# THE INFLUENCE OF CROP COVER ON SOIL EROSION BY SPLASH

BY

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Dedicated to Nick, my husband, for his unwavering support in so many ways.

## DECLARATION

I hereby declare that this thesis is my original work and has not been presented in any other University. All quotations have been distinguished by quotation marks and all sources of information specifically acknowledged.

Signed____________________

Mrs B. M. Mati

This thesis has been submitted for examination with our approval as the Principal University Supervisors.

Signed____________________

Dr. M. Zobisch

Signed____________________

Prof. D.B. Thomas

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## F. LIST OF ABBREVIATIONS AND SYMBOLS

A Rainfall amount in millimetres.

α Significance level in an analysis of variance test.

AI The product of rainfall amount and intensity.

cm Centimetres.

°C Degrees centigrade.

E Rainfall kinetic energy.

EI The product of rainfall kinetic energy and intensity.

et al And others.

F value obtained in an analysis of variance test to determine the significance level of two or more variables.

Fig. Figure.

g Grams.

h Hours.

J Joules.

kg Kilograms.

I Rainfall intensity.

m Metres.

mm Millimetres.

r Value of correlation coefficient.

Weighted splash: Total splash per percent bare space under a crop.

## G. ABSTRACT

This study involved determining the influence of crop cover on splash erosion. This was done on 16 plots of 4 treatments of maize, beans, intercrop (maize & beans) and bare fallow (control), with 4 replications of each treatment.

The highest total amount of splash was recorded on bare fallow land, followed by maize, then beans and intercrop respectively. Soil splash per unit bare space was found to be highest under maize, while beans, intercrop and bare fallow had equal amounts of splash per unit exposed surface area for a given amount of rainfall.

The amount of soil splash per mm of rain decreased exponentially with the percent crop cover in all the treatments. For a given percent crop cover, soil splash per mm of rain was constant for maize, beans and intercrop for crop covers less than 40%. For covers exceeding 40%, for a given amount of crop over, splash was highest under maize, followed by beans and intercrop respectively.

The amount of splash per mm rain also decreased exponentially with crop height. For a given crop

height, splash per mm of rain was highest on maize, followed by intercrop and then beans respectively.

The best erosivity factor for splash erosion in this area was the $AI_{45}$ index, defined as the product of the rainfall amount and its maximum 45-minute intensity, with a correlation coefficient of 0.821. Both the total splash and the splash per exposed area increased with each of the rainfall erosivity indices as power functions.

The percent splash transport downslope was found to be unrelated to either rainfall characteristics or crop cover and height. The amount of soil splashed downslope was about 7 times that splashed upslope on bare fallow, and about 6 times on maize cropped plots. For beans and intercrop, power relations existed between upslope and downslope splash, but the overall effect was that the ratio of splash downslope to upslope was less than that for maize and bare fallow plots.

The amount of soil splashed downslope decreased with increase in crop cover for all the treatments. For a given percent crop cover, splash downslope was highest under maize, followed by beans and then intercrop respectively. The amount of soil splashed upslope was found to be unrelated to crop cover.

The amount of soil splashed both upslope and downslope increased with the rainfall $AI_{45}$ index. For a given $AI_{45}$ value, splash downslope was highest on bare fallow, followed by maize, beans and then intercrop respectively. For a given $AI_{45}$ value, soil splash upslope was highest on bare fallow, and lowest on maize, beans and intercrop equally.

Statistical analysis of the basic data showed that replications were not different ($\alpha=0.01$), and daily splash amounts showed highly significant difference ($\alpha=0.05$). The analysis of variance tests for comparing treatments showed that all treatment pairs were different ($\alpha=0.05$) except between beans and intercrop. The t-test for the relationships between splash amount and crop cover or rainfall erosivity values, for highly correlated data were all highly significant ($\alpha=0.05$)

# CHAPTER 1

## 1.0 INTRODUCTION

### 1.1 Raindrop erosion

Soil erosion by water begins with the detachment of soil aggregates by impacting raindrops. Translocation of the detached soil particles may be caused by raindrop impact as splash, through gravitational force downslope as creep, or by overland flow. Consequently, erosion can be regarded as two separate ordered processes; detachment followed by transport. Thus, the total soil loss at any given time can be partitioned into the loss contributed by the surface-water flow, and that contributed by raindrop impact.

The severity of erosion depends on the quantity of material supplied by detachment, and the capacity of the eroding agents to transport it (Morgan, 1986). Thus, erosion is either detachment-limited (when transport capacity exceeds detachment ability) or transport-limited (when detachment ability exceeds transport capacity). The recognition of which factor, detachment or transport, is limiting is important in the selection of the appropriate conservation method.

Raindrop erosion (splash erosion or simply splash) is the result of the detachment and transport of soil particles by the impact force of the raindrops. This force has to overcome particle weight and the cohesive forces binding the particles together. However, the efficiency of this force in causing erosion depends on the surface soil conditions, such as the erodibility of the soil, the type and amount of vegetation, land slope and the orientation of the raindrops with respect to the ground.

The raindrop kinetic energy when released on the soil particles has two effects. First, it provides a consolidating force, compacting the soil. This creates a thin surface crust, enhancing the clogging of pores. Secondly, it provides a velocity to some soil particles dislocating them and leading to splash transport. The detached soil particles are splashed and fall back to the surface in a more dispersed state. This process continues as rainfall proceeds, consequently, many physical properties of the surface soil change with time, causing soil splash detachment to change with time.

The energy imparted by raindrop impact also contributes greatly to erosion by shallow flows. The energies of the falling drops are transferred to the surface flow in the form of turbulence and help to detach the soil and to hold materials in suspension. The combined effect of splash detachment and transport is a levelling of the surface, and on sloping ground, in a gradual movement of surface particles down the slope. This type of erosion is not obvious, but it influences the amount of soil removed from the land by subsequent runoff.

## 1.2 Significance of the study

Soil erosion is becoming an increasing problem in Kenya. This is due to more land being cleared for cultivation, and the existing farmlands being more intensively cultivated to accommodate the expanding population. As agricultural activities spread on to very steep slopes and marginal lands, the effects of soil erosion are already being felt, especially with the sedimentation of streams and reservoirs (Ogweny, 1978; Barber, 1982) and the development of gullies (Reid, 1983). The long term effects include loss of top soil, which is the most fertile, resulting in lower land productivity. Added to this will be the loss of rain water as runoff and reduced infiltration, hence reduced soil moisture storage, leading to poor crop stand and consequently, poor yields.

Although it is apparent that soil erosion is a serious problem that threatens agricultural as well as natural resources, yet quantitative data for predicting actual and potential erosion have been very scarce in Kenya. For effective soil conservation planning, there is a need to identify the real causes of erosion. There has been much emphasis by researchers on studying erosion processes mainly by considering surface runoff. In Kenya, studies on erosion such as by Ulsaker and Kilewe (1984), Barber (1982), Lewis (1985), Omwega (1989) have dwelt on surface runoff as the main causative factor in erosion. Most of these studies have ignored or failed to isolate splash erosion as a contributory factor to the whole erosion process.

Most of the research on raindrop erosion (Al-Durah and Bradford, 1982 (a & b); Moldenhauer and Koswara, 1968; Bauer, 1985; Nearing and Bradford, 1987) have been laboratory studies, using simulated rainfall and soil or sand trays. While this type of data may be used universally, the field data, such as obtained by Morgan (1982) and Bolline (1980), may not correlate well under tropical conditions. This is due to differences in soil types, climate, vegetation types and management. Thus there is a need to generate indigenous data based on local field conditions.

The major food crops in Kenya include maize and beans. Since these are annual cultivated crops, they leave the land bare at certain times in the growing cycle. This is most critical at the beginning of the growing season before crop establishment. Crop cover develops gradually and at varying rates and amounts, influencing the rate and amount of erosion that can occur. Though some studies of soil erosion under these crops have been done (Ulsaker and Kilewe, 1984; Lewis, 1985; Omwega, 1989) mainly by runoff sampling, it would be useful to consider that portion of erosion that occurs even before the onset of runoff. It is this raindrop erosion that contributes some of the soil particles carried away by the runoff flows, while also enhancing compaction and sealing of the soil. This subsequently reduces infiltration, thereby increasing surface runoff and soil loss.

To fully appreciate the process of erosion under these crops, it is necessary to isolate raindrop erosion (splash) as a distinct process, and to study it for the three most common systems of arable farming practised in Kenya; namely, maize grown as a pure stand, beans pure stand and intercropped maize and beans.

Therefore, this study has the following objectives:

(i) To determine the effect of crop cover on splash detachment and transport.

(ii) evaluate the influence of crop height on raindrop erosion.

(iii) evaluate the effect of rainfall characteristics (amount, intensities, energy) on splash detachment and transport.

(iv) to determine the influence of slope on soil erosion by splash.

# CHAPTER 2

## 2.0 LITERATURE REVIEW

### 2.1 Factors affecting raindrop erosion

The amount of soil splash from raindrop impact depends upon forces which tend to detach soil material and opposing forces which resist particle movement. Three major variables interact in this dynamic process (Park et al., 1982) namely; rainfall characteristics, soil characteristics and the environment which includes the prevailing vegetation, ground slope and wind speed and direction.

#### 2.1.1 Rainfall characteristics

Soil erosion is a work function and the source of energy to perform this work is rainfall. The potential of rain to cause erosion is referred to as rainfall erosivity. It is a function of the various physical characteristics of rainfall such as its energy and momentum, which are themselves functions of rainfall intensity, and raindrop characteristics such as drop diameter, fluid density, standard deviation of drop size distribution and velocity of the falling drop.

#### 2.1.1.1 Rainfall momentum

Rainfall momentum, a product of mass and velocity of the raindrops, is a measure of the pressure exerted by rainfall on the soil. Though not a popular measure of rainfall erosivity, momentum has been associated with rainfall intensity, hence erosivity. Lal (1981) related rainfall intensity and amount to momentum as follows:

$$\text{Momentum } (J\ m^{-2}s^{-1}) = 6.67P + 9.32 \qquad [2.1]$$

$$\text{Momentum } (J\ m^{-2}s^{-1}) = 4.79I_{30} + 8.74 \qquad [2.2]$$

Where, P is rainfall amount in mm and $I_{30}$ is the 30-minute intensity.

Various studies on soil detachment by rainsplash have shown that it occurs as a result of rainfall momentum and kinetic energy (Roose, 1980; Gregory, 1980; Morgan, 1981). In Nigeria, Lal (1981) found momentum to be directly related to the amount of soil detached. Rose (1960) observed that the mass of soil detached per unit area was more closely related to momentum than to kinetic energy of rainfall. More recent research has correlated raindrop energy, rather than momentum to splash detachment.

### 2.1.1.2 Rainfall energy

When a raindrop falls on the soil surface, it releases both its potential and kinetic energies. Research has shown that it is the kinetic energy component that contributes most to soil erosion. Rainfall erosivity, is a function of the kinetic energy and the rainfall intensity for a specified duration. A lot of research has been done to develop an erosivity index that best correlates with soil loss. Wischmeier's (1958) $EI_{30}$ index, the product of a raindrop's kinetic energy and its 30-minute intensity is widely used as it is the standard universal soil loss equation (USLE) erosivity index. This index has been verified in many parts of the world (Bolline, 1980; Zanchi and Torri, 1980; Lal et al, 1980; Roose, 1980), sometimes with minor differences.

Here in Kenya, Ulsaker and Onstad (1984) found that two of the best rainfall erosivity factors are total kinetic energy times the maximum 30-minute intensity ($EI_{30}$), and rainfall amount times the maximum 30-minute intensity ($AI_{30}$). In Zimbabwe, Hudson (1981) found the KE>25 index (the total kinetic energy of the rain falling at intensities of more than 25 mm $h^{-1}$) to be more appropriate.

The $EI_{30}$ index is sometimes superseded by other indices. Elwell and Stocking (1973) found that for plots with high and medium crop covers, rainfall erosivity was best correlated by the $EI_5$ and $EI_{15}$ (energy x the maximum 5- and 15-minute intensity) respectively.

Kinetic energy of the rain is itself related to rainfall intensity. Wischmeier and Smith (1958) obtained the following relationship between rainfall kinetic energy and intensity.

$$Y = 916 + 331\log_{10}X \quad [2.3]$$

Where, Y = Kinetic energy in foot tons/acre.

X = Rainfall intensity in inches/hour.

This relationship has been expressed in SI units as follows (Morgan, 1986).

$$E = 11.87 + 8.73\log_{10}I \quad [2.4]$$

Where, E is the rainfall kinetic energy in J $m^{-2}$ $mm^{-1}$

I is the rainfall intensity in mm $h^{-1}$.

The kinetic energy, and thus erosivity of tropical rainstorms is different from that of temperate climates. Elwell and Stocking (1973) obtained the following relationship for Southern Africa.

$$KE = 29.8 - 127.5/I \quad [2.5]$$

Where, KE is the kinetic energy (J $m^{-2}$).

I is the rainfall intensity.

Similarly, Lal (1981) found that for Ibadan, Nigeria, the kinetic energy was related to rainfall intensity as follows;

$$KE = 18.18I_{30} + 18.18 \qquad [2.6]$$

Where, KE is kinetic energy ($J\ m^{-2}$).

$I_{30}$ is maximum 30-minute intensity ($mm\ h^{-1}$).

In Kenya, Ulsaker and Onstad (1984) obtained the following relationships between rainfall kinetic energy, its intensity and amount for Machakos area.

$$EI_{30} = 0.206AI_{30} - 3.9 \qquad [2.7]$$

Also, $$EI_{30} = 9.00A - 97.4 \qquad [2.8]$$

Where $EI_{30}$ is the kinetic energy ($MJ\ mm\ ha^{-1}\ h$), A is rainfall amount in mm, and $I_{30}$ is the maximum 30-minute intensity in $mm\ h^{-1}$. In the Kabete area, Tefera (1983) found that soil loss and runoff were more highly correlated with the rainfall amount and the $EI_{15}$ index (energy times the maximum 15-minute intensity).

The energy and intensity interaction was found (Wischmeier and Smith, 1958) to be a good measure of the decreasing infiltration rate during the rainfall, and also the protection against raindrop splash, which is afforded by the film of flowing water.

Soil detachment by rainsplash is also related to energy and intensity of the rain. Meyer and Wischmeier

(1969) observed that for moderate to intense storms, kinetic energy per unit area varies with intensity in the following manner.

$$D_R = S_{DR} A_i I^2 \quad [2.9]$$

Where, $D_R$ is the soil detachment by rainfall.

$S_{DR}$ is a soil type function.

While, $A_i$ is the area of increment.

I is the rainfall intensity (mm $h^{-1}$).

Morgan (1985) found that the rate of detachment ($D_s$) of soil particles varies with kinetic energy (KE) and intensity (i) of the rainfall, soil properties and ground surface conditions with the following relationship.

$$D_s = k_1 KE^b \quad [2.10]$$

$$D_s = k_2 i^c \quad [2.11]$$

Where, $k_1$ and $k_2$ are exponentially derived indices of soil detachability by raindrop impact, b=1.0 and c=2.0.

Field splash measurements by Bolline (1980) revealed the following relationship between splash amounts (Y) and rainfall erosivity assessed with the $EI_{30}$ index.

$$Y\ (t/ha) = 2.24(EI_{30})^{0.876}. \quad [2.12]$$

For tropical climate, Lal (1981) found sand splash to be related to rainfall intensity with the equation:

$$S = 17.6I_{30} + 1.64 \quad [2.13]$$

Where, S is the sand splash (g $m^{-2}$).

$I_{30}$ is the maximum 30-minute intensity (mm $h^{-1}$).

Soil erosion, and hence splash detachment, has also been related to rainfall amount. According to Lal (1988) for high rainfall intensities in the tropics, soil loss is related to the product of rainfall amount per storm (A in cm) with the maximum 7.5 minute intensity ($I_m$ in cm $h^{-1}$).

Thus, soil loss = $AI_m$. [2.14]

Using sand splash, Lal (1981) found that the kinetic energy (KE) of the rain was related to rainfall amount (P in cm) as follows.

$$KE = 24.50P + 27.6 \qquad [2.15]$$

Consequently, sand splash (S) was related to rainfall amount as follows.

$$S = 22.7P + 19.73. \qquad [2.16]$$

This shows that raindrop erosion is influenced by rainfall amount.

#### 2.1.1.3 Raindrop size

Rainfall erosivity is also related to raindrop size and its fall velocity. Epema and Riezebos (1983) observed that rainfall erosivity is related to drop diameter and velocity by equations of the form:

$$R = D^p V^q \qquad [2.17]$$

Where, R is the erosivity of rainfall.

D is equivalent drop diameter.

V is fall velocity (m $s^{-1}$).

p and q are coefficients.

A similar relationship was obtained by Ghadiri and Payne (1977), who found that rainfall erosivity (R) was proportional to the square of the velocity (V) and the drop diameter (D).

Thus, $R = V^2 D$. [2.18]

They also observed that the stress of droplet impact and stress caused by the flowing fluid jets and by static loads is not uniformly distributed, but is concentrated around the circumference of a circle.

High rainfall intensity is generally associated with big drop size and high drop density. For tropical rainstorms, median drop sizes above 3 mm have been recorded. Lal et al. (1980) obtained an exponential relationship between raindrop size and rainfall intensity as follows:

$$D_{50} = 2.59I^{04}$$ [2.19]

Where $D_{50}$ is median drop size in mm.

I is the intensity in mm $h^{-1}$.

This relationship indicates a decrease in drop size with increase in intensity beyond 50 mm $h^{-1}$.

Large drops produce more splash than small ones.

Bubenzer and Jones (1971) observed that the mean splash rate of soils exposed to rainfall of a nearly constant kinetic energy, level, and impact velocity was influenced by drop size at the lower energy levels. The smaller drops produced significantly less splash than the larger ones, even though the kinetic energy, total rainfall mass and impact velocity were almost constant. As the energy level increased, the influence of drop size decreased.

Raindrop shape also affects the amount of soil splash. Riezebos and Epema (1985) found that by changing the height of fall from 0.57 to 0.62 and then to 0.67 m the amount of splash changed from 0.78 and then to 0.28 to 0.88 m respectively. This was because the drop shape at 0.57 m and 0.67 m fall height was prolate and at 0.62 m fall height, the shape was oblate. The shape of falling drops tend to oscillate between a prolate and an oblate shape. According to Huang et al. (1982) the amount of soil detached by raindrop impact is affected by the vertical impact stress distributions, which are responsible for shape of the raindrop impact crater, and the development of destabilising tensile forces at crater boundaries.

### 2.1.2 Soil type

Soil characteristics affecting raindrop splash include; particle size, degree of aggregation, percentage clay content, organic matter, surface area, and the amounts of exchangeable sodium and soluble salts. In addition, mechanical properties of the soil such as soil deformation characteristics, bulk density, matric potential, soil shear strength and the surface micro-relief determine the resistance that the soil offers to raindrop impact.

The soil shear strength has in particular been associated with resistance to splash detachment. Al-Durrah and Bradford (1981) obtained the following relationship for soil detachment and its shear strength:

$$D = a + b(KE/T_f) \qquad [2.20]$$

Where, D is the amount of soil detached (mg/drop).

KE is raindrop kinetic energy (J).

$T_f$ is soil shear strength (kpa).

a and b are constants.

By comparing different soil types, resistance to splash detachment was found (Quansah, 1981) to increase in the order of gravelly sand, sandy clay and clay loam. This agrees with the findings of Farmer

(1973) who found that peak detachability occurred for smaller particle sizes under splash alone as compared to during overland flow.

Splash detachment is most severe on particles of medium size (100$\mu$m). This is because coarser particles are rather heavier while finer material has higher cohesion, which resists erosion. The erosion rate for each particle fraction depends on three factors (Bauer, 1985): (i) particle diameter which determines its resistance to detachment and transport, (ii) the erosive capacity of the flow and (iii) the availability of the particle fraction at the soil surface.

Aggregate stability also plays an important role during splash detachment. Lal (1981) observed that soils with a weak or single-grain structure, consisting mainly of primary soil separates, are more easily splashed than soils with well developed structure because the aggregates require some energy to be detached prior to being splashed.

Antecedent soil moisture also affects raindrop splash. In dry soil, the drops are easily absorbed into the pores and the soil suction is very high, therefore, splash rates are not very high. Once the soil surface is uniformly wetted, not all the pores are filled with water, a situation of high stability is then reached. The resistance to water intake becomes higher and the droplet bursts, forming the water corona. Thus, splash rates will increase from dry situation to wetted condition, and decrease again at the liquifying stage.

Soil management also affects its resistance to splash. Alberts et al. (1987) found that for soils that had been subjected to five years' continuous soybean and corn cultivation, the splash was significantly higher and strength significantly lower for the soybean cropped soil, as compared to the corn-cropped soil.

Soil bulk density and matric potential also affect its splash characteristics. Al-Durrah and Bradford (1981) found that the weight of soil splash was reduced as bulk density increased and matric potential decreased. This was because near-surface shear strength increased as bulk density increased and matric potential decreased.

### 2.1.3 Wind

There is limited data on the effect of wind on raindrop splash. Splash saltation can be considered as a pluvio-eolian process, whereby the role of waterdrops cannot be clearly distinguished. Normally, rainsplash is a function of wind direction and velocity. Wind direction relative to the direction of the land slope can affect soil loss prediction as it affects the detaching ability of the raindrops, whose angle of impact is influenced by the wind. In addition, for a specific rain intensity measured in a vertical rain gauge, the energy of impact per unit area of land surface would not be accurately determined for a wind driven rain.

The high energy load of tropical rainstorms is partly attributed to the high winds accompanying them. Lyles et al. (1969) reported 68 percent more detachment with a 48 km $h^{-1}$ wind driven rain than where there was no wind. Similarly, Lal et al. (1980) observed that those storms in which peak intensity and peak wind velocity coincided were highly erosive. Wind alters the angle of raindrop impact, by adding a horizontal component to drop velocity, consequently increasing its detaching capacity.

### 2.1.4 Land slope

It is a well known fact that on sloping land, raindrop impact causes the net splash reaction to be in a downhill direction (Schwab et al., 1971). For soil transport by rainsplash, the percentage of total splashed soil that moves downslope is related to the percent slope. Research has shown that for a 10% slope, 75 percent of the splashed soil moves downslope and 25 percent uphill, although the net downslope movement is the product of a soil type factor and rainfall intensity (Meyer and Wischmeier, 1969).

The slope steepness also affects soil splash to a small extent. By comparing splash effects on different slopes, Farmer (1973) found that as slope steepness increased, there was a slight increase in the amount of soil material detached.

Sometimes during oblique rainfall, the splash saltation flux can be oriented upslope. Moeyersons (1983) found that net flux equals zero for slopes between 19° and 17° when rainfall obliquity was 20°. Thus, the net splash direction depends not only on the slope inclination, but also on slope orientation with reference to wind direction.

### 2.1.5 Vegetation

The soil surface and the above surface cover, mainly the prevailing vegetation and subsequent litter, protect the soil from raindrop impact, by intercepting and absorbing raindrop kinetic energy thus reducing soil erosion (Othieno and Laycock, 1977; Rose, 1960). Of the total rain falling on vegetated land, some of the water may evaporate from the leaves, but most reaches the ground surface either by stemflow or by reforming into droplets that for close growing vegetation, have little chance to pick up speed and gain further kinetic energy.

Vegetation varies significantly in its characteristics and structure. This depends on the lay out of the leaves at different heights, affecting the proportion of water that either drips directly or falls slowly as stemflow. As the plant grows, the percentage interception area increases, while the volumes of stemflow and leafdrip increase, consequently, soil detachment is reduced. Plant cover appears to be more effective in protecting the soil in high energy rather than low energy storms. This is because the raindrops coalesce under low rainfall intensities becoming larger and more erosive, unlike on bare ground, resulting in relatively more splash.

Research has shown that plant covers generally reduce splash erosion. Hudson (1981) found that by covering the soil with a mosquito gauze, soil erosion was reduced to only 1 percent of that from an unprotected soil. In another study, Bolline (1980) found that crop cover reduces splash erosion. He obtained mean splash amounts of 69.6 t/ha/yr for naked soil as compared to 51.5 t/ha/yr for land cropped with sugarbeets.

The type and height of the vegetation also affect the splash amounts. Chapman (1948) observed that forest canopy does not reduce erosion, but rather, it was the litter and the lesser vegetation that reduces erosion in a forest. He found that the median drop size was about twice as big for pine cover as for open field. Also, the kinetic energy per millimetre of rain per unit area of soil surface was greater under pine than in the open field.

Similar results were also obtained by Morgan (1985a) who found that the percentage of rainfall volume reaching the ground surface decreased with increasing canopy cover only slightly till 50 percent of the cover was attained, then more rapidly till 90 percent cover. He also found that detachment rates under corn increased with canopy cover while with soybeans, soil detachment decreased as cover increased for high intensity rainfall, as compared to bare soil. Thus crop cover was found to modify the relationship between detachment and rainfall energy as follows

(Morgan, 1985b).

$$D_s = k_1(KEe^{-aINCEP})^b \qquad [2.21]$$

Where, $D_s$ is the rate of detachment.

$k_1$ is the index of soil detachability.

KE is the kinetic energy.

a ranges from 0.03 to 0.15.

b is an exponent, usually 1.0.

INCEP is percentage of rainfall that contributes to permanent interception and stemflow and does not contribute to splash detachment.

The unusual behaviour of splash under vegetal cover was explained by Finney (1984), who measured the percentage of storm rainfall reaching the ground separately as throughfall, leafdrip and stemflows. The kinetic energy of rainfall under plant covers was less than on bare ground and it increased as canopy area increased, resulting in a negative relationship between soil detachment and kinetic energy. This is because as the plant grows, the percentage interception area increases, the volume of throughfall decreases, while the volumes of stemflow and leafdrip increase. Thus soil detachment is reduced.

Soil surface cover as by mulching has also been found to reduce splash erosion. Gantzer et al. (1987) observed that the addition of corn or soybean residues increased soil strength and reduced soil splash in a log-linear manner. The most pronounced effects were observed during peak microbiological activity periods during residue decomposition. Corn residues reduced splash and increased strength more than soybean residue. Thus suggesting that the type of material on the soil surface also affects splash rates.

## 2.2 Mechanics of raindrop erosion

### 2.2.1 Importance of raindrop erosion

Raindrop erosion is the soil splash resulting from the impact of waterdrops on soil particles or on thin water surfaces (Hudson, 1981). Thus, soil detachment due to raindrop impact is the mass of soil actually dislodged per unit area. While this may appear to be a harmless process, splash transport or the net soil movement in the resultant direction of the splash can result in a lot of soil loss. On sloping land, substantial net downslope splash transport has been recorded (Ekern, 1950; Quansah, 1981), while during wind-driven storms, net splash transport in the windward direction occurs (Wischmeier and Smith, 1958).

Apart from losses through direct splash transport, raindrop erosion is also responsible for a large portion of soil material transported by surface runoff. Impacting raindrops break down soil aggregates, releasing soil particles that are more susceptible to erosion by runoff. Research has shown that soil loss increases ten times when water is applied as a spray in comparison with the same rate of application as surface flow (Rose, 1960). The effect of impacting raindrops is also associated with soil compaction and surface sealing, which modifies the infiltration process, and increases runoff (Roose, 1980). This consequently increases total soil loss and reduces soil moisture storage.

Though crop cover is usually associated with reduced soil loss, research has shown that with splash erosion, this is not always applicable (Morgan, 1982a; Noble and Morgan, 1983; Chapman, 1948) as with certain vegetation, especially tall types, splash has been found to increase with cover. This kind of disparity can only be recognised by separating raindrop erosion from the total soil loss.

Other studies have shown that under certain topographical conditions, soil detachment is influenced more by raindrop impact than by overland flow. Young and Wiersma (1973) found that soil loss was decreased by 90 percent when raindrop impact was decreased by 89 percent, therefore, indicating that detachment was primarily caused by raindrop splash.

### 2.2.2 Mechanics of splash detachment

Detachment, is the removal of transportable fragments of soil material from a soil mass by an eroding agent, usually falling raindrops, running water or wind (Farmer, 1973). Raindrop splash is associated with the mechanics of the raindrop itself. According to Epema and Riezebos (1983), drops are either in acceleration or have reached their terminal velocity during their fall through air. During the acceleration phase, the movement of drops initially takes place under laminar flow conditions. After a certain distance of fall during acceleration, conditions become turbulent, and finally, under turbulent conditions, the terminal velocity is attained. The drop reaches the soil surface in this condition.

The vertical force of the drop is transformed to lateral shear caused by radial flow of the impacting drop. Al-Durrah and Bradford (1982b) found that the impulsive loading caused by the impacting drop does not permit time for drainage, thus there is no change in total soil volume or bulk density. The soil surface is deformed under the impulsive load application of the drop, but vertical strain under the impact area is compensated by a bulge around the perimeter of the depression. At this stage, soil particle detachment is caused by shear stresses of the radial flow acting on the bottom and sides of the cavity and on the circular bulge.

Soil detachment by rainfall takes place in three stages (Lal, 1981). First, when the soil is still dry, detachment results from collision of elastic bodies. In the second stage, the soil is fluidized and the impacting raindrops cause the splash of the fluidized soil. In the third stage, the fluidized soil is covered by an overland flow that, combined with the impacting raindrops, causes the detachment of the soil aggregates. Hydration energy or heat of wetting plays a significant role in the first stage. Hydration energy is a function of soil moisture potential and the antecedent soil moisture content, thus, the higher it is, the greater is the soil detachment.

