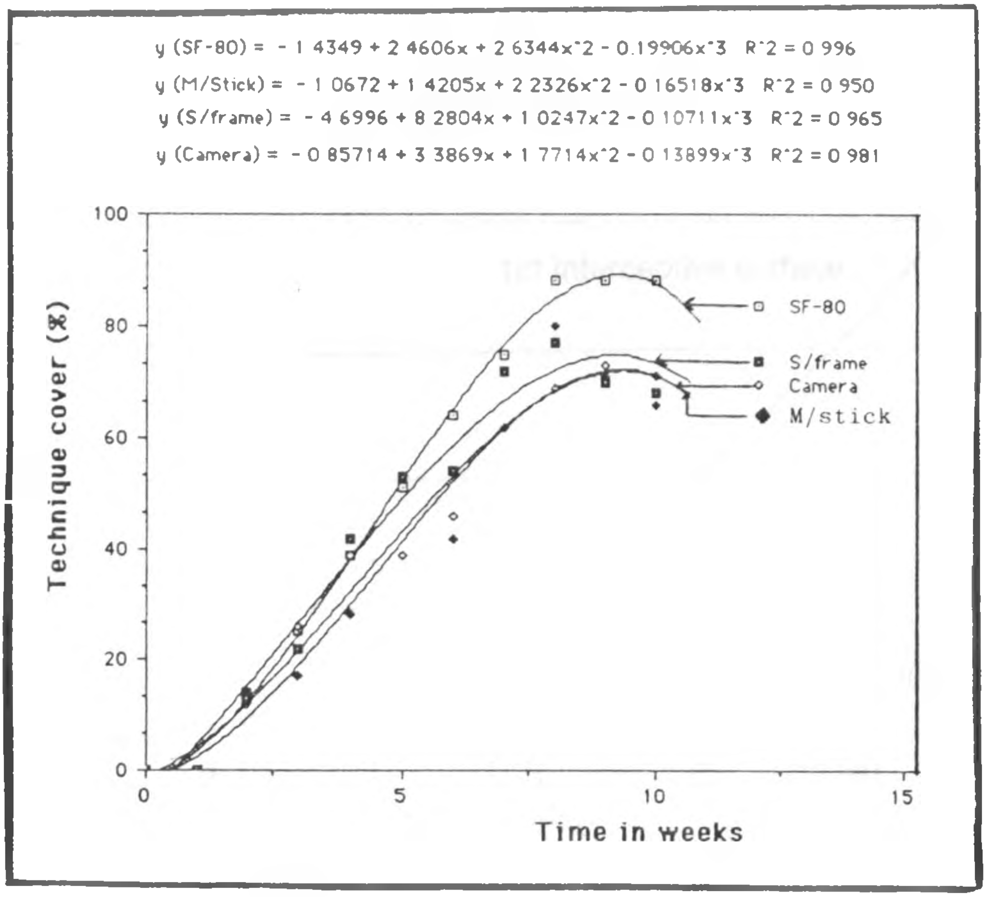


Fig 4.1 Comparison of cover measurement techniques on bean cover

Crop height was highly correlated to cover. The r-values for the beans and maize were 0.917 and 0.921 respectively (Table 4.1). Beans attained the lowest maximum height while maize attained the highest maximum. It follows that an intercrop of the two provides a multi-storey canopy arrangement which can be quite effective in intercepting reformed and re-falling erosive raindrops and also for cushioning oblique rainfall drops (Fig. 4.2).

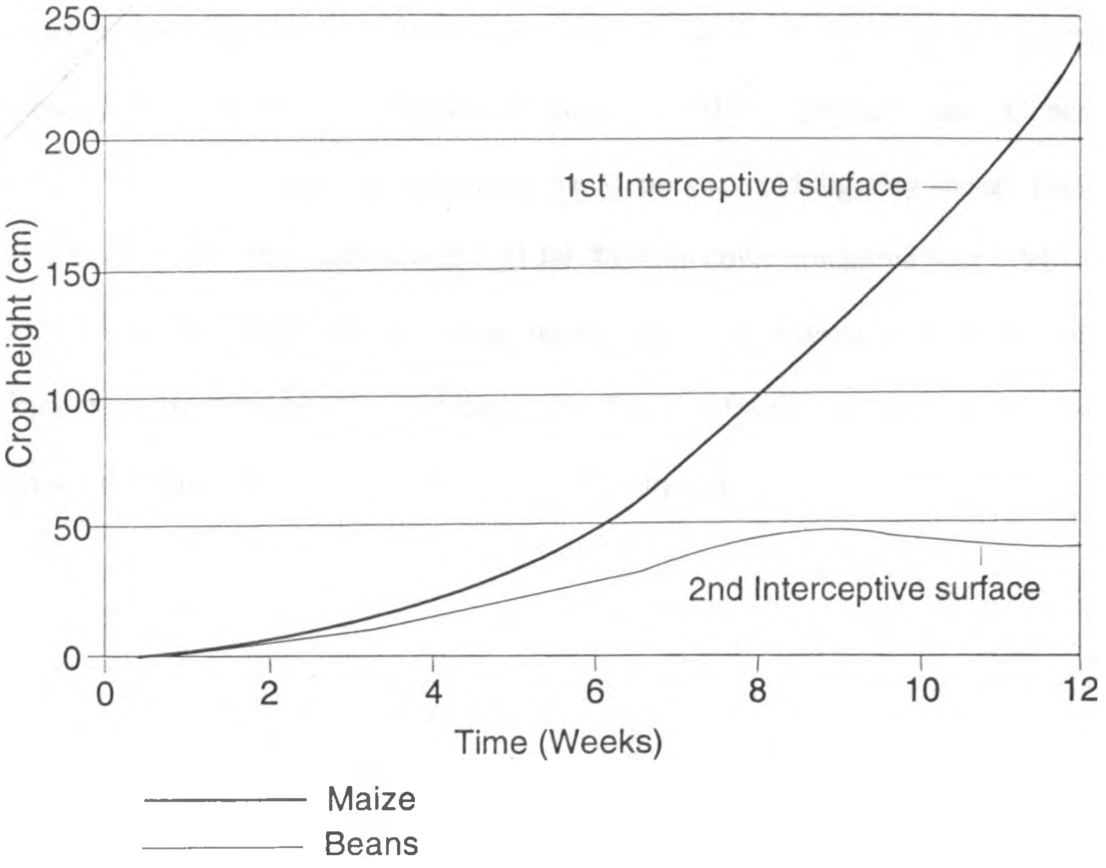


Fig 4.2 Variations in crop height between maize and beans

Table 4.1 Correlation between height and cover.
(Assuming normal plant population)

	Bean	Maize
Correlation equation	C = 0.7H - 8.9	C = 0.5H + 7.0
Correlation coefficient (r)	0.92	0.92
Standard error (r)	0.13	0.14
Slope (C)	1.4	1.9
Standard error (C)	0.19	0.29
Y-intercept (H)	12.4	-15.1
95% CI Significance	***	***

4.2 Comparison of Cover Evaluation Techniques

The linear regression output for all pairs of comparison gave correlation co-efficient values in the range of 0.95 - 0.99 (Table 4.2, 4.3, 4.4). However, except for the intercrop, the correlation co-efficient values for the Ceptometer and Camera comparisons were always higher than for the Metre stick and Sighting frame. These were 0.98 for the Maize cover and 0.97 for the bean cover compared with 0.94 for maize cover and 0.91 for the bean cover respectively. This is because the camera and Ceptometer are more objective contrary to the Sighting frame and Metre stick whose increased human judgement makes them more subjective.

