77-17,070

AINA, Patrick Oladipo, 1949-
THE EFFECTS OF RAINFALL, SOIL AND MANAGEMENT FACTORS ON SOIL EROSION OF NIGERIAN TROPICAL SOILS.

The Ohio State University, Ph.D., 1977
Agronomy

Xerox University Microfilms, Ann Arbor, Michigan 48106

THE EFFECTS OF RAINFALL, SOIL AND MANAGEMENT FACTORS ON SOIL EROSION OF NIGERIAN TROPICAL SOILS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Patrick Oladipo Aina, B.Sc.

* * * * *

The Ohio State University
1977

Reading Committee:

G. S. Taylor
D. J. Hoff
G. O. Schwab

Approved by

George S. Taylor
Adviser
Department of Agronomy

ACKNOWLEDGMENTS

I wish to express my profound indebtedness to my adviser, Professor G. S. Taylor for his guidance, patient counseling and encouragement throughout the course of my graduate program. My special thanks go to Dr. Rattan Lal (Soil Scientist, International Institute for Tropical Agriculture, Ibadan, Nigeria) for his time, effort and assistance freely given in supervising the research in Nigeria. I also express my thanks to Professors D. J. Hoff, G. O. Schwab and V. J. Mayer for serving on the examining committee.

The financial support received from the U.S.A.I.D. and the University of Ife is gratefully acknowledged. Appreciation is expressed to the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria for providing the opportunity and facilities to conduct my research in Nigeria and to Dr. B. L. Schmidt and the entire faculty in the department for providing the educational experience in agronomy at the Ohio State University, Columbus, Ohio.

I wish to express my warm appreciation to the staff of IITA Service Laboratory for their assistance in chemical analysis; staff of IITA soil physics section for assisting in the field work; Mr. Larry R. Drees for his assistance in the mineralogical investigations; Drs. Dev Hundal, A. Tiarks, and Messers Zaki Ghazalli, and Bob Parkinson for the benefit of their knowledge and opinions they have given on numerous occasions; faculty, staff and graduate students of the Department of Agronomy and many passing acquaintances whose cordial companionship has made my stay a pleasant one at the Ohio State University, Columbus, Ohio. Special appreciation is expressed to Lin Fauver for typing the manuscript.

Finally, I am indebted to my mother, Ajiyegbe Aina, for her moral support and inspiration which have immeasurably influenced my own development.

VITA

November 22, 1949...............	Born - Iloro-Ekiti, West Nigeria
1972...........................	B.S. in Agriculture, University of Ife, Ile-Ife, Nigeria
1973...........................	Graduate Assistant, Department of Soil Science, University of Ife, Nigeria
1973-1977......................	Research Associate, Department of Agronomy, Ohio State University, Columbus, Ohio

PUBLICATIONS

"Infiltration of Water into Two Nigerian Soils Under Secondary Forest and Subsequent Arable Cropping" Geoderma, 15:51-59

"Soil and Crop Management in Relation to Soil Erosion in the Rainforest Region of Western Nigeria" Proc. National Soil Erosion Conference, Purdue University, West Lafayette, Indiana. May 1976.

FIELDS OF STUDY

Major Field: Soil Physics

Soil Science: Professors G. S. Taylor, E. O. McLean, D. J. Hoff, T. G. Arscott, R. H. Miller, N. E. Smeck, T. J. Logan

Agricultural Engineering: Professor G. O. Schwab

Agricultural Statistics: Professors P. E. Smith and W. R. Harvey

Civil Engineering: Professors V. T. Ricca and O. W. Mintzer

Physics: Professors A. F. Prebus, W. D. Ploughe, and C. Yang

Mathematics: Professors J. Riner, J. T. Scheick, H. Colson

Chemistry: Professor R. E. Gerkin

Engineering Graphics: J. Kamen

Agroclimatology: Professor N. W. Hopper

Plant Physiology: Professors M. L. Evans, M. G. Cline

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

Appendix Tables

LIST OF FIGURES

Figure		Page

Appendix Figures

INTRODUCTION

Like elsewhere in the topics, Nigeria is plagued by serious soil erosion problems. Evidences of water erosion commonly observed in most parts of the country include gullying, extensive areas of exposed subsoil with considerable amounts of gravels on the surface, and brown coloring of river waters due to high contents of suspended solids. The extent of erosion is generally not known. However, a few studies have confirmed the severity of erosion in Nigeria (Chalk, 1963; Ofomata, 1964; and FAO, 1965).

Soil erosion is due to an interaction of several factors: The major ones are erosive nature of rainfall, highly erodible soils, hilly topography, deforestation and soil mismanagement. Most rains occur in thunderstorms of high intensities and large drop sizes. It is not uncommon to have rainfall intensities over 200 mm/hr. An analysis of raindrop size distribution by Kowal et al. (1975) showed that erosive storms frequently have more than 60% of the drops greater than 3 mm diameter. Surface soils are prone to erosion because of their characteristic sandy, non-cohesive nature and poor structural development. Soil mismanagement is as conducive to erosion as the factors already mentioned. Subsistence farming normally results in complete removal of vegetation, consequently exposing soils on slopes that were previously stabilized by dense natural vegetation. This condition is intensified by increasing population pressure on agricultural lands, forcing a decline in traditional shifting cultivation and increasing the percentage of land under continuous cultivation. In spite of these hazards, most farmers are not undertaking erosion control measures.

Little information is available for predicting and intervening erosion under tropical conditions. Considerable research on erosion has been done in the temperate regions. This research often does not apply in tropical regions because of the wide disparity in climatic and soil factors between temperate and tropical regions (Hudson, 1971; Elwell and Stocking, 1973; Ahmad and Breckner, 1974). Soil erosion research under tropical conditions becomes imperative for planning meaningful erosion control programs.

The research reported herein concerns soil erosion by water. The research was undertaken at the International Institute for Tropical Agriculture (IITA) in Nigeria during 1975. It included field studies with two cropping seasons and supplemental laboratory investigations. Its primary objectives were (a) to investigate the effects of tillage techniques on soil, water and nutrient losses, (b) to study the effects of some cropping systems on ground cover and its relation to runoff and soil loss from different slopes, (c) to determine the relative erodibility of selected soils under conditions of simulated rainfall in the laboratory, and (d) to describe the rainfall characteristics in regard to drop size distribution, intensity and wind.

The two tillage treatments were no-tillage with surface mulch provided by previous crop residues and conventional tillage that plowed in the residues. Soybeans (*Glycine max*) were grown on the tillage plots. The cropping systems for the year were rotations of soybeans-soybeans and pigeon peas-pigeon peas (*Cajanus cajan*), one crop of monoculture cassava (*Manihot esculenta*) and a mixed cropping of cassava and corn (*Zea mays*). In the laboratory, nine Nigerian soils were studied for their relative erodibilities. This study involved the exposure of soil to rainfall at two levels of rainfall intensities, three durations and two slopes. Soil erodibility was related to certain physical and chemical properties of soil. Some erosivity indices were computed from the measured rainfall characteristics and discussed in relation to their adaptability under the tropical conditions of the experiment.

REVIEW OF LITERATURE

Studies on soil erosion date back to 1880 when Elwald Wollny (Baver, 1938), a German Professor of Agriculture, pioneered the first scientific investigations. Apparently, his work was the result of an early recognition of the serious hazard of erosion to agriculture. Soil erosion generally results in loss of topsoil with its relatively high contents of plant nutrients and organic matter. Several investigations have shown that removal of topsoil has caused significant yield reductions for many crops (Table 1). In a recent study, Lal (1975) reported yield reductions of 40% for corn and 50% for cowpeas (Vignia unguiculata) due to a loss of 2.5 cm of surface soil from an alfisol in Nigeria. Erosion on cropland has also been reported to be a major source of pollution in surface waters (Haan, 1971; Robinson, 1971). Mineral sediments and agrichemicals were listed as the principal polutants. Water pollution from erosion is of increasing concern in many nations today.

The severity of soil erosion varies from one location to the other, depending on the magnitude of erosive factors. A knowledge of the effects of these factors on erosion is prerequisite to an understanding of the erosion process as well as the development of erosional control measures.

TABLE 1

EFFECT OF DEPTH OF TOPSOIL ON YIELD OF CORN*

Depth of Topsoil (inches)	Bushels per acre+			
	Indiana	Iowa	Missouri	Ohio
0	19	-	16	-
2	32	56	25	-
4	41	69	38	33.7
6	48	83	46	46.4
8	54	97	54	51.1
9	-	-	-	59.5
10	58	102	60	-
12	64	125	64	-
13	67	-	-	

*Uhland, R.E. 1949 Crop yields reduced by erosion. USDA, SCS-TP-75 (Stallings 1957 pp 211).
+1 Bushel/acre = 0.0625 metric tons/ha

A. Factors of Soil Erosion

The soil erosion process has been considered by Ellison (1945) as consisting of detachment and transportation phases. It is basically a function of rainfall and soil factors. Soil particles are detached from the soil mass by falling raindrops and are subsequently transported in suspension by flowing surface water or runoff. Major factors influencing soil erosion on agricultural lands are climate, soil properties, topography, vegetation (cover) and management practices.

1. Climate

Climate components that affect erosion are precipitation, wind, temperature and solar energy. Precipitation is the most important factor in the humid tropics. Erosivity depends on the amount, distribution, intensity and drop size distribution of individual rainstorms. Total rainfall per se is not strongly related to water erosion (Wischmeier, 1959; Hudson, 1971). Rainfall erosivity may be explained in terms of annual or seasonal rainfall distribution pattern. The severity of soil erosion in the tropics has been partly attributed to seasonal rainfall distribution (Bosazza, 1953). When wet periods of high intensity rainstorms alternate with a severe dry season, the climate is much more erosive than in regions where rainfall is more uniformly distributed. The former is quite typical of the tropics. Soil erosion will also be more serious if erosive rains come in the early parts of the growing season before adequate plant protection has been established.

Erosion usually occurs whenever rainfall intensity exceeds the infiltration rate of unprotected soil. Several studies have stressed the importance of rainfall intensity in the erosion process. Neal (1938) demonstrated that erosion increased according to a power function of rainfall intensity when slope, soil and rainfall amounts could be regulated. Fournier (1967) observed that rainfalls with a maximum intensity less than 90 mm/hr rarely caused erosion in Upper Volta. Hudson (1971) reported a lower threshold value of 25 mm/hr for Rhodesia.

Erosion has been related to maximum rainfall intensities during variable short rainfall periods. The reports by Wischmeier and his associates in the USA are perhaps the most thorough investigations of this kind (Wischmeier, Smith and Uhland, 1958; Wischmeier and Smith, 1958; Wischmeier, 1959). Results from their studies showed high correlations between soil loss and the 30-minute rainfall intensity (I_{30}). Correlations were further improved by using the product of rainfall kinetic energy and I_{30}. Elwell and Stocking (1973) in Rhodesia suggested the use of maximum rainfall intensities over shorter periods (I_{15} or I_5) as indicators of erosivity on soils with high infiltration rates or good vegetation cover.

High correlations between soil loss and rainfall energy have been widely reported in the literature. These high correlations are not unexpected since erosion is accomplished by the energy that detaches and transports soil materials. Hudson (1971) reported from research in Rhodesia that only kinetic energies corresponding to rainfall intensities greater than 1 inch per hour (KE > 1) were better predictors of erosion. His conclusions are based on observations that rainfall with lower intensities produces little or no soil erosion. His hypothesis has not been widely tested under tropical conditions.

Reports of some other workers have indicated that the momentum of rainfall could be equally reliable measure of rainfall erosivity (Rose, 1960; Elwell and Stocking, 1973; Williams 1969). However, the rainfall kinetic energy is the most widely used parameter.

Kinetic Energy Measurements

The work potential of rainfall is furnished by the kinetic energy of the falling raindrops. Several methods have been developed for the evaluation of the total kinetic energy imparted by the countless raindrops comprising a single storm. Direct measurements of rainfall energy such as those reported by Neal and Baver (1937) and Rose (1958) have been unsuccessful. These earlier measurements entailed direct weighing of raindrops on the pan of sensitive balance or measuring work done by letting rain drive a paddle wheel (Hudson, 1965). Kowal et al (1975) ascribed the inaccuracy of these methods to the negligible raindrop forces that are masked by wind effects which make such methods very unreliable.

In most cases, rainfall energy has been evaluated indirectly by computing energy from raindrop characteristics. For example, kinetic energy is related to the mass and velocity of a single falling drop as follows:

$$KE = MV^2/2 \quad (1)$$

where KE is the kinetic energy, M is the mass of raindrop and V is its terminal velocity. Laws (1941) made use of high speed photography to measure the terminal velocities of various raindrop sizes. His results were in good agreement with those of Gunn and Kinzer (1949) who used a different technique. The latter workers measured the velocities of water drops from oscillography record of pulses produced by allowing electricity charged drops to fall known distances through induction rings. Terminal velocities are well documented from both studies for a wide range of drop sizes. Their data have been used by many investigators for the computation of kinetic energy of rainstorms of known drop size distribution (Wischmeier et al., 1958; Carter et al., 1974). Perhaps the most well known equation is:

$$KE = 916 + 331 \log_{10} I \quad (2)$$

derived by Wischmeier and Smith (1958) from the published data of Laws, Gunn and Kinzer and the drop size distribution data of Laws and Parsons (1943). In this equation, KE is the kinetic energy of the storm (in foot-ton per acre inch) and I is the rainfall intensity (in/hr).

Raindrop Size Measurements

A number of methods have been used to measure raindrop size, the earliest recorded measurements being those by Lowe (1892), Hudson, 1971). His method involved catching raindrops on sheets of slate that had been ruled into squares to facilitate the measurement of splash diameter. The relationship between splash size and raindrop diameter was determined independently. Wiesner (1895) modified this technique by use of dye-treated absorbent paper instead of slates. The imprint spot formed by a falling raindrop on the paper was related to the size of water drops. A generalized form of the relationship between splash diameter and drop size is reported by Hudson (1971) as:

$$D = AB^b \tag{3}$$

where D is the drop diameter, S is the stain diameter and a and b are constants which account for the characteristics of the paper used. Hall (1970) found the method to be successful only for evaluating raindrop sizes less than 2 mm diameter. Splash losses at higher drop sizes would make the method unsuitable for use on tropical rainstorms which are characteristically of drop sizes greater than 2 mm.

Some methods of measuring raindrop sizes utilize costly and complicated equipment that limits their routine use. Such methods as high speed photography (Mutchler, 1967; Rogers et al., 1967). Use of radar (Marshall and Palmer, 1948; Atlas and Plank, 1953) and atomic sampling (Mason and Ramanadham, 1953) have been reviewed by Kowal et al. (1975).

Kowal, Kijewski and Kassam (1975) in Nigeria, recently reported the use of a device that records raindrop sizes continuously by using a transducer disc as the sensor. The signals generated by the impact of raindrops upon the sensor surfaces are amplified and recorded graphically as pulse amplitudes from which drop size distribution and corresponding kinetic energy are computed. A major limitation of the device is the damping effect on the transducer due to its retention of water, even when a domed sensor is used.

The most reliable and accurate method so far has been the "flour pellet" method of measuring raindrop sizes. The method was proposed by Bentley in 1940 and has been used with reasonably good precision in both temperate (Laws and Parsons, 1943; Carter et al., 1974) and tropical regions (Hudson, 1971). The method consists of exposing sifted flour briefly to the rain. Raindrops thus caught form dough pellets which are oven dried and weighed. The weights of the raindrops are then computed by using an appropriate calibration between drop size and pellet weight.

Wind

The influence of wind on rainfall erosivity is not fully known. However, studies by Rogers et al. (1967) and Lyles et al. (1969) indicate that wind can significantly increase the kinetic energy wind-driven rainstorms. The latter workers reported that considerably more soil was lost from soil clods that were exposed to

13.4 m/sec winds than those exposed to no wind. They hypothesized that wind increases the kinetic energy by increasing drop sizes, agreeing with the earlier findings from Blanchare's (1950) wind tunnel experiments. Increase in drop sizes is suggestive of coalescing of drops to form larger drops. Because most tropical rainstorms are accompanied by high velocity winds, they are likely to increase the raindrop sizes and terminal velocities. Such effect of high velocity winds on drop size distribution may cause a deviation from the drop size-velocity relationship established by Laws (1941) and Gunn and Kinzer (1949). Therefore, quantitative effects of wind on drop sizes and size-velocity relationship for tropical wind-driven storms are needed.

Temperature and Solar Energy

Temperature and solar energy have indirect effects on soil erosion. Both factors affect the soil moisture regime, which influences the soil's acceptance of rainfall and hence runoff and erosion.

2. Soil Erodibility

Raindrop impacts and scouring action of runoff water cause soil particles to be detached and removed as fine textural separates in the erosional process. Other erosional factors being equal, differences among soils in their erodibility is a result of soil physical and chemical properties. According to Baver (1972), these may be broadly classified as (1) those properties that determine the soil infiltration rate (porosity of the soil surface, antecedent soil moisture and permeability of the soil profile); and (2) those that resist the dispersion of soil particles during rainfall through soil structural stability. Factors affecting permeability and water infiltration into soils have been reviewed by Parr and Bertrand (1960). However, these factors have not been widely related to soil erodibility.

According to Bennett (1926), soil texture, structure, organic matter content and chemical composition are dominant soil properties influencing erodibility. Middleton (1930) investigated the physical and chemical properties of some soils which had been observed to erode differently in the field. He observed that the resistance to erosion was related to the "erosion ratio" ratio of (silt + clay)/(gravel + sand) of eroded sediments to that of original soil, "dispersion ratio" ratio of (silt + clay) in dispersed state to that in originally undispersed sample, organic matter content and total exchangeable bases. In 1935, Bouyoucos proposed the "clay ratio" as an index of erodibility. Clay ratio is the ratio of sand to (silt + sand) of the soil. It is based on textural analysis and resembles Boyd's (1922) "mechanical ratio" and Middleton's dispersion ratio.

The indices given by Middleton and Bouyoucos are based on the erroneous assumption that only dispersed aggregates are erodible. These indices are also dependent on the content of (silt + clay) of the soil. Because of this limitation, these indices have not been efficient as erosion predictors in many soils. Chibber et al. (1961) reported that none of the three indices was efficient in predicting erosion on soils of northern India.

Resistance of soil to dispersion is dependent on the amount and distribution of water stable aggregates. Attempts to use aggregation criteria as indices of soil erodibility started with Gerdel's (1937) work. Gerdel reported strong negative relationships between size and stability of aggregates and erodibility of soil. However, a number of studies indicate a general lack of agreement as to what aggregate size is most efficient as an index of erosion. This lack of agreement could be due to the differences in techniques employed by various workers. Lack of a systematic method of characterizing soil aggregates is generally observed in the literature. The wet sieving (Yoder, 1936) and McCalla's (1944) water drop methods are probably most widely used in soil aggregate stability studies. Bryan (1969) found that the latter method reflects more closely the process of aggregate dispersion by high-velocity raindrops than the wet sieving technique. Thus, the water drop method may be expected to be more efficient than the wet sieving for high-intensity rainfall situations in the tropics. This finding has been confirmed from the results of erodibility studies that employed the water drop technique for tropical soils in Puerto Rico (Smith and Cernuda, 1951), and in Nigeria (Bruce-Okine and Lal, 1975). Some indices incorporate the soil organic matter content because of its beneficial role in aggregation and infiltration capacity of soils

(Wischmeier and Smith, 1965).

Soil moisture characteristics also relate to the erosional behavior of soil. The antecedent moisture content and the moisture equivalent are particularly important determinants of the amount of rainfall a soil can take before it runs off. Neal (1938) reported that the rate of infiltration varied approximately inversely as the square root of the antecedent soil-moisture content. Fournier (1967) attributed the severe erosion on tropical and Mediterranean soils to the tendency of these soils to be near saturation moisture content because of the high frequency of rains during the rainy periods.

The dispersion of soil aggregates upon wetting is influenced by chemical charactertics such as pH, and exchangeable ions. Al was found to be more effective in reducing swelling and slaking than Fe on some Hawaii soils (El-Swaify and Emerson, 1975). Wallis and Stevan (1961) studied the erodibility of some California wildland soils and reported a negative correlation between erodibility (as determined by dispersion and surface aggregation ratios) and concentrations of Ca, Mg and (Ca + Mg). No significant correlation was found with K and Na.

3. Topography

A rolling topography is conducive to erosion because the velocity of runoff is affected by slope. As the slope increases so does the velocity of flow and the amount of soil splashed downslope. In addition to slope steepness, soil erosion is also much affected by slope length. Both slope length and steepness have been studied extensively in relation to soil erosion (Duley and Hays, 1932; Musgrave, 1947; Neal, 1938; Zingg, 1940; Smith and Wischmeier, 1957).

Zingg (1940) proposed the following exponential relation between soil loss and slope steepness:

$$X_c = 0.65S^{1.49} \tag{4}$$

where X_c is the total soil loss (in tons per acre) and S is the land slope in percent. Hudson and Jackson (1959) suggested an exponent of 2 rather than 1.49 in Zingg's equation in order to account for erosion losses in the tropics. Smith and Wischmeier (1957) reported a soil loss-slope relationship given by the parabolic equation.

$$A = 0.43 + 0.30S + 0.043S^2 \tag{5}$$

where A is the soil loss in tons per acre and S is the percent slope. Woodruff (1947) concluded from various erosion studies that slope ceases to be a significant factor in the rate of erosion on slopes of less than 4 percent. Similar observations were reported by Fournier (1967) in Rhodesia. He reported that erosion was just as severe on very slight slopes of 1-2% as on steep gradients, indicating that the dominant factor of erosion was the high rainfall impact energy rather than transport by runoff.

The time dependence of the slope-soil loss relationship becomes more important in the tropics than in the temperate region because of the high rate of soil deterioration in the former. In long-term erosion studies, involving field plots on an alfisol in Niergia, Lal (1976) reported no significant differences in soil loss between 10 and 15 percent slopes after 4 years.

Runoff-slope relationships seem to be primarily a function of soil properties such as infiltration and surface-sealing characteristics. Wischmeier (1966) reported a logarithmic relationship. Other studies have shown no relation between slope and runoff (Borst and Woodburn, 1942). Dulley and Kelly (1939), from their various studies on soil types, slopes and surface conditions, observed only slight decreases in infiltration rates with increases in slope. More recently, Lal (1976) in Nigeria, reported no significant differences in runoff losses from bare fallow plots of an alfisol on slopes ranging from 1 to 15 percent.

Research has not yielded a consistent slope length-erosion relationship. Total erosion loss increases with slope length (Zingg, 1940), because of larger exposed ground surface area. Loss per unit area depends on other factors which complicate the relationship between slope length, soil loss and runoff. Musgrave (1935) observed that soil loss and runoff on the highly permeable Marshall silt loam only increased with slope length when the rainfall intensity was much greater than the soil infiltration rate. When the latter condition was met, the greater erosion was probably due to greater accumulation of runoff on larger slopes. Other studies have shown that soil loss per unit area was an exponential function of slope length (Zingg, 1940).

The relationship between length of slope, soil loss and runoff is also significantly influenced by the nature or curvature of the slope which could result from previous erosion. Gard and Van Doren (1950) reported that on a 5 percent slope, runoff and soil loss per unit area was less on 210-foot concave plots than on 140-foot regular plots. Young and Mutcher (1969) observed that soil loss from irregular slopes depended on the steepness of a short section of the slope immediately above the point of measurement.

4. Plant Cover and Management

Surface cover constitutes the greatest deterrent to soil erosion because it offsets the effects of raindrops as precursors of erosion. Cover is much influenced by soil and crop management practices. Both factors are therefore more appropriately discussed toegeher in relation to soil erosion. Cover on soil surface may be in the form of growing vegetation or plant residue mulches. Baver (1972) classified the major effects of vegetation on erosion into four categories: (1) interception of rainfall by the vegetative canopy, (2) decrease in the velocity of runoff and the cutting action of water, (3) root effects in increasing granulation, porosity and biological activities associated with vegetative growth and their influence on soil porosity and (4) the transpiration of water leading to subsequent drying of the soil.

The vegetation canopy intercepts raindrops, reduces their kinetic energy and thereby minimizes soil dispersion by raindrop impact. Baver (1972) quoting the works of Wollny (1880), Haynes (1948) and Smith et al. (1945) reported interception values ranging from 7 to 55 percent of the total rainfall. Because intercepted rainfall does not reach the land surface directly, the effect of vegetation could be very significant in decreasing soil erosion. The percentage interception of raindrops by canopy is variable. It depends on such crop morphology as canopy characteristics and height (Screenivas et al., 1947), as well as rainfall characteristics which influence the velocity of sbusequent leaf drips and stem flow.

The outstanding influence of cover on erosion is exemplified by Hudson's (1957) experiments in Rhodesia. Under mosquito-guaze suspended 14 cm above a plot of bare soil, the average annual erosion observed for 4 years was 2.4 tons/ha. The erosion was approximately that observed under a dense cover of Digitaria spp (2.8 tons/ha). During the same period, soil loss and runoff from a bare plot without gauze were 127 and 13 times those from the plot under gauze, respectively. Similar effects of cover on erosion has been reported by many workers for plant residues when used as surface mulch. Taylor and Hays (1960) observed that a good mulch of chopped corn-stalks and manure provided excellent erosion control for continuous corn of Fayette silt loam soil with 16 percent slope. In a recent study in the tropics, Lal (1975) found that plant residue mulch applied at a rate of about 4 tons/ha significantly reduced the serious erosion losses on soils. Similar observations have also been reported by Meyer and Mannering (1961) in the U.S.

The reduction in erosion due to adequate plant cover has also been attributed to some factors other than rainfall interception.

One major beneficial effect is improved infiltration rates of soil. A linear relation between vegetal cover and infiltration rate has been confirmed by several studies (Horner and Lloyd, 1940; Borst et at., 1945; and Bertoni et al., 1958). Lawes (1961), using small catchment gauges, recorded infiltration rates ranging from over 120 mm/hr under mulch to less than 10 mm/hr for bare soil in Nigeria. Wilkinson and Aina (1976) related increased infiltration to the beneficial effect of vegetal cover on biological activities such as those of ants, earthworms and termites. These activities have been found to contribute significantly to the high infiltrability typical of tropical soils under forest (Bates, 1960).

Recognizing the importance of cover in erosional process, Wilkinson (1975) and Elwell and Stocking (1976) proposed the use of percent area of soil covered by begetation as an index of erosion. In the various studies reviewed in the literature, percent canopy cover was measured by aerial photographs and occassionally related to the leaf area index of the crop (Hudson, 1971; Wilkinson, 1975).

Crops vary in the amount of cover they provide and the rapidity with which it is established. A good management system (essentially tillage and cropping) must relate crop differences to soil and crop management practices. The traditional role of tillage in seeded preparation and weed control for row crops has been shown to be unnecessary for many soils. Instead, it has been reported in the U.S. that tillage reduces the structural stability of some soils (Burwell et al., 1966). Structural deterioration on tropical soils brought about by tillage is exceptionally rapid with consequential serious erosion problems on these soils (Fournier, 1967). Roose's (1967) work in Senegal showed that mechanical cultivation increased erosion compared with traditional hoe cultivation. Similar observation has been reported from Dahomey by Verney and Williams (1965). Erosion control therefore calls for minimum disturbance on such soils.

The beneficial effects of such minimum-tillage practices as the plow-plant, strip planting, mulch tillage and zero-tillage in conservation farming are well documented in the temperate regions (Harrold, 1960; Shear and Moshler, 1969; Triplett et al., 1970). The concept of no-tillage desginates a procedure whereby a crop is planted directly into a chemically-killed sod or crop residue mulch with no prior mechanical seed bed preparation (Jones et al., 1968). In other words, total soil disturbance is limited to that required for proper placement of seeds. On well drained and moderately well drained soils, the advantage of no-tillage in reducing soil loss and runoff has been striking and consistent. Triplett et al. (1973) reported that on a Wooster silt loam soil of 21 percent slope and planted to no-tillage corn a soil loss of less than 100 lb/acre occurred after a 5-inch rain. Similar results have been observed at the Coshocton watershed experiments by Harrold and Edwards (1972). In addition to significant reductions in erosion on these soils, no-tillage system resulted in greater crop yields than did conventional tillage. Jone et al. (1968) and Triplett et al. (1973) reported corn yield increases as highe as 39 percent. Greater water and nutrient availability was considered to be a major factor for the higher crop yields under the no-tillage system. Lal (1973) indicated that the "supra-optimization" of soil temperature and higher soil organic matter content under no-tillage (with surface mulch) are the most important factors for higher crop yields and drastic reductions in erosion on some tropical soils.

The beneficial effects of no-tillage in conservation farming are yet to be realized for a wide range of tropical soils. However, from the studies already conducted in Nigeria by Lal (1975), in Zaire by Muller and Bilerling (1953) and in Ghana by Kannegieter (1967) the no-tillage method doesn't work for all crops on all soils, there is need to establish its potency for the variety of crops and soil conditions of the tropics. An example of tropical crops that may not be adaptable to no-tillage method are cassava (Manihot esculenta) and yams (Dioscorea spp). These crops require loosened soil (mounds) for maximum development of their tubers (Berger, 1964).

Erosion on agricultural lands also depends on cropping practices. Hudson's (1971) statement that "erosion depends not only on what crop is grown but how it is grown" seems quite appropriate. The essence of a good cropping-management system is to keep the soil surface covered and minimize soil disturbance, particularly at the time the climate (rainfall) is most erosive. Table 2 shows the result of Hudson's (1971) work in Rhodesia involving the production of maize at two levels of management. This work supports the hypothesis that optimum conditions for profitable crop production generally coincides

TABLE 2

EROSION FROM MAIZE PLOTS AT DIFFERENT PRODUCTIVITY LEVELS AT MAZOE, RHODESIA. (HUDSON AND JACKSON, 1959)

Season	Productivity level*			
	1		2	
	Runoff %	Erosion t/ha	Runoff %	Erosion t/ha
1955-6	8	6.3	14	22.6
1956-7	18	26.4	20	58.8
1957-8	1	1.5	4	4.5
average yield, ton/ha	5		10	

*1. 37,000 plants/ha, maximum economic fertilizer application, crop residues ploughed in.
2. 24,700 plants/ha, medium economic fertilizer application, crop residues removed.

with management specifications for erosion control.

The importance of crop residues, cover crops, and sod-based rotations in control of erosion has been shown by several studies. It was found from over 30 years of field experiments in Iowa that although erosion losses were greatly reduced when maize was grown with large nitrogen applications, losses were further reduced by growing the maize in rotation with meadow (Moldenhauer et al., 1967). In earlier studies in Missouri where a number of rotation studies had been conducted, Miller and Krusekopf (1932) reported that erosion losses with continuous corn were 50 percent of that from bare fallow. Continuous corn caused about twice as much soil loss as corn following clover. A number of workers have reported on the significance of the sequence of rotation crops in erosion control (Wischmeier, 1960; Hays, 1961; Hudson, 1971).

In Africa, similar experiences on the performance of crop rotations on soil erosion have been reported. Hudson (1971) reported that rotations of maize and tobacco with some commonly used grasses in Africa were effective in reducing erosion losses. However, the residual effect of the grass rotation in sustaining low rate of erosion was short-lived as soon as the grass was replaced by maize. Hudson (1971) attributed this to the characteristic rapid structural deterioration of tropical soils. He suggested the use of mulch, either as surface mulch or incorporated in soil, to boost the role of rotations.

In West Africa, the farming system is becoming more conducive to erosion with the progressive decline of the traditional bush-fallow and shifting cultivation practices. Lands are cleared by cutting and burning in situ, and more lands are brought into continuous cultivation because of increasing population pressure on agricultural lands. Most farmers grow two crops per year, depending on the length of rainy season. Crops (mainly food crops) are grown on mounds or ridges with little or no conservation practice. Mixed cropping generally predominates over monocropping. Mixtures of six crops have been reported (Norman, 1970). There may be a combination of cereals, legumes and root crops such as cassava and yams (*Dioscorea* spp). Greenland (1975) has suggested the use of mixed cropping as a means of providing continuous live cover over the erosive period. In mixed cropping, the second and subsequent crops are planted after the first crop is established. One crop frequently remains on the ground long after others have been harvested. Thus, the soil has plant cover for a longer period and with a greater canopy density than would be the case with single crop. Various crop mixtures including cereals, legumes and root crops have been tested in the tropics for their compatibility in terms of higher yields and lower nutrient requirements than the corresponding crops under monculture (Andrews, 1970; Steel, 1972; Greenland, 1975).

B. Methods of Evaluating Soil Erosion

Erosion research has been largely of an applied nature, involving on-site determinations of soil erosion. One method involves the direct measurement of changes in soil surface level as described by Gleason (1957). Gleason used bottlecaps on soils driven cup-side down and flush with the ground surface. These would make pedestals at the end of an erosive rain, and the heights of these pedestals were related to the amount of sheet erosion. He also used the 'spike and washer' device (Hudson, 1964) to monitor gully erosion. This method was later tried by Hudson (1964) in Rhodesia. Because of great soil variability, soil is not washed uniformly over the entire exposed surface. Direct measurements of changes in soil surface are therefore crude means of evaluating erosion on agricultural lands. Hudson (1971), however, argued that it could prove useful for measuring localized erosion, such as in gullies, or on road embankments. Erosion on cropland requires a more accurate determination.

Quantitative measurements of erosion are more frequently and most accurately obtained by determining the amount of eroded soil, runoff and nutrient losses from permanent plots. A plot size of 22m x 2m has been most widely used in the U.S. where considerable conservation work has been done. The development of various runoff collection devices to facilitate accurate measurement of erosion losses has been reviewed by Wischmeier (1962).

For a number of years soil erosion studies made use of field plots and natural rainfall. In order to remove the constraint imposed by the erratic nature of natural rainfall, researchers began to use simulated rainfall intensively during the 1930's. Water was applied by various means ranging from hand-held sprinklin cans (Duley and Hays, 1932) to the refined automatic application devices used today.

Following the documentation of natural rainfall characteristics by Laws (1941), Laws and Parsons (1943) and Gunn and Kinzer (1949), simulators were developed to reporduce fairly accurately such rainfall characteristics as intensity, drop size distribution and terminal velocities. The nozzle type F rainfall simulator of Wilm (1943) produced rainfall with drop sizes comparable to those of natural rainfall, but the velocities at impact were still less than those of natural rainfall. Recently developed rainfall simulators were reviewed by Hall (1970). These are characterized by downward sprays and are more efficient in reproducing the terminal velocities of natural raindrops. Young and Burwell (1972) compared the kinetic energy of their simulator with that of natural rainfall. Simulated rain intensities 6.35 and 12.7 cm/hr respectively, gave kinetic energies of 76 and 70 percent of natural rainfall with similar intensities. Use of rainfall simulators in erosion studies is now generally acknowledged to be appropriate, and many workers have used them on standard field plots (Wischmeier and Smith, 1965; Bryan, 1970; Yamamoto and Anderson, 1973; Dangler et al., 1975).

Microplots of about one or two meters square have also been used alone with simulated rainfall.. Neal (1938) used a 1/1000-acre soil tank filled with Putnam silt loam. He studied the effect of slope and rainfall characteristics on soil loss and runoff. Woodruff (1947) used the same technique in his greenhouse studies in order to relate erosion to crop cover, rainfall and slope. Recently, Munn et al. (1973) and Hoyt (1975) used 122cm x 30cm x 15cm boxes and single nozzle rainfall simulator to study the movement of various soil nutrients in relation to different conditions of rainfall, cover and slope.

While results from the microplot technique may not be directly extrapolated to field plot conditions, it is adequate for making rapid qualitative erosion investigations. Such studies may serve as preliminary studies in a pilot project. Soil erosion can also be accurately related to some factors such as slope steepness, rainfall characteristics, soil properties and management practices.

Erosion Prediction

Development of empirical equations and indices for predicting soil loss started in the early 1940's as a result of field and laboratory erosion studies in the U.S. (Wischmeier et al., 1958). Wischmeier (1962) reviewed various attempts to formulate prediction equation by several workers (Zingg, 1940; Smith, 1941; Browning et al., 1947; Musgrave, 1947; Van Doren and Bartelli, 1956). In the late 1950's, the universal soil loss equation (USLE) was developed by Wischmeier and his co-workers (Wischmeier, Smith and Uhland, 1958).

The soil-loss equation is:

$$A = R\ K\ L\ S\ C\ P \qquad (6)$$

where A is the computed average annual soil loss in tons per acre from a specific under a specific rainfall pattern, cropping-management plan, and applied conservation practices. R is the rainfall factor and is a measure of the erosive potential of average annual rainfall in the locality. It is called the rainfall-erosion index. Iso-erodent maps are available for most of the U.S. which present local R-values for use in soil loss prediction. K is the soil erodibility factor and is the average soil loss in tons per acre per unit of erosion index (A/R) from a particular soil in cultivated continuous fallow with a standard plot length (72.6 feet) and 9 percent slope. The factor K has been correlated with a series of physical and chemical soil properties discussed earlier under the section "soil erodibility". Topographic factors, L and S adjust the soil loss estimate to the specific slope length and percent slope existing on the field. Graphs have been presented for evaluating their combined effect in various combinations (Wischmeier et al., 1958). The cropping-management factor, C, is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean-tilled fallow on identical soil and slope and under the same rainfall. It reflects the combined effects of cover, crop sequence, productivity level, length of growing season, tillage practices, residue management and the expected time distribution of erosive rainstorms with respect to seeding and harvest dates in the locality. The erosion-control practice, P, takes into account the erosion control benefits gained by such practices as contouring, strip cropping or by combining terraces with contouring. Values and computations of each component parameter of the USLE are well laid out in the U.S. Department of Agriculture Handbook No. 182.

The adaption of the USLE has not been established under the various conditions of the tropics. Because of the disparity between tropical and temperate climates and between soil conditions, several investigations have suggested modifications of the R and K factors. For example, Hudson (1971) suggested the use of KE > 1 index in the tropics instead of R. (Recall that $R = EI_{30} \times 10\text{-}2$). Fournier (1960) also proposed a broad climatic approach combining an empirical rainfall factor, P^2/P (where P is the rainfall in mm in the wettest month and P is the annual rainfall) with an average relief factor. The limitations of his approach were that the local variations in slope, soil properties, vegetation and land use were not considered. High wind velocities have been regarded as being typical of tropical rainstorms and according to some workers (Ahmad and Breckner, 1974) should be incorporated in the erosivity index for the tropics. Lal (1976) reported that soil losses in Nigeria were better correlated with AI_m (product of rainfall amount, A, and intensity, I, in cmxcm/hr) than EI_{30} of the USLE. Elwell and Stocking (1976) proposed a percent ground cover index which according to them did not require long-term and expensive field measurements. However, an earlier study by Wilkinson (1975) on erosion-cover relationships in Nigeria showed low correlations between erosion losses and percent canopy cover. His result suggests that factors other than the vegetal cover are involved in erosion prediction index that is based on cropping-management factor.

It follows, therefore, that an urgent need exists for erosion studies in the tropics to evaluate the erosive potentials of the various factors influencing soil erosion. Furthermore, the adaptability of efficient conservation techniques already established for temperate conditions need to be tested under tropical conditions.

MATERIALS AND METHODS

A. Field Erosion Studies

The field experiments were designed to study soil erosion losses on field plots of different slopes under conditions of natural rainfall and selected tillage and cropping practices.

1. Experimental Site and Soil

The site of the experimental plots was located in the soil physics section of the experimental farm of the International Institute for Tropical Agriculture (IITA) near Ibadan in Nigeria. IITA is on a 1,000 hectare site, five kilometers north of Ibadan with a tropical climate and an annual rainfall of about 1200 mm. Some weather data of the area are given in Table 3.

The soils used were part of an alfisol toposequence (Figure 1), locally known as the Egbeda association (Smyth and Montgomery, 1962) or Paleustalf by the USDA soil taxonomy system (Soil Survey Staff, 1975). The soils are exceptionally well-drained. They are characterized by a deep, red clayey profile with a sandy surface soil and a layer of angular and subangular quartz gravels in the horizon immediately below the surface layer (Moormann et al., 1975).

TABLE 3

WEATHER DATA FOR IITA IN 1975[1]

	Average Daily Values									Monthly Values	
				Temperature			Relative Humidity				
Month	Rain mm	Evaporation mm	Radiation (g cal cm^{-2})	Min. °C	Max. °C	Mean °C	Min.	Max. %	Mean	Rain mm	Evaporation mm
Jan	0.0	4.58	372	16.9	34.0	25.4	21	92	56	0.0	142
Feb	2.7	4.86	436	21.6	34.7	28.1	35	92	64	76	136
Mar	2.9	5.35	460	23.3	34.7	29.0	46	95	70	90	166
Apr	6.5	4.86	500	22.3	33.1	27.7	56	98	77	194	146
May	6.6	4.32	442	22.2	31.9	27.1	62	97	80	204	134
Jun	6.4	4.06	446	22.4	31.1	26.8	62	97	80	191	122
Jul	4.7	3.11	349	22.1	29.3	25.7	68	97	82	147	97
Aug	3.0	2.48	287	22.0	27.9	24.9	72	97	85	94	77
Sept	3.8	2.64	285	21.1	28.4	24.7	69	98	83	113	79
Oct	9.2	3.79	377	20.9	30.2	25.6	58	97	77	285	118
Nov	1.9	3.70	371	22.3	31.8	27.0	52	98	75	58	111
Dec	0.6	3.25	368	19.3	31.9	25.6	40	95	68	19	101
Year	4.0	3.91	391	21.3	31.5	26.4	53	96	75	1430.5	1428

[1]/T.L. Lawson, 1975. IITA Weather report.