The soil detachment process is very short-lived. Ghadiri and Payne (1980) found that on the solid surface, the initial splash emerges within 0.2 milliseconds of impact, as an almost horizontal thin disc of water, with a velocity 3 to 5 times that of the falling drop. Rebound forces of high pressure (several bars) act over small annular areas of the target surface. The disc of splash water becomes slower and thicker, and forms an expanding water crown (or splash corona) which then differentiates into thicker and thinner zones, finally breaking off at its outer edge into splash droplets.

Peak impact pressures during detachment occur in an annular ring around the centre of the impact area. Nearing et al. (1987), found that the crater (central part) in sand splash, was always shallow compared with a deeper annular ring away from the centre. Impact pressures also increased with both density and water suction. Target shear strength and impulse are involved in cratering. Ghadiri and Payne (1985) found that splash force (F) and time (t) show a close relationship with crater volume (V).

Thus, $F/V \alpha 1/t$ [2.22]

They also found that cavity formation in liquid targets showed craters at their maximum depth and were all hemispherical in shape, with depth never exceeding one half of the diameter.

Splash detachment has been found to be a function of the kinetic energy of the rain. According to Morgan (1982) splash detachment is related to rainfall kinetic energy with equations of the form:

$$\text{Splash detachment} = aKE^b \qquad [2.23]$$

Where KE is the kinetic energy ($J\ m^{-2}$), a is a constant and b ranges from 0.8 for sandy soils to 1.8 for clays. Ghadiri and Payne (1985) found that 20 percent of the raindrop kinetic energy is accounted for in the splash droplets, about 25 percent in crater formation, and only 2 percent in rotational and surface energy droplets.

Both splash weight and splash angle are affected by frictional and cohesional forces between soil particles and soil deformability. Al Durrah and Bradford (1982a) found that soil deformability has a direct influence on splash angle, while cohesional forces between soil particles predominantly determine the weight of material splashed.

### 2.2.3 Mechanics of splash transport

It is very difficult to separate rainsplash transport from detachment because the very movement of soil particles during detachment is itself a transport process. Thus splash transport can be regarded as the net soil movement from the original position of rest of the particles, onto new positions of relative instability before runoff occurs.

Moldenhauer and Kemper (1969) observed that before runoff occurs on a tilled soil, large surface pores are usually filled with soil material to a point where intake rate is exceeded by rainfall rate. This is accomplished by the removal of material from the large clods by shearing action of the drops. The amount of material removed is increased as the clod becomes weaker due to wetting. Material detached by raindrops is carried into lower pores by infiltrating water. Finally, the material thus washed in reduces the surface pore sizes to a point where intake rate is exceeded by rainfall rate.

The capacity of rainfall to transport soil by splash is a function of slope steepness, amount of rain, soil properties, micro-topography and wind velocity (Meyer and Wischmeier, 1969). By raindrop impact, soil particles are displaced and thrown outwards in a splash corona. Bauer (1985) found that the angle of trajectory is around 30° when the soil is dry or has a very thin water film. When the water film becomes thicker (0.1 mm), the angle increases rapidly to about 60°-80°.

Styczen and Hogh-Schmidt (1988) observed that, since the distance of transport is related to the kinetic energy received by the soil particles from raindrop impact, both the mean transport distance, and the deviation from the mean increase when energy increases. Poesen and Savat (1980) found that the more cohesive a soil, the more is the energy required for detachment, and also the further is the transport distance and the greater is the variation in transport distance. This was supported by Al Durrah and Bradford (1982b), who found that detached particles of more resistant soils move with a higher velocity when splashed, and also, more erodible soils, which have greater splash angles, move furthest during splash.

## 2.3 Predicting raindrop erosion

Prediction of raindrop erosion is a complex exercise because it is a dynamic process, involving many variables that are changing both in space and time. Therefore the device used should provide data on the total amount of soil splashed by the raindrops or splash detachment. To do this effectively, Morgan (1981) suggests that the system must adequately isolate splash from the effects of sediment movement by overland flow and soil surface creep. It must not be affected by relative changes in the height of the device with respect to the soil surface as a result of ground lowering, compaction, frost or swelling and shrinking of the soil. Also, it must not interfere with the properties of rainfall close to the ground surface and should be acceptable environmentally.

Raindrop erosion may therefore be measured directly in the field, or through laboratory experiments using simulated rainfall. It can also be deduced by measuring variables related to splash such as rainfall intensity and drop characteristics.

### 2.3.1 Field measurements of splash

Very few studies of splash detachment have been done in the field. In most of those that have been done in the field, Ellison's splash cups have been used. These are small cups (Lo et al., 1985) containing pre-wetted, uniformly compacted sand of known particle size, as shown in fig. 2.1. The cups are exposed to the rain, and the amount of sand lost from the cup as a result of the action of raindrops is measured. The splash so lost is collected in a shallow bucket into which the cup is placed.

For soil splash under crop covers, Morgan (1981) designed a more suitable splash cup. This one, as

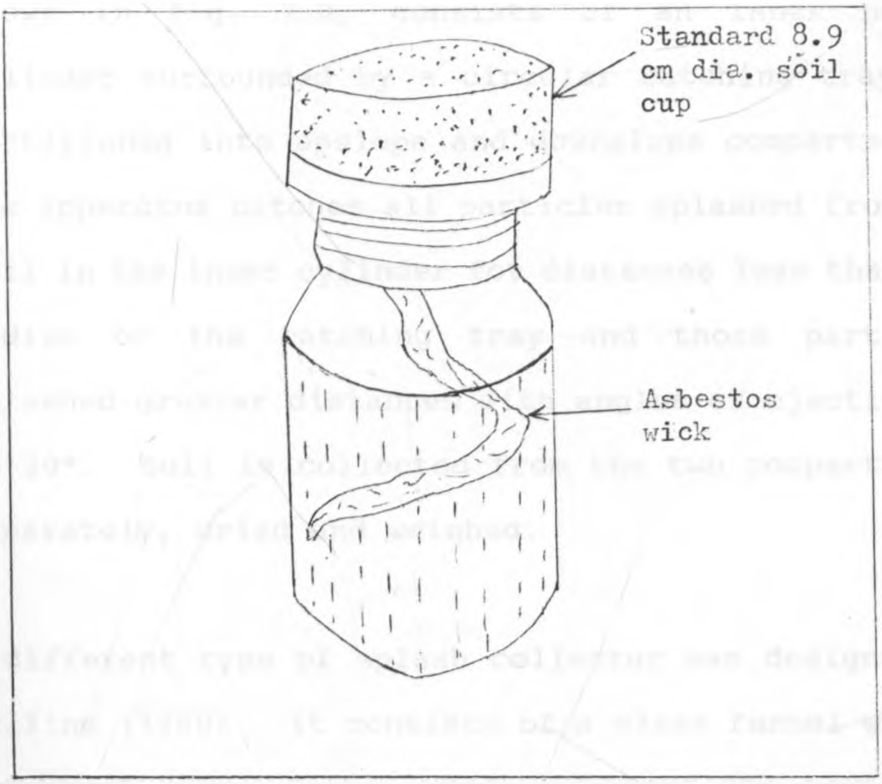



Fig. 2.1 Ellison's splash cup equipment (Lal, 1988).

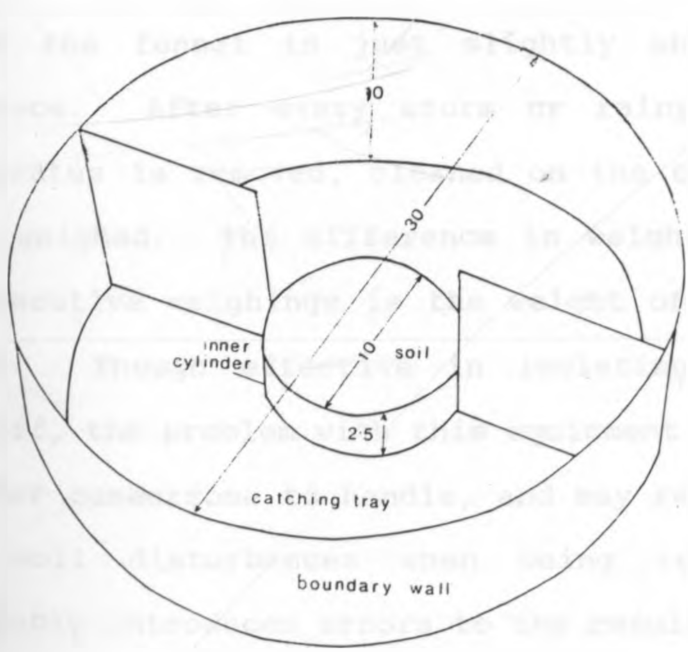



Fig. 2.2 Morgan's field splash cup (Morgan, 1981).
(All dimensions in cm).

shown in fig. 2.2, consists of an inner hollow cylinder surrounded by a circular catching tray and partitioned into upslope and downslope compartments. The apparatus catches all particles splashed from the soil in the inner cylinder for distances less than the radius of the catching tray and those particles splashed greater distances with angles of ejection up to 20°. Soil is collected from the two compartments separately, dried and weighed.

A different type of splash collector was designed by Bolline (1980). It consists of a glass funnel with a rot-proof glass filter which collects the particles projected by raindrop impact. The funnel leads into a bottle which is buried below the soil surface so that the funnel is just slightly above the soil surface. After every storm or rainy period, the apparatus is removed, cleaned on the outside, dried and weighed. The difference in weight between two consecutive weighings is the weight of the retained soil. Though effective in isolating splash from runoff, the problem with this equipment is that it is rather cumbersome to handle, and may result in a lot of soil disturbances when being replaced which probably introduces errors to the results.

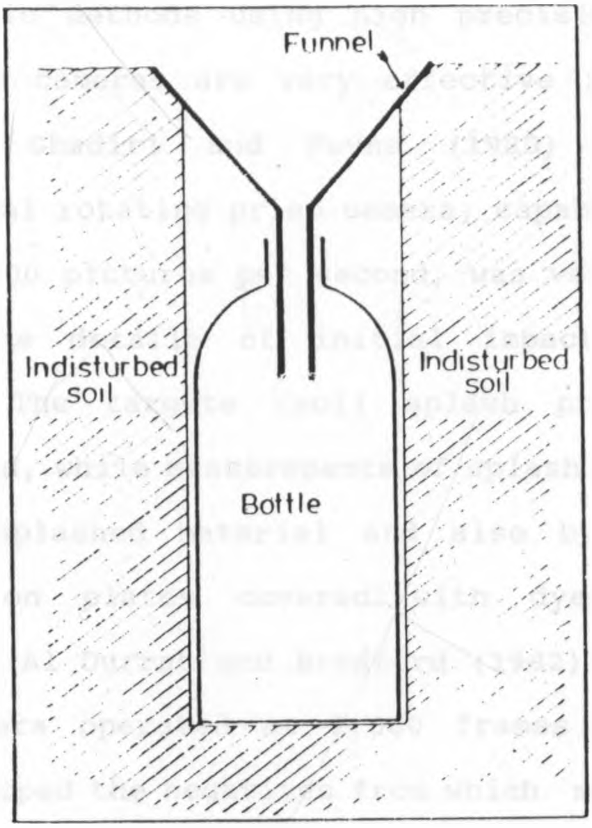



Fig.2.3 Bolline's splash trap (Bolline, 1980)

**2.3.2 Laboratory methods**

Laboratory methods of measuring direct splash action are more common because it is possible to control such variables as drop diameter, rainfall intensity, wind, slope and soil type; factors that complicate splash prediction in the field. Two broad methods are used; (i) photographic methods, and (ii) direct splash measurement.

#### 2.3.2.1 Photographic methods

Photographic methods using high precision and very high speed cameras are very effective in measuring splash. Ghadiri and Payne (1980) found that conventional rotating prism camera, capable of speeds up to 10,000 pictures per second, was very useful in showing the details of initial impact and early splash. The targets (soil splash process) were illuminated, while measurements of splash were made by weighing splashed material and also by collecting droplets on plates covered with dyed gelatine. Similarly, Al Durrah and Bradford (1982) used a high speed camera operated at 2,000 frames per second. They developed the negatives from which splash angles were measured on the prints using a protractor.

Though the photographic method is accurate and easy, it may not be applicable under field conditions where rainstorms occur at any time. It is also an expensive method, requiring high technological inputs that may be out of reach in certain circumstances. Otherwise it is a useful method for studying the mechanics of splash detachment.

#### 2.3.2.2 Direct splash measurement

Direct measurements of splash in the laboratory are also in most cases done using Ellison's splash cups (Al Durrah and Bradford, 1981; Moldenhauer and Koswara, 1968). In the laboratory, the splash cups are placed under a rainfall simulator. The sample is placed in a small pan underlain by sand with free drainage. Splash losses are collected on the pan or on panels placed near the pan.

Modifications of Ellison's splash cups are also commonly used. Yamamoto and Anderson (1973) used ordinary core samplers in place of cups to test soil splash from undisturbed soil samples. Similarly, Poesen and Savat (1980) used flumes filled to a depth of 5 cm with air-dried sand which was well drained at its base. Splash traps and beakers, well isolated from any direct splash activity were used to collect the splashed-out sand obtained using rainfall simulators.

A completely different type of splash measuring device was designed by Kerenyi (1981). It consisted of an open box-like splash recipient vessel, 400 mm by 300 mm and 500 mm high. Two such vessels were placed facing each other on a sand tray placed on a slope.

One box catches the upslope splash and the other downslope. This equipment then facilitates measurement of net splash transport.

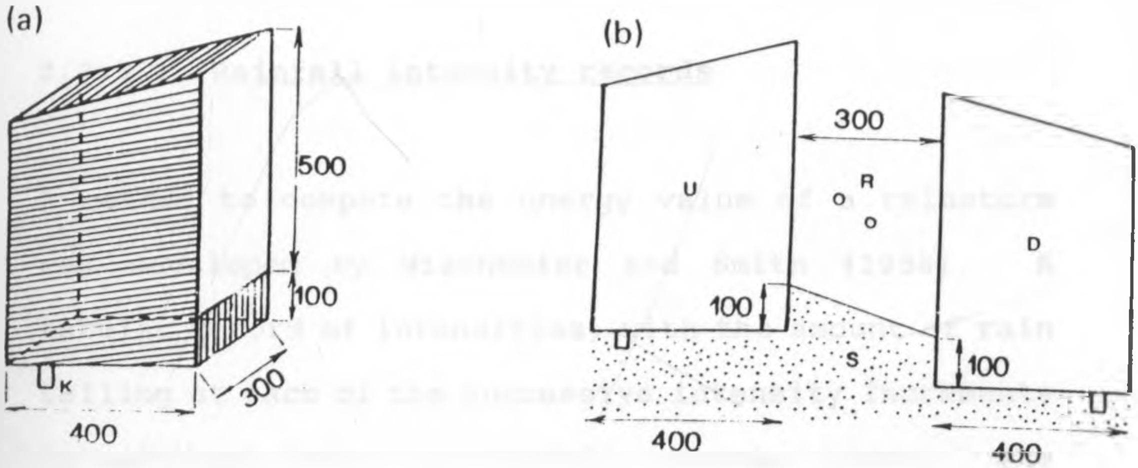



Fig. 2.4 Kerenyi's splash trap (Kerenyi, 1981). (a) The recipient vessels and (b) their position in the experimental set up. K is the outlet tube, R the raindrops, S is the sand, D the vessel at the lower end of the slope and U is the vessel at the upper end of the slope. (All dimensions in mm).

### 2.3.3 Empirical methods

These are methods of determining raindrop erosion without directly measuring the amount of soil splashed. By measuring the various variables that affect splash, equations are used to deduce the amount of raindrop erosion. Where resources and time may not facilitate direct splash measurement, these methods are usually easier, quicker and cheaper to apply.

This is achieved by assessing the erosivity of rainfall through computations from measurements of raindrop size using such techniques as the flour pellet method, or the dyestain method. Direct measurements of rainfall properties such as impact stress, momentum and energy are also used.

#### 2.3.3.1 Rainfall intensity records

A method to compute the energy value of a rainstorm was developed by Wischmeier and Smith (1958). A tabular record of intensities, with the amount of rain falling at each of the successive intensity increments is obtained from the rainfall recorder chart. The table is entered with the mid-value of a specific intensity increment. The corresponding energy figure from the table multiplied by the amount of rain falling at this rate describes the energy value of the increment of the storm. The total of these partial products gives the total energy value of the storm. This energy value can then be used to calculate the amount of splash detachment expected for a given soil.

#### 2.3.3.2 The flour pellet method

This method is used to determine the median drop size of rainfall. Knowing the drop diameter, splash detachment can consequently be deduced. This is achieved by exposing to the rain, pans containing a small amount of fine, uncompacted kitchen flour for a few seconds (Chapman, 1948). The droplets are left in the pan until the dough pellets that are invariably formed are hardened, and the latter are then separated from the flour and dried to a constant weight in an oven at about 110°c. The weight of the raindrops is then computed from the weight of the oven-dry pellets.

#### 2.3.3.3 The dyestain method

This is another method of estimating drop size distribution, and it depends on the assumption that a drop falling upon a uniform absorbent surface (e.g., Whatman no.1 paper) produces a stain whose diameter is proportional to the diameter of the drop. The distribution of drop sizes is obtained by comparing the size of the stains with those produced by drops of known diameter. The relationship between drop diameter and stain diameter is determined by prior calibration experiments. According to Hall (1970), this method is suitable for drops that exceed 1 mm in diameter.

#### 2.3.3.4 Acoustic method

In this method, the noise of rain falling on a diaphragm is picked up by a microphone which gives out a measurable signal (Hudson, 1981). By tuning the circuit, this method can be adjusted to measure rainfall intensity, momentum or kinetic energy. De Wulf and Gabriels (1980) designed a similar instrument for evaluating the energy load of rainstorms. The acoustic vibrations caused by the impact of raindrops on a suitable sensor are transformed into electric pulses and recorded graphically on a time scale. The graphic record is analyzed by sorting the pulses into several energy classes.

#### 2.3.3.5 Pressure transducers

Pressure transducers are devices that measure rainfall momentum by recording the physical displacement of a target sensor against an elastic spring or gravity (Hudson, 1981). The target sensor can be a diaphragm pressure transduce of unbounded strain gauge type, capacitance, or semi-conductors. These are high inertia pressure transducers and are fairly sophisticated and expensive. Nearing and Bradford (1987) used a piezoelectric pressure transducer calibrated in force units. The transducer was calibrated in shock tube, which provided pressure steps with rise in times on the order of 1$\mu$s. They found that the transducer had a highly linear response to applied force.

#### 2.3.3.6 Piezoelectric sensors

In this type, also used to measure raindrop size, changes in pressure on a quartz crystal generate an electric signal. With this device, it is necessary to achieve the right balance between (i) sensitivity and damping of the echoes, and (ii) the possibility of interference between drops which arrive at the sensor in rapid succession (Hudson, 1981). Otherwise, data generated by the sensor still needs to be sorted and analyzed in a form that can be used to deduce rainfall erosivity.

## 2.4 Assessing crop cover amounts

When vegetation is one of the variables that interact during soil erosion studies, it is important to know the proportion of ground that is covered, even if that cover is some distance above the ground. This gives a measure of the efficiency of vegetation to intercept raindrops or alternatively, the proportion of bare ground open to direct raindrop splash.

The most simple, least costly and most practical techniques for direct measurement of vegetative cover are ground-based vertical photography, and use of a quadrat sighting frame. Studies have shown (Stocking, 1988) that a quadrat sighting frame is a better method for routine field measurements as compared to vertical photography because it provides more details and is cheaper for repeated observations. Some of the methods commonly used to assess crop cover are described below.

### 2.4.1 Overhead photography

In this method, overhead photographs of plants are taken at some distance vertically above the plants using the following procedure as described by Adams and Arkin (1977). A board marked at regular intervals, say 10-cm increments, is placed between plant rows for use as a scale to measure a 1-$m^2$ soil-surface area on an enlargement. A scale sheet overlay with a random dot grid is superimposed over the photograph on a light box.

The amount of cover is determined by dividing the number of dots on all leaves within the 1-$m^2$ area by the total number of dots in the area. The main problem with this method is that it underestimates the percentage cover because it suffers from excessive radial displacement.

### 2.4.2 Simple sighting frame

This method as described by Stocking (1988) consists of two horizontal bars set directly above each other. Ten small holes are drilled at regular intervals along each bar so that an observer may peer through a hole in the top bar and see a small area of the ground through the corresponding hole in the lower bar. The observer then records the presence or absence of a leaf or other item of intercepting vegetation. After a predetermined number of observations, the results are expressed as a percentage. Though easy and quick, this method can introduce errors due to biases of the observer. It is also not suitable for tall-growing crops.

### 2.4.3 Improved mirror sighting frame

This is a modification of the simple sighting frame (Stocking, 1988) which removes errors and biases, and allows the measurement of tall-growing vegetation. This equipment, instead of looking vertically down, the instrument uses adapted gun-sights on sliding cursors to look obliquely downward onto a strip of mirror. The observer sees the reflected image of the crop leaves outlined against the sky. Cover assessment is done just like with the simple sighting frame.

### 2.4.4 Wire quadrat sighting frame

This is a canopy measuring quadrat frame consisting of a wooden frame with taut cross wires stretched across the frame in both directions making many small squares of 5 cm by 5 cm. This is held over the crop canopy close to the crop manually or over a stand. The canopy is observed from above the quadrat. Squares showing half and more than half coverage of canopy are counted as full cover, while those showing less than half are counted as zero cover.

### 2.4.5 Meter-stick method

This method as outlined by Adams and Arkin (1977) uses a meter stick to measure the percent area shaded by crop canopy. The meter stick is placed on the soil surface parallel with and against the plant row. The shaded area on the meter stick is measured and totalled to the nearest centimetre. The stick is then moved at regular intervals across the row until the distance between the plant rows has been traversed.

Ground cover between the rows is calculated from the meter stick measurements as follows:

$$\text{Ground cover (\%)} = \frac{\text{Total shade for n positions}}{\text{Row width x n}} \text{x100}$$

Where n is the number of positions of stick traversed.

### 2.4.6 String and bead method

Although this method is usually used to assess residue cover (Sloneker and Moldenhauer, 1977) it can also be adapted to measure crop cover. In this method, a string with beads attached at regular intervals is pulled diagonally across each plot. Beads that touch a piece of vegetation are counted. This is repeated for the other diagonal. Crop cover is the fraction of the total number of beads that touch vegetation divided by the total number of beads on the string. The problem with this method is that it does not take into account the underlying layers of vegetation, thus it tends to underestimate the amount of cover.

### 2.4.7 Spatial quantum sensor

The spatial quantum sensor (Adams and Arkin, 1977) 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 is used to measure the amount of light intercepted by vegetation, consequently giving an indication of the amount of crop cover.

Ground cover by spatial quantum sensor is measured on transects at 5-cm intervals, then it instantaneously integrates irradiance along the sensor. Light transmitted (T) to the spatial quantum sensor on the soil surface at each transect is compared with light measured with the same sensor above the plant canopy.

Thus, $T = \frac{\text{Sensor output below canopy}}{\text{Sensor output above canopy.}} \times 100$

Ground cover for each transect = 100-T.

Ground cover is then averaged for all transects.

### 2.4.8 Traversing quantum sensor

Though not commercially available, the traversing quantum sensor can be easily assembled and used to measure crop cover by light interception method. It consists of the following units (Adams and Arkin, 1977); (i) a track, 3 m long, (ii) a reversible motor, (iii) a digital voltmeter, (iv) two integrator circuits, (v) two photosynthetically active radiation quantum cells, one reversing the track, the other stationary above the crop canopy, (vi) an alternating current power source, and (vii) a cable.

Voltage output of the overhead and traversing quantum cells are integrated separately and simultaneously during the traverse. Output of the two cells is compared to determine the light intercepted by the canopy. Like the spatial quantum sensor, ground cover is calculated from light transmitted to the sensor.

A comparison by Adams and Arkin (1977) revealed that the meterstick method of measuring crop cover using the shadow projected by crop canopy is more accurate, faster, simpler and more economical than either the spatial quantum sensor or the traversing quantum sensor methods.

# CHAPTER 3

## 3.0 MATERIALS AND METHODS

### 3.1 The research site

This study was conducted at the University of Nairobi, Kabete Campus field station. The Campus is located approximately 12 kilometres West-North-West of Nairobi city centre. The altitude is about 1940 m above sea level.

The area receives a mean annual rainfall of 1006 mm which is characterised by two seasonal peaks viz the long rains (March to May) and the short rains (October to December). The average seasonal rainfall for the long and short rains is 506 mm (50%) and 285 mm (28%) respectively, while the dry months contribute 215 mm (22%).

The mean annual temperature is 17.6°c. Potential evaporation ($E_o$) is estimated to be 1727 mm, while potential evapotranspiration which is taken as $2/3E_o$ is estimated to be 1152 mm. According to the Kenya Soil Survey agro-climatic zonation methodology (Sombroek et al., 1982), the climate of the area is classified as semi-humid.

## 3.2 Soil characteristics

A detailed soil survey conducted by Gachene (1989) revealed that the area is underlain by Nairobi trachytes of tertiary age. The area comprises of an upland with gently undulating to hilly topography. The soils are well drained, very deep, dark red friable clay soils. They have an ABC sequence of horizon, with clay cutans and small, soft manganese/iron concretions in the B-horizon. Organic carbon is moderate in the topsoil and the base saturation is below 50%. The soils are classified as humic nitisols (FAO system of classification).

Soil samples for the determination of texture classification and soil erodibility were collected from four locations on the two experimental terraces immediately after land preparation. At each location, surface soil samples were taken at depths not exceeding 5 cm. Texture as determined by sieving and hydrometer methods revealed that the soil contains 19% sand, 21% silt and 60% clay.

To determine soil erodibility, the amount of fine sand fraction (it was 30%) was determined by sieve analysis, while soil organic matter, found to be 2.24%, was determined by the Walkley-Black method

(Black, 1965). Using the nomograph for computing the erodibility value (k), in metric units, of a soil (Wischmeier et al. 1971), the soil erodibility was found to be 0.23.

### 3.3 The splash traps design

The splash traps as shown in figure 3.1 are box-like structures with one open side, designed as a modification of similar equipment used by Kerenyi (1981) in the laboratory. This type of design was adopted because, compared to other methods such as Ellison's splash cups and Morgan's cups, it is more suited to diverse crop covers such as maize. For such a crop, a small diameter cup would not collect splash from a representative proportion of area under the crop. The equipment also isolates splash detachment from runoff effects, while excess rain water does not affect the use or accuracy of the equipment.

Each splash trap is 750 mm long by 200 mm wide and 500 mm high with a gently sloping roof. It has spiked legs to facilitate firm placement on the ground and crossed steel rods so that it stands just 10 mm above the ground surface. Inside the trap is a fixed wire-gauze tray above which a Whatman no.1 filter paper is placed, and hooks 140 mm above the trap floor to

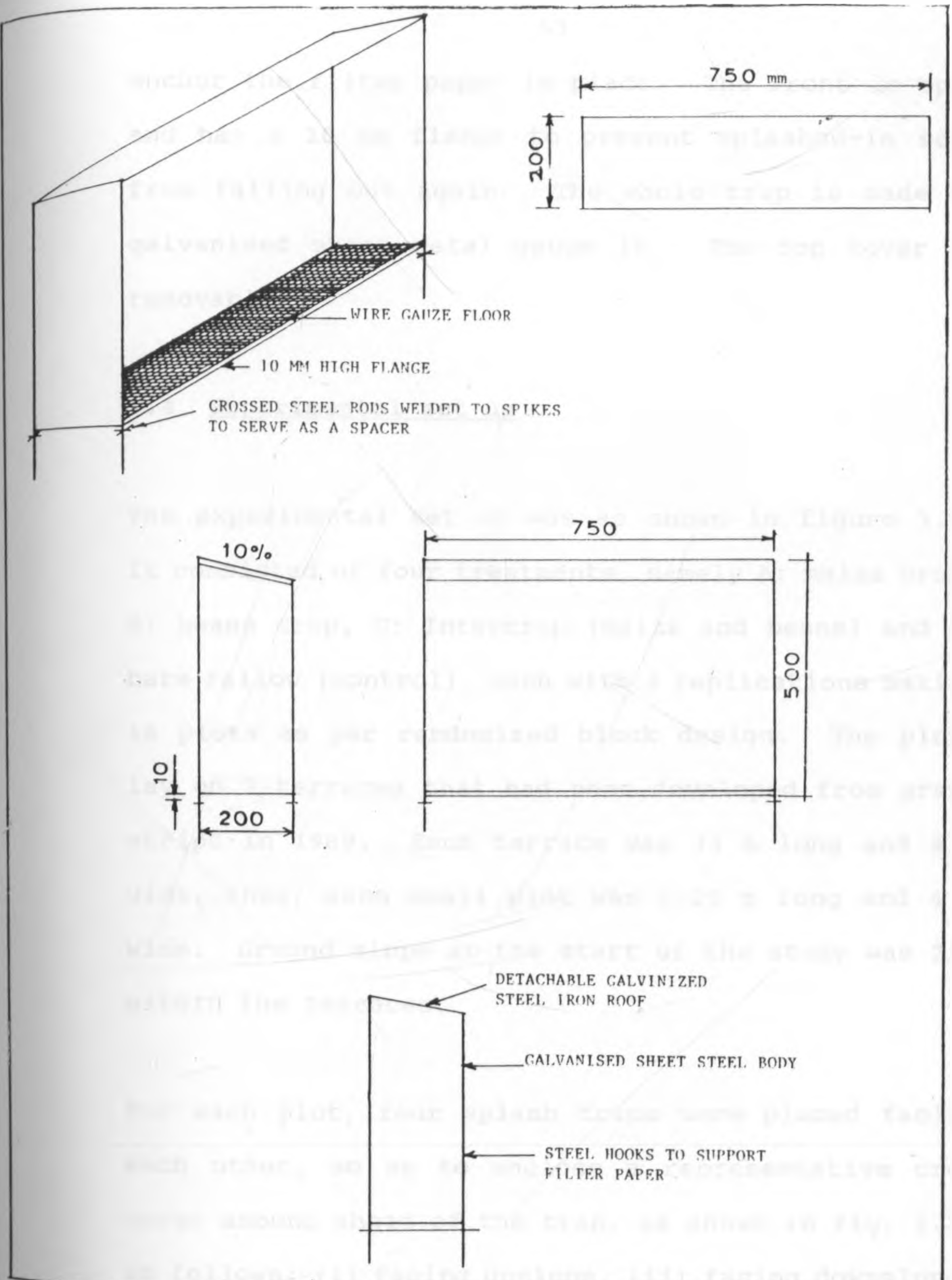



Fig 3.1 The splash trap design (all dimensions in mm)

anchor the filter paper in place. The front is open and has a 10 mm flange to prevent splashed-in soil from falling out again. The whole trap is made of galvanised sheet metal gauge 18. The top cover is removable.

