COMPARATIVE EVALUATION OF DIFFERENT TECHNIQUES FOR SOIL EROSION ASSESSMENT IN FIELD PLOTS

By

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DECLARATION

I, Peter W. Mtakwa, hereby declare to Senate of the Sokoine University of Agriculture that this dissertation is my own original work and has not been submitted for a degree in any other University.

PMtakwa
Signature

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ABSTRACT

Four techniques for assessing soil erosion were comparatively evaluated in field plots in bare - fallow as well as in plots under a maize - cowpea sequence for two consecutive seasons in 1985 at IITA, Ibadan, Nigeria. The techniques assessed were: Tracer, (Aluminium Paint), Nails (16 and 25 nails per plot), Rill and Universal soil loss equation (USLE) technique. Soil loss determined by these techniques was compared to that measured by the conventional runoff plot technique. Soil loss measured by the conventional runoff plot technique was used for determining the influence of the various techniques on the magnitude of soil erosion.

The Tracer technique was discontinued before the end of the study because it was difficult to accurately monitor the movement of the sprayed paint particles.

The techniques employed in assessing soil erosion had no significant influence (5% level) on the magnitude of soil loss and did not interfere with erosional processes.

There was significantly more soil loss (1% level) in bare - fallow than in plots under a crop. In the first season, soil loss from bare - fallow plots was 153.3 $Mgha^{-1}$ compared to only 40.2 $Mgha^{-1}$

in plots under maize. In the second season, bare - fallow plots lost 87.5 Mg soil ha^{-1} compared to a soil loss of 39.4 $Mgha^{-1}$ from plots under cowpea. Maize and cowpea reduced the amount of soil loss by 3.8 and 2.2 times, respectively. There was more deterioration of soil physical conditions in bare - fallow than in plots under a maize - cowpea sequence. Between the beginning of the first and the end of the second season there was a significant (1% level) increase in dry bulk density in bare - fallow plots whereas the increase was nonsignificant (5% level) in plots cropped to a maize - cowpea sequence. During the same period, cumulative infiltration and equilibrium infiltration rate fell by 41 and 37%, respectively, in bare - fallow plots compared to an increase (improvement) of about 26 and 37% (cumulative infiltration and equilibrium infiltration rate, respectively) in plots under a maize - cowpea sequence.

There was no significant difference (5% level) between soil loss determined by the 16 nails or 25 nails and conventional runoff plot technique. Also, soil loss determined by 16 nails did not differ significantly (5% level) from that determined by the 25 nails technique.

Soil loss determined by rill technique on six plots (3 bare - fallow and 3 plots with maize) at the end of the first season was significantly (5% level) lower than that measured by the conventional runoff plot technique. Rill - estimated soil loss was 143.2, 108.8 a and 121.9 $Mgha^{-1}$ for 11, 11 and 8% slope, respectively, compared to 201.5, 162.0 and 166.4 $Mgha^{-1}$ measured by the conventional runoff plot technique. Soil erosion measured by the rill technique on three bare - fallow plots in 10 different dates was also significantly (1% level) lower than that determined by the conventional runoff plot technique.

In the first season, the USLE significantly (1% level) underestimated soil loss. Soil loss estimated by the USLE in the first season respectively for 11, 11 and 8% slope was 128.8, 144.3 and 85.9 $Mgha^{-1}$ compared to 167.6, 156.1 and 136.3 $Mgha^{-1}$ measured by the conventional runoff plot technique. In the second season, however, there were no differences in erosion rates determined by the two techniques.

Cowpea grain yield was significantly (5% level) and negatively correlated to soil loss (r = 0.74).

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INTRODUCTION

1.1. History and extent of soil erosion

Accelerated erosion and consequences of its effects on productivity are as old as agriculture. Productive farming gave rise to early civilization. But as a result of soil mismanagement, soil erosion ensued and agricultural productivity fell. The latter led to the collapse of many empires of the early civilization whose ruined cities now lie amid barren wastes that once were the world's most fertile lands (Bennett, 1939; Ellison, 1947; Stallings, 1957; Jacks and Whyte, 1972).

Soil erosion is still a major problem today. Bennett (1939) estimated that about 3 billion tons of soil were eroded from fields and pastures in the United States in 1939. Williams (1967) estimated an annual soil loss in the United States at about 4 billion tons in 1967.

Nowhere is soil erosion more severe and its effects more drastic than in the tropics. These regions are characterised by aggressive climatic conditions, high population densities and rapidly increasing use of marginal lands causing an increased and sometimes irreversible land degradation (Lal, 1976a, 1985; El-Swaify et al.,1980; ASA, 1982). Hudson (1971) reported that all forms of water-induced erosion occur in the tropics. By some conservative estimates, the current rate of annual degradation of land that is being rendered unproductive ranges from 5 to 7 million hectares (Kovda, 1977).

Severity of the erosion hazard has been indicated by many (Greenland and Lal, 1977; Dregne, 1978, 1982; El-Swaify et al., 1982; Lal, 1982, 1985). In humid West Africa, deforestation and mechanized farming cause severe soil loss (Kowal, 1972a, b; Wilkinson, 1975a, b; Lal, 1976a; Greenland and Lal, 1977). In Nigeria, soil erosion by water is a serious problem in most of the agro-ecological regions (Palmer, 1958; Floyd, 1964, 1965; Kowal, 1970; Babalola and **Chheda,** 1975; Jones and Wild, 1975; Aina et al., 1976). Oyebande (1981) reported a maximum annual suspended sediment yield of 483 Mg km^{-2} $year^{-1}$ in Nigeria.

In the semiarid and Sahel regions of West Africa, lack of adequate vegetation at the beginning of the rainy season caused severe erosion on arable lands (Fauck, 1977). Adu (1972) reported a loss of about 0.9 m of soil by sheet and rill erosion in one year in northern Ghana. Some severely eroded savanna lands had lost all of the top soil above the unweathered parent rock. In the Sahel region of central Niger, gullies 150 to 300 m long usually develop during the one rainy season (Talbot and Williams, 1978). A similar type of culturally - induced soil erosion is reported in the delta of the Niger River in Mali (Barth, 1978). Savat and Poesen (1977) observed in Central Africa that the sandy dome-shaped hills south of Kinshasa were denuded by splash and discontinuous runoff.

Erosion in Francophone West Africa has been extensively reported by Roose (1967) and Charreau (1969, 1972). Considerable work has been done in the forest region of Ivory Coast at Abidjan (Roose, 1967, 1973).

Some of the earlier reports of erosion in East Africa have been by King (1939), Thompson (1939) and Ducker and Hoyle (1948). A comprehensive review of erosion in Tanzania has been published by Rapp et al. (1972). Results of erosion research in Kenya have been reported by Gethin - Jones (1936), Maher (1950) and Brook (1955).

Rapp (1975) reported that annual sediment yields from the semiarid plains of Dodoma and Arusha Districts in Tanzania were as high as 200-730 m^3 km^{-2}. In another study from semiarid Tanzania, Christiansson (1981) reported high erosion rates, corresponding to sediment yields of 174 to 602 m^3 km^{-2} $year^{-1}$. Watson (1975) and T.W.M.P (1976) report that the soils on the slopes of the Usambara Mountains in Tanzania are highly susceptible to erosion.

In Kenya, Dunne (1977, 1979) and Edwards and Blackie (1981) monitored sediment load from catchments of various sizes and observed that the long-term geological rate of erosion in these tropical environments for undisturbed catchments range from 20 to 200 Mg km^{-2} $year^{-1}$. This load is excessive, however, for heavily grazed and cultivated catchments. Nyambok and Ogweny (1979) reported severe sheet and gully erosion in the Kamburu/Gitaru hydroelectric dam catchment in Kenya.

Elsewhere, Hutchinson et al. (1958), found from their investigations at Namulonge, that 10 times more runoff occurred from bare plots than from grass - covered plots, and that grass mulch was twice as effective as stone mulch in terms of runoff control. Sperow and Keefer

(1975) reported soil erosion losses from the same research station in Uganda under different crops.

In Lesotho, Chakela (1981) reported annual sediment yield of as much as 1800 Mg km^{-2}. The suspended sediment load alone in Lesotho ranged from 270 to 1400 Mg km^{-2} year^{-1}.

Extensive erosion work from Zimbabwe (former Rhodesia) has been reported by Hudson (1957), Hudson and Jackson (1959) and Elwell and Stocking (1973a, b). Hudson (1957) reported that annual soil loss from continuous maize plots over a period of six years was 6.7, 3.7 and 3.1 m^{3}ha^{-1}, respectively, for slopes of 3.5, 2.5 and 1.5 degrees. The average annual soil loss from a bare-fallow plot was 141.3 m^3 ha^{-1} year^{-1} as compared with 1.2 m^3 ha^{-1} year^{-1} from a weed-free bare plot with a wire gauze suspended above it.

In Malawi, Balek (1977) reported high sediment load of 1804 Mg km^{-2} year^{-1}. Virgo and Munro (1978) observed that about 6000 km^2 of central plateau region of Tigrai, Ethiopia, was affected by severe erosion.

Characteristics common to all eroded areas in Africa include destruction of vegetation cover through deforestation, overgrazing, fires etc.,accompanied by sheet, gully or wind erosion, increasing desert encroachment and shortage of water for human and animal consumption.

1.2. History of erosion research.

Rainfall erosion research began with the work of Wollny in Germany in the latter half of the nineteenth century. Nelson (1958) refers to Wollny as 'the father' of soil conservation research. Wollny's studies included the relation of erosion to steepness and orientation of slope, density of vegetal cover and soil type. His work has been discussed by Baver (1939) and Stallings (1957).

In the United States of America, erosion research began in 1917 with establishment of plots for study of the effect of soils, slope and crops on runoff and erosion by Professor M.F. Miller of the University of Missouri (Smith & Wischmeier, 1962). Others soon followed Professor Miller's lead, using techniques developed by his earlier assistant, Dr. F.L. Duley. Between 1929 and 1933 similar work was started by H.H. Bennett and L.A. Jones of the United States Department of Agriculture. They established ten Federal-State experiment stations on the more critical erosion areas of the United States. Studies were started on eighteen additional soils during the next decade. Several of the stations added terrace and strip crop design, gully control and small single practice watersheds as parameters for investigations in addition to soil, crop and slope studies. Most of these early studies were discontinued by 1943. In 1960 studies were underway on eighteen soils.

Laws and Parsons of the Soil Conservation Service, United States Department of Agriculture, conducted fundamental studies dealing with rainfall characteristics, drop velocity, drop size distribution and splash during the period 1936 to 1940. Additional basic studies were started during and after World War II by many scientists in other parts of the world including Ellison (1944), Bisal (1960), Mihara (1952), McIntyre (1958), Rose (1960), Hudson (1961) and the Soil Conservation Research Division of the Agricultural Research Service, U.S. Department of Agriculture.

Empirical equations were developed beginning in 1941 for estimating average annual field soil loss for different combinations of soil, slope, cropping, management and conservation practices. Data for derivation and field use of these equations were those from the field plots established during the early 1930s. In 1953, a Runoff and Soil Loss Data Laboratory was established at Lafayette, Indiana, by the Soil and Water Research Division of the Agricultural Research Service, U.S. Department of Agriculture, in cooperation with Purdue University (Wischmeier, 1955). Practically all runoff and soil loss data from field plots in the United States have been assembled at this laboratory. Research has been directed toward development of improved methods for the prediction of field soil loss and runoff.

Tropical Africa, the region lying within 23° North and South of equator, has a history of over 50 years of research in soil erosion. Some observations reported in literature, however, are based on qualitative reconnaissance surveys and lack a strong data base (Lal, 1985). The lack of supporting technical data has led to erroneous and conflicting estimates of the erosion hazard. For example, estimates of denudation by Fournier (1963) and Strakhov (1967) differ by several orders of magnitude. Lal (1985) cautions that in the long run guestimated research information is bound to produce more harm than good.

1.3. Estimation of soil erosion

Quantitative determinations of the extent and impact of soil erosion in the tropics are very scanty (El-Swaify and Dangler, 1982). There are generally two methods for estimating soil erosion. These are:

1.3.1. Indirect methods.

Several correlation equations for predicting sheet and rill erosion have been proposed. The so-called Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978), is the most widely used (Roose, 1977a; FAO, 1978). Other equations of similar nature were proposed by Musgrave (1947), Gottschalk and Brune (1950) and Farnham _et al._ (1966), to mention but a few. In these equations, the annual soil loss rate is usually correlated with rainfall, soil erodibility, length and steepnes of slope, crop and crop management and soil conservation practices.

Such correlations are usually not comprehensive. The many possible variations in climate and watershed conditions are so great that it is impossible to develop a comprehensive correlation covering all types and gradations in variations. All empirically derived prediction equations involve experimental errors and potential estimation errors due to effect of unmeasured variables. As a result, errors up to 400 per cent are not uncommon with the use of such equations (Beer et al., 1966). Wischmeier (1976) advised that soil losses computed by the USLE must be recognised as the best available estimates rather than as absolute data.

The Universal Soil Loss Equation was developed in the mid western United States where it works well. To transfer the USLE would require determination of the appropriate values for each of the factors: rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C) and conservation (supporting) practices (P) (Foster et al., 1982). Data to quantify these variables are very sketchy in the tropics (El-Swaify and Dangler, 1982; Lal, 1981a). Such equations as the USLE are only applicable on an annual basis. Most of the empirical equations estimate sheet (rill and interill) erosion (De Jong et al., 1982) and do not apply to gully erosion and mass flow.

In addition to correlation equations, some models have been developed in the tropics from a knowledge of environmental characteristics (Stocking, 1973, 1980; Elwell , 1978). Some of these models can be adapted for other regions of tropical Africa. Attempts have also been made to assess erosion hazard using soil surveys (Heusch, 1980).

1.3.2. Direct methods

Many techniques are employed in estimating soil loss without using correlation equations. The techniques include: the use of conventional runoff plots; use of erosion pins, pegs and stakes; use of tracers such as fluorescent dyes to monitor soil creep; small agricultural watersheds with appropriate monitoring equipment; use of exposed tree roots; measurement of rill and gully dimensions; radioactive fallout etc. Most of these techniques are employed in various parts of the world. However, the conventional runoff plot technique is perhaps the most widely used direct method of estimating soil erosion.

1.4. Statement of the problem.

Field installations and relevant equipment needed for determination of soil erosion are very expensive. The cost of installing runoff plots varies with location, inflation rate and methodology used. Furthermore, there is lack of standardization of methodologies. Most equipment used is designed by the user according to his financial resources. Erosion research techniques are more of an art than a science. The data obtained by different methodologies can not be easily compared. Any methodology adopted should, as much as possible, be standardized, simple and direct. Moreover, the techniques adopted should be evaluated for different soil management and cropping systems.

1.5. Objectives

The objectives of this study were, therefore,:

(i) to develop simple, direct and economic techniques of monitoring soil erosion in different systems of soil management and cropping, and

(ii) to comperatively evaluate the performance of these techniques with standard conventional equipment.

CHAPTER 2

LITERATURE REVIEW

2.1 Methods for soil erosion estimation

2.1.1 Direct methods

2.1.1.1 Conventional runoff plots

Erosion research has largely been of an applied nature, conducted on field plots ranging in size from about 20m^2 to 0.81 ha (Smith & Wischmeier, 1962). The early plots were generally 40m^2 with a slope length of 22.1m. All runoff from plots was caught in large tanks. Today several types of fractionating devices have been developed to reduce the large volume of soil and water to be handled. These devices also allow the use of larger plots. Lal (1976a)used a multidivisor soil and water - collecting system which was a modification of that described by Wiltshire (1947, 1948). A common feature of a multidivisor set up is that only a fraction of the runoff, either 1/3, 1/5, 1/7, 1/9, 1/11 or any odd fraction, is channelled into any one tank at a time. Sometimes as many as three tanks and two divisor units are used in a series.

The major problem with runoff plots is that they are expensive to install and maintain. Furthermore, they can not be used for estimating within - the - plot soil deposition.

2.1.1.2 Tracer methods.

2.1.1.2.1 Radioactive fallout

Recent studies have shown that a direct estimate of soil loss can be achieved by determining the amount and distribution of ^{137}Cs derived from radioactive fallout (Ritchie *et al.*, 1974; Ritchie & McHenry, 1975; McHenry and Ritchie, 1977; McCallan *et al.*, 1980; Brown *et al.*, 1981). With this method, both erosion and deposition can be measured in the same field (De Jong *et al.*, 1982; McHenry and Bubenzer, 1982). Mitchel *et al.* (1980) used ^{137}Cs to estimate erosion. They compared the results with loss estimated using the USLE. The results did not compare favourably. Ritchie and McHenry (1975) found ^{137}Cs loss from watersheds to correlate logarithmically with soil loss as calculated by USLE and measured in small plots.

Tracing radioactive fallout requires the use of expensive and sophisticated equipment.

2.1.1.2.2 Use of dyes

In Nigeria Lewis (1981) monitored soil creep in different slopes using dyes and estimated soil erosion by collecting data on the movement of soil particles sprayed with phosphorescent dyes and aluminium paint. The study was carried out on bare-fallow plots. Annual soil loss during 13 to 46 years of hop cultivation were measured on six slopes of Lower Bavaria, in the Federal Republic of Germany, using copper added as a fungicide as a tracer (Schwertmann & Schmidt,. 1980). The annual soil loss was found to vary between 28 and 63 Mg ha^{-1} and was highly correlated with the product LS K of the Universal Soil Loss equation.

2.1.1.3 Water rills

Rills are erosion channels small enough to be obliterated by normal tillage practices. They are formed when runoff flow's shear characteristics exceed soil's resistance to them and flow's transport capacity is greater than available detached material (Meyer et al., 1975; Meyer, 1981). Particles moving off the plot do so primarily by transport in rills (Young and Mutchler, 1969). Measuring the volume of rills, therefore, makes it possible to estimate soil loss due to erosion. Sobolev (cited by Gerasimenko, 1980) proposed the use of water rills to quantitatively determine water erosion. In the Soviet Union, Gerasimenko (1980) evaluated the reliability of the method of water rills and concluded that the method was very objective and practical. Gerasimenko formulated principles of applying the water rill method. It has been suggested that for greater accuracy one must have 20 measurement sites along the length of each water rill in winter-crop fields and 30 in autumn-plowed fields. Five to ten depth measurements in the cross section of a microchannel have also been suggested. The water rills studied by Gerasimenko were in basin slopes, from 100-400m long with gradients from 1 to 6°.

2.1.1.4 Stakes, pegs, erosion pins and nails

Wooden stakes, pegs and iron and steel pins and nails have been extensively used in soil erosion assessment (Schumm, 1967; Hudson, 1971; Hadley, 1977; Zachar, 1980; Thorne, 1981).

2.1.1.4.1 Wooden stakes and pegs

Colbert (1956) employed wooden stakes exposed 153mm set at selected sites to monitor erosion but found no correlation between erosion and slope angle. Six of the stakes were lost to vandals. Schumm (1956) used wooden stakes (464mm x 6mm) driven flush to soil surface. Stake separation was 0.3m. Soil erosion was estimated in 16 transects on diversely oriented slopes. In Japan, Takei <u>et</u> <u>al</u>. (1981) also determined erosion by the peg method. They took monthly measurements over a 10 - year period on three plots (of 28 to 35° slopes), and found that the annual rate of erosion from each plot was almost constant.

2.1.1.4.2 Iron rods, movable contour plotting frames, erosion pins/nails

The technique of erosion pins was pioneered during Schumm's studies of the Amboy Perth Claypit in 1952 (Schumm, 1956). Miller and Leopold (1962) were the first to use this technique along with washers as an aid to recording. This technique has since become the most widely used through the Vigil Network system (Emmett, 1965). The Vigil Network also includes some of the most protracted erosion studies. Leopold and Emmett (1972) have reported erosion measurements from sites where 9 years of data have been collected.

Steel as well as iron and brass rods have been widely used in erosion research (Schumm, 1956; Hadley and Schumm, 1961; Schumm and Lusby, 1963; Pinczes, 1971; Imeson, 1971, 1974). In Tanzania, Temple and Murray-Rust (1972) used angle - iron rods (900mm x 30mm) to show heavy ground advance on the Eastern Uluguru Mountains. The rods were graduated in inches and sunk to half length in lines down the centre of a 10-m cleared plot. The method worked well.

Other erosion researchers have used movable contour plotting frames and bars. Campbell (1970a, 1970b, 1973, 1974) used a movable contour plotting frame allowing 25 measurements in a 25 metre square accurate to 0.5mm. The frame was mounted on 4 modified erosion pins. Both soil loss and soil deposition were recorded. Streeter (1975) used a movable contour plotting bar (a modified version of Campbell's frame) mounted on 2 erosion pins. Results of Streeter's study, however, are not known.

Erosion pins and nails have been extensively used in the study of soil retreat as evidenced by several authors (Disecker and Richardson, 1961, 1962; Miller and Leopold, 1962; Emmett, 1965, 1974; Leopold et al., 1966; Disecker and McGinnis, 1967; Bridges, 1969; Tinker, 1970; Clayton and Tinker, 1971; Disecker & Sheridan, 1971; Bridges and Harding, 1971; Haigh, 1974; Kirkby and Kirby, 1974; Thorne and Lewin, 1979; Millington, 1981). Measurements of hillslope erosion, sediment yield and bank erosion that occur during a single rainstorm are rare. Usually only seasonal or annual estimates are made. Hadley and Lusby (1967) reported a rare occasion when they were able to estimate erosion and sediment yield from a single storm. After a high intensity thunderstorm they measured the length of pins exposed (32 erosion pins). The volume of the sediment eroded from the slopes and that delivered to a reservoir at the lower end of the basin compared favourably.

It is ironic that erosion pins have been used mostly in large plots or watersheds in hillslope erosion studies and rarely on small plots that usually allow measurements from single rainstorms.

2.2 Indirect Methods

2.2.1 The Universal Soil Loss Equation (USLE)

Equations commonly used for predicting soil loss and describing erosion control measures were developed primarily in the Corn Belt (Midwest) of the United States. Historical review of the steps leading to their development were given by Wischmeier and Smith (1978), Mitchell and Bubenzer (1980) and Holdenhauer and Foster (1981). First, a relationship between soil loss and slope length and steepness was developed by Zingg (1940). Crop cover and conservation practice parameters were added the following year by Smith (1941). In 1946 the Musgrave equation emerged, with the addition of a rainfall parameter (Musgrave, 1947). Based on data from over twenty-five years research from which the rainfall parameter was modified and the soil susceptibility to erosion (erodibility factor) quantified the Universal Soil Loss Equation (USLE) for predicting sheet and rill erosion was proposed (Wischmeier and Smith, 1961, 1965). This equation is now the most widely used model for predicting sheet (interrill) and rill erosion (Wischmeier and Smith, 1978). It has the form:

$$A = R.\ K.\ LS.\ C.\ P \text{ -------(1.1)}$$

where A = estimated average annual soil loss; $Mgha^{-1}$

R = rainfall erosivity index, a number which indicates the erosivity of the rain; Jha^{-1}

K = Soil erodibility factor, a number which reflects the liability of a soil type to erosion; MgJ^{-1}

LS = Slope length and steepness factor; dimensionless. The length factor, L, is a ratio which compares the soil loss with that from a field of specified length of 22.1m. Slope steepness factor, S, is a ratio which compares the soil loss with that from a field of specified slope (9%).

C = crop management factor, a ratio which compares the soil loss with that of a standard treatment (bare-fallow); dimensionless

P = erosion - control supporting (conservation) practice factor, a ratio which compares the soil loss with that from a field with no conservation practice (ploughed up and down the steepest slope; dimensionless.