Table 4.2 **Regression output for comparison of cover evaluation techniques on Maize crop cover**

X-Value	Y-Value	Regression Equation	r	Std. Err. Coef	Std. Err. Y Estimate
SF-80	Camera	y = 0.66x	0.99	0.02	2.8
SF-80	S/Frame	y = 0.81x	0.98	0.02	4.2
SF-80	M/stick	y = 0.77x	0.98	0.03	4.8
S/Frame	Camera	y = 0.80x	0.98	0.03	3.9
S/Frame	M/Stick	y = 0.94x	0.97	0.05	6.7
M/Stick	Camera	y = 0.85x	0.98	0.03	4.0

Table 4.3 **Regression output for comparison of cover evaluation techiques on Bean crop cover**

X-Value	Y-Value	Regression Equation	r	Std. Err. Coeff	Std. Err. Y Estimate
SF-80	Camera	y = 0.82x	0.98	0.02	4.11
SF-80	S/Frame	y = 0.88x	0.97	0.03	5.93
SF-80	M/Stick	y = 0.81x	0.97	0.03	5.82
S/Frame	Camera	y = 0.93x	0.96	0.03	6.14
S/Frame	M/Stick	y = 1.08x	0.95	0.04	7.19
M/stick	Camera	y = 1.004x	0.95	0.04	7.14

r : correlation co-efficient, Std Err: Standard error,
Coef : Coefficient, Est : Estimate

Table 4.4 **Regression output for comparison of Cover evaluation Techniques on the Bean/Maize Intercrop**

X-Value	Y-Value	Regression Equation	R^2	Std. Err. Coeff	Std. Err. Y Estimate
SF-80	Camera	y = 0.75x	0.98	0.02	3.62
SF-80	S/Frame	y = 0.98x	0.99	0.02	3.58
SF-80	M/Stick	y = 0.90x	0.99	0.01	2.34
S/Frame	Camera	y = 0.81x	0.98	0.02	3.35
S/Frame	M/Stick	y = 0.97x	0.98	0.02	3.94
M/Stick	Camera	y = 0.83x	0.98	0.02	3.23

R^2 Co-efficient of determination.

Comparison of the pair-wise r-values however showed that the cover techniques were not significantly different at 95% and 99% CI (Table 4.5). Consequently, all the techniques could generally be used for routine field estimation of crop cover.

Table 4.5a **Comparison of the seasonal correlation co-efficients between techniques on maize cover**

i	r_i	z_t	z_t^2	n_t	$n_t - 3$	$(n_t - 3)z_t$	$(n_t - 3)z_t^2$
1	0.99	2.65	7.02	10	7	18.55	49.14
2	0.99	2.44	5.95	10	7	17.08	41.65
3	0.97	2.09	4.37	10	7	14.63	30.59
Total					21	50.26	121.38

$X^2_{cal} = 121.38 - (50.26)^2/21 = 1.09$ ns.

X^2 (0.01,2df) = 9.21
X^2 (0.05,2df) = 5.99

Table 4.5b **Comparison of the seasonal correlation co-efficient between techniques on Bean cover**

i	r_t	z_t	z^2_t	n_t	$n_t - 4$	$(n_t - 4)z_t$	$(n_t - 4)z^2_t$
1	0.99	2.65	7.02	13	9	23.85	63.18
2	0.97	2.09	4.37	13	9	18.81	39.33
3	0.96	1.95	3.80	13	9	17.55	34.20
4	0.95	1.83	3.35	13	9	16.47	30.15
Total					36	76.68	166.86

$X^2_{cal} = 166.86 - (76.68)^2/36 = 3.532$ ns.

X^2 (0.01, 3df) = 11.345
X^2 (0.05, 3df) = 7.915

Where z_t is given as: $\mathbf{z_t = 0.5\ ln\{[1+r] / [1-r]\}}$

4.3 Calibration of Cover Evaluation Techniques

The calibration test on the other hand showed that the Camera method was the most accurate while the ceptometer was the least accurate. The sighting frame was more accurate than the metre stick (Tables 4.6 and 4.7).

The inaccuracy of the ceptometer and metre-stick was attributed to the exaggerated shadows due to the sun's position in the northern hemisphere. Even at solar noon, the shadows were translated southwards.

Table 4.6 Calibration results of the Cover Evaluation Techniques

Physical plant model % cover	Camera % cover	Dc	S-frame % cover	Ds	M-stick % cover	Dm	SF-80 % cover	Dsf
0	0	0	0	0	0	0	0	0
5	11	6	10	5	14	9	15	10
13	21	8	25	13	31	18	44	31
20	34	14	31	11	46	26	51	31
21	35	14	36	15	49	28	56	35
28	41	13	39	11	53	25	61	33
35	43	8	51	16	59	24	67	32
51	62	11	61	10	67	16	75	24
60	72	12	71	11	78	18	81	21
100	100	0	100	0	100	0	100	0
Mean deviation		10.8		11.5		20.5		27.1

Where: S-frame: Sighting-frame, SF-80: Ceptometer, M-stick: Metre-stick, C: cover, D[c,s,m,sf]: deviations from actual cover for the camera, sighting-frame, metre-stick and ceptometer respectively.

The sighting-frame overestimated cover during the early vegetative phase because even hole coverage of below half was counted as half. Cover could be underestimated when above average (50%) because of quantifying all hole coverage below full as half.

Table 4.7 Regression output of cover estimation techniques against physical plant models

	X Variable	% cover Physical	plant models			
Y-Variable	Std.err Y Est	R^2	X Coeff	Std.Err coeff	Regression equation	Cover factor
Camera	8.37	0.92	1.14	0.06	y = 1.14x	0.88
S/frame	8.9	0.91	1.14	0.064	y = 1.14x	0.88
M/stick	16.5	0.69	1.25	0.12	y = 1.25x	0.80
SF-80	21.8	0.47	1.33	0.16	y = 1.33x	0.75

corrn: correction, R_2: co-efficient of determination. SF-80: Ceptometer.

Repeatability was highest for the ceptometer followed by the camera and lowest for the sighting-frame (Table 4.8). This is because the ceptometer and camera are more objective than the subjective sighting frame and metre stick. The results of the sighting-frame, metre-stick and ceptometer were all influenced by placement. The accuracy and precision of the photographic technique was also influenced by the position of the projected cover slide on the dot overlay.

Table 4.8 Comparison of the precision of the cover measurement techniques

	Technique	standard	deviation	
Plant model % Cover	Camera % cover	S/Frame % cover	M/stick % cover	SF-80 % cover
0	0	0	0	0
5	2.2	0	1.7	2.5
13	2.0	8.2	1.0	3.1
20		2.2		
21	3.6	6.9		3.4
35	4.2		8.0	4.4
48	1.7	6.5	6.5	2.0
60	3.2		4.0	3.0
100	0	0	0	0
Mean	2.8	6.0	4.3	3.1

Analysis of variance showed that the techniques were generally independent during the initial and final vegetative growth stages of the cover crops (Appendix. 4). However, for the bean crop, at the mid growth stage, there was no statistical evidence that the techniques were significantly different.