### 3.4 Experimental set up

The experimental set up was as shown in figure 3.2. It consisted of four treatments, namely A: maize crop, B: beans crop, C: Intercrop (maize and beans) and D: bare fallow (control), each with 4 replications making 16 plots as per randomized block design. The plots lay on 2 terraces that had been developed from grass strips in 1989. Each terrace was 34 m long and 4 m wide, thus, each small plot was 4.25 m long and 4 m wide. Ground slope at the start of the study was 25% within the terraces.

For each plot, four splash traps were placed facing each other, so as to enclose a representative crop cover amount ahead of the trap, as shown in fig. 3.3, as follows; (i) facing upslope, (ii) facing downslope, (iii) facing predominant wind direction, and (iv) facing predominant leeward direction. By coincidence, the slope direction was at right-angles to the mean wind direction, therefore, all four splash traps were perpendicular to each other. Since there were 16 plots, the total number of splash traps set up in the field were 64. Plates 1-8 in appendix 1 show this setup.

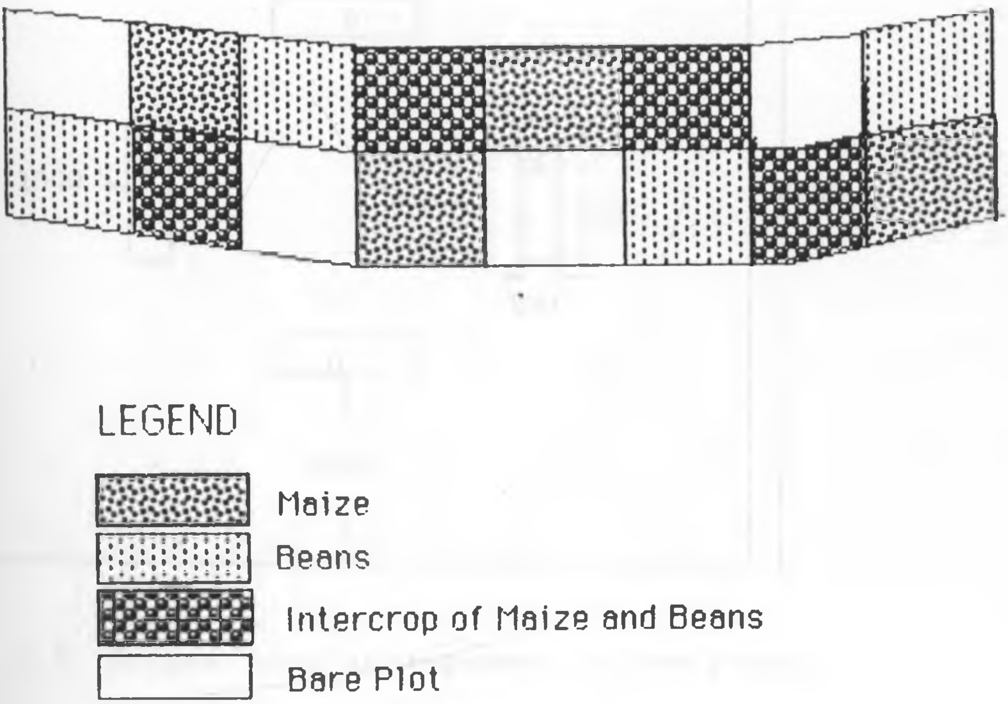



Fig. 3.2 Experimental set-up

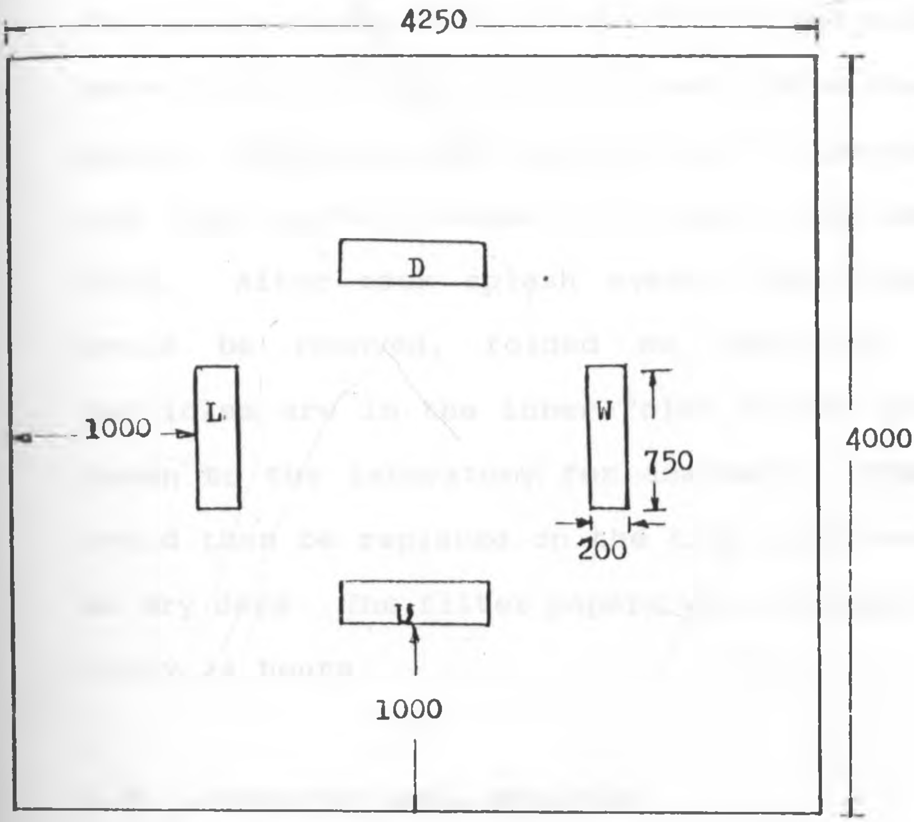



Fig. 3.3 Splash trap arrangement in the field.

Legend

U - Upslope facing trap
D - Downslope facing trap
W - Windward facing trap
L - Leeward facing trap

NB: Trap directions taken with respect to the centre of the plot. (All dimensions in mm).

## 3.5 Measurement of splash detachment in the field

For splash measurement in the field, the splash traps were first fitted with pre-dried and weighed filter papers. The papers had been cut to fit the trap bottom and sides up to a height of 14 cm at the back of the trap. After each splash event, the filter papers would be removed, folded so that all the soil particles are in the inner folds of the paper, then taken to the laboratory for analysis. Fresh papers would then be replaced on the trap, and dusted daily on dry days. The filter papers were changed only once every 24 hours.

## 3.6 Laboratory soil analysis

The filter papers with the splashed soil material would then be oven-dried at 105°c for 24 hours. The dry weight of soil and paper would then be taken. The mass of soil splash from each trap was then deduced by subtracting the weight of the oven-dry empty paper. The soil obtained was then saved from each treatment for future particle size analysis. Since the amount of soil on most occasions was too small for particle size analysis, this exercise was abandoned.

### 3.7 Measurement of crop cover parameters

This involved measuring both the percent area shaded by the crop canopy, and also the crop height. Both measurements were done on the same day, once a week, beginning 1 week after germination. For crop cover measurements, a simple sighting frame was designed and used. This type of equipment was selected because it is simple, affordable and has been found to be satisfactory for field measurements (Stocking, 1988).

#### 3.7.1 Design and use of the simple sighting frame

Details of the constructional features of the simple sighting frame used for crop cover measurements are shown in fig. 3.4. It consists of two horizontal metal bars, each 1 m long 5 cm wide set directly above each other, and supported above the ground by angle-iron bars of adjustable length on tripod stands. Ten small holes of 10 mm diameter are drilled 100 mm apart on each bar so that the holes are vertically concentric.

In use, the sighting frame was placed in a representative position within the cropped area, preferably at right angles to the crop rows. The observer then peered through the upper hole directly downwards over the crop canopy to see a small patch of

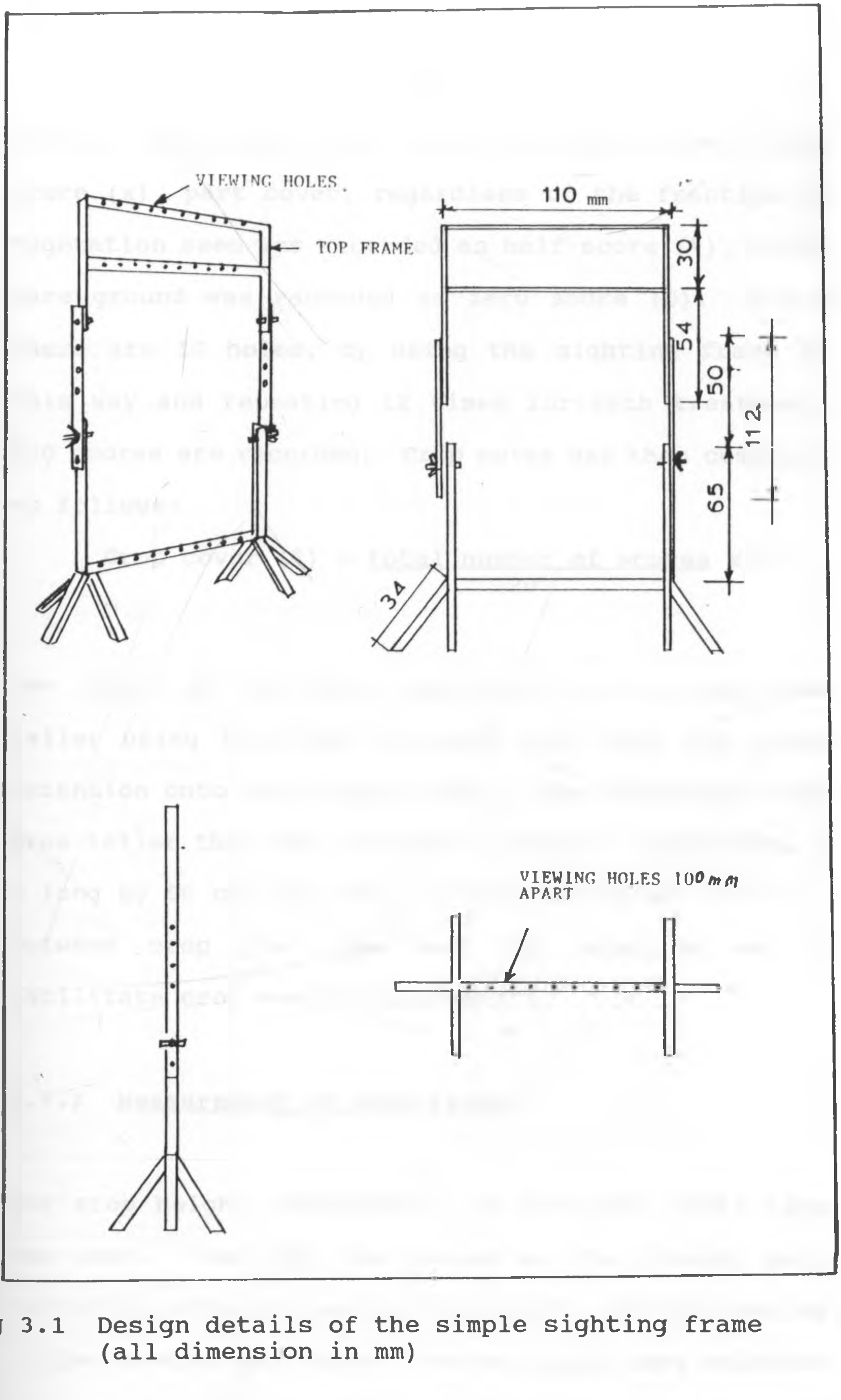



Fig 3.1 Design details of the simple sighting frame (all dimension in mm)

foliage or ground. Full cover was recorded as a full score (x), part cover, regardless of the fraction of vegetation seen was recorded as half score (\), while bare ground was recorded as zero score (0). Since there are 10 holes, by using the sighting frame in this way and repeating 12 times for each treatment, 120 scores are recorded. Crop cover was then computed as follows:

$$\text{Crop cover (\%)} = \frac{\text{total number of scores}}{120} \times 100$$

The height of the frame was raised as the crop grew taller using the four wing-nuts that hold the frame extension onto the tripod stand. When the maize crop grew taller than the observer's height, a platform, 1 m long by 50 cm wide and 1 m high, designed to fit between crop rows was used for stepping on to facilitate crop cover measurements.

### 3.7.2 Measurement of crop height

For crop height measurement, an ordinary steel tape was used. The tape was placed on the ground, held vertically straight against the plant, and the reading at the growing apex taken. Twelve plants were selected at random and their heights taken for each treatment. The mean of these 12 measurements was then calculated to deduce crop height values.

### 3.8 Climatic records

Though nearly all climatic factors affect rainsplash and crop cover directly or indirectly, by affecting such variables as antecedent soil moisture, amount and type of vegetative cover, the most relevant factors are rainfall parameters and wind factors. In this study, only rainfall records were taken.

#### 3.8.1 Rainfall records

Both recording rain gauge and manual gauges were used in this study. Twelve manual gauges are distributed around the field onto which this study was carried out. A siphon type recording rain gauge, situated 50 m from the research plots was used to get recorder charts for rainfall intensity assessments. These records were verified with those obtained from the main meteorological station situated about 200 m from the site.

#### 3.8.2 Wind records

These were to be obtained from the main meteorological station, situated 200 m from the research site. Unfortunately, there was no automatic recorder but wind speeds were read from an ordinary anemometer three times during the day. There were no night-time readings. Therefore, since most of the rainstorms occurred at night, and due to the relative difference in distance and surrounding vegetation between the two areas, wind data was found to be unreliable, and subsequently, irrelevant.

### 3.9 Duration of the study

Data was collected from the experimental plots in two rainy seasons: The short rains of October 1990-February 1991, and the long rains of March-June 1991. In both seasons, the same crops were grown i.e maize, beans, intercrop of maize and beans and bare fallow plots. During the second season, the crops were rotated.

The beans in the second season at first failed to germinate and planting had to be repeated two weeks later. This affected the rate of crop development for intercropped maize and beans as compared to the previous season, but did not significantly change the relationship with splash.

Statistical analysis of the data from both seasons using the analysis of variance method (Miller and Freud, 1985), showed that there was no significant difference ($\alpha=0.05$) between the results of the two seasons. Thus, all the data was treated as belonging to the same population.

### 3.10 <u>Statistical data analysis</u>

The results of this study have been presented as the amount of soil (in grams) splashed across the 75 cm long boundary. Since the area from which the splashed particles originate could not be determined, then the splash amounts could not be expressed in units of quantity per unit area. Thus, splash could only be expressed as quantity crossing a specified length of boundary, regardless of the area from which the particles originate.

The basic data, consisting of splash amounts from each trap and their replications, was subjected to analysis of variance tests. It was found that replications were not different ($\alpha=0.01$) while daily results themselves showed highly significant difference ($\alpha=0.05$). For comparing whether the results from the treatments are different, the analysis variance test was done, with the results in table 7.1 of appendix 3. For ($\alpha=0.05$) there was a significant difference between all pairs of treatment combinations except between beans and intercrop.

To determine the best fit curve for each relationship, regression correlation was done with a computer using lotus software. This gave the correlation coefficient (r), the standard error of estimate (e), the coefficient of x, and the constant of the relationship. From this information, the curve with the highest r-value and the lowest e-value was adopted and plotted. This also facilitated the development of a regression equation suitable for the particular relationship.

To test the statistical significance of the data, t-tests were performed on the correlation coefficients. The t-values of all the relationships are shown in the corresponding tables. For all highly correlated data, the t-values were highly significant.

# CHAPTER 4

## 4.0 RESULTS AND DISCUSSION

### 4.1 Soil characteristics

#### 4.1.1 Soil type

Since splash erosion affects the topsoil, then surface soil characteristics are of utmost importance in this study. Results of the texture analysis of topsoil samples from the research site were found to contain 60% clay, 21% silt and 19% sand. Therefore, these soils can be classified as clay. According to Bauer (1985), soils of median particle size (100μm) have the highest splash amounts. This would mean that the soils used in this study are relatively resistant to splash detachment because they are finer (60% clay), presumably due to higher cohesion between the particles.

To relate soil splash to soil properties, Bubenzer and Jones (1971) found that percent clay was a better indicator of splash than various combinations of particle size, aggregate index, bulk density, organic matter and moisture content. Other soil parameters include soil type and size of structural aggregates

(Rose, 1960) aggregate size, stability and surface area (Al-Durrah and Bradford, 1982; Yamamoto and Anderson, 1973).

Soil structure, affects splash detachment by influencing the stability and size of clods present after tillage. Thus soils with massive or columnar structure will yield larger, more stable clods, which are likely to be more resistant to splash detachment, than those from soils with granular or crumb structure. Small clods have greater susceptibility to disintegration by raindrop impact (Lyles, 1977) as they saturate faster than large ones. Moldenhauer and Koswara(1968) showed that the most serious erosion occurs on soils with a loose surface layer of assorted size clods, especially recently ploughed and harrowed soils.

The structure of the soil in this study was found to be sub-angular blocky, friable when moist, sticky and plastic when wet. Land preparation was by manual hoeing, the clods that resulted were small and weak, breaking down easily with the first few storms of the rainy season. This was because the soil structure had been destroyed as a result of previous cultivation (3 years) and also the tillage method used. This means that the soil surface condition could not effectively inhibit splash erosion.

An appraisal of the soil fertility (Gachene, 1989) revealed that the topsoil is adequately supplied with bases, but phosphorus levels are low. The organic carbon content and total nitrogen levels are moderate. This would suggest strong chemical bonding and relatively good stability against splash detachment. It also suggests that crop performance is good, offering more protection to the soil against erosive agents.

#### 4.1.2 Soil erosion

Soil erodibility is the property of a soil depicting its vulnerability to erosion under given circumstances (Hudson, 1981). According to Amezquita and Forsythe (1985), erodibility involves those soil properties that affect the infiltration rate and permeability, and the changes in time that occur in those soil properties and others that determine the effect of the dispersion, splashing, abrasion and transporting forces of rainfall and runoff.

The soil erodibility for the research site, as determined using the nomograph of Wischmeier et al. (1971) was 0.23. This can be considered a medium erodibility factor. Since it cannot be simplified to show the specific effect of detachability and transport by splash alone, then for the purposes of predicting splash detachment, this factor is not very useful. According to Shaxson (1980), soil loss estimation by the Universal soil loss equation (USLE) and Soil loss estimation method for Southern Africa (SLEMSA) considers soil losses when detachment processes are limiting. This underestimates the importance of detachment processes, especially on bare ground.

Another index of soil erodibility used in this study was the flocculation index, which was 78.4%. This is a ratio that compares the amount of clay in a sample previously treated with a dispersing agent, with a sample where the agent is omitted. It assumes that only clay which is in a dispersed condition can be eroded. Thus from the high flocculation index of the soil, it shows that the clay fraction is easily dispersed, and therefore, easily detached and eroded. Thus, though soil erodibility is rather low, it appears that the soil in this study is relatively unstable against raindrop detachment, due to its high flocculation index and weakened structure.

## 4.2 Rainfall characteristics

### 4.2.1 Rainfall distribution

The mean monthly rainfall for Kabete field station and the actual monthly rainfall obtained over the duration of this study are shown in fig. 4.1. The total rainfall amount during the two crop growing seasons, found to be 849 mm, was slightly more than the mean amount of 834 mm for the same duration. During the short rains season, most of the rain fell in the months of October and November 1990 (90 mm and 126 mm respectively) at a time when the ground surface was either bare or sparsely covered with the crop. In the long rains season, rainfall was heaviest in the months of April and May 1991, when the crops were bigger. Thus, rainfall distribution during the experimental period was fairly good as it was possible to get soil splash over a wide range of crop covers.

It was observed that splash detachment was obtained for all rainfall amounts of 8 mm and over. Splash was also obtained for lower rainfall amounts, the minimum being 4 mm, whereas some storms of as much as 7 mm did not yield any splash. Though on average, rainfall intensity increased with amount (fig. 4.2), some high intensities were got for low rainfall amounts,

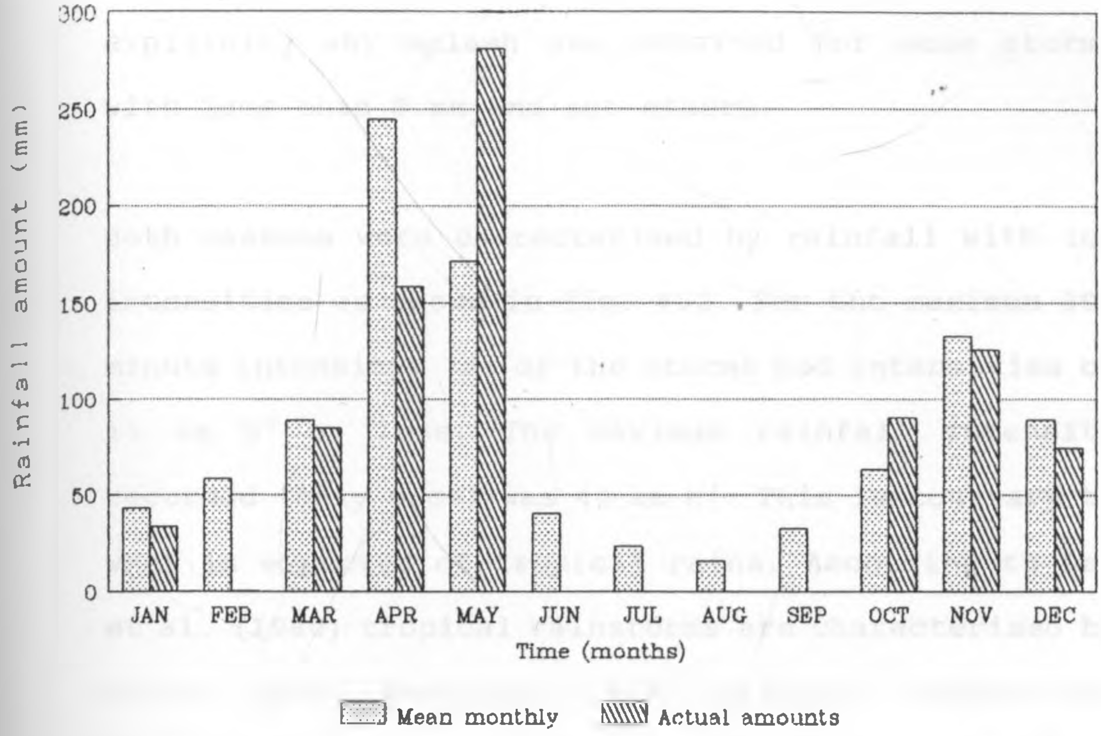



Fig. 4.1 Monthly rainfall distribution

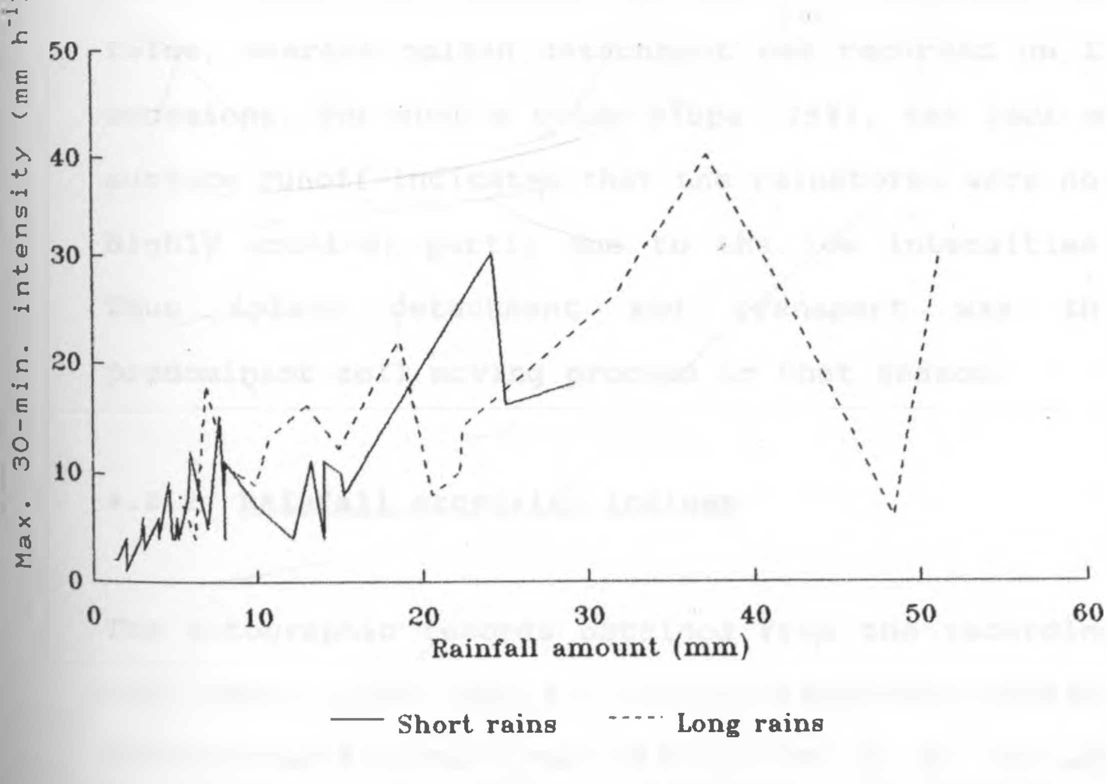



Fig. 4.2 Maximum 30-minute rainfall intensity vs amount

explaining why splash was obtained for some storms with less than 8 mm and not others.

Both seasons were characterised by rainfall with low intensities as shown in fig. 4.2. For the maximum 30-minute intensity, 78% of the storms had intensities of 15 mm $h^{-1}$ or less. The maximum rainfall intensity recorded (only once) was 40 mm $h^{-1}$. This is contrary to what is expected of tropical rains. According to Lal et al. (1980) tropical rainstorms are characterised by short, heavy downpours, with rainfall intensities normally exceeding 25 mm $h^{-1}$, and even intensities of 50 mm $h^{-1}$ occur quite often. During the short rains season, runoff was recorded (within the locality) only twice, whereas splash detachment was recorded on 18 occasions. For such a steep slope (25%), the lack of surface runoff indicates that the rainstorms were not highly erosive, partly due to the low intensities. Thus splash detachment and transport was the predominant soil moving process in that season.

### 4.2.2 Rainfall erosivity indices

The autographic records obtained from the recording rain gauge, were used to calculate maximum rainfall intensities for the time intervals of 5, 15, 30 and 45-minutes respectively. In computing the energy value of each rainfall event for the splash producing storms, the following procedure was adopted (USDA, 1978).

Clock time and the corresponding rain depth time were read from the chart at each point where the slope of the pen-line changes and these were tabulated. Clock times were subtracted to obtain the time intervals. Then consecutive rainfall depths were subtracted to obtain incremental rainfall amounts. The intensity for each increment was calculated as the incremental amount divided by the time intervals multiplied by 60. The energy per mm of rain in each interval was calculated using the following equation (Morgan, 1986).

$$KE = 11.86 + 8.73 \log_{10} I \qquad [4.1]$$

Where, KE is the kinetic energy of rain in J $m^{-2} mm^{-1}$.

I is the rainfall intensity in mm $h^{-1}$.

The incremental energy amounts were then calculated by multiplying the energy per mm by the corresponding rainfall amount at that intensity. Total energy (E) was the sum of all the incremental energies.

The KE>25 method (Morgan, 1986) was tried and found to be inappropriate for this data. This was because the incremental rainfall intensities were very low and this method is suitable for high rainfall intensities, at least in excess of 25 mm $h^{-1}$.

The following rainfall erosivity indices were deduced for use in this study: (i) the rainfall amount (A) in mm, (ii) the total rainfall energy (E) in J $m^{-2}$. as calculated above, (iii) the maximum rainfall intensity ($I_5$, $I_{15}$, $I_{30}$ and $I_{45}$) for each duration of 5, 15, 30 and 45 minutes respectively, (iv) the EI-indices ($EI_5$, $EI_{15}$, $EI_{30}$, and $EI_{45}$), the product of the rainfall energy and its maximum 5, 15, 30 and 45-minute intensities respectively, and (v) AI-indices ($AI_5$, $AI_{15}$, $AI_{30}$ and $AI_{45}$), the product of the rainfall amount and its maximum 5, 15, 30 and 45-minute intensities respectively.