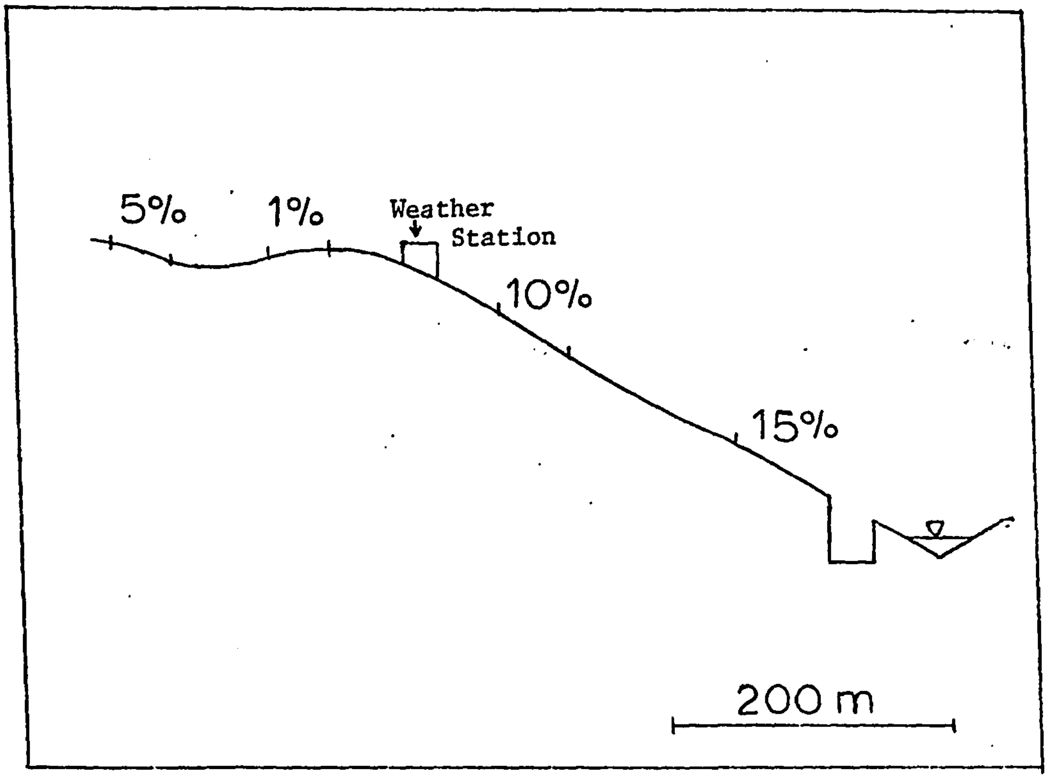


Figure 1. Locations of runoff plots of different slopes along the toposequence (Lal, 1976)

2. The Erosion Plots

The 24 experimental plots were established in 1972 (Lal, 1976) on natural slopes of 1, 5, 10 and 15 percent. Five plots of 25m x 4m were established on each slope while the two additional ones of 37.5m x 4m (long plots) and 12.5m x 4m (short plots) were on the 10 and 15 percent slopes. Each plot was enclosed on two sides by asbestos strips protruding about 30 cm above the ground. The upper end was bounded by a gutter having its banks covered with short thick grass. The base or lower end of each plot was connected by a flume and trough to a 120cm x 70cm x 50cm sediment tank (Figure 2). Each plot was buffered by grassed 1-meter wide borders. The construction and operation of the plots have been described by Lal (1976).

3. Treatments

A factorial experiment consisting of 2 tillage, 3 cropping and 1 control (bare fallow) treatment for each slope was established. The design also allowed for the evaluation of the effect of slope length at 2 levels (12.5m and 37.5m long) on 10 and 15 percent slopes. The layout of field plots and treatments is illustrated in Figure 3.

Tillage Treatments

The tillage treatments were no-tillage versus conventional tillage for soybeans (Glycine max).

The no-tillage plots had not been plowed for four years. Weeds were killed by applying paraquat from a pressure-regulated hand sprayer three days before planting at the rate of 2 liters/ha.

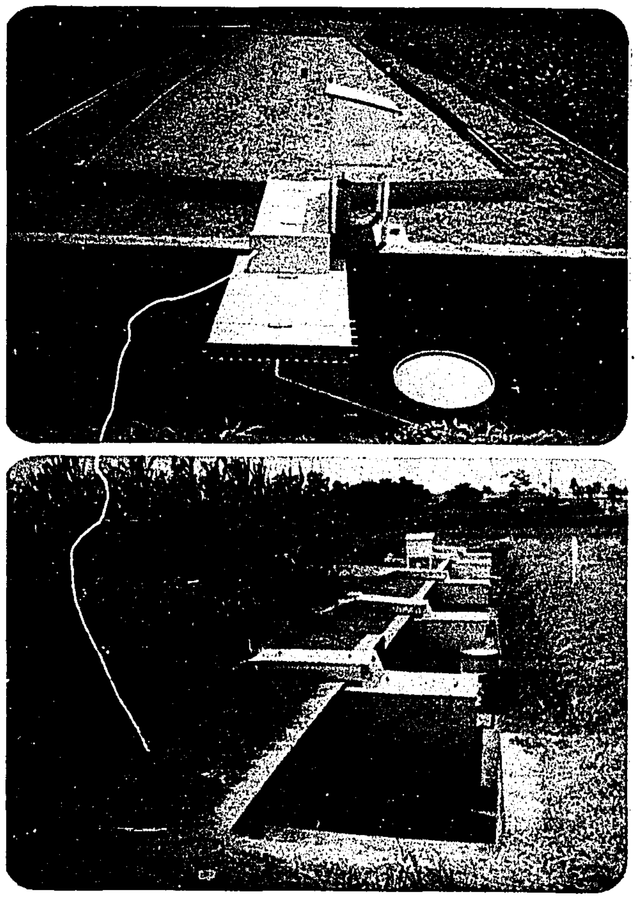


Figure 2. Photographs showing runoff plot with soil and water collection system.

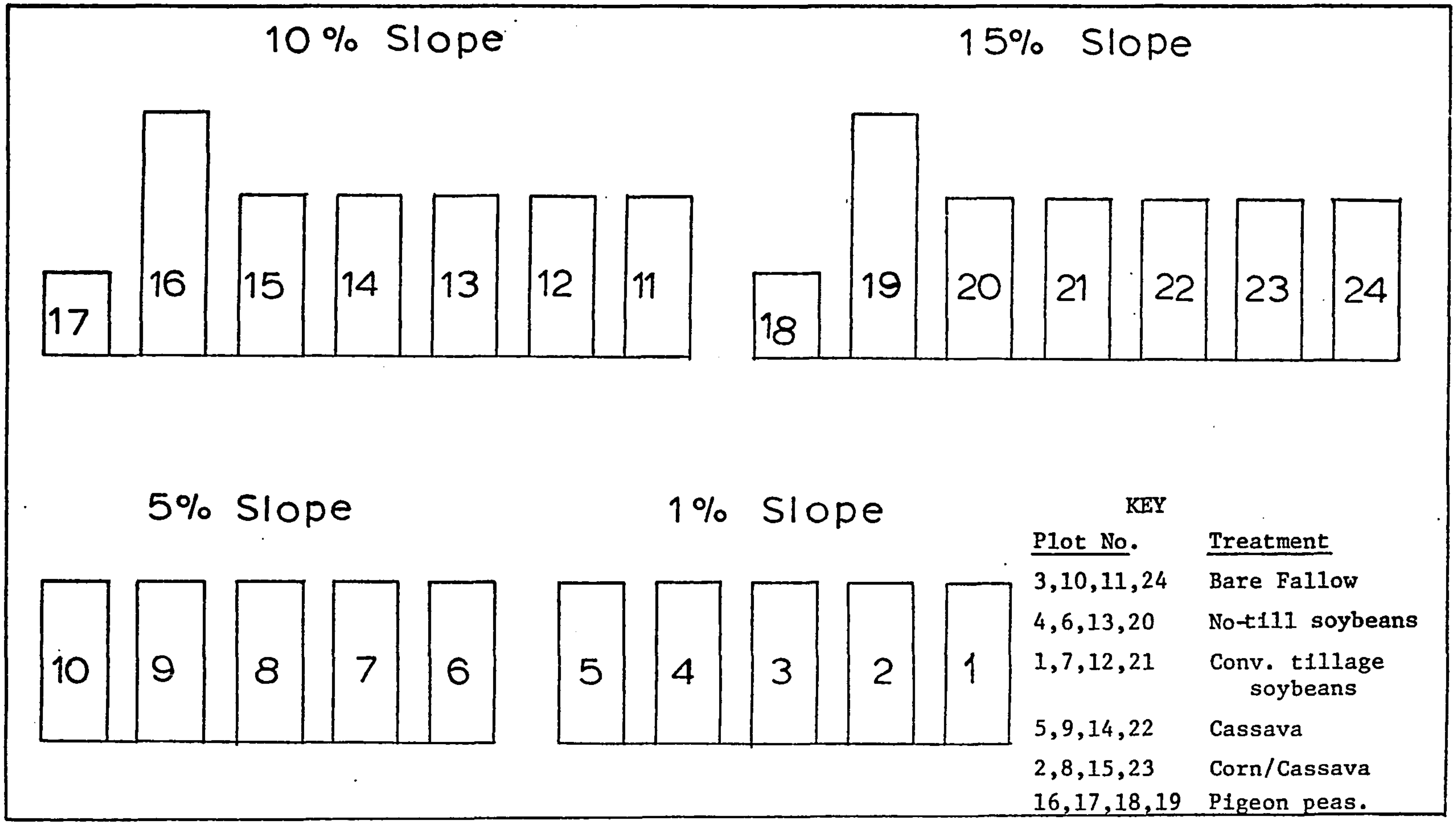


Figure 3. Layout of field plots and treatments.

Plots were mulched with the previous season crop residue at about 5 metric ton per hectare (maize stovers for the first season and soybeans stovers for the second crop season). Mulching at this rate proveded about 80% ground cover. Seeding was done in rows prepared manually with a cutlass just prior to seeding. Subsequent weeding on these plots was also done manually.

The conventional tillage soybean plots and all the cropping and bare fallow treatments were disc-plowed and harrowed, using the "Agria" implement. Weeding was done with a hand-hoe which involved mechanically stirring the ground surface.

Cropping Systems

These consist of bi-annual rotations of soybean-soybean pigeon peas-pigeon peas (*Cajanus cajan*), one crop of monoculture cassava (*Manihot esculenta*), a mixed cropping of cassava and corn (*Zea mays*), and a bare fallow treatment. All plots were conventionally plowed. Cassava being a perennial crop (but harvested at the end of first year) gave only one crop. Only one crop of corn could be successfully grown in a mixed cropping of corn and cassava. The shading effect of an established cassava canopy prevented the development of the second season corn crop. The same cultivars of soybeans and pigeon peas were planted in the first and second seasons. The cropping treatments are summarized in Table 4. It may be of interest to note that Cassava is planted from stem cuttings, about 51 cm long chopped from the entire stem length. Planting is done by burying 50 to 65 percent of each cutting in the soil.

TABLE 4

SUMMARY OF AGRONOMIC PRACTICES CARRIED OUT UNDER DIFFERENT CROPPING TREATMENTS

Treatment	Crop Variety	Plant Spacing	Fertilizer Rate (kg/ha)
Soybeans-soybeans*	"Bossier"	50cm x 5cm	26 P, 30 K
Pigeon peas-pigeon peas+	3D-8103	50cm x 12.5cm	26 P, 30 K
Monoculture Cassava	"Isunikan kiyan"	1m x 1m	No fertilizer application
Mixed cassava and maize	"Isunikan kiyan" and "TZBC4"	1m x 1m and 50cm x 25cm	120 N, 26 P, 30 K + 240 N (second dose)
Bare fallow	-	-	120 N, 26 P, 30 K

*The samé applies to no-tillage soybeans.
+Pigeion peas were grown on the long and short plots on 10 and 15% slope.

4. Procedure

Agronomic Practices

All plantings were made up and down the slope and done simultaneously for all crops on April 12, 1975 for the first sason and on August 8, 1975 for the second season (soybeans and pigeon peas). Fertilizer application was by broadcast at the time of planting. In the case of cassava and maize mixed cropping treatment, a second nitrogen application was made by side-dressing four weeks after planting. Following planting operations, each of the plowed plots were smoothed with a hand-rake in order to elimate compaction and depressions that were created by foot-tramping during the operations. Weeding was done regularly throughout the season.

Sampling of Runoff and Soil Losses

Following each erosive rainstorm, the depth of runoff collected in the tank and the drum was measured for subsequent computation of the total volume of runoff from each plot. The runoff and soil mixture was thoroughly mixed by stirring, and two one-liter samples were quickly withdrawn by immersing one-liter plastic bottles into the middle of the tank. After draining the tank, the soil sediment left in the tank (and occasionally the drum) and on the flume were completely scraped into polythylene bags, labelled and weighted. A moisture sample was then taken (at weighing) from each bag for moisture content determinations. These moisture content values were later used to convert the fresh weight of the eroded soil to dry weight basis. The eroded soil samples were left to air dry in the polythylene bags.

The runoff aliquot samples were immediately stored in the laboratory at room temperature to prevent volatilization of some of the nutrients such as N and P. One of the samples was saved for chemical analysis. The other sample was filtered in the laboratory, usually after adding a teaspoonful of magnesium chloride salt to facilitate rapid settling of the soil particles, to determine the sediment density of runoff on a dry weight basis. The sediment density was used in computing the total amount of soil in the runoff for each plot. The latter when added to the sediment loss represents the total soil removed from each plot under the prevailing rainfall conditions.

Plant Measurements

Plant measurements commenced two weeks after planting and were taken subsequently at seven day intervals. Germination counts were taken for two weeks, starting three days after seeding. Other measurements included plant heights, measured from the soil surface to the tip of the extended leaves; length and maximum width of leaves; and rainfall interception by crop canopy.

The total canopy area of each plot was the summation of the area of individual leaves measured on 5 plants per plot. The area of each leaf was obtained by multiplying the length by the width and by a correction factor (r). The correction factor for each crop was used to compensate for the non-rectangular configuration of the leaves. r was taken as the ratio of the leaf area computed from length x width to the area of a piece of paper of a predetermined density (mass/area) and made out into the exact configuration as the fresh leaf. The area of the piece of paper was computed from:

$$\text{Area} = (\text{weight of paper "leaf"})/\text{density}$$

Percent ground cover by crop canopy was also determined weekly by aerial photography. A representative rectangular area of 4m x 1m was visually chosen for each cropped plot. Aerial photographs of the representative area were taken vertically downwards from the top of a six-foot quadrupod ladder. Area not covered by plant canopy in each 12cm x 10cm print (photograph) was determined by a planimeter and expressed as a proportion of the total area of the photograph.

Crops were harvested in August, 1975 for the first season soybeans, pigeon peas and maize, and on December for second season. The yields were expressed on a dry weight basis following moisture content determination. Crop yields under cassava monoculture and mixed cropping of cassava and core were expressed in terms of calories/ha (Platt, 1965) to facilitate comparison of the two treatments.

Rainfall interception measurements involved the determination of the proportation of total rainfall that penetrated the canopy. Rain gages were positioned under each crop canopy and in the bare plots to facilitate this determination.

Field Soil Moisture Determinations

Soil moisture regime of each plot was monitored weekly at 30-cm intervals to a depth of 120cm using the moisture neutron probe equipment. A Toxler neutron probe model 104A having a 100-millicurie of Am-Be and a 47.4mm diameter probe was used. Two aluminum tubes, 50.8mm diameter and 150cm long, were installed in each plot (each in the upper and downslope ends) and served as access tubes for the neutron probe. The average readings at each access tube was used in computations for each plot. Neutron probe readings were given in counts per second. Conversion to volumetric or gravimetric moisture content values was by appropriate calibration of the instrument.

One access tube was installed adjacent to the plots in relatively undisturbed soils on each of the four slopes. A5-cm bucket auger was used to make the hole just large enough for the tube without significant changes in soil's natural state around the tube. Since changes in texture and bulk density of the soil are known to affect neutron probe reading (Lal, 1974). Calibration was done at these sites following the procedure by Lal (1974).

Field Infiltration Measurements

Infiltration measurements were made during the dry seasons that terminated the field studies. A double-ring infiltrometer method (Parr and Bertrand, 1960) was used. The steel inner ring was 30cm in diameter and the outer ring was made from a grease drum 53cm in diameter. Both rings were driven 8cm into the ground using a metal plate tamper. The source of water to the inner ring was a calibrated 180-liter drum connected to the inside. A 10-cm constant head of water was maintained in both rings by manual control. Three replications were made for each of the 20 plots. Infiltration was similarly measured for the same soils that were under secondary forest on 1 and 15 percent slopes. These soils had been relatively undisturbed for four years and had high biotic (earthworm) activity.

B. Laboratory Erosion Studies

The relative erodibility and some related factors of nine benchmark soils of Nigeria were investigated under laboratory conditions involving the use of simulated rainfall and soil trays (microplots).

1. Soils and Sample Sites

Nine soils were selected on the basis of distinct differences in physical, and chemical attributes and expected hydrologic behavior. They were:

Alagba (Oxic Paleustalf)
Apomu (Typic Ustorthent)
Dangappe (Oxic Paleustalf)
Egbeda (Oxic Paleustalf)
Funtua (Oxic Tlaplustalf)
Ikom (Orthoxic Tropohumult)
Itagunmodi (Oxic Paleustalf)
Ngala (Typic Chromustert)
Onne (Typic Paleudult)

Because Egbeda soil was also used in the field erosion studies, its erodibility was used as a benchmark for comparison with the other soils. Tables 5 and 6 give some physical and chemical properties of the soils used in the study. The soils were classified by

Harpstead (1973) and Moormann et al. (1975) and are shown in Table 6.

Soil samples were collected from the surface 0-15cm after surface debris and vegetation has been removed. None of the sites had been cultivated for the last five years. Figure 4 shows the location of the sample sites which represented appreciable land areas and different ecological zones from the wet and humid southern to the hot and dry northern parts of Nigeria.

2. Preparation of Microplots

Eighteen boxes, two for each soil, were constructed from wood treated with linseed oil. Each box was 122cm long, 35cm wide and 15cm deep (Figure 5A). The bottom was screened off and further reinforced with a steel grate that offered firm support for the soil while at the same time facilitating free drainage. The downslope end of the box was replaced with sheet metal. This side could then be adjusted to coincide with the upper soil surface. Soil samples were air dried, crushed and sieved through a 10mm screen. The bottom of the box was then lined with a double layer of cheesecloth before packing the soil in the box. The soil was packed to bulk density corresponding to that in the field, according to the procedure described by Munn et al. (1974). Some preliminary studies showed that subjecting the unpacked soil to a rainfall intensity of 6.2 cm/hr for 30 minutes using nozzle type 5B would settle the soils to field densities after 24 hours.

TABLE 5

SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS STUDIED

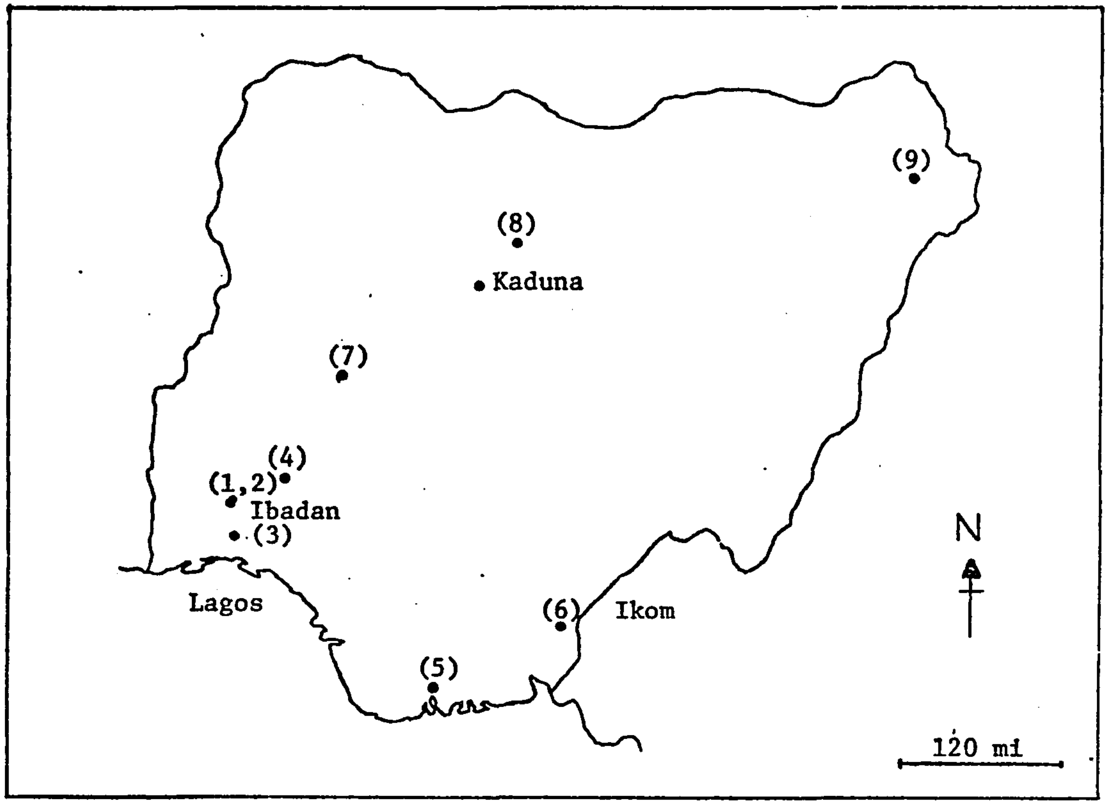
Soil Type	Mechanical Analysis			Plasticity			Moisture Equivalent
	Sand %	Silt %	Clay %	Index %	Limit %	Ratio %	%
Alagba	77.2	12.4	10.4	9.6	20.2	1.44	12.7
Apomu	85.7	6.9	7.4	0.0	--	--	7.3
Dangappe	76.9	16.7	6.4	5.2	7.8	1.85	6.8
Egbeda	59.6	20.0	20.4	7.0	10.0	1.95	19.4
Funtua	22.3	63.3	14.4	6.9	24.3	1.38	18.3
Ikom	40.0	20.6	39.4	11.6	36.8	1.43	29.6
Itagunmodi	35.4	26.2	38.4	7.7	17.0	1.79	28.5
Ngala	37.2	24.4	38.4	10.1	14.6	1.75	27.2
Onne	81.1	3.5	15.4	4.1	--	--	11.4

Soil Type	Organic Matter	pH	Exchangeable Bases					Available P	Total N
			CEC	Ca	Mg	K	Na		
			me/100 g					ppm	%
Alagba	2.58	6.5	7.05	4.40	2.34	0.11	0.20	9.13	0.32
Apomu	2.40	5.9	7.41	5.12	1.67	0.28	0.34	11.32	0.28
Dangappe	1.05	6.2	3.60	2.33	0.85	0.15	0.30	11.75	0.09
Egbeda	2.96	6.2	8.32	5.70	1.67	0.60	0.35	5.18	0.50
Funtua	1.55	5.9	4.93	2.42	1.55	0.60	0.35	4.09	0.16
Ikom	3.15	5.8	11.01	8.97	1.51	0.19	0.10	29.20	0.41
Itagunmodi	3.53	5.9	10.08	7.31	2.01	0.40	0.38	6.28	0.50
Ngala	1.34	7.3	18.11	13.21	3.34	1.01	0.52	48.03	0.15
Onne	2.49	4.0	4.31	0.40	0.10	0.09	0.30	52.63	0.21

TABLE 6

CLASSIFICATION OF SOILS STUDIED

Soil	Parent Material	Native Vegetation	Annual Precipitation (cm)	Classification
Alagba	Coastal Sediments	Rain Forest	150-200	Oxic Paleustalf
Apomu	Colluvial Material	Rain Forest	150-200	Typic Ustorthent
Dangappe	Cretaceous Sandstone	Savanna (Guinea)	100-125	Oxic Paleustalf
Egbeda	Banded Geneiss	Rain Forest	150-200	Oxic Paleustalf
Funtua	Loess Deposits	Savanna	100-125	Oxic Paleustalf
Ikom	Olivine Basalt	Rain Forest	200-250	Orthoxic Tropohumult
Itagunmodi	Amphibolite	Rain Forest	125-150	Oxic Paleustalf
Ngala	Alluvium	Savanna	75-100	Typic Chromustert
Onne	Coastal Sediments	Rain Forest	200-250	Typic Paleudult



KEY

SOIL TYPE

1. Apomu
2. Egbeda
3. Alagba
4. Itagunmodi
5. Onne
6. Ikom
7. Dangappe
8. Funtua
9. Ngala

Figure 4. Map of Nigeria showing soil sample sites.

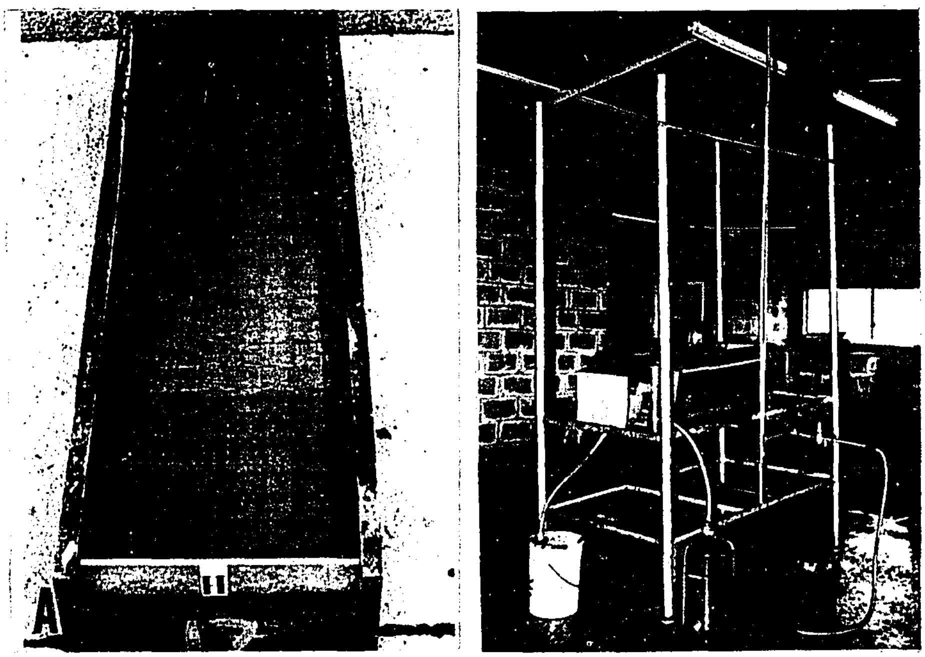


Figure 5. Photographs showing (A) a soil tray and (B) laboratory microplot and runoff collection system.

Prior to rainfall application, the soil box was placed on a sand box that was constructed from sheet metal of dimensions slightly less than the outer dimensions of the soil box. The sand box contained acid-washed quartz sand and was used an an innert filter for percolation water. It also had an outlet at its downslope end. The sand box was mounted on a platform that could be tilted to different slopes. A sheet metal hood surrounded the soil box to prevent rainfall and spattered soil from falling into the sand. An assembly of flume and collection trough was connected to the lower end of the soil box. Two pre-calibrated 20-liter plastic carboys were connected separately by rubber hoses to the runoff trough and sand box outlet. Figure 5B shows a typical arrangement described above. Care was taken to ensure that any leaks were sealed with wax before rainfall applications.

3. The Rainfall Simulator

A rainfall simulator similar to the one described by Bertrand and Parr (1961) was designed and constructed for use in this study. It consisted of a sprinkler head containing a nozzle, a pressure-regulating and stabilizing valve and a 30-psi water pressure gauge connected to the water line. Full-cone, medium-angle, center-jet nozzle types 5B and 7LA were used. These were obtained from the Spray Engineering Company, Burlington, Massachussetts, U.S. Only nozzle type 7LA was used in the main study because type 5B produced rainfall of intensities and drop sizes much lower than those of natural rainfall of the area. Calibration of the nozzle in terms of drop-size distribution and terminal velocity was previously made according to the methods of Bertrand and Parr (1961). The calibration results are given in Appendix Table 1.

4. Treatments

The treatments for each soil consisted of combinations of slope, rainfall intensities and duration selected to reflect the topographic and rainfall characteristics of the respective area:

(1) The two rainfall intensities were 12.5 and 17.5 cm/hr respectively at predetermined pressure values of 10 and 6.25 psi.

(2) Three levels of rainfall durations were chosen to give 2.1, 4.2 and 6.3 cm rainfall, respectively, at each intensity.

(3) Slopes of 5 and 10 percent were used for each combination of intensity and duration.

(4) Additional nutrient movement studies were made at two levels of each NPK fertilizer applications. One of the duplicate boxes under each soil received 10gm urea, 30gm single super phosphate and 10gm muriate of potash. These rates correspond to those commonly used on arable crop-lands in Nigeria. No fertilizer was applied to the other replicate microplot.

5. Procedures

The sprinkler head was centered directly above the microplot and at 274cm elevation above the soil surface. The microplot sheet metal cover was then put in place. Calibration of the intensity was empirically made before each rainfall application or "run". Two 10cm rain gauges were used to record the rainfall.

To start a run, the sheet metal cover on the microplot was quickly removed to expose the microplot to rainfall. Each run was subsequently terminated by replacing the cover before turning off the water source. Chemical characteristics of the tap water used for the runs are given in Table 7.

Two consecutive runs were made. The first called a "dry run" (Dangler et al., 1976) was made at the air dry moisture content of the soil; while the second called a "wet run" followed 24 hours later at an initial moisture content near field capacity. This procedure was followed to relate rainfall distribution pattern and antecedent moisture content to erosion. Air drying the microplots between the wet and dry runs generally took one week since these studies were made in the dry hot season. Cracks resulting from drying were alwasy sealed with mud slurry before each dry run.

For each run, records were made of the time of initiation of runoff (time of start of continuous flow or runoff over the flume), rates of runoff and percolation volume. During dry druns, the moisture content at the initiation of runoff was occasionally determined from soil samples taken from 0-5cm depth. At the end of

TABLE 7

CHEMICAL CHARACTERISTICS OF TAP WATER USED FOR THE LABORATORY SIMULATED RAINFALL

pH	6.2
EC	180 µmhos/cm
Ca	21.0 ppm
Mg	3.65 ppm
K	5.04 ppm
NO_3-N	0.91 ppm
Available P	0.08 ppm

each run, the volumes of runoff and percolation collected in the carboys were measured. Procedures for handling runoff, leacate and soil loss and for computations of erosion losses were the same as reported for the field erosion studies.

C. Rainfall Characteristics

The intensity, dropsize distribution and annual monthly distribution of rainfall and wind velocity were monitored during 14 storms. Erosivity indices were also computed from rainfall data and related to soil losses obtained from field erosion studies under the different rainfall conditions.

1. Annual Rainfall Distribution, Intensities and Energy

These rainfall characteristics were computed from rainfall data obtained with a recording rain gauge that was located near the field erosion plots. Peak intensity and maximum intensities at 5, 7.5, 15, 22.5, 30, 45 and 60-minute intervals were computed for each storm. The kinetic energy of the storm was calculated by equation (2) (Wischmeier and Mannering, 1969) computations of indices: EI_{30}, $KE > 1$, AI and AIV are shown in Appendix Table 2. EI_{30} is the product of the kinetic energy of the storm (E) and the 30-minute intensity (I_{30}). $KE > 1$ is the kinetic energy of rainfall with intensities greater than 1 inch per hour (2.5 cm.hr). The erosivity, AI was computed from the following equation:

$$AI = \sum A_i I_i \qquad (7)$$

where A_i is the amount of rain in increment i (cm) and I is the intensity of the rain in increment i (cm/hr). AIV is the product of rainfall amount, A (cm), maximum intensity, I (cm/hr) and wind velocity, V (km/hr).

2. Wind Velocity

Wind velocity profile during each rainstorm was recorded by an anenometer at a height of 1 meter from the ground surface. Average wind velocity in km/hr was computed from times of uniform rainfall intensity. The latter were obtained from uniform slopes on the rainfall amount versus time curves of the rainfall charts.

3. Raindrop Size Distribution

The flour pellet method as given by Hudson (1963) was used to monitor size-distribution of raindrops. Raindrops were sampled in pre-calibrated wheat flour that was sifted to pass through a 210-micron sieve.

Flour Calibration

An apparatus, described by Lal (1975) was used to provide water at constant head and uniform room temperature (22°C). Glass tubes and hypodermic needles of different diameter openings were used to provide a range of water drop sizes needed for the calibration. Each tube was connected to the spout of a water bottle and drops were allowed to fall until the drop size and rate of formation were fairly constant. Ten drops were then allowed to fall into a clean, pre-weighed, 25-ml graduated cylinder containing two drops of parafin. The parafin prevented evaporation of the water drops. The cylinder was then quickly weighed with the contents. From the weight of water, the average weight of a single water drop was calculated. Drops were then caught in a pan containing a 2.5-cm thick layer of freshly sifted flour. This process was repeated twice for each drop size or tube size.

The dough pellets formed from the water drops were allowed to air dry in the flour for 24 hours at room temperature (22°C). They were then separated from the flour and dried in the oven at 105°C for 24 hours and weighed. The "mass ratio" of Laws and Parsons (1943) was computed for each drop size by dividing the average drop mass by the average pellet mass formed from each drop size. The result of this calibration is shown in Figure 6.

With this procedure it was impossible to produce drops of 3 mg or less from tube openings. Therefore, the hypodermic needle opening was coated with vaseline. The needle was agitated and 50 or more water drops was taken immediately.

Raindrop Sampling and Processing

Aluminum pans 25cm diameter, containing a 2.5-cm layer of freshly sifted wheat flour were used to sample raindrops by exposing them to rainfall for a period of 2 seconds. Sampling was done at 3 to 4 different times during each storm to ensure that a wide range of intensities was covered. The time of sampling was recorded. The rainfall intensity at the corresponding time was read from the

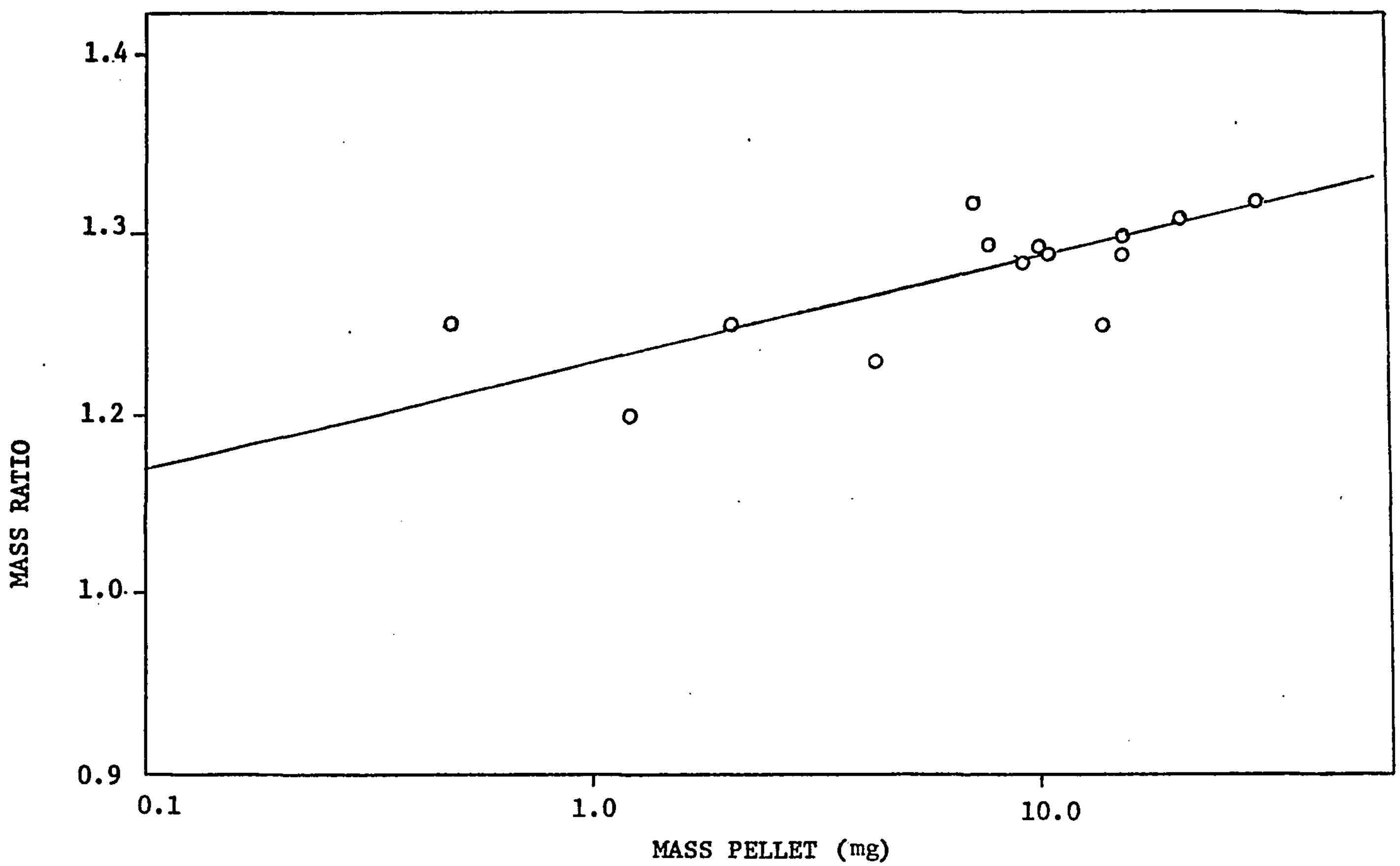


Figure 6. Relation between mass ratio (drop mass/pellet mass) and pellet mass

rain gauge chart so that raindrop samples could be related to specific rainfall intensities. Freshly-sifted dry flour was used for each sampling. After each sampling the dough pellets were treated in the same manner as indicated for calibration. Oven dry pellets were then separated into size classes by a set of standard sieves with mesh sizes ranging from 0.02 to > 4mm. Pellets in each size class were weighed and counted after discarding the large, nonspherical ones. The latter may result from one drop coalescing with another. The occurrence of these pellets was less than 2 percent.

The average raindrop mass of each size class was calculated from equation (8):

$$m = P \times R \qquad (8)$$

where m is the average drop mass (in mg), P is the average pellet mass (mg) and R is the mass ratio corresponding to P in the calibration curve. The average draindrop diameter was then computed by the equation:

$$D = (6m/\pi)^{1/3} \qquad (8)$$

where D is the raindrop diameter (mm) and m is the drop mass (mg).

Computation of Raindrop Size Distribution

Cumulative volumes computed as the percentages of total mass of the sample in each size class (Laws and Parsons, 1943) were plotted against average drop diameter to generate the cumulative volume curves such as shown in Appendix Figure 1. The median drop size (D_{50})

is taken as the drop size at 50 percent volume of the curve. Cumulative volume percentages were then read from the curves for each rainfall sample at 0.25mm drop size intervals. These values were averaged to give the size distribution and are reported as percentage of total volume of rainfall contributed by drops of various sizes. This procedure of computation is summarized in Appendix Table 3.

D. Laboratory Analyses

1. Soil Analysis

All soil samples and field and laboratory eroded sediments were air dried and weighed prior to crushing with a mortar and pestle. The soil was sieved to pass through a 2mm screen. The material 2mm was washed, dried and weighed to determine the gravel content. The fine earth fraction ($<$ 2mm) was used in the following analyses.

Physical Analysis

Particle Size Analysis

Particle size distribution was determined by the hydrometer method (Bouyoucos, 1962) using sodium hexametaphosphate as the dispersing agent.

Moisture Retention and Available Water Holding Capacity

Moisture retention was determined on sieved samples using a blotter-paper type of tension table for 0, 30, and 60 cm suctions and a porous plate extractor for determinations at 0.3, 1.0, 2.0, 3.0, and 15 atmospheres.

Available water holding capacity (AWC) was calculated as follows:

AWC = moisture content at 15 atm - moisture content at 3 atm

Atterberg Limits

The liquid limite, plastic limit and shrinkage limite were etermined in duplicate for each benchmark soil using ASTM procedures D-423-66, D-424-59 and D-427-61 respectively (American Society for Testing and Materials, 1972).

Moisture Equivalent

Moisture equivalent was determined by the Briggs-McLane (1907) method.

Aggregate Stability

Aggregate stability tests were performed on small peds by the wet sieving method (after Van Bavel, 1950) and the raindrop technique as outlined by Bruce-Okine and Lal, (1975). Prior to these tests the peds were equilibrated fro about 28 days in vacuum desiccators containing saturated copper sulphate solution. The latter provided a relative humidity of 98 percent at 25°C.

Chemical Analysis

The chemical analyses were performed at the analytical laboratory of IITA, using the following standard procedures:

pH

pH of the soil extract solution was measured on a Beckman Zeromatic pH meter using a combination glass electrode.

Organic Carbon

Organic carbon content of soil was determined by the dichromate-oxidation method.