At all stages of crop growth, there was no interaction between the techniques and the crop. Hence any technique can be used for cover evaluation on any crop without fear of crop damage. However, differences will be manifested in the accuracies obtained and in the ease of handling of the cover measuring equipments.

4.4 Appropriateness of Field Utilization of the Cover Evaluation Techniques

The electronic devices (camera and ceptometer) are expensive and they are readily available in developed countries. The ceptometer takes the least time to give the estimated canopy cover while the camera takes the longest time since the films need to be processed. Of the locally available techniques, the metre-stick is cheaper than the sighting-frame. However, more time in the field is needed by the metre-stick due to the actual measuring of the shadows projected on it. The use of the electronic devices requires prior training, especially the camera where one is required to know its operation and the use of the projector and dot grids to estimate canopy cover. The sighting-frame requires the least skill prior to usage.

4.5 Comparison of the Conventional 0-0.5-1 and the 0-0.25-0.75-1 Systems of Using the Sighting Frame

The correlation between both systems was highly significant and ranged from 0.95 - 0.98 (Fig. 4.3; Table 4.9). Although both approaches exaggerated crop cover, the proposed system, 0-0.25-0.5-0.75-1 was a better estimator of the cover. Best estimates of cover for both was recorded when cover was near critical cover (36% - 51%), (Appendix.5)

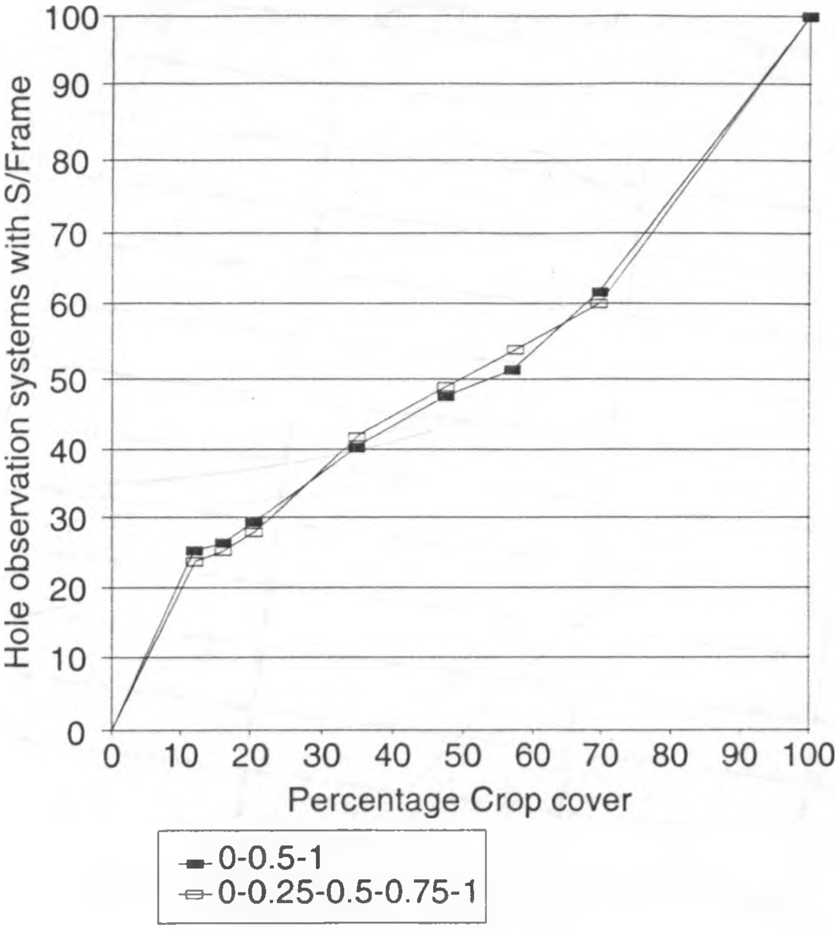


Fig 4.3 Comparison of 0-0.5-1 and 0-0.25-0.5-0.75-1 systems of assessing ground cover using the sighting frame .

Table 4.9 Correlation output between the 0-0.5-1 and the 0-0.25-0.5-0.75-1 systems.

X-Variable	Y-Variable	r	Regression Equation	S.E (b)	Sign
N1	C1	0.97	$y=1.05x+0.91$	0.13	***
N2	C2	0.95	$y=1.03x-0.2$	0.12	***
N3	C3	0.98	$y=0.92x+4.1$	0.07	***
N4	C4	0.95	$y=0.85x+4.5$	0.10	***
N5	C5	0.98	$y=0.81x+4.8$	0.07	***
R	N	0.97	$y=0.79x+9.7$	0.07	***
R	C	0.96	$y=0.76x+10.9$	0.07	***

N :0-0.25-0.5-0.75-1 system, C :0-0.5-1 system, 1-5 Replicates, r: correlation coefficient, *** = Highly significant at 95% CI; R: reference crop cover

4.6 Energy Interception

The short rains season was marked by lateness in occurrence, commencing in November rather than in October. The rains lasted for about 3 months. The intensity and storms/day were quite skewed, ranging from 1 mm/hr - 103 mm/hr and 1 - 18 respectively (Appendix. 6). A total of 325 mm of rain was received in the season. This pattern of rainfall is also reflected in the rainfall energy and rainfall energy intercepted (Table 4.10). Cover development on the contrary, took a steady progression. The fields were most vulnerable to erosion in the first two and last three weeks of the season. Of much conservation implication are the extreme rainfall events that occurred during the tenth and twelfth week of the season (Table 4.10; Appendix 6). The bean field was the most vulnerable since by this time, cover had fallen to around 50% while Maize and the intercrop had 60% and 70% cover respectively. Daily total rainfall energy ranged from 63 J/m^2 to 1134 J/m^2 (Appendix.6). Figure 4.4 is the seasonal cover model and can be used as a tool for defining time and place specific soil conservation options. Conservation techniques that provide sufficient cover throughout the year and yet contribute to allowable crop yield, should be emphasized. Interception was highest with the intercrop. This was attributed to the high and evenly distributed horizontal coverage. The multi-storey canopy cover arrangement of the intercrop also helps in cushioning the through-fall.