For these erosivity indices, their correlation coefficients with splash detachment, and also the standard errors of estimate are shown in table 4.1. The best erosivity indices were found to be both the $AI_{45}$-index and the $AI_{30}$ index (r=0.821). Rainfall kinetic energy (r=0.810), the rainfall amount (r=0.804) and the $EI_{45}$-index (0.800) were also good erosivity indices. All the rainfall intensity indices were the poorest, the best being $I_{45}$ (r=0.642) while the $AI_5$-index (r=0.413) showed negligible correlation with splash detachment. Table 7.2 in appendix 4 shows the values of the best erosivity indices.

Table 4.1

Correlation coefficients, standard errors of estimate and statistical t-values for rainfall erosivity indices with total splash from bare fallow land.

| Rainfall factor | Correlation coefficient | Std. error of estimate | t-value |
|---|---|---|---|
| A | 0.804 | 0.611 | 7.406 |
| E | 0.810 | 0.603 | 7.565 |
| $I_5$ | 0.413 | 0.937 | 2.484 |
| $I_{15}$ | 0.580 | 0.838 | 3.900 |
| $I_{30}$ | 0.631 | 0.798 | 4.455 |
| $I_{45}$ | 0.642 | 0.789 | 4.856 |
| $EI_5$ | 0.733 | 0.700 | 5.902 |
| $EI_{15}$ | 0.703 | 0.960 | 5.414 |
| $EI_{30}$ | 0.797 | 0.621 | 7.228 |
| $EI_{45}$ | 0.800 | 0.617 | 7.303 |
| $AI_5$ | 0.761 | 0.667 | 6.425 |
| $AI_{15}$ | 0.815 | 0.596 | 7.704 |
| $AI_{30}$ | 0.821 | 0.588 | 7.876 |
| $AI_{45}$ | 0.821 | 0.587 | 7.786 |

The number of observations for each set of data was 32. The tabulated t-value in all the cases was 2.038. Therefore, all the erosivity indices are statistically significant.

Since splash is the result of soil dislocation due to the energy imparted by the raindrop on the soil, the erosivity values calculated above were correlated with rainfall energy. Rainfall kinetic energy (E) was found to vary as a power function of rainfall amount (A) as follows:

$$E = 20A \qquad (r=0.989) \qquad [4.2]$$

This equation differs very much with the one obtained by Lal (1980) for Ibadan, Nigeria. He derived the following linear equation:

$$E = 24.50A + 27.6 \qquad [4.3]$$

In Southern Africa, Elwell (1980) obtained this relationship:

$$E = 18.48A \qquad [4.4]$$

The big variation can be attributed to the differences in rainfall characteristics, since the research site receives rainfall with lower intensities than the tropical regions mentioned here.

Kilewe, (1987) related the product of rainfall energy (E) and its 30-minute intensity ($I_{30}$), with rainfall amount for Machakos area as follows:

$$EI_{30} = 7.059A - 5.347 \qquad [4.5]$$

This is quite different from the result of this study where, $EI_{45}$ was more highly correlated with rainfall than $EI_{30}$ as follows:

$$EI_{45} = 46A^{1.44} \qquad (r=0.865) \qquad [4.6]$$

According to Meyer and Wischmeier (1969) for moderate to intense storms, kinetic energy per unit area (KE) is proportional to intensity (I) as follows:

$$KE \ \alpha \ I^{0.14} \qquad [4.7]$$

This does not agree with the results of this study where, rainfall energy was found to correlate better with $I_{45}$ than $I_{30}$, giving the following equation:

$$E = 39.8(I_{45})^{0.89} \qquad (r=0.690) \qquad [4.8]$$

Where, E is the rainfall energy (J $m^{-2}$).

$I_{45}$ is the maximum 45-minute intensity.

This also differs with relations obtained for other tropical regions such as Lal (1981) who found that for Ibadan, Nigeria the relationship was as follows:

$$E = 18.18I_{30} + 18.18 \qquad [4.9]$$

The rainfall energy was also related to the product of rainfall amount (A) and its intensity as follows:

$$E = 0.03(AI_{45})^{1.48} \qquad (r=0.942) \qquad [4.10]$$

## 4.3 Crop characteristics

### 4.3.1 crop cover development

Crop cover development, during the two growing seasons is shown combined in fig. 4.3a and 4.3b. The equations of these relationships and their correlation coefficients are shown in tables 4.3a and b. For all crops, percent cover increased sharply with time during crop development. Crop cover amount and rate of development was also higher for beans and intercrop than for maize. Beans were harvested earlier than maize, leaving the land bare and reducing the amount of cover under intercrop. Consequently, data collection for beans and intercrop ceased earlier than for maize. At any given time, crop cover was highest for intercrop followed by beans and lastly maize respectively.

For all the crops, height increased as a power function of time (weeks) during the crop growing period. The rate of bean height growth was the slowest, while for intercrop, effective crop height taken as the height of the maize plants, initially increased at a lower rate than that of maize on pure stand. This can be attributed to the competition with the beans, which reduces crop development. In the later stages of crop growth, there was no difference in height between maize on pure stand and intercrop because the beans matured earlier. Therefore, at any given time, the tallest crop was maize followed by intercrop and then beans respectively.

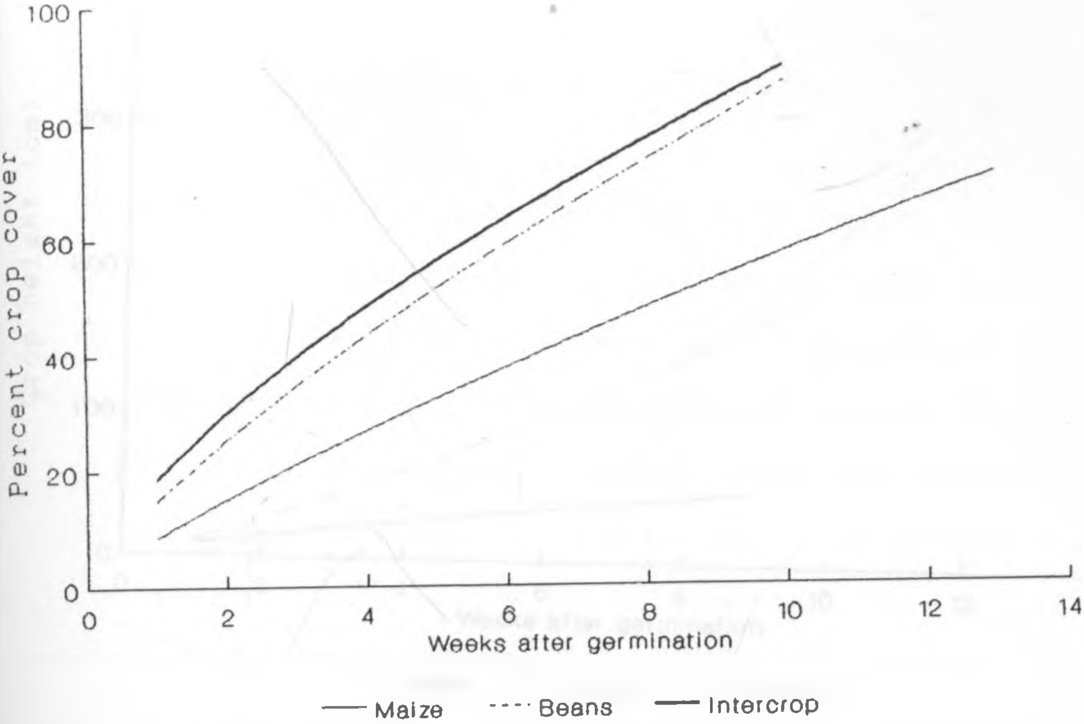



Fig. 4.3a Crop cover development

Table 4.3a Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.3a.

| Treatment | Equation | Correlation coefficient | Std. error of Y est | t-values |
|---|---|---|---|---|
| Maize | $C = 2.74T^{11.4}$ | 0.790 | 2.275 | 7.058 |
| Beans | $C = 14.97T^{0.76}$ | 0.897 | 1.315 | 11.115 |
| Intercrop | $C = 18.82T^{0.67}$ | 0.939 | 1.201 | 14.955 |

Where, C is the percent crop cover, and T is the time in weeks after crop germination. The number of observations are 25, 19 and 20 for maize, beans and intercrop respectively. The t-values are all significant ($\alpha=0.05$).

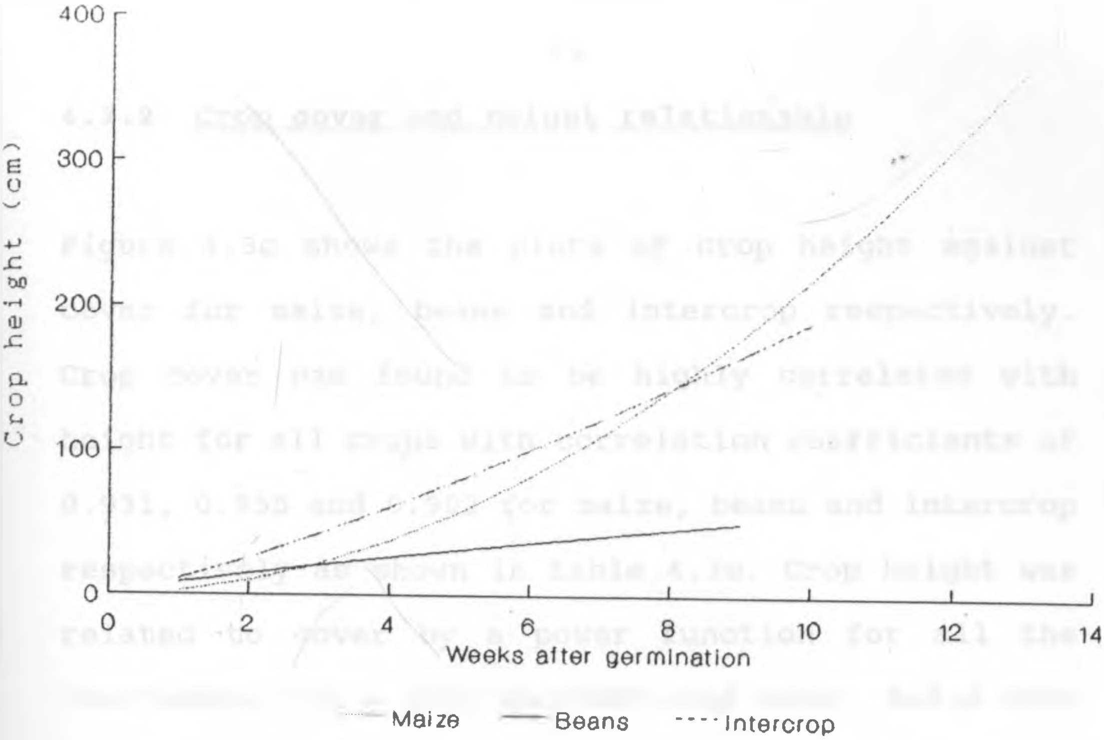



Fig. 4.3b Crop height development

Table 4.3b Regression equations, correlation coefficients and standard errors of estimate for the curves in fig.4.3b.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $H = 2.56T^{1.93}$ | 0.866 | 2.340 | 9.486 |
| Beans | $H = 8.49T^{0.81}$ | 0.954 | 1.202 | 17.429 |
| Intercrop | $H = 10.72T^{1.25}$ | 0.970 | 1.256 | 21.854 |

Where H is the crop height in cm, and T is the time in weeks after crop germination. The number of observations are 24, 18 and 20 for maize, beans and intercrop respectively. The t-values are all significant ($\alpha$=0.05).

### 4.3.2 Crop cover and height relationship

Figure 4.3c shows the plots of crop height against cover for maize, beans and intercrop respectively. Crop cover was found to be highly correlated with height for all crops with correlation coefficients of 0.931, 0.955 and 0.902 for maize, beans and intercrop respectively as shown in table 4.3c. Crop height was related to cover by a power function for all the treatments. For a given percent crop cover, maize crop was tallest followed by intercrop, while beans were the shortest. This is due to the wider spacings and slower rate of growth of the maize as compared to the beans.

## 4.4 Soil splash detachment

The mean of soil splash amounts got from all 4 traps in each treatment, on each day were added to obtain the total splash detachment. These are shown in tables 7.3, 7.4 and 7.5 of appendix 4, together with the rainfall amount, crop cover and height. The amount of soil splash is a function of climate (rainfall and wind), soil type, land surface characteristics and vegetation. For every splash event, the soil type and land surface characteristics are assumed constant. Therefore the major variables affecting total splash.

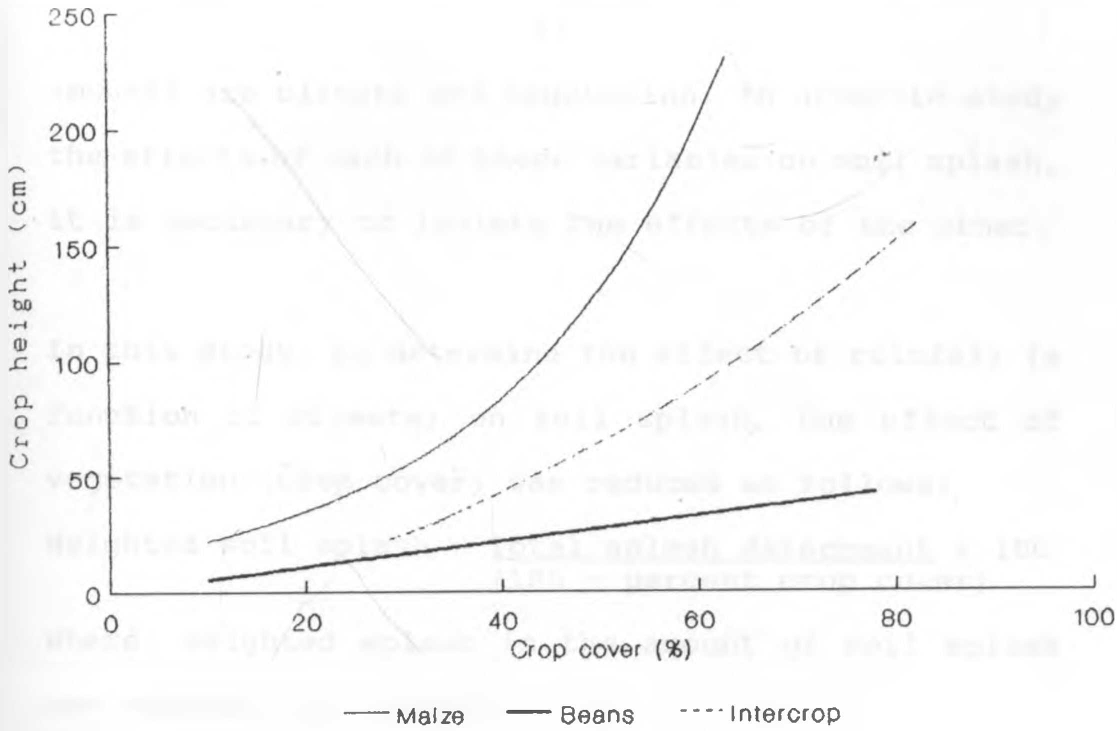



Fig. 4.3c Crop cover vs height for all treatments

Table 4.3c Regression equations, correlation coefficients, and standard errors of estimate for the curves in fig.4.3c.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t- values |
|---|---|---|---|---|
| Maize | $H = 14.17e^{0.044c}$ | 0.931 | 1.313 | 13.970 |
| Beans | $H = 0.54C$ | 0.955 | 1.172 | 17.635 |
| Intercrop | $H = 0.048C^{1.84}$ | 0.902 | 1.318 | 11.443 |

Where, H is the crop height in cm, and C is the subsequent percent crop cover. The number of observations are 27, 24 and 23 for maize, beans and intercrop respectively. The t-values are all significant ($\alpha$=0.05).

amounts are climate and vegetation. In order to study the effects of each of these variables on soil splash, it is necessary to isolate the effects of the other.

In this study, to determine the effect of rainfall (a function of climate) on soil splash, the effect of vegetation (crop cover) was reduced as follows:

$$\text{Weighted soil splash} = \frac{\text{Total splash detachment}}{(100 - \text{percent crop cover})} \times 100$$

Where, weighted splash is the amount of soil splash per exposed bare surface.

This was assuming that effective splash occurs only from the area not covered by vegetation. According to Hudson (1981) the amount of splash erosion is related to the amount of bare ground exposed to raindrop impact rather than to the amount of crop cover available..

To determine the effect of crop cover on splash erosion, the effect of rainfall was reduced as follows:

$$\text{Splash per mm rain} = \frac{\text{Total splash amount}}{\text{Rainfall amount}}$$

This gave the amount of soil splash per mm of rainfall for each splash event.

Since wind data was not available, soil splash data was treated as a function of rainfall erosivity factors and crop cover characteristics. By ignoring the effect of wind, it was found that the differences in soil splash amounts in the two traps placed perpendicular to the slope direction could not be explained. There was usually more splash in the East facing trap than in the West facing one.

### 4.4.1 Crop cover factors

Crop cover characteristics assessed in this study were percent canopy cover and crop height. The effect of each of these factors were correlated with splash detachment per unit rainfall amount for the cropping systems used. Both cover and height were found to influence splash detachment as explained below.

#### 4.4.1.1 Percent crop cover

Splash detachment was found to be related to percent crop cover with correlation coefficients of 0.653 for maize, 0.639 for beans and 0.697 for intercrop. Splash detachment per millimetre of rain, plotted against percent crop cover for maize, beans and intercrop, is shown in fig. 4.4. Splash detachment was found to be related to crop cover by exponential equations as follows:

Maize: $S = 1.24e^{-0.024c}$ [4.11]

Beans: $S = 1.59e^{-0.026c}$ [4.12]

Intercrop: $S = 1.64e^{-0.028c}$ [4.13]

Where, S is the splash detachment per mm rain (g $mm^{-1}$).

c is the percent crop cover.

Fig.4.4 shows that there is an exponential decrease in splash detachment with each increment in percent crop cover. This agrees with Elwell (1981), who found that there is an exponential decrease in detachment with increasing cover for all vegetation regardless of canopy height. Other studies (Rickson and Morgan, 1988) show that soil detachment will decrease exponentially with increasing percentage cover for crops up to 50 cm high, and decrease linearly with cover for canopy cover that exceeds 50 cm.

The reduction in splash can be attributed to the fact that vegetation protects the soil from erosion by intercepting the raindrops and absorbing their kinetic energies harmlessly. Some water may evaporate from the leaves, but most reaches the ground surface either by stemflow or by reforming into droplets that for close-growing vegetation, have little chance to pick up speed and gain further kinetic energy. Therefore, the more the crop cover, the less is the splash erosion.

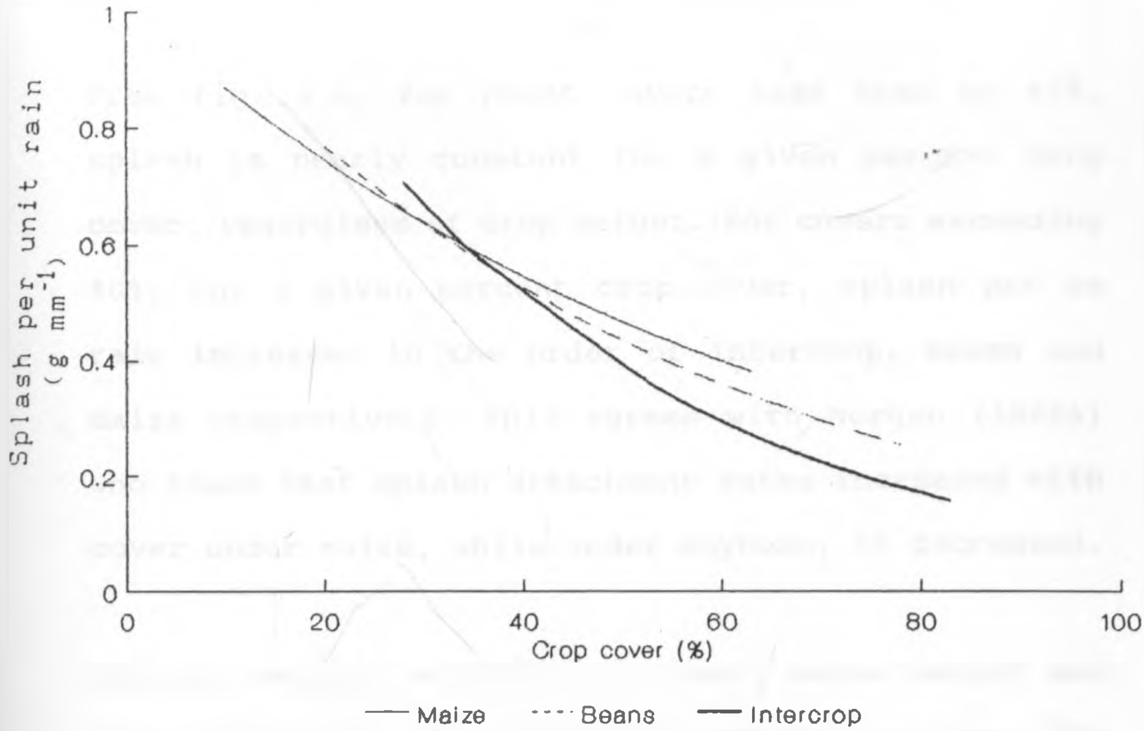



Fig. 4.4 Splash per mm rain vs percent crop cover

Table 4.4 Regression equations, correlation coefficients, and standard errors of estimate for the curves in fig. 4.4.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 1.24e^{-0.024c}$ | 0.653 | 1.523 | 4.723 |
| Beans | $S = 1.59e^{-0.026c}$ | 0.639 | 1.777 | 4.550 |
| Intercrop | $S = 1.64e^{-0.028c}$ | 0.697 | 1.696 | 5.324 |

Where, S is the splash detachment per mm of rain, and c is the percent crop cover. The number of observations are 27 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

From fig. 4.4, for plant covers less than to 40%, splash is nearly constant for a given percent crop cover, regardless of crop height. For covers exceeding 40%, for a given percent crop cover, splash per mm rain increases in the order of intercrop, beans and maize respectively. This agrees with Morgan (1985a) who found that splash detachment rates increased with cover under maize, while under soybean, it decreased.

This is because at 40% crop cover, maize height was about 80 cm, thus the taller the vegetation grows, the more is the energy of the drop reaching the ground as result of leafdrip. Where there is a close growing crop such as under intercrop, the beans intercept all the drop reducing their erosivity.

From the above results, it was also found that an increase in crop cover of 40% reduces splash detachment by 55%, while a cover of 60% reduces it by 76% as compared to bare ground. This agrees with Shaxson (1980) who found that for grassland conditions, a 40% cover over bare ground can reduce splash erosion by about 85-90%. This is a higher reduction than that recorded in this study because of differences in rainfall characteristics, plant morphology and soil types.

#### 4.4.1.2 Crop height

Splash detachment per millimetre of rain is shown plotted against crop height as in fig. 4.5. The correlation coefficients of these relationships are 0.675, 0.618 and 0.690 for maize, beans and intercrop respectively. The regression equations for these curves are as follows;

Maize: $S = 1.06e^{-0.01H}$ [4.14]

Beans: $S = 1.14e^{-0.04H}$ [4.15]

Intercrop: $S = 0.68e^{-0.01H}$ [4.16]

Where, S is the soil splash per mm rain (g $mm^{-1}$)

H is the crop height in cm.

From fig. 4.5, it appears that as crop height increases, splash detachment decreases for all crops. For a given crop height, more soil splash occurs under maize than intercrop, with beans allowing the least amount of soil splash. Thus it would appear that the taller the crop the more is the splash. It also happens that the taller the crop, the more is the cover. Thus, there appears to be a disparity which is explained by the fact that for a given crop height, cover is more for beans than intercrop and maize, while intercrop has more cover than maize. Therefore, this relationship with cover seems to have the overriding effect on soil splash.

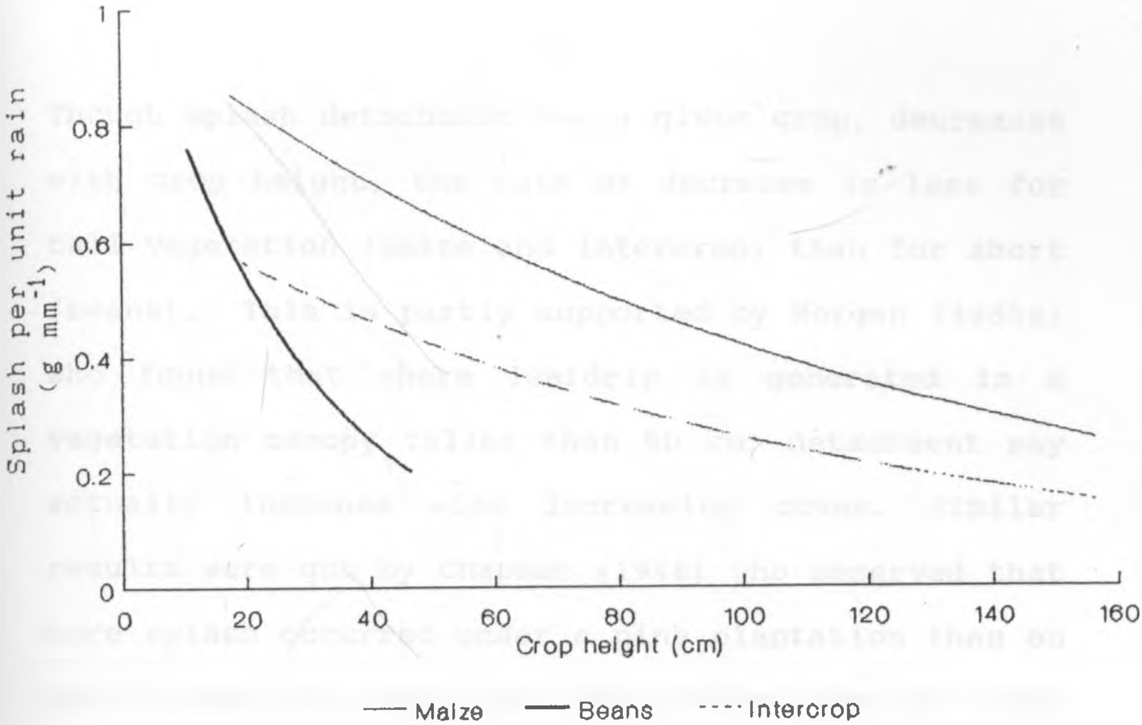



Fig. 4.5 Splash per mm rain vs crop height

Table 4.5 Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.5.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 1.06e^{-0.01H}$ | 0.675 | 1.964 | 5.011 |
| Beans | $S = 1.14e^{-0.04H}$ | 0.618 | 1.718 | 4.306 |
| Intercrop | $S = 0.68e^{-0.01H}$ | 0.690 | 1.190 | 5.221 |

Where, S is the splash detachment per mm of rain and H is the crop height in cm. The number of observations are 27 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

Though splash detachment for a given crop, decreases with crop height, the rate of decrease is less for tall vegetation (maize and intercrop) than for short (beans). This is partly supported by Morgan (1985a) who found that where leafdrip is generated in a vegetation canopy taller than 50 cm, detachment may actually increase with increasing cover. Similar results were got by Chapman (1948) who observed that more splash occurred under a pine plantation than on bare ground. He found that median drop size was twice as big for pine cover than for open field, and therefore the kinetic energy of the rain was higher.

These results can be explained by the fact that under tall crops, raindrops coalesce to form larger droplets, which are able to gain enough momentum as they fall and consequently cause splash detachment. Under intercrop, the larger drops from leafdrip are intercepted by the bean cover, reducing their momentum and hence erosivity. The least splash detachment occurs under beans because since they are very short, leafdrip does not result in erosive drops. Also, bean height has very little effect on splash detachment because the change in height during crop growth stage is very small.

### 4.4.2 Rainfall erosivity factors

#### 4.4.2.1 Rainfall amount

Rainfall amount was found to be highly correlated with splash detachment (r=0.804). A power equation was obtained to describe the effect of rainfall amount on a bare fallow land as follows:

$$S = 0.54A^{1.17} \quad [4.17]$$

Where, S is splash detachment from bare soil surface (g).

A is the rainfall amount (mm).

This relationship is quite different from the one obtained by Lal (1981) who found that splash detachment was related to rainfall amount linearly as follows:

$$S = 22.7A + 19.73 \quad [4.18]$$

Where, S is the sand splash (g $m^{-2}$).

This variation can be attributed to the differences in rainfall characteristics between the two areas, as mentioned earlier, and also the fact that the above relationship is for sand, rather than soil under field conditions.

A comparison of the effects of rainfall amount on splash detachment under maize, beans and intercrop are shown in fig. 4.6a and b. The equations and correlation coefficients of these curves are shown in tables 4.6a and b. Both figures show that in all the cases, splash detachment increases with rainfall amount for all the treatments. From fig.4.6a, it is apparent that when total values of splash are taken, maximum detachment occurs on bare ground, while maize cover allows much higher splash than either beans or intercrop. Though there is no significant difference in the splash obtained from beans and intercrop on a daily basis, for a given amount of rainfall more splash occurs under beans than under intercrop.