The erosivity index (R) used in the USLE is computed as a product of the kinetic energy, E, and the maximum 30-minute rainfall intensity, I_{30}. Details on computation of R are given in section 3.4.1.2

K factor values determined from a unit plot (Wischmeier and Smith, 1965) or by use of a rainfall simulator are usually referred to as 'measured' K values, whereas those determined from the nomogram developed by Wischmeier et al. (1971) are termed 'estimated' K values. The measured K factor values reported for tropical soils fall in the range of 0 - 0.67 MgJ^{-1} (Roose, 1977b; Lal, 1984). Estimates of soil erodibility based on the nomogram are not always reliable (Ngatunga et al., 1984; Vanelslande et al., 1984).

The Standard slope length used in determining K values is 22.1m. Thus the slope length factor L is calculated from the identify:

$$L = \left[\frac{\text{Field slope length } (\cancel{\text{metres}})}{22.1\ \cancel{\text{metres}}} \right]^{m} \quad \text{———} \quad (1.2)$$

where m is a constant whose magnitude varies with slope steepness (explained below).

The slope steepness (S) part of the LS factor is based on per cent slope as calculated by the land slope approach adjusted so the standard 9% slope has the value of 1.0. S factor is defined as:

$$S = 0.065 + 0.045s + 0.0065s^2 \text{ ——— } (1.3)$$

where s is the vertical fall per 100 units along the land surface. The slope length and steepness are combined into a single LS factor by the equation:

$$LS = \left[\frac{\text{Field slope length (metres)}}{22.1 \text{ metres}}\right]^m (0.065 + 0.045s + 0.0065s^2) \text{ ——— } (1.4)$$

where m = 0.2 for $s < 1\%$; m = 0.3 for s = 1 to 3%; m = 0.4 for s = 3.1 to 4.9%; m = 0.5 for $s \geqslant 5\%$; and s = the vertical fall per 100 units along the land surface.

Cover and management effects can not be independently evaluated because their combined effect is influenced by many significant interrelations. Almost any crop can be grown continuously or it can be grown in rotations. Crop sequence influences the length of time between successive crop canopies, and it also influences the benefits obtained from residual effects of crops and management. The overall erosion - reducing effectiveness of a crop depends largely on how much of the erosive rain occurs during those periods when the crop and management practices provide the least protection. The change in effectiveness of plant cover within the crop year is gradual. For practical purposes, the year is divided into a series of cropstage periods defined so that cover and management effects may be considered approximately uniform within each period. Wischmeier and Smith (1978) give a detailed account of how to compute the C - factor for use in the USLE.

In general, whenever sloping soil is to be cultivated and exposed to erosive rains, the protection offered by close - growing crops in the system needs to be supported by practices that will allow runoff water and thus reduce the amount of soil it can carry. The most important of these cropland practices are contour tillage, stripcropping on the contour and terrace systems. By definition, factor P in USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture. P values have been determined for contouring, contour stripcropping and contour - farmed terraced fields for various land slopes (Wischmeier and Smith, 1978).

2.5 Rainfall characteristics

In addition to rainfall amount, rainfall intensity, distribution of storm intensity, kinetic energy, momentum and drop size are important variables affecting soil erosion.

2.5.1 Rainfall intensity.

Tropical rains are more erosive than temperate rains because of the high intensity of tropical storms. A majority of the tropical rainstorms fall in the category of 'erosive' storms, while only 5 to 10 per cent of temperate storms are erosive. Tropical storms are generally accompanied by high - intensity winds which further increase their aggressiveness. Jansson (1982) prepared a map of Africa depicting 1-h maximum rainfall with 2-year return period. Some Guinean, Soudanian and Zambesian ecological regions lie within the zones that have a 1-h maximum rainfall intensity of 50 - 75 mm h^{-1}. Consequently, some of these regions have an annual runoff of 400 - 2000mm (Jansson, 1982).

In general, runoff increases with increasing annual rainfall (Balek, 1977).

Localized rainfall intensities exceeding 100 mmh^{-1} sustained for 10-15 minutes are frequently observed (Wilkinson, 1975a; Kowal and Kassam, 1976; Lal, 1981b). Lal (1976a) observed that at Ibadan, Nigeria, 15, 10 and 30 per cent of storms during 1972, 1973 and 1974 respectively, had 7.5-minute maximum intensities greater than 75 mmh^{-1}. He also observed storms with rainfall intensities greater than 130 mmh^{-1}. At Samaru (in the Northern Guinea Savanna zone with an average annual rainfall of 1100 mm), Kowal and Kassam (1976) reported individual storms exceeding 50 mm and peak intensities of 120 to 160 mmh^{-1} are not uncommon. Roose (1971) observed in Abidjan, Ivory Coast, that it is common for 150 - 200 mm of rain to be received in 24 h with a sustained intensity of 40 mmh^{-1}. Rains with an intensity of 120 mmh^{-1} sustained for 10 minutes are often observed, and rainstorms with amounts of 90 and 107 mm received in 24 h have a return period of 5 and 10 years, respectively. Dunne and Leopold (1978) who prepared an isohyetal map of Kenya, found that, in tropical areas with high annual rainfall, the rains sustain maximum intensity for 1 h, with a return period of 2 years. High rainfall intensities have been reported elsewhere in the tropics. Kampen (1974) reported intensities of 85 - 100 mmh^{-1} sustained for 30 min in Hyderabad, India. Ramaiah and Sreenivas (1975) reported maximum 30-minute values of 84 mmh^{-1} in the Mysore region of Southern India. Rains as intense as 100 mmh^{-1} commonly occur in Sri Lanka (Joshua, 1977). High-intensity rains are particularly damaging at times when the vegetation cover is poor (Wilkinson, 1975b; Stocking and Elwell, 1976).

2.3.2 Intensity distribution.

Some storms have their highest intensities in the beginning and lowest intensities during the later stages. Most storms at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, fit this pattern. Lal (1976a) recorded, at IITA, an intensity of 213 mm h^{-1} during the first 5 minutes of a storm in April, 1973. Other storms begin with medium intensity and reach their peak in the middle. Composite storms have their peak intensities within two or three hours of one another. Each intensity distribution presents a different soil erosion hazard.

2.3.3 Rainfall erosivity and erosivity indices

The role of kinetic energy of the rain drop in soil detachment has long been recognized (Ellison, 1947; Ekern and Mukenhirn, 1947; Woodburn, 1948). Ellison (1947) reported that the detachment hazard (D_1) is directly proportional to the product of detachability (D_2) and the detaching capacity of the rain (D_3) and inversely proportional to the resistance factor (R) of the surface covers and mulches in reducing runoff velocity (Equation 2.1):

$$D_1 = (D_2 \times D_3)/R \qquad (2.1)$$

Mokerjee's (1950) experiments conducted in India showed a high correlation between rainfall intensity and the amount of eroded soil. Mihara (1953) attributed soil erosion less to running water and more to raindrop impact. Ekern's (1954) findings related erosivity exponentially to rainfall intensity. Similar results have been reported by Adams (1957) and Tamhane _et al_. (1959). Free (1960) reported that only lasting rain of high intensity combined with some packing and sealing

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before the rainfall caused runoff and soil losses. The relationship of ratio of infiltration to runoff with rainfall energy was exponential and of the hyperbolic type. Rose (1960) concluded that the rate of soil detachment per unit area was influenced more by momentum than the kinetic energy of the storm per unit area and time.

Wischmeier (1955) reported that the combination of rainfall energy and rainfall amount was the most important variable affecting soil erosion. Later, Wischmeier et al. (1958) showed that the correlations between both soil loss and total rainfall of individual storms and rainfall in 5 - 15 - or 30 - minute intervals were poor. The product of the kinetic energy of the storm and the 30 - minute intensity, termed EI_{30}, was most significantly correlated with the soil loss.

Although the EI_{30} index (R factor) is the best known method of calculating erosivity of rainfall, the index has not been entirely satisfactory, particularly for tropical rainstorms. The intensity used in EI_{30} index is generally below 50 mmh^{-1}, but storms of much higher intensities are frequent in the tropics (section 2.3.2). Rogers et al. (1967) indicated that calculating the kinetic energy from rainfall intensity was satisfactory. However, this may not be satisfactory in the tropics where rainstorms are often preceded by high winds. Lyles et al. (1969) found that wind-driven rain considerably increased soil loss. Ahmad and Breckner (1974) found in Trinidad that correlations of soil loss with the EI_{30} index were generally low.

Wilkinson (1975a) developed an empirical equation relating the EI_{30} index to the time (t) taken to attain peak rainfall intensity:

$$EI_{30} = 18e^{-0.18t} + 4.0 \text{--------} (2.2)$$

Similarly, Roose (1977a) developed a regression equation relating the EI_{30} index to the annual rainfall amount for many locations in West Africa. For the monsoon rains from June to September, a linear equation was obtained: $EI_{30} = 0.5\ P_{annual} + 0.05$---(2.3) where P_{annual} = annual rainfall (mm). A logarithmic relation, however, was obtained for inland stations in Ivory Coast, Burkina Faso (former Upper Volta), Senegal, Niger, Cameroon, Chad and Madagascar. Based on these indices, isoerodent maps have been prepared for Africa. Other rainfall indices have been proposed for use in the tropics.

Fournier (1956) and Fournier and Henin (1959) analysed the sediment load values of more than 140 rivers in Europe, Asia and the United States and found a significant correlation between total annual erosion ($Mgkm^{-2}$) and the rainfall coefficient equation:

$$C = p^2/P \text{------} (2.4)$$

where p is the monthly rainfall during the wettest month of the year and P is the annual rainfall. C is the rainfall coefficient.

The soil loss or "specific degradation", was expressed as Equation 2.5:

$$D = a\ C - b \text{ ------} (2.5)$$

where D is the specific degradation or soil loss and a, b are coefficients whose magnitudes depend upon the orographic coefficient (O) of Equation 2.6:

$$O = H^2/S \text{------} (2.6)$$

H is the height of the terrain above base level and S is its projected area.

Fournier's index was more significantly correlated with erosion in the tropics than in the temperate climate and with steeper than with gentler slopes. This climatic index is useful for large watersheds. However, for small areas the erosivity of the climate, particularly in relation to soil management, cannot be easily predicted by this index.

Hudson and Jackson(1959) found in their studies in Zimbabwe that the El_{30} was less effective in Southern Africa. Experiments conducted in Zimbabwe by Hudson (1971) indicated that the cumulative kinetic energy of storms with intensities greater than 25 mmh^{-1} was better correlated than the El_{30} index and called this index KE>1 index. Hudson (1971) pointed out that storms with intensity of less than 25 mmh^{-1} were not erosive.

Lal (1976a) devised another erosivity index and called it AIm index. The AIm index is the product of the maximum intensity (Im) in cmh^{-1} and total rainfall (A) in cm. The annual index AI_M is calculated according to the equation (2.7):

$$AI_M = \left[\sum_{1}^{12} \sum_{1}^{n} (ai_m) \right] \quad \text{———}(2.7)$$

where a is the total rainfall in any one storm in cm and i_m is the maximum storm intensity in cmh^{-1} and n is the number of rainy days in the month. Lal (1976c, d) reported a better correlation with AI_m than either EI_{30} or KE>1. AI_m index has advantages over the EI indices because it includes maximum intensity which is an important factor in tropical rainstorms. It also includes total rainfall, taking into account the fact that a very intense storm that lasts only a short period and that results in low total rainfall is usually non-erosive. When maximum intensity and total rainfall are combined in one index they provide a more accurate indication of rainstorm erosivity than using either of the variables alone. Moreover, the AIm index is simple to compute. Table 1 shows some of the most common equations used for calculating kinetic energy, E

Table 1. Equations relating kinetic energy, E, and intensity, I

Equation	Units	
	Energy	Intensity
1. $E = 916 + 331 \log I$	Foot - tons / acre-inch	in h^{-1}
which converts to		
2. $E = 210 + 89 \log I$	Mg-m $ha^{-1} cm^{-1}$	cmh^{-1}
or to		
3. $E = 11.9 + 8.7 \log I$	J $m^{-2} mm^{-1}$	mmh^{-1}
This relationship has also been expressed in kg-m m^{-2} and in $MJha^{-1}$		
4. $E = 29.82(1-e \quad 0.0444 \; 0.214)$	$Jm^{-2} mm^{-1}$	mmh^{-1}
5. $E = 30 - \frac{125}{I}$	Jm^{-2} mm^{-1}	mmh^{-1}
6. $E = 9.81 + 11.25 \log I$	Jm^{-2} mm^{-1}	mmh^{-1}

After Hudson (1981)

2.4 Soil erodibility

Susceptibility of a soil to erosion, or soil erodibility, is a dynamic property that changes with time and its magnitude varies with soil characteristics (Equation 3.1):

K(t) = f (structure, texture, organic matter, amorphous Fe, and

Al oxides)-------(3.1)

$\frac{dK}{dt}$ = f (soil and crop management and land use)----(3.2)

where K is soil erodibility and t is time.

Soil erodibility is a composite factor comprising "detachability" and "transportability". Whereas detachability depends on soil and rainfall characteristics, transportability is governed by overland flow, with or without rill systems and their characteristics.

A numerical index of soil erodibility (K), as defined in the universal soil loss equation (Wischmeier and Smith, 1978), can be measured directly in the field by establishing a "Unit plot" (Wischmeier and Smith, 1965) or it can be estimated using simulated rainfall or simply from soil properties - for example using the nomogram developed by Wischmeier et al. (1971).

Factors affecting soil structure, slaking and water transmission characteristics also affect soil erodibility. However, the factors that affect soil detachability may not be necessarily the same as those that affect transportability. Soil erodibility is often related to soil properties such as organic matter content, exchangeable cations, percentage of water-stable aggregates, the mean weight diameter of aggregates, dispersion ratio, clay ratio, particle size distribution and free Fe_2O_3 and Al_2O_3 contents (Bryan, 1968; Lugo - López, 1969; Yamamoto and Anderson, 1973; Jungerius, 1975; Kandiah, 1976; Bhatia and Samarah, 1976; Sahi et al., 1977; Chandra and De, 1978; Bhola and Jayaram, 1978; Singh and Verma, 1978; Collinet and Valentin, 1979; Olofin, 1980; Hamblin, 1982). Bruce - Okine and Lal (1975) at Ibadan, Nigeria, used a laboratory technique to determine factors affecting detachment of some tropical soils. De Vleeschauwer et al. (1978) compared the detachability of 8 Nigerian soils using 14 different erodibility indices. Experiments conducted at Ulu Langat District in Malaysia by Olofin (1980) indicated the erodibility indices maximum angle of slope, sand/silt+clay ratio, aggregate stability and shear ratio to be most related to soil erodibility. In Tanzania, Ngatunga et al. (1984) computed 6 erodibility indices for three different soils and related them to soil erodibility. Many researchers have observed the percentage of water stable aggregates to be a good index of soil erodibility (Yamamoto and Anderson, 1973). In francophone West Africa, various researchers have compared stability of aggregates to wet sieving after pretreatment with organic liquids, such as alcohol and benzene (Henin et al., 1958). The amount of colloidal fraction, in dispersed or aggregated state, has also been widely used (Combeau and Monnier, 1961). However, more often, it is observed that the field behaviour of a soil in regard to water erosion is not related to any one index but to a number of indices.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

3.1.1. Location

The study was carried out in runoff plots installed at the experimental farm of the International Institute of Tropical Agriculture, IITA, Ibadan, Nigeria. IITA is located about latitude 7° 29' N, longitude 3° 54' E and at an elevation of between 186 and 240 metres above sea level.

3.1.2 Climate

IITA lies in the transitional zone between the humid and subhumid tropical climate.

This region has a bimodal rainfall pattern, with the main season (Season 1) from late March to late July. This is followed by a dry spell of about one month (referred to as the August - break). The shorter season (Season 2) lasts from late August till mid - November. December to March constitute the major dry season. A greater part of the rains come as intense thunderstorms accompanied by moderate to strong winds. The average annual rainfall varies from 980 to 1200 mm. (Moormann _et al._, 1975). Annual temperature ranges from an average minimum of 21.3°C to an average maximum of 31.2°C. Extreme daily minimum and maximum temperatures of 8.3°C and 38°C, respectively, have been recorded. Mean monthly relative humidities reach a minimum in February and a maximum in August. Potential evaporation is marked with a peak in March but falls to its lowest values in August when insolation is at a minimum (Moormann *et al*., 1975). A summary of the climatic data recorded at IITA during the 1985 study period is given in Table 2 and Fig. 1. Weather records for the same period in 1984 are shown in Table 3 and Fig. 2 for comparison. It should be noted that 1985 was an unusually wet year. It had a total rainfall of 1734 mm, which is 40% above normal, on the basis of the 20 - year average of 1270 mm rainfall per annum. The study was conducted for two seasons, season 1 and season 2, 1985.

Table 2. Climatic data for IITA, Ibadan: January - October, 1985

	Rainfall mm	Evaporation mm	Temperature (°C) Min	Temperature (°C) Max	Temperature (°C) Mean	Rel. Humidity (%) Min	Rel. Humidity (%) Max	Rel. Humidity (%) Mean
January	0.8	122.7	22.7	32.6	27.7	41	96	69
February	0.2	150.7	21.5	34.9	28.2	20	94	57
March	117.7	157.7	24.1	33.5	28.8	42	92	67
April	142.1	129.9	23.6	32.2	27.9	52	93	73
May	163.0	131.1	23.0	30.6	26.8	60	96	78
June	230.0	97.9	22.6	29.1	25.9	65	96	81
July	378.5	89.2	21.5	27.5	24.5	66	95	81
August	229.7	89.6	22.2	28.3	25.3	67	95	81
September	302.6	97.3	21.4	27.8	24.6	67	96	82
October	169.4	117.0	22.1	29.9	26.0	58	95	77

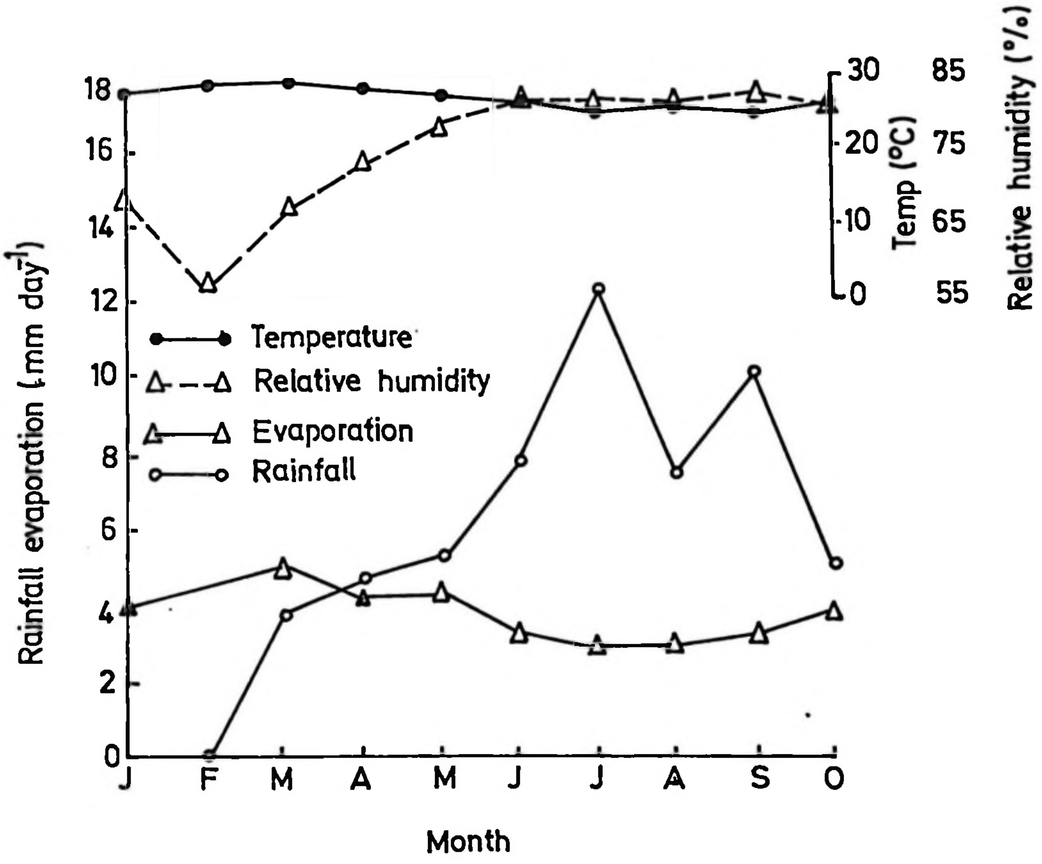

Fig. 1. Climatic data for IITA, Ibadan: January to October, 1985

Table 3. Summary of climatic data, IITA, Ibadan: January - October, 1984

	Rainfall	Evaporation	Temperature, ^{o}C			Relative Humidity (%)		
Month	(mm)	(mm)	Min	Max	Mean	Min	Max	Mean
January	0.0	136.8	20.1	31.8	26.4	31	96	63
February	2.7	179.7	22.2	35.3	28.8	31	92	62
March	90.1	165.2	23.2	34.2	28.9	45	96	71
April	85.3	142.5	23.3	31.9	27.5	57	97	77
May	311.0	121.9	22.8	31.2	27.0	61	97	79
June	136.2	114.5	22.1	29.9	26.0	63	96	80
July	103.9	111.3	22.1	29.1	25.7	64	97	81
August	262.9	101.9	21.9	28.8	25.4	65	94	80
September	185.9	104.4	22.0	28.6	25.3	67	96	82
October	127.5	121.6	22.4	29.9	26.2	63	97	81

After IITA (1985)

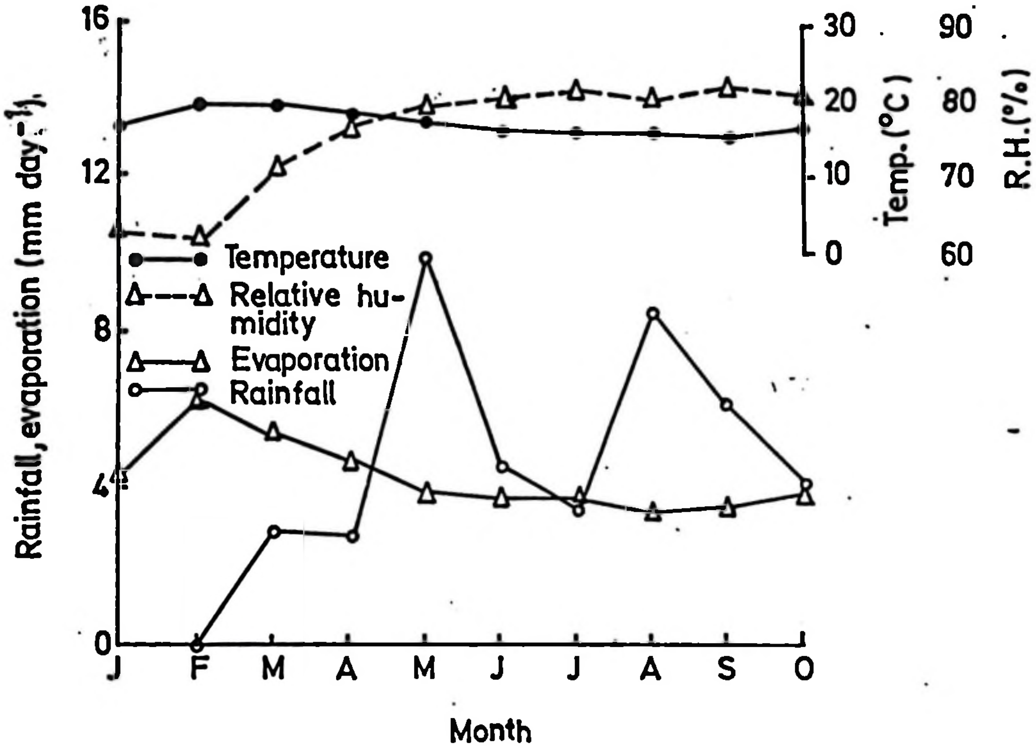

Fig.2. Climatic data, IITA, Ibadan: January to October, 1984

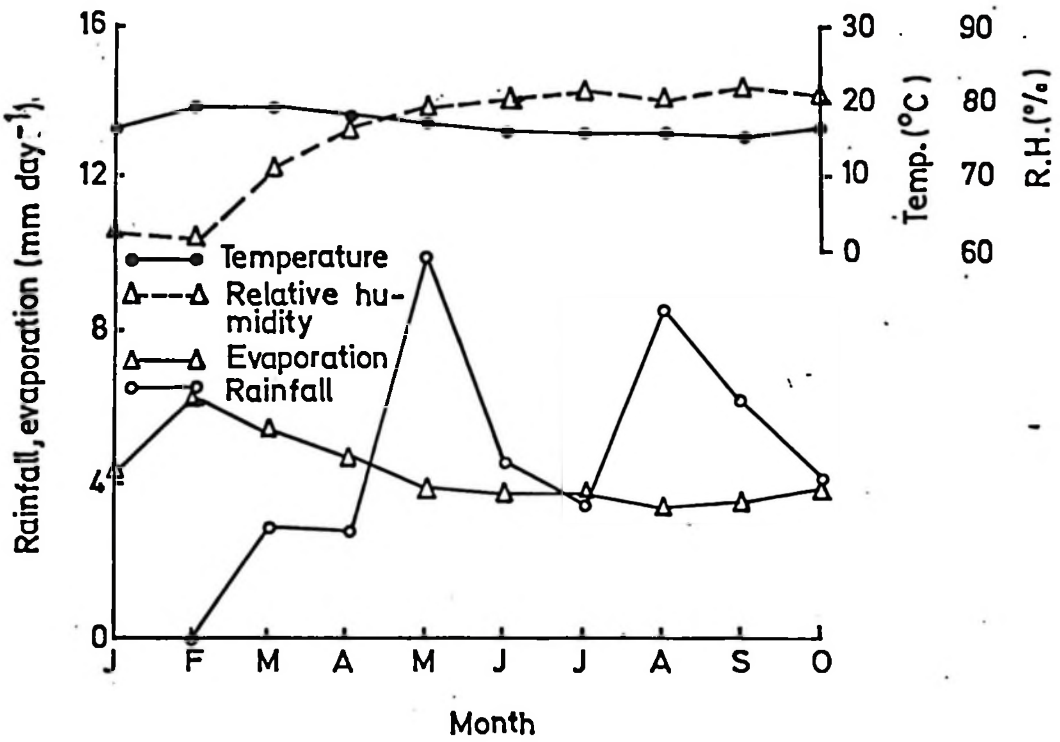

Fig.2. Climatic data, IITA, Ibadan: January to October, 1984

3.1.3 Soils

The runoff plots were constructed on well drained soils belonging to the Ibadan series (Smyth & Montgomery, 1962). These soils are derived from fine-grained biotite gneiss and schist parent materials. They are medium - to light - textured near the surface, with sandy-clay to clay subsoil and a layer of angular and sub-angular quartz gravel immediately below. These soils are classified as Oxic Paleustalf (USDA), Ferric Luvisol (FAO) or alfisol. Details of the pedological, physical and chemical characteristics for these and similar soils are described by Moormann et al. (1975). A summary of some physical and chemical characteristics of the top 0-10 cm of each plot are given in Table 4a and 4b for season 1 and season 2, respectively.