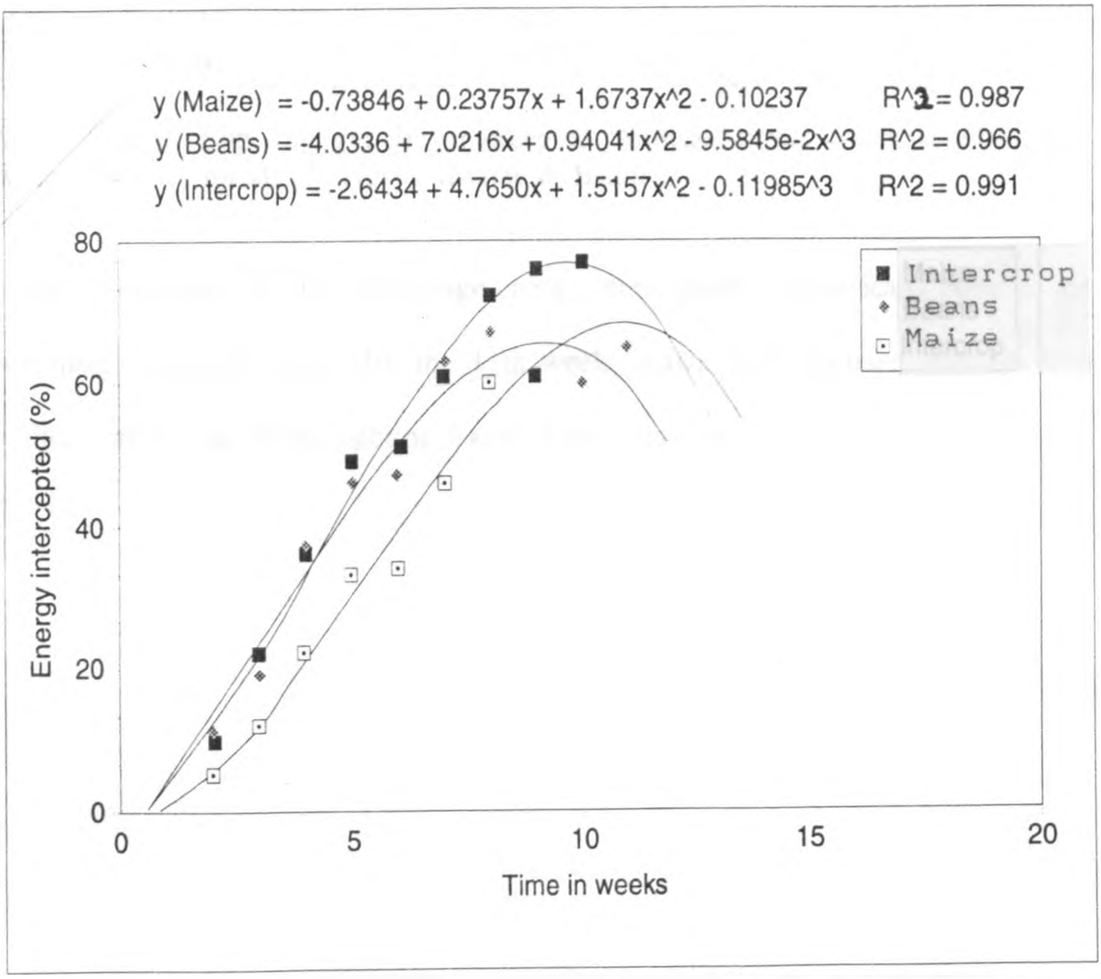


Fig. 4.4 Short rains season cover model

Table 4.10 Rainfall energy intercepted and crop canopy cover

		Maize		Beans		InterC	
Time (Weeks)	Total Energy	Adj % cover	Eng-Int	Adj % cover	Eng-Int	Adj % cover	Eng-Int
0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0
2	891	5	45	11	98	10	89
3	717	12	86	19	136	22	158
4	122	22	27	37	45	36	44
5	0	33	0	46	0	49	0
6	158	34	54	47	74	51	81
7	376	46	173	63	237	61	229
8	602	60	361	67	403	72	434
9	0	61	0	61	0	76	0
10	500	-	-	60	300	77	385
11	1178	-	-	65	766	-	-
12	1125	-	-	44	495	-	-
13	1261	-	-	39	491	-	-

Adj: Adjusted; Eng: Energy; Int: Intercepted. Adjusted cover values were based on sighting frame, InterC: Intercrop (Maize & Beans).

Based on equation 3.3, the percentage energy intercepted is numerically equal to the percentage adjusted cover. By the 11th week, maize had attainned a height that limited further use of the sighting-frame. Hence the missing data.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Cover Evaluation Techniques

Any of the four techniques could be used for routine estimation of row crop cover. However, the camera could do better for irregular crop cover and residue mulch. The applicability of the Ceptometer should always be restricted at solar noon. This method would give more accurate cover values when used on crops with broad leaves. Although the metre-stick is the cheapest and fastest method, its application is limited by the cloud cover and wind conditions of the day. It can however be reliable for residue cover estimation since light and wind are not limiting. The ceptometer and camera methods are also expensive. This would limit their use in developing countries.

5.1.2 Recommended Cover Evaluation Technique

The modified sighting-frame can be adopted for routine cover estimation, research and monitoring in Kenya. It can be assempled from locally available materials. The equipment is very portable. It can be dismantled and transported easily to any place. Anyboby can use it as it does not require a lot of skill. When crop height and observer's height become limiting, the modified sighting-frame can be converted into a point quadrat by introducing 'Hit points' and adjusting cover values with an appropriate correction term.

5.1.3 Potential of Empirical Relationship Between Crop Cover and Crop Height

The high correlation between crop height and cover suggests that an empirical relationship between the two can be developed for normal plant population and spacing, such that:

$$\mathbf{C_c = f[H_c] \ldots\ldots\ldots\ldots\ldots\ldots\ldots [5.1].}$$

Where: C_c is the crop % cover

H_c is the crop height

This would make it possible to estimate canopy cover from crop height, without having to measure it in the field. However this will be crop specific and most applicable during the vegetative phase.

5.1.4 The Preliminary Rainfall Interception Model

Extreme rainfall events seldom occur at SAREC station. Long duration, low intensity storms are most prevalent. However, as a tool for defining appropriate conservation measures, the following preliminary rainfall energy interception model was suggested:

$$\mathbf{REI = k\ [C^a, H^b\ ] \ldots\ldots\ldots\ldots\ldots\ldots\ldots [5.2]}$$

Where:

C = Degree of horizontal field coverage.

H^b = Canopy height

k,a,b = Experimentally determined constants.

5.2 Recommendations

5.2.1 Cover Evaluation Techniques.

There is need for more research to improve on the accuracy of estimation of the modified sighting-frame. This can be achieved by increasing the number of sighting holes and also the adoption of a more accurate cover quantifying system like the proposed 0-0.25-0.5-0.75-1 system.

More research is needed to develop the most reliable correction factors for all the cover evaluation techniques.

Future research should also seek to recommend evaluation techniques for specific plant species.

The preliminary rainfall energy interception model (5.2) points to the need to ensure maximum horizontal ground coverage and also establishment of multi-storey canopy structures as the rule of thumb in preventing splash erosion.

More research is also needed to develop locality specific interception models due to spatial differences in rainfall and soils. Such models should be simple and easy to be used by local land users for soil erosion control.

5.2.2 Conservation Implications of Cover Trends

Crop cover development usually assumes a sigmoid trend (Figures 2.3,4.1 and 4.4). Erosion risks are highest during the early vegetative stages when the virtually bare soil surface is exposed to heavy rainfall.

Effective soil erosion control should therefore ensure that the field is protected throughout the year, and the faster vegetation cover develops, the quicker bare soils patches will be protected, resulting into a small proportion of the seasons total rainfall having erosive effect (Baum et al, 1990).