These results agree well with other studies on splash detachment under crop covers (Morgan, 1982; Shaxson, 1980). This is explained by the fact that crop cover intercepts raindrops, releasing them onto the ground at lower terminal velocities, hence reducing their erosivity. In addition, the crop covers trap some of the splashed soil particles before they fall back onto the ground, which cling onto the leaves, and are washed off by subsequent storms.

Figure 4.6b shows the relationship between rainfall amount and splash detachment per unit bare space, when the effect of crop cover is removed. This shows that at low rainfall amounts, splash detachment is nearly

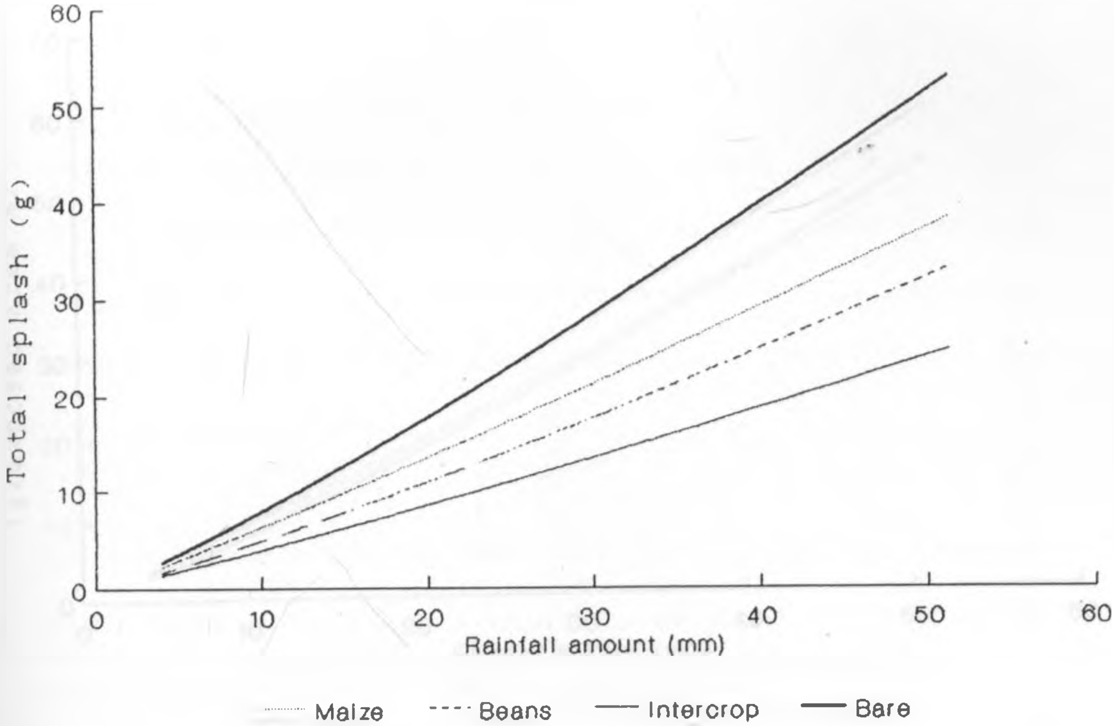



Fig. 4.6a Total splash vs rainfall amount

Table 4.6a Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.6a.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.49A^{1.11}$ | 0.785 | 1.857 | 6.941 |
| Beans | $S = 0.33A^{1.17}$ | 0.756 | 2.056 | 6.326 |
| Intercrop | $S = 0.3A^{1.12}$ | 0.680 | 2.363 | 5.080 |
| Bare | $S = 0.54A^{1.17}$ | 0.804 | 1.842 | 7.406 |

Where, S is the total splash detachment in grams and A is the rainfall amount in mm. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha=0.05$).

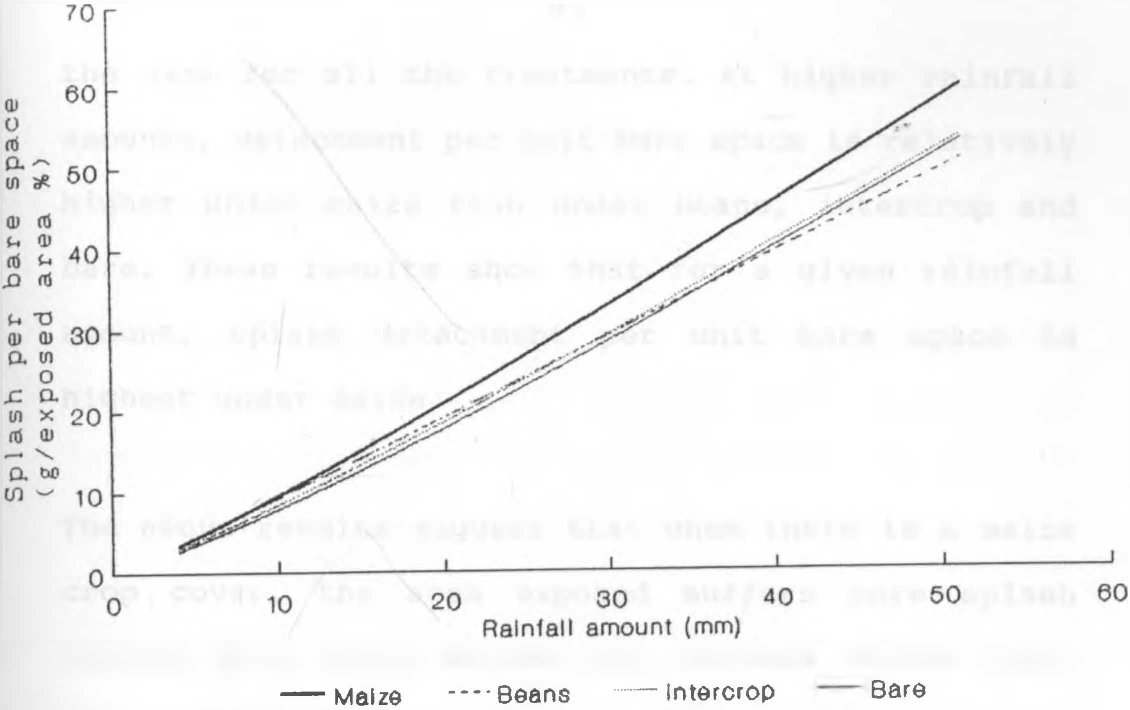



Fig. 4.6b Weighted splash vs rainfall amount

Table 4.6b Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.6b.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.73A^{1.12}$ | 0.842 | 1.664 | 8.549 |
| Beans | $S = 0.85A^{1.04}$ | 0.790 | 1.770 | 7.058 |
| Intercrop | $S = 0.63A^{1.13}$ | 0.825 | 1.730 | 7.996 |
| Bare | $S = 0.54A^{1.17}$ | 0.804 | 1.842 | 7.406 |

Where, S is the splash detachment (in grams) per percent exposed area and A is the rainfall amount in mm. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha=0.05$).

the same for all the treatments. At higher rainfall amounts, detachment per unit bare space is relatively higher under maize than under beans, intercrop and bare. These results show that for a given rainfall amount, splash detachment per unit bare space is highest under maize.

The above results suggest that when there is a maize crop cover, the area exposed suffers more splash erosion than would be the case on bare fallow land. One explanation for this unexpected result is that the area exposed under a crop cover suffers both the direct raindrop splash action, and also the effects of leafdrip, as the ground surface is poorly covered, especially during heavy storms. Therefore, this causes more splash on the exposed bare space than on bare ground.

Another explanation is that these results assume that the area shaded by the crop does not experience splash detachment. In reality, splash takes place even under crop cover, especially as a result of leafdrip. Since the actual area subjected to splash erosion is larger than the measured bare space, the real splash per exposed area should be much less.

The other discrepancy that may have lead to these results is the orientation of the raindrops with respect to the ground. Crop cover is measured vertically downwards, while the actual cover against raindrops is sometimes modified (reduced) during oblique rainfall, resulting in less effective cover over the soil. Thus the exposed area is actually larger than the calculated value, leading to a higher than normal splash detachment per unit area.

Splash per unit bare space is more for maize because since the crop is tall and with little surface or near surface cover, the drops emanating from leafdrip are able to gain momentum and achieve a large enough terminal velocity to be erosive, especially during heavy storms. Beans and intercrop intercept raindrop impact effectively, and due to the presence of beans in the intercrop, any leafdrip from the maize plants is also intercepted. Thus, splash occurs only on the exposed surfaces from natural rainfall, and therefore, it is the same as splash from bare fallow land.

#### 4.4.2.2 Rainfall intensity

Rainfall intensity was found to be the poorest erosivity index for splash detachment. The intensity value that correlated most highly with splash detachment was the maximum 45-minute intensity (r=0.642). The relationship between rainfall intensity ($I_{45}$) and splash detachment was as follows:

$$S = 0.96(I_{45})^{1.17} \qquad [4.19]$$

Where, S is the splash detachment from bare fallow land.

$I_{45}$ is the maximum 45-minute intensity.

This relationship agrees with the findings of Morgan (1985b) who found that splash detachment is related to intensity by equations of the form:

$$D_s = kI^c \qquad [4.20]$$

Where, $D_s$ is the splash detachment.

k is a constant dependent on soil type.

$I^c$ is the rainfall intensity.

The main difference between this equation and the one obtained in this study is that the exponent (c) is 1.17, rather than 2 as proposed by Morgan (1985b).

Lal (1981) found that sand splash is linearly related to rainfall intensity as follows:

$$S = 17.60I_{30} + 1.64 \qquad [4.21]$$

Where, S is sand splash (g $m^{-2}$).

$I_{30}$ is the maximum 30-minute intensity (mm $h^{-1}$).

This difference can be attributed to the wide variations in the rainfall intensities since in this study, most of the intensities were below 15 mm $h^{-1}$, compared to those used by Lal (1981) most of which exceeded 50 mm $h^{-1}$.

The relation between total splash detachment (absolute values) and rainfall intensity for all the treatments is shown in fig.4.7a. In addition, table 4.7a shows the correlation coefficients, standard errors and equations of the curves. This shows that all the equations have similar exponents. The correlation coefficients are quite low suggesting that the relation between rainfall intensity and total splash is a weak one. This is because rainfall intensities are calculated from only part of a storm. By excluding the rest of the storm, poorer relation are got.

Figure 4.7a shows that for all the treatments, total splash increases by a power function with rainfall intensity. From these curves, for a given rainfall intensity, more splash occurs on bare fallow land than under the cropped areas. By comparing the splash detachment from the cropped treatments, maize cover was found to allow more splash than either beans or intercrop. Though the difference in splash between beans and intercrop is statistically insignificant, intercrop has the lowest splash detachment.

For total (absolute) splash detachment, both beans and intercrop offer more cover over the soil, intercepting

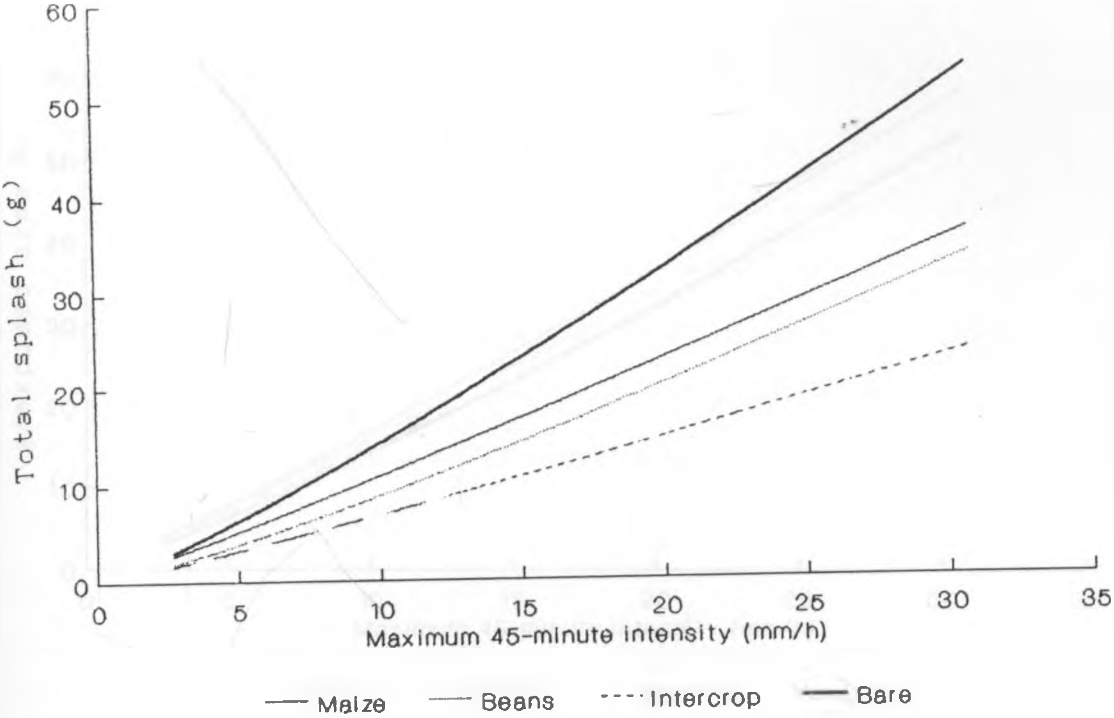



Fig. 4.7a Total splash vs maximum 45-minute intensity

Table 4.7a Regression equations, correlation coefficients and standard errors of estimate for the curves in fig.4.7a.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.93I^{1.07}$ | 0.604 | 2.219 | 4.151 |
| Beans | $S = 0.57I^{1.19}$ | 0.608 | 2.396 | 4.194 |
| Intercrop | $S = 0.55^{1.1}$ | 0.528 | 2.707 | 3.405 |
| Bare | $S = 0.96I^{1.17}$ | 0.642 | 2.201 | 4.586 |

Where, S is the total soil splash detachment in grams and I is the maximum 45-minute intensity of the rain. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

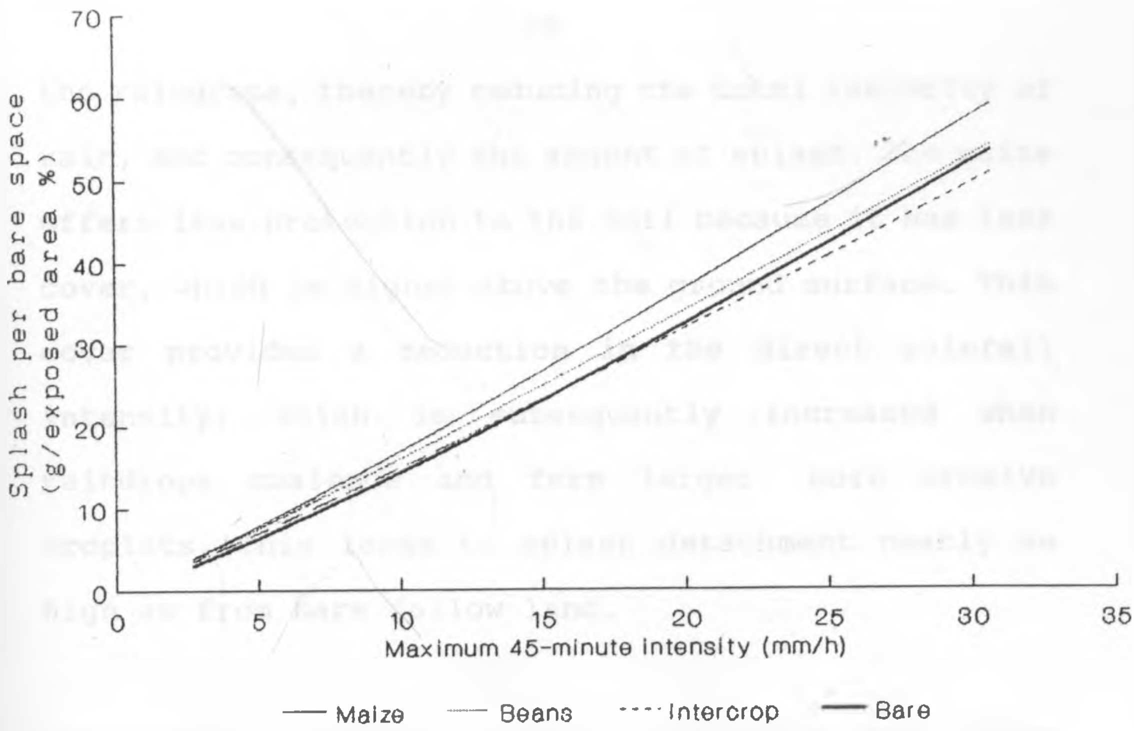



Fig. 4.7b Weighted splash vs maximum 45-minute intensity

Table 4.7b Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.7b.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 1.31I^{1.11}$ | 0.663 | 2.026 | 4.851 |
| Beans | $S = 1.32I^{1.08}$ | 0.655 | 2.024 | 4.748 |
| Intercrop | $S = 1.21I^{1.09}$ | 0.633 | 2.121 | 4.479 |
| Bare | $S = 0.96I^{1.17}$ | 0.642 | 2.201 | 4.586 |

Where, S is the splash detachment (g) per percent exposed area and I is the maximum 45-minute rainfall intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha=0.05$).

the raindrops, thereby reducing the total intensity of rain, and consequently the amount of splash. The maize offers less protection to the soil because it has less cover, which is higher above the ground surface. This cover provides a reduction in the direct rainfall intensity, which is subsequently increased when raindrops coalesce and form larger, more erosive droplets. This leads to splash detachment nearly as high as from bare fallow land.

The relation between rainfall intensity and splash detachment from all the treatments excluding the effects of crop cover is shown in fig.4.7b. This shows the weighted total splash detachment, per percentage exposed area under the crop, plotted against the maximum 45-minute rainfall intensity. Table 4.7b shows that the weighted values have higher correlation coefficients with rainfall intensity than the absolute ones. This means that the weighted splash detachment is a better estimator for the relationship than absolute total splash. The equations shown in table 4.7b are all power equations with exponents very similar to those of the control results but the constants are different. This suggests that the rate of change of splash detachment with intensity is the same regardless of the type and amount of cover available. The main difference is the constant of proportionality of the relationship.

From fig.4.7b, it is apparent that for a given rainfall intensity, splash detachment per percent exposed area is more for maize than for beans, intercrop and bare fallow. Also, splash per exposed surface area under beans and intercrop is the same as that from bare surface. This can be attributed to the fact that only very low rainfall intensities were received during the span of the study. Thus at low intensities, leafdrip from the maize plants produces larger drops than natural rainfall resulting in more splash on the exposed area between the plants, than on bare fallow land.

#### 4.4.2.3 Rainfall energy

Rainfall kinetic energy was found to be highly correlated with splash detachment (r=0.810). Thus splash detachment was found to be related to rainfall energy by the following power equation:

$$S = 0.02E^{1.15} \qquad [4.22]$$

Where, S is the splash detachment (g) from bare fallow land.

E is the rainfall energy ($J\ m^{-2}$).

This equation agrees with the one proposed by Morgan (1985b) as follows:

$$D_s = k_1 KE^b \qquad [4.23]$$

Where, $D_s$ is the rate of detachment of soil particles from bare ground, KE is the kinetic energy of the rainfall and $k_1$ is a constant dependent on the soil type. The exponent (b), found to be 1.15 in this study, is very close to the value (b=1.0) proposed by Morgan (1985b). This shows that rainfall kinetic energy is a good estimator for splash detachment.

The plots of total splash detachment with rainfall kinetic energy for all the treatments are shown in fig.4.8a. In all the treatments, splash increases with energy by power equations as shown in table 4.8a. For a given rainfall energy, splash detachment is a maximum on bare fallow land, followed closely by maize, then beans. Intercrop allows the lowest amount of splash. Thus, the higher the crop cover, the less is the splash detachment for a given rainfall energy. This can be explained by the fact that rainfall energy is reduced when crop cover intercepts raindrops, especially under beans and intercrop which have more cover. Thus, splash detachment is also reduced.

Weighted splash detachment from all the treatments is plotted against rainfall energy (fig.4.8b). This is the amount of splash per the percentage of exposed space in the cropped area. The equations and

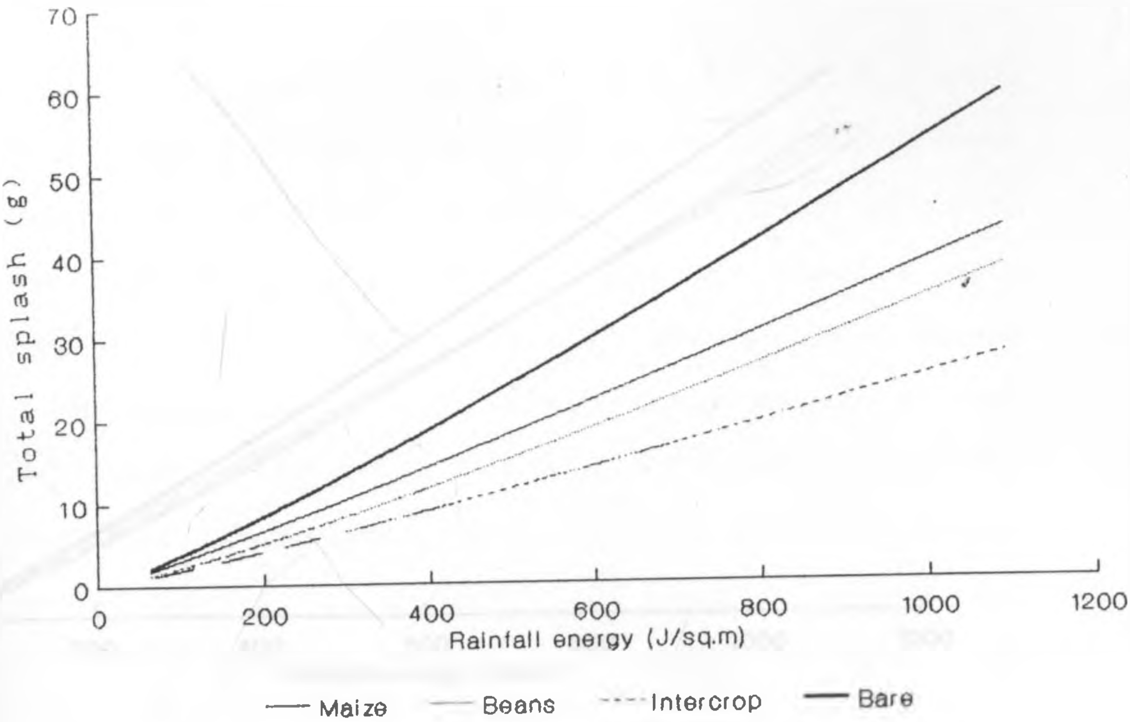



Fig. 4.8a Total splash vs rainfall kinetic energy

Table 4.8a Regression equations, correlation coefficientsand standard errors of estimate for the curves in fig. 4.8a.

| Treatment | Equations | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.02E^{1.1}$ | 0.793 | 1.839 | 7.129 |
| Beans | $S = 0.01E^{1.18}$ | 0.775 | 1.766 | 6.717 |
| Intercrop | $S = 0.01E^{1.11}$ | 0.686 | 2.347 | 5.164 |
| Bare | $S = 0.02E^{1.15}$ | 0.810 | 1.828 | 7.565 |

Where, S is the total splash detachment in grams and E is rainfall kinetic energy in J $m^{1}$. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

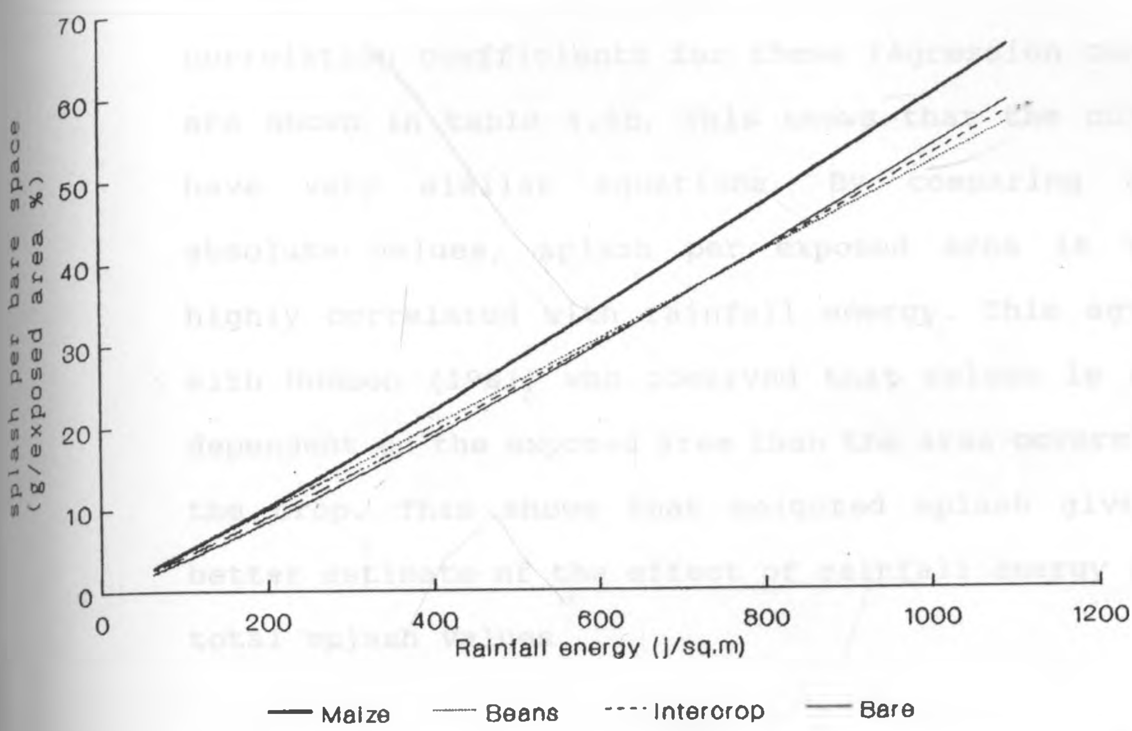



Fig. 4.8b Weighted splash vs rainfall kinetic energy

Table 4.8b Regression equations, corrrelation coefficients and standard errors of estimate for the curves in fig 4.8b.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.03E^{1.1}$ | 0.845 | 1.657 | 8.655 |
| Beans | $S = 0.04E^{1.03}$ | 0.801 | 1.747 | 11.376 |
| Intercrop | $S = 0.03E^{1.1}$ | 0.816 | 1.751 | 7.732 |
| Bare | $S = 0.02E^{1.15}$ | 0.810 | 1.828 | 7.565 |

Where, S is the splash detachment in grams per percent exposed area and E is the rainfall kinetic energy in J $m^{-1}$. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

correlation coefficients for these regression curves are shown in table 4.8b. This shows that the curves have very similar equations. By comparing with absolute values, splash per exposed area is more highly correlated with rainfall energy. This agrees with Hudson (1981) who observed that splash is more dependent on the exposed area than the area covered by the crop. This shows that weighted splash gives a better estimate of the effect of rainfall energy than total splash values.

From fig.4.8b, it is apparent that for a given rainfall energy, the most splash occurs under maize, while beans, intercrop and bare seem to have the lowest and equal amounts of splash per exposed surface. At the lower energy levels, there is no significant difference between the treatments. This is explained by the fact that though maize gives some cover which intercepts raindrop energy, the canopy is high enough for the droplets that reform as leafdrip to gain enough kinetic energy, and to be more erosive than ordinary raindrops because they (leafdrip) are larger. Beans and intercrop (due to the bean cover below the maize) on the other hand are able to absorb most of the raindrop energy, and since beans are short, leafdrip does not produce erosive drops. This means that for the exposed area, splash detachment is the result of natural rainfall only, and therefore, same as that from bare ground.

#### 4.4.2.4 The EI-index

The EI-indices ($EI_5$, $EI_{15}$, $EI_{30}$ and $EI_{45}$) the product of rainfall energy and its 5, 15, 30 and 45-minute intensities respectively, were also found to correlate well with splash detachment. The $EI_{45}$ was the most highly correlated (r=0.800). Splash detachment was related to the $EI_{45}$ index by the following power equation.

$$S = 0.06(EI_{45})^{0.7} \qquad [4.24]$$

Where, S is the splash detachment (g) from bare fallow land and $(EI)_{45}$ is the product of rainfall energy and its 45-minute intensity (J $m^{-2}$ mm $h^{-1}$).

The EI-index (energy x intensity) gives units of power (J $m^{-2}$ mm $h^{-1}$), therefore it serves to determine the effect of rainfall power on splash detachment.

The total splash detachment plotted against the $EI_{45}$-index are shown in fig. 4.9a. These curves are very similar to those for energy, but the correlation coefficients (table 4.9a) though not as high as those of energy, are higher than those for intensity alone. This suggests that by combining energy with intensity, a poorer erosivity index is obtained, due to the effect of rainfall intensity, which is itself a poor index. From fig.4.9a, most splash occurs on bare fallow, followed closely by maize cover areas. Both beans and intercrop have the same effect on splash, having the lowest detachment levels. As explained for rainfall energy, splash detachment is reduced by crop cover. Although intercrop has higher cover than beans, splash is the same because it is the beans cover that plays a predominant role in intercepting rainfall energy, hence power.