Total N

Total N was determined by Kjedahl digestion method. The nitrogen content in the digest was measured colorimetrically on a Technicon Model II autoanalyzer at 630 mu wavelength. (General Operating Procedure Manual, Technicon Laboratory, Andsly, N.Y. 1966).

Exchangeable Bases and Cation Exchange Capacity

Ca, K and Na were determined by atomic absorption spectroscopy and Mg and Mn by flame spectrosphotometry methods following their extraction with 1N ammonium acetate solution. Exchangeable Al and H were determined by extracting with 1N KCl. Cation exchange capacity was the summation of exchangeable cations.

Available P

Available P in soil was determined by the Bray-1 method (1945).

Mineralogical Analysis

Clay mineralogical analysis was done at the mineralogy laboratory at the Ohio State University, Department of Agronomy. X-ray diffraction of the Mg-saturated clays were performed on samples after separation of the clay sedimentation using the automatic fractionater (Wilding et al., 1971).

2. Chemical Analysis of Runoff and Percolation Water

Runoff and leachate samples from field and simulated erosion studies were also analysed as follows:

electrical conductivity - using conductivity bridge;

NO_3-N - determined by the colorimeter method involving brucine solution;

PO_4-P - measured colorimetrically at 400 mu wavelength using venado-molybdate reagent;

Ca, Mg, and K as already discussed under soil analysis.

E. Statistical Analysis

The statistical analyses of the results consisted of a analysis of variance for the various treatment variables, regressions and correlations (simple, multiple and ploynomial forms). Use was made of the Statistical Analysis System (SAS) computer programs of the Department of Statistics, North Carolina State University (Service et al., 1972) and facilities at the Ohio State University computer center.

RESULTS AND DISCUSSION

A. Climatic Factors and Erosivity

1. Distribution of Rainfall Amount and Intensity

Total annual precipitation at Ibadan, Nigeria for 1975 was 1320 mm. Eighty-eight percent of this occurred during the two cropping seasons. Figure 7 shows the bi-model annual distribution of rainfall, with peak rainfall amounts usually in June and October and a short dry season in August. The occurrence of erosive storms was more frequent within the first 60 days following seeding (Figure 8), averging about one storm every 3 days. These storms produced from 2.5mm to 60mm of rain. Several storms of less than 10mm amounts caused erosion when they occurred within two days following an intensive rainfall.

Any single storm was characterized by a range of intensities with peak intensity generally occurring early in the storm. A frequency distribution of peak intensities given in Figure 9A shows that 33% of the storms had peak intensities between 50 and 75 mm/hr. 16% between 75 and 100 mm/hr and 5 to 7% of the storms had over 100 mm/hr. About 55% of the storms attained these peak intensities during the first five minutes (Figure 9B). These results are in agreement with those reported for Ile-Ife, some 50 miles from Ibadan,

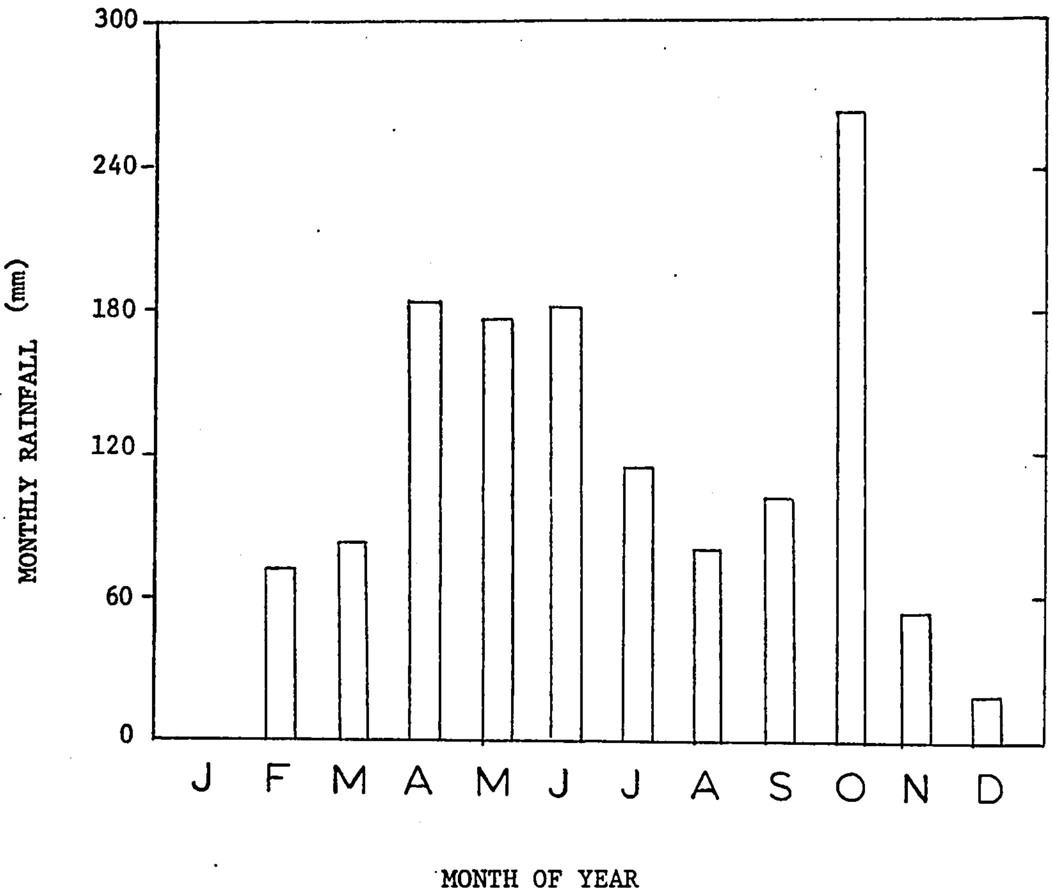


Figure 7. Distribution of monthly rainfall at Ibadan in 1975 as measured at the experimental site.

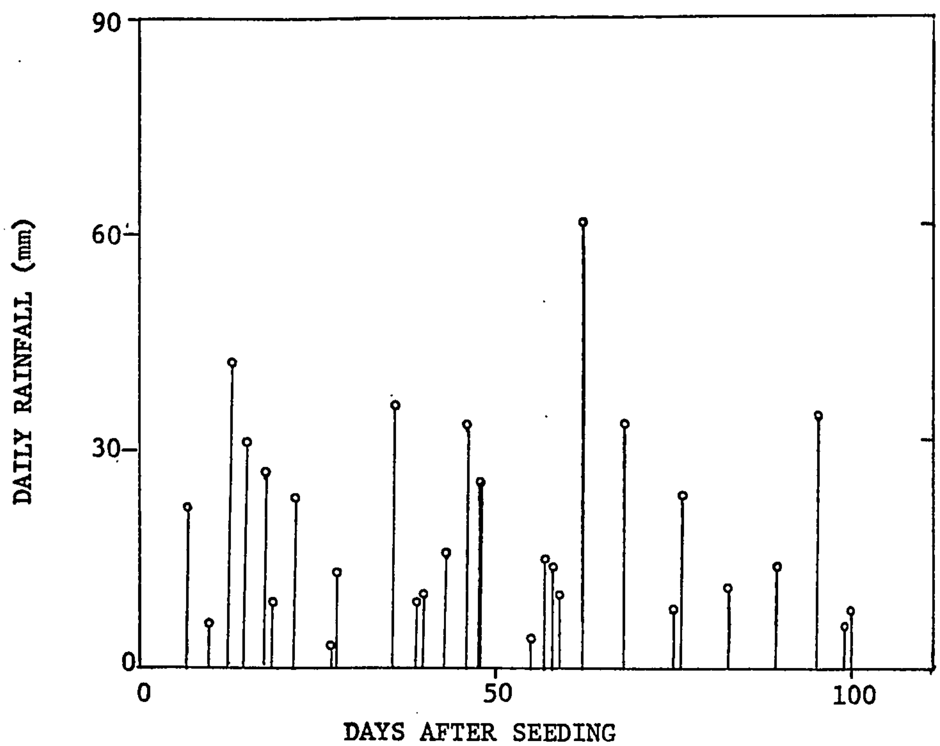


Figure 8. Distribution of rainfall during first cropping season at the experimental site (April-July, 1975).

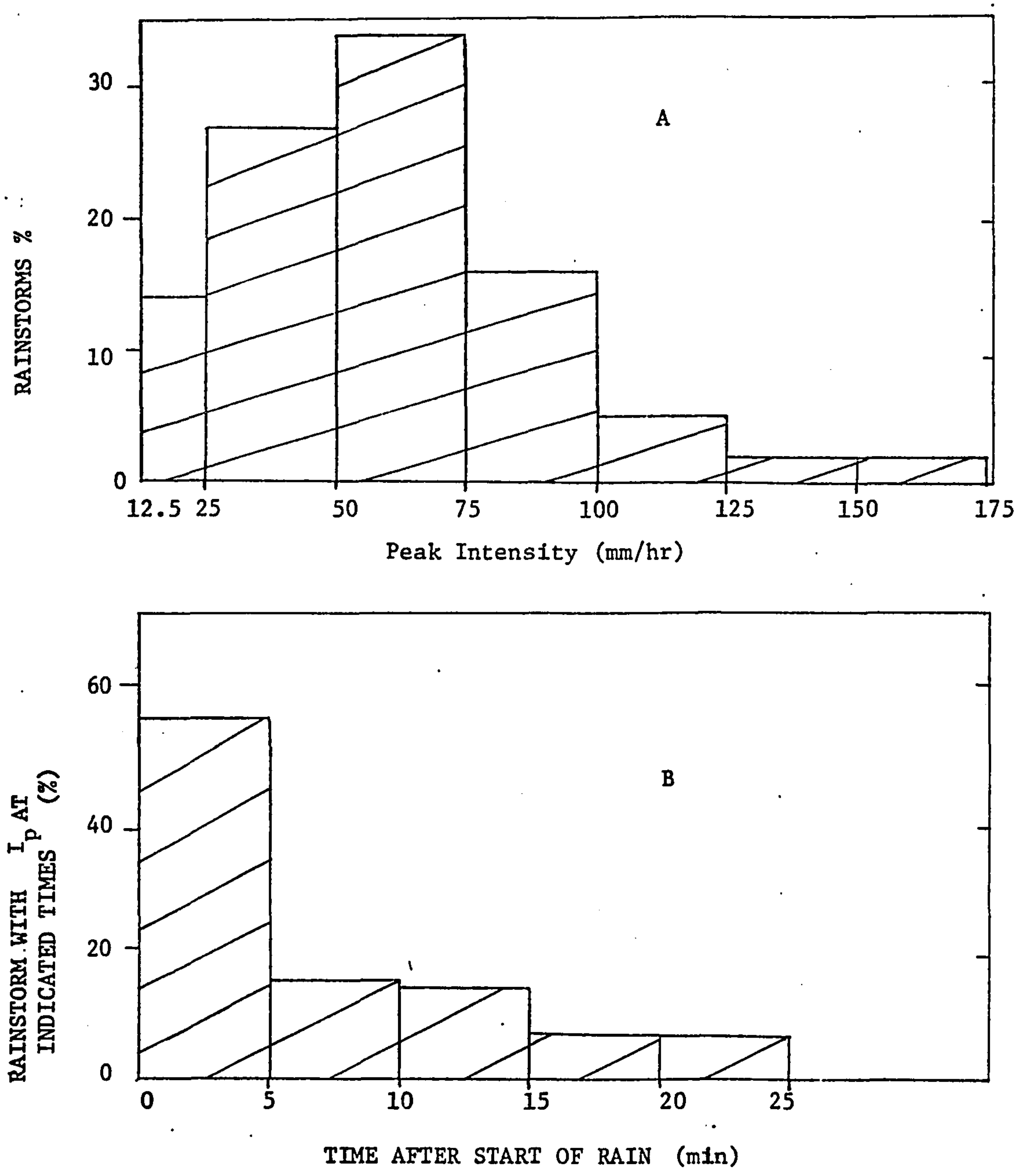


Figure 9. Distribution of (A) peak rainfall intensities, I_p and (B) times of occurrence of the peak intensities.

by Wilkinson (1975). Distribution of the high intensity rainstorms indicates their high erosion potential. This is further illustrated by the distribution of maximum 30-minute intensities (Figure 10). It will later be shown that I_{30} is strongly related to erosion from the field plots. I_{30} of the erosive storms ranged from 12.5 to 225 mm/hr. Nearly 40% of the storms had I_{30} greater than 75 mm/hr.

2. Median Raindrop Sizes

Median raindrop sizes at different rainfall intensities are given in Figure 11. These results were based on analysis of 12 erosive storms with median raindrops ranging from 1.50mm to 4.65mm diameter. For storms with intensity higher than 5 cm/hr, more than 55% of the raindrops were greater than 3mm diameter (Appendix Figures 2-11). Median raindrop sizes varied considerably for given rainfall intensities. This variability could be due to air temperature, storm duration or winds.

The equation of best fit for the median drop size-intensity data was of the form:

$$D_{50} = 1.1296 - 0.3909I - 0.0306I^2 + 0.0010I^3 \qquad (10)$$

where D_{50} is the median drop size (mm) and I is the rainfall intensity (cm/hr). This relationship could be approximated by equation 11:

$$D_{50} = 2.66I^{0.264} (r^2 = 0.59) \qquad (11)$$

equation 11 differs from that reported by Laws and Parsons (1943),

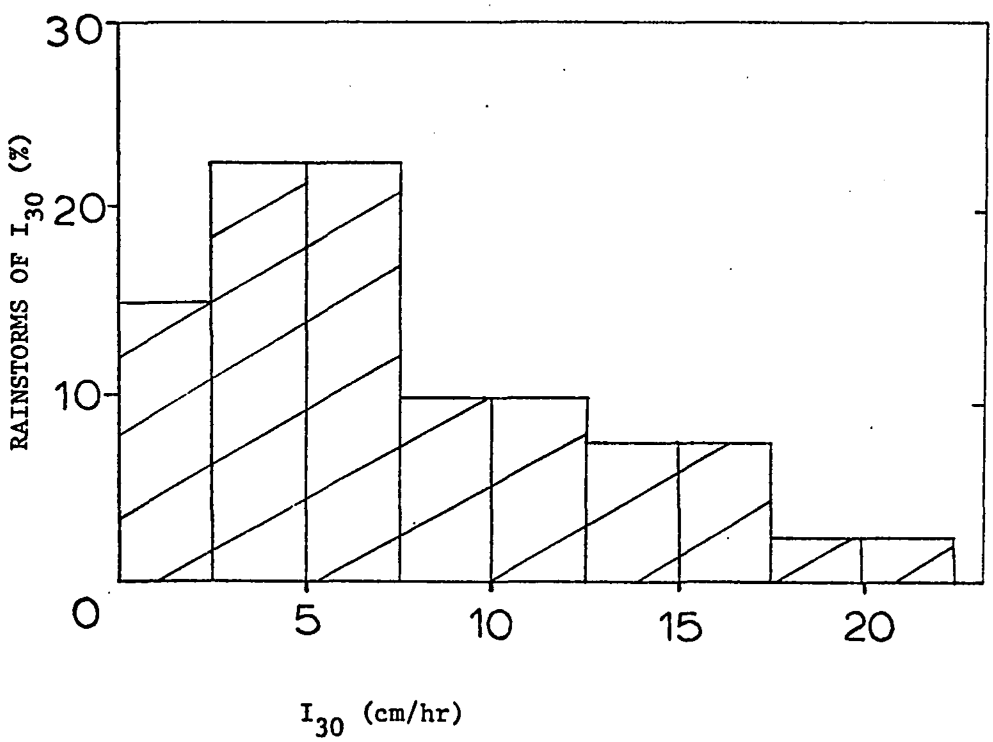


Figure 10. Distribution of maximum 30-minute rainfall intensities, I_{30}

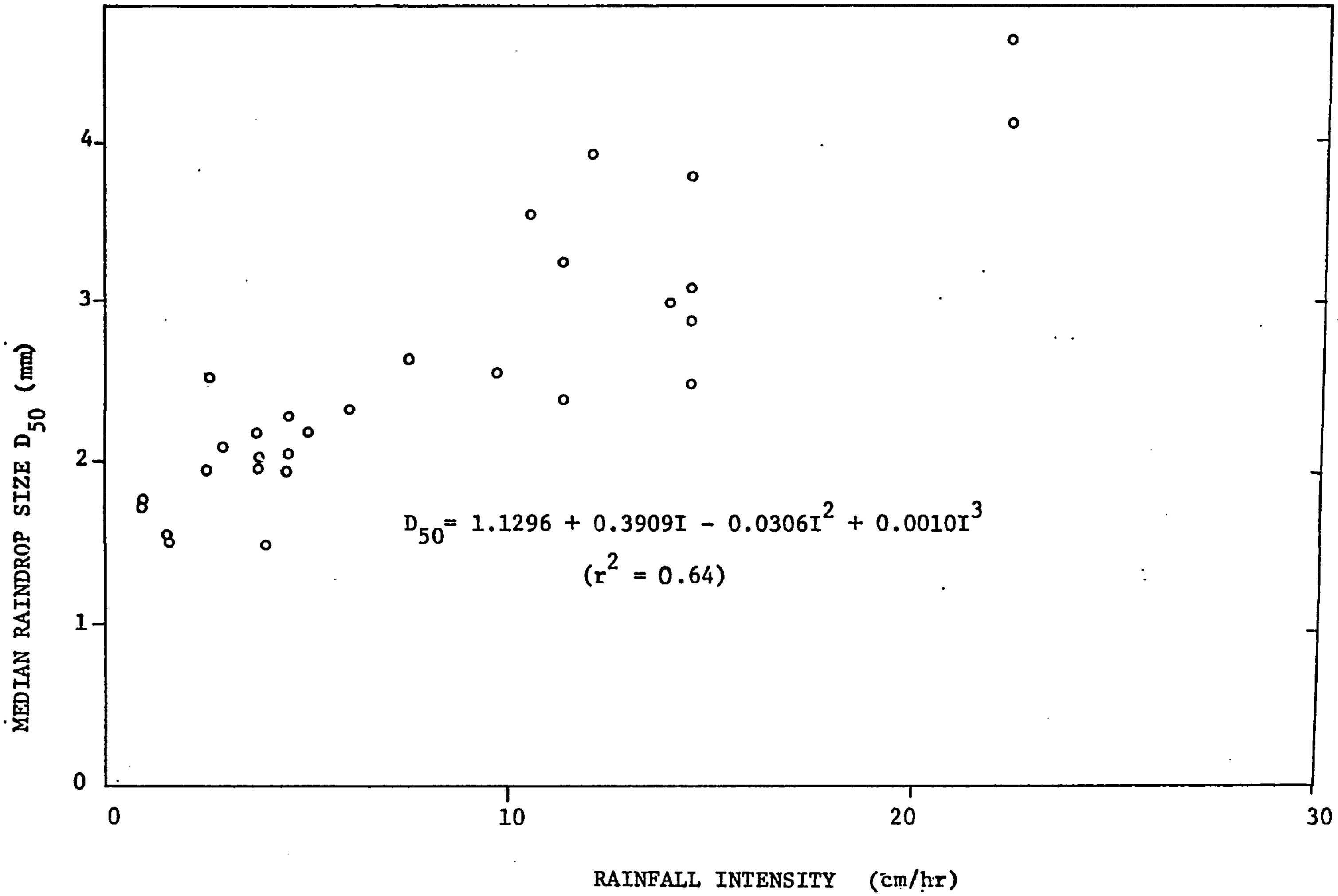


Figure 11. Relation of median raindrop size to rainfall intensity

namely:

$$D_{50} = 2.23I^{0.182} \tag{12}$$

comparing equations 11 and 12, one can see that drop sizes determined in this study were larger than those reported for the temperate regions. Median raindrop size was significantly correlated with rainfall intensity at 1% level of probability giving r value of 0.78 (Table 8). This relatively high correlation indicates the strong dependence of large drop size on rainfall intensity.

3. Effect of Wind on Rainfall Characteristics

Most of the rainstorms were accompanied by high velocity winds. Peak wind velocities ranged from 5 km/hr to over 55 km/hr, usually occurring at the start of a storm. Wind profiles during ten rainstorms were recorded from anenometer charts. They show a time lag between the occurrence of peak wind velocity and peak rainfall intensity. A typical wind velocity distribution is shown in Figure 12. Wind velocities were fairly constant over short periods of uniform rainfall intensities. Table 8 shows that rainfall intensity increased with wind velocity, although the correlation between these parameters was not very high (r = 0.40). Median raindrop size also increased with wind velocity (r = 0.43). Wind accounted for only 18% and 16%, respectively, of the variability in median drop size and rainfall intensity.

The positive correlation between drop size and wind velocity suggests a coalescing of small drops to form larger ones. The wind

TABLE 8

SIMPLE CORRELATION BETWEEN MEDIAN RAINDROP SIZE (D_{50}), RAINFALL INTENSITY (I) AND WIND VELOCITY (W)

Variables	Correlation Coefficient r	r^2
D_{50}, I	0.78**	0.61
D_{50}, W	0.43*	0.18
I, W	0.40*	0.16

r^2 = proportion of variability explained.

*Significant at 5% level of probability.

**Significant at 1% level of probability.

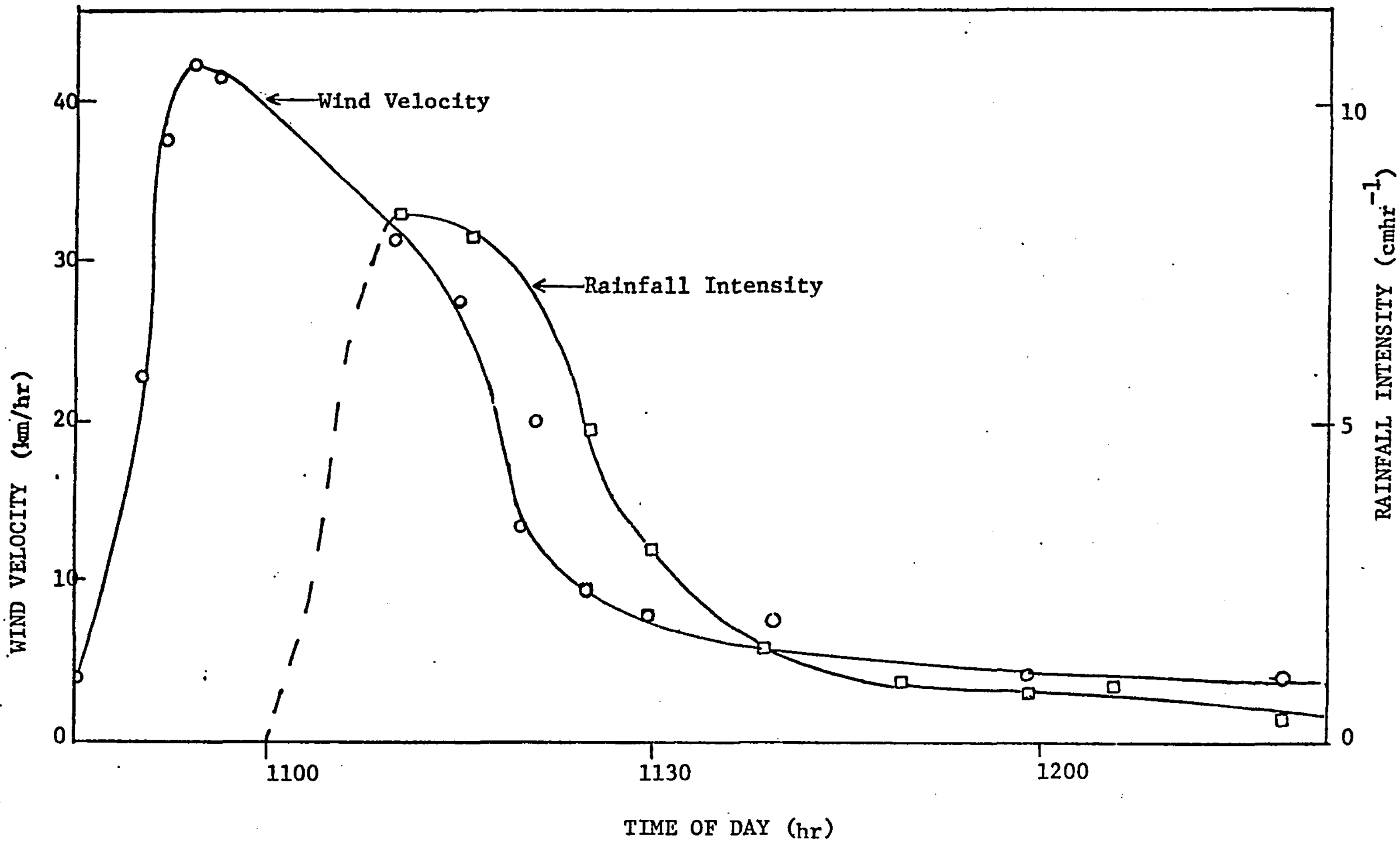


Figure 12. Wind velocities and rainfall intensities for rainstorm of May 17, 1975.

effect could account for the larger drop sizes reported in this study when compared to those reported in the temperate regions for comparable rainfall intensities by Laws and Parsons (1943), Carter et al. (1974). The increase in rainfall intensity at high wind velocities could be caused by large drop sizes and increased terminal velocities of drops. Either condition would mean an increase in kinetic energy of rainfall.

4. Kinetic Energy of Rainfall and Erosivity Indices

The kinetic energy of each storm was calculated using equation 2 and was related to erosion on field bare plots. Correlation coefficients between rainfall kinetic energy and soil loss were unusually low, ranging from 0.44 on 1% slope to 0.57 on 15% slope plots. Results of the correlcations between the various erosivity indices and erosion on bare plots are given in Table 9. Although the correlation coefficients are all significant at 1% level, EI_{30} (product of kinetic energy and maximum 30-minute intensity of rainfall) was the least efficient index of erosion. The low correlations between rainfall kinetic energy, EI_{30} and erosion may be attributed to an under-estimation of the rainstorm energy by using equation 2. In addition to higher efficiencies in predicting erosion, the AI and AIV indices are easier to compute. Table 9 also shows strong relationship between rainfall energy and sand losses from standard splash cups ($r = 0.93$). This indicates a discrepancy between field and splash cup results as regard to the relationship between erosion and rainfall energy. The discrepancy may limit the

TABLE 9

SIMPLE CORRELATION BETWEEN EROSIVITY INDICES AND
(A) SOIL LOSS FROM FIELD PLOTS AND
(B) SAND LOSS FROM SPLASH CUPS
All correlation coefficients are significant at 1% probability level.

Erosivity Index[1]	Correlation Coefficient r	
	A	B
EI_{30}	0.71	0.88
KE > 1	0.80	0.92
AI	0.81	0.87
AIV	0.83	0.92

[1]Indices are defined on page 54

extrapolation of the results of such splash erosion investigations to field plot conditions. Regression analysis on the splash erosion data (Figure 13) further shows a close relationship between amounts of splashed sand and rainfall amount ($r = 0.81$). This was not the case under field plot conditions.

B. Field Erosion Studies

1. Erosion Losses from Bare Fallow Plots

Soil Loss and Runoff

Table 10 summarizes soil loss and runoff from bare fallow plots on different slopes. Annual soil loss ranged from 10 metric tons/hectare on 1% slope to 150 metric tons/hectare on 5% slope. These are equivalent to annual losses of 0.8mm and 11.7mm of topsoil, respectively. Hudson (1971) considered the tolerance erosion rate to be 10-12.5 metric tons/ha. In view of this consideration, the losses encountered in this study may be regarded as serious. A soil loss of 10 metric tons/ha/year on 1% slope is particularly indicative of the high susceptibility of this soil to erosion. The lower soil losses on 10 and 15 percent slopes will be explained in a later section.

Runoff paralleled soil losses on the different slopes. Runoff on 1 and 5 percent slopes was 30 and 38cm respectively. These losses of water may be considered serious in view of the high evaporation rates and low water holding capacity of the soil.

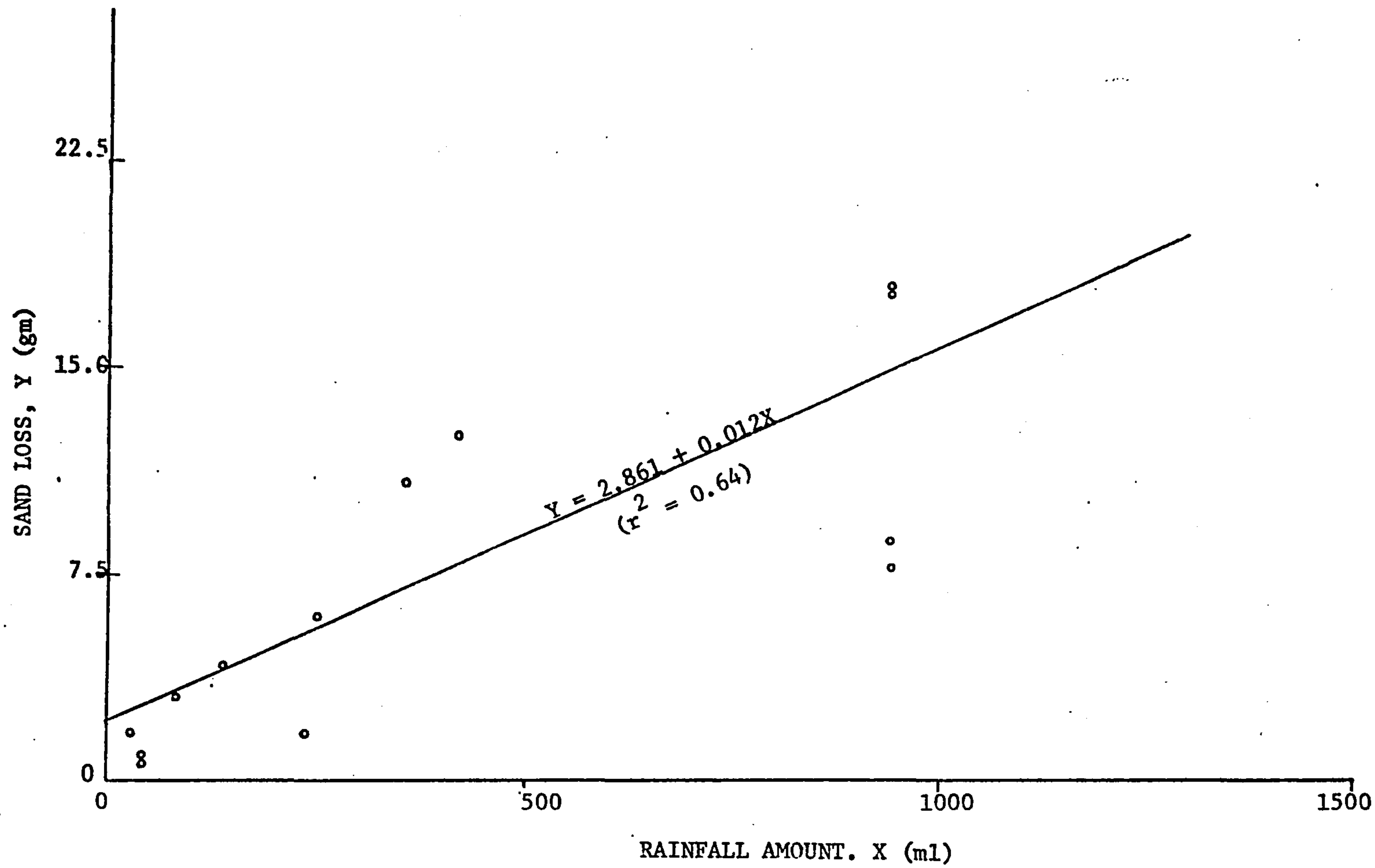


Figure 13. Relationship between rainfall amount and splash losses from splash cups filled with 270 µm quartz sand.

TABLE 10

ANNUAL SOIL LOSS AND RUNOFF FROM BARE-FALLOW PLOTS ON DIFFERENT SLOPES IN 1975.

Plot slope %	Soil Loss metric ton/ha	Runoff % of rainfall
1	10.3	33.6
5	148.2	44.3
10	76.1	21.7
15	81.7	30.5
LSD(0.05)	59.2	11.3

Nutrient Loss

Annual losses of plant nutrients averaged 202, 9 and 4 kg/ha for total-N, available P and K, respectively. More than 60% of the total loss of exchangeable Ca, Mg and K was in the runoff water. Losses of Ca and Mg were generally high. Their enrichment ratio (ratio of nutrient concentration in eroded sediment to that in the soil) ranged from 1.0 on 10% slope to 3.1 on 15% slope. These high losses of Ca and Mg were probably due to exposure of the subsoil (rich in Ca and Mg) to erosion on the bare plots. Organic matter content of the eroded sediments was about 1.5 fold that of the soil.

2. Effect of Soil Properties on Erosion

Soil Texture

No significant correlation was obtained between erosion and the primary soil separates (Appendix Table 4). Apparently, the soil separates are arranged in varying proportions into structural units that have to be detached into particles that can be transported in runoff. Soil erosion may therefore be more related to the resistance of these structural units to dispersion than the proportion of the primary soil separates. However, soil loss decreased with gravel content of the surface soil (0-15cm depth), probably because of raindrop interception by surface exposed gravels.

Soil Moisture Retention Characteristics

Moisture retention at saturation and 1/3-bar pressure were significantly correlated with sand, silt and clay, but was not significantly related to erosion. Moisture retention of the surface soil did not vary appreciably at pressures above 2 bar pressure because of the predominance of sand fraction 60-65%). This is indicative of high proportion of drainable pores in the surface soil. Inactivation of these pores by surface crusting probably caused erosion to occur before soil saturation was attained, hence the poor relationship between erosion and moisture retention characteristics.

Organic Matter Content

Erosion was strongly related to the soil organic matter content. The correlation coefficient between the two parameters was -0.71. There was also a negative correlation ($r = -0.84$) between the amount of eroded silt and soil organic matter. These results suggest the involvement of soil organic constituents in the stability of soil aggregates, as has been reported by Pereira and Jones (1954).

3. Effect of Slope Characteristics on Erosion

Slope Steepness

Soil loss generally increased with slope (Table 10). Greater slopes cause more soil splash downhill and higher runoff velocity. Consequently soil-carrying capacity of runoff increases with slope. The soil loss-slope relationship for the bare fallow plots was unusual. Soil loss on 10% slope was not different from that on 15% slope but was considerably lower than from 5% slope (Table 10). Similar results have been reported by Ahmad and Breckner (1974) on some Tobago soils. It should be recalled that the bare fallow plots had been continuously exposed to erosion for four years prior to this study. This long term erosional process had depleted easily erodible particles (silt and clay) on the steeper slopes. As a result, a higher sand fraction was now associated with slope, whereas silt content was found to decrease with slope ($r = -0.72$). Loss of fine earth materials also increased the gravel content on the surface horizon of the greater slopes ($r = 0.70$). A good proportion of these gravels were on the surface of the plots (Figure 14), "mulching" the surface against rainfall impacts. The textural changes in the surface horizon undoubtedly increased infiltration and consequently reduced runoff and soil loss on 10 and 15 percent slopes. The slope-soil loss relationship for bare fallow was of the form:

$$Y = 0.05X^{1.33} \qquad (13)$$

where Y is soil loss (metric ton/ha/cm rain) and X is percent slope.

Slope Length

The effect of slope length on runoff and soil loss was evaluates only on 10 and 15 percent slopes under pigeon peas rotation. Total soil loss (per plot) on the 37.5m (long) plots was about 2 fold that on the 12.5 (short) plots. Greater soil loss on the long plots may

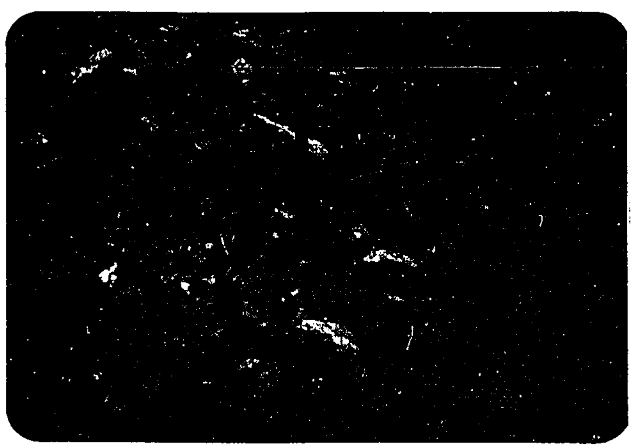


Figure 14. Photographs showing a bare plot on 15% slope with exposed gravels on the surface.

be due to increased erosion potential from a greater accumulation of runoff (hence runoff velocity) on longer slopes. However, there were no large differences in soil loss between the long and shot plots when soil loss was expressed on per-unit-area basis (Table 11). Soil loss averaged 103 and 90 metric tons/ha for the short and long plots, respectively. Runoff was also higher on the short plots than on the long plots. Similar results have been reported by Wischmeier and Smith (1965).

The slope length-erosion relationship was undoubtedly influenced by the shape of the plots. On 10% slope, the shot plot was regular while the long plot was covex with curvature about 27m from the collection symtem. On 15% slope, the short plot was concave and the long plot was complex with a convex curvature about 27m and the concave curvature about 10m from the collection system. Lower soil losses and runoff on the long plots and on 15% slope (Table 11) could be due to the decreasing steepness at the bottom of the concave slopes. This change in slope steepness results in sheet flow and sediment deposition.

4. Effect of Tillage on Soil Erosion

Soil loss and runoff under no-tillage and conventional tillage soybean rotations are presented in Table 12. No-tillage method effectively eliminated soil erosion from slopes ranging from 1 to 15%. On the other hand, annual soil loss averaged 39 metric tons/ha under conventional tillage. Runoff from the no-tillage plots was considerably lower than from conventionally plowed plots. Average runoff was 1.2

TABLE 11

EFFECT OF SLOPE LENGTH ON SOIL LOSS AND RUNOFF UNDER PIGEON PEAS ROTATION

Plot Slope %	Soil Loss 12.5 m	Soil Loss 37.5 m	Runoff 12.5	Runoff 37.5
	metric ton/ha		% of rainfall	
10	158.3 a	117.0 a	55.1 c	21.0 d
15	47.3 b	62.2 b	19.8 d	12.8 d

Numbers followed by the same letter do not differ significantly at 5% probability level.

TABLE 12

EFFECT OF TILLAGE METHOD ON ANNUAL SOIL LOSS AND RUNOFF UNDER SOYBEANS ROTATION (Total rainfall = 1150 mm)

Plot Slope	Soil Loss		Runoff	
%	No-tillage	Conventional Tillage	No-tillage	Conventional Tillage
	metric ton/ha		% of rainfall	
1	0.0	0.4	0.7	3.7
5	0.0	21.9	1.1	18.2
10	0.0	66.1	1.7	22.9
15	0.0	68.0	1.7	15.0
LSD(0.05)	16.9		12.4	

and 15% of total precipitation, respectively, for no-tillage and conventional tillage. Apparently, lower erosion losses under no-tillage system was due to the provision of surface mulch and minimal disturbance of the soil by the no-tillage. More earthworm costs were observed on the no-tillage plots and the improved granualtion probably contributed to greater infiltration.

Effect of Tillage Practices on Crop Performance

Early germination of soybeans and final stands were greater with no-tillage (Figure 15). Percent germination was 90 and 60% for no-tillage and conventional tillage soybeans, respectively. Improved seed germination with no-tillage could be due to greater moisture storage and more favorable temperature associated with the surface mulch. Faster growth rate was exhibited by soybeans under no-tillage (Figure 16). Faster growth rate is of importance because canopy cover will be more quickly established to offset the effects of erosive storms, most of which come in the early parts of the cropping season. Differences in canopy density between no-tillage and conventional tillage soybeans are illustrated in Figure 17. Crop yields under the two tillage treatments are compared in Figure 18. Soybean yields averaged 1635 and 1210 kg/ha under no-tillage and conventional tillage, respectively. Greater nutrient reserve (Table 13) and less weed infestation (Figure 19) apparently contributed to the higher yields under the no-tillage system.

TABLE 13

EFFECT OF TILLAGE METHOD ON NUTRIENT LOSS BY EROSION UNDER SOYBEANS-SOYBEANS ROTATION
Each value is the average of 4 plots.