3.2 Plots

3.2.1 Plot size and layout

Measurements were taken on runoff plots established in 1975 on natural slopes of about 11, 11 and 8 per cent for Block I, II and III, respectively (Table 4a, 4b). There was no land forming done. Plots were 10 x 2m, with a 1m buffer between adjacent plots. The experimental plots were arranged in a factorial format using the Randomized Block Design with two factors replicated three times. There were six plots in each block. The field layout of the experiment is shown in Fig. 3.

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Table 4a. Physical and chemical characteristics of the soil (0–10 cm), season 1

Block	Plot	Slope (%)	% Org. Carbon	Mechanical Analysis(%)			Gravel (%)	Db (Mgm^{-3})		Dp* (Mgm^{-3})	Resistance+ (kgm^{-2})
				Sand	Silt	Clay		Overall	Fine earth		
I	1	11.8	1.34	52.0	20.9	27.1	32.8	1.38	0.91	2.64	9.1
	2	11.7	1.53	56.6	18.0	25.4	39.6	1.42	0.85	2.64	9.8
	3	10.7	1.99	56.2	18.4	25.4	25.9	1.32	0.96	2.65	13.7
	4	10.3	1.94	53.1	19.6	27.3	22.1	1.40	1.07	2.63	9.5
	5	10.6	1.89	51.4	19.7	28.9	16.9	1.43	1.17	2.65	10.9
	6	10.9	1.88	51.3	20.6	28.1	8.8	1.30	1.13	2.63	6.3
II	7	12.8	1.39	58.1	20.9	21.0	47.0	1.61	0.85	2.71	17.1
	8	13.0	1.64	59.3	20.4	20.3	29.1	1.44	1.00	2.67	11.0
	9	11.7	1.42	61.4	18.6	20.0	48.9	1.50	0.76	2.66	12.4
	10	10.5	1.28	57.6	20.3	22.1	39.9	1.53	0.90	2.67	12.9
	11	10.2	1.25	66.8	13.0	20.2	37.0	1.46	0.92	2.66	10.1
	12	9.5	1.06	66.1	15.7	18.2	24.7	1.50	1.12	2.64	8.5
III	13	7.3	1.50	63.1	16.9	20.0	18.3	1.49	1.20	2.63	13.1
	14	7.7	1.06	65.4	16.6	18.0	16.8	1.43	1.18	2.64	7.0
	15	7.9	0.99	65.8	16.1	18.1	15.1	1.44	1.21	2.67	6.8
	16	7.6	0.88	67.0	17.0	16.0	18.9	1.48	1.19	2.67	7.3
	17	8.7	0.90	66.0	16.6	17.4	21.4	1.50	1.17	2.67	6.2
	18	8.4	1.08	66.3	16.6	17.1	14.5	1.42	1.20	2.67	4.1

Table 4b. Physical and chemical characteristics of the soil (0-10cm), season 2

Block	Plot	Slope (%)	% Org. Carbon	Mechanical Analysis(%)			Gravel (%)	Db (Mgm^{-3})		Dp* (Mgm^{-3})	Resistance^{++} (kgm^{-2})
				Sand	Silt	Clay		Overall	Fine earth		
I	1	12.2	1.58	58.6	18.4	23.0	32.8	1.59	1.04	2.67	18.0
	2	11.5	1.76	58.6	17.0	24.4	38.5	1.54	0.92	2.66	15.0
	3	10.8	1.44	61.3	18.0	20.7	26.6	1.58	1.14	2.68	15.7
	4	10.0	1.56	59.1	16.8	24.1	24.9	1.53	1.12	2.68	15.3
	5	10.6	1.43	53.7	19.0	27.3	23.0	1.45	1.08	2.92	8.7
	6	10.7	1.32	54.3	18.4	27.3	12.3	1.53	1.29	2.67	13.3
II	7	12.8	1.34	61.0	20.0	19.0	40.6	1.56	0.91	2.70	16.7
	8	12.8	1.50	64.0	15.7	20.3	37.5	1.61	0.99	2.69	21.3
	9	11.5	1.29	64.0	17.2	18.8	32.2	1.67	1.12	2.68	9.1
	10	10.7	1.33	60.1	20.5	19.4	30.3	1.53	1.04	2.68	10.7
	11	9.7	1.31	73.4	10.6	16.0	37.2	1.65	1.02	2.69	9.7
	12	9.5	1.32	68.4	13.6	18.0	25.5	1.52	1.11	2.66	13.0

Table 4b continued

Block	Plot	Slope (%)	% Org. Carbon	Mechanical Analysis(%)			Gravel (%)	Db (Mgm^{-3})		Dp* (Mgm^{-3})	Resistance++ (kgm^{-2})
				Sand	Silt	Clay		Overall	Fine earth		
III	13	6.9	1.28	64.2	15.2	20.6	23.0	1.54	1.17	2.65	11.3
	14	7.6	1.33	72.8	12.1	15.1	24.7	1.61	1.20	2.68	15.2
	15	7.7	1.39	72.0	12.6	15.4	19.1	1.73	1.39	2.67	12.5
	16	7.8	0.96	68.4	15.6	16.0	29.0	1.62	1.15	2.67	12.7
	17	8.9	1.11	73.3	12.7	14.0	12.3	1.71	1.49	2.70	10.0
	18	8.1	0.99	67.8	16.1	16.1	12.5	1.56	1.35	2.69	10.7

Particle density corrected for gravel content by the equation Dp = (Gravel fraction x 2.65 Mgm^{-3})

(Fine earth fraction x Dp not corrected for gravel) .... (4);

+, ++Penetrometer resistance readings taken when soil moisture content was 5–10% and 6–10%, respectively.

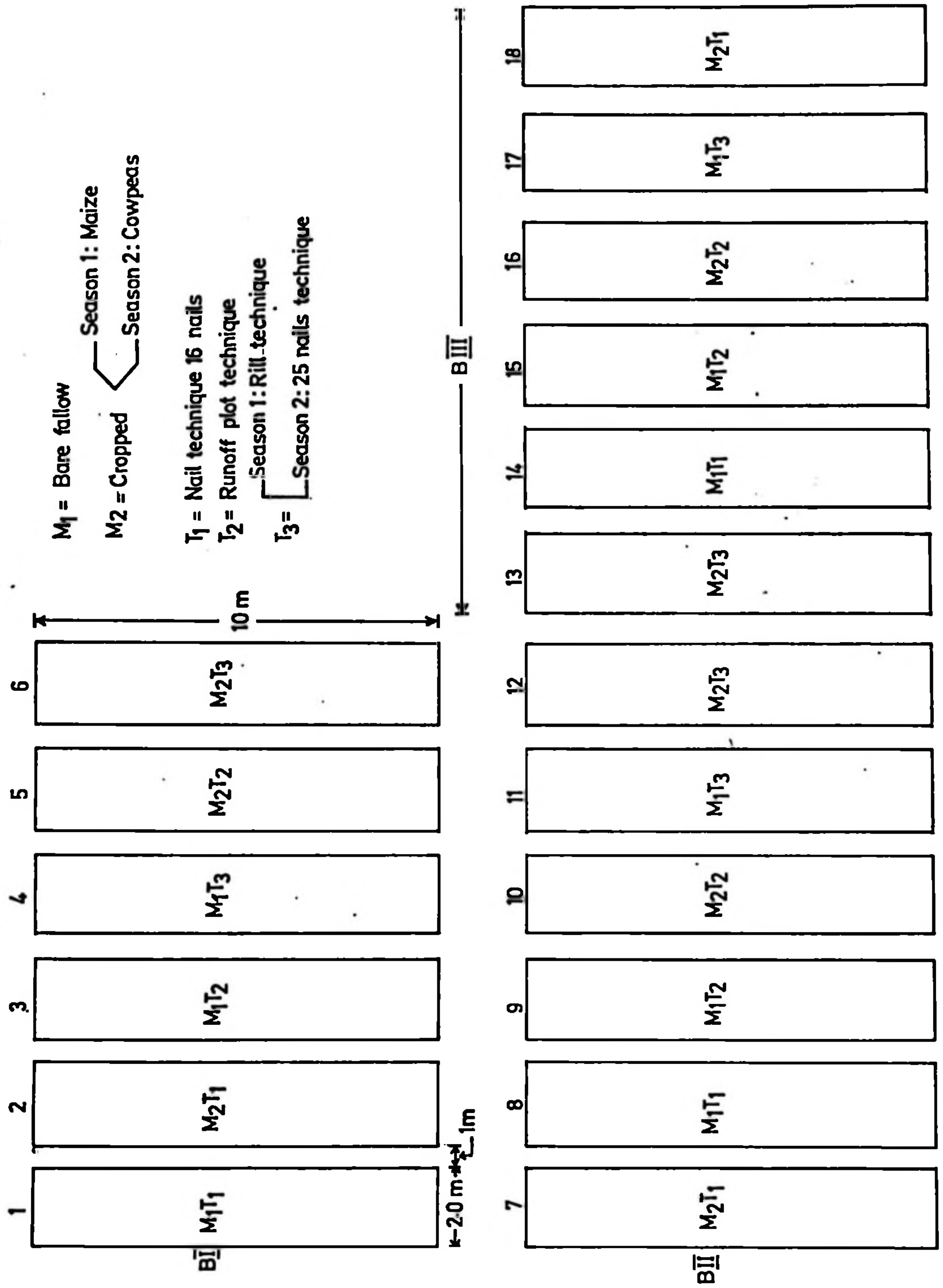


Fig. 3. Field experiment layout.

3.2.2 Treatment factors

There were two treatment factors, namely:

3.2.2.1 Soil surface management systems.

This treatment had two levels. Nine of the plots were kept under bare-fallow and designated management system 1 (M_1). The remaining nine were sown to maize in season 1 and cowpeas in season 2. This cropping system was termed management system 2 (M_2).

3.2.2.2 Erosion assessment techniques.

There were three erosion assessment techniques employed. Technique 1 (T_1) was assessment by use of 16 nails. The second technique, T_2, was soil erosion assessment by the conventional runoff plot technique (referred to as 'T_2' or 'Conventional technique'). In season 1 the Rill technique formed the third technique (T_3). In season 2, 25 nails technique was T_3.

3.2.3 Runoff and soil measuring system

Each plot was constructed with an impervious asbestos edging 30 cm below and 15 cm above ground on both sides to prevent runoff entering from outside (Lal, 1976a). The top edging consisted of 30 cm asbestos sheeting below the ground and a 15 cm-high earth embankment that made it possible to rotovate with a small tractor. Each plot was a complete drainage area. The plot edging was attached to a soil - and water - collection system at the lower side. Runoff passed through a multidivisor flume made of metal designed by Dr. R. Lal of the Soil Physics section of Farming Systems Programme and constructed by the

Physical Plant Services (PPS) workshop of IITA, Ibadan, Nigeria. The multidivisor flume is 50 cm long and 50 cm wide. It has a gate in the middle 10 cm that intercepts about 1/5 of the runoff and leads it into a 17-mm diameter hole in the divisor which has a hose connection that leads the runoff to a 230-l collection drum placed below ground at the lower side of the plot. The flume is designed such that part of the metal body in the upslope - side is bent downwards and buried to a depth of 15 cm to prevent any displacement from its installed position. Plate 1 shows a bare runoff plot with its runoff - and soil - collecting system.

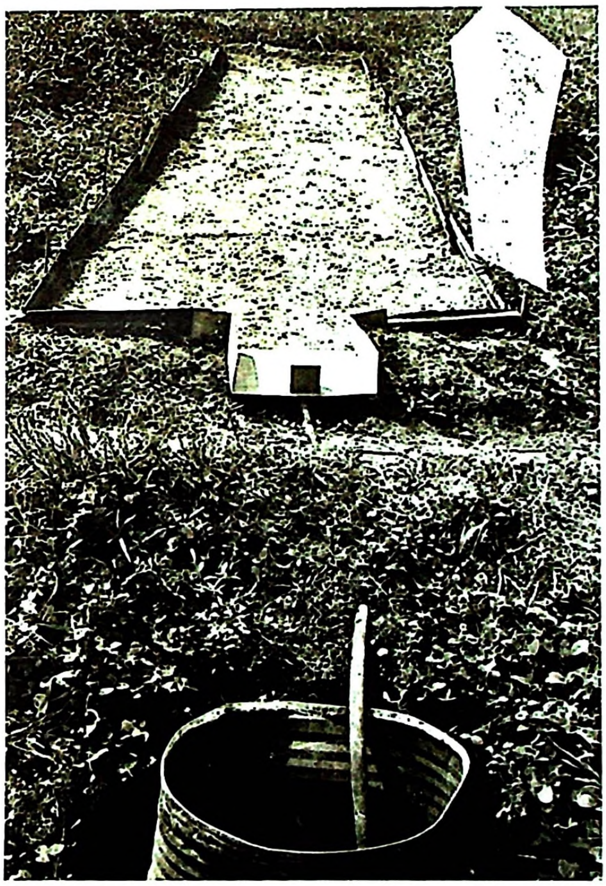


Plate 1: Bare runoff plot showing edging, multidivisor flume, hose attachment and collecting drum.

3.2.4. Weather station

A weather station was installed at the highest point within the same toposequence (about 300 m from the runoff plots). A self-recording rain - gauge (Belfort Model 5 - 780), an ordinary rain gauge, an American class A pan evaporimeter, a pyreliograph (Belfort), a hygrothermograph and an anemometer were installed in this station (Lal, 1976a).

3.3 Ploughing and crop establishment

In both season 1 and season 2 all plots were rotovated by a small tractor. Rotovation was done up and down the slope to permit maximum erosion. Half the plots were left as bare - fallow and half were cropped to maize - cowpea sequence. Two days before seeding, all plots were treated with the herbicide paraquat (1,1'-dimethyl -4, 4'- bypridinium ion) at the rate of 2.5 l ha^{-1}. Bare-fallow plots were always maintained free of weeds. Maize and cowpea were weeded as and when necessary.

3.3.1 Crop establishment in season 1

Maize (Zea mays L.) variety TZSR was seeded on 13 April, 1985 with a hand - operated jab planter. The crop was planted in lines running up and down the slope at a spacing of 75 cm by 25 cm, two seeds per hole. Two weeks after emergence, the seedlings were thinned to one plant per hole, giving a population of about 53,000 plants per hectare. The fertilizer was applied at 120 kg N ha^{-1} (40kg at planting and 80kg at 4 weeks) as urea; 13kg P ha^{-1}as single superphosphate; and 30kg K ha^{-1} as muriate of potash. The fertilizer mixture was band - applied to the maize plots. There were no major diseases or pests. Maize was harvested manually on 25 July, 1985, and grain yield was expressed at 14 per cent moisture content.

3.3.2 Crop establishment in season 2

Cowpea [*Vigna unguiculata* (L.) Walp.] variety TVx3236 was seeded in lines running up and down the slope on 8 August, 1985. Seeding was done with a hand operated jab planter. Cowpeas were spaced 75 x 20 cm, three seeds per hole. The seedlings were thinned to two per hill two weeks after seeding, giving a density of about 133 000 plants ha^{-1}. Fertiliser application for P and K was similar to that of maize, but only 30 kg N ha^{-1} was applied. Cowpea leaf - eating and pod - boring insects were controlled by weekly sprays of dimethoate (O, O - dimethyl S - methylcarbamoylmethyl phosphorodithioate) and decamethrin [(S) - α - cyano - m - phenoxybenzyl (1 *R*, 3 *R*) -3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane-carboxylate], at the rate of 1lha^{-1} & 0.5l ha^{-1}, respectively. The crop was harvested from 21 October to the end of the month. Grain yield was expressed as seed weight at 10 per cent moisture content.

3.4 Rainfall, runoff and soil loss data collection

In each plot water runoff and soil loss were determined by the conventional method. For the plots that had technique 1 (16 nails in both season 1 and season 2) and technique 3 (rill for season 1 and 25 nails for season 2) as treatments, therefore, there were two sets of soil loss measurements: one by the conventional technique, the other by technique 1 or technique 3. Soil erosion determined by the conventional technique was used as the basis for evaluating soil loss measured by other techniques, and for carrying out correlation and regression analyses. Only the soil loss was monitored by the nail and rill techniques. Data were collected after every rainstorm or a group of smaller storms for all except the rill technique. In the rill technique only one measurement was taken at the end of the season because the procedure was very long and tedious. However, a separate set of measurements was done on three bare plots, one plot in each block.

Computations of rainfall amount, intensity, kinetic energy and erosivity were based on information obtained from charts of the daily recording rain gauge. The rainfall charts analysed were those of erosive storms which occurred during the study period, when crops were in the field (April to July, August to October).

3.4.1 Erosivity indices

The following erosivity indices were determined.

3.4.1.1 Kinetic energy (E)

Kinetic energy was calculated relative to rainfall intensity using the modified Wischmeier and Smith (1978) equation (5.1) thus:

$E_1 = 11.9 + 8.7 \log I$ .... (5.1).

Where I = rainfall intensity in a segment of the rainfall chart, mmh^{-1}, and E_1 the kinetic energy in the same segment, $Jm^{-2}mm^{-1}$. The total energy for each segment was obtained by multiplying E_1 by the rainfall in the segment (Equation 5.2).

$$E\ (Jm^{-2}) = E_1(Jm^{-2}\ mm^{-1}) \times \text{Rainfall amount (mm)} \quad \ldots\ldots\ldots \quad (5.2)$$

where E is the total kinetic energy for each segment with units in Jm^{-2}.

3.4.1.2 EI_{30} (Wischmeier et al., 1958)

This index was calculated as the product of the total kinetic energy, E, of the storm and the 30 - minute maximum intensity, I_{30}. The 30 - minute maximum intensity was defined by Wischmeier (1959) as twice the maximum amount of rain falling in any 30 - minute period. The index was calculated as per equation 5.3:

$$EI_{30} = E \times I_{30} \quad \ldots\ldots\ldots\ldots \quad (5.3)$$

where E = total kinetic energy, Jm^{-2}, I_{30} = 30 - minute maximum intensity, mmh^{-1}, EI_{30} index = $Jm^{-2}\ mmh^{-1}$. EI_{30} index units were converted from $Jm^{-2}\ mmh^{-1}$ to $Jha^{-1}\ mmh^{-1}$ by multiplying by $10^4 m^2\ ha^{-1}$. These were later converted to 'convenient' sized numbers for individual storms and annual values (R) by dividing by $10^7\ mmh^{-1}$ giving EI_{30} in Jha^{-1}. Another procedure was to calculate I in cmh^{-1} and E in Jm^{-2} and then to divide EI_{30} by 100 cmh^{-1} to get R in Jm^{-2} which is the same value as R in Jha^{-1}.

$EI_{7.5}$ was calculated as 8 times the maximum amount of rain falling in any 7.5 - minute period.

3.4.1.3 AIm (Lal, 1976a)

This index was measured as the product of the maximum intensity, Im, in cmh^{-1} and the total rainfall, A, in centimeters. The annual index AI_m was calculated according to the equation (given in section 2.3.3 as Equation 2.7):

$$AI_M = \left[\sum_1^{12} \sum_1^{n} (ai_m) \right]$$

where a is the total rainfall in any one storm in cm and i_m is the maximum storm intensity in cmh^{-1} and n is the number of rainy days in the month. AI_M is in $cm^2\ h^{-1}$.

3.5 Erodibility indices

The following erodibility indices were computed:

3.5.1 Clay ratio, C.R. (Bouyoucos, 1935)

The C.R. index was calculated as (Equation 6.1):

$$C.R. = \frac{\%\ (Sand + Silt)}{\%\ Clay} \quad \ldots\ldots\ldots\ldots \quad (6.1)$$

where Sand was the fraction having a diameter of 0.05 to 2.00 mm, Silt = all fractions with a diameter of 0.002 - 0.05 mm; and clay particles were particles with diameter < 0.002 mm. Particle size determination was done by the pipette method (Day, 1965).