By excluding the effect of crop cover, weighted splash detachment per exposed area was obtained as shown in fig.4.9b. The equations of these curves and their correlation coefficients are shown in table 4.9b. Compared to total splash values, weighted splash is a better estimator of the EI-index versus splash detachment relationship. Fig.4.9b shows that at low EI-values, there is no significant difference in the amount of splash obtained from either cropped or bare ground. At higher values of EI, maize produces more splash per exposed area than beans, intercrop and bare fallow. The reason for these results can be attributed to the fact that at low rainfall power, splash from the exposed areas under beans and intercrop are equal to that from bare fallow land. At higher rainfall

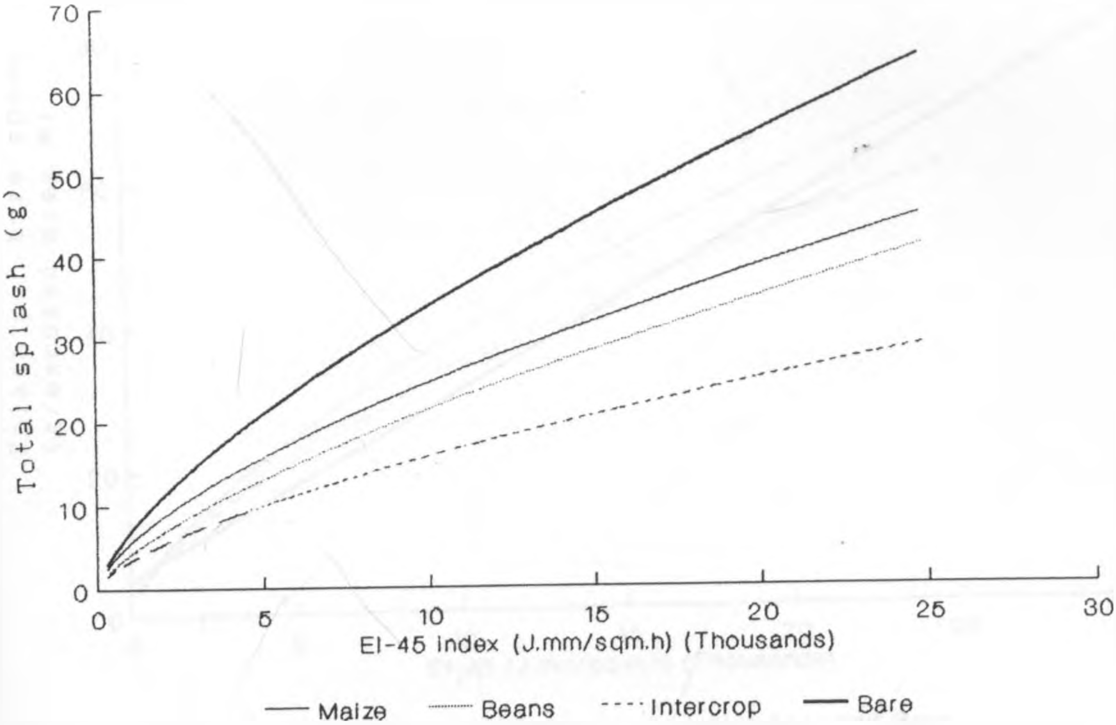



Fig. 4.9a Total splash vs EI-45 index

Table 4.9a Regression equations, correlation coefficients and standard errors of estimate for the curves in fig.4.9a.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.06(EI)^{0.65}$ | 0.771 | 1.889 | 6.631 |
| Beans | $S = 0.03(EI)^{0.71}$ | 0.763 | 2.038 | 6.465 |
| Intercrop | $S = 0.04(EI)^{0.66}$ | 0.670 | 2.389 | 6.943 |
| Bare | $S = 0.06(EI)^{0.7}$ | 0.800 | 1.853 | 7.303 |

Where, S is the total splash detachment in grams and EI is the product of rainfall energy and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha=0.05$).

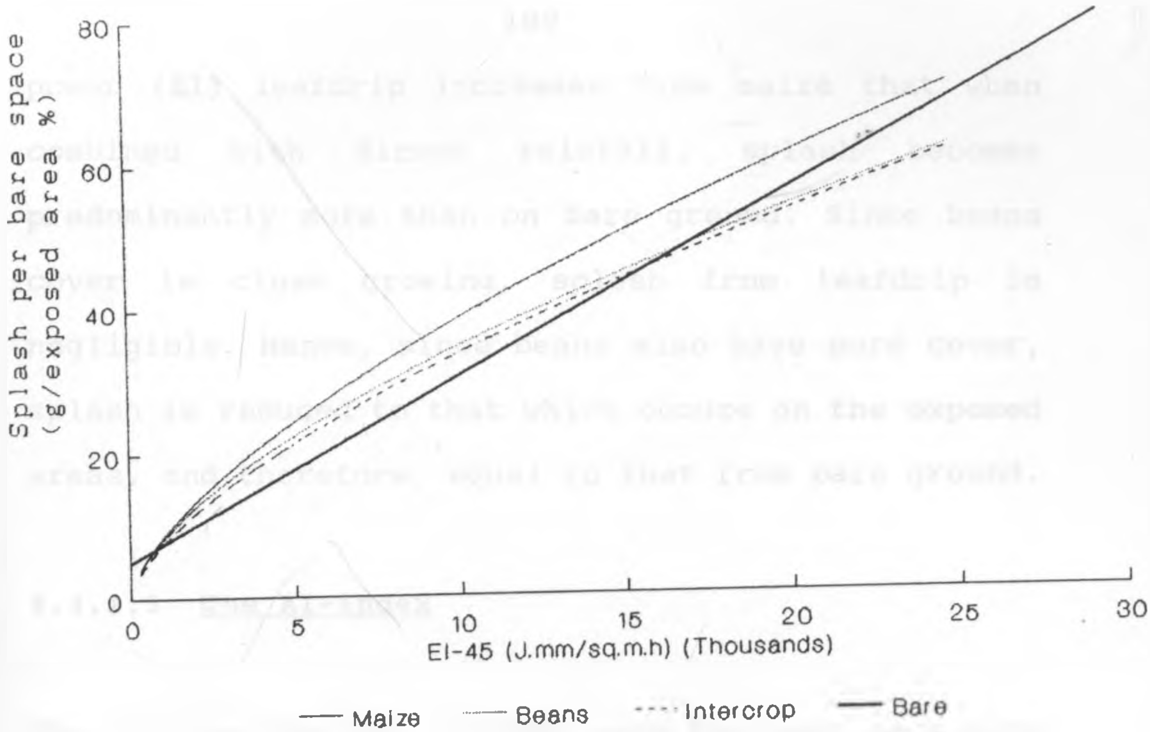



Fig. 4.9b Weighted splash vs EI-45 index

Table 4.9b Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.9b

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.09(EI)^{0.66}$ | 0.831 | 1.689 | 8.182 |
| Beans | $S = 0.11(EI)^{0.63}$ | 0.801 | 1.749 | 7.328 |
| Intercrop | $S = 0.08(EI)^{0.66}$ | 0.800 | 1.791 | 7.303 |
| Bare | $S = 0.06(EI)^{0.7}$ | 0.800 | 1.853 | 7.303 |

Where, S is the splash detachment (g) per percent exposed area and EI is the product of rainfall energy and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

power (EI) leafdrip increases from maize that when combined with direct rainfall, splash becomes predominantly more than on bare ground. Since beans cover is close growing, splash from leafdrip is negligible. Hence, since beans also have more cover, splash is reduced to that which occurs on the exposed areas, and therefore, equal to that from bare ground.

#### 4.4.2.5 The AI-index

The $AI_{45}$ and the $AI_{30}$ indices were the best erosivity indices both with r-value of 0.821. The relationship between splash detachment and the AI-index was as follows:

$$S = 0.35\ (AI_{45})^{0.74} \qquad [4.25]$$

Where, S is the splash detachment from bare fallow land (g) and $AI_{45}$ is the product of rainfall amount and its maximum 45-minute intensity.

Since the AI-index was the best erosivity index it can be adopted for predicting splash detachment. Fig.4.10a shows the plot of total (absolute) splash against the AI-index. It shows that splash increases with rainfall AI-index. For a given AI-value, more detachment occurs on bare fallow than on cropped land. Also, maize cover allows more splash than both bean and intercrop treatments, whose splash characteristics are the same.

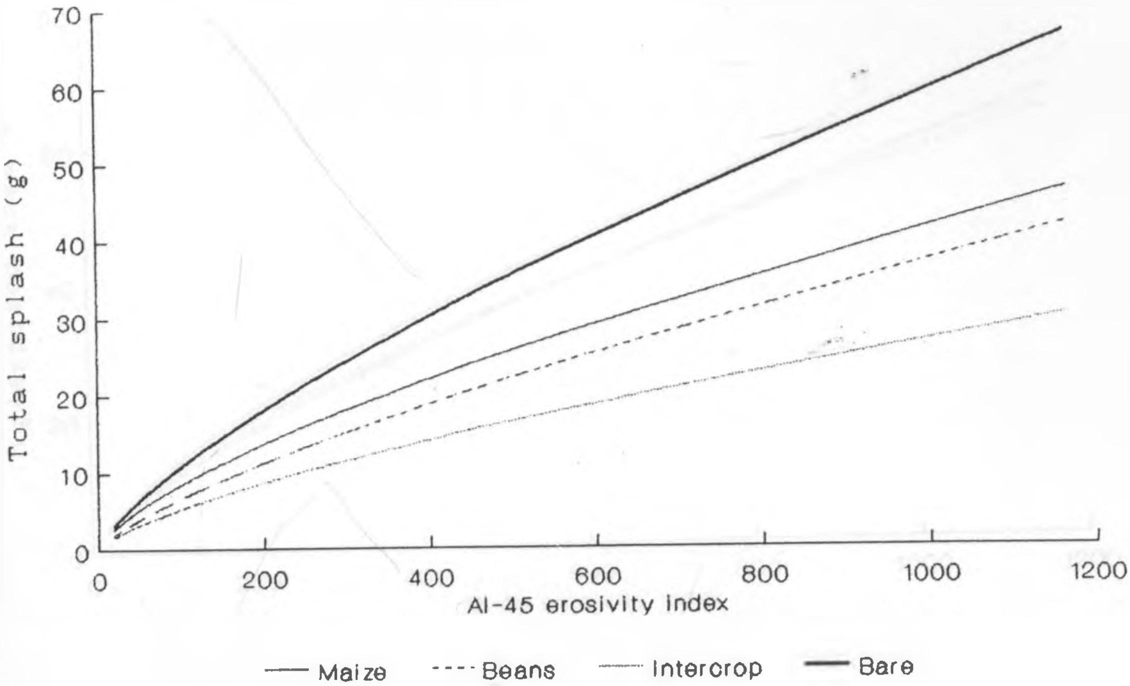



Fig. 4.10a Total splash vs AI-45 index

Table 4.10a. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig.4.10a.

| Treatment | Equation | Correlation coefficient | Std. error of est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.34(AI)^{0.7}$ | 0.790 | 1.846 | 7.058 |
| Beans | $S = 0.21(AI)^{0.75}$ | 0.774 | 2.010 | 6.695 |
| Intercrop | $S = 0.2(AI)^{0.71}$ | 0.686 | 2.347 | 5.164 |
| Bare | $S = 0.35(AI)^{0.74}$ | 0.821 | 1.799 | 7.876 |

Where, S is the total splash detachment in grams and AI is the product of rainfall amount and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

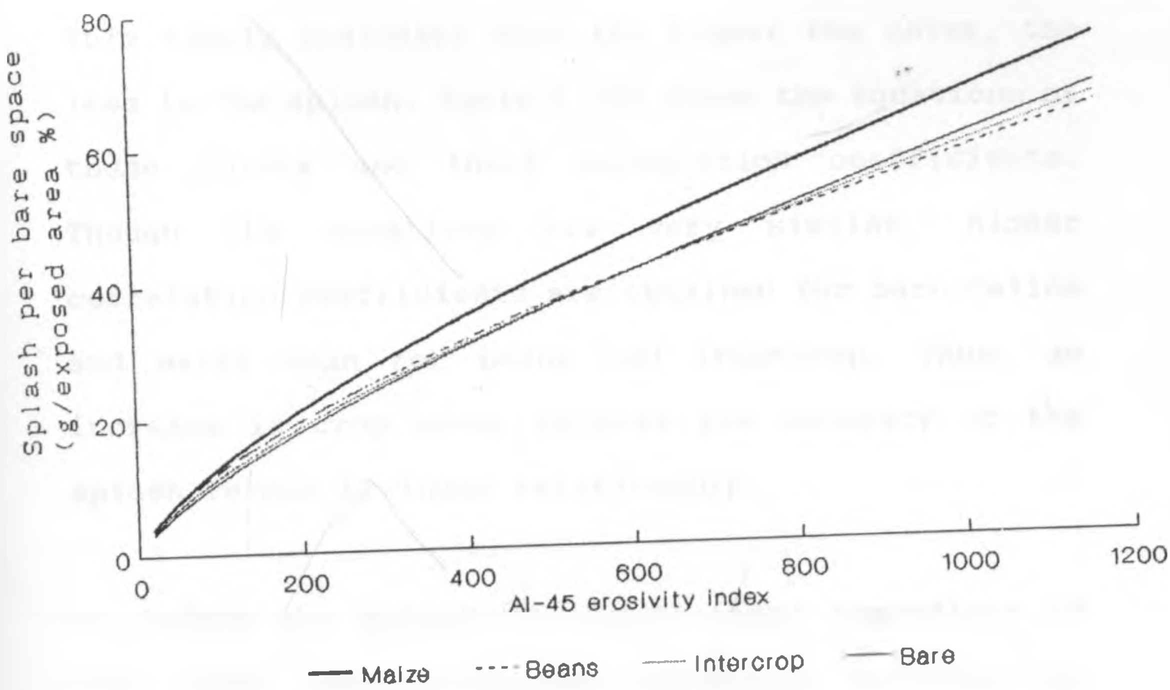



Fig. 4.10b Weighted splash vs AI-45 index

Table 4.10b. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig.4.10b.

| Treatment | Equation | Correlation coeffients | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S = 0.49(AI)^{0.71}$ | 0.856 | 1.631 | 9.069 |
| Beans | $S = 0.56(AI)^{0.67}$ | 0.819 | 1.709 | 7.818 |
| Intercrop | $S = 0.44(AI)^{0.71}$ | 0.829 | 1.719 | 8.119 |
| Bare | $S = 0.35(AI)^{0.74}$ | 0.821 | 1.799 | 7.876 |

Where, S is the splash detachment (g) per percent exposed area and AI is the product of rainfall amount and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

This simply indicates that the higher the cover, the less is the splash. Table 4.10a shows the equations of these curves and their correlation coefficients. Though the equations are very similar, higher correlation coefficients are obtained for bare fallow and maize than for beans and intercrop. Thus, an increase in crop cover reduces the accuracy of the splash versus AI-index relationship.

To deduce the effect of the AI-index regardless of crop cover, weighted splash detachment is calculated as the splash amount per exposed area under the crop. This is shown plotted against the AI-index in fig. 4.10b. The equations and correlation coefficients of these equations are shown in table 4.10b. This shows that weighted splash is better correlated with the AI-index than absolute values. From fig.4.10b splash detachment increases with AI-index. Also, weighted splash is higher under maize than under beans, intercrop and on bare fallow land. Reasons for this behaviour are as explained for the rainfall kinetic energy and rainfall amount characteristics.

## 4.5 Splash transport

Splash transport, the net soil displacement in a given direction, for the purposes of this study was taken to occur as a result of rainfall obliquity (caused by high wind speeds) and the effect of the land slope. According to Schwab et al (1981), factors affecting the direction and distance of soil splash are slope, wind, surface condition and such impediments to splash as vegetation cover and mulches. Since wind data was not available, the only splash transport considered here is that which occurs due to the orientation of the slope.

Splash transport downslope was calculated as the difference between the soil in the upslope facing trap (trap that receives particles splashed downslope), minus that in the downslope facing trap (trap that receives particles splashed upslope). The percent splash transport was subsequently calculated as follows:

$$\text{Splash transport downslope} = \frac{(S_D - S_U)}{(S_D + S_U)} \times 100\ (\%) \qquad [4.26]$$

Where, $S_D$ is the amount of soil splashed downslope.

While, $S_U$ is the amount of soil splashed upslope.

The values of total and percent splash transport downslope for all the treatments are shown in tables

7.6 and 7.7 of appendix 4 respectively. When regression analysis was done, the percent splash transport was found to be unrelated to either rainfall erosivity indices (rainfall amount, intensity, kinetic energy, EI-index and AI-index) or crop cover and height. This suggests that for a given slope and soil type, splash transport due to slope inclination is constant regardless of rainfall characteristics and crop cover. Thus it would appear that the variables that affect splash transport were not assessed in this study.

The mean splash transport from the bare fallow land was 69 percent. This is a large proportion of the soil that moves downslope on a slope of 25%. It has been observed in other studies (Wischmeier and Mannering, 1969) that 75% of the splashed soil moved downhill on a 10% slope while only 25% moved uphill. This is much higher than the results of this study especially since the slope is much steeper. This difference can be attributed to soil and rainfall characteristics.

### 4.5.1 Relationship between upslope and downslope splash

The amount of soil splashed downslope on a bare fallow land was found to be linearly related to that which falls upslope with a correlation coefficient of 0.854. Soil splash downslope was linearly related to that upslope on bare fallow and under maize crop. The relations for beans and intercrop were power equations. This is shown by the curves in fig. 4.11. The relationship between upslope and downslope splash can therefore be expressed as follows:

$$S_D = 6.65 S_U + 0.54 \quad [4.27]$$

Where, $S_D$ is the amount of soil splashed downslope, and $S_U$ is the amount splashed upslope.

This clearly shows that though the amount of soil splashed downslope increases with that upslope, the amount of soil splashed downslope is nearly seven times that splashed upslope. Since the slope of the land remained constant throughout the study, the splash transport cannot be related to slope steepness. Ekern (1950) reported that the percentage of the soil which moved downslope equalled the percent slope plus 50. This was not ascertained in this study. For downslope splash under beans and intercrop, the ratio of downslope to upslope splash was much lower than that for maize and bare fallow.

The net splash transport occurs in the downslope direction because, according to Schwab (1981), when a raindrop falls on the soil, its kinetic energy

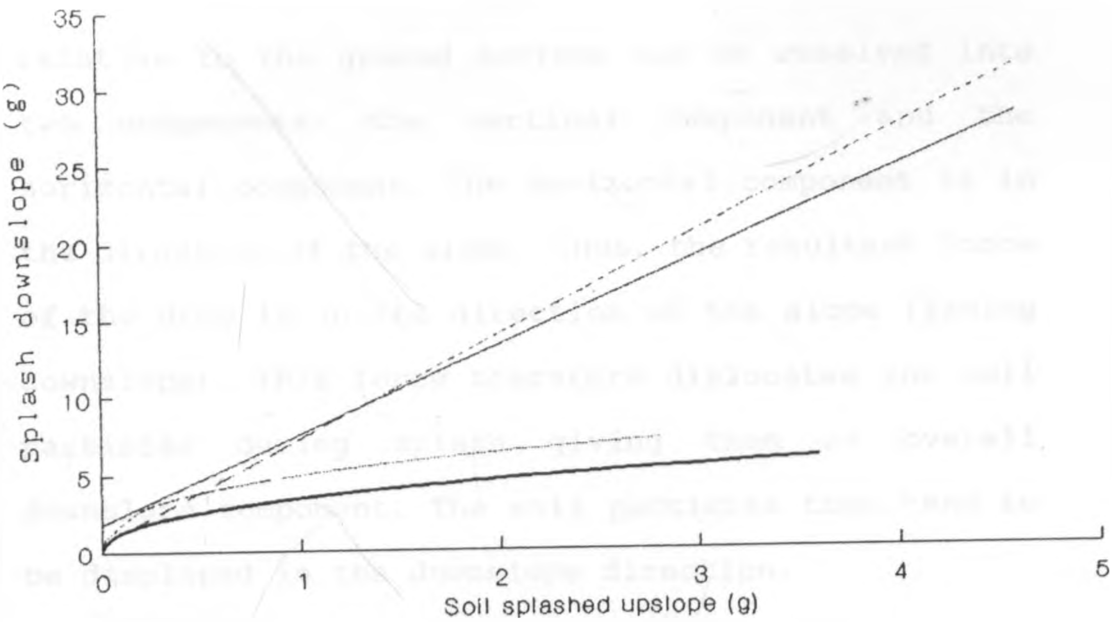



Fig. 4.11 Relationship betwsen upslope and downslope splash

Table 4.11. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.11.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $SD = 5.75SU + 1.74$ | 0.758 | 4.747 | 6.365 |
| Beans | $SD = 4.83SU^{0.36}$ | 0.695 | 2.368 | 5.295 |
| Intercrop | $SD = 3.5SU^{0.42}$ | 0.773 | 2.266 | 6.674 |
| Bare | $SD = 6.65SU + 0.54$ | 0.854 | 4.652 | 8.991 |

Where, SD is the amount of soil splashed downslope, and SU is the amount splashed upslope (g). The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

relative to the ground surface can be resolved into two components: the vertical component and the horizontal component. The horizontal component is in the direction of the slope, thus, the resultant force of the drop is in the direction of the slope (facing downslope). This force therefore dislocates the soil particles during splash giving them an overall downslope component. The soil particles then tend to be displaced in the downslope direction.

### 4.5.2 Effect of crop cover on splash transport

The net splash transport downslope after regression analysis, was found to be independent of crop cover amounts. Since the percent of splash downslope was not constant for different crop covers, then the variations seen in table 7.7 of appendix 4. must be due to parameters not measured in this study such as antecedent soil moisture, wind speed and direction, soil shear strength, surface roughness, etc.

To relate soil movement under crop covers, the amounts of soil splashed into the upslope and downslope traps were correlated separately with the percent crop cover for each treatment. Fig. 4.12 shows the plots of downslope splash against percent crop cover for maize, beans and intercrop respectively. These curves show

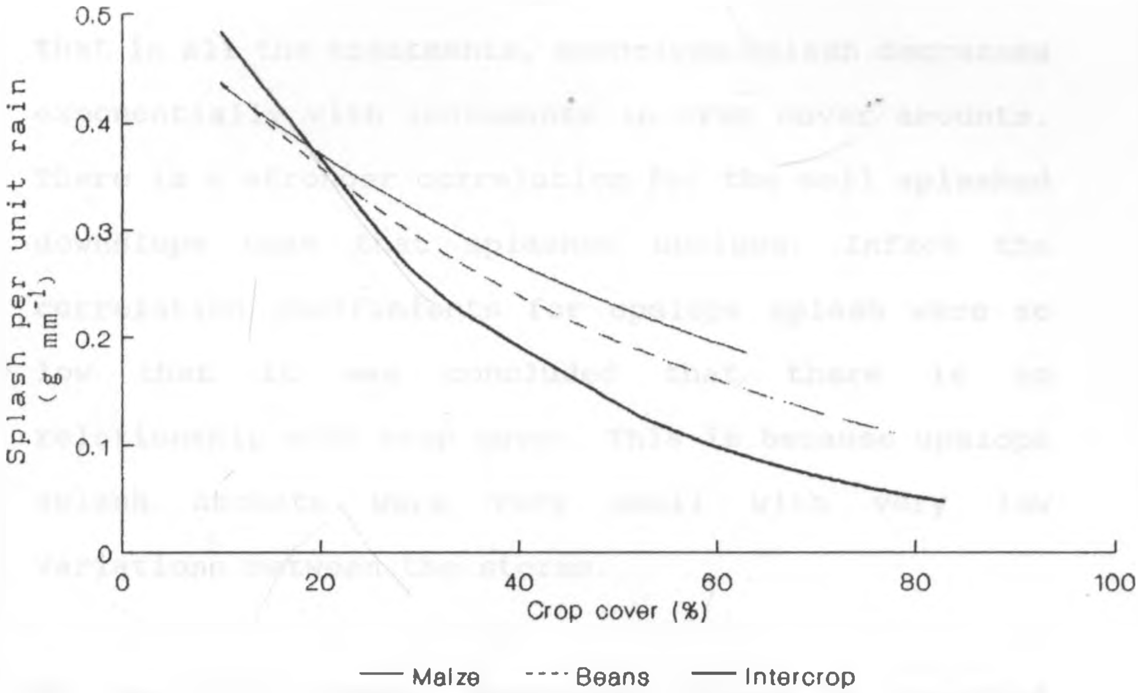



Fig. 4.12 Splash downslope vs percent crop cover

Table 4.12. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.12.

| Treatment | Equation | Correlation coefficients | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S_D = 0.51e^{-0.02c}$ | 0.547 | 1.639 | 3.579 |
| Beans | $S_D = 0.64e^{-0.02c}$ | 0.599 | 1.990 | 4.097 |
| Intercrop | $S_D = 0.73e^{-0.03c}$ | 0.829 | 1.726 | 8.119 |

Where, $S_D$ is the soil splash downslope (g) and c is the percent crop cover. The number of observations are 27 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

that in all the treatments, downslope splash decreases exponentially with increments in crop cover amounts. There is a stronger correlation for the soil splashed downslope than that splashed upslope. Infact the correlation coefficients for upslope splash were so low that it was concluded that there is no relationship with crop cover. This is because upslope splash amounts were very small with very low variations between the storms.

At low crop covers, downslope splash is constant regardless of crop type. At higher covers, more splash occurs under maize than under beans, with intercrop allowing the least amount of splash downslope. Crop height was found to be independent of percent downslope splash, and also both the splash downslope and upslope. The lowest splash amounts occur under intercrop, which provides the most cover. Thus soil splash downslope is affected by crop type.

### 4.5.3 Effect of rainfall on splash transport

The percent net splash transport downslope, after regression analysis, was found to be unrelated to rainfall erosivity indices such as amount, intensity, energy, energy times intensity and amount times intensity (A, I, E, EI, and AI respectively). Thus the net splash transport is independent of rainfall characteristics.

To relate splash transport to rainfall, upslope and downslope splash amounts were separately correlated with $AI_{45}$ index. This was because the AI-index had been proven to be the most highly correlated with splash. Figure 4.13a shows the plots of both the upslope and downslope splash amounts against rainfall for bare fallow. Regression equations,correlation coefficients and standard errors of estimate of these relations are also shown in table 4.13a

These equations show that, downslope splash increases as a power function with rainfall amount. The upslope splash was poorly correlated with rainfall, because the total splash amounts were very small.