Tillage Method	Sediment			Runoff		
	Total-N	P	K	NO_3-N	P	K
	kg $ha^{-1} yr^{-1}$					
No-tillage	0.0	0.0	0.0	0.29	0.08	0.77
Conventional tillage	205.5	1.9	4.7	3.7	1.3	16.8

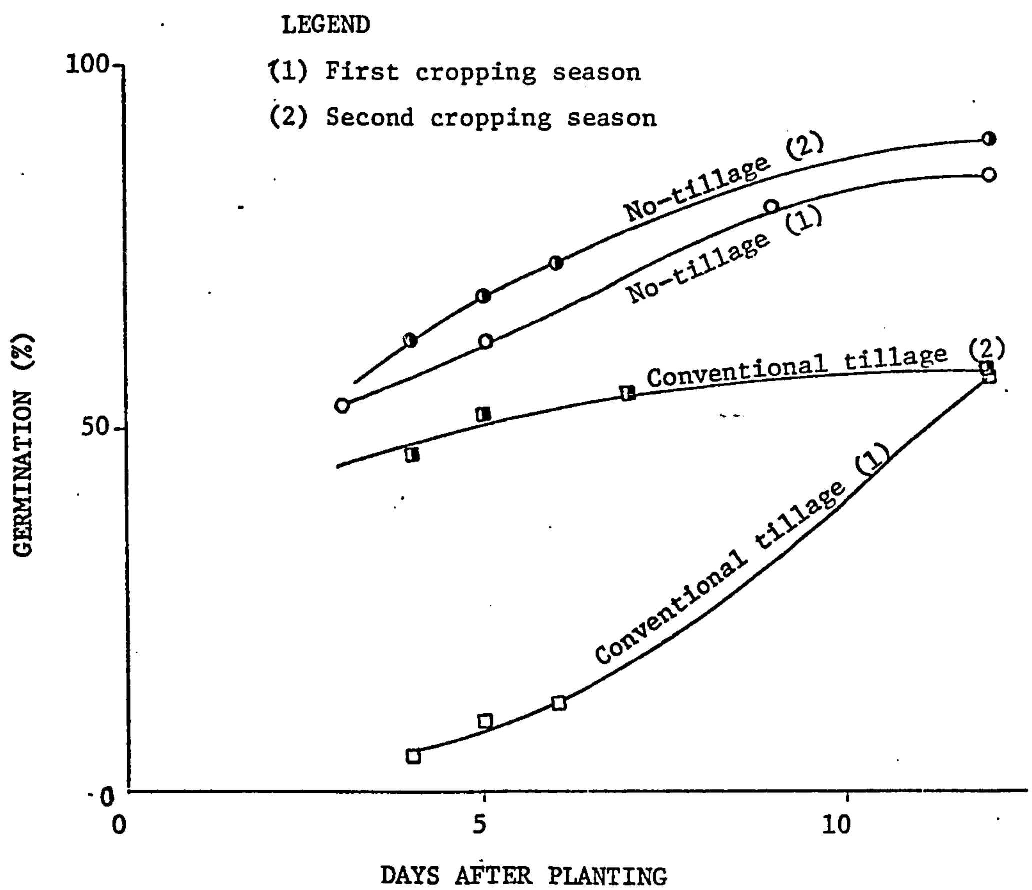


Figure 15. Effect of tillage method on soybean germination in the field plots.

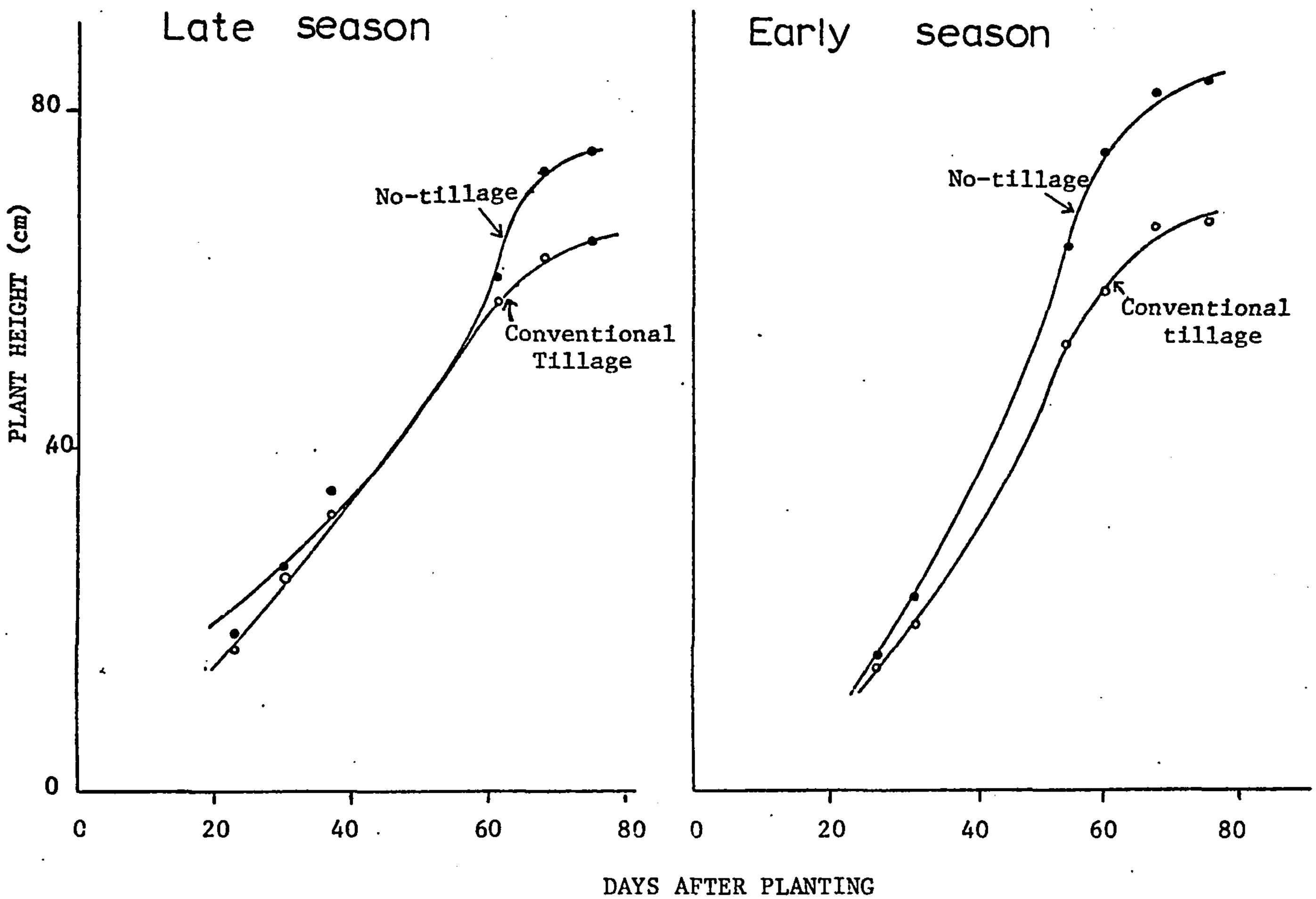


Figure 16. Effect of tillage method on soybean growth in the field plots.
(Each value is the mean of 4 plots with 10 measurements per plot)

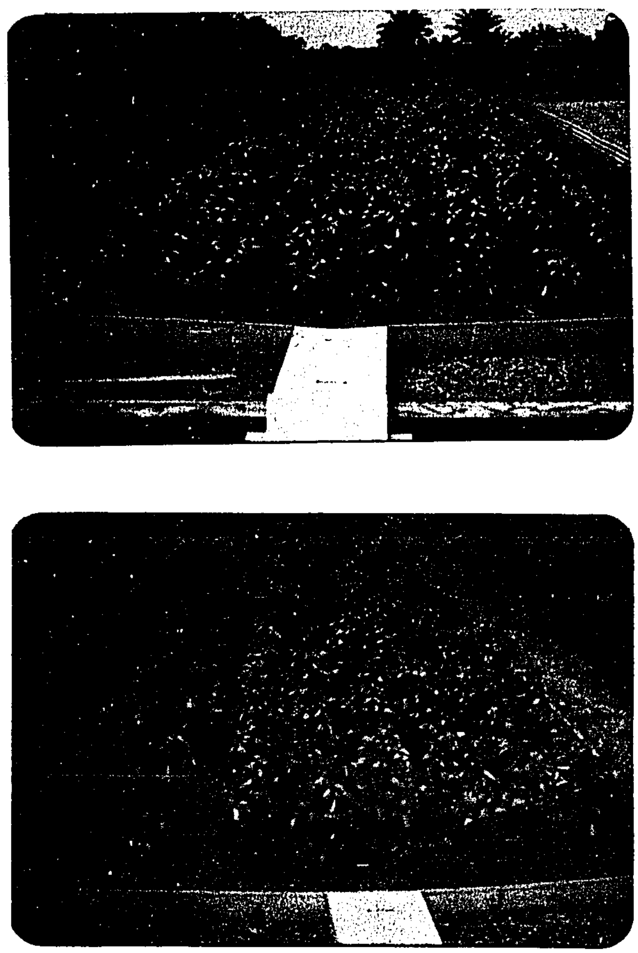


Figure 17. Soybean crops under (A) no-tillage and (B) conventional tillage on 1% slope. Photographs were taken 40 days after planting.

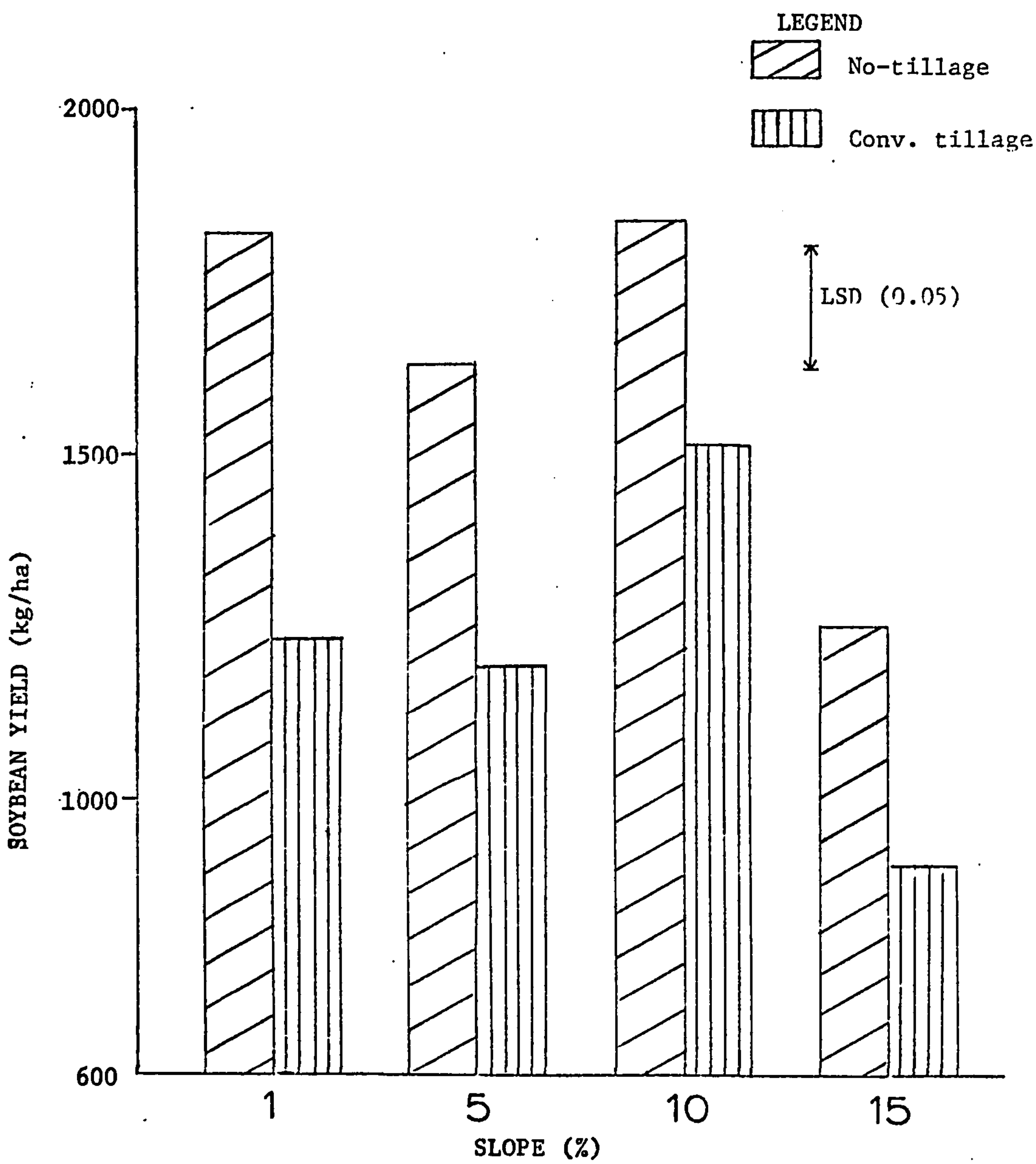


Figure 18. Effect of tillage method on soybean yield

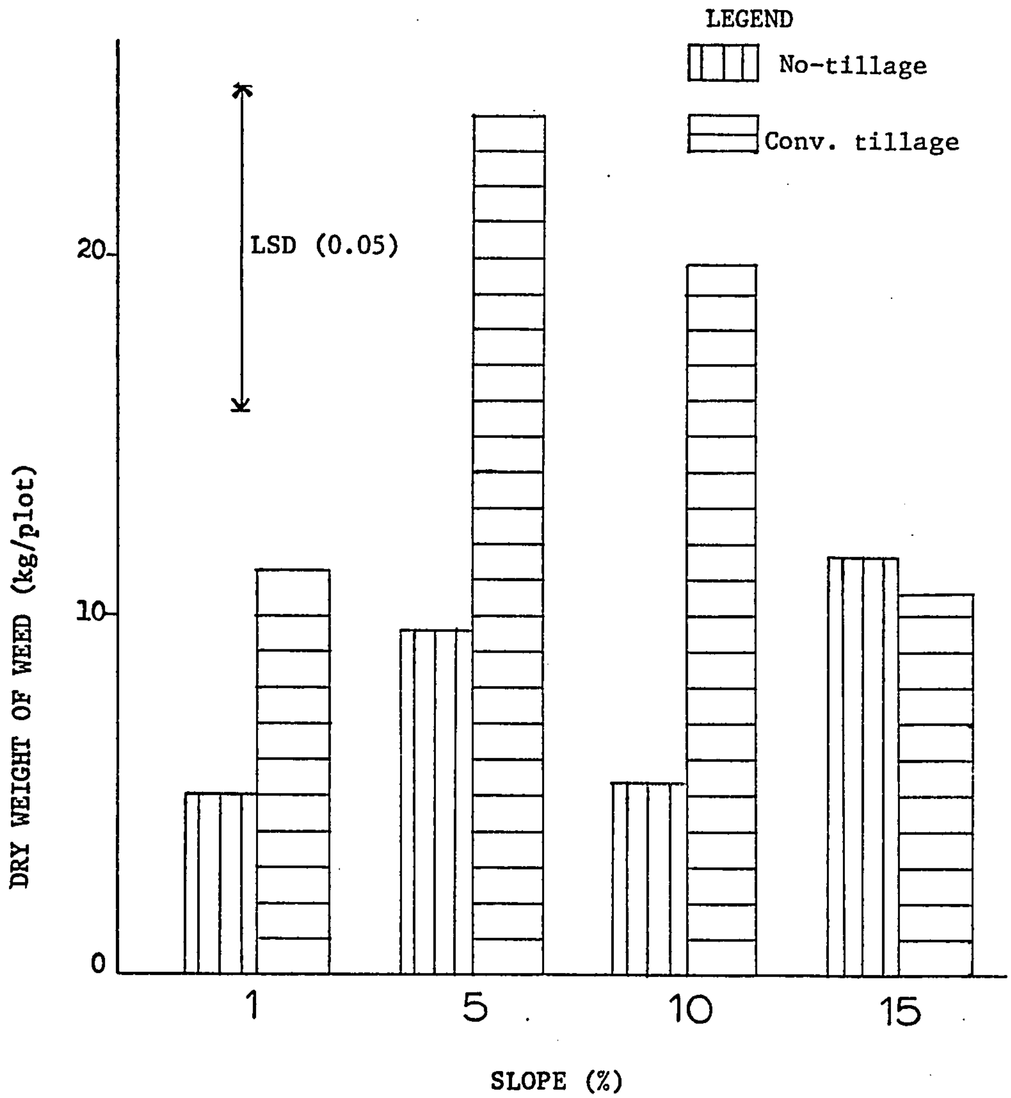


Figure 19. Dry weight of weed on soybean plots as influenced by tillage method in the second cropping season.

Effect of Tillage Method on Soil Properties

Some soil physical and chemical characteristics were determined at the start and termination of the field plot studies. Changes in soil properties were related to the magnitude of erosion on the different plots.

Soil Texture

Textural changes generally indicate an increase in the sand fraction and a decline in silt fraction on the conventional tillage plots Appendix Table 4. This result is not unexpected because finer particles (silt and clay) are more erodible than coarser particles (Meyer and Monke, 1965). Although, some textural changes are generally not significant because of the negligible depth of eroded topsoil (relative to sampling depth), they will be appreciable over a longer preiod of study.

Soil Infiltration Characteristics

Infiltration characteristics of the soil under no-tillage and conventional tillage are compared in Appendix Figures 12-15. Infiltration rates were consistently higher under no-tillage than under conventional tillage on all the slopes. Average infiltration rates were 45 and 35 cm/hr for no-tillage and conventional tillage plots, respectively. The latter will be reduced, considerably by crusting from the exposure of soil to rainfall impacts. Corresponding cumulative infiltration in 3 hours was 180cm and 140cm. Higher infiltration of the soil under no-tillage may be attributed to greater earthworm activity and protection of soil surface from rainfall impacts.

Soil Chemical Characteristics

Changes in soil organic matter content, N, P and K are under the different tillage methods are summarized in Figure 20. Soil organic matter content was higher at the end of the experiments despite erosional losses of organic matter under conventional tillage. The organic matter accumulation under the no-tillage and conventioanl tillage treatments was due to additions from crop residues. Organic matter content accumulation in the former was about 6 fold the latter, implying a higher mineralization rate for plowed-in residue.

Total-N was lower by 9 and 35 percent, respectively under no-tillage and conventional tillage at the end of the roration. This result was probably due to the high rate of organic matter mineralization typical of most tropical soils. Greater changes under conventional tillage resulted from high erosional loss NO_3-N and organic matter. Because of the coarse texture of the topsoil, much leaching of NO_3-N will be expected.

Available P content was higher under no-tillage at the end of the rotation by about 56%, while under conventional tillage P content was lower by 13% compared to the initial content at the start of the rotation. Duley (1926) and Munn et al. (1973) have reported that major loss of P is in the form of eroded soil. These results are consistent with their findings. The no-tillage soybeans and higher P reserve because there was no soil loss.

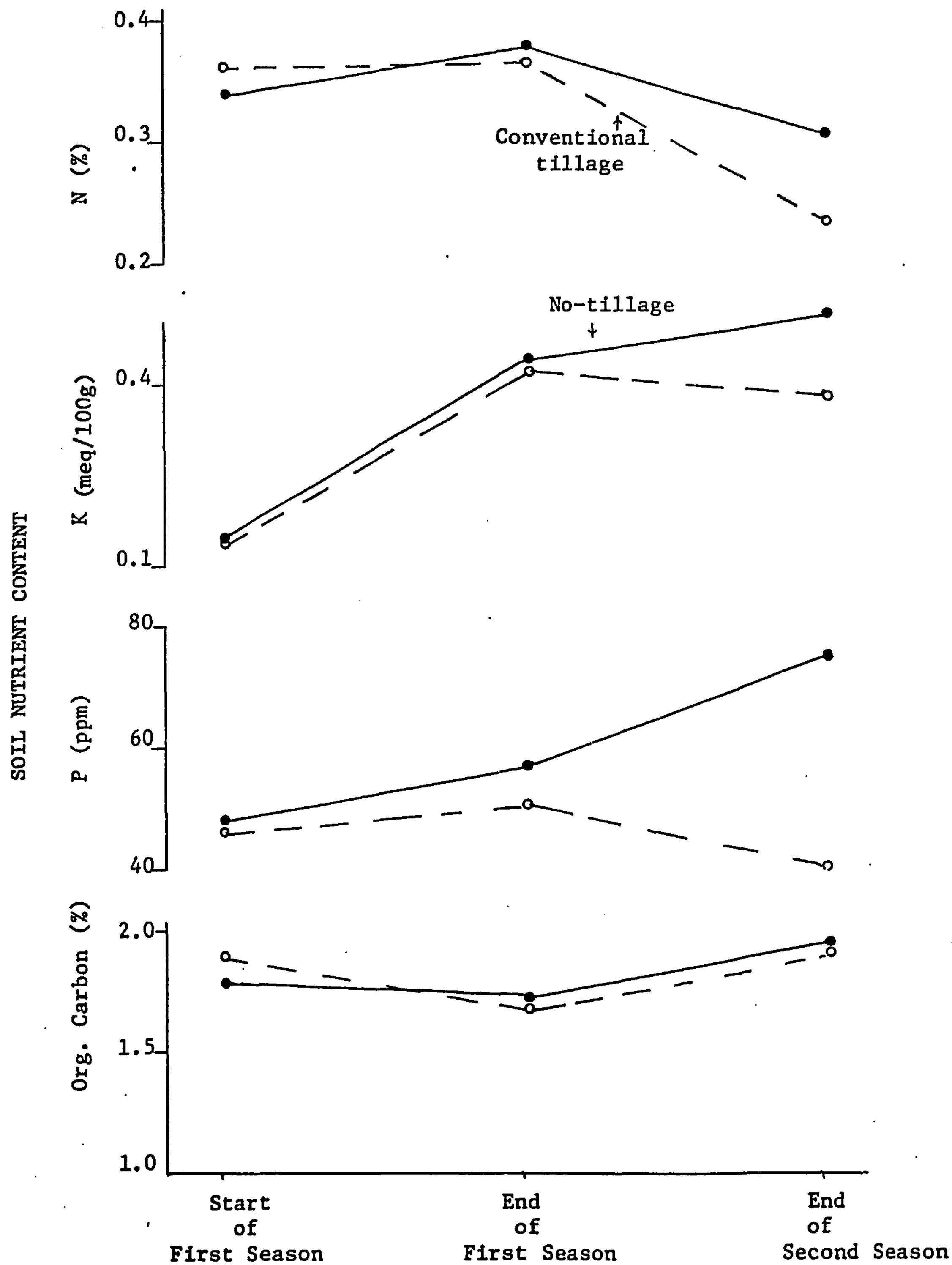


Figure 20. Nutrient content of soil as influenced by tillage method under soybean-soybean rotation.

There were 3.6 and 2.6 fold increases in K content of the soil at the end of the no-tillage and conventional tillage soybean rotations, respectively. These increases are attributable to the use of crop residue (as surface mulch or plowed in).

5. Effect of Cropping Systems on Erosion

Table 14 summarizes soil loss and runoff under different crop rotations. Annual soil loss averaged 39, 69, 96, and 109 metric tons/ha for rotations of soybeans-soybeans, corn and cassava mixed cropping, pigeon peas-pigeon peas was averaged over 4 plots of two different lengths because of the less significant effect of slope length on soil loss under the various systems. Soil oss from bare fallow plot was higher than that from corresponding cropped plot on 1 and 5 percent slopes.

Soil loss increased with slope under the different cropping systems (Figures 21 and 22), but runoff was lower on 10 and 15 percent slopes than on 5% slope for cassava and mixed cropping of corn and cassava. Regression analysis of soil loss and runoff on slope is presented in Tables 15 and 16.

Nutrient Loss

Tables 17 and 18 show plant nutrient losses under the various cropping treatments. The losses of nutrients followed similar trend as soil loss, with monoculture cassava having the highest annual loss of 380 kg/ha N, 46 kg/ha K and 5 kg/ha P Most of the K lost by erosion was in runoff. Amounts of nutrients lost on the short and

TABLE 14

EFFECT OF CROPPING SYSTEMS ON ANNUAL
SOIL LOSS AND RUNOFF
Each value is the average of 4 plots.

Cropping System	Soil Loss metric ton/ha	Runoff % of rainfall
Soybeans-soybeans	39.1	15.1
Corn and cassava mixed	68.8	20.9
Monoculture cassava	109.1	27.9
Pigeon peas-pigeon peas[1]	96.2	31.2

[1]Plots are of 2 different lengths--12.5 and 37.5 m.

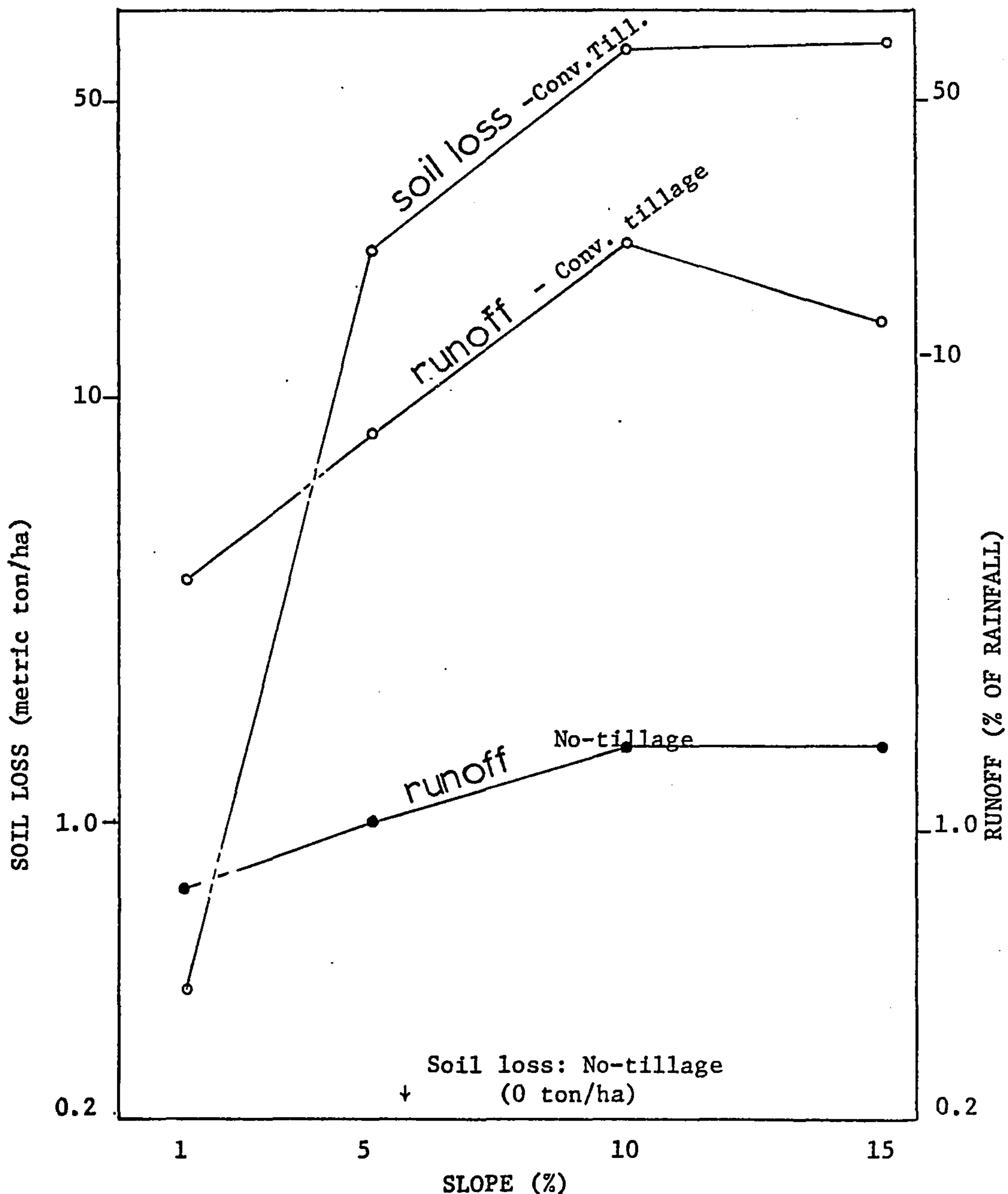


Figure 21. Effect of slope on annual soil loss and runoff under no-tillage and conventional tillage soybean rotations.

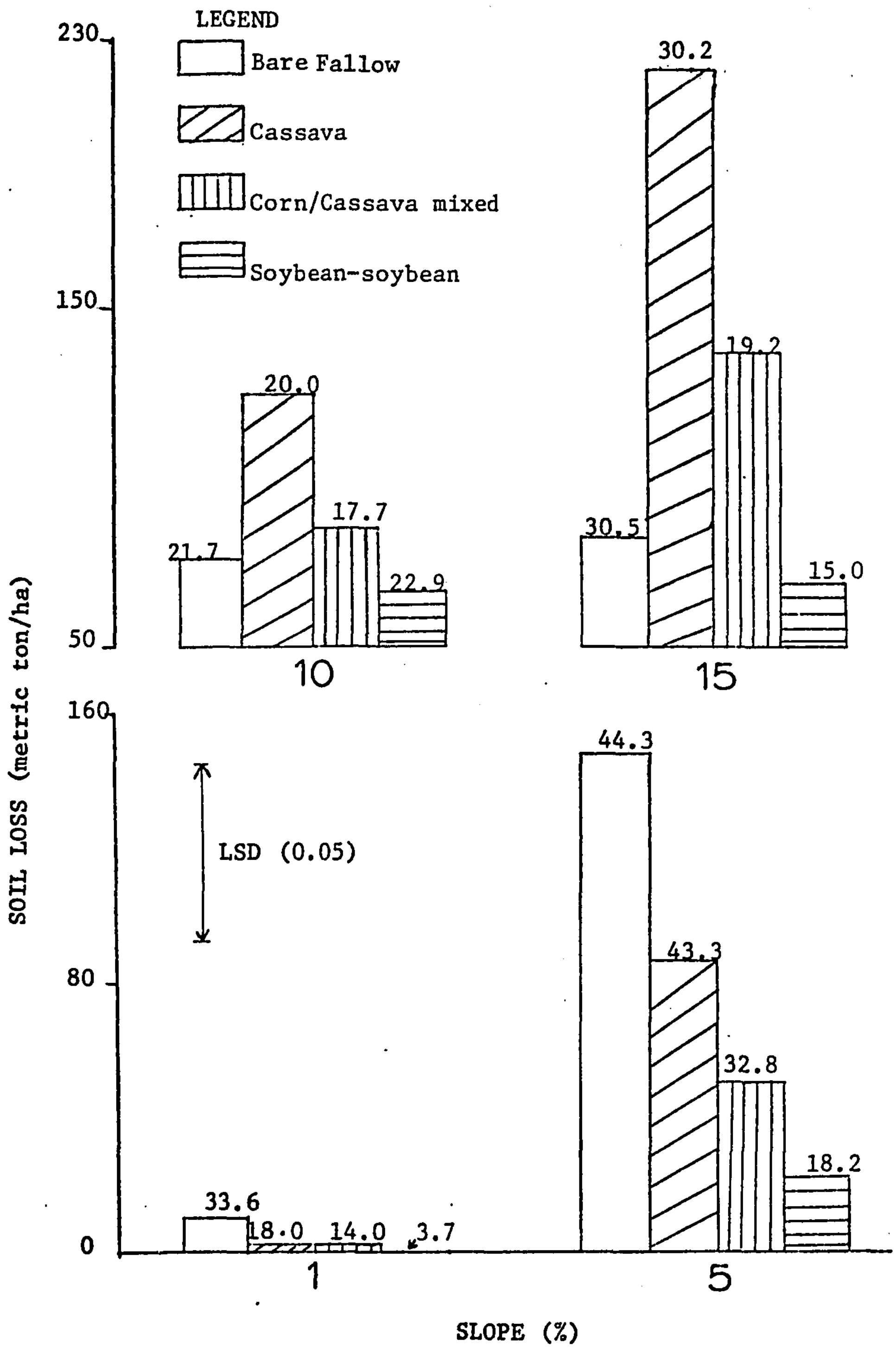


Figure 22. Effect of slope on annual soil loss under different cropping treatments. (Numbers on top of figures correspond to runoff values in % total rainfall).

TABLE 15

SIMPLE REGRESSION OF SOIL LOSS, Y (IN METRIC TON/HA/CM RAIN) ON PERCENT SLOPE, X UNDER DIFFERENT CROPPING TREATMENTS

Treatment	r	Regression Equation
Bare fallow	0.60*	$Y = 0.05X^{1.33}$
Soybeans-soybeans	0.44*	$Y = -0.085 + 0.088X$
Monoculture cassava	0.75*	$Y = -1.279 + 1.307X^{0.5}$
Corn and cassava mixed	0.41*	$Y = -0.584 + 0.616X^{0.5}$

r = correlation coefficient.

*Significant at 5% level of probability.

TABLE 16

SIMPLE REGRESSION OF RUNOFF, Y (IN % OF RAINFALL) ON PERCENT SLOPE, X UNDER DIFFERENT CROPPING TREATMENTS

Treatment	r	Regression Equation
Bare fallow	0.60*	$Y = -1.06X^2 + 9.07X + 42.98$
Soybeans-soybeans	0.48*	$Y = -0.44X^2 + 7.59X - 1.12$
Soybeans-soybeans (no-till.)	0.35	$Y = 0.10X + 0.76$
Monoculture cassava	0.65*	$Y = -1.79X^2 + 19.70X + 6.25$
Corn and cassava mixed	0.50*	$Y = -1.17X^2 + 13.2X + 12.35$

r = correlation coefficient.

*Significant at 5% probability level.

TABLE 17

EFFECT OF CROPPING SYSTEMS ON
NUTRIENT LOSS BY EROSION
Each value is the average of 4 plots.

Cropping System	Eroded Sediment			Runoff		
	Total-N	P	K	NO_3-N	P	K
Bare fallow	165.8	3.3	5.7	8.6	2.2	38.2
Soybeans-soybeans	205.5	1.9	4.7	3.7	1.3	16.8
Monoculture cassava	379.8	2.9	14.9	7.1	1.7	31.4
Corn and cassava mixed	229.9	3.3	8.4	5.7	1.6	29.0

TABLE 18

EFFECT OF SLOPE LENGTH ON NUTRIENT LOSS BY EROSION UNDER PIGEON PEAS-PIGEON PEAS ROTATION
Each value is the average of 2 plots.

Slope Length	Nutrient Loss					
	Eroded Sediment			Runoff		
	Total-N	P	K	NO_3-N	P	K
m	kg/ha/year					
12.5	245.0	4.34	8.95	3.71	1.11	13.10
37.5	245.5	3.54	7.83	3.43	1.40	17.11

long slopes (under pigeon peas) were essentially the same.

Crop Performance Under Different Cropping Systems

Canopy Characteristics

Figure 23 shows the amounts of canopy cover provided at varying periods of growth of the different crops. Fifty percent cover was attained 38, 45, 50 and 63 days after planting by soybeans, mixed corn and cassava, pigeon peas and monoculture cassava, respectively. Photographs of such covers are presented in Figure 24. Figure 25 illustrates the role of crop canopy in reducing erosion under the different systems. Soil loss was generally high in the early parts of the cropping season because of inadequate canopy cover as well as the occurrence of erosive storms. Soil loss decreased subsequently with increasing amount of canopy cover. Regression of soil loss on percent ground cover by crop canopy is shown in Table 19. Figure 25 indicates that reduction of erosion by crop canopy is attributable to the interception of rain drops by the canopy. Proportion of rainfall intercepted by canopy at 90% ground cover varied from 28% for cassava, 40% for mixed cropping of corn and cassava to 58% for soybeans. Differences in rainfall interception capacities are explainable in terms of the crop characteristics. Greater rainfall interception by the mixed cropping of corn and cassava (compared to monculture cassava) was because of the greater amount of canopy cover and second season mulching with corn stover residue. Figure 26 shows that corn developed more rapidly than cassava in the first season. The cassava

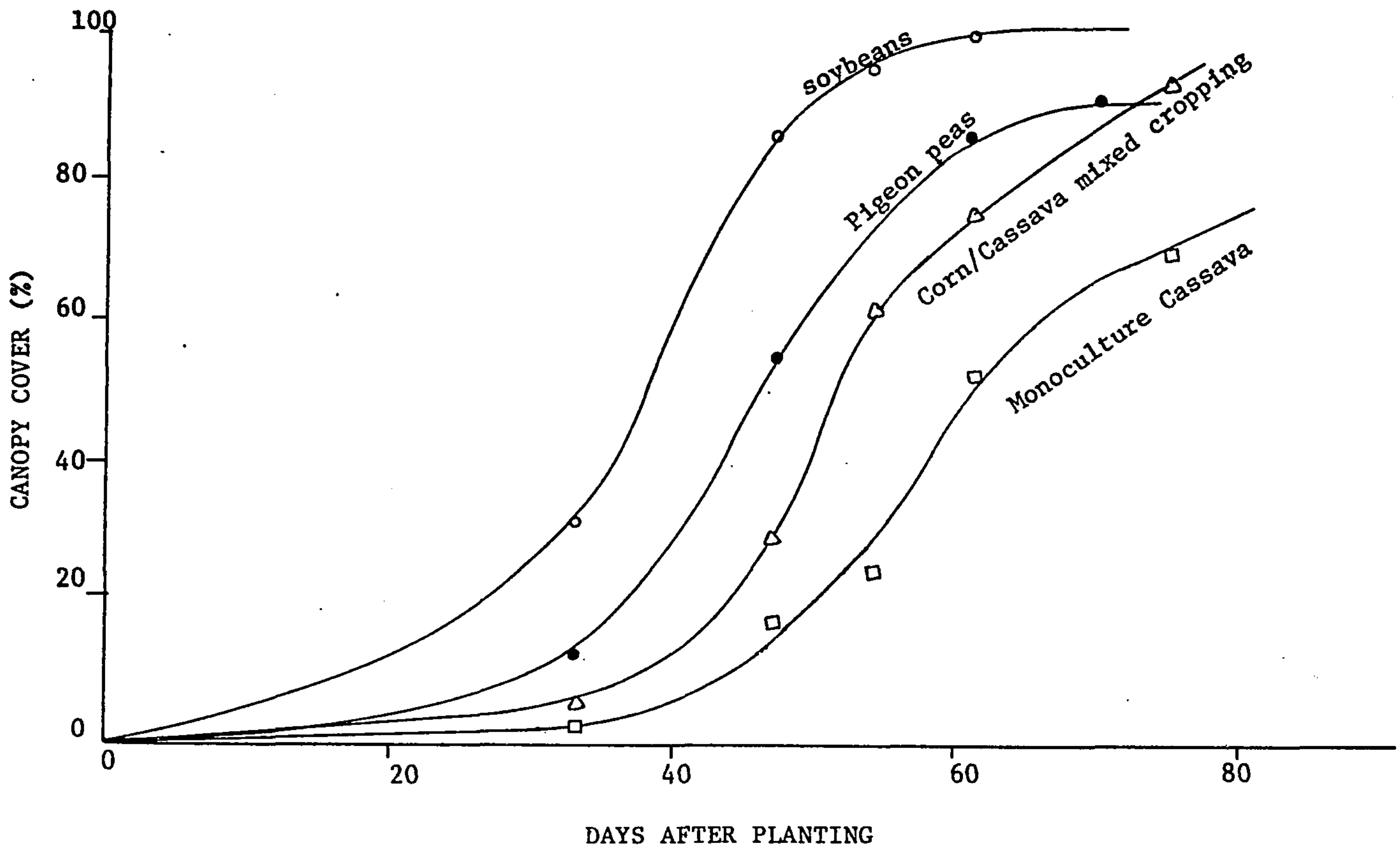


Figure 23. Canopy cover at varying growth stages of different crops

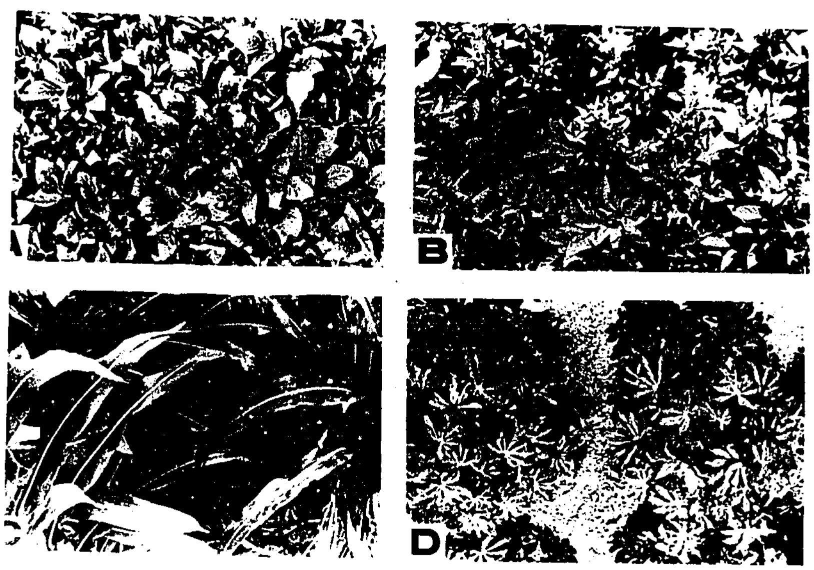


Figure 24. Overhead photographs showing soil cover under (A) soybeans (B) pigeon peas, (C) mixed cropping of corn and cassava and (D) monoculture cassava at 47, 61, 47 and 61 days after planting respectively.