These demands for better skills in both soil and crop management on the part of the farmer. Researchers concur on the adoption of the following and any other cultural practices for appropriate soil conservation.

1. Appropriate land use based on land use suitability classifications.
2. Tillage systems that ensure adequate tilth and residue/mulch cover).
3. Timely planting of viable seeds to ensure good take off and first establishment of ecologically adapted crop types and varieties.
4. Integrated weed, insect pests, and disease management.
5 Appropriate harvesting and residue management methods.
6. Cropping systems that reconcile between high crop yields and sufficient ground cover throughout the year.
7. Balanced fertilizer application.
8. Appropriate crop spacing to ensure high yields and optimum ground cover.

REFERENCES

Adams, J.E. and Arkin,G.F. 1977. A light interception method for measuring row crop ground cover. Soil Sc. soc.Am J.41. 789-792.

Agro-climatic zone Map of Kenya, 1980. Kenya Soil Survey. Ministry of Agriculture. Nairobi.

Amphlett, M.B. 1986. Soil Erosion research project Brumbwe, Malawi. Summary report. 0078.

Baum, E.,Wolff,P and Zobisch, M.(Eds). 1990. Topics in Applied Resource Management in the Tropics. Experience with Available Conservation Technologies. DITSL. Witzenhausen. 23-31.

Bolline, A. 1977. La vitesse de l'erosion sous culture en reion limonense. In. soil erosion and conservation. Morgan, R.P.C (ed). Willey. New York.

Cackett, K.E. 1964. A simple device for measuring canopy Cover. Rhod. J.agric. Res.2.56-57.

Chleg, J-L and Dupriez, H. 1988. Vanishing Land and Water. Soil and Conservation in Dry Lands. MacMillan. London. 24-26.

Corak, S.J., Kaspar, T.C and Meek, D.W. 1993. Evaluating methods for measuring residue cover. J. Soil and Water Conservation. 48 (1) 70 - 74.

Curran, P.J., and Williamson, H.D.1985. The accuracy of ground data used in remote sensing investigations. In. Pierson et al.1988. Observer differences in determining crop residue cover in the Alaskan subarctic.J.SWC.43.6.493-495.

El-Swaify, S.A. 1990. Research needs and applications to reduce erosion and sedimentation in the tropics.In. Research needs and applications to reduce erosion and sedimentation in tropical steeplands. R.R.Ziemer, C.L.O'Loughlin and L.S. Hamilton (eds). Proceedings Fiji Symposium,June 1990. Publ.No.192.3-13.

Elwell, H.A. 1980. Design of safe rotational systems. Dev. of conserv and Extension, Harare, Zimbabwe.

Elwell, H.A. 1978. Soil loss estimation. Compiled works of Rhodesian multi-disciplinary team on soil estimation. Salisbury. Dept.Cons and Extn.Aug.1978. Mimeo.

Elwell, H.A. 1984. Sheet erosion from arable lands in Zimbabwe. In. Mckyes, E.1989. agricultural engineering soil mechanics. Elsevier. Tokyo. 172-180.

Elwell,H.A. and Wendelaar,F.E. 1977. To initiate a vegetal cover data bank for soil loss estimation. Res. Bull. 23/Sep. Dept. Consern and Extension. Salisbury. 1-42.

Elwell, H.A and Stocking, M.A. 1974. Rainfall parameters and a cover model to predict runoff and soil loss from grazing trials in Rhodesian sundveld. Pro. Grassland Soc. of Southern Africa. 157-164.

Elwell,H.A and Gardner,S. 1975. Comparison of two techniques for measuring percentage Canopy cover of row crops in erosion research programmes. Research Bulletin 19. Dept. of Conservn and Extn. Harare. Zimbabwe.

Finney,H.J. 1984. The effect of crop covers on rainfall characteristics and splash detachment. Journal of Agricultural Engineering Research.29,337-343.

Flanagan,J.E.F. and Lane,L.J. 1991. WEPP Hillslope Profile Erosion Model. National soil Erosion Research Laboratory service. Indiana. Report. No.7

Fuls,E.R. and Bosch,J.H. 1991. The influence of below-average rainfall on the vegetational traits of a patch-grazed semi- arid grassland. Journal of Arid Environments. 21:13-20.

Gachene, C.K.K.1989. Soils of the Erosion research farm. Dept.soil.Sc. University of Nairobi.

Ghadiri, H. 1978. Raindrop impact, Soil splash and Cratering. In: Problems and Prospects. Pro. Conservn. 80.July, 1980.

Ghadiri, H and Payne,D. 1977. Raindrop Impact stress and the breakdown of soil crumbs. J.Soil Sc. 28, 247-58.

Gardner. T., Cyril,C and Adrian,W. 1989. Field measurements for Soil management studies. In: Pushparajah, E. et al (Ed). the establisment of soil mngt expts on sloping lands. IBSRAM. Tech. notes No. 3. Bangkok. 361.

Hartwig,R.O. and Laflen,J.M. 1978. A metre Stick method for measuring Crop residue Cover. J.SWC. Vol.33. 90-91.

Hillel, D. 1982. Introduction to soil physics. Academic press. Toronto. 29.

Holy, M. 1980. Erosion and Environment. Environmental Sciences and application. Pergamon. Oxford. 75-135.

Holzhey, C.S and Mausbach,M.J. 1977. Using soil taxonomy to estimate K values in the USLE. In: Soil Conservn. Problems and Prospects. Proc. Cons.80.

Hudson, N. 1981. Soil Conservation. Batsford academic and educational. London. 62-70.

Jansson,M.B. 1982. Land erosion by water in different Climates. Uppsale University. UNGI Rapport No.57.32-35.

Laflen J.M. and Hintz,E.A. 1981. Measuring crop residue cover. J. SWC. 1 (10218). Ames. Project 2454.

Laflen, J.M. and Hartwig,R.O. 1978. A Metre Stick method for measuring crop residue cover. J.SWC.33. 90-91.

Laflen, J.M, Lane,L.J and Foster.R.G. 1991. A new generation of erosion prediction technology. Journal of soil and Water Conservation. 46:(1). 34-38.

Lal, R. 1974. Soil erosion and shifting agriculture. In: Soil productivity aspects of agroforesrty. ICRAF. Nairobi. 40.

Lal, R. 1990. Soil Erosion in the Tropics. McGraw-Hill.

Lang,R.D.and McCaffrey,L.A.H.1984. Ground cover - Its effects on soil loss from Grazed Runoff Plots. Gunnedah. J.Soil conservation. NSW. 40: 56-60.

Littleboy, M., Silburn, D.M. Freebairn, D.M.D,and Woodruff,D.R. 1989. PERFECT. Productivity, Erosion, Runoff Functions to Evaluate Conservation Techniques.

Lo, K.F.A. 1990. Erosion problems and research needs of tropical soils. In: Research Needs and Applications to Reduce Erosion and Sedimentation in Tropical Steeplands.Pro.Fiji Symposium, June 1990. IAHS-AISH Publ. No. 192.24-33.