The amounts of downslope splash for all the treatments are shown plotted against rainfall amount in figure 4.13b. Their equations, correlation coefficients and standard errors are shown in table 4.13b. This shows that for all the treatments, splash downslope increases exponentially with rainfall amount. For a given amount of rainfall, more splash is received the lower the crop cover i.e. splash increases from intercrop, beans, maize and bare respectively. This

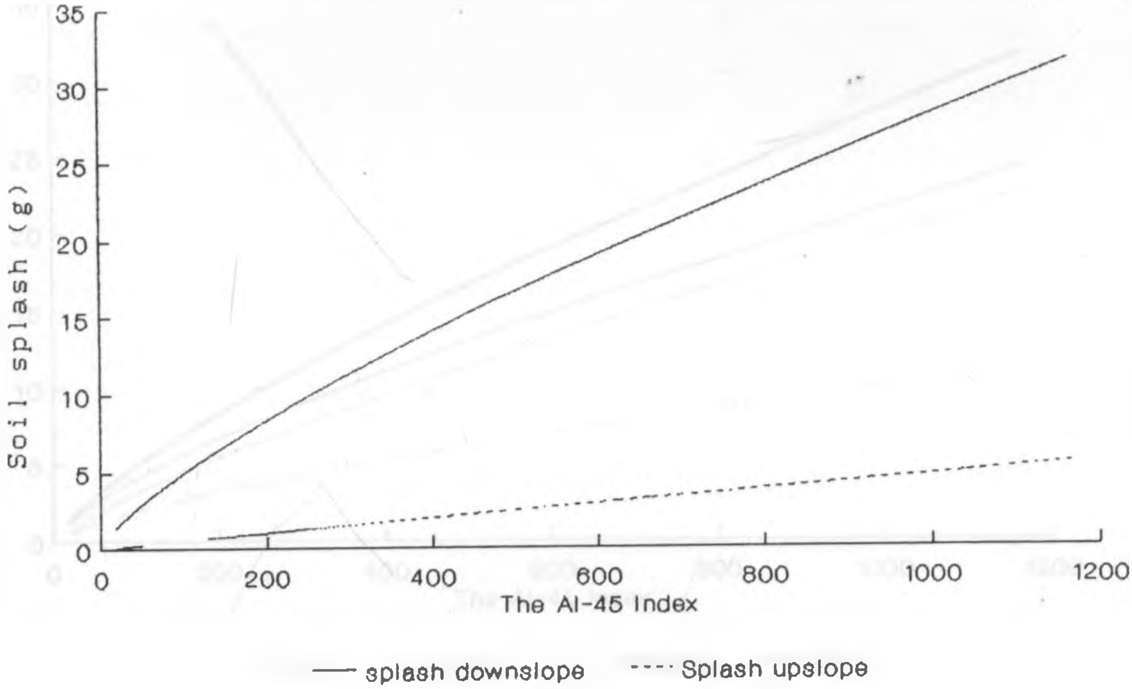



Fig. 4.13a Splash movement vs AI-45 Index (bare fallow)

Table 4.13a. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.13a.

| Soil splash | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Downslope | $S_D = 0.15(AI)^{1.5}$ | 0.820 | 1.826 | 7.847 |
| Upslope | $S_U = 0.01(AI)^{-0.95}$ | 0.567 | 4.797 | 3.770 |

Where, $S_D$ is the amount of soil splashed downslope per mm of rain, $S_U$ is the amount splashed upslope and AI is the product of the rainfall amount and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

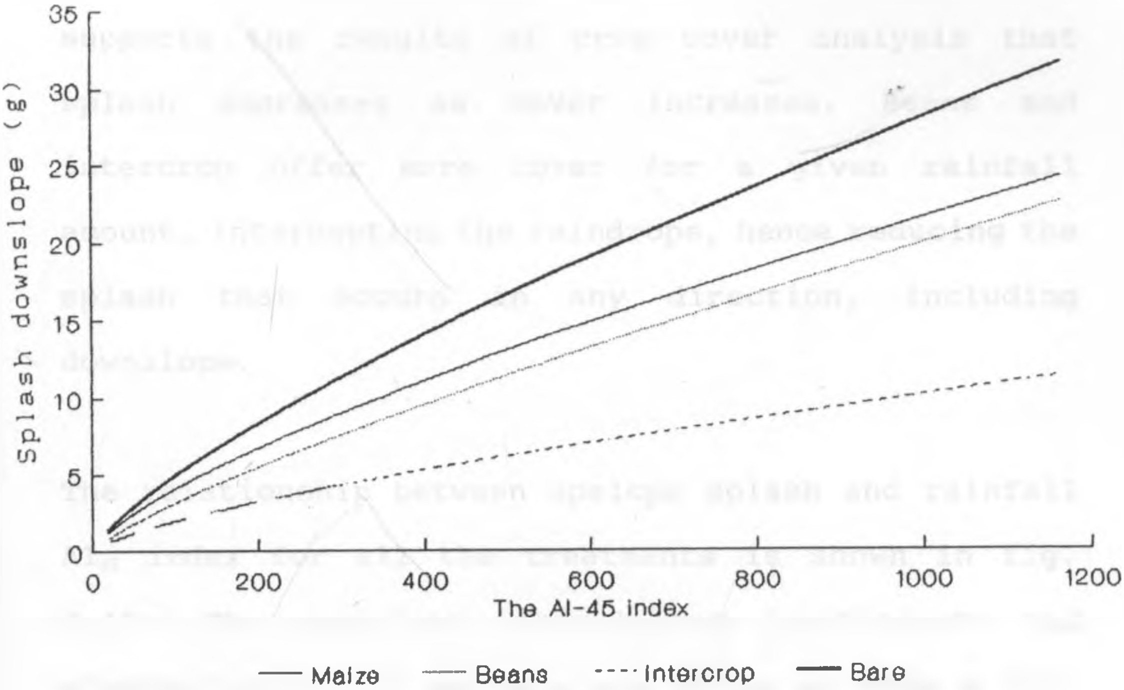



Fig. 4.13b Splash downslope vs rainfall AI-45 index

Table 4.13b. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.13b.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S_D = 0.14(AI)^{0.73}$ | 0.830 | 1.744 | 8.151 |
| Beans | $S_D = 0.08(AI)^{0.81}$ | 0.880 | 2.168 | 10.148 |
| Intercrop | $S_D = 0.07(AI)^{0.96}$ | 0.629 | 2.721 | 4.432 |
| Bare | $S_D = 0.15(AI)^{0.76}$ | 0.820 | 1.826 | 7.848 |

Where, $S_D$ is the amount of soil splashed downslope (g) and AI is the product of rainfall amount and its maximum 45-minute intensity. The number of observations are 32 for each of the treatments. The t-values are all significant ($\alpha$=0.05).

supports the results of crop cover analysis that splash decreases as cover increases. Beans and intercrop offer more cover for a given rainfall amount, intercepting the raindrops, hence reducing the splash that occurs in any direction, including downslope.

The relationship between upslope splash and rainfall $AI_{45}$ index for all the treatments is shown in fig. 4.13c. The equations, correlation coefficients and standard errors of estimate are shown in table 4.13c. These curves show that for a given rainfall event, soil splash upslope is drastically reduced by the presence of a crop cover. This is because the crop cover partly intercepts the splashed soil particles, in addition to reducing the direct splash action, thereby drastically reducing the amount of soil splashed.

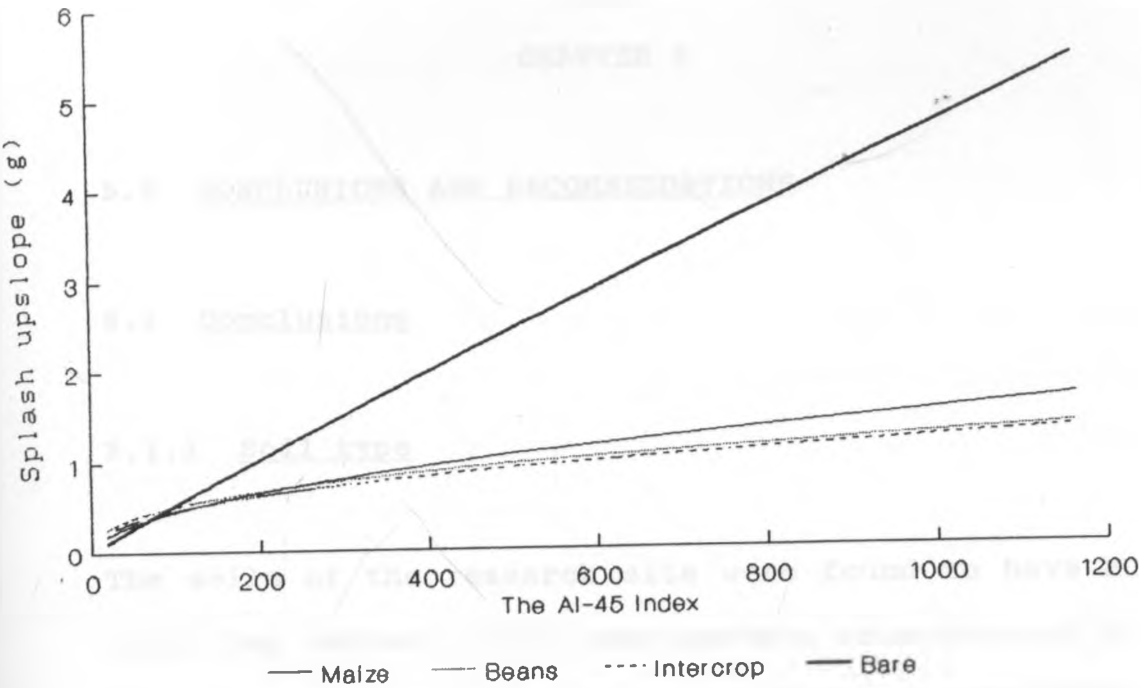



Fig. 4.13c Soil splash upslope vs rainfall AI-45 Index

Table 4.13c. Regression equations, correlation coefficients and standard errors of estimate for the curves in fig. 4.13c.

| Treatment | Equation | Correlation coefficient | Std. error of Y est. | t-values |
|---|---|---|---|---|
| Maize | $S_U = 0.02(AI)^{0.64}$ | 0.488 | 1.437 | 3.062 |
| Beans | $S_U = 0.004(AI)^{0.93}$ | 0.513 | 1.773 | 3.273 |
| Intercrop | $S_U = 0.002(AI)$ | 0.495 | 1.624 | 3.120 |
| Bare | $S_U = 0.01(AI)^{0.95}$ | 0.567 | 1.568 | 3.770 |

Where, $S_U$ is the amount of soil splashed upslope and AI is the product of rainfall amount and its maximum 45-minute intensity. The number of observations are 32 for all the treatments. The t-values are all significant ($\alpha$=0.05).

# CHAPTER 5

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

#### 5.1.1 Soil type

The soils of the research site were found to have a high clay content (60%), poor surface structure and a high flocculation index. These are factors associated with a high degree of aggregation and consequently, decreased splash detachment. Though no comparative studies were done, large quantities of splash were sometimes obtained (e.g. 65 grams of soil from a 15.2 mm storm) showing that splash erosion can contribute alot of soil loss.

The soil characteristics were assumed to remain constant through the growing season. Changes in soil physical structure as a result of surface levelling due to continued erosion, differences in antecedent soil moisture and the effect of crop roots on the soil may have had an effect on the amount of soil splashed, which was very difficult to quantify. It was not possible to do texture analysis on the splashed soil samples because the amounts obtained were too small.

### 5.1.2 Rainfall distribution

The total amount of rainfall received during the two growing seasons was slightly more than the mean seasonal amount. Soil splash was received from all storms of 8 mm and over, suggesting that a threshold value of 8 mm of rain exists before splash can occur under similar conditions.

Rainfall intensities were rather low in both seasons and splash was obtained from storms with as low as 4 mm $h^{-1}$. This suggests that rainfall intensity alone is not a good indicator of the erosivity of a storm.

### 5.1.3 Percent crop cover

It was found that for a given percent crop cover, total splash detachment per unit of rainfall is constant for the three crop types when covers are less than 40%. For crop covers exceeding 40%, splash per mm rain was highest under maize, followed by beans and lowest under intercrop, for a given percent crop cover. Since splash per unit of rain decreases exponentially with crop cover in all the cropping systems, then small additional amounts of cover result in larger reductions in soil splash.

### 5.1.4 Crop height

Splash detachment decreases exponentially with crop height. For a given crop height splash per mm rain was highest under maize, the lowest occurs under beans while intercrop is intermediate. Since for a given crop height beans have more cover than maize or intercrop, then the taller a crop is per given crop cover, the more is the splash.

### 5.1.5 Rainfall amount

Splash detachment was found to increase as a power function of the rainfall amount. For a given amount of rain, total splash decreased with crop cover, while splash per fraction of exposed surface was highest under maize, and constant under beans, intercrop and on bare ground. This means that the exposed surface under maize suffers more splash erosion than on bare ground. This is explained by the presence of large drops from leafdrip which contribute more splash under maize as there is no near-surface cover.

Beans and intercrop on the other hand allow splash only from natural raindrops, since leafdrip cannot gain enough kinetic energy to be erosive as it traverses only a very short distance. Thus, splash on the exposed surfaces is similar to that on bare ground.

### 5.1.6 Rainfall intensity

Though rainfall intensity was the poorest erosivity factor. This was because rainfall intensity does not represent the characteristics of the entire storm. Thus, it does not account for that portion of the storm outside of duration of maximum intensity taken. Therefore, it underestimates the erosivity of the entire storm.

The maximum 45-minute intensity was the most highly correlated with splash detachment. This was rather different from the conventional maximum 30-minute intensity usually associated with runoff erosion. This longer duration can be attributed to the nature of rainstorms in this region which are on average of lower intensities and longer duration than in other tropical regions. The relationship of rainfall intensity with splash detachment was very similar to that of rainfall amount.

### 5.1.7 Rainfall energy

Rainfall kinetic energy, was found to correlate well with total splash detachment. For a storm of given kinetic energy, total splash increased from intercrop, beans, maize with bare fallow having the highest amount of splash. Therefore, total splash increased with decrease in crop cover. Splash per exposed surface area was highest under maize, and constant for the other treatments. The reasons for this are as explained for rainfall amount.

### 5.1.8 The $EI_{45}$ Index

The $EI_{45}$ erosivity index was a better estimator of splash detachment than rainfall intensity, but poorer than rainfall energy. Thus, though the EI-index is usually associated with runoff erosion, it is not an accurate index for assessing splash erosion. The plots of total and weighted splash with rainfall $EI_{45}$ index are curves rather than straight lines, but their relationship with the four treatments is similar to that of rainfall kinetic energy.

### 5.1.9 The $AI_{45}$ index

This was found to be the best erosivity factor, with $AI_{15}$, $AI_{30}$ and $AI_{45}$ being better than all the other erosivity indices. Since both $AI_{30}$ and $AI_{45}$ are equally highly correlated with splash, then both can be taken to be the actual predictors of splash erosion in this region. The plots of total and weighted splash with the AI-index are curves similar to those of the EI-index. Thus, for a given AI-value, total splash increases as crop cover decreases. Weighted splash is constant for beans, intercrop and bare, while it is higher for maize, for a given AI-value. Thus all the erosivity indices show that splash detachment under crop covers are related to rainfall characteristics in a very similar manner.

#### 5.1.10 Splash transport

The percent splash transport in the downslope direction was found to be independent of both the rainfall characteristics and the crop cover. In all the treatments, splash was found to be more downslope than upslope. Soil splash downslope was about seven times that occurring upslope on bare fallow land, while under maize crop, it was about six times. Under beans and intercrop, the proportion of soil splash downslope as compared to upslope was comparatively lower. Therefore, an increase in crop covers caused a reduction in the amount of soil splashed downslope, and consequently, total splash transport.

The amount of soil splashed downslope was well correlated with the percent crop cover but soil splash upslope was very poorly related to crop cover. For a given percent crop cover, soil splash downslope was more under maize followed by beans. Intercrop had the least soil for the same cover. Thus, the type of crop affects the amount of soil movement by splash downslope. Soil splash both upslope and downslope was found to be unrelated to crop height.

The amount of soil splashed downslope was found to increase with rainfall characteristics such as the $AI_{45}$ -index. For a given rainfall amount ($AI_{45}$) soil splash increased with reduction in crop cover. The amount of soil splashed upslope similarly increased with rainfall $AI_{45}$ values. Soil splash upslope on bare fallow was substantially more than that from all the cropped areas. This shows that crop cover reduces soil splash more effectively in the upslope direction.

## 5.2 Recommendations

### 5.2.1 Soil type

In order to evaluate the influence of soil type on splash detachment, specific studies on the soil are required, by comparing the test soil with others, e.g. sand whose splash characteristics are known.

Antecedent soil moisture is very important in soil erosion studies in order to remove variations between the treatments from consecutive storms. Though these factors were not assessed, they should be considered in future studies.

### 5.2.2 Rainfall distribution

In this study, soil splash was collected only once every 24 hours. Thus each splash event consisted of soil obtained from one or more storms during that period. The effect of each individual storm and its characteristics was therefore masked. Thus to improve the accuracy of predicting storm erosivities, splash should be collected after each individual storm , although this may be impractical especially at night.

### 5.2.3 Rainfall erosivities

Though soil splash correlated well with all the rainfall erosivities used in this study, the $AI_{45}$-index and the $AI_{30}$-index (the product of rainfall amount and its maximum 45 and 30-minute intensities respectively) were the best indicators of splash erosion. Thus, the AI-index can be used as the best erosivity index for splash erosion in this region.

### 5.2.4 Soil splash detachment

The differences in the splash amounts received in the traps placed perpendicular to the slope could not be explained due to lack of wind data. It is therefore important to include wind speed and direction as they are also major factors affecting not only the net splash transport, but also the rainfall characteristics of the particular storm.

Total soil splash was found to be quite substantial, even when runoff did not occur. Since during the short rains season (when rainfall intensities were lower) out of 18 splash producing storms, in only 2 was there runoff, then splash erosion contributes significantly to overall land degradation. Thus, measures that reduce splash erosion should be practised even when runoff is not expected.

### 5.2.5 Percent crop cover

It was observed that an increase in crop cover, reduces soil splash exponentially in the three crop types. Thus by allowing the establishment of crop covers, soil erosion is consequently reduced, first by the reduction in splash erosion. Also, for a given percent crop cover, more splash is obtained under maize than beans and intercrop during later stages of growth. Therefore, crops that have more cover per given height are to be preferred for controlling splash erosion.

### 5.2.6 Crop height

It was observed that the taller a crop grows (and hence the more the cover) the less is the soil splash. Also, short crops reduce soil splash more effectively than tall ones for a given height of crop. Therefore, short-growing crops, especially those with a spreading habit, are to be preferred to tall ones for the prevention of splash erosion.

### 5.2.7 Rainfall amount

Increases in rainfall amount results in higher splash regardless of crop type. Since for a given amount of rainfall, splash decreases with cover, then, soil splash can be reduced by increasing cover. Also, as rainfall amount was well correlated with soil splash, and since it is the easiest rainfall characteristic to measure, then rainfall amount can effectively be used as an index of splash erosion.

### 5.2.8 Rainfall intensity

Maximum rainfall intensities for specified durations were deduced from rainfall recording charts. Since this takes account of only part of the storm, poor correlation with splash results. This means that rainfall intensity alone is not a good estimator for splash erosion.

### 5.2.9 Rainfall energy

Rainfall kinetic energy was highly correlated with soil splash, thus it can be used as an index of splash erosion. Also, since splash per exposed area is higher under maize than under beans, intercrop or on bare ground, it shows that leafdrip from maize plants can gain enough kinetic energy and result in extra splash erosion. This confirms the necessity of short-growing crops to intercept raindrops and reduce their energy. Thus, intercropping maize and beans is preferred to growing maize as a pure stand as a method of reducing splash erosion.

### 5.2.10 The EI-index

The EI-index is universally recognised as a good estimator of runoff erosion. For splash erosion, it was found to be poorer than rainfall amount, energy or the AI-index. Thus, the EI-index is not a very accurate method of predicting splash erosion in this region.

### 5.2.11 The AI-index

The $AI_{45}$ and the $AI_{30}$ were equally the most highly correlated erosivity indices with splash detachment. Therefore, in this region, the $AI_{45}$-index, which was only slightly better than the $AI_{30}$-index is recommended as the best rainfall factor affecting splash erosion.

### 5.2.12 Splash transport

The amount of soil splashed downslope is about 7 times that splashed upslope on bare fallow land, while under maize, splash downslope is about 6 times that which goes upslope. Under beans and intercrop, this proportion is reduced to about 1-3. Therefore, crop cover reduces the amount of soil movement downslope especially beans and intercrop. Thus, an increase in cover is recommended as a method or controlling splash transport downslope. Also, the inclusion of short growing crops under tall ones such as with intercrop of maize and beans is recommended as being very effective in reducing net splash movement.

## 6.0 References

Adams, J.E. and G.R. Arkin. 1977. A light interception method for measuring row crop ground cover. Soil Sci. Soc. Am. J. 41:789-792.

Alberts, E.E., C.J. Genitzer and P.A. Remley. 1987. Influence of soybean and corn cropping on soil erodibility, splash and strength. Agronomy Abstracts. December, 1984

Al-Durrah, M.M. and J.M. Bradford. 1981. New methods of studying soil detachment due to waterdrop impact. Soil Sci. Soc. Am. J. 45:949-953.

Al-Durrah, M.M. and J.M. Bradford. 1982(a). Parameters for describing soil detachment due to single waterdrop impact. Soil Sci. Soc. Am. J. 46: 836-840.

Al-Durrah, M.M. and J.M. Bradford. 1982(b). The mechanism of raindrop splash on soil surfaces. Soil Sci. Soc. Am. J. 46: 1086-1090.

Amezquita, E. and W.M. Forsythe. 1985. Rainfall intensity, erosivity and erodibility in Turrialba, Costa Rica. In: Soil conservation and productivity. Pla Sentis, I. (ed). Proceedings of IV International Conference on Soil Conservation. Maracay, Venezuela. pp. 316-326.

Barber, R.G. 1983. The magnitude and sources of soil erosion in some humid and semi-arid parts of Kenya and the significance of soil loss tolerance values in soil conservation in Kenya. In: Proceedings of the 2nd soil and water conservation workshop. Thomas D.B. and Senga W.M. (eds). University of Nairobi. March 10-16 1982. Occasional Paper No. 42: 20-46.

Bauer, B. 1985. Contribution of splash to soil erosion by water. In: Soil erosion and productivity. Pla Sentis I. (ed). Proceedings of IV international conference on soil conservation. Maracay, Venezuela. Pp 82-83.

Black, C.A. 1965. Methods of soil analysis. Agronomy no. 9.

Bolline, A. 1980. Splash measurement in the field. In: Assessment of erosion. De Boodt, M. and D. Gabriels (eds). Proceedings of a workshop, Ghent, Belgium. Feb.27-Mar.3 1978. Pp 441-454.

Bubenzer, G.D. and B.D. Jones. 1971. Drop size and impact velocity effects on the detachment of soils under simulated rainfall. Trans. Amer. Soc. Agric. Engrs. 14(4):625-628.

Chapman, G. 1948. Size of raindrops and their striking forces at the soil surface in a red pine plantation. Trans. of the American Geophysical Union. 29:664-670.

De Wulf, F. and D. Gabriels. 1980. A device for analyzing the energy load of rainstorms. In: Assessment of soil erosion. De Boodt, M. and D. Gabriels (eds). Proceedings of a workshop, Ghent, Belgium. Feb. 27-Mar. 3rd 1978. John Wiley & Sons. Chichester, NY.

Ekern, P.C. 1950. Raindrop impact as the force initiating soil erosion. Soil Sci. Soc. Am. Proc. 15:7-10.

Ellwell, H.A. 1981. A soil loss estimation technique for Southern Africa. In: Soil Conservation Problems and Prospects. Morgan, R.P.C. (ed). John Wiley and Sons Chichester, New York. Pp. 281-292.

Elwell, H.A. and M.A. Stocking. 1973. Rainfall parameter for soil loss estimation in a subtropical climate. J. Agric. Eng. Res. 18:169-177.

Epema, G.R. and H.T. Riezebos. 1983. Fall velocity of waterdrops at different heights as a factor influencing erosivity of simulated rain. In: rainfall simulation, runoff and soil erosion. De Ploey, J. (ed). Catena Supplement 4:19-33.

Farmer, E.E. 1973. Relative detachability of soil particles by simulated rainfall. Soil Sci. Soc. Am. Proc. 37:629-633.

Finney, H.J. 1984. The effect of crop covers on rainfall characteristics and splash detachment. Journal of Agric. Eng. Res. 29:337-343.

Gachene C.K.K. 1989. Soils of the erosion research farm. Kabete campus, Department of Agricultural Engineering, University of Nairobi.

Gantzer, C.J., G.A. Buyanovsky, E.E. Alberts and P.A. Remley. 1987. Effects of soybean and corn residue decomposition on soil strength and splash detachment. Soil Sci. Soc. Am. J. 51(1):202-206.

Ghadiri, H. and D. Payne. 1977. Raindrop impact stress and the breakdown of soil crumbs. J. Soil Sci. 28:247-258.

Ghadiri, H. and D. Payne. 1980. A study of soil splash using cine-photography. In: Assessment of soil erosion. De Boodt, M. and D. Gabriels (eds). Proceedings of a workshop, Ghent, Belgium. 27th Feb.-3rd Mar.1978. John Wiley & Sons. pp.185-192.

Ghadiri, H. and D. Payne. 1985. Mechanism of crater formation by raindrop impact. In: Soil erosion and productivity. Pla Sentis I. (ed). Proceedings of the IV International conference on soil conservation. Maracay, Venezuela. pp.59-81.

Gregory, J.M. 1980. Consideration of force components of raindrops in the detachment of soil. In: Assessment of erosion. De Booodt, M. and D. Gabriels (eds). Proceedings of a workshop, Ghent, Belgium. 27th Feb.-3rd Mar. 1978. John Wiley & Sons. pp.485-494.

Hall, M.J. 1970. Use of the stain method in determining the drop size distributions of coarse liquid sprays. Trans. Amer. Soc. Agric. Engrs. 30:33-37,41.

Huang, C., J.M. Bradford and J.H. Cushman. 1982. A numerical study of raindrop impact phenomena: The rigid case. Soil Sci. Soc. Am. J. 46(1): 14-19.

Hudson, N. 1981. Soil conservation. Batsford Academic and Educational. London.

Kerenyi, A. 1981. A study of the dynamics of drop erosion under laboratory conditions. Proceedings of a symposium. IAHS-AISH Publication no.133: 365-372.

Kilewe, A.M. 1987. Prediction of erosion rates and the effects of topsoil thickness on soil productivity. Unpublished PHD thesis. Department of Soil Science, University of Nairobi.

Lal, R. 1981. Analysis of different processes governing soil erosion by water in the tropics. In: Erosion and sediment transport measurement. Proceedings of a symposium. Florence, Italy. June 22-26, 1981. IAHS-AISH Publication no. 133: 351-364.

Lal, R. 1988. Erodibility and erosivity. In: Soil erosion research methods. Lal R. (ed). Soil and Water Conservation Society. pp.141-160.

Lal, R., T.L. Lawson and A.N. Anastase. 1980. Erosivity of tropical rains. In: Assessment of erosion. De Boodt, M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. 27th Feb.-3rd Mar.1978. John Wiley & Sons. pp.143-151.

Lewis L.A. 1983. Land degradation monitoring programme of the National Environment and Human Settlements Secretariat. Ministry of Environment and Natural Resources. Kiambu District, Kenya. First pilot study.

Lo, A., S.A. El-Swaify, E.W. Dangler and L. Shinshiro. 1985. Effectiveness of the $EI_{30}$ as an erosivity index in Hawaii. In: Soil erosion and conservation. El-Swaify, S.A., W.C. Moldenhauer and A. Lo (eds). Proceedings of a conference. Hawaii, U.S.A. Jan.16-22 1983. pp.384-391.

Lyles, L., L.A. Disrud and N.P. Woodruff. 1969. Effects of soil physical properties, rainfall characteristics and wind velocity on clod disintegration by simulated rainfall. Soil Sci. Soc. Am. Proc. 33: 302-306.

Meyer, L.D. and W.H.Wischmeier. 1969. Mathematical simulation of the process of soil erosion by water. Trans. Amer.Soc. Agric. Engrs. 12(6): 754-758,762.

Miller, I. and J.E. Freud. 1985. Probability and statistics for engineers and scientists. Prentice/Hall International Inc. New Jersey. Third edition.

Moeyerson, J. 1983. Measurements of splash saltation fluxes under oblique rain. In: Rainfall simulation, runoff and soil erosion. Jan de Ploey (ed). Catena Supplement No. 4: 33-57.

Moldenhauer, W.C. and W.D. Kemper. 1969. Interdependence of waterdrop energy and clod size on infiltration and clod stability. Soil Sci. Soc. Am. Proc. 32(2): 297-301.

Moldenhauer, W.C. and J. Koswara. 1968. Effect of initial clod size on characteristics of splash and water erosion. Soil Sci. Soc. Am. Proc. 32: 875-879.

Morgan, R.P.C. 1981. Field measurement of splash erosion. In: Erosion and sediment transport measurement. Proceedings of a symposium. Florence, Italy. June 22-26 1981. IAHS-AISH Publication no.133: 373-382.

Morgan, R.P.C. 1982. Splash detachment under plant covers: Results and implications of a field study. Trans. Amer. Soc. Agric. Engrs. 25:987-991.

Morgan, R.P.C. 1985(a). Effect of corn and soybean canopy on soil detachment by rainfall. Trans. Amer. Soc. Agric. Engrs. 28(4): 1135-1140.

Morgan, R.P.C. 1985(b). Establishment of plant cover parameters for modelling splash detachment. In: Soil erosion and conservation. El-Swaify S.A., W.C. Moldenhauer and A. Lo (eds). Proceedings of a conference. Honolulu, Hawaii. Jan.16-22 1983. Soil Conservation Society of America. pp.377-383.

Morgan, R.P.C. 1986. Soil erosion and conservation. Longman Scientific and Technical. John Wiley & Sons. New York.

Nearing, M.A. and J.M. Bradford. 1987. Relationships between waterdrop properties and forces of impact. Soil Sci. Soc. Am. J. 51: 425-430.

Nearing, M.A., J.M. Bradford and R.D. Holtz. 1987. Measurement of waterdrop impact pressures on soil surfaces. Soil Sci. Soc. Am. J. 51(5): 1302-1306.

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

Omwega, A.K. 1989. Crop cover, rainfall energy and soil erosion in Githunguri (Kiambu District), Kenya. PHD thesis. University of Manchester.

Ogweny, G.S. 1978. Problems of soil and water conservation within the upper Tana catchment. In: Soil and Water Conservation in Kenya. Report of a workshop. University of Nairobi. Sept.21-23 1977. IDS Occasional Paper no.27: 87-91.

Othieno, C.O. and D.H. Laycock. 1977. Factors affecting soil erosion within tea fields. Tropical Agriculture. 54(4): 323-330.

Park, S.W., J.K. Mitchell and G.D. Bubenzer. 1982. Splash erosion modelling; Physical analysis. Trans. Amer. Soc. Agric. Engrs. 25: 357-371.

Poessen J. and J. Savat. 1980. Particle size separation during erosion by splash and runoff. In: Assessment of erosion. De Boodt M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. Feb.27th-Mar.3rd 1978. John Wiley & Sons. pp.427-439.

Quansah, C. 1981. The effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. J. of Soil Sci. 32: 215-224.

Reid, L.M. 1983. A reconnaissance survey of erosion processes in Machakos district. In: Soil and water conservation in Kenya. Proceedings of a second national workshop. Nairobi. Mar.10-13, 1982. pp.105-122.

Riezebos, H.T. and G.F. Epema. 1985. Drop shape and erosivity. Part II: Splash detachment and erosivity indices. Earth surface processes and landforms. 10: 69-74.

Roose E.J. 1980. Approach to the definition of rain erosivity in West Africa. In: Assessment of erosion. De Boodt M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. Feb.27th-Mar.3rd 1978. pp. 154-164.

Rose, C.W. 1960. Soil detachment caused by rainfall. Soil Science. 89: 28-34.

Schwab, G.O., R.K. Frevert, T.W.Edminster and K.K. Barnes. 1971. Soil and Water conservation Engineering. 3rd edition. John Wiley & Sons. New York.

Shaxson, T.F. 1980. Reconciling social and technical needs in conservation work on village farmlands. In: Soil Conservation Problems and Prospects. Morgan, R.P.C. (ed). Wiley, Chichester, U.K. Pp. 385-397.

Slonecker L.L. and W.C. Moldenhauer. 1977. Measuring the amounts of crop residue remaining after tillage. J. of Soil and Water Conservation. 22: 231-238.