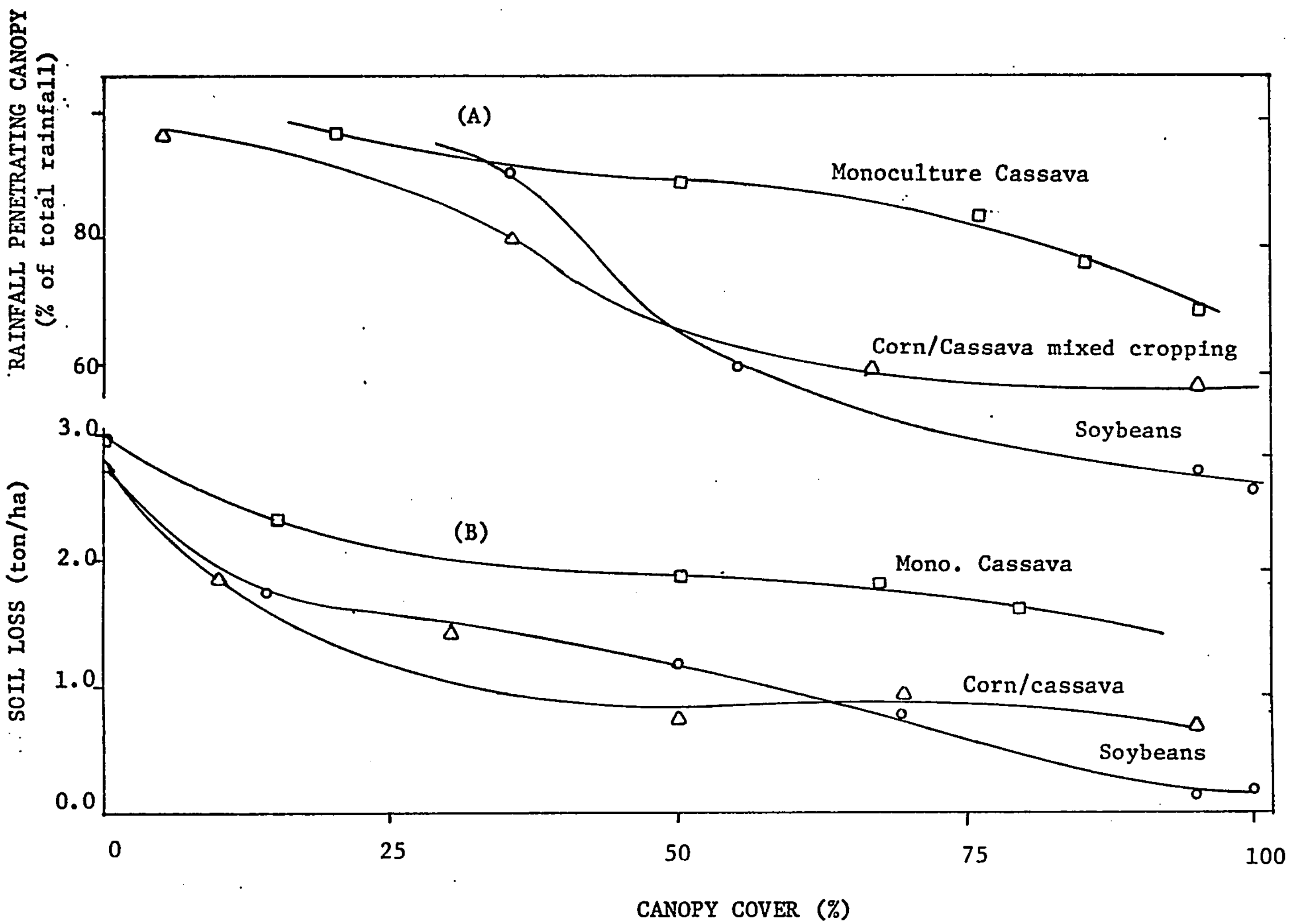


Figure 25. Effect of crop canopy on rainfall interception (A) and soil loss (B).

TABLE 19

SIMPLE REGRESSION OF SOIL LOSS, Y (IN METRIC TON/HA/CM RAIN) ON PERCENT GROUND COVER OF DIFFERENT CROPS
All correlation coefficients are significant at 1% probability level.

Crop	r	Regression Equation
Soybeans	0.63	$Y = 5.38e^{-0.04X}$
Pigeon peas	0.94	$Y = 3.27e^{-0.01X}$
Corn-cassava mixed	0.84	$Y = 2.20e^{-0.01X}$
Cassava monoculture	0.90	$Y = 2.71e^{-0.01X}$

r = correlation coefficient.

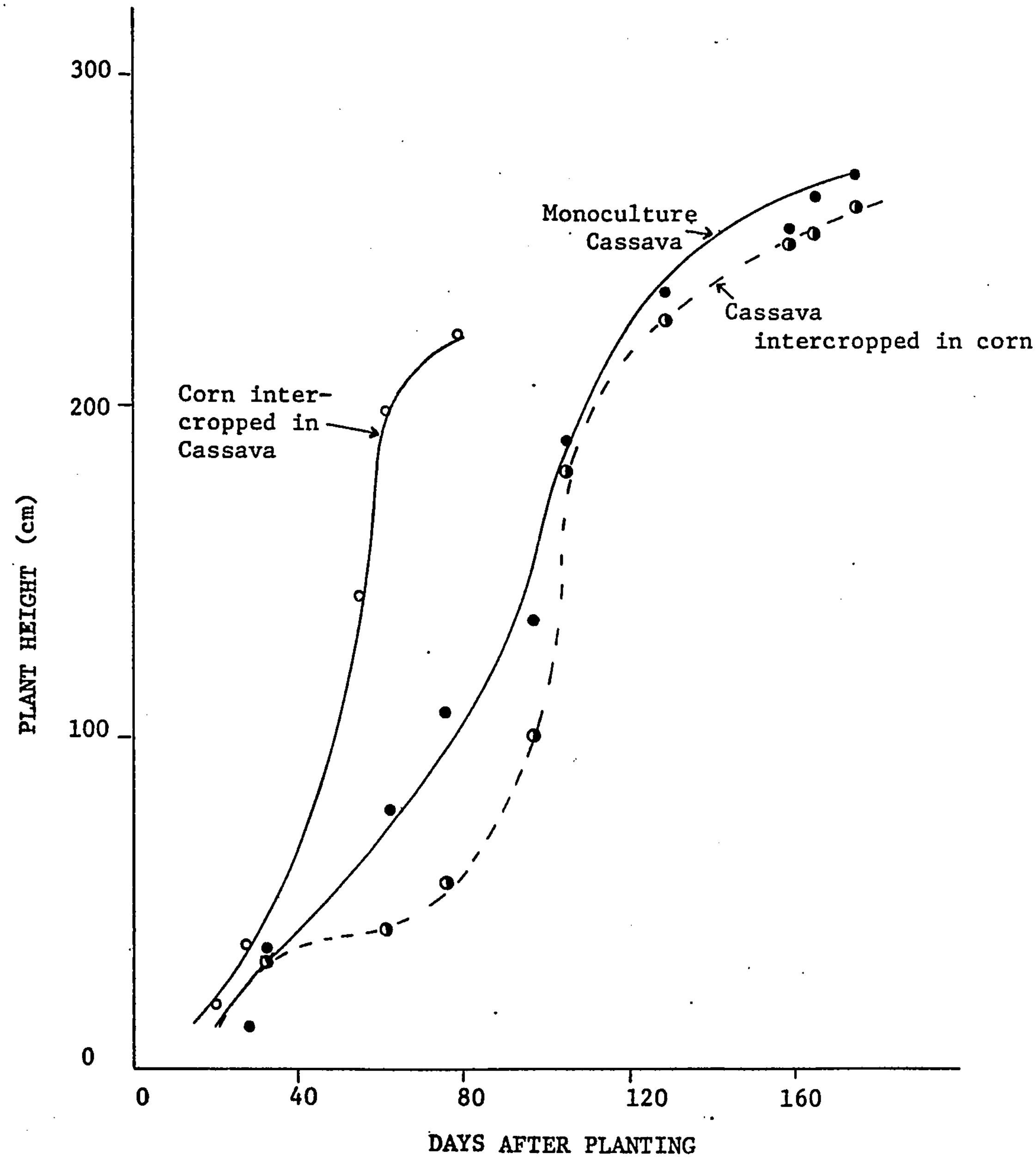


Figure 26. Effect of mixed cropping system on growth of corn and cassava.

plants therefore formed a lower canopy layer (beneath corn) intercepting more rainfall and leaf drippings than did cassava monoculture. Soybeans, on the other hand, are much shorter with greater canopy cover.

The relationship between leaf area index (LAI) and percent canopy cover of the different crops is presented in Figure 27. The two parameters were not linearly related. LAI at 90% canopy cover was 2, 2.5, 5 and 10 for intercropped cassava, soybeans, intercropped corn and monoculture cassava, respectively.

Corn Yields

Crop yield, in terms of total calorie value, under mixed cropping of corn and cassava was about 1.4 fold that under cassava monoculture (Figure 28). For yields of individual crops, intercropped cassava yield was only 50% that of monoculture cassava. Yields were 5 and 10 metric tons/ha, respectively. LAI and canopy density were considerably lower for intercropped cassava because of competition between the two crops for space and nutrients. Figure 29 shows these differences in canopy density between monoculture and intercropped cassava which could account for the differences in yields. Yields averaged 1210 and 900 kg.ha for soybeans and pigeon peas, respectively.

Cropping Effect on Soil Properties

Soil Texture

Changes in soil texture were statistically not significant

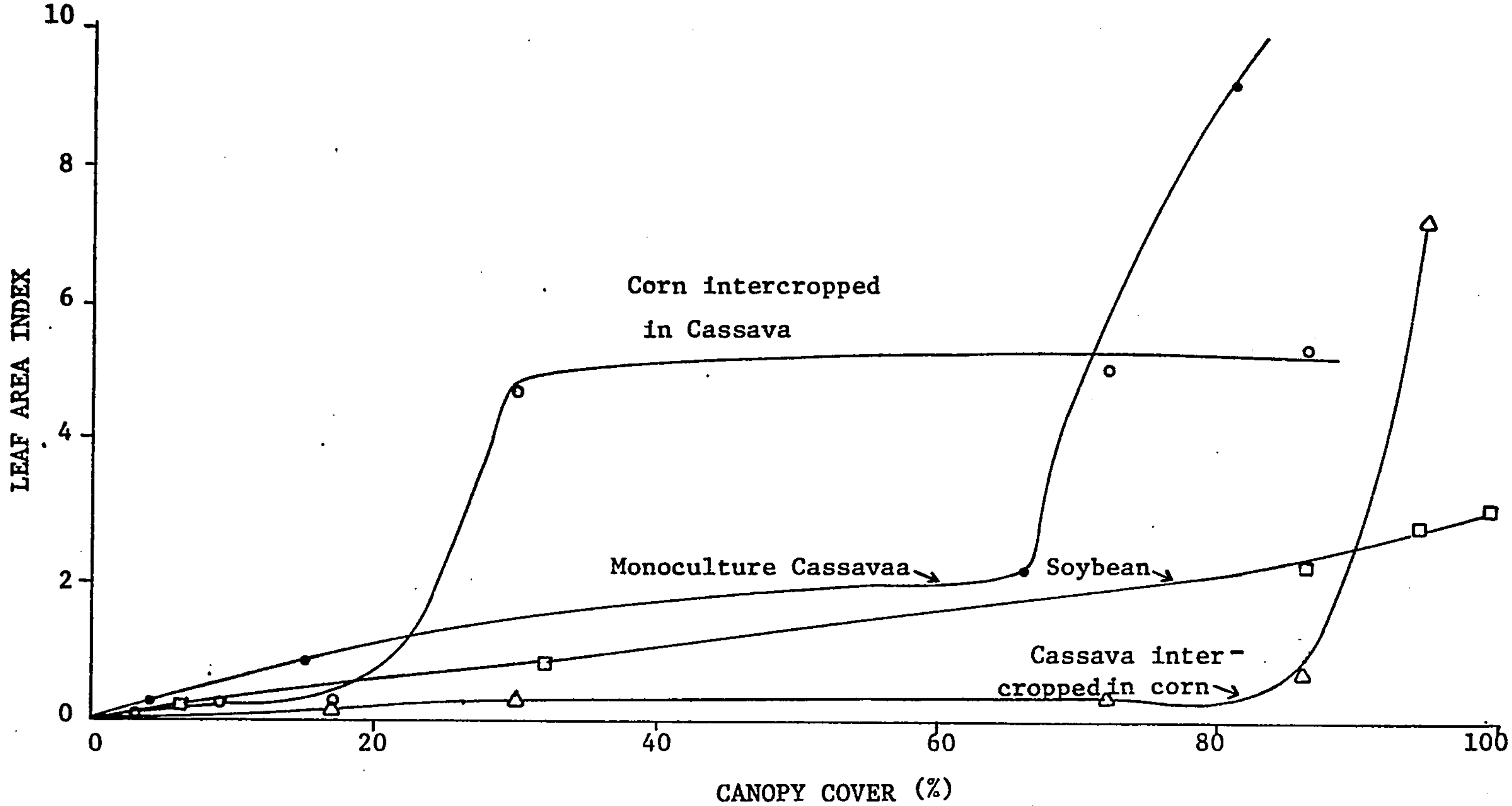


Figure 27. Relation of leaf area index to canopy cover of different crops

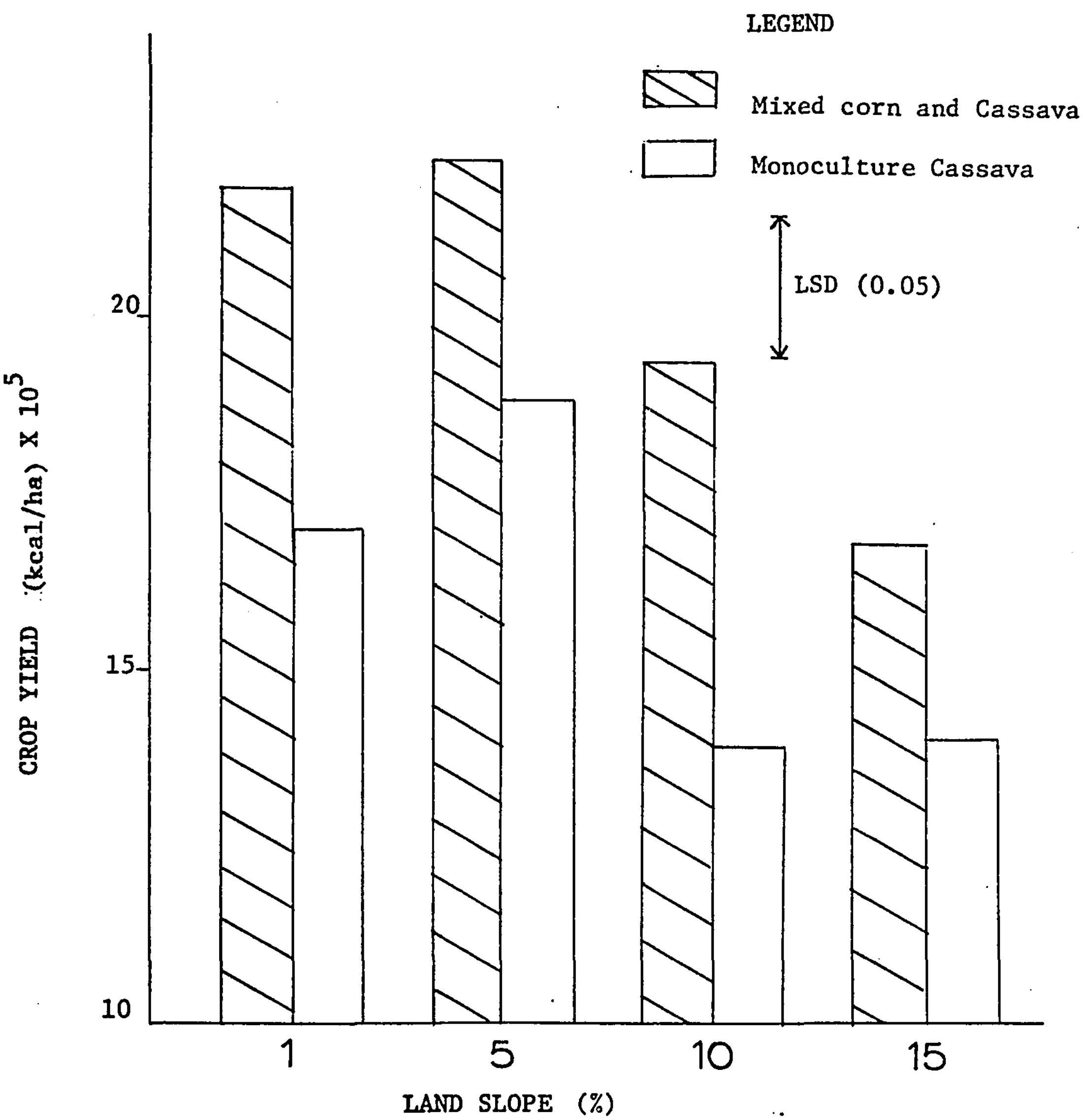


Figure 28. Effect of mixed cropping system on crop yield

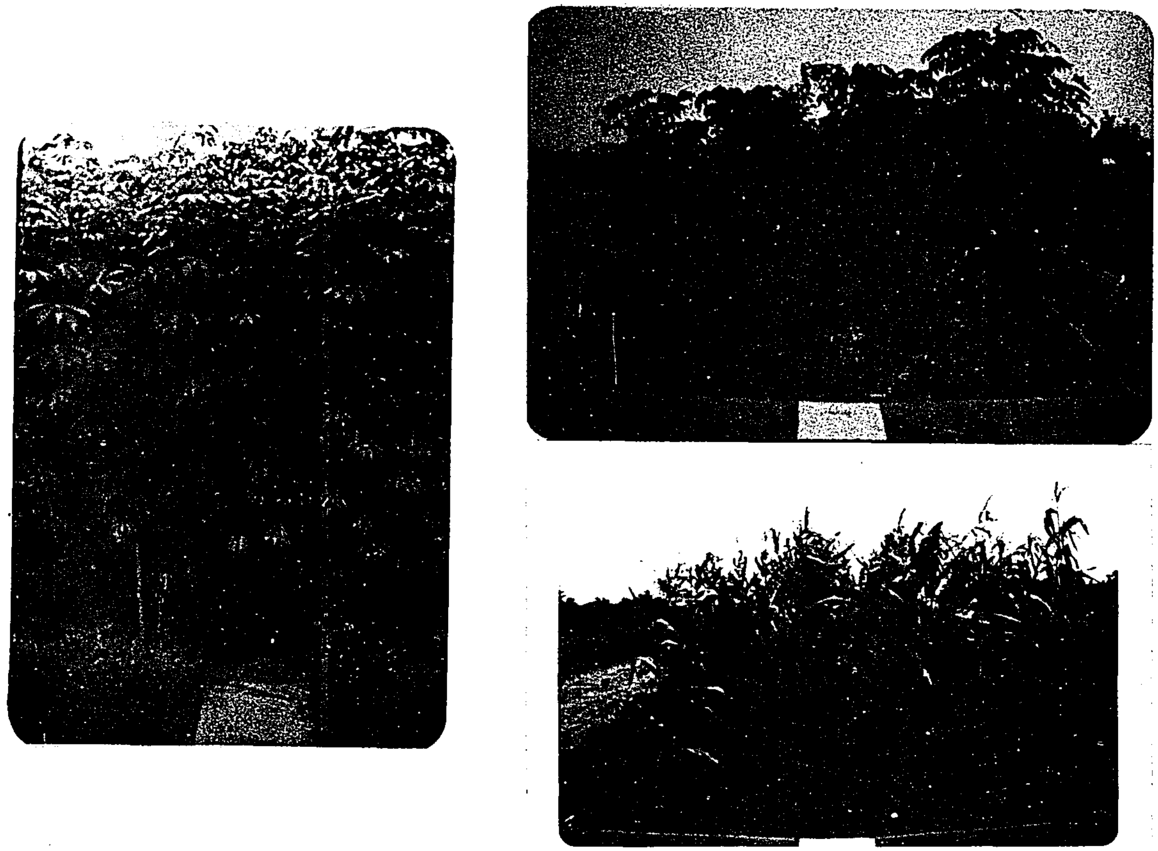


Figure 29. Photographs showing differences in canopy density between (A) monoculture cassava and (B) intercropped cassava 3½ months after planting. Photographs were taken 5 days after harvesting the corn crop in the latter (C).

because of the relatively short period of study and negligible depth of eroded topsoil relative to sampling depth. However, there was a slight increase in the coarse (sand and gravel) and clay fractions of the soil at the end of the crop rotations (Appendix Table 5). Increase in clay content could be due to a reduction in the depth of topsoil by erosion. The proportion of eroded silt decreased with the amounts of soil loss under the various treatments. Soybeans rotation had the highest eroded silt proportion, implying that soybean was most effective in reducing runoff velocity. Finer soil particles will be transported by slow moving runoff water. Conversely, bare fallow plots had the highest proportion of eroded sand fraction. There was a strong relationship (r = 0.81) between the amount of eroded clay and rainfall erosivity. On the basis of this relationship, differences in the amounts of eroded clay may be explained in terms of the relative amounts of rainfall unintercepted by the canopy. Amount of eroded clay was highest for cassava monoculture and least under soybeans rotation.

Soil Infiltration Characteristics

Infiltration rates of the soil following the crop rotations are reported in Figure 30 for the different treatments. Cumulative infiltration after 3 hours averaged 142, 115, 70 and 45cm for soybeans (with conventional tillage), mixed cropping of corn and cassava, monoculture cassava and bare fallow, respectively. The low infiltration for bare fallow is attributable to soil capping (from rainfall impacts) and exposure of the subsoil which is usually less

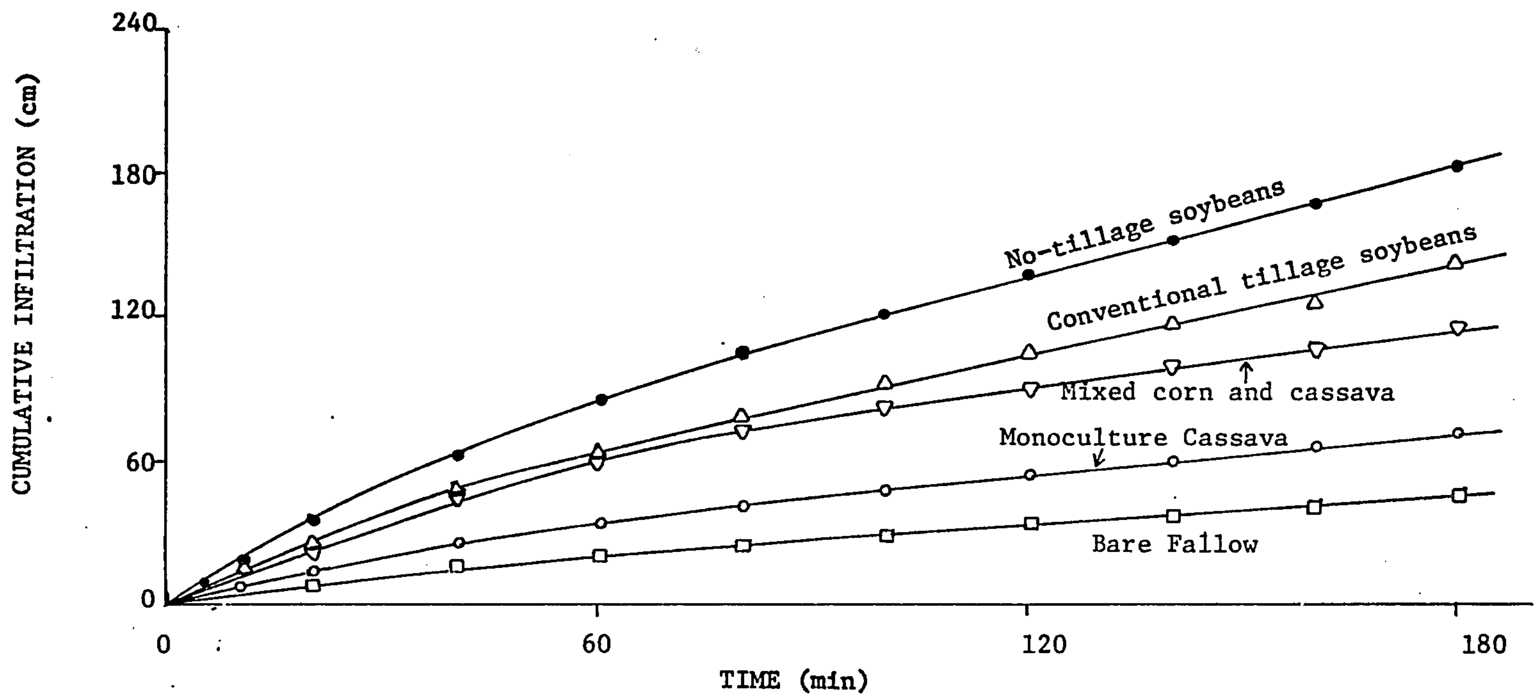


Figure 30. Infilltration characteristic of the soil as influenced by tillage and crop rotation treatments. (Each value is the mean of 4 plots with 3 measurements per plot)

permeable than the topsoil. Infiltration characteristics of the soil indicate the extent of deterioration of the surface soil structure permitted by the various treatments. Under a bush fallow, the infiltration rate of the soil was considerably higher (130 cm/hr) compared to rates ranging from 9 cm/hr for bare fallow to 39 cm/hr under soybeans. It is apparent from this comparison that low infiltration was associated with compaction and crusting of the soil by rainfall impactes and a decline in earthworm activities.

Soil Chemical Properties

Changes in soil chemical properties at the end of the rotations reflected closely the extent of soil erosion under individual cropping treatments. Eroded soil was generally higher in plant nutrients than the soil (Table 20). With the exception of K, enrichment ratio was greater than unity for all the nutrients. Leaching and greater loss of K in runoff may be the reasons for the low enrichment ratio for K. Despite the high losses, some nutrients accumulated over the rotational period. The cahnges in soil nutrients are shown in Figure 31.

Lower organic matter contents at the end of the first season could be due to high erosional losses and mineralization. The same explanation can be extended for the changes in total-N. The organic matter content of the bare fallow soil derived principally from humified fraction, hence did not change essentially during the period. Accumulation of available P resulted from additions from P-fertilizer and negligible loss of P by erosion while release of K from added

TABLE 20

ENRICHMENT RATIO[1] OF DIFFERENT NUTRIENTS AS INFLUENCED BY DIFFERENT CROPPING SYSTEMS
Each value is the average of 4 plots.

Treatment	Org. Carbon	N	P	K	Ca	Mg
Bare fallow	1.45	1.36	1.08	0.79	1.71	1.80
Monoculture cassava	1.43	1.34	0.85	0.87	1.15	1.29
Corn and cassava mixed	1.41	1.40	1.35	0.73	1.19	1.22
Soybeans-soybeans	1.26	1.13	1.15	0.61	1.21	0.88
Pigeon peas-pigeon peas (long plot)	1.07	0.96	1.35	0.95	1.01	1.08
Pigeon peas-pigeon peas (short plot)	1.19	1.26	1.55	0.97	1.47	2.11

[1]Enrichment ratio is the ratio of the nutrient content of eroded sediment to that of the soil.

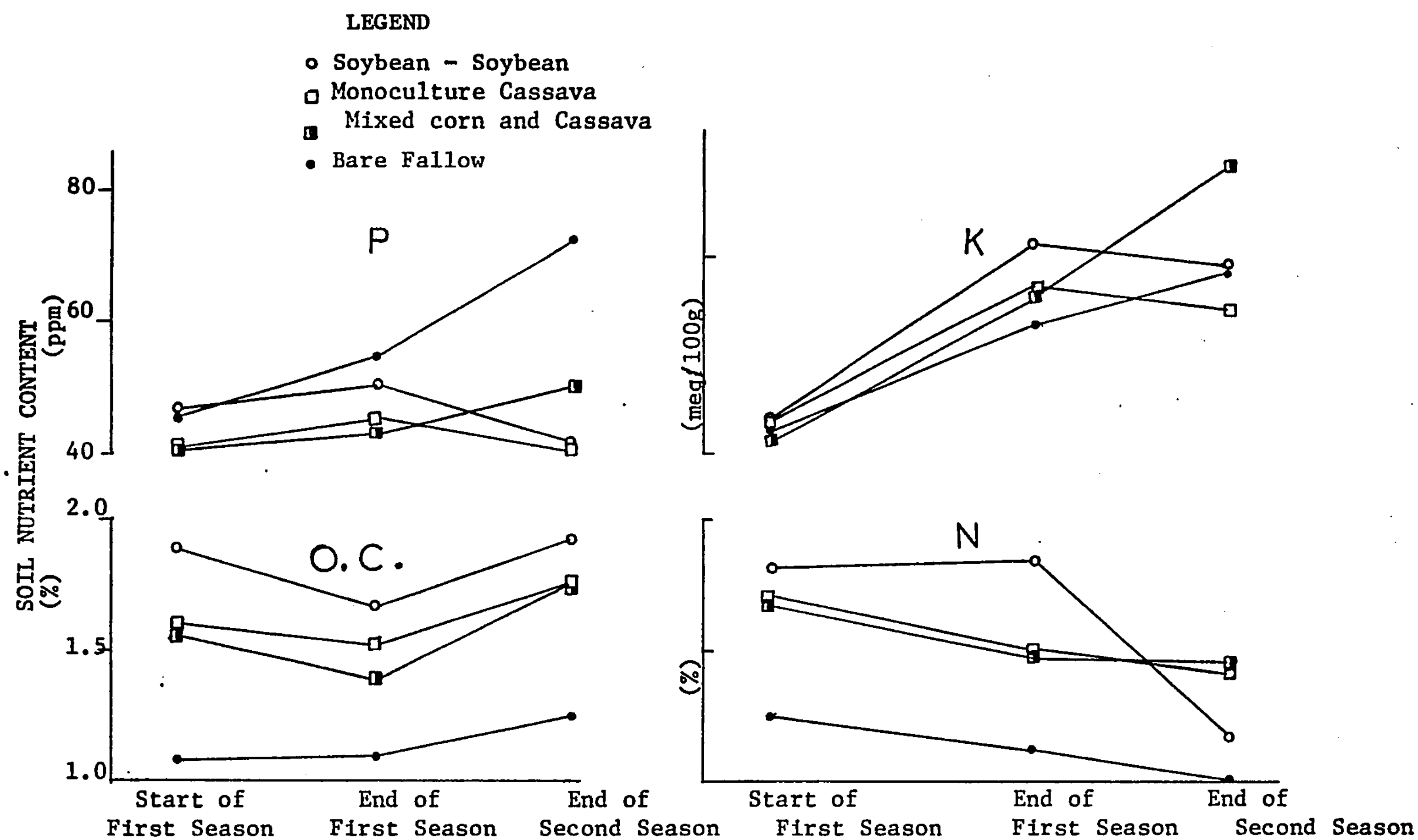


Figure 31. Nutrient content of soil as influenced by different cropping systems

crop residues caused its accumulation under soybeans and mixed cropping of corn and cassava.

6. <u>The Universal Soil Loss Equation (USLE)</u>

It will be recalled that the universal soil loss equation (Wischmeier et al., 1968) relates soil loss to the product of 6 factors of erosion in the following manner:

$$A = R\ K\ LS\ C\ P$$

where R is the summation of monthly EI_{30} for the year; K, the erodibility factor is the ratio of annual soil loss, A to R; L,S are slope factors which are unity for 72.6 feet long plots on 9% slope; C and P are, respectively crop management and conservation practice factors which are unity for conditions of bare fallow where planting is up and down the slope. Factors were evaluated following the procedure in the U.S.D.A. Handbook No. 282 (Wischmeier and Smith, 1965).

Distribution of erosivity factor, R for Ibadan in 1975 is presented in Figure 32. Total R for the 2 cropping seasons was 853 which represented 88% of annual value. This R value compares with that of southeast U.S. (Florida) which is considered high (Wischmeier and Smith, 1965). K was 0.01, 0.17, 0.09 and 0.10 for bare fallow plots on 1, 5, 10 and 15% slopes, respectively. Reasons for the lower soil losses on the greater slopes have been previously discussed. Erosion potential of the 10 and 15% slopes were under-estimated by the K values. C and P factors were evaluated differently from the

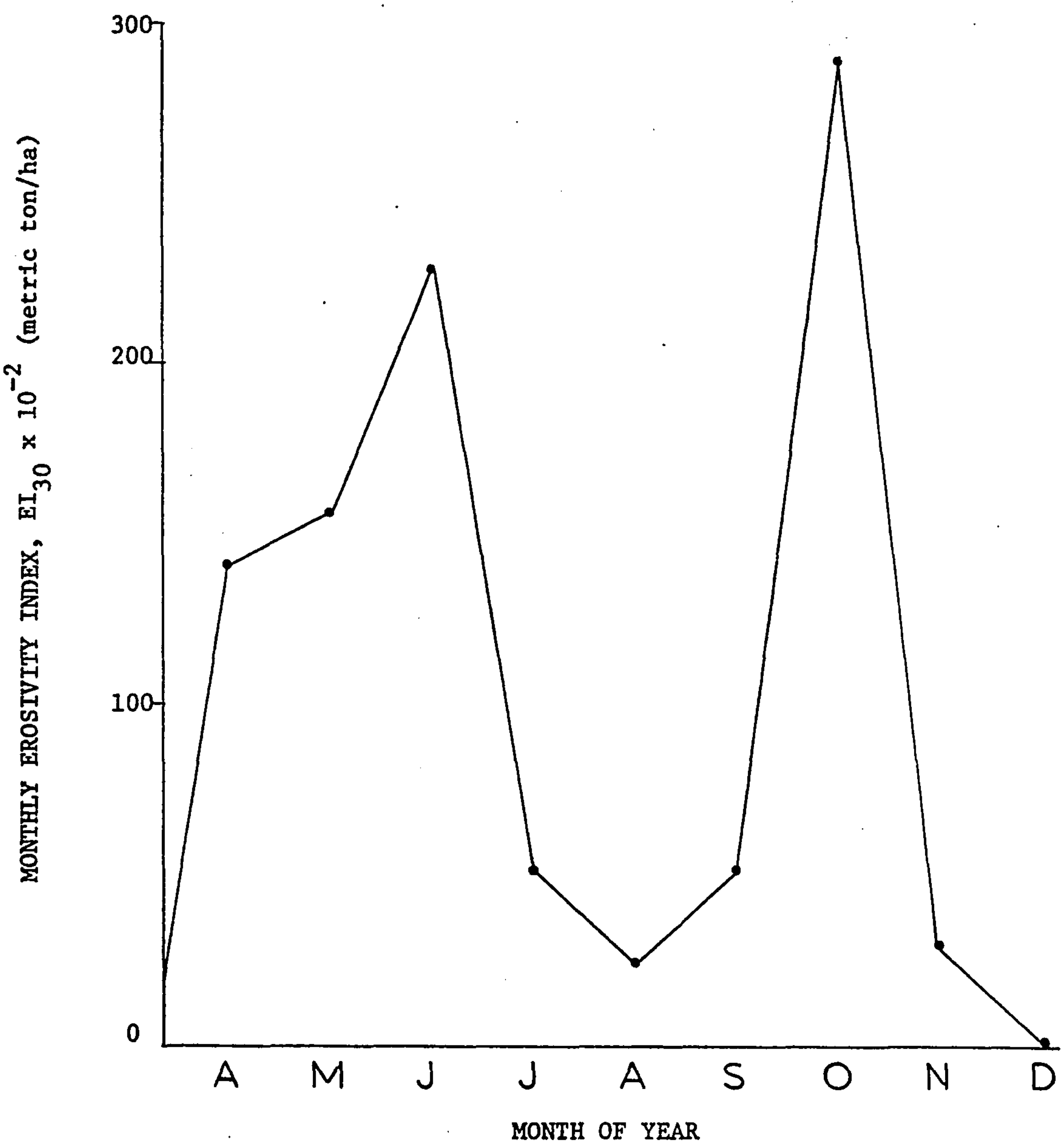


Figure 32. Monthly values of EI_{30} index for Ibadan in 1975.

procedure indicated in the handbook. C and P were evaluated on 5% slope plots and adjusted to 9% slope conditions. This decision was made because soil losses from bare fallow plots were lower than from the corresponding cropped plots on 10 and 15% slopes. In order to relate more to the local conditions, C and P were computed for each cropping season using Figure 33 and the following crop stages:

Stage 1 - 0 to 2 weeks after seeding
2 - 2 to 6 weeks
3 - 6 to 10 weeks
4 -10 weeks after seeding to harvest

Fallow stage was not considered because planting is not normally done in the periods preceding the croppings seasons. There was also no erosion record for these periods. Values of C and P factors are given in Table 21 for the different crops. C values ranged from 0.19 for soybeans to 0.72 for cassava in the first cropping season. Values were considerably lower in the second season because fairly adequate canopy cover had been established in the second season before the advent of most erosive storms. The C values reflected the erosion potential of individual cropping systems. Compared to conventional tillage, planting soybeans with no-tillage reduced the value of C from 0.19 to 0.0004.

Adaptability of the USLE to Tropical Conditions

The erosion prediction potential of the R (EI_{30}) index in this study has been discussed. R accounted for 50% of the variability in soil loss on 10% slope. Similar results have been reported on

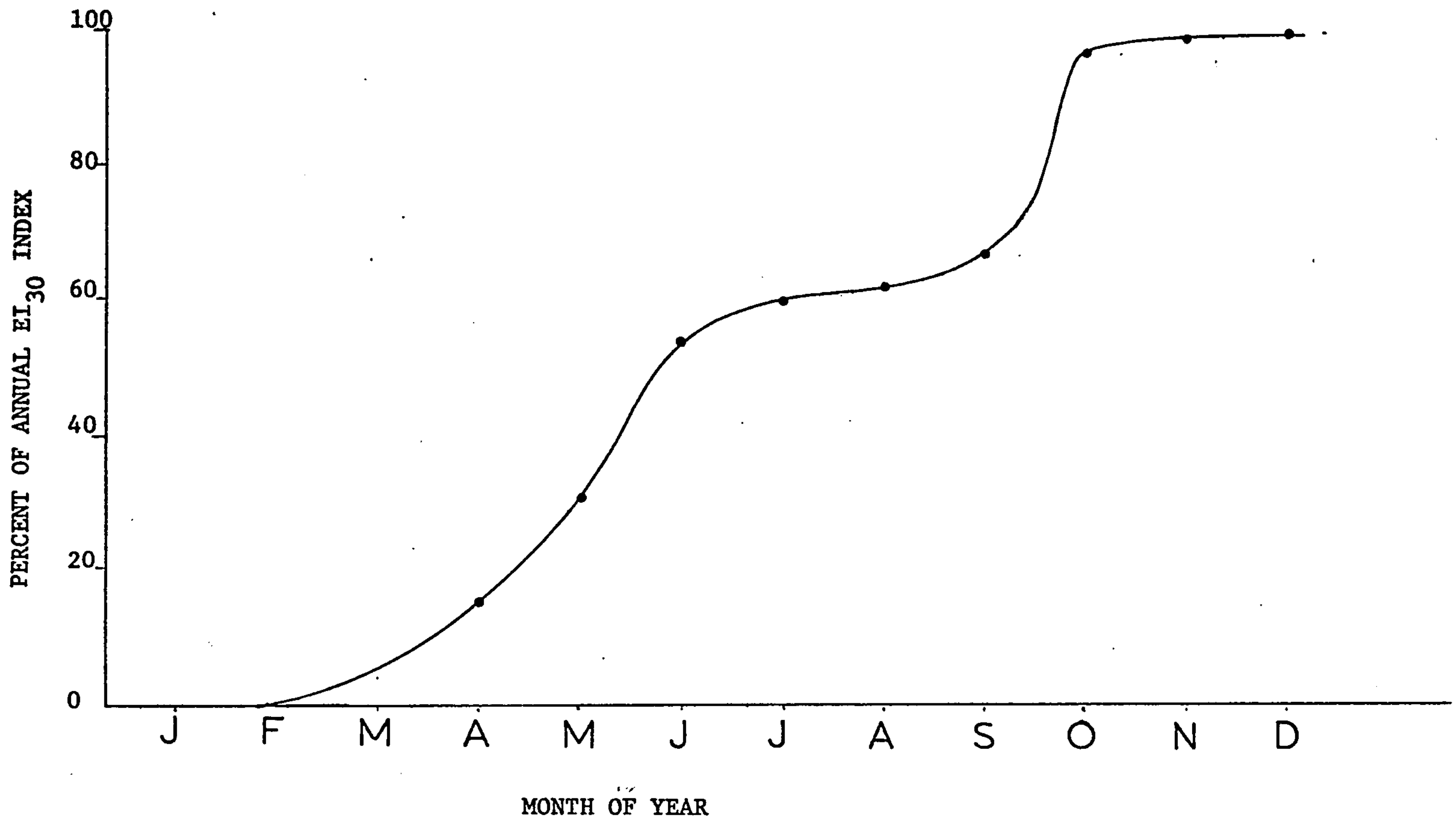


Figure 33. Cumulative distribution of EI_{30} index for Ibadan in 1975

TABLE 21

CROP MANAGEMENT FACTOR, C OF THE UNIVERSAL SOIL LOSS EQUATION FOR DIFFERENT CROPS

Crop	First Season	Second Season
Cassava (monoculture)	0.72	0.39
Corn and cassava (mixed)	0.43	0.05
Soybeans (with conv. tillage)	0.19	0.02
Soybeans (with no-tillage)	0.0004	0.0002

some other tropical soils by Ahmad and Breckner (1974). This low erosion prediction potential of R could be due to the energy (drop size) -intensity relationship reported earlier in text, which deviated from the one on which the USLE was developed. Soil erosion potential of the soil was under-estimated by the erodibility factor, K because of the high vulnerability of the soil to erosion. K should therefore be considered to be more variable under similar conditions of the study. Such K factor will consider the level of soil deterioration that had resulted from past erosional process. Erosion-slope length relationship was a function of the nature of the slope. A relationship developed was a function of the nature of the slope. A relationship developed entirely on length of plot (as did the USLE) may therefore be misleading.