Major Crops Tehnical Handbook. 1981. Ministry of Agriculture and Livestock development. Agricultural Information Centre.

Mati, B.M. 1991. The influence of Crop Cover on Soil Erosion by Splash. MSc. thesis. University of Nairobi.(DAE)

Meyer, L.D. 1981. Modelling conservation practices. In Soil Conservation. Problems and Prospects. Morgan,R.P.C. (ed). willey. Toronto.31-36.

Miller, C.A. 1985. Methods of measuring or estimating amounts of crop residue and cover/ residue per acre, and accueacy of measurements. Agron. Tech. Note. No. AK-1. Soil Cons. Serv. USDA. Alaska.

Molloy, J.M and Moran, C.J. 1991. Compiling a field manual from overhead photographs for estimating crop residue cover. Soil use and Mngt. Vol.7.No. 4. 177-182.

Morgan, R.P.C. 1986. Soil erosion and conservation. Wiley. NewYork. 44-47.

Morin, J., Benyamini, Y., and Michaeli, A. 1981. The effect of raindrop impact on the dynamics of soil surface crusting and water movement in the profile. Journal of Hydrology. 52,321- 36.

Morrison, J.E.Jr., Chichester, F.W and Escobar,D.E. 1989. Measurement of residue cover with dot screens. J.Soil and Water Cons. 44: 542-544.

Nair, P.K.R. 1984. Soil prodctivity aspects of agroforestry. ICRAF.Nairobi.40

Noble, C.A. and Morgan, R.P.C. 1983. Rainfall interception and splash detachment with a brussels sprouts plant: a laboratory simulation. Earth surface processes and landforms.8,569-577.

Noordwijk, M. 1989. Tree roots as components of agroforestry systems. In: Research into soil management and Agroforestry. Report on an IBSRAM/ICRAF workshop. Nairobi.

Otieno, C.O. and Laycock,D.H. 1977. Factors affecting soil erosion within Tea fields. Tropical Agric. 54: 323-30.

Paglial, M., Lamarca,M and Lucamante,G. 1983. Micromorphometic and Micromorphological investigations of clay loam soil in Viticulture Under Zero and Conventional tillage. J.Soil Sc. 34.391-403.

Pierson, B.J; Lewis, C.E, and Birklid C.A. 1988. Observer differences in determining crop residue cover in the Alaskan subarctic. J.SWC. 43. 6. 493-495.

Renard,K.G., Foster,G.R., Weesies,G.A., and McCool,D.K. 1992. Predicting soil erosion by water. A guide to conservation Planning with Revised Universal Soil Loss Equation (RUSLE). Draft-Agricultural Handbook. USDA-Agricultural Research Service.

Ruangpanit. N. 1983. Percent crown cover related to wter and soil losses in mountainous forest in Thailand. In: Elswafy, S.A. et.al. Soil Erosion and conservation. SWC. Soc. Ankeny. Iowa.

Screenivas.L, Johnston, J.R and Hill,H.W. 1947. Some relationships of Vegetation and soil detachment in the erosion process. Pro. soil Sc. Society of America. 12.471-474.

Shaxson, T.F.1980. Reconciling Social and Technical needs in conservation work on village farmlands. In: Soil conser. Problems and Prospects.Pro. Conser.80.Silsoe. R.P.C.Morgan (ed) 385-93.

Skidmore, E.L. 1988. Wind erosion. In: Research needs and Applications to reduce Erosion and Sedimentation in Tropical steeplands. R.R.Ziemer, C.L. O'loughlin, and L.S. Hamilton (eds). Pro. Fuji International Symposium.Sura. June 1990. IAHS. Publ.No.192.

Sloneker I.L and Moldenhauer,W.C. 1977. Measuring the amounts of crop residue remaining after tillage.J. SWC. 32. (50) 231-236.

Steel,G.D.R. and Torrie, J.H. 1981. Principles and Procedures of Statistics. A Biometrical Approach. McGRAW.HILL. Auckland.

Stocking,M.A. 1988. Assessing Vegetion cover and management effects. In. Soil Erosion Research Methods. Lal R.(ed). SWC society. Ankeny. Iowa. 163-185.

Styczen, M and Hogh-Schmidt, K. 1988. A New Description of Splash Erosion in relationship to Raindrop sizes and Vegetation. In: Erosion Assessment and Modelling. Morgan, R.P.C. and Ridison, R.J. (eds). Report. EUR. 10860.

TAC/CGIAR, 1988. In: Reijntjes,C. 1992. Farming for the future. Macmillan, ILEIA. Netherlands. 2.

Tidmarsh, C.E.M and Havenga,C.M. 1955. The wheel point method of survey and measurement of semi-open grassland and Karoo Vegetation in South Africa. Botanical Survey of S/A Memoir. No. 29. Pretoria.

Vogel, W.G. 1987. A manual for training reclamation inspectors in the fundamentals of soils and revegetation. SWC. Soc. Ankeny. 178.pp

Walsh, J. 1991. Preserving the Options: Food Productivity and Sustainability. Issue in Agriculture. No.2. CGIAR.

Warren, W.J. 1963. Estimation of foliage denseness and foliage angle by inclined point quadrat. Austr.J.Bot. 11, 95-105.

Wiersum,K.F. 1985. Effects of various vegetation layers of an Acacia auricaliformis forest plantation on sueface erosion in Java, Indonesia,In.El-swaify,S.A., Moldenhauer, W.C and Lo, A.(eds). soil erosion and conservation, Soil sci. soc.Am,79-89.

Williams, J.R. 1975. Sediment-yield prediction with Universal soil loss equation using runoff energy factor. In PERFECT. A computer simmulation of Productivity, erosion, runoff Functions to Evaluate Conservation Techniques. Queensland. 41.

Williams, T.H.L. 1979. An error analysis of the photographic technique for measuring percent vegetative cover. Soil Sc.Soc of America. J.43, 578-82.

Wilkinson, G.E. 1975. Canopy characteristics of Maize and the effect on soil erosion in western Nigeria. Tropical Agric.52:289-97.

Young A.1989. Agroforestry for Soli Conservation. ICRAF. Nairobi.

Zar,J.H. 1984. Biostatistical Analysis. PRENTILE-HILL. New Jersey.315,479.

Zobisch, M.A. 1986. Survey and assessment of soil erosoin processes in the grazing areas of Machakos, Kenya. DER TROPENLANDWIRT supplement 27, 206 pages.

APPENDICES

Appendix 1 Electronic devices specification

1.1 Sunfleck Ceptometer Operation Functions

Function 1. Photosynthesis Active Radiation (PAR)

Function 2. Sunfleck Measurement

Function 3. Unattended PAR measurement and Display of PAR memory.

Function 4. Unattended Sunfleck measurement and Display of sunfleck memory.

Function 5. Continuous sunfleck and PAR reading.

Function 6. Setting the time.

Function 7. Threshold and single sensor setting.

Function 8. Send/Erase Memory and individual sensor Dump.

1.2 Camera and Lens specifications

Camera model: Olympus OM-4 Ti.