3.5.2 M - Parameter (Wischmeier and Smith, 1978)

The index 'M' is defined as (Equation 6.2):

$$M = \%(Silt + Very\ fine\ sand) \times \%(Silt + Very\ fine\ sand + sand > 0.10mm) \quad \ldots\ldots\ldots\ldots \quad (6.2)$$

3.5.3 Percent water-stable aggregates > 4 mm, WSA>4mm (Yoder, 1936)

The index WSA > 4 was computed as in equation 6.3

$$\text{WSA} > 4 = \frac{\text{Wt of aggregates in 4 mm sieve after wet sieving}}{\text{Wt of original sample}} \cdot 100 \quad \ldots\ldots(6.3)$$

Corrections for sand were made. The equation for WSA > 4 corrected for sand was:

$$\text{WSA} \quad 4 = 100 \left[\frac{(\text{Wt of aggregates + sand}) - (\text{Weight of sand})}{(\text{Wt of original sample} - \text{Wt of sand})} \right] \quad \ldots\ldots(6.4$$

3.5.4 Gravel content, G

This index was computed according to Equation (6.5):

$$G = \frac{\text{Wt of gravel (diam.} > 2.0 \text{ mm)}}{\text{Wt of test sample (i.e. Wt of gravel + fine earth)}} \cdot 100 \quad \ldots\ldots\ldots\ldots(6.5)$$

3.5.5. Mean weight diameter, MWD (Van Bavel, 1950)

The MWD index was calculated as (Equation 6.6):

$$\text{MWD} = \sum_{1}^{n} x_i \, w_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6.6)$$

Where x_i is the mean weight diameter of any size range of aggregates separated by wet sieving (Yoder, 1936) and w_i is the weight of aggregates in that size range as a fraction of the total dry weight. Correction for sand was done by subtracting the weight of sand from the weight of aggregates in each size range as well as from the total dry weight.

3.5.6 Geometric mean diameter, G.M.D. (Mazurak, 1950).

The G.M.D. was calculated according to equation 6.7:

$$GMD = \exp \left[\frac{\sum_{i=1}^{n} wi \log x_i}{\sum_{i=1}^{n} wi} \right] \quad \text{..........} \quad (6.7)$$

where wi is the weight of aggregates in a size class with average diameter x_i and $\sum_{i=1}^{n}$ wi is the total weight of the sample. Correction for sand was as in (3.5.5)

3.6 Chemical analysis

Organic carbon content of the soil was determined by the dichromate - oxidation method of Walkley and Black (1934)

3.7 Physical characteristics of the soil

3.7.1 Mechanical analysis

Particle size determination was done by the pipette method (Day, 1965).

3.7.2 Bulk density (Db)

Bulk density was determined by the core method (Blake, 1965a).

Overall bulk density was computed as:

$$Db = \frac{\text{Oven dry weight of whole sample}}{\text{Volume of core}} \quad \text{.........} \quad (7.1)$$

and expressed in Mgm^{-3}

Bulk density of the fine earth fraction was calculated after correcting for gravel content. It was calculated thus:

$$D_b \text{ (fine earth)} = \frac{\text{Oven dry weight of whole sample x fine earth fraction}}{\text{Volume of core}} \quad \ldots(7.$$

This was also expressed in Mgm^{-3}.

3.7.3 Particle density, D_p

Particle density was determined according to the Blake (1965b)method. The particle density reported is that corrected for gravel content. Equation (4) in section 3.1.3 indicates how the correction was done.

3.7.4 Infiltration

Infiltration rate was monitored in all plots before the experiment started in season 1, at the end of season 1 and at the end of season 2. The double-ring method was used. The outer cylinder (buffer) had a diameter of 30 cm and was 30 cm long; the inner ring had a diameter of 20 cm and was 25 cm long. Both rings were driven vertically into the ground to a depth of 10 cm. Water was introduced and maintained above the soil in both cylinders. The rate at which water in the inner cylinder was draining into the soil was measured using a stick and ruler. The recording was continued consecutively for 120 minutes at each station. Infiltration rate was calculated from the relationship:

$$i = St^{\frac{1}{2}} + At \quad \ldots\ldots\ldots\ldots\ldots (8) \quad \text{(Philip, 1957)}$$

where i = cumulative infiltration; S = Soil water sorptivity;
t = time; A = transmissivity

3.7.5 Penetrometer resistance

The penetrometer Model LC-2 (Soil Test Inc., IU. USA) was used for determining penetrometer resistance. The penetrometer dial gauge was set to zero and the instrument held in a vertical position. The cone point was slowly pushed into the soil at a constant rate. Readings were taken at 10 cm depth. After each reading the cone was withdrawn from the soil and cleaned. Five readings were taken in each plot and their average was taken as the penetrometer resistance for the plot. Penetrometer resistance was read directly in $kgcm^{-2}$.

3.8 Runoff and/or soil erosion monitoring techniques

3.8.1 Tracer technique

In the first season, the tracer method (Lewis, 1981) was tried. Beginning 5 m upslope from the apron of each plot assigned to this technique, aluminium paint was applied using a hand-held sprayer. The paint was applied as a 1- to 2- cm wide band perpendicular to the slope. After each rainstorm event the maximum straight line distance that the sprayed particles had moved from their previous location was measured using a metre rule which permitted accuracies up to 1 mm. This technique was abandoned because in most rainstorm events the sprayed particles were carried beyond the lower end of the plot, hence no measurements could be taken. Moreover, it was difficult to determine from what location the particle had come in subsequent rainstorms.

3.8.2 Technique 1: 16 nails technique

In this technique, ordinary galvanized iron nails were used. Nails were 10 cm long, of 4.7 mm diameter, and were painted with aluminium paint to prevent rusting. The nails were driven flush with ground surface after being placed in lines 3 m apart. Within - row spacing was 0.5 m. Fig. 4a shows nail arrangement in plots assigned to technique 1. (Figure 4b is referred to in section 3.8.4.2)

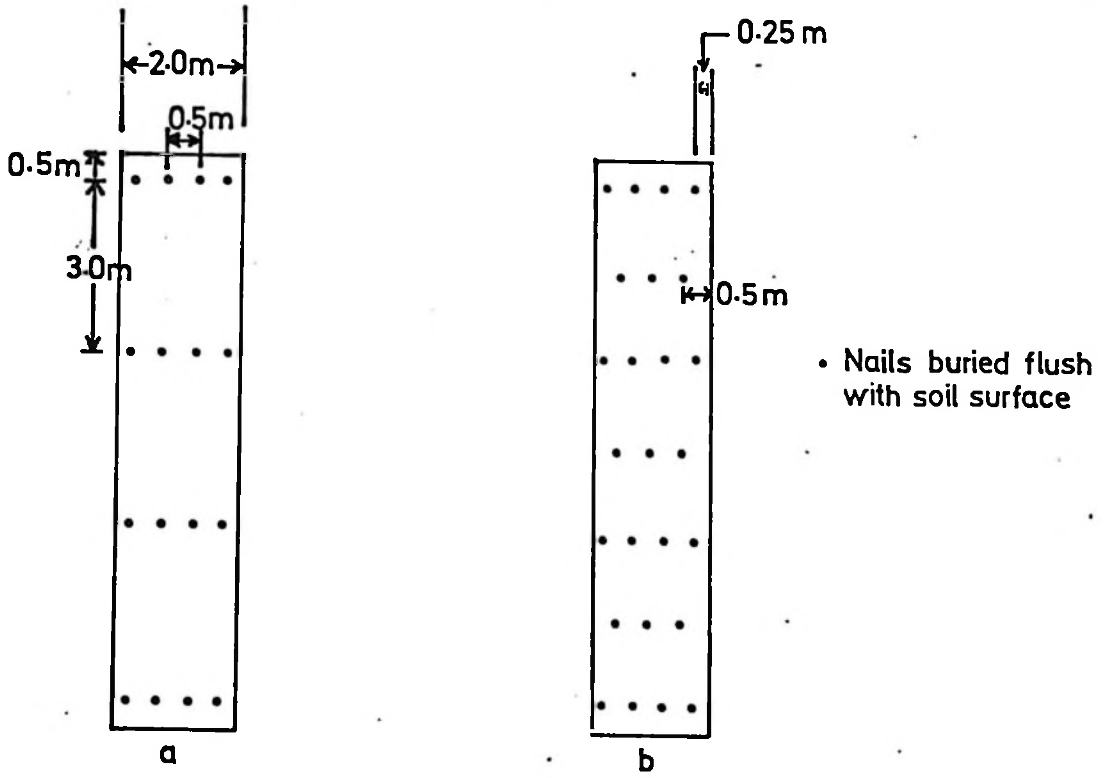


Fig. 4. Placement of nails in plots: (a) 16 nails (season 1). (b) 25 nails (season 2).

After each rainstorm or a group of smaller rainstorms the height of each nail above (or below) soil surface was measured using a small ruler. Measurements were taken to the nearest millimeter. Exposures (or burial) of all nails were summed up and soil loss was calculated as:

$$\text{Soil loss } (\mathrm{Mg}/20\mathrm{m}^2) = \frac{\text{Total expossure (mm)}}{16 \text{ nails}} \cdot \text{Plot area } (\mathrm{m}^2) \cdot \text{Bulk density } (\mathrm{Mgm}^{-} \quad \frac{1\mathrm{m}}{10^3\ \mathrm{mm}} \quad \ldots\ldots\ldots\ldots \quad (9.1)$$

where total exposure could be positive or negative depending on whether there was net exposure or burial, respectively.

After each measurement the nails were again set flush with soil surface.

3.8.3 Technique 2: Conventional runoff plot technique

The construction of the runoff plots is described in section 3.2.3 of this thesis.

Soil and runoff water from each plot was collected after every erosive rainstorm or a group of smaller storms. Runoff was measured volumetrically if it was not more than about 10 l. For high runoff events, the height of water in the drum was measured using a calibrated metre - rule and the volume of runoff calculated by the formula: Volume= $\pi r^2 h$, where r is the radius of the drum and h is the height of runoff water in the drum. The drum contents were then thoroughly stirred and a sample of about 500 ml was taken from the stirred contents. The runoff sample was taken to the laboratory for sediment concentration determination.

After the sample was taken, runoff water was poured out using a bucket and the soil in the drum was removed, weighed and a sample taken for moisture determination in order to arrive at oven-dry weight of the eroded soil. Soil on the flume was collected and its dry weight determined.

Calibration of the multidivisor flume was done by pouring 10 l of water at the entrance of the flume and the fraction collected in the drum. The amount collected in the drum was expressed as a fraction of the original 10 l and this fraction was used for calculating the total runoff as well as the total soil loss from the plot.

In the laboratory, the 500 ml runoff sample was filtered through a Whatman no. 42 ashless filter paper using a Buchner funnel and vacuum flask. The weight of the sediments was found and divided by 500 ml to find the sediment concentration. Sediment concentration was multiplied by total runoff to find total sediments in runoff water. The summation of total soil loss, collecting flume soil loss and total sediment in runoff water gave the grand total soil loss from the plot.

3.8.4 Technique 3

3.8.4.1 Rill technique

In season 1, technique 3 of estimating soil erosion was by the rill method.

Two sets of plots were used for monitoring soil loss by the rill technique because measuring the dimensions of rills is a very lengthy and tedious procedure. In the first set were the 6 regular plots (plots assigned to technique 3). In these plots only one reading was taken, at the end of the season. In the second set, three bare plots, one in each block, were used for monitoring erosion by the rill technique. In this latter set erosion was monitored after every heavy rainstorm. A total of 10 measurements were taken on the three bare plots.

Before taking the dimensions of the rills, each plot was divided into five equal segments of 2 meters each by drawing faint lines across the plot. Water rills were located on each segment by visual inspection. The average length, width and depth of each rill in all segments was measured using a metre - rule accurate to 1 mm. The volume of each rill was calculated as a product of its length, width and depth. The summation of the volume of all rills gave the volume of soil lost from each plot. Soil loss from each plot was calculated as:

Total volume of rills x Bulk density of the soil, and reported in Mg/20 m^2

3.8.4.2 25 nails technique

In season 2, technique 3 was the monitoring of soil erosion using 25 nails. The nails were 10 cm long, 4.7 mm in diameter and were painted with aluminium paint to avoid rusting. They were driven flush with the soil surface. Fig. 4b in section (3.8.2) shows how the nails were laid out in the field. After each erosive storm or a group of smaller storms, the height of each nail above or below soil surface was measured. This was referred to as "nail exposure" and it had a positive value if the nail was exposed above the ground, and a negative if the nail was buried. If there was neither exposure (above soil surface) nor burial of the nail, "nail exposure" had a value of zero. The summation of "nail exposure" for all nails in a plot gave total nail exposure, which was used for calculating soil loss according to Equation 9.2:

$$\text{Soil loss } (\text{Mg}/20\text{m}^2) = \frac{\text{Total nail exposure (mm)}}{25 \text{ nails}} \times 20\text{m}^2 \times D_b(\text{Mgm}^{-3}) \times \frac{1\text{m}}{10^3\text{mm}} \quad \ldots(9.2$$

After each measurement the nails were again driven flush with the soil surface.

3.8.5 The USLE technique

Soil loss was estimated by the Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith (1965) according to the equation:

$A = R.K.LS.C.P$ (Equation 1.1, quoted in section 2.1)

where A = estimated average annual soil loss; Mgha^{-1}

R = rainfall erosivity index; Jha^{-1}

K = soil erodibility factor; MgJ^{-1}

LS = slope length and steepness factor; dimensionless

C = crop cover and management factor; dimensionless

P = erosion - control - supporting (conservation) practice factor; dimensionless.

R was computed as a product of the kinetic energy, E, and the maximum 30 - minute intensity, I_{30}. Equations for computing E, EI_{30} and R indices are given in sections 3.4.1.1 and 3.4.1.2 of this report.

Estimates of K value used in the USLE were made using the nomogram developed by Wischmeier *et al.* (1971) modified to give K in SI units (Troeh *et al.*, 1980).

The LS factor was calculated from the relationship;

$LS = \left[\frac{\text{Field slope length}}{22.1}\right]^m (0.065 + 0.045s + 0.0065s^2)$ as defined in section 2.1, Equation 1.4

Soil erosion estimation by the USLE technique was conducted only on bare - fallow plots, hence C and P factors had the value 1.0 each. Annual soil loss from bare - fallow plots were thus estimated according to equation 9.3:

$A = R.K.LS$ ....(9.3)

where A, R, K, LS are as defined above.

'Measured' K values for bare - fallow plots were computed from field soil loss according to Equation 9.4:

$K = \frac{A}{R.LS}$ ....(9.4)

where K = erodibility index, MgJ^{-1}; A = measured annual soil loss, $Mgha^{-1}$; R = erosivity index, Jha^{-1} and LS = slope length and steepness factor for each plot; dimensionless.

3.9 Analysis of results

The 'GENSTAT' computer programme (Alvey et al., 1980) was adopted for statistical analyses. Soil loss determined by the various techniques was subjected to analysis of variance in the randomized block design format (Alvey, 1981).

3.9.1 Analysis of variance was performed in order to determine the effect of the different treatments on soil loss and runoff.

3.9.2 Paired t - tests (Little and Hills, 1978) were performed to compare means of soil loss determined by conventional versus (vs) 16 nails technique; conventional vs rill technique; and conventional vs 25 nails technique. A t - test for independent samples was done for comparing means between the 16 nails and 25 nails techniques.

3.9.3 Regression and Correlation Analysis

Regression and correlation analyses were carried out to test the relationship between soil loss and runoff, soil loss and erosivity indeces, soil loss and erodibility indices, runoff and erosivity indices, rainfall and runoff, rainfall and soil loss, and rainfall and erosivity indices.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Rainfall

Data on rainfall amount and intensity, runoff and soil loss for individual rainstorms during the study period are shown in Appendix Ia and Ib.

During season 1 there were 642 mm of rainfall from 21 rainstorms which fell between 01 May and 20 July. Forty - eight per cent of the storms fell within 1 to 3 days of each other, 48 per cent fell at an interval of 4 to 7 days while 4 per cent were separated from one another by more than 7 days.

Fig. 5 shows the frequency distribution of rainfall intensity for season 1 and 2. During the first season, the 7.5 - minute maximum intensities of 67 per cent of the rainstorms were greater than 25 mmh^{-1} compared to 64 per cent of the rainstorms in season 2. The 7.5 - minute maximum intensities of 38.5% of the rainstorms in season 1 and 32% of those during season 2 were greater than 50 mmh^{-1}. Intensities exceeding 75 mmh^{-1} were recorded for 10% of the rainstorms during season 1 and 16% of those during season 2. The 7.5 - minute maximum intensities of 5% of rainstorms in season 1 and 8% of the storms in season 2 were more than 100 mmh^{-1}. In season 1, 5 per cent of the rainstorms had a 7.5 - minute maximum intensity of between 150 and 175 mmh^{-1}. This finding confirms that tropical storms are usually very intense. Wilkinson (1975a) and Lal (1976c) reported peak rainfall intensities exceeding 200 mmh^{-1} in southwestern Nigeria. Kampen (1974) reported intensities of 85-100 mmh^{-1} sustained for 30 minutes in Hyderabad, India. Ramaiah and Sreenivas (1975) reported I_{30} values of 84 mmh^{-1} in the Mysore region of southern India. Rains as intense as 100 mmh^{-1} are common in Sri Lanka (Joshua, 1977). These intensities are much higher than those in temperate climates and may be the reason for the high soil erosion observed in the tropics.

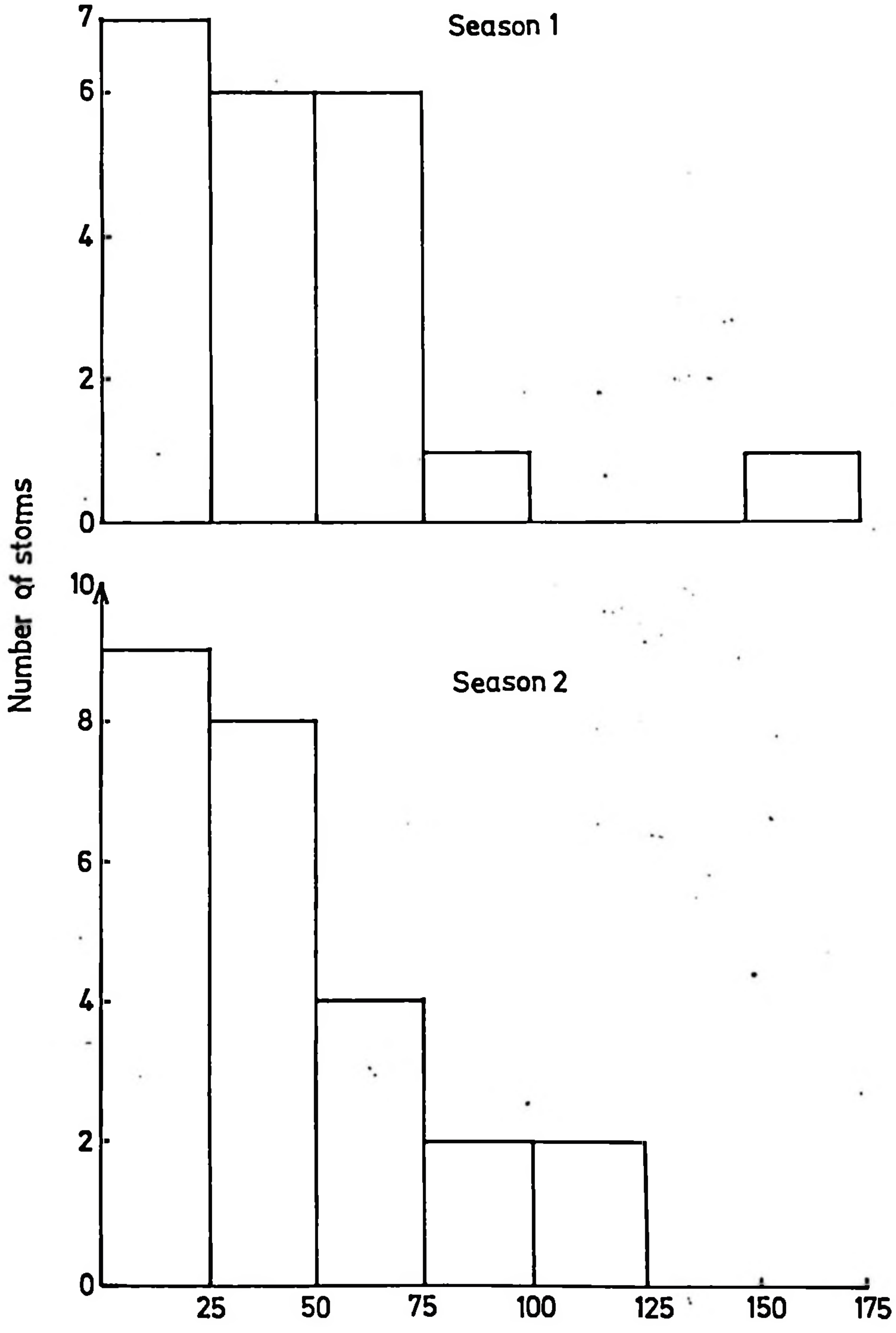


Fig. 5. Rainfall intensity distribution of storms for the first and second season.

There was significantly more runoff from bare - fallow plots than from maize plots (1% level) in season 1 (Table 5).

Table 5. Effect of surface management and soil erosion assessment techniques on surface runoff (mm), determined by the conventional technique, season, 1^{+}

		Technique^{ns}			Mean	
		Nail	Conventional	Rill		
Management**	Bare	315.9	317.3	302.6	311.9	S.E.±11.9
	Maize	198.1	180.5	168.5	182.4	
	Mean	257.0	248.9	235.6	247.2	
		S.E. ± 14.6				

S.E. of an interaction mean = ± 20.6

+Average of 3 replications; **Significant at P 0.01; ^{ns}Nonsignificant at P 0.05

Total runoff from bare plots was 310 mm, or about 48 per cent of total rainfall during the period under study (Appendix Ia). Runoff from maize plots was about 182 mm accounting for about 28 per cent of total rainfall for the same period. When rain falls on a bare surface it tends to batter the soil surface thus sealing off soil pores (Duley, 1939; Ellison and Slater, 1945). Sealed pores do not allow water to infiltrate hence it leaves the plot as surface runoff (Mc Intyre, 1958; Tackett and Pearson, 1965). Surface soil in a plot under vegetative cover, however, is not subjected to beating by raindrops. As a result, most of the soil voids in a vegetated soil allow water to infiltrate thus minimizing surface runoff. Moreover, some crop débris on the soil surface tends to impede water running on the surface, giving it more time to infiltrate. This does not happen in a bare soil surface. Generally, runoff is low in vegetated surfaces because rates of infiltration of water through the vegetated surfaces are high compared to those on bare soil (Woodward, 1943). Many researchers (Baver, 1956; Rege, 1959; Meyer et al., 1975; De Vleeschauwer, 1978; Lal & Akinremi, 1983) have reported that a soil under a crop or vegetative cover is a good habitat for macrofauna. Soil macrofauna such as earthworms loosen the soil and make it porous such that water is facilitated to infiltrate into the soil rather than become a part of overland flow (Lal and Akinremi, 1983). This is the reason for the observed large quantities of runoff in bare - fallow plots and less runoff in maize plots. Another reason for the generally high runoff percentage is the short time lapse between subsequent rainstorm events. A dry soil has a higher affinity for water than a saturated one.

In season 2 rainfall was lower than in the first season. There were about 499 mm of rain between 17 August and 15 October, 1985 (Appendix Ib). Bare plots lost about 51 per cent of rainfall (252 mm) as surface runoff. A total of 149 mm was lost from cowpea plots, accounting for about 30 per cent of the rainfall during the season. About 88 per cent of the rainstorms occurred within 1 to 3 days of each other; 8% within 4 to 7 days and only 4 per cent fell within more than 7 days of each other.

High rainfall intensity was probably a major contributing factor to higher percentage runoff along with the more closely spaced rainstorm events in season 2 than in season 1. Soil which is already wet when rain falls upon it will attain its final infiltration rate quickly and start losing excess water as overland flow. Shaxson (1975) points out that high antecedent soil moisture in the soil profile can hinder acceptance of large volumes of incident rainfall, causing surface runoff.

Table 6 shows correlation coefficients and simple linear regression equations of runoff with rainfall amount for bare and cropped plots in the two seasons.