It is apparent from the analysis of the factors of the USLE that modifications are needed in the factors R, K, L and S for the equation to be adaptable to the tropical conditions represented in this study. The AI and AIV have been proposed as alternative erosivity indices because they were better predictors of erosion than R. AIV index also incorporates the wind factor that is a distinguishing component of most tropical rainstorms.

C. Laboratory Erosion Studies

1. Effect of Soil Type on Leacheate and Erosion Losses

Figure 34 gives the quantities of soil loss, runoff for each soil from an application of a total precipitation of 52.4cm. Soil

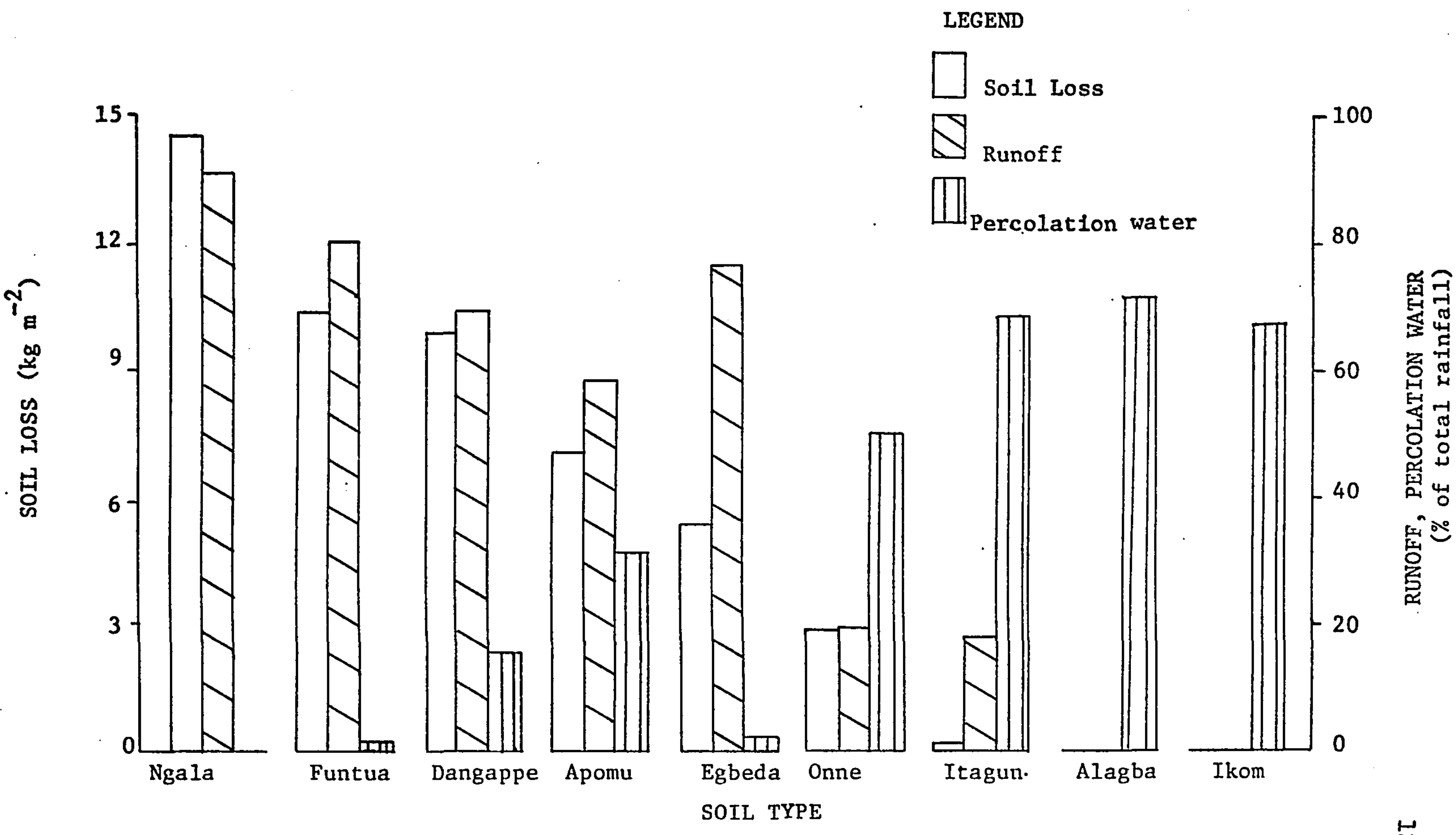


Figure 34. Total soil loss, runoff and percolation water from laboratory microplots (total of all treatment combinations)

losses ranged from 0 for Alagba and Ikom to 14.4 kg/m^2 on Ngala soil. Runoff paralleled soil losses on all the soils. Ngala had the highest runoff of 91% of total precipitation. On the other extreme are the Alagba and Ikom soils that had no runoff. Soils with low runoff generally had large amounts of leachate. Variations in susceptibilities were as significant within a soil order . For instance, the order alfisol includes the least susceptible soils (Alagba) as well as highly susceptible soil (Funtua) that had 10.4 kg/m^2 soil loss and 80 percent runoff. The same holds true for Ikom, Itagunmodi and Onne soils which are ultisols.

Soil loss and runoff from the reference soil (Egbeda) on field plots were higher compared to laboratory microplot. These differences can be expected because of the large size of the field plots that tend to favor more runoff accumulation and hence greater soil loss compared to laboratory microplots. These results suggest that erosion losses determined in the laboratory may not be directly extrapolated to field conditions. However, this technique is useful in studying relative susceptibility and effects of factors of erosion.

2. Effect of Soil Properties on Erosion

Soil Texture

Correlation coefficients between soil loss and soil separates (sand, silt and clay) were not significant at 5% level. Similar results were obtained under field erosion studies. However, with the exception of Ngala soil (vertisol), soils higher in clay (> 20%) and organic matter appeared to be less susceptible to erosion. The effect of these soil constituents are probably related to improved aggregation. Funtua soil had the highest proportion of silt (63%) and was most erodible except Ngala soil.

Soil Moisture

Erosion from dry run is compared with that from wet run at different rainfall intensities in Figures 35, 36, and 37. Wet run consistently gave higher runoff and soil loss than did dry run on most of the soils. Soil loss under dry run was 59, 40, 31, 22 and 16 percent of that under wet run for Ngala, Apomum Egbeda, Funtua and Dangrappe soils, respectively (Figure 35). Lower erosion observed under dry run is not unexpected since the rate of rainfall infiltration decreases with soil antecedent moisture content. Effect of initial soil moisture content on erosion varied considerably with soil type, rainfall characteristics and slope. The differences between erosion from wet run and dry run were more singificant with 17.5 cm/hr rainfall intensity on 10% slope (Figure 36). The Ngala soil was equally erosive regardless of antecedent soil moisture on 10 percent slope. On the other extremes were Onne and Apomu soils that had no soil loss and runoff under dry run regardless of slope at 12.5 cm.hr rainfall intensity. These results were closely related to the elapsed time required to initiate runoff on the different soils (Table 22). The elapsed times from start of rainfall application and initiation of runoff reflect the times required for surface aggregates to rupture.

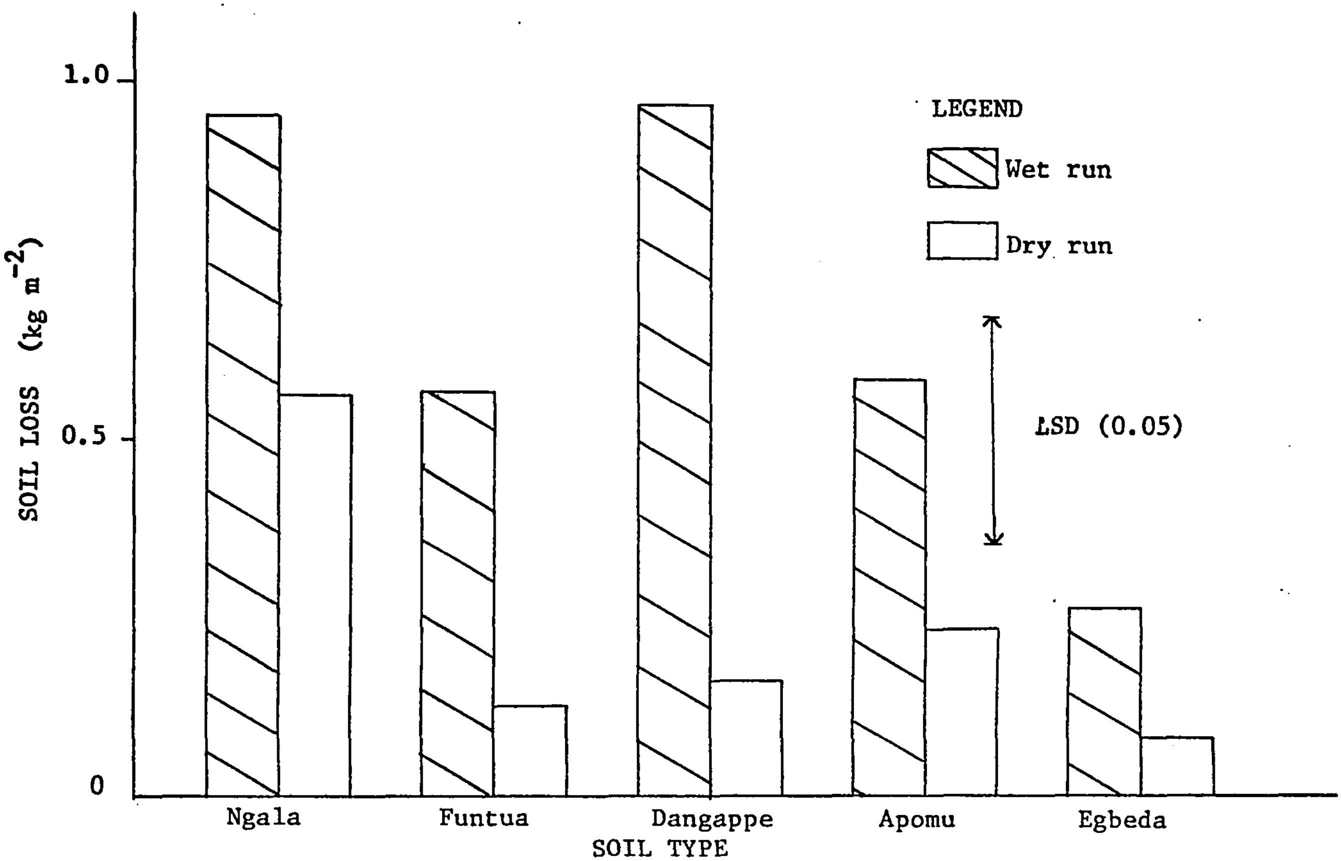


Figure 35. Effect of initial moisture content on soil loss and runoff (indicated in parenthesis) from different soils under 5% slope and 2.1 cm rainfall of 17.5 cm/hr intensity

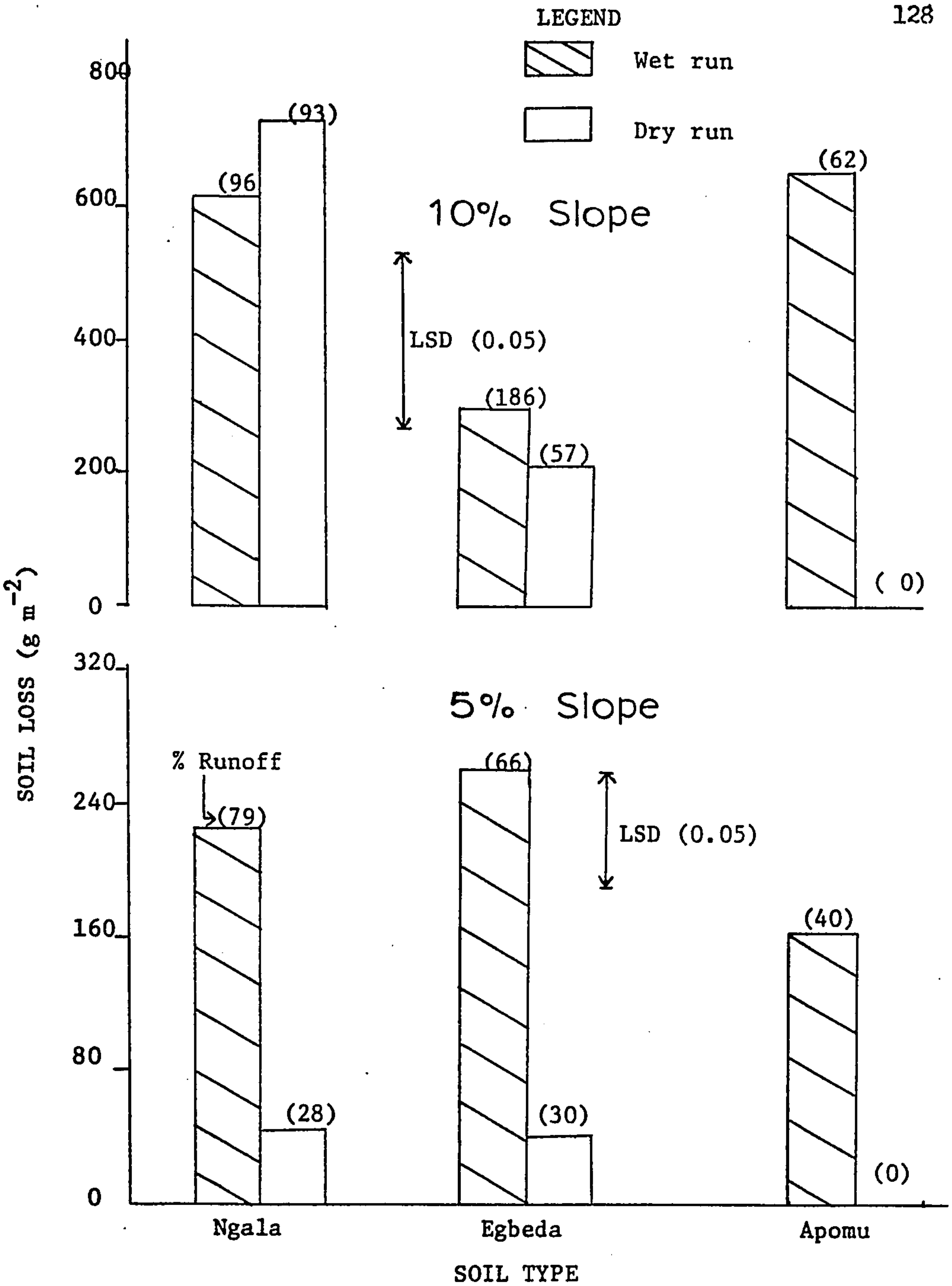


Figure 36. Effect of initial moisture content on soil loss and runoff (indicated in parenthesis) from different soils.

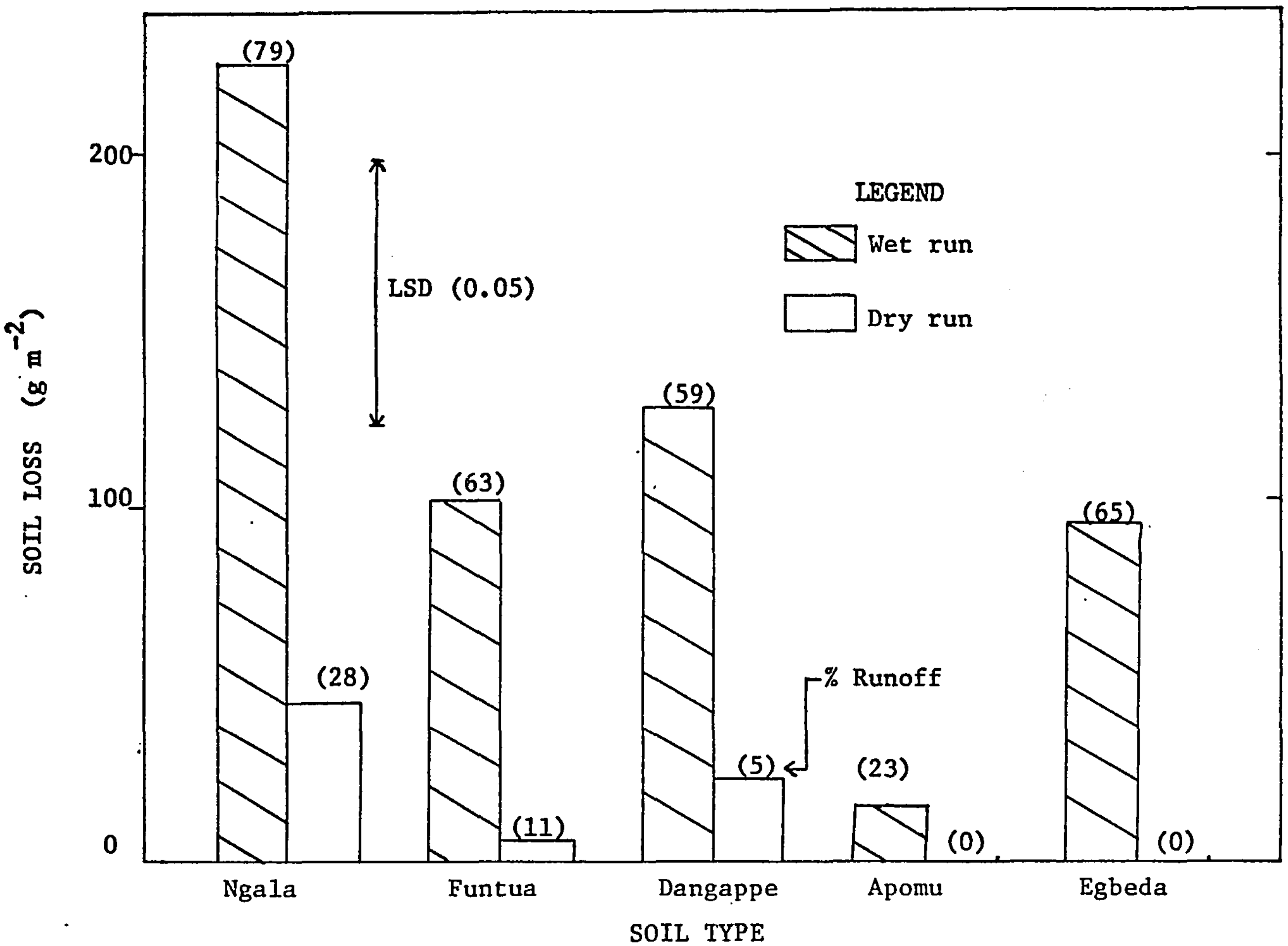


Figure 37. Effect of initial moisture content on soil loss and runoff (indicated in parenthesis) from different soils under 5% slope and 2.1 cm rainfall of 12.5 cm/hr intensity.

TABLE 22

THE INFLUENCE OF SOIL TYPE ON RUNOFF INITIATION TIME AND FINAL INFILTRATION RATES

Soil Type	Time (min.)		Infiltration (cm/hr)[1]	
	Dry Run	Wet Run	5% Slope	10% Slope
Ngala	3	0.5	1.2	1.4
Funtua	8	1.0	3.6	2.3
Dangappe	12	1.0	6.0	3.3
Apomu	18	2.5	8.4	4.6
Egbeda	12	1.5	4.7	2.2
Onne	18	2.5	15.1	9.4
Itagunmodi	>30	6.5	11.7	10.2
Alagba	>30	>30	17.2	16.0
Ikom	>30	>30	17.7	16.3

[1]Each value is the average of 6 treatment combinations.

Moisture Retention Characteristics

Moisture retention at field capacity and moisture equivalent were closely related to soil sand and clay fractions. Correlation coefficients between moisture equivalent and sand were -0.82 and between moisture equivalent and clay was 0.96. However, neither of the moisture retention characteristics was significantly related to erosion from the soils. Runoff occurred generally at a moisture content close to field capacity.

Correlation coefficient between soil moisture content at runoff initiation and 1/3-bar moisture potential was 0.83 (Figure 38).

Aggregate Stability

The wet sieving and water drop techniques of aggregate stability are compared in Table 23. The data shows that all the soils except Ikom, Alagba and Itagunmodi were relatively structurally unstable. Lack of agreement between the aggregate stability analysis was due to the different techniques used. The laboratory microplot method seems to reflect more closely the contrasting behavior of soils under field conditions with regard to rainfall and soil characteristics. Surface structural conditions were essentially unchanged at the end of the experiments on Ikom, Alagba and Itagunmodi soils that are characterized by high clay and organic matter contents. On the other hand, the Ngala soil became very massive at the surface following rainfall application.

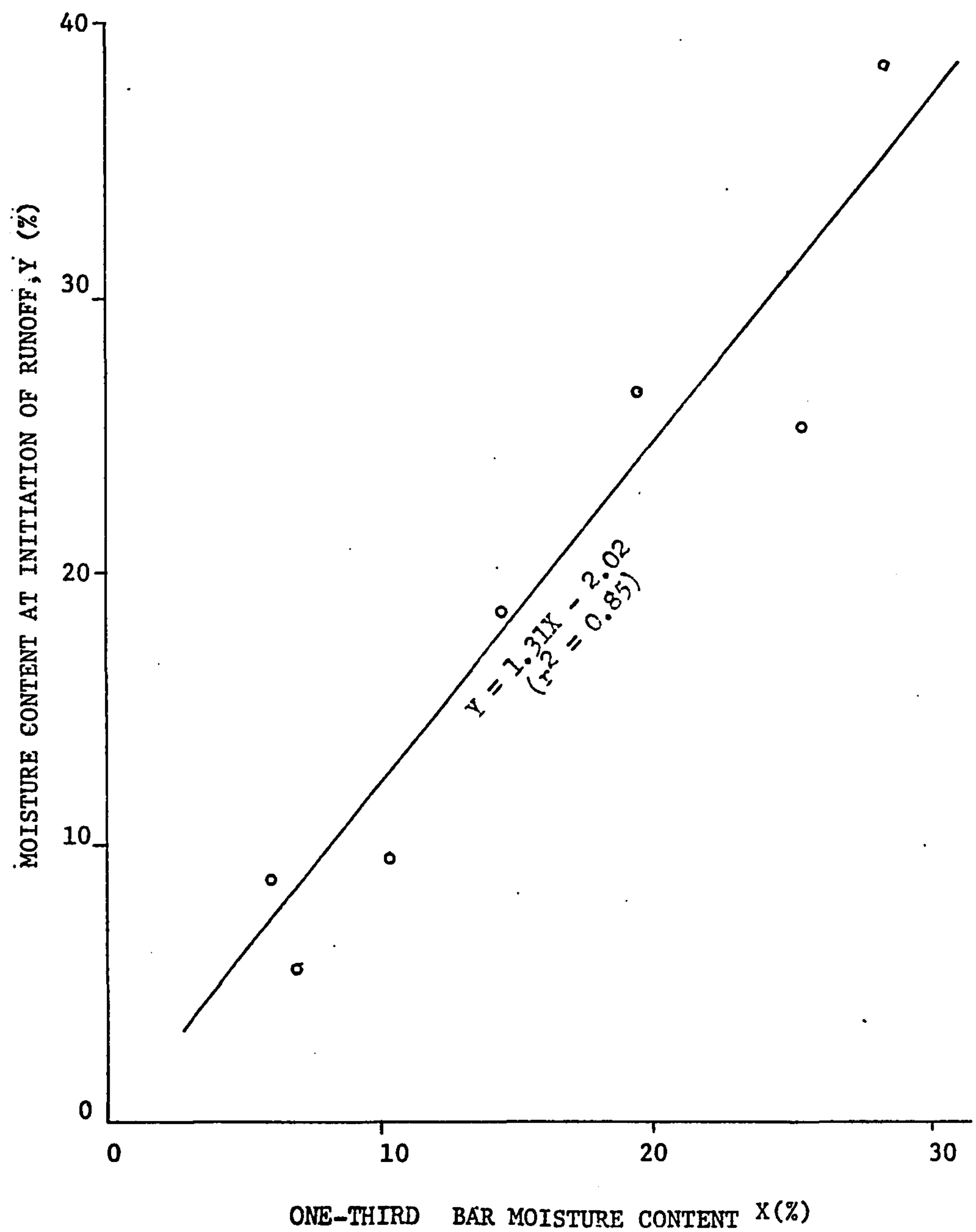


Figure 38. Correlation between soil moisture content at 1/3-bar and at initiation of runoff

Soil Infiltration Characteristics

Final infiltration rates ranged from 2 cm/hr for Ngala to 18 cm/hr for Ikom and Alagba (Table 23). Infiltration rates were closely related to amounts of erosion on the soils (r = 0.87). Aggregate stability of soil correlation coefficients between infiltration rate and aggregate stability were 0.64 and 0.87 by water drop technique and by simulator method, respectively and were significant at 1% probability level. The high susceptibilities of soils (such as Ngala, Funtua) to erosion are therefore attributable to restricted water infiltration due to structurally unstable soil.

Chemical Characteristics

The principal chemical soil characteristics most closely related to erosion on the soils were organic matter, exchangeable bases and mineralogical composition. Although the organic matter contents of the soils were generally low (ranging from 1 to 3.5 percent), correlation between soil loss and organic matter content was fairly high (r = 0.80). Organic matter was also correlated with wet sieving aggregate index (r = 0.72) and moisture retention at 1/3-bar (r = 0.96). These results confirm the reports from several studies (Periera and Jones, 1954; Lugo-Lopez and Juarez, 1959; Monnier, 1965) that emphasized the role of organic matter in stabilizing soil aggregates and improving water retention characteristics of tropical soils.

Of the exchangeable bases, only Na and K showed any significant effect on soil erosion. They both had positive correlation coefficients (r) with soil loss. r was 0.67 and 0.71 for K and Na,

TABLE 23

COMPARATIVE ANALYSIS OF THE ERODIBILITY OF SOILS

Soil Type	Method[1]				
	Wet Sieving	Water Drop		Lab. Microplot	
	Index	Index	Rating	Index	Rating
Ngala	1.80	0.007	very stable	0.94	highly erodible
Funtua	3.50	0.083	highly erodible	0.66	highly erodible
Dangappe	3.81	0.091	highly erodible	0.66	highly erodible
Apomu	6.53	0.125	highly erodible	0.68	highly erodible
Egbeda	2.89	0.077	mod. erodible	0.35	mod. erodible
Onne	4.60	0.063	mod. erodible	0.34	mod. erodible
Itagunmodi	1.21	0.027	stable	0.01	very stable
Alagba	0.72	0.009	very stable	<0.001	very stable
Ikom	0.55	0.009	very stable	<0.001	very stable

[1]Methods of erodibility analysis are defined on page 133

respectively. Correlations of Na and K with soil infiltration rate were of the same magnitude (but negative) as with soil loss. High Na and K probably increased soil dispersion because of their large hydrated radii. This effect would reduce infiltration of water into soil and consequently increase erosion on the soils, such as experienced on the Ngala soil.

Kaolinite was the predominant clay mineral in the soils except Ngala and to a lesser extent, Apomu soils that contained primarily smectite. CEC and available water holding capacity of the soils were generally low because of low organic matter and the predominance of kaolinite and sesquioxides in the soils. CEC ranged from 4 meq/100g on Dangappe (Oxic Paleustalf) to 18 meq/100g on Ngala which contained high smectite content. The high susceptibility of Ngala soil to erosion is attributable to the swelling nature of the soil due to high smectite composition. It was observed that percolation of water was generally restricted to the top 5cm of the microplot during the runs.

3. Effect of Slope on Soil Loss and Runoff

Soil loss and runoff generally increased with slope (Table 24). The soil loss-slope steepness relationship on Egbeda was similar to that under field conditions. Soil losses between 5 and 10 percent slopes were not significantly different for certain soils. This relationship appeared to be characteristic of the medium textured soils that had appreciable amounts of silt (20% - 60%) and sand (20% - 60%). The coarser textured soils (Apomu and Onne) were highly

TABLE 24

EFFECT OF SLOPE ON SOIL LOSS AND RUNOFF
IN LABORATORY MICROPLOTS
Each value is the total of 6
treatment combinations.

Soil Type	Soil Loss (kg m^{-2})		Runoff (% of rainfall)	
	5% slope	10% slope	5% slope	10% slope
Ngala	6.40	7.75	93	90
Funtua	4.75	5.50	77	84
Dangappe	3.10	6.70	62	77
Apomu	1.25	5.70	47	70
Egbeda	2.35	2.95	70	83
Onne	0.0	2.80	0	40
Itagunmodi	0.0	0.15	0	36

permeable and less erodible on 5% slope. As the slope increased soil loss increased at a fast rate because of increased runoff velocity and low resistance of the soils to rainfall impacts. Negligible erosion occurred on Itagunmodi and practically none on Ikom and Alagba soils (regardless of slope). This was due to the high infiltration and stability of these soils. Results of the analysis of variance on the erosion data are presented in Table 25, 26, and 27). The results indicate that increased soil loss associated with 10% slope was due to more significant increases in runoff and runoff sediment density.

4. Effect of Rainfall Characteristics on Erosion

Increasing rainfall intensity from 12.5 to 17.5 cm/hr increased soil loss from 2 to 15 fold (Table 28). The statistical analysis tables show that the effect of intensity on erosion on the soils was more significant than the effect of slope steepness. Increase in intesnity also contributed more significantly to the increases in the sediment density of runoff than did slope steepness. More soil loss and runoff were generally associated with larger amounts of rainfall or rainfall duration. This is logical, since all the wet runs were made at about the same initial soil moisture contents. However, no such strong relationship existed between erosion and total precipitation because of variable antecedent soil moisture.

Correlations between soil loss and some erosion prediction indices are presented in Table 29. With the exception of the erodibility indices, K_D (index determined by the water drop technique)

TABLE 25

ANALYSYS OF VARIANCE FOR A SPLIT-SPLIT-PLOT
EXPERIMENT ON SOIL LOSS

Source of Variation	Degrees of Freedom	Total Sum of Squares	Mean Sum of Squares	'F'
Main Plots:				
Soils	6	16.220	2.703	9.26**
Slope (s)	1	3.077	3.077	10.54*
Error (a)	6	1.751	0.292	
Sub-Plots:				
Intensity (I)	1	7.788	7.788	28.79**
S I	1	.0004	.0004	.002
Error (b)	12	3.246	0.271	
Sub-Sub-Plots:				
Rainfall (A)	2	6.901	3.450	27.63**
S×A	2	0.447	0.223	1.79
I×A	2	1.210	0.605	4.84*
S×I×A	2	0.010	0.005	0.04
Error (c)	23	2.872	0.125	

*F ratio significant at 5% probability level.

**F ratio significant at 1% probability level.

TABLE 26

ANALYSIS OF VARIANCE FOR A SPLIT-SPLIT-PLOT EXPERIMENT ON RUNOFF

Source of Variation	Degrees of Freedom	Total Sum of Squares	Mean Sum of Squares	'F'
Main Plots:				
Soils	6	63045.6	10507.6	19.29**
Slope (s)	1	7733.8	7733.8	14.20**
Error (a)	6	3268.2	544.7	
Sub-Plots:				
Intensity (I)	1	960.2	960.2	21.42**
S I	1	2.33	2.33	0.05
Error (b)	12	537.8	44.8	
Sub-Sub-Plots:				
Rainfall (A)	2	802.1	401.1	9.54**
S×A	2	29.3	14.1	0.35
I×A	2	30.2	15.1	0.36
S×I×A	2	3.02	1.51	0.04
Error (c)	24	1009.5	42.1	

**F ratio significant at 1% probability level.

TABLE 27

ANALYSIS OF VARIANCE FOR A SPLIT-SPLIT-PLOT EXPERIMENT ON SEDIMENT DENSITY

Source of Variation	Degrees of Freedom	Total Sum of Squares	Mean Sum of Squares	'F'
Main Plots:				
Soils	6	968.6	161.4	39.66**
Slope (s)	1	43.9	43.9	10.80*
Error (a)	6	24.4	4.07	
Sub-Plots:				
Intensity (I)	1	196.1	196.1	12.31**
S I	1	0.72	0.72	0.04
Error (b)	12	191.1	15.9	
Sub-Sub-Plots:				
Rainfall (A)	2	11.02	5.51	1.61
S×A	2	14.13	7.06	2.07
I×A	2	0.81	0.40	0.12
S×I×A	2	2.84	1.41	0.42
Error (c)	24	82.0	3.42	

*F ratio significant at 5% probability level.

**F ratio significant at 1% probability level.

TABLE 28

SOIL LOSS (in $gm/m^2/cm/rain$) FROM LABORATORY MICROPLOTS AS INFLUENCED BY RAINFALL INTENSITY

Soil Type	Rainfall Intensity (cm/hr)			
	12.5		17.5	
	5% slope	10% slope	5% slope	10% slope
Ngala	123.0	273.9	390.1	354.0
Funtua	77.5	128.7	302.2	314.0
Dangappe	39.1	183.5	208.8	352.0
Apomu	5.8	126.4	98.8	329.7
Egbeda	40.4	38.2	149.2	193.5
Onne	0	73.1	0	152.0
Itagunmodi	0	2.2	0	7.1

TABLE 29

CORRELATION BETWEEN SOIL LOSS AND VARIOUS EROSION INDICES AS DETERMINED ON LABORATORY MICROPLOTS

Variable[1]	r	r^2
EI	0.66**	0.44
AI	0.71**	0.62
K_D	0.34	
K_S	0.50	
K_r	0.89**	0.81

[1]Indices are defined on page 133

and K_S (index determined by the wet sieving method) all the indices were significantly related to erosion on the laboratory micoplots. Erosivity index, EI (porduct of rainfall energy and intensity) was, however, slightly less than AI index (product of rainfall amount and intensity). K_r index is defined as the ratio of soil loss from microplots (in kg m^{-2}) to total energy (Joule m^{-2}) of artificial rainfall.

5. Nutrient Movement in Different Soils

Erosional losses of N, P, K, Ca and Mg are summarized in Table 30 for each soil. High losses of exchangeable Ca and Mg in sediment, runoff and percolation water reflected their initially high availability in the different soils. Ca and Mg losses averaged 14.5 and 2.9 g/m^2, respectively from the application of 52cm total precipitation. The losses are equivalent to 348 kg/ha Ca and 70 kg/ha Mg per year with an annual precipitation of about 120cm and comparable erosivity. On Egbeda soil, N, P, and K losses were 15.9, 0.15 and 3.8 g/m^2 which amount to 159, 1.5 and 38 kg/ha, respectively. These losses are serious based on results reported earlier in this study for field plots. Ngala, Funtua and Dangappe soils had greater losses than from Egbeda soil (Table 31). Most of the N lost by erosion was in eroded sediments. Higher K was lost in runoff than in sediment. Proportion of P in sediment was directly related to the pH of the soil which apparently increased P mobility. For example, the Ngala soil had the highest soil pH (7.3) and highest P loss in eroded sediment (0.63 g/m^2) of all the soils. The inherently low nutrient status in the soils

TABLE 30

TOTAL NUTRIENTS IN SEDIMENT AND RUNOFF
FROM LABORATORY MICROPLOTS
Each value is the total for all
treatment combinations.

Soil Type	Eroded Sediment					Runoff				
	Total N	Bray-1 P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	NO_3^--N	Available P	Available K	Available Ca	Available Mg
	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$	$g\ m^{-2}$
Ngala	19.17	0.63	4.88	45.2	6.63	1.02	0.17	4.86	6.03	2.02
Funtua	15.31	0.15	1.65	10.45	1.39	1.23	0.37	3.26	6.52	2.32
Dangappe	26.03	0.03	1.19	16.80	1.81	0.41	0.14	1.48	6.68	1.43
Apomu	10.72	0.10	0.38	6.39	0.48	1.54	0.02	1.05	6.22	1.93
Egbeda	14.48	0.07	0.85	10.50	1.02	1.40	0.08	2.92	6.20	3.30
Onne	4.14	0.18	0.14	1.59	0.13	0.26	0.05	0.98	1.61	0.66
Itagunmedi	0.33	0.01	0.02	0.21	0.02	0.23	0.01	0.64	2.15	0.41
Alagba	0	0	0	0	0	0	0	0	0	0
Ikom	0	0	0	0	0	0	0	0	0	0

TABLE 31

CONCENTRATIONS OF NUTRIENTS IN ERODED SEDIMENT, RUNOFF AND LEACHATE FROM LABORATORY MICROPLOTS

Soil Type	N			P			K		
	Eroded Sediment[a]	Runoff[b]	Leachate	Eroded Sediment	Runoff	Leachate	Eroded Sediment	Runoff	Leachate
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
Ngala	1130	2.89	0	41.91	0.45	0	312.8	13.41	0
Funtua	1060	4.09	0	11.29	1.32	0	140.8	10.75	0
Dangappe	310	1.39	6.14	12.17	0.58	0.47	31.28	8.39	46.0
Apomu	1310	5.44	6.29	12.17	0.10	0.18	46.92	4.49	59.2
Egbeda	2500	4.67	2.96	8.86	0.22	0.31	125.1	9.42	157.8
Onne	1250	2.45	5.65	53.81	0.61	0.30	43.01	8.21	24.0
Itagunmadi	2380	2.60	4.35	3.11	0.15	0.47	109.5	5.58	21.07
Alagba	0	0	2.18	0	0	0.22	0	0	24.70
Ikom	0	0	3.56	0	0	0.29	0	0	21.50

[a]Total-N.

[b]NO_3-N.

used in this study (see Table 5) is typical of most soils in the tropics and poses a major problem to agriculture.

Figure 39 shows the proportion of added nutrients lost by erosion on individual soils. The data indicate that P losses paralled the sediment losses on these soils. Highest P loss was 25% of added P. On the other hand, 30 to 70 percent of added N and 35 to 80 percent of added K were lost by erosion on the various soils. Lower lossed of P are attributable to their unavilability due to low pH and high Al contents of the soils. The high P loss on Onne soil could be due to the sandy texture of this soil which favors P mobility. In addition, this soil had high available P content initially (52.6 ppm).

Considerable losses by leachate were also observed on some of the soils that were coarse textured or that showed high infiltration rates, such as Apomu, Egbeda, Dangappe, Funtua and Onne. Leachate losses imply a depletion of nutrients from upper parts of the micro-plots. This would probably result in subsequent lower runoff concentrations of the nutrients. Results summarized in Figure 40 are indicative of the serious leaching losses on these soils. Nutrient concentrations of NO_3-N, available P and K in leachate water were similar to those from runoff. The serious leaching losses may be attributed to the low CEC and coarse texture of the soils.