Sombroek, W.G., H.M.H. Braun and B.J.A. Van der Pouw. 1980. The exploratory soil map and agro-climatic zone map of Kenya. Report no. E1; Kenya Soil Survey, Nairobi.

Stocking, M.A. 1988. Assessing vegetative cover and management effects. In: Soil erosion research methods. Lal, R. (ed). Soil and Water Conservation Society. Wegeningen, The Netherlands. Pp.163-185.

Styczen, M. and K. Hogh-Schimdt. 1988. A new description of splash erosion in relation to raindrop sizes and vegetation. In: Erosion assessment and modelling. Morgan, R.P.C. and R.J. Rickson (eds). Report EUR 10860 EN. Commission of the European Communities. Luxemberg. Pp.147-184.

Tefera, F. 1983. The effect of narrow grass strips in controlling soil erosion and runoff on sloping land. Unpublished MSC. thesis. Department of Agricultural Engineering, University of Nairobi.

Ulsaker, L.G. and A.M. Kilewe. 1984. Runoff and soil erosion for an alfisol in Kenya. East African Agricultural and Forestry Journal. Special Issue no. 44: 210-241.

Ulsaker, L.G. and C.A. Onstad. 1984. Relating erosivity factors to soil loss in Kenya. Soil Sci. Soc. Am. J. 48: 891-896.

United States Department of Agriculture. 1978. Predicting rainfall erosion losses. A guide to conservation planning. Agriculture Handbook no. 537.

Wischmeier, W.H. and J.V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Amer. Proc. 33(1): 131-137

Wischmeier, W.H. and D.D. Smith. 1958. Rainfall energy and its relationship to soil loss. Transactions of the American Geophysical Union. 39(2): 285-291.

Wischmeier, W.H., C.B. Johnson and B.V. Cross. 1971. A soil erodibility nomograph for farmland and construction sites. J. of Soil and Water Conservation. 26:189-193

Yamamoto, T. and H.W. Anderson. 1973. Splash erosion related to soil erodibility indexes and other forest soil properties in Hawaii. Water Resources Research. 9: 336-345.

Young, R.A. and J.L. Wiersma. 1973. The role of rainfall impact in soil detachment and transport. Water Resources Research. 9: 1629-1636.

Zanchi, C. and D. Torri. 1980. Evaluation of rainfall energy in Central Italy. In: Assessment of erosion. De Boodt M. and D. Gabriels (eds). Proceedings of a workshop. Ghent, Belgium. Feb.27th-Mar.3rd 1978. Pp. 133-142.

Appendix 1

Plates

Plate 1. Maize crop showing splash traps

Plate 2. Beans crop plot.

Plate 3. Intercrop (maize and beans) plot

Plate 4. Bare fallow plot

Plate 5. Measuring crop cover using the simple sighting frame.

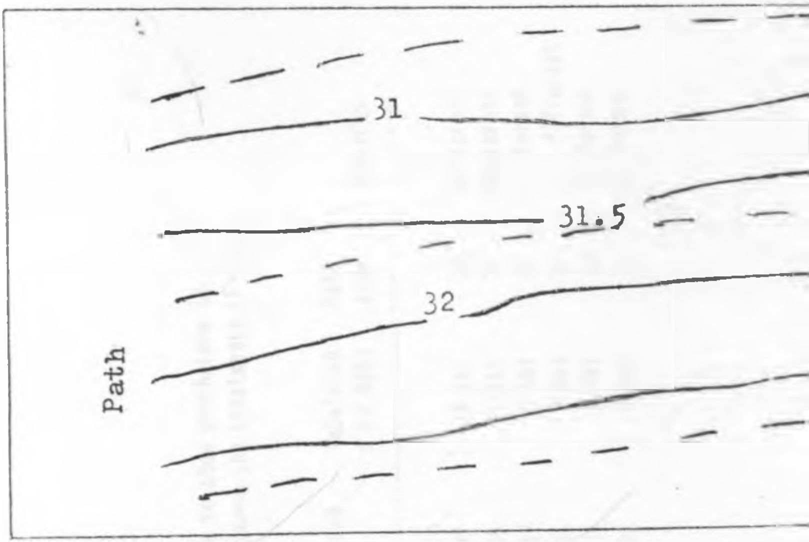
Plate 6. Measuring crop height with a steel tape

Plate 7. Splash trap showing the trapped soil on the filter paper.


Plate 8. Soil obtained from downslope facing (soil splashed upslope) and Upslope facing (soil splashed downslope) traps.

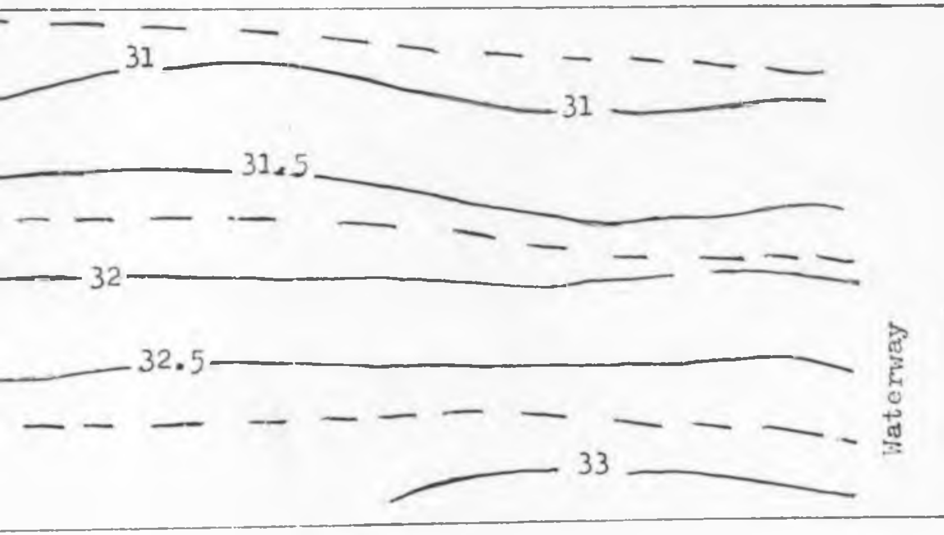
## Appendix 2

**Contour map of the research site**




NOTE

1. All contour values add 1910
2. Terrace banks denoted by — — —




CONTOUR MAP FOR RESEARCH SITE
"SOIL SPLASH EXPERIMENT"

SCALE 1:100

APPENDIX 3

Table 7.1

Analysis of variance tests to show whetherere is a significant difference between the treatments (F-te).

| Treatment combination | Calculated F-value | Tabulated F (0.005) | Data size | Remarks |
|---|---|---|---|---|
| Maize & beans | 12.397 | 4.161 | 32 | Different |
| Maize & intercrop | 17.695 | 4.161 | 32 | Different |
| Maize & bare | 7.749 | 4.161 | 32 | Different |
| Beans & intercrop | 3.131 | 4.161 | 32 | Not different |
| Beans & bare | 15.07 | 4.161 | 32 | Different |
| Intercrop & bare | 12.731 | 4.161 | 32 | Different |

Appendix 4

Table 7.2

Rainfall characteristics during both seasons.

| Total Rain (mm) | E | I-45 | EI-45 | AI-45 | Total splash (Bare fallow) |
|---|---|---|---|---|---|
| 4.0 | 63.7 | 6.0 | 382.4 | 24.0 | 2.4 |
| 4.8 | 82.9 | 4.0 | 331.4 | 19.2 | 1.1 |
| 5.1 | 100.3 | 4.0 | 401.2 | 20.4 | 2.4 |
| 5.2 | 84.3 | 3.7 | 311.8 | 19.2 | 5.9 |
| 5.3 | 261.4 | 11.3 | 2953.5 | 59.9 | 5.4 |
| 6.2 | 116.0 | 6.7 | 777.4 | 41.5 | 3.7 |
| 6.4 | 110.0 | 4.0 | 440.0 | 25.6 | 5.6 |
| 6.9 | 147.1 | 8.7 | 1279.6 | 60.0 | 12.6 |
| 7.0 | 121.7 | 3.3 | 401.5 | 23.1 | 1.3 |
| 8.0 | 151.2 | 6.1 | 922.5 | 48.8 | 10.7 |
| 8.0 | 184.9 | 10.7 | 1978.8 | 85.6 | 7.8 |
| 8.1 | 145.9 | 6.9 | 1006.6 | 55.9 | 12.5 |
| 8.7 | 172.8 | 6.9 | 1192.6 | 60.0 | 12.3 |
| 9.9 | 170.6 | 6.7 | 1143.0 | 66.3 | 5.8 |
| 10.0 | 183.2 | 6.0 | 1099.3 | 60.0 | 6.5 |
| 12.1 | 206.6 | 4.0 | 826.3 | 48.4 | 10.9 |
| 13.0 | 214.7 | 8.7 | 1868.0 | 113.1 | 10.1 |
| 13.2 | 247.1 | 9.1 | 2248.7 | 120.1 | 11.7 |
| 14.0 | 213.2 | 2.7 | 575.7 | 37.8 | 10.2 |
| 14.0 | 263.9 | 6.7 | 1768.1 | 93.8 | 8.4 |
| 14.9 | 294.9 | 9.3 | 2742.3 | 138.6 | 7.6 |
| 15.0 | 254.6 | 6.7 | 1705.6 | 100.5 | 8.0 |
| 15.2 | 271.5 | 7.3 | 1981.7 | 111.0 | 66.8 |
| 20.5 | 374.6 | 5.3 | 1985.2 | 108.7 | 12.9 |
| 22.2 | 395.0 | 8.7 | 3436.1 | 193.1 | 11.0 |
| 22.4 | 391.0 | 9.6 | 3754.0 | 215.0 | 19.3 |
| 25.0 | 546.1 | 12.0 | 6552.6 | 300.0 | 16.3 |
| 29.2 | 586.5 | 15.3 | 8972.7 | 446.8 | 49.5 |
| 31.7 | 686.4 | 18.7 | 12836.1 | 592.8 | 63.0 |
| 37.2 | 663.9 | 30.7 | 20382.3 | 1142.0 | 29.9 |
| 48.4 | 838.6 | 5.3 | 4444.7 | 256.5 | 27.0 |
| 51.3 | 1093.7 | 22.7 | 24827.0 | 1164.5 | 61.6 |

Table 7.3

Values of rainfall amount, total splash and weighted splash obtained in the study.

| Rainfall amount mm | Total soil splash (g) | | | | Weighted splash (g/bare space) | | |
|---|---|---|---|---|---|---|---|
| | Maize | Beans | Intercrop | Bare | Maize | Beans | Intercrop |
| 4.0 | 2.18 | 1.43 | 1.53 | 2.44 | 3.30 | 3.49 | 3.64 |
| 4.8 | 0.68 | 0.44 | 0.38 | 1.08 | 1.45 | 2.00 | 1.52 |
| 5.1 | 3.29 | 2.89 | 2.22 | 2.43 | 5.48 | 7.41 | 5.84 |
| 5.2 | 4.96 | 4.91 | 3.48 | 5.92 | 4.96 | 4.91 | 3.48 |
| 5.3 | 6.00 | 5.53 | 5.30 | 5.38 | 6.00 | 5.53 | 5.30 |
| 6.2 | 3.15 | 2.59 | 1.05 | 3.65 | 5.08 | 4.54 | 2.69 |
| 6.4 | 5.85 | 4.50 | 5.73 | 5.58 | 5.85 | 4.50 | 5.73 |
| 6.9 | 5.60 | 4.70 | 1.52 | 12.58 | 13.02 | 15.67 | 4.90 |
| 7.0 | 1.08 | 0.39 | 0.26 | 1.31 | 2.16 | 1.34 | 1.53 |
| 8.0 | 8.71 | 5.31 | 4.79 | 10.66 | 10.13 | 12.95 | 11.40 |
| 8.0 | 7.17 | 7.43 | 7.68 | 7.81 | 10.86 | 10.32 | 11.46 |
| 8.1 | 5.07 | 4.20 | 3.93 | 12.45 | 13.70 | 16.80 | 15.72 |
| 8.7 | 4.10 | 5.10 | 2.70 | 12.30 | 8.20 | 10.85 | 7.71 |
| 9.9 | 3.63 | 3.50 | 2.58 | 5.78 | 6.05 | 6.36 | 6.79 |
| 10.0 | 7.76 | 3.33 | 4.04 | 6.46 | 9.95 | 5.46 | 6.22 |
| 12.1 | 8.99 | 3.33 | 3.21 | 10.93 | 20.91 | 13.88 | 14.59 |
| 13.0 | 10.03 | 7.72 | 10.63 | 10.13 | 11.27 | 7.72 | 10.63 |
| 13.2 | 11.81 | 9.44 | 8.85 | 11.69 | 13.73 | 13.11 | 13.21 |
| 14.0 | 9.91 | 8.33 | 7.75 | 10.22 | 11.01 | 10.41 | 10.78 |
| 14.0 | 8.43 | 4.64 | 6.06 | 8.44 | 10.81 | 7.61 | 9.32 |
| 14.9 | 6.48 | 7.10 | 4.38 | 7.60 | 15.80 | 25.36 | 15.64 |
| 15.0 | 8.63 | 8.76 | 8.86 | 7.96 | 10.03 | 12.17 | 13.22 |
| 15.2 | 65.51 | 54.69 | 65.35 | 66.82 | 65.51 | 54.69 | 65.35 |
| 20.5 | 6.67 | 7.05 | 2.83 | 12.85 | 12.13 | 14.39 | 8.09 |
| 22.2 | 11.10 | 11.16 | 9.38 | 10.97 | 17.08 | 15.50 | 19.54 |
| 22.4 | 11.13 | 10.80 | 8.85 | 19.33 | 19.88 | 21.18 | 24.58 |
| 25.0 | 10.63 | 6.56 | 4.83 | 16.25 | 21.26 | 22.62 | 28.41 |
| 29.2 | 45.31 | 34.12 | 28.86 | 49.54 | 50.34 | 42.65 | 40.08 |
| 31.7 | 24.37 | 18.20 | 6.33 | 63.00 | 51.85 | 43.33 | 19.18 |
| 37.2 | 28.00 | 18.00 | 19.25 | 29.88 | 43.75 | 27.27 | 42.78 |
| 48.4 | 21.70 | 21.23 | 17.40 | 26.95 | 30.56 | 23.59 | 25.97 |
| 51.3 | 42.77 | 45.53 | 27.18 | 61.60 | 67.89 | 73.44 | 64.71 |

Table 7.4

Values of rainfall amount, percent crop cover and total soil splash obtained.

| Rainfall amount mm | Percent crop cover Maize | Beans | Intercrop | Total soil splash (g) Maize | Beans | Intercrop |
|---|---|---|---|---|---|---|
| 4.0 | 34 | 59 | 58 | 2.18 | 1.43 | 1.53 |
| 4.8 | 53 | 78 | 75 | 0.68 | 0.44 | 0.38 |
| 5.1 | 40 | 61 | 62 | 3.29 | 2.89 | 2.22 |
| 5.2 | 0 | 0 | 0 | 4.96 | 4.91 | 3.48 |
| 5.3 | 0 | 0 | 0 | 6.00 | 5.53 | 5.30 |
| 6.2 | 38 | 43 | 61 | 3.15 | 2.59 | 1.05 |
| 6.4 | 0 | 0 | 0 | 5.85 | 4.50 | 5.73 |
| 6.9 | 57 | 70 | 69 | 5.60 | 4.70 | 1.52 |
| 7.0 | 50 | 71 | 83 | 1.08 | 0.39 | 0.26 |
| 8.0 | 14 | 59 | 58 | 8.71 | 5.31 | 4.79 |
| 8.0 | 34 | 28 | 33 | 7.17 | 7.43 | 7.68 |
| 8.1 | 63 | 75 | 75 | 5.07 | 4.20 | 3.93 |
| 8.7 | 50 | 53 | 65 | 4.10 | 5.10 | 2.70 |
| 9.9 | 40 | 45 | 62 | 3.63 | 3.50 | 2.58 |
| 10.0 | 22 | 39 | 35 | 7.76 | 3.33 | 4.04 |
| 12.1 | 57 | 76 | 78 | 8.99 | 3.33 | 3.21 |
| 13.0 | 11 | 0 | 0 | 10.03 | 7.72 | 10.63 |
| 13.2 | 14 | 28 | 33 | 11.81 | 9.44 | 8.85 |
| 14.0 | 10 | 20 | 28 | 9.91 | 8.33 | 7.76 |
| 14.0 | 22 | 39 | 35 | 8.43 | 4.64 | 6.06 |
| 14.9 | 59 | 72 | 72 | 6.48 | 7.10 | 4.38 |
| 15.0 | 14 | 28 | 33 | 8.63 | 8.76 | 8.86 |
| 15.2 | 0 | 0 | 0 | 65.51 | 54.69 | 65.35 |
| 20.5 | 45 | 51 | 65 | 6.67 | 7.05 | 2.83 |
| 22.2 | 35 | 28 | 52 | 11.10 | 11.16 | 9.38 |
| 22.4 | 44 | 49 | 64 | 11.13 | 10.80 | 8.85 |
| 25.0 | 50 | 71 | 83 | 10.63 | 6.56 | 4.83 |
| 29.2 | 10 | 20 | 28 | 45.31 | 34.12 | 28.86 |
| 31.7 | 53 | 58 | 67 | 24.37 | 18.20 | 6.33 |
| 37.2 | 36 | 34 | 55 | 28.00 | 18.00 | 19.25 |
| 48.4 | 29 | 10 | 33 | 21.70 | 21.23 | 17.40 |
| 51.3 | 37 | 38 | 58 | 42.77 | 45.53 | 27.18 |

Table 7.5

Values of rainfall amount, crop height and total soil splash obtained.

| Rainfall amount mm | Crop height (cm) | | | Total soil splash (g) | | |
|---|---|---|---|---|---|---|
| | Maize | Beans | Intercrop | Maize | Beans | Intercrop |
| 4.0 | 50.3 | 29.2 | 48.0 | 2.18 | 1.43 | 1.53 |
| 4.8 | 129.0 | 46.5 | 117.8 | 0.68 | 0.44 | 0.38 |
| 5.1 | 63.8 | 32.9 | 62.0 | 3.29 | 2.89 | 2.22 |
| 5.2 | 0.0 | 0.0 | 0.0 | 4.96 | 4.91 | 3.48 |
| 5.3 | 0.0 | 0.0 | 0.0 | 6.00 | 5.53 | 5.30 |
| 6.2 | 101.3 | 19.7 | 97.0 | 3.15 | 2.59 | 1.05 |
| 6.4 | 0.0 | 0.0 | 0.0 | 5.85 | 4.50 | 5.73 |
| 6.9 | 148.2 | 37.2 | 146.8 | 5.60 | 4.70 | 1.52 |
| 7.0 | 91.3 | 42.8 | 77.8 | 1.08 | 0.39 | 0.26 |
| 8.0 | 23.3 | 29.2 | 48.0 | 8.71 | 5.31 | 4.79 |
| 8.0 | 50.3 | 12.6 | 24.2 | 7.17 | 7.43 | 7.68 |
| 8.1 | 200.3 | 45.3 | 208.5 | 5.07 | 4.20 | 3.93 |
| 8.7 | 124.4 | 30.6 | 115.1 | 4.10 | 5.10 | 2.70 |
| 9.9 | 104.6 | 21.3 | 99.6 | 3.63 | 3.50 | 2.58 |
| 10.0 | 33.3 | 17.1 | 35.6 | 7.76 | 3.33 | 4.04 |
| 12.1 | 198.6 | 40.4 | 145.0 | 8.99 | 3.33 | 3.21 |
| 13.0 | 0.0 | 0.0 | 0.0 | 10.03 | 7.72 | 10.63 |
| 13.2 | 23.3 | 12.6 | 24.2 | 11.81 | 9.44 | 8.85 |
| 14.0 | 17.8 | 10.8 | 19.7 | 9.91 | 8.33 | 7.76 |
| 14.0 | 33.3 | 17.1 | 35.6 | 8.43 | 4.64 | 6.06 |
| 14.9 | 156.2 | 39.4 | 157.4 | 6.48 | 7.10 | 4.38 |
| 15.0 | 23.3 | 12.6 | 24.2 | 8.63 | 8.76 | 8.86 |
| 15.2 | 0.0 | 0.0 | 0.0 | 65.51 | 54.69 | 65.35 |
| 20.5 | 117.8 | 27.6 | 110.0 | 6.67 | 7.05 | 2.83 |
| 22.2 | 62.8 | 14.9 | 65.2 | 11.10 | 11.16 | 9.38 |
| 22.4 | 114.5 | 26.0 | 107.4 | 11.13 | 10.80 | 8.85 |
| 25.0 | 91.3 | 42.8 | 77.8 | 10.63 | 6.56 | 4.83 |
| 29.2 | 17.8 | 10.8 | 19.7 | 45.31 | 34.12 | 28.86 |
| 31.7 | 132.3 | 32.8 | 125.7 | 24.37 | 18.20 | 6.33 |
| 37.2 | 75.6 | 16.5 | 74.5 | 28.00 | 18.00 | 19.25 |
| 48.4 | 40.6 | 6.8 | 40.4 | 21.70 | 21.23 | 17.40 |
| 51.3 | 89.4 | 18.1 | 85.8 | 42.77 | 45.53 | 27.18 |

Table 7.6

Values of average soil splash downslope (D) and upslope (U) for all the treatments, with the rainfall amount and the AI-45 index.

| | | Soil splash amounts (g) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall | | MAIZE | | BEANS | | INTERCROP | | BARE | |
| amount mm | AI-45 | D | U | D | U | D | U | D | U |
| 4.0 | 24.0 | 0.90 | 0.28 | 0.80 | 0.03 | 0.60 | 0.20 | 0.98 | 0.33 |
| 4.8 | 19.2 | 0.38 | 0.03 | 0.13 | 0.00 | 0.13 | 0.00 | 0.40 | 0.00 |
| 5.1 | 20.4 | 1.48 | 0.45 | 0.88 | 0.33 | 0.68 | 0.28 | 0.90 | 0.45 |
| 5.2 | 19.2 | 1.74 | 0.40 | 2.70 | 0.20 | 2.65 | 0.10 | 4.48 | 0.18 |
| 5.3 | 59.9 | 3.00 | 0.23 | 2.70 | 0.50 | 1.63 | 0.23 | 3.00 | 0.45 |
| 6.2 | 41.5 | 2.13 | 0.00 | 1.53 | 0.00 | 0.45 | 0.00 | 1.83 | 0.13 |
| 6.4 | 25.6 | 3.27 | 0.10 | 2.57 | 0.33 | 3.60 | 1.63 | 3.38 | 0.28 |
| 6.9 | 60.0 | 3.43 | 0.07 | 2.73 | 0.80 | 0.63 | 0.00 | 5.65 | 0.58 |
| 7.0 | 23.1 | 0.70 | 0.03 | 0.13 | 0.00 | 0.08 | 0.00 | 0.88 | 0.00 |
| 8.0 | 48.8 | 2.48 | 1.50 | 2.90 | 0.93 | 1.90 | 1.43 | 2.53 | 1.93 |
| 8.0 | 85.6 | 2.83 | 0.63 | 2.25 | 0.55 | 1.63 | 0.38 | 3.70 | 0.43 |
| 8.1 | 55.9 | 2.37 | 0.37 | 1.97 | 0.70 | 0.78 | 0.28 | 5.35 | 1.03 |
| 8.7 | 60.0 | 1.57 | 0.23 | 2.43 | 0.00 | 0.80 | 0.20 | 5.83 | 0.40 |
| 9.9 | 66.3 | 2.07 | 0.40 | 1.57 | 0.27 | 0.70 | 0.20 | 1.88 | 0.95 |
| 10.0 | 60.0 | 3.58 | 0.25 | 1.95 | 0.15 | 1.38 | 0.03 | 3.25 | 0.13 |
| 12.1 | 48.4 | 3.70 | 0.68 | 1.20 | 0.40 | 0.80 | 0.28 | 4.85 | 0.80 |
| 13.0 | 113.1 | 5.83 | 0.10 | 4.43 | 0.23 | 6.08 | 0.20 | 5.30 | 0.28 |
| 13.2 | 120.1 | 4.75 | 1.33 | 3.60 | 1.23 | 2.85 | 1.25 | 4.48 | 1.28 |
| 14.0 | 37.8 | 3.38 | 0.75 | 1.88 | 0.55 | 1.80 | 0.33 | 3.25 | 1.23 |
| 14.0 | 93.8 | 3.76 | 1.91 | 3.50 | 0.86 | 2.78 | 0.94 | 3.71 | 1.12 |
| 14.9 | 138.6 | 2.85 | 0.33 | 2.50 | 0.37 | 1.30 | 0.10 | 3.40 | 0.38 |
| 15.0 | 100.5 | 4.05 | 0.48 | 4.40 | 0.35 | 3.18 | 0.40 | 3.43 | 0.43 |
| 15.2 | 111.0 | 30.98 | 4.61 | 28.25 | 1.95 | 31.32 | 2.93 | 31.46 | 3.10 |
| 20.5 | 108.7 | 3.27 | 0.43 | 3.83 | 0.87 | 1.03 | 0.33 | 5.28 | 1.05 |
| 22.2 | 193.1 | 7.30 | 0.23 | 7.00 | 0.23 | 5.40 | 0.85 | 6.67 | 0.30 |
| 22.4 | 215.0 | 5.13 | 0.93 | 7.20 | 0.83 | 3.10 | 1.20 | 8.10 | 1.85 |
| 25.0 | 300.0 | 5.05 | 1.00 | 2.58 | 0.90 | 1.08 | 0.65 | 8.50 | 0.85 |
| 29.2 | 446.8 | 20.39 | 3.02 | 15.68 | 2.03 | 11.11 | 2.02 | 19.09 | 3.29 |
| 31.7 | 592.8 | 12.93 | 0.93 | 7.93 | 0.60 | 2.70 | 0.25 | 32.97 | 3.35 |
| 37.2 | 1142.0 | 15.30 | 0.50 | 10.23 | 0.33 | 7.20 | 2.18 | 15.70 | 0.65 |
| 48.4 | 256.5 | 10.60 | 0.90 | 10.70 | 2.80 | 8.98 | 0.85 | 12.68 | 2.08 |
| 51.3 | 1164.5 | 23.97 | 1.13 | 21.73 | 1.37 | 11.63 | 1.48 | 29.60 | 4.60 |

Table 7.7

Percent splash transport downslope, rainfall amount and percent crop cover for each treatment.

| Rainfall (mm) | Crop cover (%) | | | Splash transport downslope (%) | | | |
|---|---|---|---|---|---|---|---|
| | Maize | Beans | Intercrop | Maize | Beans | Intercrop | Bare |
| 4.0 | 34 | 59 | 58 | 53 | 93 | 50 | 50 |
| 4.8 | 53 | 78 | 75 | 85 | 100 | 100 | 100 |
| 5.1 | 40 | 61 | 62 | 53 | 45 | 42 | 33 |
| 5.2 | 0 | 0 | 0 | 63 | 86 | 93 | 92 |
| 5.3 | 0 | 0 | 0 | 86 | 69 | 77 | 74 |
| 6.2 | 38 | 43 | 61 | 100 | 100 | 100 | 87 |
| 6.4 | 0 | 0 | 0 | 94 | 77 | 11 | 85 |
| 6.9 | 57 | 70 | 69 | 96 | 55 | 100 | 81 |
| 7.0 | 50 | 71 | 83 | 92 | 100 | 100 | 100 |
| 8.0 | 14 | 59 | 58 | 25 | 51 | 14 | 13 |
| 8.0 | 34 | 28 | 33 | 64 | 61 | 62 | 79 |
| 8.1 | 63 | 75 | 75 | 73 | 48 | 47 | 68 |
| 8.7 | 50 | 53 | 65 | 74 | 100 | 60 | 87 |
| 9.9 | 40 | 45 | 62 | 68 | 71 | 56 | 33 |
| 10.0 | 22 | 39 | 35 | 87 | 86 | 96 | 92 |
| 12.1 | 57 | 76 | 78 | 69 | 50 | 48 | 72 |
| 13.0 | 11 | 0 | 0 | 97 | 90 | 94 | 90 |
| 13.2 | 14 | 28 | 33 | 56 | 49 | 39 | 56 |
| 14.0 | 10 | 20 | 28 | 64 | 55 | 69 | 45 |
| 14.0 | 22 | 39 | 35 | 33 | 61 | 49 | 54 |
| 14.9 | 59 | 72 | 72 | 79 | 74 | 86 | 80 |
| 15.0 | 14 | 28 | 33 | 79 | 85 | 78 | 78 |
| 15.2 | 0 | 0 | 0 | 74 | 87 | 83 | 82 |
| 20.5 | 45 | 51 | 65 | 77 | 63 | 51 | 67 |
| 22.2 | 35 | 28 | 52 | 94 | 94 | 73 | 91 |
| 22.4 | 44 | 49 | 64 | 69 | 79 | 44 | 63 |
| 25.0 | 50 | 71 | 83 | 67 | 48 | 25 | 82 |
| 29.2 | 10 | 20 | 28 | 74 | 77 | 69 | 71 |
| 31.7 | 53 | 58 | 67 | 87 | 86 | 83 | 82 |
| 37.2 | 36 | 34 | 55 | 94 | 94 | 54 | 92 |
| 48.4 | 29 | 10 | 33 | 84 | 59 | 83 | 72 |
| 51.3 | 37 | 38 | 58 | 91 | 88 | 77 | 73 |