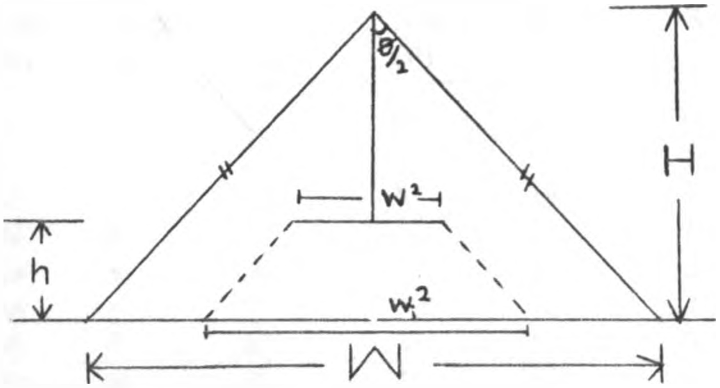
Lens:
Focal length: 18mm. Angle of view: 100^0.
Diaphram operation: Automatic.
F/stop range: 3.5 to 16
Minimum focus: 0.25m.
Minimum field size: 30cm x 20cm.
Focusing: Straight helicoid.
Weight: 250g. Maximum diameter: 62mm.
Filter size: 72mm screw-in .

1.3 Projector Specifications

Model: CABIN 150M
Projection lens: f/2.8 60mm colour corrected wide angle lens.
Lamp: 150W - CEW.
Cooling system: Compressed air cooling by propeller fan.
Dimensions: 215x88x185mm; Weight: 1.4 kg.

Available accessories: Auto-changer accepting up to 40 cardboard slides. Film Strip attachment for projection of horizontal films; Manual slide change.

Appendix 2. Derivation of the relationship between true ground cover and projected cover for correcting projection errors when using the photographic technique



Where: H: height of camera above the ground
h: height of plant canopy above the ground.

w^2: True area (Horizontal coverage).
w_i^2: Projected area.
0: angle lens makes with the ground.

$$\tan\frac{\theta}{2} = \frac{w_1}{2H} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad [i]$$

$$\frac{\tan\theta}{2} = \frac{w}{2(H-h)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad [ii]$$

Hence:

$$\frac{w_i}{2H} = \frac{w}{2(H-h)} \quad . \; . \; . \; . \; . \; . \; . \; . \quad [iii]$$

$$w = w_i\frac{(H-h)}{(H)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad [iv]$$

$$w^2 = w_1^2\left(\frac{H-h}{H}\right)^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad [v]$$

Appendix 3

3.1 Crop height data

Date	Day No.	Week No.	Maize (P)	Beans (P)	Maize (I)	Beans (I)
2/11/92	0	0	0	0	0	0
9/11/92	8	2	7	5	7	5
16/11/92	15	3	12	8	14	7
23/1192	22	4	23	16	27	14
30/11/92	29	5	36	23	36	21
7/12/92	36	6	47	20	48	21
14/12/92	43	7	69	34	62	33
21/12/92	50	8	98	45	85	46
28/12/92	58	9	132	47	119	50
5/01/93	65	10	157	44	147	45
12/01/93	71	11	191	41	174	42
18/01/93	78	12	237	41	242	44

P: pure crop stand, I: intercrop.

3.2 Crop Cover Values

3.2.1 Beans.

	Technique	Percentage	cover		
Time (Weeks)	SF-80	M/Stick	S/Frame	Camera	Std. Dev
0	0	0	0	0	0
1	0	0	0	0	0
2	14	14	13	12	0.9
3	25	17	22	26	4.0
4	39	28	42	39	6.2
5	51	39	53	39	7.5
6	64	42	54	46	9.7
7	75	72	72	62	5.7
8	88	80	77	69	7.9
9	88	71	70	73	8.4
10	88	66	68	71	10
11	81	61	74	68	8.5
12	60	48	50	56	5.5
13	40	37	45	35	4.3

3.2.2 Maize

	Technique	Percentage		Cover	
Time (Weeks)	SF-80	S/Frame	M/Stick	Camera	Std. Dev
0	0	0	0	0	0
1	0	0	0	0	0
2	10	6	6	5	2.2
3	20	14	12	12	3.8
4	32	25	19	16	7.1
5	40	38	26	22	8.9
6	49	39	28	34	8.9
7	63	53	49	41	9.1
8	77	68	60	53	10.3
9	83	70	68	58	10.3
10	91	65	75	58	14.3
11	89	-	83	59	15.9
12	89	-	85	-	-
13	93	-	88	-	-

3.2.3 Intercrop

	Technique		Percentage		Cover
Time (Weeks)	SF-80	S/Frame	M/Stick	Camera	Std.Dev
0	0	0	0	0	0
1	0	0	0	0	0
2	15	11	14	12	1.8
3	28	25	25	23	2.1
4	40	41	37	34	3.2
5	52	56	49	46	4.3
6	67	58	60	53	5.8
7	79	70	76	60	8.4
8	90	82	82	64	10.9
9	93	87	86	69	10.2
10	95	88	91	-	4.7
11	97	-	82	64	17.6
12	93	-	78	-	-
13	94	-	-	-	-

Appendix 4 Analysis of Variance

1 ANOVA (Split-plot)

Crop Phenological stage: Early Vegetative. (14/12/92)

Source	df	ss	mss	F cal	F tab
Block	3	129.6			
Crop	2	2659.4	1329.7	14.6	10.92
Error (a)	6	546.6	91.1		
Main plot total	11	3335.6			
Tech (T)	2	1249.4	624.7	14.94	6.01
T x C	4	9.1	2.28	0.06	4.58
Error (b)	18	752.8	41.8		
Subplot total	35	5346.9			

Fcal: F-calculated; Ftab: F-tabulated; T: technique; C: crop

Comparison of the mean cover values by the least significant difference (LSD)

LSD = t(18 df, 99% CI) = 13.2)

1. Maize

   41 53 56 . for Camera, S/frame and M/stick respectively.
2. Beans

   62 72 74. for Camera, S/frame and M/stick respectively.
3. Intercrop

   60 70 74. for Camera, S/frame and M/stick respectively.

2 ANOVA (Split plot) 21/12/92

Source	df	ss	mss	F cal	F tab
Block	2	26.7			
Crop (c)	2	1428.6	714.3	24.9	18.0
Error (a)	4	114.8	28.3		
Main plot total	8	1570.1			
Tech (T)	3	2803.8	934.6	32.6**	5.09
T x C	6	7.2	1.2	0.042	4.01
Error (b)	18	515.8	28.7		
Subplot total	35	4896.9			

Comparison of means by LSD

LSD ,t(18 df,99% CI) = 12.6.

1. Maize.

55 60 69 78. for Camera, M/stick, S/frame Ceptometer respectively.

2. Beans.

66 76 78 89 for Camera, S/frame, M/stick and Ceptometer respectively.

3 Intercrop

64 78 82 90. for camera, M/stick, S/frame and Ceptometer respectively.

3 ANOVA RBD Beans (25/1/93)
Phenological stage: Mid maturity

Source	df	ss	mss	F cal	F tab
Total	15	1083.8			
Block	3	614.3	204.8	8.68	6.99
Tech	3	257.3	85.5	3.64ns	6.99
Error	9	212.2	23.6		

ns: not significant at 99% CI.