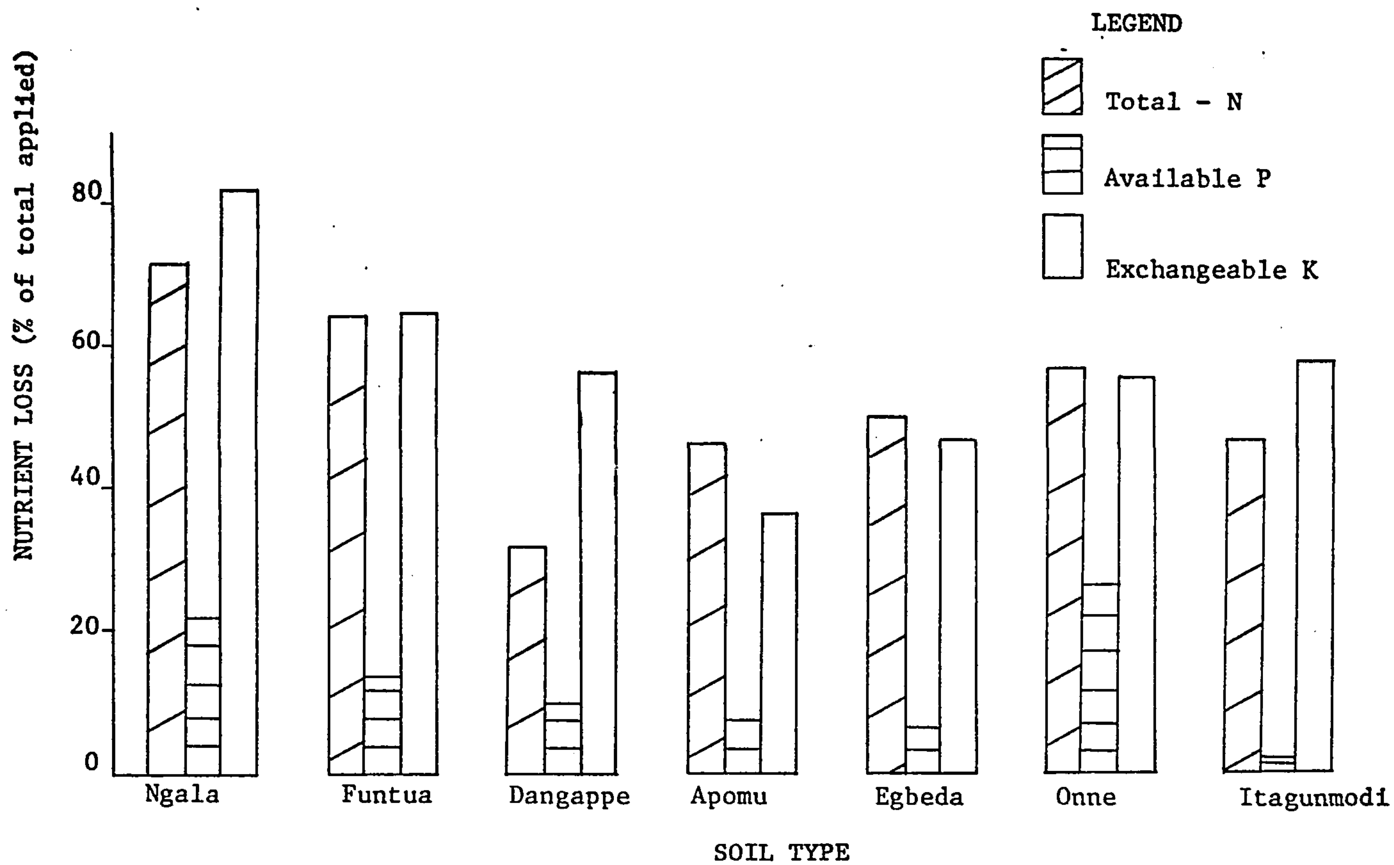


Figure 39. Proportion of added nutrients lost by sediment and runoff from different soils in laboratory microplots

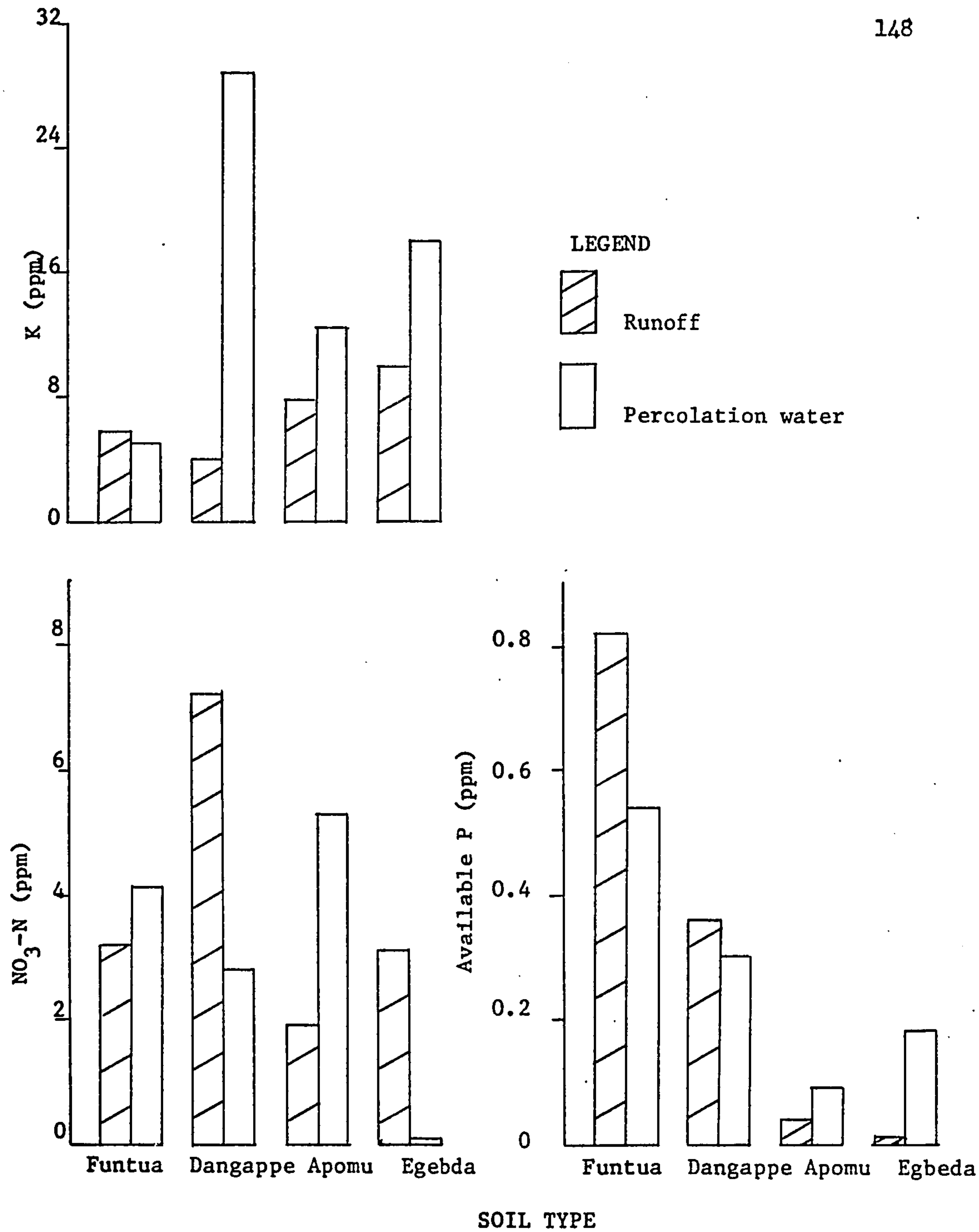


Figure 40. Relative concentrations of N, P, K in runoff and percolation water from laboratory microplots subjected to 12.5 cm/hr utensity rainfall on 5% slope.

6. Soil Erodibility Analysis

K_r index (defined on page 133) ranged from 0.06 to 0.43 for the dry run compared to a range from 0.16 to 0.77 for the wet run on 5 percent slope (Table 32). Indices were much higher for soils on 10 percent slope. There were also high correlation coefficients between K_r and soil organic matter (r = -0.79), infiltration rate (r = -0.87), exchangeable Na (r = 0.71) and exchangeable K (r = 0.67).

Egbeda soil was the reference soil with K_r of 0.346 on 10 percent slope. On field plots, this soil was considered erodible by Bruce-Okine and Lal, (1975). Soils on laboratory microplots having higher K_r values were therefore classified as moderately to highly erodible. Six of the nine soils used fell into this category (see Table 22). Vertisol was the most susceptible order and alfisols were generally more erodible than ultisols. The susceptibility of the soils to erosion was in the following order: Ngala (Vertisol) > Funtua (Alfisol) > Dangappe (Alfisol) > Apomu (Entisol) > Egbeda (Alfisol) > Onne (Ultisol) > Itagunmodi (Ultisol) > Ikom (Ultisol) = Alagba (Alfisol).

TABLE 32

ERODIBILITY INDICES, Kr FOR DIFFERENT SOILS ON LABORATORY MICROPLOTS

Soil Type	5% Slope		10% Slope
	Dry "Run"	Wet "Run"	(Wet Run)
Ngala	0.43	0.77	0.94
Funtua	0.09	0.57	0.66
Dangappe	0.07	0.37	0.80
Apomu	0.08	0.16	0.68
Egbeda	0.06	0.28	0.35
Onne	0.001	0.001	0.34
Itagunmidi	0.001	0.001	0.02
Alagba	0	0	0
Ikom	0	0	0

SUMMARY AND CONCLUSIONS

The present study was conducted at International Institute for Tropical Agriculture, Ibadan, Nigeria during 1975. It was designed to (1) investigate the effects of no-tillage versus conventional tillage and selected cropping systems on erosion losses from field plots of 4 different slopes, (2) characterize the climate with respect to erosivity parameters, and (3) determine the relative susceptibilities of some tropical soils in relation to soil and rainfall factors under laboratory conditions. The adaptability of the universal soil loss equation was also considered.

Results of the field plot and rainfall characteristics studies indicated that the tropical climate was very erosive. The high erosivity was due to (1) a high proportion of large raindrops (> 2.5mm), (2) high rainfall intensities and (3) greater proportion of rainstorms occurring before vegetation cover is established. Soil loss was an exponential function of slope (exponent was 1.33 for bare plot). The erodibility factor K of the universal soil loss equation was considerally underestimated on 10 and 15 percent slopes (K = 0.10) than on gentle slopes (K = 0.18 for 5% slope) because of the past erosion history of these plots. Erosion losses per unit area were slightly higher on the shorter plots than on the longer plots due to the concave curvature of the latter.

The following erosivity indices were computed from the rainfall data and related to erosion from field bare fallow plots: EI_{30}, the product of energy and maximum 30-minute intensity of rainfalls; $KE > 1$, kinetic energy of rainfall with intensities greater than 1 in/hr; AI, the product of amount and intensity of rainfall; and AIV, the product of rainfall amount, intensity and wind velocity. These indices were equally good predictors of erosion on field plots with correlcation coefficients of 0.71, 0.80, 0.82 and 0.83 for EI_{30}, $KE > 1$, AI and AIV, respectively.

The effects of no-tillage and conventional tillage practices on erosion with soybeans were compared for 1, 5, 10 and 15 percent slopes. Soil erosion was completely eliminated on all slopes under no-tillage while conventional tillage gave an average soil loss of 40 metric tons/ha during the rotation period. Crop yields increased up to 35% under no-tillage and were apparently associated with greater availability of nutrients, greater water storage and better germination under the no-tillage system.

Soil loss under monoculture cassava was 43 percent higher than under mixed cropping of corn and cassava but was not significantly different under pigeon peas rotation. Soil loss under soybeans was the lowest (40 tons/ha/year) and was about one-half of that from mixed cropping of corn and cassava. Runoff and nutrient losses paralleled the soil losses under the different cropping systems. Differences in erosional losses were related to the differential rates of canopy cover provided by the cropping systems. These differences were reflected in the crop management factor, C of the universal soil loss equation which was 0.72, 0.43, 0.19 and 0.004, respectively, for monoculture cassava, mixed cropping of corn and cassava, conventional tillage soybeans and no-tillage soybeans.

In a laboratory study, nine soils in boxes were subjected to treatments involving combinations of slope (5 and 10%), rainfall intensity (12.5 and 17.5 cm/hr) and durations (7, 10, 20 and 30 minutes) at air-dry and field capacity moisture regimes of the soils. The soils showed a wide range of susceptibilities to erosion. Six of the soils were considered moderately to highly erodible, with susceptibilities to erosion in the following order: Ngala (Vertisol) > Funtua (Haplustalf) > Dangappe (Paleustalf) > Apomu (Ustorthent) > Egbeda (Paleustalf) > Onne (Paleudult) > Itagunmodi (Paleustalf) > Alagba (Paleustalf) > Ikom (Tropohumult). Nutrient losses of N, P, K, Ca and Mg in these soils were related to their relative erodibilities and soil mineralogy.

The high susceptibility of the soils to water erosion is due to high climatic erosivity and low resistance of the soils to dispersion. Erosion can be considerably reduced by adequate and timely protection of the ground surface. Practices that raise the organic matter and fertility status of the soils would increase vegetative cover and reduce erosion. Such practices as the no-tillage and mixed cropping seem to be suitable conservation practices under tropical conditions. The applicability of the universal soil loss equation requires some modifications in the erosivity, erodibility and slope factors. The erodibility and the erosion-slope relationship as evaluated in that equation should reflect the erosion history of these soils.

APPENDIX

TABLE 1

CALIBRATION OF NOZZLES ACCORDING TO DROP VELOCITY

Nozzle Type	Water Pressure lb in^{-2}	Average Height of Projection, h cm	Velocity* $v_0^2 = 2gh$ m^2/sec^2	Terminal Velocity** $v_t = [v_0^2 + 2gs]^{1/2}$ m/sec
	3	22	4.31	7.62
	5	52	10.19	7.99
7LA	6	57	11.17	8.05
	8	72	14.11	8.23
	10	97	19.01	8.53
	3	20	3.92	7.59
5B	5	45	8.82	7.91
	6	55	10.78	8.03
	7.5	70	13.72	8.21

*$g \simeq 9.8$ m/sec^2.

**s = height of nozzle above microplot = 2.73 m.

Kinetic energy ($Joule/m^2cm$) was 314.65 at 12.5 cm/hr and 354.53 at 17.5 cm/hr intensities using nozzle 7LA.

TABLE 2

AN ILLUSTRATIVE COMPUTATION OF SOME RAINFALL CHARACTERISTICS
(Rainfall of 10/10/75)

1	2	3	4	5	6	7	8	9	10	11
Time of Day	Time Interval (min)	Rainfall inch	Amount (a) cm	Rainfall Intensity (I) cm/hr	aI (4×5) cm/hr	$\log_{10} I$ cm/hr	E $210 + 89 \log_{10} I$ ton-meter/ha cm	Total E (8 × 4) metric ton-meter/ha	KE > 1 metric ton-meter/ha	Wind Velocity km/hr
1753										35.4
1758	5	0.25	0.64	7.68	4.92	0.885	288.77	184.8	184.8	32.2
1800	2	0.05	0.13	3.90	0.51	0.591	262.60	34.1	34.1	19.3
1803	3	0.20	0.51	10.20	5.20	1.009	299.80	152.9	152.9	21.7
1807	4	0.15	0.38	5.70	2.17	0.756	277.28	105.4	105.4	14.5
1814	7	0.18	0.46	3.94	1.81	0.595	262.96	121.0	121.0	16.1
1823	9	0.04	0.10	0.67	0.07	-0.174	194.51	19.5	--	12.9
1930	7	0.03	0.08	0.69	0.06	-0.161	195.67	15.7	--	16.1
2055	25	0.00	0.00	0.00	0.00	--	--	0.0	--	8.1
2057	2	0.05	0.13	3.90	0.51	0.591	262.60	34.1	34.1	13.7
2105	8	0.11	0.28	2.10	0.59	0.322	238.66	66.8	--	8.1
2117	12	0.03	0.08	0.40	0.03	-0.398	174.58	14.0	--	8.1
Total		1.09	2.79		15.87			748.3	632.3	

Maximum 30-minute intensity = 4.42 cm/hr.

$EI_{30} \times 10^{-2} = 748.3 \times 4.42 \times 10^{-2} = 33.07.$

$A = 2.79$ cm; $I_p = 10.20$ cm/hr (peak intensity); V_p (wind velocity at peak intensity) = 25 km/hr.

$AIV = 2.74 \times 10.20 \times 21.7 = 617.5.$

$AI_m = \Sigma aI = 15.87.$

TABLE 3

AN ILLUSTRATIVE COMPUTATION OF DROP SIZES FOR A SINGLE RAIN-SAMPLE OF 10/10/75

Sieves size	Mass of all pellets M	Number of pellets n	Mass of avg pellet $m=(M/n)$	Mass ratio R	Mass of all drops $M_d=RM$	Mass of avg drop $m_d=Rm$	Mass of avg drop $d=[(6/\pi)m_d]^{1/3}$	Percent of total mass $100M_d/\Sigma M_d$	Cumulative volume
mm	mg		mg		mg	mg	mm	%	%
>4.00	0	0	0	0	0	0	0	0	100
2.36-4.00	0	0	0	0	0	0	0	0	100
2.00-2.36	35.01	3	11.67	1.10	38.50	12.84	2.90	12.29	93.97
1.68-2.00	86.06	13	6.62	1.08	92.88	7.15	2.39	29.65	72.90
1.40-1.68	68.00	16	4.25	1.06	72.08	4.51	2.05	23.01	46.57
1.19-1.40	52.18	24	2.17	1.04	53.82	2.25	1.62	17.18	26.47
0.85-1.19	14.95	13	1.15	1.01	15.15	1.16	1.31	4.84	15.40
0.71-0.85	31.20	60	0.52	0.98	30.38	0.51	0.99	9.70	8.19
0.60-0.71	11.04	46	0.24	0.95	10.45	0.23	0.76	3.34	1.67
ΣM_d					313.26				

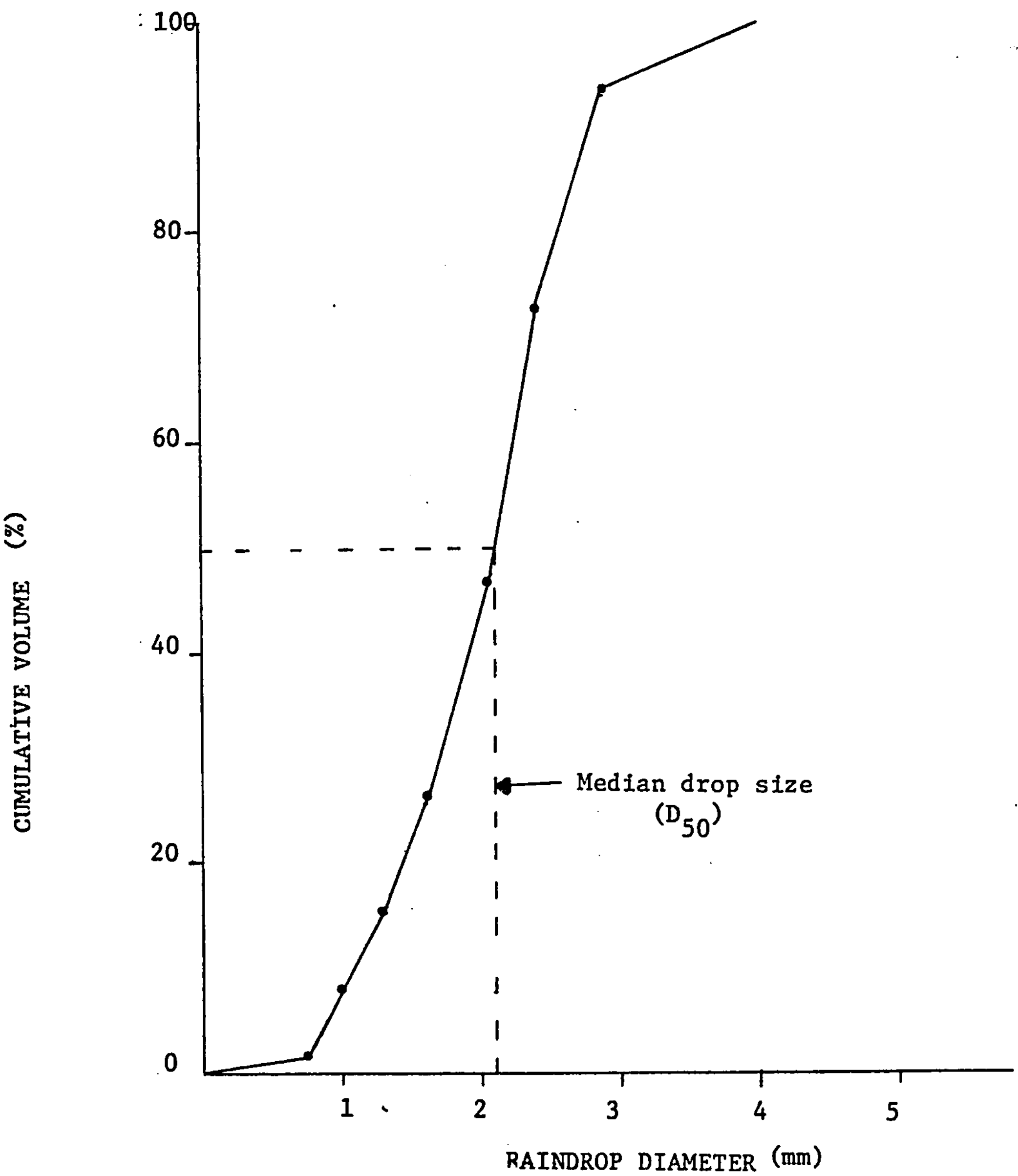


Figure 1. Cumulative frequency curve for determining median drop size.

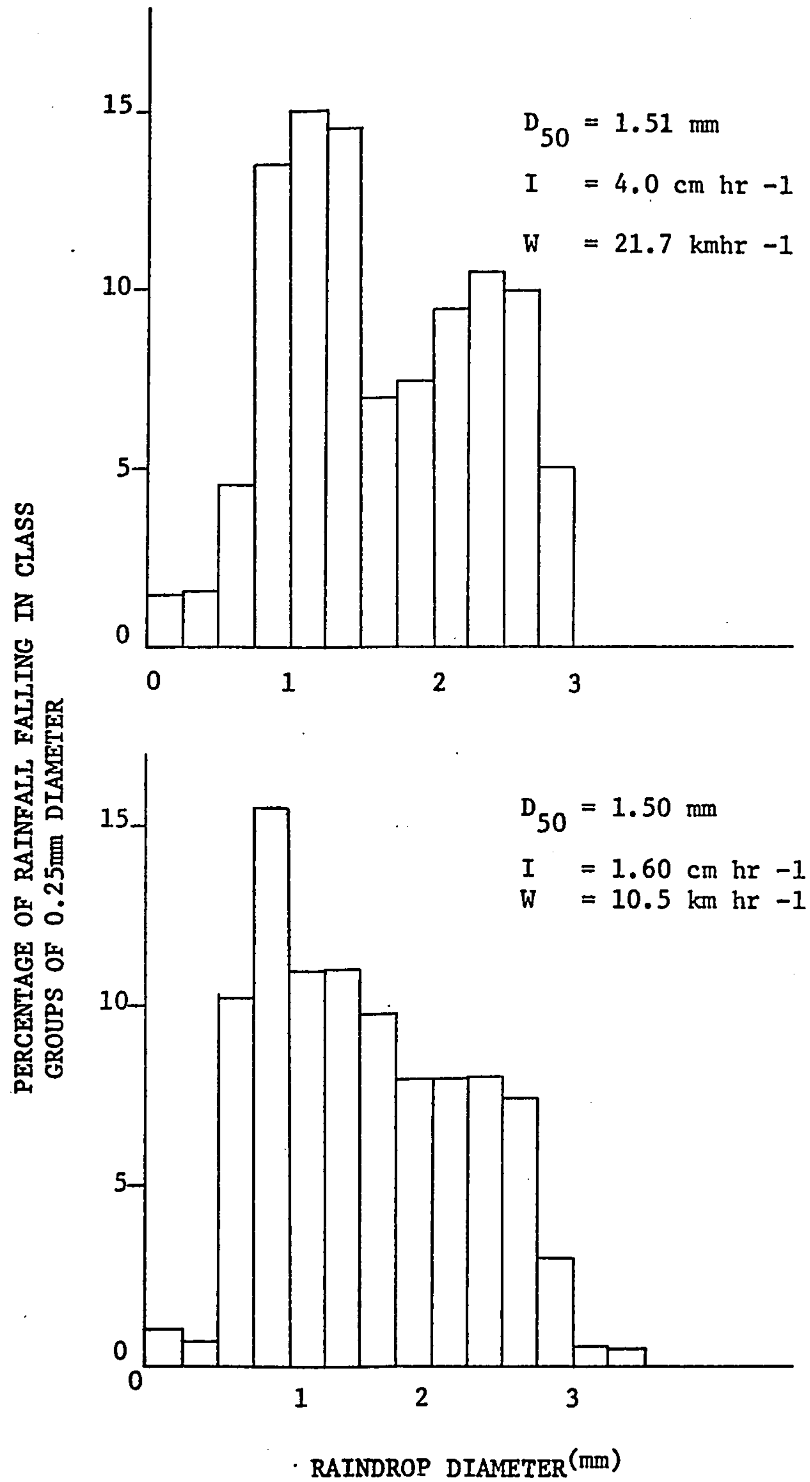


Figure 2. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W

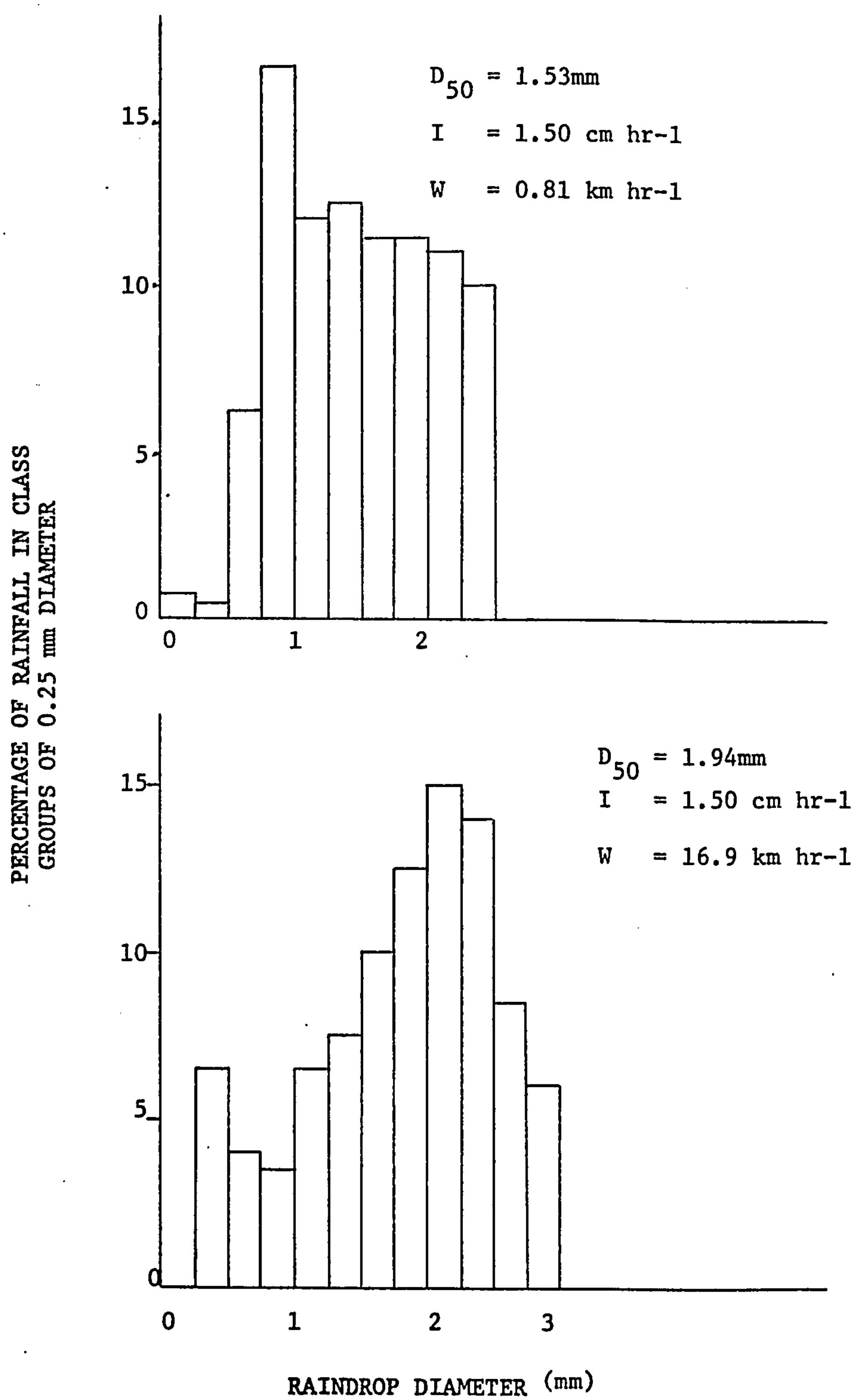


Figure 3. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

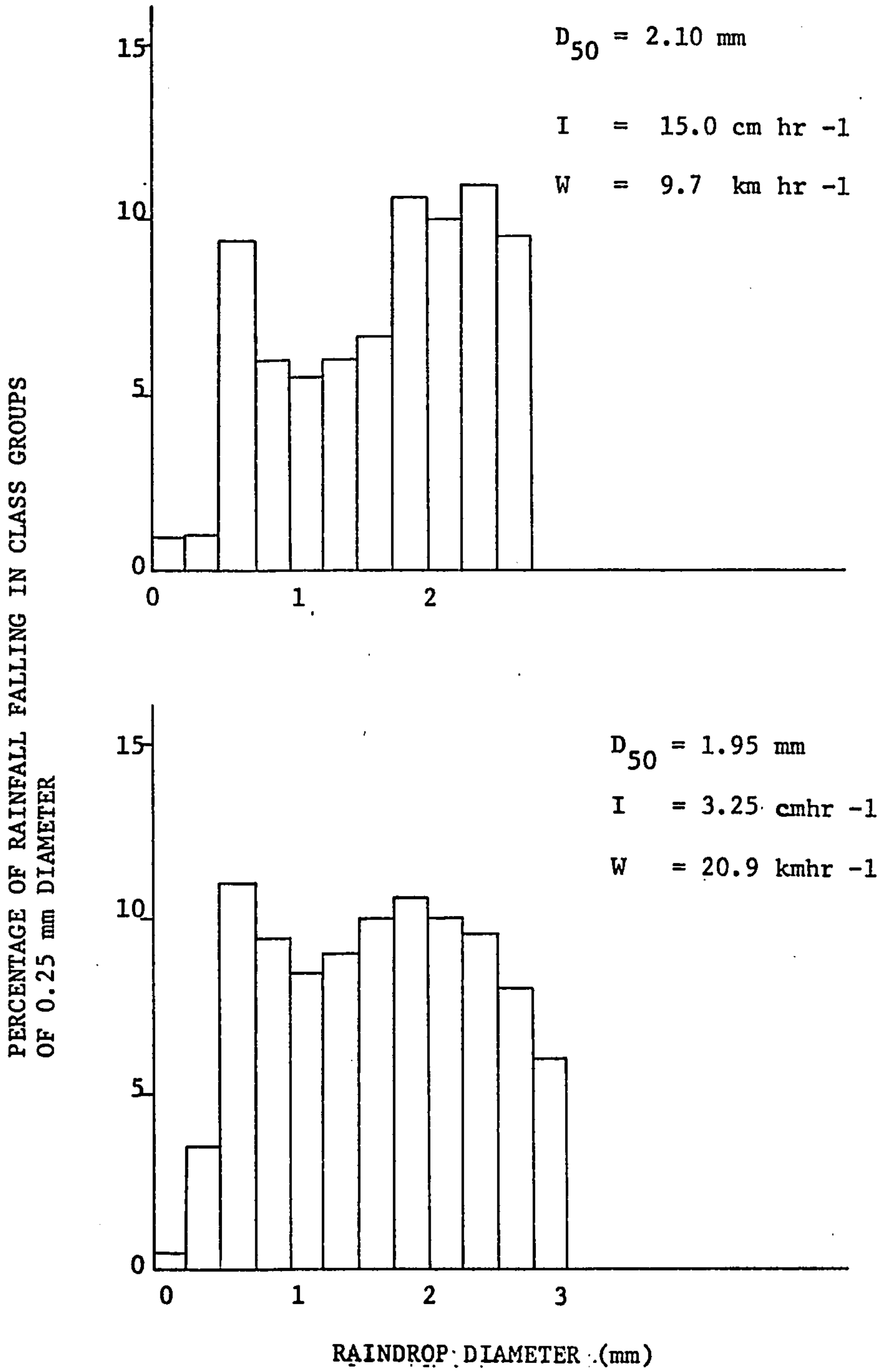


Figure 4. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W

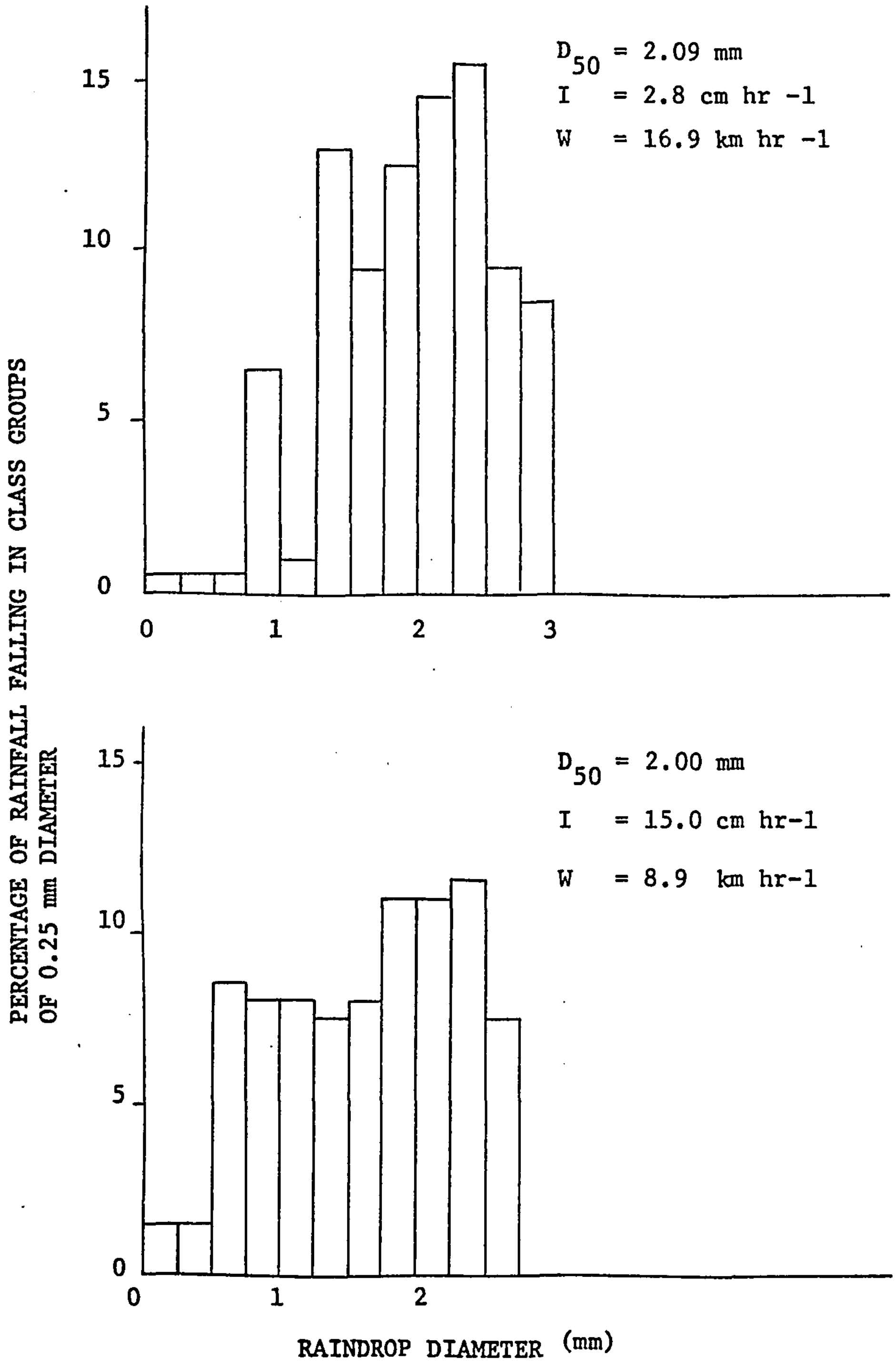


Figure 5. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W

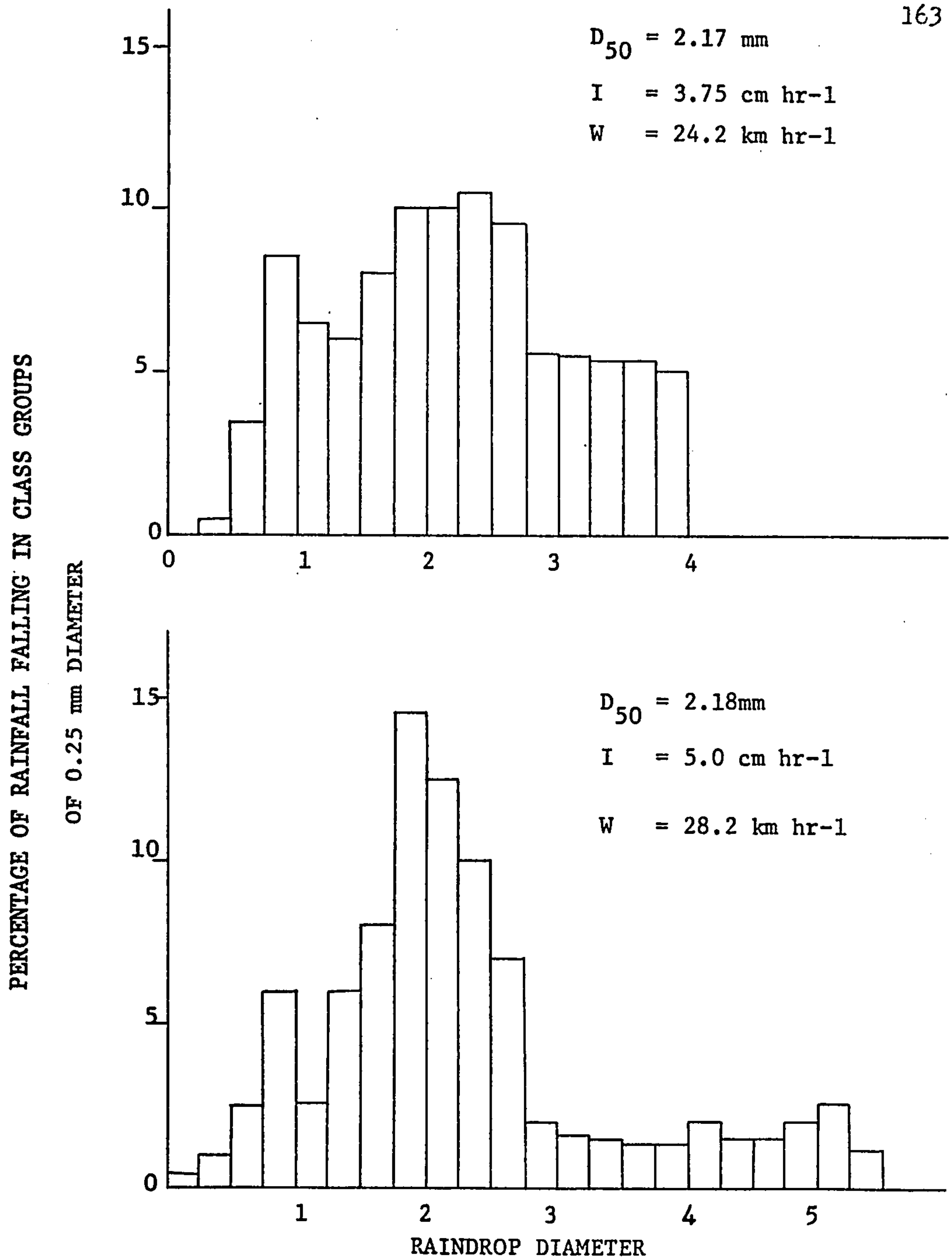


Figure 6. Raindrop size distibution at indicated rainfall intensities, I and wind velocities, W.