Table 6. Correlation coefficients and simple linear regression for runoff in bare and cropped plots with rainfall amount

Surface cover	Season	Regression equation	r
Bare	1	$Y = 0.55X - 2.80$	0.94**
Maize crop	1	$Y = 0.50X - 6.04$	0.90**
Bare	2	$Y = 0.56X - 1.24$	0.97**
Cowpea crop	2	$Y = 0.49X - 4.83$	0.89**

WHERE Y is the dependent variable, runoff (mm of runoff)

X is the independent variable, rainfall amount (mm)

r is the correlation coefficient; ** Significant at 1% level.

In both seasons runoff was highly (1% level) and positively correlated with rainfall in both bare plots and plots under maize or cowpeas. The correlation coefficients were higher on bare plots than on plots under maize or cowpeas explaining 88 per cent of the variations in runoff in bare plots and about 81% of the observed variations in runoff in plots under maize in season 1. In the second season rainfall explained 94% of the observed variations in runoff in bare plots and 75% in plots under cowpeas. This indicates that one can predict the amount of runoff from rainfall more accurately in bare plots than in plots under either maize or cowpeas. The intercept was more negative in plots under maize and cowpeas than in bare - fallow, implying that more rain would have to fall before it caused runoff in plots under a crop compared to the amount of rainfall required to initiate runoff in bare - fallow plots.

The higher regression coefficients in bare - fallow plots than those for plots under crops in both seasons imply that a unit increase in rainfall amount would cause more runoff in bare - fallow than in plots having a crop. This is in agreement with the results that there was significantly more runoff in plots maintained under bare - fallow than in those under either maize or cowpeas. Ngatunga _et al._ (1984) conducted experiments on three soils in Tanzania, maintained some plots as bare - fallow and others under mulch or grass cover. They recorded significantly more runoff in bare - fallow than in plots under mulch or grass cover. Similar results have been reported by several authors (Baver, 1956; Hudson, 1957; Singh _et al._, 1967; Battawar and Rao, 1969; Elwell and Stocking, 1974; Babalola and Chheda, 1975; Lal, 1976a; Aina _et al._, 1977; Obi, 1982).

4.2 Soil erosion

4.2.1 Season 1

4.2.1.1 Conventional technique

The mean soil loss determined by the conventional technique was used for determining the effect of management and techniques on soil erosion. Soil erosion from bare plots differed significantly (1% level) from that under maize (Tables 7a, 7b). This indicates the influence of soil surface management on soil erosion. Bare - fallow plots sufferred more erosion because they had no vegetal cover. Meyer et al. (1975) reported that a crop canopy was able to dissipate raindrop impact energy and decrease rill erosion to half that without canopy cover. Young and Wiersma (1973) argued that a canopy that protects the soil from raindrop impact reduces soil detachment and transport. Baver (1956) pointed out that vegetative cover reduces erosion and runoff through interception by the canopy, decreasing velocity of runoff and cutting action of water, root effects in increasing granulation and porosity, biological activities associated with vegetation and influence on porosity and transpiration of water leading to subsequent drying out of the soil. These views are shared by many (Rege, 1959; Singh et al., 1967; Battawar and Rao, 1969; Elwell and Stocking, 1976; Lal, 1976b; Aina et al., 1977; Lal, 1983a; Lal and Akinremi, 1983).

The data in Tables 7a and 7b show that there was no significant effect (5% level) of erosion assessment techniques on the magnitude of soil loss and there existed no interaction between management and techniques. These results indicate that the techniques employed in assessing soil erosion had

Table 7a. Analysis of Variance over effect of surface management and erosion assessment techniques on soil loss ($Mgha^{-1}$) determined by the conventional technique, season 1^{+}

Source of variation	DF	SS	MS	F_H
Block stratum	2	1 079.4	539.7	
Block * Plot stratum				
Management	1	57 664.1	57 664.1	197.631**
Techniques	2	1 204.8	602.4	2.065^{ns}
Managem. * Techn.	2	1 307.2	653.6	2.240^{ns}
Residual	10	2 917.8	291.8	
Total	15	63 093.8	4 206.3	
Grand Total	17	64 173.8		

Blocks S.E. = 9.48; C.V. % = 9.8; Block * Plot: S.E. = 17.08, C.V. % = 17.7; $^{+}$Average of 3 replications; **Significant at 1% level; ^{ns}Nonsignificant (5% level)

Table 7b. Effect of surface management and soil erosion assessment techniques on soil loss ($Mgha^{-1}$) determined by the conventional technique, season 1^{+}

		Technique^{ns}			Mean	
		Nail	Conventional	Rill		
Management**	Bare - fallow	176.1	147.5	136.4	153.3	S.E. ± 8.1
	Maize	39.6	40.6	40.2	40.1	
	Mean	107.8	94.1	88.3	96.7	
		S.E. ±	9.9			

S.E. of an interaction mean = ± 14.0 (C.V. = 17.7%)

$^{+}$Average of 3 replications; **Significant at 1% level; ^{ns}Nonsignificant (5% level) no influence on the magnitude of soil erosion and did not interfere with the erosional processes.

Analysis of variance on soil loss assessed by the different techniques indicated that surface management systems, erosion assessment techniques as well as interactions differed significantly (1% level, Table 8). For example, there was more soil loss in bare - fallow than in maize plots. Erosion assessment by the nail technique did not differ significantly from that measured by the conventional technique but both differed significantly (5% level) from the rill technique (Fig. 6)

Table 8. Analysis of Variance over soil loss determined by three techniques, season 1[a]

Source of Variation	DF	SS	MS	F_H
Block Stratum	2	392.8	196.4	335.848**
Block × Plot Stratum			-	
Management	1	46 309.4	46 309.4	335.848**
Techniques	2	6 995.5	3 497.8	25.367**
Management × Techn	2	5 006.0	2 503.0	18.153**
Residual	10	1 378.8	137.9	
	15	59 689.8	3 979.3	
Grand Total	17	60 082.6		

Blocks: SE = ± 5.72, CV% = 6.4; Block * Plot: SE = ± 11.74, CV% = 13.2

[a] Average of 3 replications. **Significant at 1% level

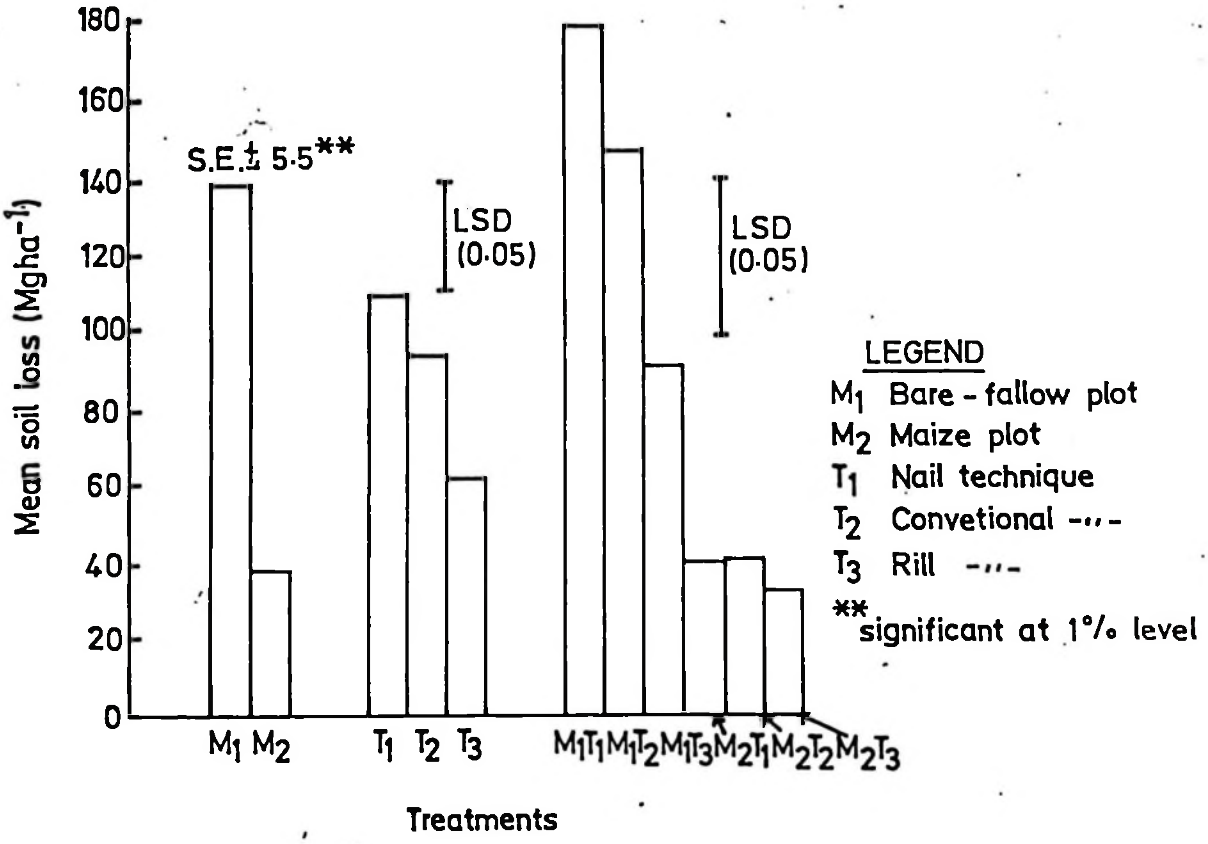


Fig.6. Mean soil loss from bare - fallow and maize plots measured by different techniques, season 1.

4.2.1.2 Conventional vs nail, rill and USLE techniques

T-tests for paired samples were carried out for soil losses recorded in season 1 by nail versus conventional method on the same plot $^{(T_1)}$ and rill versus conventional on same plot (T_3). There were no significant differences in the soil loss by nail and conventional method in bare, maize (or combination) plots. Soil loss measured by rill method was significantly lower (1% level) than that determined by the conventional method (Tables9a-d)

Table 9a Paired t-test for soil erosion in bare plots determined by nail and conventional techniques, season 1[a]

	Nail (Mgha^{-1})	Conventional (Mgh^{-1})	Difference (Mgha^{-1})	t_H
Sum	528.2	538.0	-9.8	
Mean	11.0	11.8	-0.2	1.22^{ns}

[a] Measurements for 16 rainstorms, 48 observations;

[ns] Nonsignificant (5% level)

Table 9b Soil erosion in maize plots, measured by nail vs by conventional technique, season 1[a]

	Nail (Mgha^{-1})	Conventional (Mgha^{-1})	Difference (Mgha^{-1})	t_H
Sum	118.7	120.2	-1.5	
Mean	2.5	2.5	0.0	0.238^{ns}

[a] Measurements for 16 rainstorms, 48 observations; [ns] Nonsignificant (5% level)

Table 9c. Soil erosion in bare and maize plots measured by rill and conventional techniques[a]

	Rill ($Mgha^{-1}$)	Conventional ($Mgha^{-1}$)	Difference ($Mgha^{-1}$)	t_H
Sum	373.9	529.9	-156.0	
Mean	62.3	88.3	- 26.0	3.02*

[a] Measured on 6 plots at the end of the season

*Significant at 5% level

Table 9d. Soil erosion in bare - fallow plots by the rill and conventional techniques[a]

	Rill ($Mgha^{-1}$)	Conventional ($Mgha^{-1}$)	Difference ($Mgha^{-1}$)	t_H
Sum	304.5	528.2	-223.7	
Mean	10.2	17.6	- 7.4	5.485**

[a] Measured on 3 plots, 10 rainstorm events

**Significant at 1% level

Appendix 3 shows values of the LS factor and K index for the two seasons. The 'Estimated' K values were obtained using the nomogram developed by Wischmeier et. al. (1971). 'Measured' K values are those computed from the relationship between seasonal soil loss and LS factor, R factor, C factor and P factor. Only K values for bare plots were measured. Table 10a shows soil loss assessed by the USLE and conventional techniques, in season 1.

Table 10a. Soil loss from bare - fallow plots assessed by the USLE (Estimated) and conventional runoff plot technique (Measured), season 1$^+$

Block No.	Plot No.	R Jha^{-1}	Estimated K MgJ^{-1}	LS	Soil loss $Mgha^{-1}$ Estimated	 Measured	 Difference
I	1	960.85	0.164	1.01	159.16	202.82	-43.66
	3	- " -	0.138	0.87	115.36	147.59	-32.23
	4	- " -	0.142	0.82	111.88	152.43	-40.55
II	8	- " -	0.165	1.18	187.08	196.08	- 9.00
	9	- " -	0.157	1.00	150.85	147.65	3.20
	11	- " -	0.122	0.81	94.95	124.69	- 29.74
III	14	- " -	0.153	0.54	79.39	129.32	-49.93
	15	- " -	0.152	0.56	81.79	147.40	-65.61
	17	- " -	0.157	0.64	96.55	132.13	-35.58

Table 10 b. Paired t-test for soil loss ($Mgha^{-1}$) determined by the universal soil loss equation and conventional runoff plot techniques, season 1$^+$

	Technique USLE	 Conventional	Difference	t_H
Sum	1 077.0	1 380.1	-303.1	
Mean$^+$	119.7	153.4	- 33.7	4.88**
			S.E. ± 13.3	

$^+$Average of 9 repetitions

**Significant at 1% level

Soil loss estimated by USLE was significantly lower (1% level) than that measured by the conventional technique (Table 9b). Soil erosion is a function of both soil erodibility and rainfall erosivity. The lower soil loss quantities estimated by the USLE may be as a result of lower estimated R and K values. Lal (1976a) and Hudson (1965) have reported that R index used in the USLE underestimates the erosivity of tropical rainstorms. A lower R value leads to lower soil loss estimates. In season 1, estimated K values ranged from 0.122 to 0.164 MgJ^{-1} while the measured K values ranged from 0.154 to 0.274 MgJ^{-1} (Table 9a). The nomogram overestimated K factor in only 1 out of 9 plots, and underestimated it in 8 out of 9 plots. The lower measured K factor probably led to the significantly lower estimated than measured soil loss. The results in the present study are similar to those reported by Ngatunga et al. (1984) who conducted their study on three soils in Tanzania and found that K factors estimated by the nomogram were lower than the measured K. Wilkinson (1975a), however, reported the estimated K for an alfisol in western Nigeria was greater than the measured K. He attributed the low measured erodibility to the presence of gravel and coarse sand. Data from the study of De Vleeschauwer et al. (1978) who studied detachability of 8 Nigerian soils showed that the estimated K values did not compare well with the simulator - determined K factor. Data reported by Mondjalis et al. (1981) in Zaire indicate that the nomogram underestimated erodibility. In Trinidad, Lindsay and Gumbs (1982) indicated that the nomogram may overestimate erodibility. Vanelslande et al. (1984) observed that the nomogram overestimated erodibility in two out of three soils they studied in Nigeria. The nomogram overestimated erodibility of a Rhodoustalf and an Oxic Paleustalf while it underestimated the K value of a Paleudult.. All these results indicate that the estimation of soil erosion rates by the universal soil loss equation using nomogram - computed K values and R suggested by Wischmeier and Smith (1978) may not always be accurate. The erosivity factor R and erodibility index K need to be modified so that they realistically reflect the erosivity of tropical rainstorms as well as the erodibility of soils in the tropics for meaningful erosion estimates by the USLE.

The results from the present study also show that soil loss estimated by the nail technique does not differ significantly from that determined by the conventional runoff plot technique. The nail technique proves to work equally well in both bare plots and for estimating erosion under maize crop. Therefore, use of nails seems to be a promising technique for assessing soil erosion.

The rill technique, on the other hand, greatly underestimated soil erosion as compared with the conventional technique. Soil erosion measurements were low both when only one reading was taken on six plots at the end of the season and when ten readings were taken on three plots during the study period. Several factors may have led to this underestimation. Runoff does not cause rills until the flow's shear characteristics exceed soil's resistance to them and the flow's transport capacity is greater than the available detached material (Meyer _et al_., 1975; Meyer, 1981). For the above to occur, the slope must be long. It seems the 10 - m plot length was not enough to allow concentration of runoff capable of forming many prominent rills. Gerasimenko (1980) monitored soil erosion by the water rills technique on slopes that were 100 to 400 m long in Russia. Gerasimenko concluded that the method was very objective and practical but cautioned, however, that for greater accuracy one must have many measurement sites along the slope as well as many depth measurements in the cross section of a microchannel. Another problem with the rill technique is the fact that it does not estimate soil loss from inter-rill areas. Soil loss by sheet wash can not be detected by the rill technique.

The USLE greatly underestimated soil loss. The low nomogram - estimated K values led to the low estimated soil loss. The nomogram is not a reliable method of quantifying the erodibility of tropical soils. El - Swaify et al. (1982) point out that erodibility values for tropical soils vary so widely that to describe the soils categorically as resistant to erosion is misleading. Of particular interest is the fact that soils in the same order but studied at different locations display wide discrepancies. For example, in both Hawaii and Puerto Rico (Dangler and El - Swaify, 1976; Barnett et al., 1971) it was found that Ultisols were very resistant to erosion as indicated by their low K values. In contrast, in Central America and Venezuela (Popenoe, 1976; Pla, 1977) Ultisols covered a wide range from "extremely low" to "extremely high" erodibility. It is evident that more detailed studies are needed to determine which parameters are strongly related to erodibility of tropical soils before the Universal soil Loss Equation can accurately predict soil erosion in the tropics.

4.2.2 Season 2

In the second season, cowpeas were grown in plots that were under maize the previous season. Techniques 1 and 2 were as in Season 1. Technique 3 was by the 25 nails technique. After noting that the nail technique worked well in the first season, it was thought important to test it further. Moreover, it was thought that by increasing the number of nails per plot, to a certain extent, the sensitivity of the technique could be increased. For example, if a soil has a bulk density of 1.32 Mgm^{-3}, and the total nail exposure from both 16 nails and 25 nails per $20m^2$ is 1 mm, the detectable soil loss from:

(a) $$16 \text{ nails} = \frac{1mm}{16} \times 20m^2 \times \frac{1.32\ Mg}{m^3} \cdot \frac{1m}{10^3 mm} \times \frac{10^3 kg}{Mg}$$

$$= \underline{1.65 kg/20m^2}$$

(b) $$25 \text{ nails} = \frac{1mm}{25} \times 20m^2 \times \frac{1.32Mg}{m^3} \times \frac{1m}{10^3 mm} \times \frac{10^3 kg}{Mg}$$

$$= \underline{1.06 kg \text{ per } 20m^2}$$

implying that 25 nails can detect smaller changes in surface elevation than the 16 nails technique.

Soil loss in bare - fallow plots was significantly higher than in plots under cowpeas (1% level) when Analysis of Variance was performed on soil loss by the conventional method. (Table 11a). Erosion assessment techniques had no effect on soil loss. There was no interaction between surface management and assessment techniques (Table 11a, 11b).

Table 11a. Analysis of Variance on the effect of surface management and erosion assessment techniques on soil loss ($Mgha^{-1}$) determined by the conventional technique , season 2^{+}

Source of Variation	DF	SS	MS	F_H
Block stratum	2	100.34	50.17	
Block X Plot Stratum				
Management	1	10 570.09	10 570.09	360.965**
Technique	2	41.39	20.69	0.707^{ns}
Managem. X Techn.	2	66.03	33.02	1.127^{ns}
Residual	10	292.83	29.28	
Total	15	10 970.34	731.36	
Grand Total	17	11 070.68		

Blocks: S.E. = 2.89, C.V. % = 4.6; Block X Plot: S.E. = ± 5.41, C.V. % =8.

$^{+}$Average of 3 replications; **Significant at 1% level; ^{ns}Nonsignificant (5% level)

Table 11b. Effect of surface management systems and erosion assessment techniques on soil loss ($Mgha^{-1}$), determined by the conventional technique, season 2^{+}

		Technique ^{ns}				
		16 Nails	Conventional	25 Nails	Mean	
Management**	Bare-fallow	90.7	98.1	82.9	87.6	S.E.±2.6
	Cowpeas	38.0	39.8	39.5	39.1	
	Mean	64.3	64.5	61.2	63.3	
			S.E. ± 3.1			

S.E. of an interactive mean = ± 4.42; C.V. = 8.5%

[+] Average of 3 replications; **Significant at 1% level;

[ns] Nonsignificant (5% level)

When soil loss measured by each method was subjected to analysis of variance, there were no main effects of the three techniques, namely 16 nails, conventional runoff plot and 25 nails techniques. There was also no interaction. Like in season 1, however, there was a highly significant difference in soil loss (1% level) recorded in bare - fallow plots compared to that recorded in plots under cowpeas. This result is depicted in Appendix IVa.

Plate 2 shows a bare plot (a) and a plot under cowpeas (b) adjacent to each other. These pictures were taken at the same time, 54 days after planting. Whereas the bare-fallow plot is devoid of vegetative cover, the cropped plot is very well protected from rainfall beating by the dense cowpea canopy. No wonder there was very significantly more erosion in the bare plots.

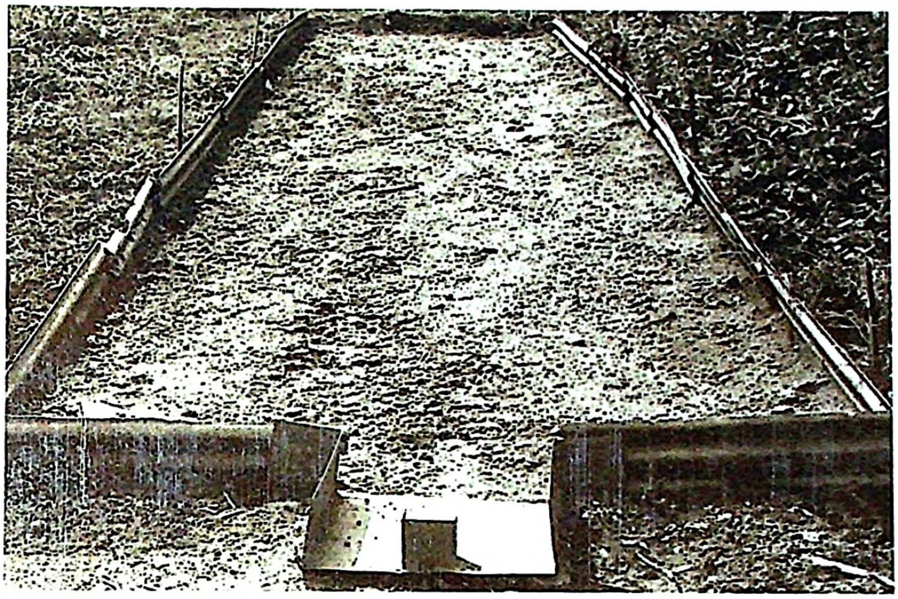


Plate 2 Runoff plots: (a) bare (b) under cowpeas 54 days after seeding.

Tables 12a, 12b and 12c show results of t-tests performed on the differences of means between soil loss determined by the 16 nails vs conventional, 25 nails vs conventional and 16 nails vs 15 nails techniques, respectively, in season 2, 1985.

When a paired t-test was performed between 16 nails and conventional technique as well as between the 25 nails technique and the conventional method there was no significant difference (5% level; Table 12a, 12b).

Table 12a. Paired t-test for soil loss determined by 16 Nails and Conventional runoff plot techniques, season 2⁺

	Technique			
	16 Nails	Conventional	Difference	t_H
Sum	399.0	386.1	12.9	
Mean	4.4	4.3	0.1	1.788^{ns}

S.E. ± 0.2

Table 12b. Paired t-test for soil loss determined by 25 Nails and Conventional runoff plot techniques, season 2⁺

	Technique			
	25 Nails	Conventional	Difference	t_H
Sum	377.3	367.1	10.1	
Mean	4.2	4.1	0.1	1.592^{ns}

S.E. ± 0.2

⁺Average of 90 repetitions ^{ns}Nonsignificant (5% level)

The lack of significant differences implied that both the 16 and 25 nails techniques were as good as the conventional technique in estimating soil loss. Since 16 nails and 25 nails were used to estimate soil erosion in different plots, their means were compared by the independent t-test. There was no significant difference between the two techniques (Table 12c).