4 ANOVA RBD Beans (1/2/93)
Phenological stage: Late maturity.

Source	df	ss	mss	F cal	F tab
Total	15	2883.4	292.7		
Block	3	108.7	36.2	0.86	6.99
Technique	3	2394.7	798.2	18.9	6.99
Error	9	380.1	42.2		

Comparison of the means by LSD

LSD : t(9 df, 99% CI) = 14.9

16 17 38 43. for M/stick, Ceptometer, Camera and S/frame respectively.

Appendix 5

Comparison of the systems 0-0.5-1 and 0-0.25-0.5-0.75-1 of cover estimation of the sighting frame

		Ref	%	crop	cover					
Trial No.	0	13	17	20	21	35	36	48	58	71
C1	0	25	35	30	25	40	45	40	40	70
N1	0	25	38	24	23	35	39	33	45	63
C2	0	20	20	35	30	30	33	50	60	70
N2	0	20	25	32	35	23	41	53	45	68
C3	0	25	30	25	30	40	40	50	55	45
N3	0	25	25	23	23	38	43	45	60	43
C4	0	30	20	30	30	45	40	50	45	65
N4	0	30	18	28	23	50	41	55	60	60
C5	0	25	25	-	30	45	-	45	55	65
N5	0	25	20	-	25	55	-	55	50	73
C6	0	-	-	-	30	-	-	-	-	-
N6	0	-	-	-	33	-	-	-	-	-
Mean C	0	25	26	30	29	40	40	47	51	63
Mean N	0	24	25	27	27	40	41	48	54	61
% err.C	0	92	53	50	38	14	11	-2	-12	11
% err.N	0	85	47	35	29	14	14	0	-7	14

Ref: Reference, err: error. C: [0-0.5-1] system, N: [0-0.25-0.5-0.75-1] system.

Appendix 6

Short rains season daily total rainfall amounts and total Kinetic Energy

Date	Week No.	No. of storms	Total rainfall amount (mm)	Total Kinetic Energy (J/M^2)
3/11/92	1	15	26	543
4/11/92	1	2	8	135
5/11/92	1	6	7	121
6/11/92	1	6	5	92
14/11/92	2	4	5	114
16/11/92	2	14	27	603
30/11/92	3	6	7	122
7/12/92	5	6	8	158
9/12/92	6	5	4	88
10/12/92	6	7	14	287
16/12/92	7	16	31	602
31/12/92	9	5	7	147
1/1/93	9	1	12	353
6/1/93	10	6	20	405
7/1/93	10	17	33	678
11/1/93	10	6	6	96
13/1/93	11	5	7	124
15/1/93	11	8	18	382
17/1/93	11	3	9	209
8/2/93	11	11	20	410
19/2/93	12	6	4	64
20/2/93	12	11	47	1134
21/2/93	12	2	4	63
Total			325	6930

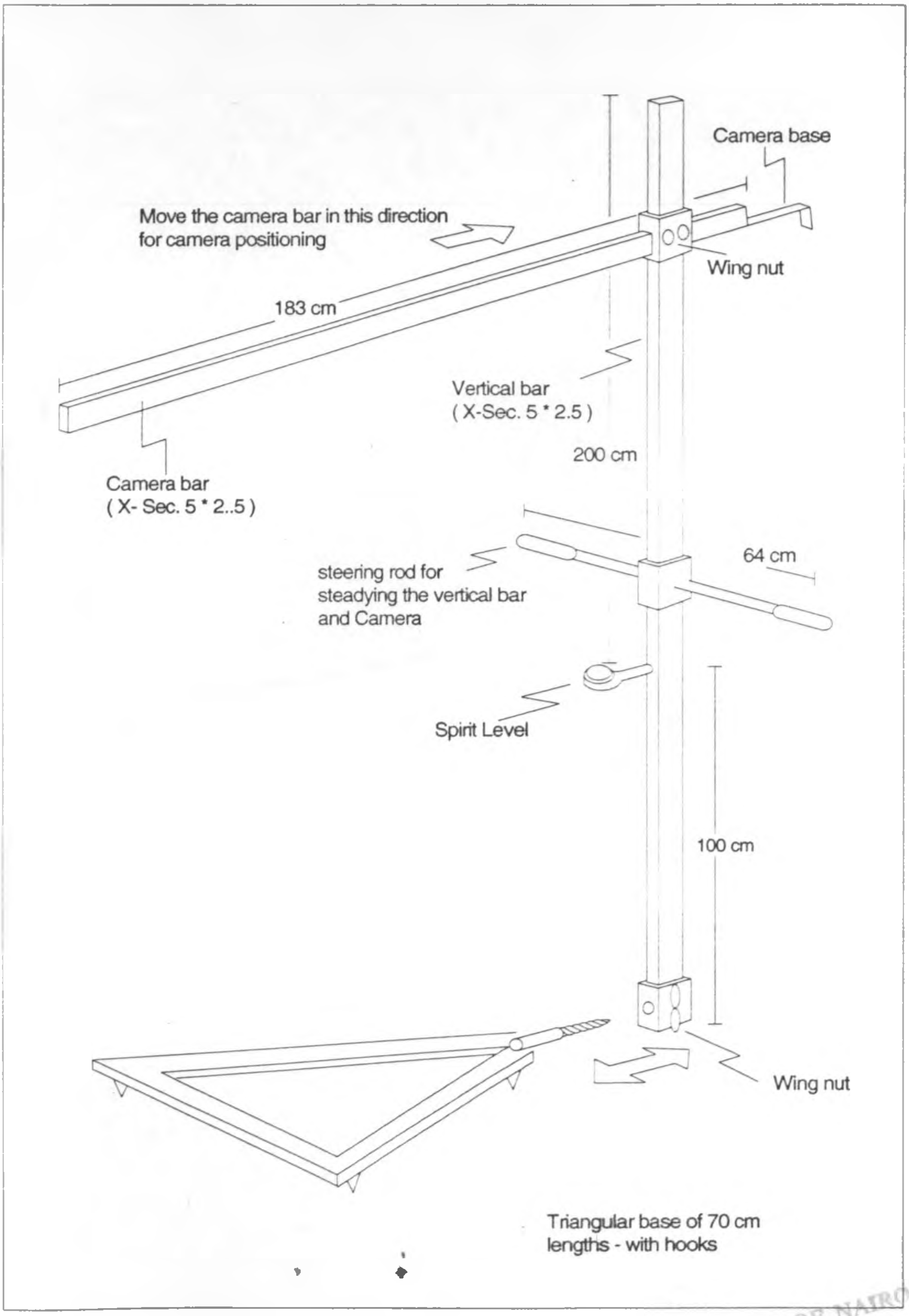
Regression of total rainfall amounts and total kinetic energy gave the following results:

R^2 = 0.979.
Co-efficient of x = 21.9.
Standard error co-efficient = 0.444
Standard error Y estimate = 38.49
Sample size (n) = 23

The regression coefficient was highly significant. This can be attributed to the rainfall characteristics of that time. Rainfall energy is however greatly influenced by the rainfall intensity.

Appendix 7

The Camera-stand Design Specification



UNIVERSITY OF NAIROBI
KABETE LIBRARY