Table 12c. t-test for independent samples for soil loss determined by 16 Nails and 25 Nails techniques, season 2[+]

	Technique			
	16 Nails	25 Nails	Difference	t_H
Sum	399.0	377.3	21.7	
Mean	4.4	4.2	0.2	0.628^{ns}

S.E. ± 0.4

[+] Average of 90 repetitions; ns Nonsignificant (5% level)

This was true in both bare - fallow as well as cowpea plots. This result shows that using 16 nails is as good as using 25 nails in these plots. It is, therefore, rational to use 16 nails on plots of 20m^2 because going for 25 nails would mean incurring more expenses (both financial and in terms of time) for extra nails which do not significantly increase the accuracy of estimation.

Although there is abundant literature on the use of erosion pins, few studies have been conducted that have consistently given comparable results between soil loss estimated by erosion pins and that measured by conventional techniques. A major reason may be the fact that the nail technique has been used mainly on large plots in hillslope erosion studies. Erosion pins have usually been placed far apart because of the big plot sizes; as a result it has been difficult to notice small changes in elevation in a single storm (Hadley and Lusby, 1967). The success of the present study may be attributed to the small size of the plots. The nails were close together, hence changes in soil surface level could be easily noticed. The nails were carefully painted to prevent rusting. In colder and more humid regions metal pins/ nails tend to rust and are more liable to frost heave compared to wooden pegs (Haigh, 1977a). Bridges (1969) claimed that rusting tends to bind erosion pins into the soil and gives an increased resistance to disturbance. However, Haigh (1977b) reported that major problems may result from use of rustable materials in longer term studies.

The nails were driven into the ground about one to two weeks after planting in both the first and second seasons. This was not done purposely. It is possible that at the time the nails were placed into the ground the soil had already settled (after rotovation). Where one drives in the nails immediately after cultivation, one has to watchout for the effect of soil settlement on the exposure of the nails. The operator must ensure least disturbance of the soil during the period of driving in the nails and making observations, otherwise soil compaction may be another source of error. Compacted soil interferes with the erosional process.

Even the most careful choice of erosion pin methodology and type cannot wholly eradicate unconscious data contamination and human error.

The degree of data contamination should be appreciated and evaluated whenever possible, although it may not always be significant. Haigh (1977a) has identified seven basic sources of contamination:

(i) disturbance during establishment,

(ii) disturbance of the pattern of soil erosion caused by the presence of the erosion pin,

(iii) disturbance of the erosion pins caused by the physical differences between them and the surrounding soil,

(iv) disturbance of the erosion nail by trampling and vandalism,

(v) the effects of variations in the erosion pins' environment,

(vi) disturbance of the erosion pin by the operator during recording and

(vii) errors during recording.

Different categories of erosion nails are subject to different types of data contamination to various degrees. Unfortunately, it has rarely proved possible to assign any precise value to any particular species of contamination. Haigh (1977a) gives suggestions on how to minimize data contamination.

Soil loss estimated by the USLE and that measured by the conventional runoff plot technique are shown in Table 13a. A paired t-test showed no significant difference (5% level) between erosion losses estimated by the two techniques (Table 13b).

Table 13a. Soil loss in bare - fallow plots assessed by the USLE (Estimated) and conventional runoff plot technique (Measured), season 2†

Block No	Plot No	R	Estimated K		Soil loss (Mgha^{-1})		
		Jha^{-1}	MgJ^{-1}	LS	Estimated	Measured	Difference
I	1	614.13	0.168	1.06	109.36	99.49	9.87
	3	- " -	0.160	0.88	86.47	90.13	-3.66
	4	- " -	0.152	0.78	72.81	87.61	-14.80
II	8	- " -	0.144	1.15	101.70	93.82	7.88
	9	- " -	0.156	0.97	92.93	86.79	6.14
	11	- " -	0.117	0.75	53.89	73.83	-19.94
III	14	- " -	0.125	0.53	40.67	78.70	-38.03
	15	- " -	0.140	0.54	46.42	90.52	-44.10
	17	- " -	0.142	0.66	57.56	87.22	-29.66

Table 13b. Paired t-test for soil loss ($Mgha^{-1}$) determined by the USLE and conventional techniques, season 2^{+}

	Technique			
	USLE	Conventional	Difference	t_H
Sum	661.81	779.11	-126.30	
Means[+]	73.53	86.57	-14.03	2.06^{ns}
			S.E. ± 9.72	

[+] Average of 9 repititions

[ns] Nonsignificant (5% level)

On the average, the measured and estimated K values compared favourably. This implies that the nommogram - estimated K values can be taken as acceptable approximations of soil erodibility during the second season. Vanelslande et al. (1984) observed that nomogram - estimated K were acceptable approximations for the first year but not for the second year for two Nigerian soils. In the second season of the present study, 6 out of 9 measured K values were lower than in season 1, 2 were higher and 1 remained constant in both seasons. In contrast, 3 out of 9 of the estimated K values were lower in the second season while 6 were higher in the second than the previous season. The change in K values is not surprising. Soil erodibility is a dynamic property which depends on soil's physical, chemical and biological processes. It is well known that soil erodibility measured in unit plots under natural rainfall conditions changes with time (Lal, 1981b, 1983b). In the second season, erosivity per mm of rainfall was smaller than in the first (1.2 compared to about 1.5). The relatively lower rainfall erosivity and the acceptable value of estimated erodibility may have contributed to the lack of significant difference between the USLE - estimated soil loss and that determined by the conventional runoff plot technique. Generally, however, studies have shown that the nomogram is not very reliable for estimating K for use in the USLE. More detailed studies are needed to determine which parameters are strongly related to erodibility of tropical soils. Much of Africa is subjected to short duration intense rainfall following drought. Hudson (1980) suggested that under these conditions an index of erodibility may need to be based on factors more directly affecting infiltration and runoff. This is in contrast to an index for temperate conditions where aggregate stability and particle dispersion may be important factors. If a measured soil erodibility (K) value is available for a soil of interest, it should be used as a first choice in the USLE. Moreover, attempts have to be made to find an erosivity index that will not underestimate the erosive power of tropical rains.

4.3 C - factor

Table 14 shows the C - factor computed as a ratio of soil loss in maize or cowpea plots to that from bare - fallow plots at different stages of crop growth.

Table 14. C - factors for soil loss

		Crop stage+			
Season	Crop	I	II	III	IV
1	Maize	0.86	0.32	0.32	0.26
2	Coepea	0.67	0.56	0.52	0.45

+Stage I = Seeding to 10% canopy cover; II 10 - 50% cover III 50 - 75% cover; IV = 75% cover to harvesting. % cover was determined photographically.

It is apparent that soil loss from maize plots from 75% canopy cover to harvest was 3.8 times less than that from bare - fallow plots (C - factor = 0.26, Table 14). Similarly, plots under 75% canopy cover of cowpea had 2.2 times less soil loss compared to bare - fallow treatments

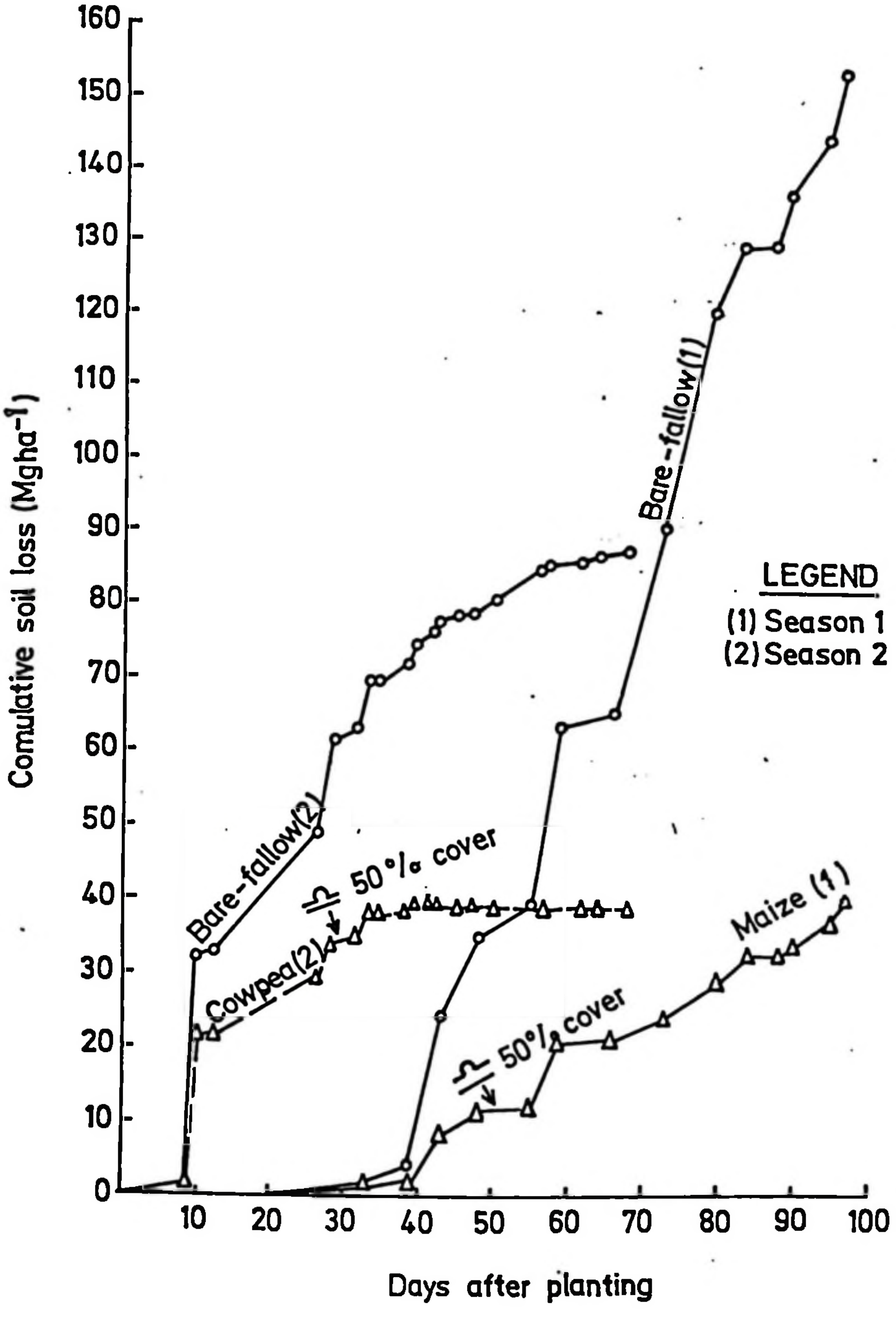


Fig.7. Comulative soil loss in bare - fallow plots and plots cropped to a maize - cowpea sequence.

(C - factor = 0.45, Table 14). This confirms reports by several researchers that soils under vegetal cover suffer less erosion than bare - fallow plots (Ngatunga et al., 1984; Edwin, 1985). One would expect cowpea to provide more protection to the soil than maize. This was not the case in the present study. The major reason is that in the second season very erosive rainstorms fell before the crop had developed 50% vegetal cover (Fig. 7). Whereas only 27% of total soil loss in maize occured before 50% cover had been developed, 89% of total soil was in cowpeas occured before cowpeas had developed 50% canopy cover. Several authors contended that erosive rains are particularly damaging at times when vegetation cover is poor (Wilkinson, 1975b; Stocking and Elwell, 1976).

4.4 Rainfall erosivity, runoff and soil erosion.

4.4.1 Relationship between rainfall amount, runoff and soil loss

Table 15a shows simple correlation coefficients and regression equations between unoff and soil loss to rainfall amount for the two seasons of the present study.

Table 15a. Correlation coefficients and linear regression equations relating runoff and soil loss and rainfall amount^{+}

(i) Bare plots

Season	Independent variable		Dependable variable		Regression equation	r
1	Rainfall amount/storm	(X_1)	Runoff	(W_1)	$W_1 = 0.55X_1 - 2.80$	0.94**
2	Rainfall amount/storm	(X_2)	Runoff	(W_2)	$W_2 = 0.56X_2 - 1.24$	0.97**
1	Rainfall amount/storm	(X_1)	Soil loss	(E_1)	$E_1 = 0.27X_1 - 1.13$	0.90**
2	Rainfall amount/storm	(X_2)	Soil loss	(E_2)	$E_2 = 0.39X_2 - 5.34$	0.89**
1	Runoff/storm	(W_1)	Soil loss	(E_1)	$E_1 = 0.23 + 0.48W_1$	0.96**
2	Runoff/storm	(W_2)	Soil loss	(E_2)	$E_2 = 0.65W_2 - 3.84$	0.85*

(ii) Plots under maize and cowpeas

Crop	Independent variable		Dependable variable		Regression equation	r
Maize	Rainfall amount/storm	(X_1)	Runoff	(W_3)	$W_3 = 0.5X_1 - 6.04$	0.90**
Cowpeas	Rainfall amount/storm	(X_2)	Runoff	(W_4)	$W_4 = 0.49X_2 - 4.85$	0.89**
Maize	Rainfall amount/storm	(X_1)	Soil loss	(E_3)	$E_3 = 0.09X_1 - 0.71$	0.77**
Cowpeas	Rainfall amount/storm	(X_2)	Soil loss	(E_4)	$E_4 = 0.23X_2 - 3.71$	0.83**
Maize	Runoff/storm	(W_3)	Soil loss	(E_3)	$E_3 = 0.53 + 0.17W_3$	0.79**
Cowpeas	Runoff/storm	(W_4)	Soil loss	(E_4)	$E_4 = 0.45W_4 - 1.39$	0.91**

+ X_1 = Rainfall amount (mm per storm), in season 1

X_2 = Rainfall amount (mm per storm), in season 2

W_1 = Runoff amount (mm per storm), from bare plots in season 1

W_2 = Runoff amount (mm per storm), from bare plots in season 2

W_3 = Runoff amount (mm per storm), from maize plots, season 1

W_4 = Runoff amount (mm per storm), from cowpea plots, season 2

E_1 = Annual soil loss ($Mgha^{-1}$) in bare plots in season 1

E_2 = Annual soil loss ($Mgha^{-1}$) in bare plots, season 2

E_3 = Annual soil loss ($Mgha^{-1}$) in maize plots, season 1

E_4 = Annual soil loss ($Mgha^{-1}$) in cowpea plots, season 2

**Significant at 1% level

There were high correlation coefficients between rainfall amount and runoff in both the first and second seasons. The relationship between runoff and rainfall was closer in the bare - fallow (Table 15a(i)) than in maize or cowpea plots [Table 15a(ii)]. Whereas variation in rainfall could explain up to 94% ($r = 0.97$, $r^2 = 0.94$) of the variations in runoff on bare - fallow plots, it accounted for only 56 to 79 per cent of the variations in runoff in maize and cowpea plots, respectively ($r = 0.75$ & 0.89). This indicates that whereas fairly good estimates of water runoff can be obtained from rainfall data for bare - fallow plots, the probability of making good runoff estimates in cropped plots is lower. Other factors seem to affect water runoff in cropped plots. Such factors as canopy cover, root density etc.. play a role in determining the amount of water leaving the soil as surface flow. Canopy cover and root density, for example, vary with the type of crop as well as the growth stage, of a crop. Since bare - fallow plots do not have these variables, runoff in bare plots is closely related to rainfall amount.

There existed high correlation coefficients between rainfall amount and soil runoff as well as between runoff and soil loss (Table 15a). The correlation coefficients were higher in bare - fallow than in plots under maize or cowpeas. The lower correlation coefficients in plots under a crop were probably due to the effect of the crop on the beating impact of the rainfall drops as well as on the shearing effect of runoff on soil. It is interesting to note that during both the first and second season, correlation coefficients between soil loss and rainfall were lower than those between soil loss and runoff. This phenomenon was true in both bare - fallow plots as well as plots under maize or cowpeas. Data recorded by Lal (1976a) in his experiments close to where the present work was done indicate a similar trend in some plots that had 5 and 10 per cent slope. In slopes with 1% and 15%, correlation coefficients between rainfall amount and soil loss were higher than those between runoff and soil loss in Lal's studies. Since the plots used during the present study had an average of 8 to 11 per cent slope, it appears that with slopes of 5 to 11 per cent runoff has a greater influence on soil erosion than rainfall amount. Because the correlation coefficients between runoff and soil loss are high, one can probably estimate soil loss from runoff data alone where the slopes of the plots do not differ significantly. Lal (1976a) cautioned against estimation of soil loss from runoff data alone because, in his study, correlation coefficients between runoff and soil loss within each slope were not high.

4.4.2 Relationship between rainfall amount and erosivity indices.

Simple correlation coefficients and linear regression equations relating rainfall amount to three erosivity indices, viz., KE, R and AI_m, are shown in Table 15b.

Table 15b. Correlation coefficients and linear regression equations relating rainfall amount to KE, R and AI_m indices+

Season	Independent variable	Dep. variable	Regression equation	r
1	Rainfall amount/storm (A_1)	KE (KE_1)	$KE_1 = 27.51A_1 - 81.16$	0.99**
2	Rainfall amount/storm (A_2)	KE (KE_2)	$KE_2 = 28.95A_2 - 84.75$	0.99**
1	Rainfall amount/storm (A_1)	R (R_1)	$R_1 = 2.25A_1 - 22.87$	0.98**
2	Rainfall amount/storm (A_2)	R (R_2)	$R_2 = 2.69A_2 - 29.09$	0.92**
1	Rainfall amount/storm (A_1)	AI_m (AIm_1)	$AIm_1 = 0.83A_1 - 7.54$	0.98**
2	Rainfall amount/storm (A_2)	AIm (AIm_2)	$AIm_2 = 0.95A_2 - 9.75$	0.92**

+A_1 = Rainfall amount (mm/storm) in season 1; **Significant at 1% level

A_2 = Rainfall amount (mm/storm) in season 2

KE_1 = KE index (Jm^{-2}/storm) in season 1

KE_2 = KE index (Jm^{-2}/storm) in season 2

R_1 = R factor (Jha^{-1}/storm) in season 1

R_2 = R factor (Jha^{-1}/storm) in season 2

AIm_1 = AIm index (cm^2h^{-1}/storm) in season 1

AIm_2 = AI_m index ($cm^2\ h^{-1}$/storm), season 2

In season 1, all three indices correlated so highly with rainfall amount ($r = 0.99$ for KE, $r = 0.98$ for R & AIm) that it is difficult to choose among them. In the second season, though, KE index maintained the highest correlation coefficient, R and AIm indices showed lower (though still highly significant) correlation coefficients. These results indicate that KE is more closely related to rainfall amount than either R or AIm index.

4.4.3 Relationship between runoff and erosivity indices.

The relationship between runoff and erosivity indices is presented in Table 15c.

Table 15c. Simple correlation coefficients and regression equations relating runoff to three erosivity indices^{+}

(i) In bare plots

Season	Independent variable	Dep. variable	Regression equation	r
1	KE (KE_1)	Runoff (W_1)	$W_1 = 0.20KE_1 - 0.64$	0.94**
2	KE (KE_2)	Runoff (W_2)	$W_2 = 0.99 + 0.02\ KE_2$	0.97**
1	R (R_1)	Runoff (W_1)	$W_1 = 5.04 + 0.24\ R_1$	0.95**
2	R (R_2)	Runoff (W_2)	$W_2 = 7.54 + 0.17\ R_2$	0.91**
1	AIm (AIm_1)	Runoff (W_1)	$W_1 = 4.05 + 0.66AIm_1$	0.96**
2	AIm (AIm_2)	Runoff (W_2)	$W_2 = 7.18 + 0.48\ AIm_2$	0.91**

(ii) In maize and cowpea plots

Crop	Independent variable	Dep. variable	Regression equation	r
Maize	KE (KE_1)	Runoff (W_3)	$W_3 = 2.01 + 0.01\ KE_1$	0.74**
Cowpea	KE (KE_2)	Runoff (W_4)	$W_4 = 0.02\ KE_2 - 2.85$	0.90**
Maize	R (R_1)	Runoff (W_3)	$W_3 = 4.54 + 0.11 R_1$	0.76**
Cowpea	R (R_2)	Runoff (W_4)	$W_4 = 2.52 + 0.16 R_2$	0.91**
Maize	AIm (AIm_1)	Runoff (W_3)	$W_3 = 3.92 + 0.32 AIm_1$	0.78**
Cowpea	AIm (AIm_2)	Runoff (W_4)	$W_4 = 2.22 + 0.46 AIm_2$	0.91**

+ KE_1 = KE index/storm (Jm^{-2}) in season 1

KE_2 = K index/storm (Jm^{-2}) in season 2

R_1 = R index/storm (Jha^{-1}), season 1

R_2 = R index/storm (Jha^{-1}), season 2

AIm_1 = AIm index/storm ($cm^2\ h^{-1}$), season 1

AIm_2 = AIm index/storm ($cm^2\ h^{-1}$), season 2

W_1 = Runoff in bare - fallow plots (mm/storm), season 1

W_2 = Runoff in bare - fallow plots (mm/storm), season 2

W_3 = Runoff in maize plots (mm/storm), season 1

W_4 = Runoff in cowpea plots (mm/storm), season 2

** = Significant at 1% level

In both seasons 1 and 2 runoff was significantly correlated with all three erosivity indices (1% level) /Table 15c (i), (ii)/. The correlation coefficients were generally higher in bare - fallow than in plots under either maize or cowpeas. In the first season AIm index had the highest correlation coefficient with runoff in both bare - fallow and plots under maize. In season 2, however, runoff was more closely related to the KE index than to either R or AIm index. The correlation coefficients between runoff and the various indices were lower than those between runoff and rainfall amount. This implies that one can estimate runoff more accurately from rainfall amount data than from erosivity data alone.

4.4.4 Relationship between soil loss and erosivity indices.

Table 15d shows the relationship between soil loss from bare - fallow, maize and cowpea plots and the indices KE, R and AIm

Table 15d. Simple correlation coefficients and linear regression equations relating soil loss to various erosivity indices^{+}

(i) Bare - fallow plots

Season	Independent variable		Dep. variable	Regression equation	r
1	KE	(KE_1)	Soil loss (E_1)	$E_1 = 0.01KE_1 - 0.05$	0.90**
2	KE	(KE_2)	Soil loss (E_2)	$E_2 = 0.01KE_1 - 3.81$	0.90**
1	R	(R_1)	Soil loss (E_1)	$E_1 = 2.70 + 0.12R_1$	0.90**
2	R	(R_2)	Soil loss (E_2)	$E_2 = 0.38 + 0.13R_2$	0.94**
1	AIm	(AIm_1)	Soil loss (E_1)	$E_1 = 2.19 + 0.32AIm_1$	0.92**
2	AIm	(AIm_2)	Soil loss (E_2)	$E_2 = 0.04 + 0.38AIm_2$	0.95**

Table 15d (ii) Maize and cowpea plots

Crop	Independent variable	Dependent variable	Regression equation	r
Maize	KE (KE_1)	Soil loss (E_3)	$E_3 = 0.70 + 0.002\ KE_1$	0.66**
Cowpea	KE (KE_2)	Soil loss (E_4)	$E_4 = 0.01\ KE_2 - 2.76$	0.83**
Maize	R (R_1)	Soil loss (E_3)	$E_3 = 1.31 + 0.02\ R_1$	0.62**
Cowpea	R (R_2)	Soil loss (E_4)	$E_4 = 0.08\ R_2 - 0.44$	0.89**
Maize	AIm (AIm_1)	Soil loss (E_3)	$E_3 = 1.20 + 0.06\ AIm_1$	0.64**
Cowpea	AIm (AIm_2)	Soil loss (E_4)	$E_4 = 0.23 AIm_2 - 0.23$	0.91**

$^+KE_1$ = KE index/storm (Jm^{-2}), season 1

KE_2 = KE index/storm (Jm^{-2}), season 2

R_1 = R index/storm (Jha^{-1}), season 1

R_2 = R index/storm (Jha^{-2}), season 2

AIm_1 = AIm index/storm ($cm^2\ h^{-1}$), season 1

AIm_2 = AIm index/storm ($cm^2\ h^{-1}$), season 2

E_1 = Soil loss/storm ($Mgha^{-1}$), season 1, bare - fallow plots

E_2 = Soil loss in bare - fallow plots/storm ($Mgha^{-1}$) season 2

E_3 = Soil loss/storm in maize plots ($Mgha^{-1}$), season 1

E_4 = Soil loss/storm in cowpea plots ($Mgha^{-1}$) season 2

** = Significant at 1% level

Correlation coefficients between the various erosivity indices and soil loss were generally lower in the first season compared to the second season. They were also lower in plots under vegetative cover /Table 15d (ii)/ compared to bare - fallow plots /Table 15d (i)/. In the second season, AIm index was the best index for estimating soil loss, accounting for 90% of the variations in soil loss for bare plots (r = 0.95) and 83% of variations in soil loss in cowpea plots (r = 0.91). In the first season, variations in the indices could explain only between 38 and 44 per cent (r = 0.62 & r = 0.66) of the variations in soil loss. A significant correlation coefficient does not always mean that the independent variable can accurately estimate variations in the dependent variable. These results show that whereas erosivity indices can be used to predict soil erosion in bare - fallow plots, they are not efficient estimaters in plots under vegetal cover. Ngatunga <u>et al</u>. (1984) working in Tanzania, reported high correlation coefficients between EI_{30} (=R), AIm and KE > 1 in bare - fallow plots and low values in mulched plots or plots under grass cover. When soil is protected by mulch, crop or grass cover, the effect of raindrop on the soil is minimized. This may explain partly the lower observed correlation coefficient in plots under maize or cowpeas.

4.5 Relationship between erodibility indices, K factor and soil loss

4.5.1 Relationship between soil erodibity (K) and erodibility indices.

Table 16a shows simple correlation coefficients and linear regression equation between the measured K factor (MgJ^{-1}) and six erodibility indices: Gravel content (G), Mean Weight Diameter (MWD), Geometric Mean Diameter (GMD); Clay - ratio (C), M - Parameter (M) and

and water stable aggregates > 4mm (WSA).

Of the six erodibility indices, only gravel content was significantly negatively correlated with erodibility factor K, r = -0.81 in season 1, r = -0.77 in the second season (Table 16a). The other five indices had low correlation coefficients. It is interesting to note that only the clay ratio seems to be positively related to K - factor implying that the higher the clay content (hence the lower the clay ratio), the lower the erodibility. This finding is similar to results reported by Rose (1960) and Epstein and Grant (1967) who found greater detachment of soil particles by rain drops as clay content increased. However, since the correlation coefficient is nonsignificant in the present study, the above conclusion may not be valid. Gravel content appears to be the only erodibility index which can give a fairly good estimate of soil erodibility. The negative correlation indicate that the greater the gravel content, the lower the soil erodibility. This is not surprising since gravel is known to protect soil from erosion (Lamb et al., 1950; Dumas, 1965; Roose 1977a; Aina et al., 1980).

4.5.2 Relationship between soil loss and six erodibility indices.

Table 16b shows simple correlation coefficients and linear regression equations relating soil loss in bare plots to 6 erodibility indices.

Table 16a. Correlation coefficients and regression equations relating measured K to erodibility indices^{+}

Season	Independent variable	Dep. variable	Regression equation	r
1	Gravel (G_1^{++})	K - factor (K_1)	$0.29 - 0.003\ G_1 = K_1$	-0.81^{*}
2	Gravel (G_2)	K - factor (K_2)	$0.31 - 0.004\ G_2 = K_2$	-0.77^{*}
1	MWD (MWD_1)	K - factor (K_1)	$0.26 - 0.02\ MWD_1 = K_1$	-0.47^{ns}
2	MWD (MWD_2)	K - factor (K_2)	$0.23 - 0.23\ MWD_2 = K_2$	-0.36^{ns}
1	GMD (GMD_1)	K - factor (K_1)	$0.25 - 0.03\ GMD_1 = K_1$	-0.61^{ns}
2	GMD (GMD_2)	K - factor (K_2)	$0.24 - 0.13\ GMD_2 = K_2$	-0.30^{ns}
1	Clay ratio (C_1)	K - factor (K_1)	$0.15 + 0.03\ C_1 = K_1$	0.27^{ns}
2	Clay ratio (C_2)	K - factor (K_2)	$0.08 + 0.08\ C_2 = K_2$	0.62^{ns}
1	M - Parameter (M_1)	K - factor (K_1)	$0.22 - 0.00\ M_1 = K_1$	-0.04^{ns}
2	M - Parameter (M_2)	K - factor (K_2)	$0.31 - 0.000 M_2 = K_2$	-0.40^{ns}
1	WSA > 4mm (WSA_1)	K - factor (K_1)	$0.24 - 0.001\ WSA_1 = K_1$	-0.45^{ns}
2	WSA > 4mm (WSA_2)	K - factor (K_2)	$0.20 - 0.004\ WSA_1 = K_2$	-0.31^{ns}

$^{+}$K - factor = MgJ^{-1}; ++Subscripts 1, 2 stand for season 1 and season 2, respectively

*Significant at 5% level; ^{ns}Nonsignificant (5% level)

Table 16b. Simple correlation coefficients and regression equations for soil loss in bare - fallow plots related to six erodibility indices[+]

Season	Independent variable	Dependent variable	Regression equation	r
1	Gravel (G_1^{++})	Soil loss (E_1)	$E_1 = 140.95 + 0.45\ G_1$	0.17^{ns}
2	Gravel (G_2)	Soil loss (E_2)	$E_2 = 88.01 - 0.01\ G_2$	-0.02^{ns}
1	MWD (MWD_1)	Soil loss (E_1)	$E_1 = 180.77 - 9.70\ MWD_1$	-0.30^{ns}
2	MWD (MWD_2)	Soil loss (E_2)	$E_2 = 85.34 + 2.94\ MWD_2$	0.13^{ns}
1	GMD (GMD_1)	Soil loss (E_1)	$E_1 = 169.18 - 11.57\ GMD_1$	-0.31^{ns}
2	GMD (GMD_2)	Soil loss (E_2)	$E_2 = 91.13 - 9.13\ GMD_2$	-0.13^{ns}
1	Clay-ratio (C_1)	Soil loss (E_1)	$E_1 = 218.02 - 17.12\ C_1$	-0.50^{ns}
2	Clay-ratio (C_2)	Soil loss (E_2)	$E_2 = 105.57 - 3.94\ C_2$	-0.56^{ns}
1	M-Parameter (M_1)	Soil loss (E_1)	$E_1 = 0.13 - 38.46\ M_1$	0.79^{*}
2	M-Parameter (M_2)	Soil loss (E_2)	$E_2 = 44.72 + 0.03\ M_2$	0.87^{**}
1	WSA > 4mm (WSA_1)	Soil loss (E_1)	$E_1 = 162.93 - 0.27\ WSA_1$	-0.15^{ns}
2	WSA > 4mm (WSA_2)	Soil loss (E_2)	$E_2 = 85.97 + 0.46\ WSA_2$	0.23^{ns}

[++] Subscripts 1, 2 stand for season 1 & season 2, respectively; [+] Soil loss in $Mgha^{-1}$

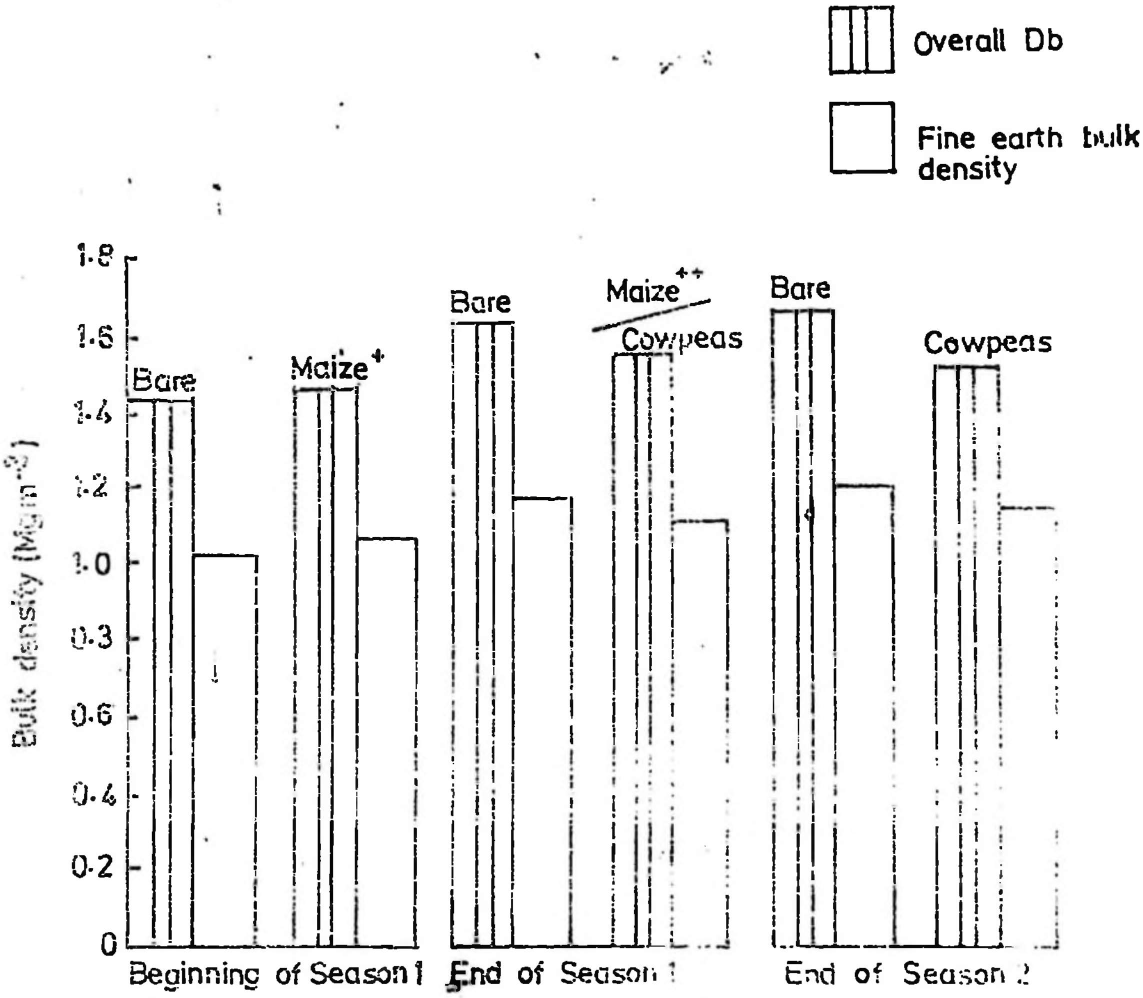
[ns] Nonsignificant (5% level); *, ** Significant at 5% and 1% level, respectively.

The results show that only the M - Parameter erodibility index correlated highly with soil loss. Rogers *et al.* (1964) reported that none of the soil physical or chemical characteristics measured explained variations in either runoff or soil loss. Rose (1960) found that the rate of detachability depended more on rainfall momentum and time per unit area than on erodibility. Erodibility is a dynamic process, it can not be easily related to indirect measurements of inherent soil characteristics such as particle size distribution (Lal, 1984). The results on the erodibility indices tested in the present study indicate that most of the indices are not efficient for estimating soil erodibility or soil loss. An efficient index should be simple to measure, capable of distinguishing subtle variations in erodibility and reliable in universal application.

4.6 Effect of surface management on soil bulk density and infiltration rate.

4.6.1 Bulk density

Fig. 8 shows the changes in dry overall bulk density as well as changes in the dry bulk density of the fine earth fraction in bare - fallow plots and plots under maize (season 1) and cowpeas (season 2).



LSD (0.05) between sampling dates = 0.08

+Taken just before rotovation, hence no maize crop

++Taken after maize harvesting but before rotovation ready for the cowpea crop

Fig.8. Bulk density (0-10cm) of bare and cropped plots taken at various times during the study period.

When bulk density was taken shortly after assigning the various treatments to the plots (before rotovation), plots assigned to bare - fallow treatment had the lowest overall Db as well as Db fine earth. When Db was determined again at the end of the first season, it was found it had increased. The increase in both Db overall and Db fine earth was greater in bare plots than in plots under maize. A third sampling taken at the end of the second season showed a further deterioration in soil physical conditions (rise in Db) in bare - fallow plots and an improvement of the same in plots under cowpeas. A combined Analysis of Variance test for bulk density for the three sampling dates showed highly significant differences (1% level) between the sampling dates, surface management systems and an interaction between sampling dates and management (Appendix IVb, Fig. 8). There was more deterioration in Db in bare - fallow plots than in those under maize or cowpea. The increase in overall bulk density between the first and third sampling date was 0.22 Mgm^{-3} for bare - fallow compared to only 0.04 Mgm^{-3} for plots under maize and cowpea (Fig. 8). The bulk density of the fine earth fraction increased by 0.17 Mgm^{-3} in bare - fallow plots, and 0.06 Mgm^{-3} in plots under maize and cowpeas during the same time. Bare plots are not protected against the beating action of raindrops which ultimately compacts the soil, leading to increased bulk density.
The lower rate of deterioration of Db in plots under a maize - cowpea sequence can be attributed to less compaction of soil by raindrop impact on it, and generally improved soil structure brought about by the presence of the crop (improved macrofouna populations, organic matter

content, soil particle-binding by roots etc.). In their experiments conducted at IITA, Lal et al. (1980) observed a decrease in dry bulk density with increase in mulch rate and attributed this to high earthworm activity on mulched plots compared to unmulched control. This emphasizes the need to always maintain the soil under some type of cover.

Fig. 7 shows that a large portion of Db is occupied by gravel (compare Db overall with Db fine earth). This is typical for many tropical soils (Lal, 1980). High bulk density in the surface horizons indicates conditions unfavourable for root development of several major crops, especially cereals (Babalola and Lal, 1977).

4.6.2 Infiltration

Studies on infiltration rate showed a trend of deterioration similar to that of bulk density. Table 17 shows the equilibrium infiltration rates in bare - fallow and plots under maize and cowpeas for the two growing seasons. Figs. 9a to 9c show cumulative infiltration with time for the same plots.

Table 17. Equilibrium infiltration rate (cmh^{-1}) in bare - fallow and plots under maize and cowpeas at three sampling dates^{+}

Surface management	Sampling date			% change between dates^{++}		
	1st	2nd	3rd	1st and 2nd	2nd and 3rd	1st and 3rd
Bare - fallow	21.6	10.0	13.6	-53.7	36.0	-37.0
Maize/cowpea	16.9	23.2	25.2	37.3	8.6	49.1

+The infiltration studies were conducted at the beginning of the first season just before rotovation (1st sampling date), at the end of the first season after harvesting but before rotovation for the second season (2nd sampling date) and at the end of season 2 after harvesting cowpeas (3rd sampling date); ++A negative percentage change indicates a decline in equilibrium infiltration rate (deterioration) while a positive one indicates a higher (improved) equilibrium infiltration rate.

At the beginning of season 1, equilibrium infiltration rate was higher in plots assigned to the bare - fallow treatments than in those assigned to maize and cowpeas (Table 17). There was higher equilibrium infiltration rate in plots under maize than in bare - fallow ones at the end of season 1 (2nd sampling date). At this sampling date, equilibrium infiltration rate in bare - fallow plots was about 54% lower than it had been at the beginning of the season. The equilibrium infiltration rate in maize plots, however, had improved (gone up) by about 37% during the same period. Between the 2nd and 3rdsampling date, infiltration rate improved in both surface management systems. At the end of the second season, equilibrium infiltration rate in bare - fallow plots was 37% lower than at the beginning of season 1, whereas maize and cowpea plots had an equilibrium infiltration rate about 49% higher than in the beginning of the first season. Likewise, cumulative infiltration in bare - fallow plots declined by 41 per cent between 1st and 3rd sampling while that for maize/cowpea plots improved by 26 per cent (Fig. 9a & 9c). Lal (1976b) reported that infiltration rates which are commonly high for fallowed soils decline rapidly with cultivation. The improved cumulative

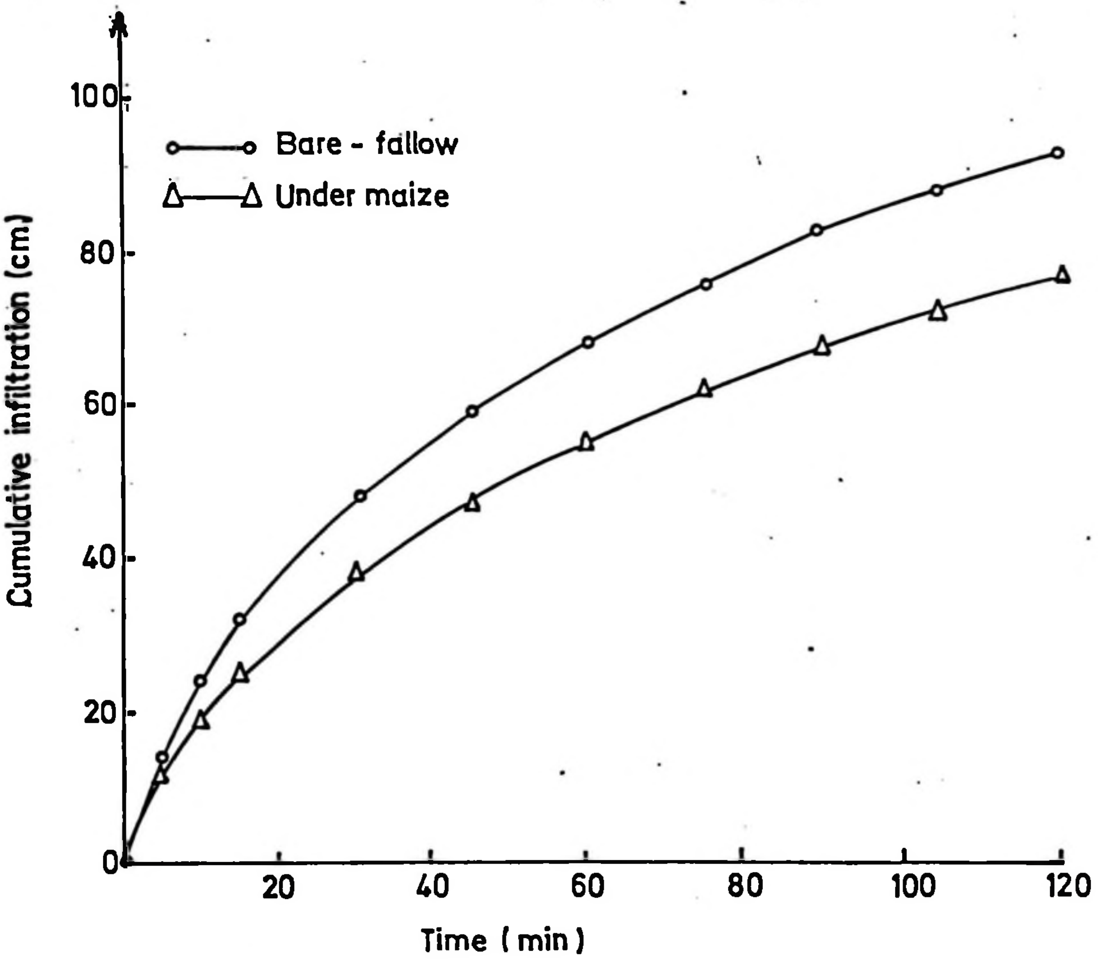


Fig. 9a. Infiltration rate at the beginning of season 1.

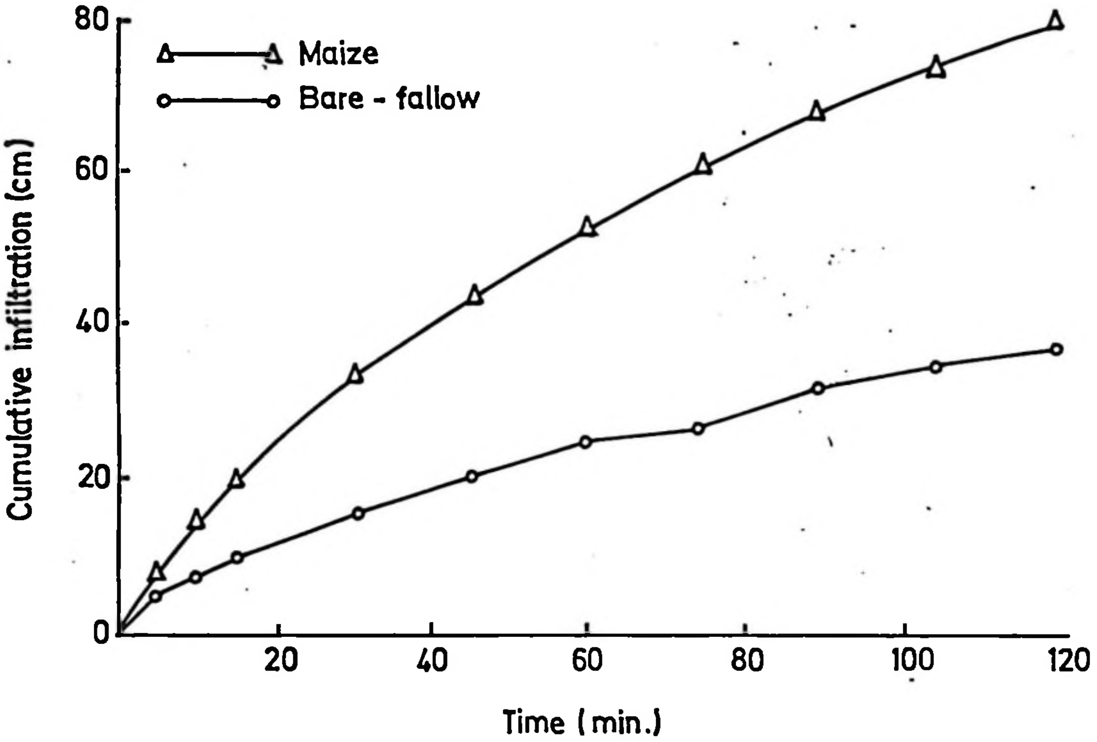


Fig.9b. Infiltration capacity of the soil as influenced by surface cover; end of first season.

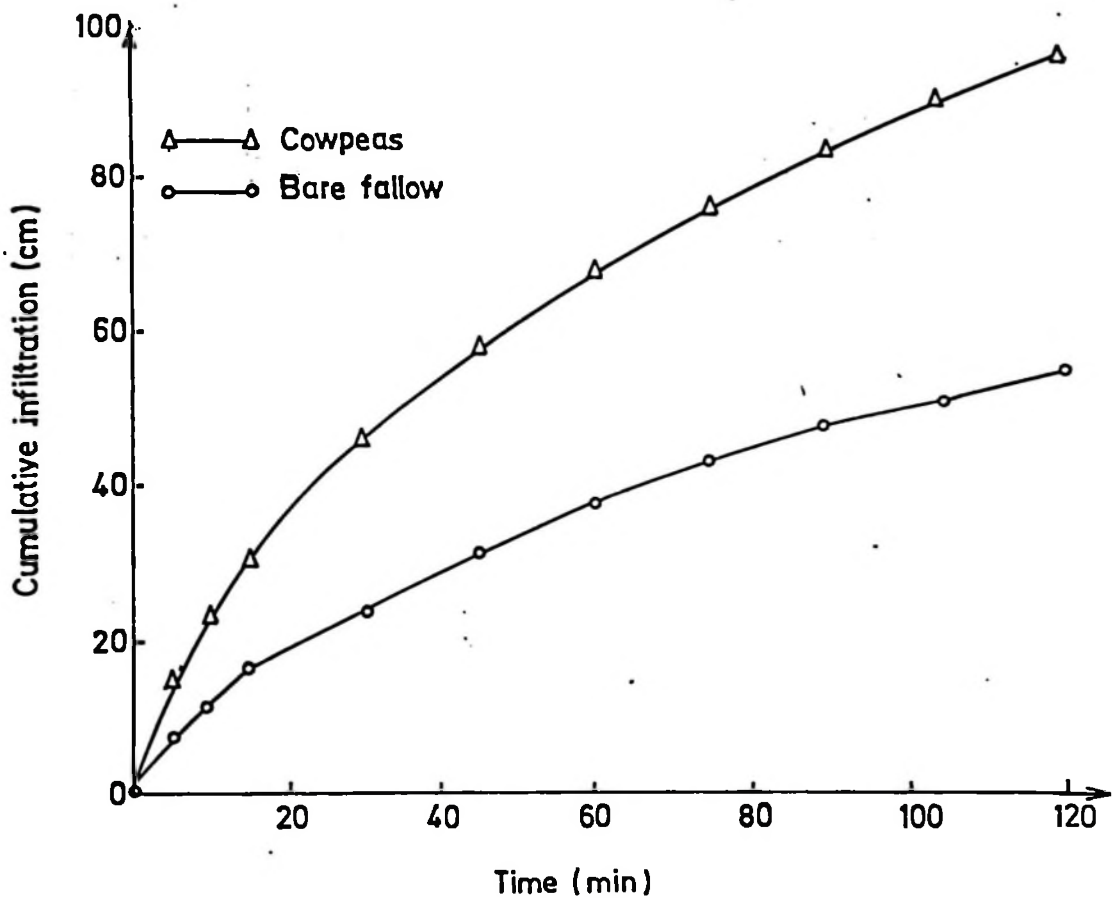


Fig. 9c. Infiltration capacity of the soil as affected by surface cover, end of second season.

infiltration and equilibrium infiltration rate observed in maize/cowpea plots was brought about by improved soil conditions rendered by the two crops. Lal et al. (1979) in their experiments conducted at IITA, Ibadan, found that the infiltration rate of a structurally degraded soil improved considerably after 2 years of fallowing under various grass and legume covers. It is interesting to note that equilibrium infiltration rates and cumulative infiltration in both bare - fallow and maize and cowpea plots were higher at the end of season 2 than at the end of season 1. This may have been brought about by soil loosening by rotovation. The artificial loosening of soil by tillage leads to a temporary maintenance of high infiltration rates. The fast decline (deterioration) in infiltration in bare - fallow plots underscores the need to protect soil surface as a good soil management practice.

4.7 Effect of soil erosion on crop yield.

The analysis of variance on both maize and cowpea yield did not show any significant difference between plots although the plots had different levels of soil loss. The author was interested in knowing whether there was any relationship between crop yield observed in season 2 and soil loss which occurred in the same plots in season 1. Simple correlation and linear regression analysis were done between cowpea yield and soil loss in the plots in season 1. The regression equation for the relationship was:

$$Y = 4.10 - 0.04\,x \quad \ldots\ldots\ldots\ldots\ldots \quad (10)$$

where Y is the yield of cowpea in Mgha^{-1} and x is soil loss (in season 1), Mgha^{-1}. There was a significant (5% level) negative correlation between soil loss and cowpea yield. About 55% of the variations in cowpea yield could be explained by variations in soil loss ($r = -0.74$). Lal, (1981a)and Edwin (1985) observed yield reductions as soil loss per plot increased in Nigeria. In Zimbabwe, Hudson and Jackson (1959) observed an inverse relationship between maize yield and soil loss. Young (1980) noted that corn yields were highly (negatively) correlated with erosion.

Erosion reduces productivity in the short run because of its effect on the top soil and in the long run because of its effect on the depth of the root zone. Soil erosion reduces the thickness of the A horizon. It also selectively reduces the components of the A horizon that are essential for crop production, namely organic matter and nutrient elements. Infiltration rate is generally lower and bulk density higher on eroded than uneroded soils. This decreases plant available water. The larger pores that hold much of the available water are the ones most likely to be destroyed by erosion (Buckman and Brady, 1969). The lower infiltration rate, higher bulk density and lower plant available water capacity reduced crop yields.

The long term effects of erosion are to reduce depth of the root zone. A shallow root zone exposes crop roots to rocks or other unweathered materials which are unfavourable to plant roots and leads to reduced crop yields (Storie, 1933). A shallow root zone reduces the plant available water capacity, which in turn largely determines the productivity of the soil (Leeper *et al.*, 1964). Several studies have shown that when soil is desurfaced yield failures ensue (Smith et al., 1948; Englestad et al., 1961; Shrader et al., 1963; Murray, 1969; Mbagwu et al., 1984a). Fournier (1963) observed a decrease in the yield of millet due to soil erosion in the Niangoloko region of Upper Volta (Burkina Faso). He calculated that an increase in the annual rate of erosion from 143 to 318 Mgkm^{-2} decreased millet yield from 727 to 352 kgha^{-1}. Rehm (1978) reported that in Cameroon the removal of 2.5 cm of top soil caused a 50% drop in maize yield and that the exposed subsoil became completely unproductive when 7.5 cm of soil was removed. In Western Nigeria, Lal (1976a) reported a maize yield reduction of 23% after 2.5 cm of soil was artificially removed. In another study, Lal (1981b) observed an exponential decline in the grain yield of maize and cowpeas with increases in cumulative soil erosion. Mbagwu et al. (1984b) studied the effects of top soil removal on maize and cowpea grain yield with variable rates of N and P application on an ultisol in southern Nigeria (Onne) and two alfisols in southeastern Nigeria. Both maize and cowpea yields were drastically reduced with removal of 5 cm top soil. None of the fertilizer combinations used was an effective substitute for top soil loss, especially for the ultisol. Soil erosion must be kept to a minimum level in order to realise high crop yields.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn and recommendations made from the present investigation are as follows:

1. Keeping plots under bare - fallow is a destructive system of maintaining the soil surface because it deteriorates soil physical properties. The soil surface must be kept under vegetal cover, mulch or other protective material.
2. The Aluminium Paint (Tracer) and Rill techniques of assessing soil erosion do not work well on short slopes. They could be tried on longer ($>$ 10 m) slopes.
3. At present the universal soil loss equation is not a reliable technique for estimating soil loss in tropical soils. There is need for detailed studies to determine which variables are strongly related to erodibility of tropical soils and to modify the erosivity index (R) so that it realistically reflects erosivity of tropical rainstorms before the USLE is adopted in the tropics.
4. The Nail technique can estimate soil loss in small plots (20 m^2) as efficiently as the conventional runoff plot method. In plots with soils similar to those under which the present study was conducted, the Nail technique should be adopted for use since it has several advantages over the conventional runoff plot method, namely: nails are cheaper to buy, are readily available, easy to install and use, do not require much maintenance and suffer less from vandalism.

CHAPTER 6

SUMMARY

Four techniques for soil loss assessment were comparatively evaluated in bare - fallow as well as in plots under a maize - cowpea sequence for two seasons. The techniques were: Aluminium Paint (Tracer), Nails, Rill and Universal soil loss equation technique. Results from these techniques were compared to those obtained by use of the conventional runoff plot technique.

There was significantly more soil loss (1% level) in bare - fallow than in plots under either maize or cowpea. Maize and cowpea were able to reduce the amount of soil loss by 3.8 and 2.2 times, respectively. There was also more deterioration of soil physical conditions (increased bulk density, reduced cumulative infiltration and reduced equilibrium infiltration rate) in bare - fallow plots than in those under a maize - cowpea sequence.

The techniques employed in assessing soil erosion had no influence on the magnitude of soil loss and did not interfere with erosional processes.

The tracer technique was discontinued before the study was concluded because it was difficult to accurately monitor the movement of the sprayed paint particles.

The rill technique did not accurately assess soil erosion. Soil loss determined by the rill technique was significantly lower (1% level) than that estimated by the conventional runoff plot technique.

In the first season, the USLE technique significantly underestimated soil loss (5% level). In the second season, however, soil loss estimated by USLE did not differ significantly (5% level) from that determined by the conventional runoff plot technique.

There was no significant difference (5% level) between soil loss determined by 16 nails, 25 nails and the conventional runoff plot technique.

The ~~erodibility~~ erosivity indices KE, R and AIm were almost equally efficient in predicting rainfall, runoff and soil erosion. The correlation coefficients between erosivity indices and runoff and soil loss were higher in bare - fallow than in plots under maize or cowpea.

Of the six erodibility indices tested, namely: Gravel content, Mean weight diameter, Geometric mean diameter, Clay ratio, M - parameter and water stable aggregates > 4mm, only Gravel content correlated significantly with soil erodibility (K). Also only the M - parameter correlated significantly with soil loss.

There was more deterioration in bulk density, cumulative infiltration and equilibrium infiltration rate in bare - fallow than in plots under a maize - cowpea sequence.

Grain yield of cowpea was significantly (5% level) but inversely related to soil loss ($r = -0.74$).

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Appendix Ia. Rainfall amount and intensity, runoff and soil loss records for individual rainstorms, season 1

Date	Rainfall		Rainfall intensity (mmh^{-1})			Runoff (mm)		Soil loss (Mgha^{-1})	
	Amount (mm)	Duration (h)	$I_{7.5}$	I_{30}	Average	Bare	Maize	Bare	Maize
01-05-1985	10.17	0.750	17.7	16.0	13.6	2.28	2.04	0.62	0.60
08 - " -	5.08	1.250	18.2	5.5	4.1	0.27	0.17	0.10	0.08
15 - " -	6.04	0.317	34.3	12.1	19.1	3.06	1.67	1.61	1.05
17 - " -	26.68	2.999	66.1	38.8	8.9				
23 - " -	31.75	4.375	47.6	27.9	7.3	4.32	3.89	2.16	1.13
26 - " -	7.30	2.000	20.7	6.0	3.7	23.93	16.19	20.31	6.26
27 - " -	46.99	7.333	71.1	71.1	6.8				
01-06-1985	35.57	3.251	44.8	44.7	11.0	19.88	12.71	10.30	2.21
08 - " -	15.24	0.500	31.8	30.5	30.5	5.42	3.49	4.21	0.79
12 - " -	68.58	15.167	69.1	64.8	4.5	47.37	37.15	24.37	8.87
19 - " -	13.97	13.000	27.3	8.5	1.1	8.59	2.93	1.64	0.16
26 - " -	73.03	16.483	88.9	88.9	4.4	47.81	33.07	24.98	3.12
02-07-1985	5.08	11.017	6.4	3.7	0.5	67.24	23.69	30.13	5.36
03 - " -	134.62	8.589	160.0	78.7	15.7				
07 - " -	39.37	5.000	66.4	66.3	7.9	26.37	18.52	8.99	2.76

Appendix Ia. continued

Date	Rainfall		Rainfall intensity (mmh^{-1})			Runoff (mm)		Soil loss ($Mgha^{-1}$)	
	Amount (mm)	Duration (h)	$I_{7.5}$	I_{30}	Average	Bare	Maize	Bare	Maize
11-07-1985	11.43	13.917	3.9	3.9	0.8	2.22	0.90	0.17	0.02
13 - " -	50.80	4.417	65.6	59.8	11.5	22.45	12.50	7.64	1.55
14 - " -	6.35	1.774	12.7	3.2	3.6				
17 - " -	3.81	1.083	3.6	3.6	3.5	13.34	4.06	7.71	3.34
18 - " -	20.96	8.133	28.6	24.1	2.6				
20 -07-1985	29.21	2.583	59.7	53.0	11.3	15.28	9.31	8.39	2.85
	642.03					309.83	182.29	153.33	40.15

$I_{7.5}$ = Maximum 7.5 - minute intensity I_{30} = Maximum 30 - minute intensity

[ ] = The storms were combined (considered as one).

Appendix Ib. Rainfall amount and intensity, runoff and soil loss records for individual rainstorms, season 2

Date	Rainfall		Rainfall intensity (mmh^{-1})			Runoff (mm)		Soil loss ($Mgha^{-1}$)	
	Amount (mm)	Duration (h)	$I_{7.5}$	I_{30}	Average	Bare	Cowpea	Bare	Cowpea
17-08-1985	26.67	15.417	67.7	35.9	1.7	14.81	14.43	2.066	2.110
18 - " -	69.85	7.117	114.3	99.6	9.8	32.78	34.10	30.641	19.990
20-08-1985	12.70	4.750	6.9	6.9	2.7	3.69	2.34	0.385	0.200
01-09-1985	3.81	0.350	17.4	7.4	10.9	39.26	27.55	16.321	7.290
03 - " -	60.96	2.630	98.2	94.0	23.2				
05 - " -	39.37	1.200	83.8	45.5	32.8	23.92	18.30	12.305	5.035
08 - " -	8.89	1.333	21.8	22.0	6.7	6.15	3.96	1.371	0.580
10 - " -	29.21	2.517	59.2	43.7	11.6	16.59	13.17	6.529	3.050
11 - " -	6.99	2.167	4.5	4.5	3.2	2.21	1.15	0.100	0.020
13 - " -	8.89	2.917	3.8	3.8	4.1	13.60	6.45	2.338	0.580
14 - " -	12.70	1.500	57.6	35.3	8.5				
15 - " -	7.62	2.083	10.2	7.6	3.7				
16 - " -	12.70	0.367	45.7	25.4	34.6	8.84	4.70	2.776	0.330
18 - " -	7.37	0.750	31.8	12.4	9.8	3.34	1.85	1.246	0.050
19 - " -	19.69	1.167	22.9	22.9	16.9	9.94	5.18	1.311	0.020
21 - " -	13.97	7.833	26.9	18.4	1.8	8.92	4.63	1.207	0.130
22 - " -	5.08	0.167	32.2	10.2	30.4				

Appendix Ib. continued

Date	Rainfall		Rainfall intensity (mmh^{-1})			Runoff (mm)		Soil loss ($Mgha^{-1}$)	
	Amount (mm)	Duration (h)	$I_{7.5}$	I_{30}	Average	Bare	Cowpea	Bare	Cowpea
24-09-1985	22.86	4.317	35.2	18.3	5.3	8.94	2.95	0.333	0.003
27-09-1985	20.32	3.550	109.3	32.8	5.7	7.29	3.55	1.914	0.014
03-10-1985	31.75	3.083	73.0	52.6	10.3	18.35	2.54	4.341	0.009
04 - " -	10.80	1.167	21.2	16.5	9.3	6.15	0.76	0.466	0.001
09 - " -	19.05	2.433	25.4	17.5	7.8	6.56	0.37	0.576	0.001
11 - " -	31.75	10.600	29.3	20.1	3.0	15.11	1.22	0.725	0.004
[14 - " -	12.07	0.767	43.7	22.6	15.7	5.92	0.34	0.589	0.001]
15-10-1985]	3.81	0.167	22.9	7.6	22.8				
	498.88					252.37	149.54	87.540	39.418

$I_{7.5}$ = Maximum 7.5 - minute intensity I_{30} = Maximum 30 - minute intensity

[ ] = The storms were combined (considered as one).

Appendix II(a). Erosivity indices for individual rainstorms, season 1

Date	Total energy Jm^{-2}	I_{30} cmh^{-1}	EI_{30} Jm^{-2} cmh^{-1}	AIm cm^2h^{-1}	$R(Jha^{-1})$ $(EI_{30}/100)$
01-05-1985	226.008	1.60	361.613	1.627	3.62
08 - " -	99.820	0.55	54.901	0.279	0.55
15 - " -	149.129	1.21	180.446	0.731	1.80
17 - " -	640.570	3.88	2 485.412	10.352	24.85
23 - " -	726.829	2.79	2 027.853	8.858	20.28
26 - " -	139.643	0.60	83.786	0.438	0.84
27-05-1985	1 220.386	7.11	8 676.944	33.410	86.77
01-06-1985	879.502	4.47	3 931.374	15.900	39.31
08- " -	378.326	3.05	1 153.894	4.648	11.54
12 - " -	1 707.101	6.48	11 062.014	44.440	110.62
19 - " -	271.647	0.85	230.900	1.188	2.31
26-06-1985	1 920.169	8.89	17.070.302	64.924	170.70
02-07-1985	78.578	0.37	29.074	0.188	0.29
03- " -	3 708.832	7.87	29 188.508	105.458	291.89
07 - " -	1 038.010	6.63	6 882.006	26.102	68.82
11 - " -	162.034	0.39	63.193	0.446	0.63
13 - " -	1 226.318	5.98	7 333.382	30.378	73.33
14 - " -	92.855	0.32	30.994	2.032	0.31
17 - " -	63.600	0.35	22.260	0.132	0.22
18 - " -	435.512	2.41	1 049.584	5.051	10.50
20 - " -	786.240	5.30	4 167.072	15.481	41.67
			96 085.512		960.85

'Convenient' sized R numbers for individual storms and annual values

$$= \frac{960\ 855.12\ Jm^{-2}\ (\text{based on } mmh^{-1}) \times (10^4 m^2 ha^{-1})}{10^7\ mmh^{-1}} = 960.85\ Jha^{-1}$$

Appendix IIb. Erosivity indices for individual ranstorms, season 2

Date	Total Energy Jm^{-2}	I_{30} cmh^{-1}	EI_{30} $Jm^{-2}cmh^{-1}$	AIm cm^2h^{-1}	R, Jha^{-1} ($EI_{30}/100$)
17-08-1985	611.499	3.59	2 195.281	7.574	21.95
18 - " -	1 911.120	9.96	19 034.755	69.571	190.35
20 - " -	215.543	0.69	148.725	0.876	1.49
01-09-1985	82.926	0.74	61.365	1.608	0.61
03 - " -	1 836.976	9.40	17 267.574	57.302	172.68
05 - " -	1 067.190	4.55	4 855.715	17.913	48.56
08 - " -	183.494	2.20	403.687	1.956	4.04
10 - " -	711.825	4.37	3 110.675	12.765	31.11
11 - " -	118.126	0.45	53.157	0.315	0.53
13 - " -	143.968	0.38	54.708	0.338	0.55
14 - " -	298.433	3.53	1 053.468	4.483	10.53
15 - " -	136.251	0.76	103.551	0.579	1.04
16 - " -	323.274	2.54	821.116	3.226	8.21
18 - " -	164.964	1.24	204.555	0.914	2.05
19 - " -	445.067	2.29	1 019.203	4.509	10.19
21 - " -	314.509	1.84	578.697	2.570	5.79
22 - " -	126.368	1.02	128.895	0.518	1.29

Appendix IIb. continued

Date:	Total Energy Jm^{-2}	I_{30} cmh^{-1}	EI_{30} $Jm^{-2}cmh^{-1}$	AIm $cm^{2}h^{-1}$	R, Jha^{-1} ($EI_{30}/100$)
24-09-1985	465.131	1.83	851.190	4.183	8.51
27 - " -	548.879	3.28	1 800.323	6.665	18.00
03-10-10985	810.792	5.26	4 264.766	16.701	42.65
04 - " -	231.780	1.65	382.437	1.782	3.82
09 - " -	409.373	1.75	716.403	3.334	7.16
11 - " -	786.305	2.01	1 580.473	6.382	15.80
14 - " -	289.142	2.26	653.461	653.461	6.53
15-10-1985	90.388	0.76	68.695	0.290	0.69
					614.13

Appendix III. Slope length and steepness factors (LS) and soil erodibility indices (K) for season 1 and season 2, 1985*

Plot No.	Season 1			Season 2		
		K - index MgJ^{-1}			K - index MgJ^{-1}	
	LS	Estimated	Measured	LS	Estimated	Measured
1	1.01	0.164	0.209	1.06	0.168	0.153
2	1.00	0.144		0.97	0.150	
3	0.87	0.138	0.177	0.88	0.160	0.167
4	0.82	0.142	0.193	0.78	0.152	0.184
5	0.86	0.142		0.86	0.153	
6	0.89	0.148		0.87	0.159	
7	1.15	0.177		1.15	0.183	
8	1.18	0.165	0.173	1.15	0.144	0.133
9	1.00	0.157	0.154	0.97	0.156	0.146
10	0.84	0.168		0.87	0.178	
11	0.81	0.122	0.160	0.75	0.117	0.161
12	0.73	0.148		0.73	0.135	
13	0.50	0.147		0.46	0.143	
14	0.54	0.153	0.249	0.53	0.125	0.242
15	0.56	0.152	0.274	0.54	0.140	0.275
16	0.53	0.169		0.55	0.161	
17	0.64	0.157	0.215	0.66	0.142	0.217
18	0.61	0.157		0.58	0.164	

* K was measured in bare plots only in both seasons.

Appendix IVa. Analysis of Variance of soil loss in bare-fallow and cowpea plots assessed by 16 nails, conventional and 25 nails techniques, season 2[a]

Source of variation	DF	SS	MS	F_H
Blocks stratum	2	71.34	35.67	
Blocks plot				
Management	1	11 410.06	11 410.06	203.400**
Technique	2	39.59	39.59	0.353[ns]
Managem. Techn.	2	61.88	61.88	0.552[ns]
Residual	10	560.97	560.97	
Total	15	12 072.51	12 072.51	
Grand Total	17	12 143.85	12 143.85	

[a] Average of 3 replications; **Significant at 1% level

[ns] Nonsignificant (5% level); S.E. ± 7.49 C.V. 11.6%

Appendix IVb. Combined Analysis of Variance table for dry bulk density taken at three sampling dates: the beginning and end of season 1 and at end of season 2^{+}

Source of variation	DF	SS	MS	F_H
Blocks stratum	2	0.093	0.046	
Blocks . Units . Stratum				
Management	1	0.058	0.058	15.614**
Techniques	2	0.004	0.002	0.572^{ns}
Sampling Dates	2	0.212	0.106	28.483**
Manag. x Techn.	2	0.026	0.013	3.476*
Manag. x Sampling Dates	2	0.061	0.031	8.295**
Techn. x Sampling Dates	4	0.014	0.003	0.937^{ns}
Manag. x Techn. x S.Dates	4	0.014	0.003	0.919^{ns}
Residual	34	0.126	0.004	
Total	51	0.515	0.010	
Grand Total	53	0.608		

$^{+}$Average of 3 replications; *, **Significant at 5% and 1% level, respectively

^{ns}Nonsignificant (5% level)

Appendix IVc. Analysis of Variance table for the effect of soil erosion on maize yield, season 1^{+}

Source of Variation	DF	SS	MS	F_H
Blocks Stratum	2	0.90	0.45	
Blocks x Plots Stratum				
Technique	2	0.43	0.21	0.154^{ns}
Residual	4	5.53	1.38	
Total	6	5.96	0.99	
Grand Total	8	6.86		

$^{+}$Nine repetitions ^{ns}Nonsignificant (5% level)

S.E. = ± 1.18; C.V. = 17.6%

Appendix IVd. Analysis of Variance table for the effect of soil erosion on cowpea yield, season 2^{+}

Source of Variation	DF	SS	MS	F_H
Block Stratum	2	0.18	0.09	
Blocks x Plots Stratum				
Technique	2	0.04	0.02	0.11^{ns}
Residual	4	0.64	0.16	
Total	6	0.68	0.11	
Grand Total	8	0.86		

$^{+}$Nine repetitions ^{ns}Nonsignificant (5% level)

S.E. = ± 0.04; C.V. = 16.2%