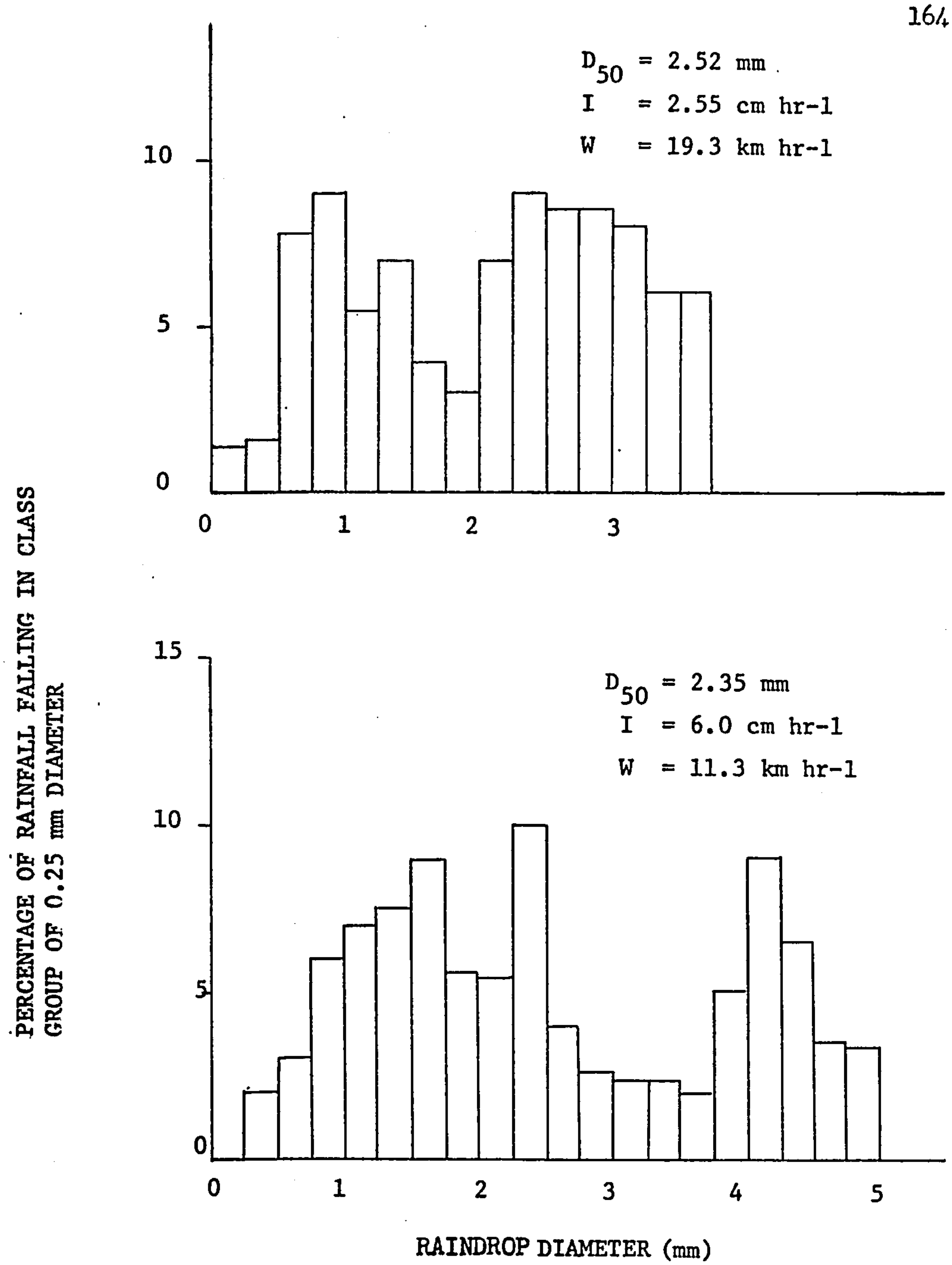


Figure 7. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

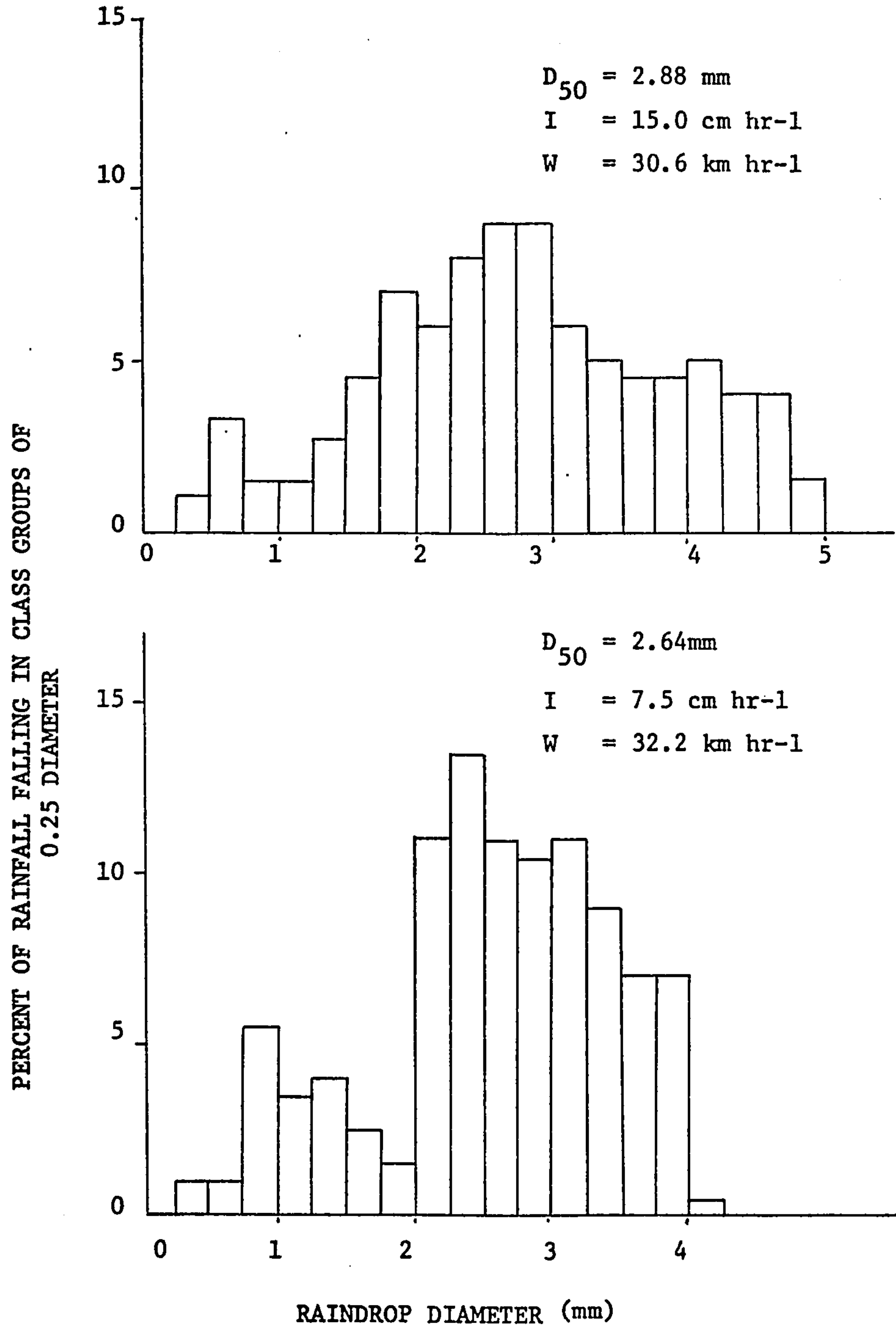


Figure 8. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

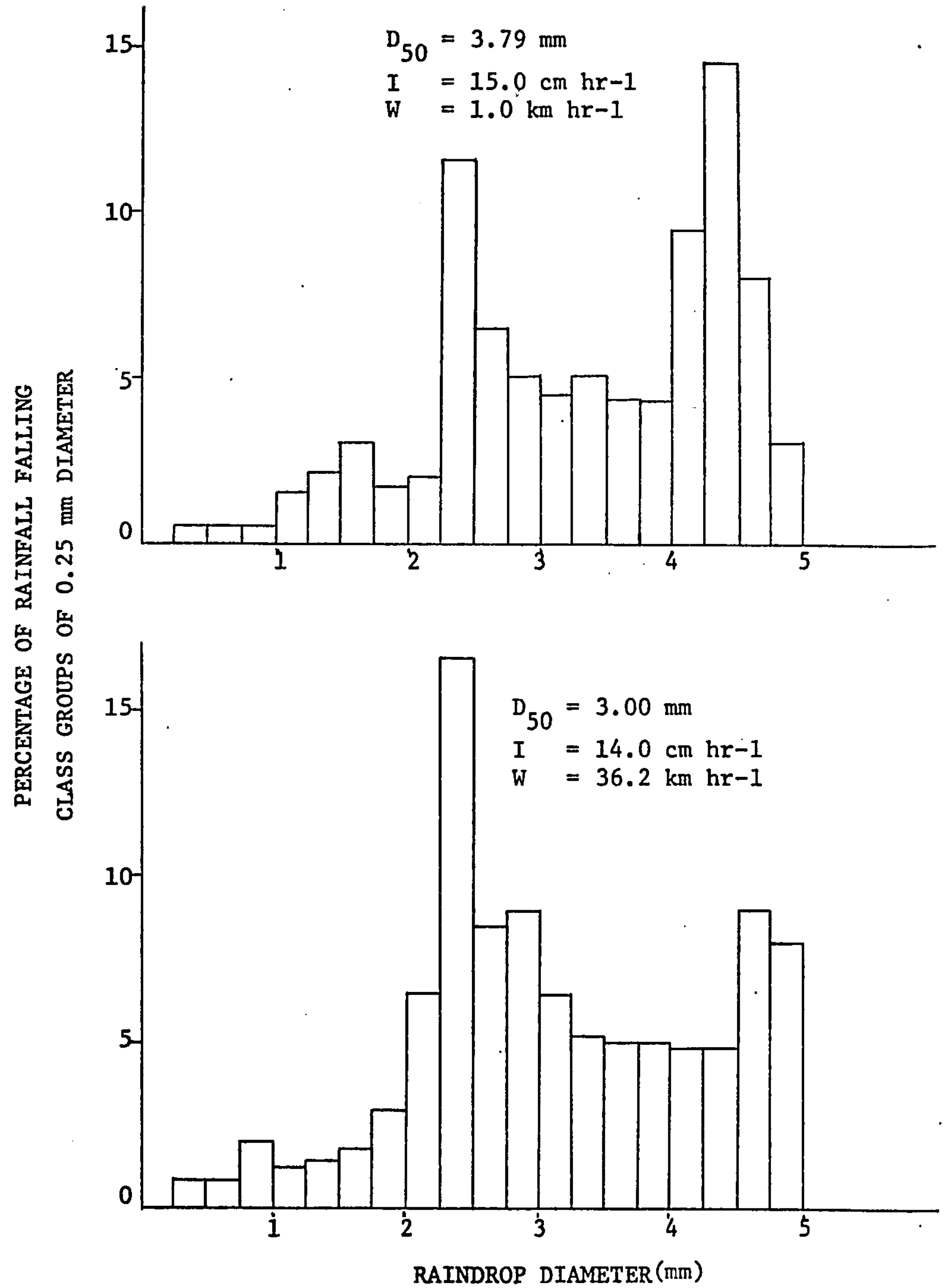


Figure 9. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

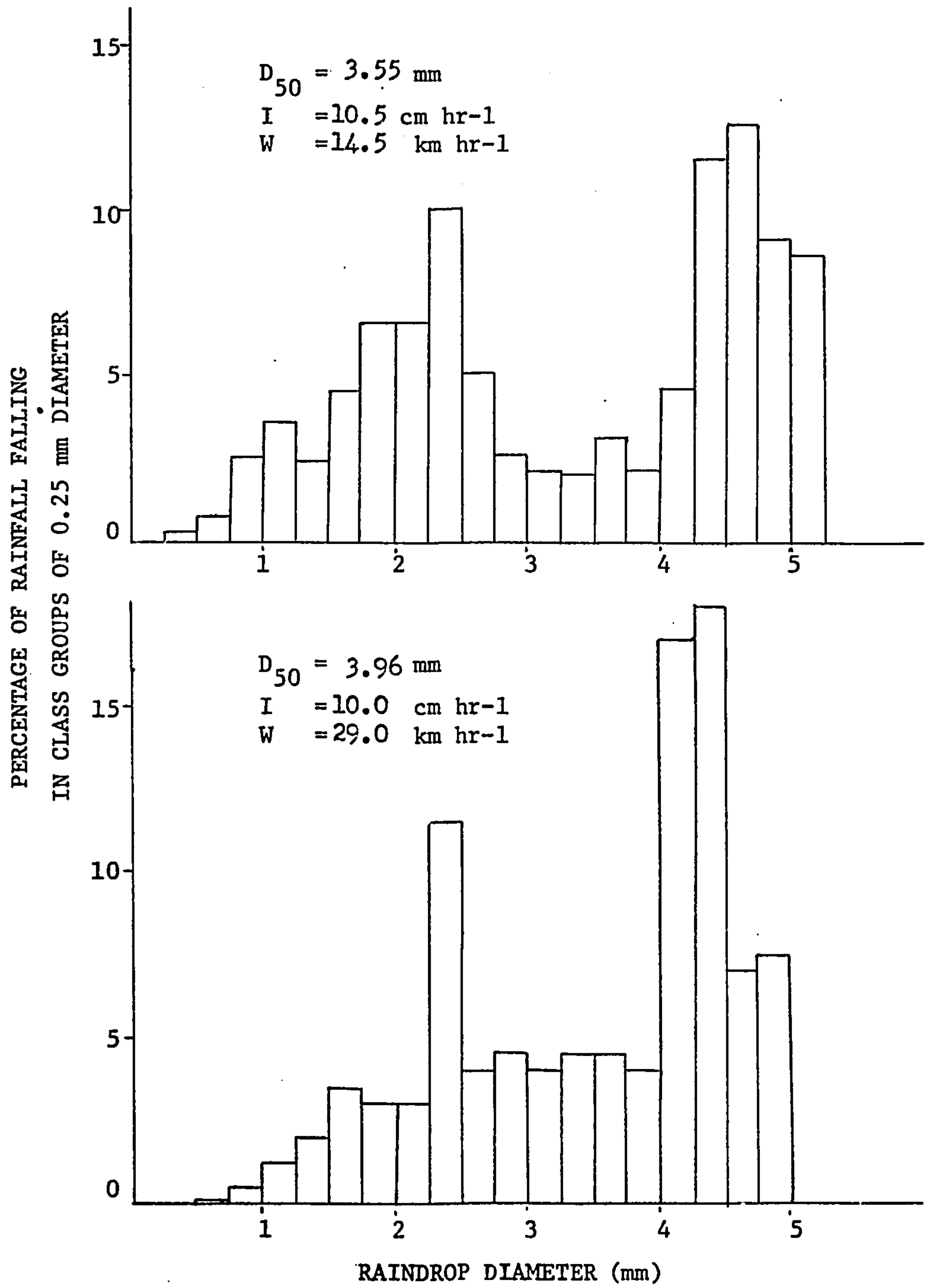


Figure 10. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

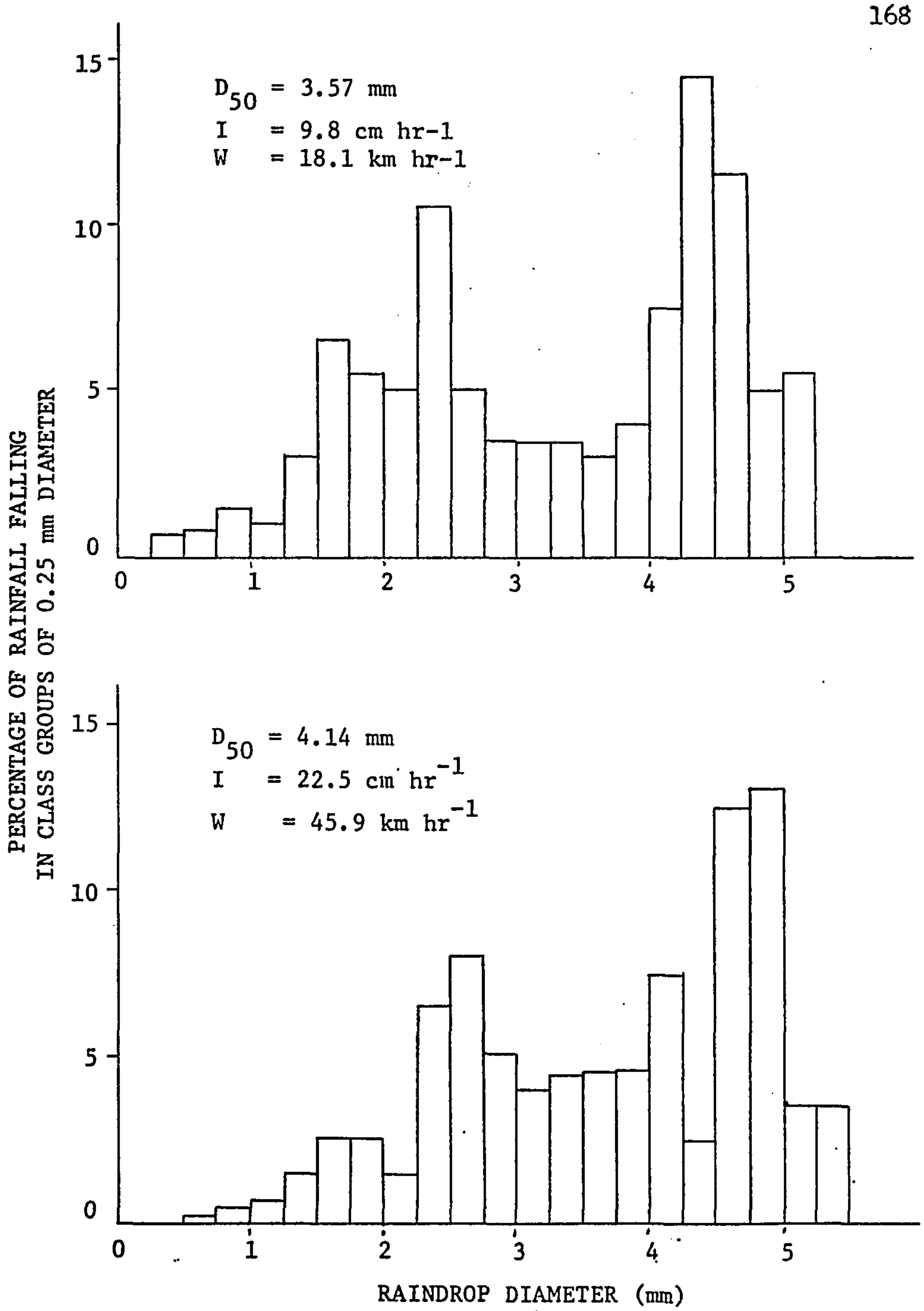


Figure 11. Raindrop size distribution at indicated rainfall intensities, I and wind velocities, W.

TABLE 4

EFFECT OF EROSION ON TEXTURE OF SOIL UNDER NO-TILLAGE AND CONVENTIONAL TILLAGE SOYBEANS

Soil Seperate	Time[1] in Rotation	No-Tillage [Slope (%)]				Conventional Tillage [Slope (%)]			
		1	5	10	15	1	5	10	15
Sand	B	66.2	62.4	68.5	65.2	65.5	61.8	65.3	65.3
	F	65.9	63.1	67.9	65.3	66.4	63.1	64.9	65.3
Silt	B	18.4	20.0	14.1	17.4	20.1	20.8	18.3	17.3
	F	17.1	16.9	14.9	17.5	15.6	16.9	15.1	16.5
Clay	B	15.4	17.6	17.4	17.4	14.4	17.4	16.4	17.4
	F	17.0	20.0	17.2	17.2	18.0	20.0	20.0	18.2

[1]B = Beginning of rotation.
F = End of rotation.

TABLE 5

EFFECT OF EROSION ON TEXTURE OF SOIL UNDER VARIOUS CROPPING SYSTEMS

Soil Seperate	Time[1] in Rotation	Monoculture Cassava [Slope (%)]				Mixed Cropping of Corn + Cassava [Slope (%)			
		1	5	10	15	1	5	10	15
Sand	B	67.5	60.8	57.2	61.8	62.4	64.5	67.4	62.2
	F	59.8	61.0	62.3	61.4	62.2	63.8	67.4	59.1
Silt	B	18.1	18.2	18.4	15.8	20.2	20.1	16.2	17.4
	F	21.2	18.0	15.5	15.4	16.8	17.2	14.4	16.7
Clay	B	14.4	21.0	24.4	22.4	17.4	15.4	16.4	20.4
	F	19.2	21.0	22.2	23.2	21.0	19.0	18.2	24.2

[1]B = Beginning of rotation.
F = End of rotation.

TABLE 6

SOIL LOSS AND RUNOFF FROM BARE PLOTS ON DIFFERENT SLOPES

	Soil Loss (ton/ha)				Runoff (mm)			
Date	1%	5%	10%	15%	1%	5%	10%	15%
4/19/75	0.52	4.89	2.28	4.29	13.60		7.75	9.64
4/21	0.04	0.87	0.38	0.77	0.54	0.48	1.15	0.42
4/24	0.36	8.31	4.93	5.46	22.52	16.91	8.98	18.23
4/26	0.24	8.61	4.45	13.46	22.19		9.58	23.18
4/29	0.18	6.27	4.54	4.22	17.94	26.91	7.63	17.20
4/30	0.10	2.18	1.76	1.23	5.72	7.22	3.69	3.27
5/3	0.17	5.16	2.39	2.30	10.67	16.99	5.72	12.28
5/8	0.03	1.38	0.24	0.00	2.72	3.14	1.11	0.28
5/9	0.12	3.72	1.94	1.55	7.17	7.28	3.69	7.19
5/17	0.13	4.57	2.74	3.30	21.53	27.48	6.99	19.55
5/20	0.08	1.31	0.95	0.52	5.01	5.01	3.23	2.77
5/21	0.06	3.16	1.24	0.29	6.33	6.33	3.69	2.21
5/24	0.10	3.27	1.39	0.40	10.30	11.62	3.69	6.33
5/27	0.23	3.46	4.96	4.38	20.87	27.48	12.94	24.17
5/29	0.21	5.78	3.17	3.32	13.60	13.60	5.67	10.30
6/6	0.01	0.64	0.00	0.00	0.18	0.46	0.00	0.00
6/8	0.10	4.34	1.04	0.47	7.65	7.65	3.69	3.32
6/9	0.03	0.93	0.01	0.04	3.60	3.41	0.46	1.11
6/10	0.08	2.68	0.45	0.08	5.01	11.62	3.69	1.57
6/13	5.41	6.39	4.94	6.90	41.35	54.57	19.55	53.25
6/19	0.09	7.38	6.21	5.78	18.89	28.14	8.32	19.55
6/26	0.03	1.62	0.46	0.43	2.49	2.49	1.11	0.37
6/27	0.15	11.65	3.72	2.79	19.55	24.17	3.69	14.26

TABLE 6 --Continued

	Soil Loss (ton/ha)				Runoff (mm)			
Date	1%	5%	10%	15%	1%	5%	10%	15%
7/4-5	0.01	6.40	2.22	1.25	18.23	27.48	3.69	14.92
7/11-12	0.01	1.74	0.64	0.08	2.58	5.01	3.69	1.85
7/17	0.01	6.80	0.83	0.04	22.19	26.83	6.33	2.30
7/20-21	0.01	6.02	1.11	0.53	3.69	19.55	9.64	5.67
7/21	0.01	0.03	0.03	0.00	2.80	3.23	2.80	0.46
10/1	0.00	1.48	3.36	3.47	3.69	16.90	16.90	20.87
10/6-7	0.28	7.09	1.74	3.40	10.30	16.91	30.12	19.55
10/9	0.00	0.01	0.01	0.02	0.46	0.55	0.65	0.37
10/10-12	0.41	6.03	2.38	3.26	3.69	27.48	5.67	5.67
10/14	0.13	1.79	0.38	0.26	1.66	3.41	3.41	1.29
10/17-18	0.33	3.98	4.74	1.73	18.23	24.84	10.30	10.30
10/22	0.36	2.47	1.91	1.56	2.50	7.65	6.99	3.23
10/23	0.04	0.02	0.01	0.02	1.75	2.95	2.12	1.66
10/25-26	0.27	5.72	2.51	4.11	3.69	22.85	20.21	12.28

TABLE 7

SOIL LOSS (TONS/HA) UNDER CASSAVA (MC) AND MIXED CROPPING OF CORN AND CASSAVA

	1%		5%		10%		15%	
Date	mc	cc	mc	cc	mc	cc	mc	cc
4/19/75	0.13	0.12	1.04	0.81	1.89	1.82	4.64	5.65
4/21	0.01	0.01	0.15	0.06	0.39	0.25	0.66	0.76
4/24	0.14	0.07	2.03	2.89	11.30	3.73	15.67	16.98
4/26	1.02	0.25	2.34	3.30	10.07	9.48	19.63	9.32
4/29	0.11	0.15	3.38	4.85	8.97	17.36	18.46	14.97
4/30	0.06	0.17	3.43	1.71	4.92	5.33	8.59	8.02
5/3	0.11	0.12	6.71	4.38	8.19	5.86	10.66	10.72
5/8	0.00	0.01	1.07	0.63	0.92	0.60	1.50	1.02
5/9	0.04	0.12	1.85	1.44	4.02	2.48	5.86	4.17
5/17	0.10	0.18	3.21	2.32	10.47	5.58	16.91	13.21
5/20	0.01	0.03	2.18	1.30	4.08	2.83	3.76	3.18
5/21	0.02	0.04	3.25	1.55	3.74	3.10	1.64	2.76
5/24	0.10	0.10	4.49	2.63	3.05	1.63	7.19	3.06
5/27	0.06	0.25	3.44	1.70	6.81	5.61	25.78	13.47
5/29	0.08	0.21	6.07	4.46	6.81	5.98	10.94	7.35
6/6	0.00	0.00	0.17	0.20	0.00	0.00	0.00	0.00
6/8	0.04	0.05	2.97	1.98	2.26	0.67	4.52	1.65
6/9	0.00	0.01	2.92	0.71	0.21	0.01	0.29	0.07
6/10	0.00	0.03	2.39	0.79	0.73	0.24	1.79	0.37
6/13	0.46	0.23	2.98	1.31	13.04	6.00	35.29	6.23
6/19	0.04	0.05	4.73	1.57	9.34	4.37	10.82	6.67
6/26	0.00	0.00	0.74	0.50	0.01	0.00	0.00	0.00
6/27	0.02	0.13	4.25	1.63	2.24	1.21	6.40	3.80

TABLE 7 --Continued

Date	1%		5%		10%		15%	
	mc	cc	mc	cc	mc	cc	mc	cc
7/4-5	0.01	0.06	3.68	2.61	2.55	0.51	3.12	1.52
7/11-12	0.00	0.04	1.19	0.30	0.14	0.02	0.34	0.42
7/17	0.04	0.01	5.99	1.47	1.16	0.28	2.11	0.48
7/20-21	0.01	0.02	4.07	1.25	0.55	0.06	1.58	0.66
7/21	0.00	0.00	0.02	0.00	0.00	0.02	0.02	0.01
10/1	0.02	0.00	0.46	0.40	1.96	0.02	0.02	0.01
10/6-7	0.03	0.00	4.28	0.57	2.46	0.30	1.03	0.15
10/9	0.00	0.00	0.23	0.01	0.29	0.00	0.37	0.01
10/10-12	0.01	0.00	0.30	0.36	0.93	0.01	0.51	0.01
10/14	0.00	0.00	0.01	0.00	0.10	0.00	0.00	0.00
10/17-18	0.01	0.01	0.62	0.13	0.22	0.12	0.64	0.03
10/22	0.00	0.00	0.21	0.02	0.07	0.01	0.06	0.01
10/23	0.00	0.01	0.11	0.00	0.01	0.00	0.01	0.00
10/25-26	0.02	0.00	0.55	0.02	1.04	0.06	0.28	0.16

TABLE 8

RUNOFF (mm) UNDER MONOCULTURE CASSAVA (mc) AND MIXED CROPPING OF CORN AND CASSAVA

	1%		5%		10%		15%	
Date	mc	cc	mc	cc	mc	cc	mc	cc
4/19/75	6.38	7.42	11.05	10.39	5.43	8.74	8.36	8.03
4/21	0.09	0.09	0.46	0.47	0.46	0.32	0137	0.42
4/24	11.95	6.33	26.16	9.64	5.01	6.99	12.94	10.30
4/26	17.00	8.41	4.40	22.24	4.77	11.05	11.71	11.29
4/29	12.37	6.71	18.98	18.98	5.06	10.74	7.40	7.30
4/30	2.80	4.40	5.76	4.40	5.10	4.44	3.69	3.69
5/3	7.75	7.37	15.68	12.37	5.72	7.04	9.07	7.65
5/8	0.09	0.09	2.31	3.04	1.20	0.88	1.01	1.01
5/9	3.27	4.40	7.22	7.15	5.72	5.06	5.10	5.10
5/17	14.92	10.30	28.85	23.61	5.76	10.39	10.39	10.30
5/20	1.89	2.31	5.01	4.35	3.23	2.31	2.81	3.23
5/21	3.69	3.69	6.99	4.35	3.69	3.69	3.69	5.01
5/24	6.33	3.69	12.94	9.64	5.67	5.67	12.28	6.33
5/27	5.67	12.94	24.83	25.50	5.67	13.60	55.89	12.94
5/29	8.98	7.65	16.91	13.60	5.67	6.99	6.99	8.98
6/6	0.00	0.00	0.18	0.28	0.00	0.00	0.00	0.00
6/8	3.60	2.95	8.98	6.33	3.14	2.12	2.31	3.69
6/9	0.09	0.55	6.99	8.98	1.57	1.10	2.03	2.03
6/10	0.09	3.14	8.98	5.67	3.69	2.77	8.98	3.69
6/13	40.69	35.41	50.61	53.25	16.91	36.07	44.66	28.80
6/19	7.65	8.98	23.51	20.21	5.01	13.60	16.91	15.58
6/26	0.00	0.18	1.48	0.55	0.28	0.00	0.00	0.37
6/27	3.69	11.62	22.85	18.89	5.01	8.98	16.25	12.94

TABLE 8 --Continued

	1%		5%		10%		15%	
Date	mc	cc	mc	cc	mc	cc	mc	cc
7/4-5	3.69	3.69	21.53	14.92	5.67	4.35	2.19	9.64
7/11-12	0.18	0.74	5.67	3.50	3.69	0.74	2.95	3.23
7/17	15.58	0.92	24.84	14.92	14.26	3.50	8.98	11.62
7/20-21	1.38	2.03	19.55	12.94	7.65	1.85	8.32	6.33
7/21	0.00	0.00	1.38	2.31	1.38	0.46	0.92	1.38
10/1	5.67	0.65	20.20	8.98	20.90	2.30	10.30	3.23
10/6-7	9.63	1.01	23.51	10.96	28.80	7.65	23.51	6.33
10/9	0.28	0.00	6.33	1.10	5.01	0.37	2.68	0.46
10/10-12	3.69	1.20	14.26	5.67	20.21	3.23	21.53	3.23
10/14	0.00	0.00	1.75	0.64	2.21	0.37	1.20	0.46
10/17-18	1.48	1.01	18.23	6.98	5.67	2.58	3.68	2.68
10/22	0.00	5.67	5.67	1.57	5.67	0.65	2.86	1.11
10/23	0.28	0.28	2.49	0.74	1.47	0.28	0.74	0.28
10/25-26	5.01	0.28	21.53	7.65	3.69	13.60	14.26	2.21

TABLE 9

SOIL LOSS (TONS/HA) UNDER ROTATIONS OF NO-TILL SOYBEANS (NT) AND CONVENTIONAL TILLAGE SOYBEANS (CT)

	1%		5%		10%		15%	
Date	NT	CT	NT	CT	NT	CT	NT	CT
4/9/75	0.00	0.06	0.00	0.53	0.00	2.08	0.00	7.26
4/21	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.02
4/24	0.00	0.04	0.01	0.62	0.00	7.62	0.00	6.91
4/26	0.00	0.06	0.00	1.90	0.00	10.23	0.03	7.06
4/29	0.00	0.05	0.00	1.94	0.00	6.90	0.01	8.57
4/30	0.00	0.07	0.00	1.14	0.00	1.72	0.00	4.60
5/3	0.00	0.02	0.00	2.36	0.00	4.93	0.00	4.80
5/8	0.00	0.00	0.01	0.43	0.00	0.11	0.00	0.12
5/9	0.00	0.01	0.02	1.71	0.00	2.40	0.02	3.57
5/17	0.00	0.03	0.00	1.93	0.00	7.42	0.00	7.75
5/20	0.00	0.00	0.00	0.70	0.00	1.50	0.00	2.28
5/21	0.00	0.00	0.00	0.83	0.00	1.94	0.00	1.24
5/24	0.00	0.02	0.00	0.68	0.03	1.05	0.00	1.54
5/27	0.00	0.02	0.00	1.12	0.00	12.96	0.00	4.62
5/29	0.00	0.01	0.00	1.49	0.00	2.82	0.01	4.19
6/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/8	0.00	0.00	0.00	0.38	0.00	0.09	0.00	0.07
6/9	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01
6/10	0.00	0.00	0.00	0.17	0.01	0.01	0.00	0.01
6/13	0.00	0.01	0.00	1.55	0.00	2.24	0.00	2.77
6/19	0.00	0.00	0.00	1.03	0.00	0.36	0.00	0.25
6/26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/27	0.00	0.00	0.00	0.59	0.00	0.16	0.00	0.00

TABLE 9 --Continued

	1%		5%		10%		15%	
Date	NT	CT	NT	CT	NT	CT	NT	CT
7/4-5/75	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00
7/11-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7/17	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
7/20-21	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
7/21	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
10/1	0.00	0.00	0.00	0.02	0.00	0.12	0.00	0.02
10/6-7	0.00	0.01	0.00	0.34	0.00	0.61	0.00	0.10
10/9	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
10/10-12	0.00	0.00	0.00	0.08	0.00	0.08	0.00	0.02
10/14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/17-18	0.00	0.00	0.00	0.04	0.00	0.09	0.00	0.20
10/22	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.01
10/23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/25-26	0.00	0.00	0.00	0.01	0.01	0.08	0.00	0.00

TABLE 10

RUNOFF (MM) UNDER ROTATIONS OF NO-TILL SOYBEANS (NT) AND CONVENTIONAL TILLAGE SOYBEANS (CT)

	1%		5%		10%		15%	
Date	NT	CT	NT	CT	NT	CT	NT	CT
4/19/75	0.09	3.69	0.23	3.60	0.55	3.74	0.46	8.36
4/21	0.09	0.00	0.09	0.09	0.00	0.18	0.09	0.09
4/24	0.37	3.69	0.92	10.30	1.01	5.67	1.01	8.98
4/26	0.09	3.69	0.51	15.91	0.78	24.84	0.69	11.67
4/29	0.09	3.69	0.46	12.99	0.55	20.21	0.50	11.00
4/30	0.09	1.42	0.18	4.40	0.18	0.18	0.18	1.75
5/3	0.18	3.60	0.18	10.34	0.65	12.94	0.37	5.72
5/8	0.09	0.00	0.18	1.15	0.18	0.92	0.18	0.18
5/9	0.09	3.26	0.18	5.06	0.37	7.19	0.28	5.72
5/17	0.42	3.60	0.51	15.68	0.92	22.19	0.74	18.89
5/20	0.00	0.00	0.18	2.26	0.18	2.81	0.18	2.31
5/21	0.09	1.29	0.09	3.69	0.18	5.67	0.18	2.21
5/24	0.18	0.28	0.18	5.01	0.28	7.65	0.28	3.51
5/27	0.18	3.69	0.46	12.28	0.78	26.82	0.65	20.21
5/29	0.18	2.77	0.28	8.31	0.46	13.60	0.46	8.32
6/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/8	0.18	0.00	0.18	3.23	0.18	1.01	0.18	0.18
6/9	0.18	0.00	0.09	0.09	0.28	0.28	0.37	0.37
6/10	0.18	0.09	0.18	1.38	0.18	0.92	0.23	0.23
6/13	0.73	3.69	0.92	36.73	1.29	43.32	1.29	26.82
6/19	0.28	0.00	0.37	5.01	0.65	5.01	0.83	2.49
6/26	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00
6/27	0.28	0.00	0.46	9.63	0.06	7.65	0.65	0.83

TABLE 10 --Continued

Date	1%		5%		10%		15%	
	NT	CT	NT	CT	NT	CT	NT	CT
7/4-5/75	0.46	0.00	0.55	1.57	0.65	2.58	0.74	0.74
7/11-12	0.28	0.00	0.18	0.09	0.37	0.83	0.37	0.46
7/17	0.55	0.27	0.46	1.01	0.65	1.57	0.92	0.83
7/20-21	0.37	0.00	0.37	0.92	0.46	0.74	0.55	0.46
7/21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10/1	0.00	0.00	0.00	10.30	0.00	10.30	0.00	7.65
10/6-7	0.83	1.57	1.01	12.94	1.29	16.25	1.11	11.62
10/9	0.37	0.00	0.37	0.55	0.28	0.83	0.28	0.46
10/10-12	0.46	0.00	0.46	5.01	0.92	5.67	0.92	3.69
10/14	0.00	0.00	0.00	0.00	0.28	0.28	0.28	0.37
10/17-18	0.55	0.18	0.74	3.69	0.83	5.01	0.92	3.69
10/22	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.65
10/23	0.28	0.00	0.28	0.00	0.46	0.00	0.55	0.28
10/25-26	0.28	0.00	0.00	5.67	0.65	5.67	0.74	2.77

TABLE 11

SOIL LOSS AND RUNOFF FROM PLOTS
OF DIFFERENT LENGTHS

	12.5 Meters				37.5 Meters			
	Soil Loss (ton/ha)		Runoff (mm)		Soil Loss (ton/ha)		Runoff (mm)	
Date	10%	15%	10%	15%	10%	15%	10%	15%
4/19/75	12.95	3.40	19.46	13.33	4.08	2.65	3.40	9.16
4/21	0.60	0.56	1.20	0.92	0.77	0.54	0.22	0.28
4/24	12.94	8.86	31.16	11.34	10.03	10.46	4.22	3.34
4/26	18.60	7.40	14.31	4.35	17.34	12.21	11.00	20.87
4/29	8.86	6.53	21.50	14.10	5.83	5.36	4.80	11.60
4/30	2.56	1.30	6.30	0.46	6.42	0.54	—	2.50
5/3	8.49	2.81	18.04	8.70	7.60	4.67	6.45	8.63
5/8	0.66	0.38	2.49	1.48	0.90	0.17	0.68	0.28
5/9	6.34	2.40	11.44	7.38	5.43	2.36	3.37	2.18
5/17	9.13	4.12	32.67	13.99	6.04	3.00	5.60	0.00
5/20	2.98	0.59	3.78	2.86	3.38	1.96	2.15	2.18
5/21	2.85	0.71	6.83	6.27	4.92	2.06	2.90	3.78
5/24	1.78	0.10	6.46	1.66	3.16	1.71	2.46	4.66
5/27	12.16	—	25.88	—	6.46	5.94	4.66	20.52
5/29	10.09	5.03	16.63	10.02	6.59	6.06	4.66	8.63
6/6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6/8	2.02	0.47	5.54	4.61	2.22	1.56	2.03	1.60
6/9	1.11	0.01	4.80	3.14	0.00	0.01	0.68	0.43
6/10	0.48	0.04	6.09	3.69	0.55	0.28	2.46	1.91
6/13	11.45	—	53.64	—	12.35	—	37.26	—
6/19	8.55	1.42	25.88	23.24	2.76	2.53	4.66	9.07
6/26	0.01	0.00	0.56	0.00	0.07	0.00	0.25	0.00
6/27	5.00	0.70	20.06	11.35	2.54	0.86	4.67	5.99

TABLE 11--Continued

	12.5 Meters				37.5 Meters			
	Soil Loss (ton/ha)		Runoff (mm)		Soil Loss (ton/ha)		Runoff (mm)	
Date	10%	15%	10%	15%	10%	15%	10%	15%
7/4-5/75	1.61	0.14	19.28	5.17	1.04	0.14	2.90	1.60
7/11-12	0.00	0.01	4.80	0.73	0.00	0.00	0.25	0.13
7/17	0.09	0.03	7.38	2.77	0.00	0.00	1.17	0.74
7/20-21	0.46	0.01	6.46	1.48	0.03	0.00	0.62	0.31
7/21	0.00	0.01	0.98	0.00	0.00	0.00	0.00	0.00
10/1	0.02	0.07	16.63	11.34	1.75	0.02	11.28	3.78
10/6-7	6.55	0.12	25.90	7.38	2.03	0.08	13.90	4.22
10/9	2.36	0.01	6.83	1.66	0.03	0.00	2.22	0.00
10/10-12	4.32	0.02	20.60	7.38	1.81	0.00	15.75	2.28
10/14	0.01	0.00	3.88	0.55	0.00	0.00	1.24	0.25
10/17-18	1.75	0.06	20.60	3.88	0.84	0.03	9.11	1.63
10/22	0.57	0.00	12.67	1.11	0.03	0.01	2.16	0.31
10/23	0.01	0.00	3.14	0.55	0.00	0.00	0.68	0.00
10/25-26	0.96	0.03	19.27	1.85	0.05	0.00	7.34	0.74

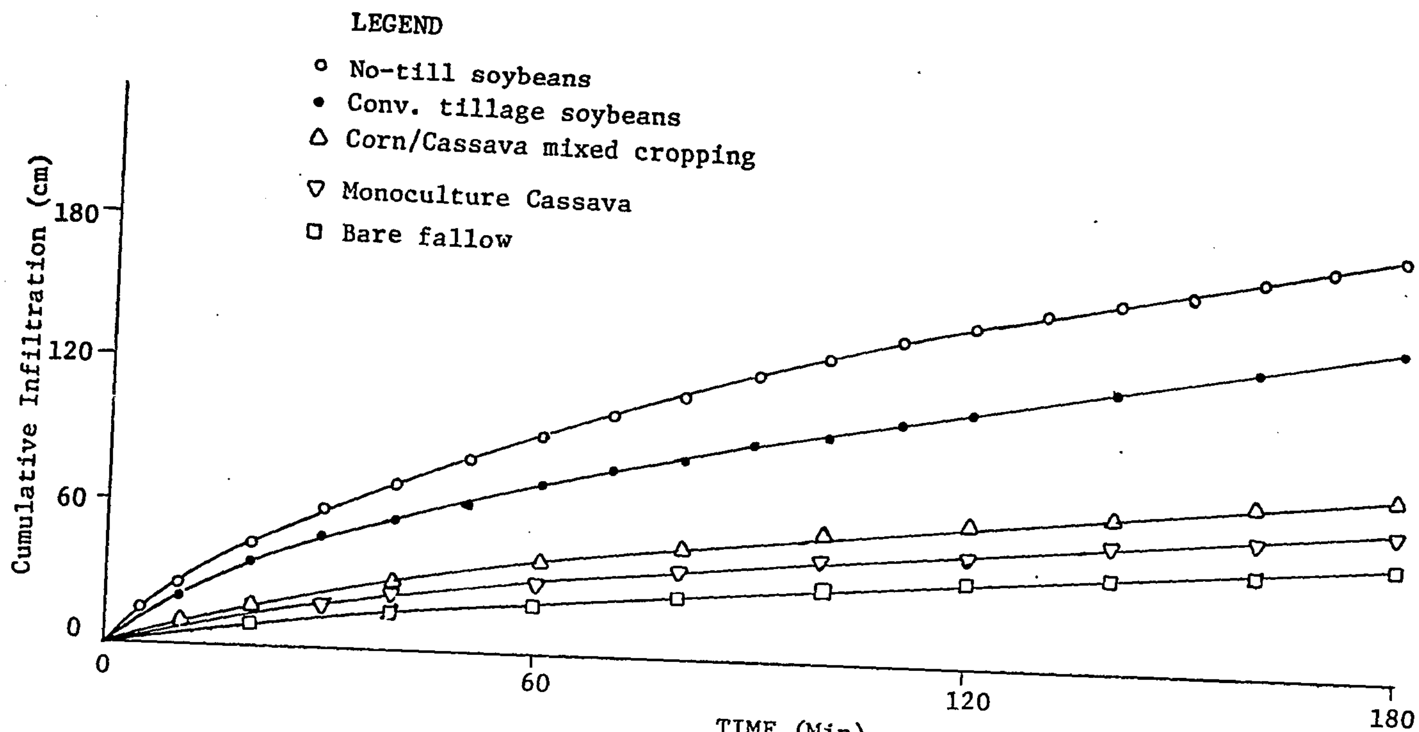


Figure 12. Infiltration characteristics of soil as influenced by tillage and cropping treatments on 1% slope

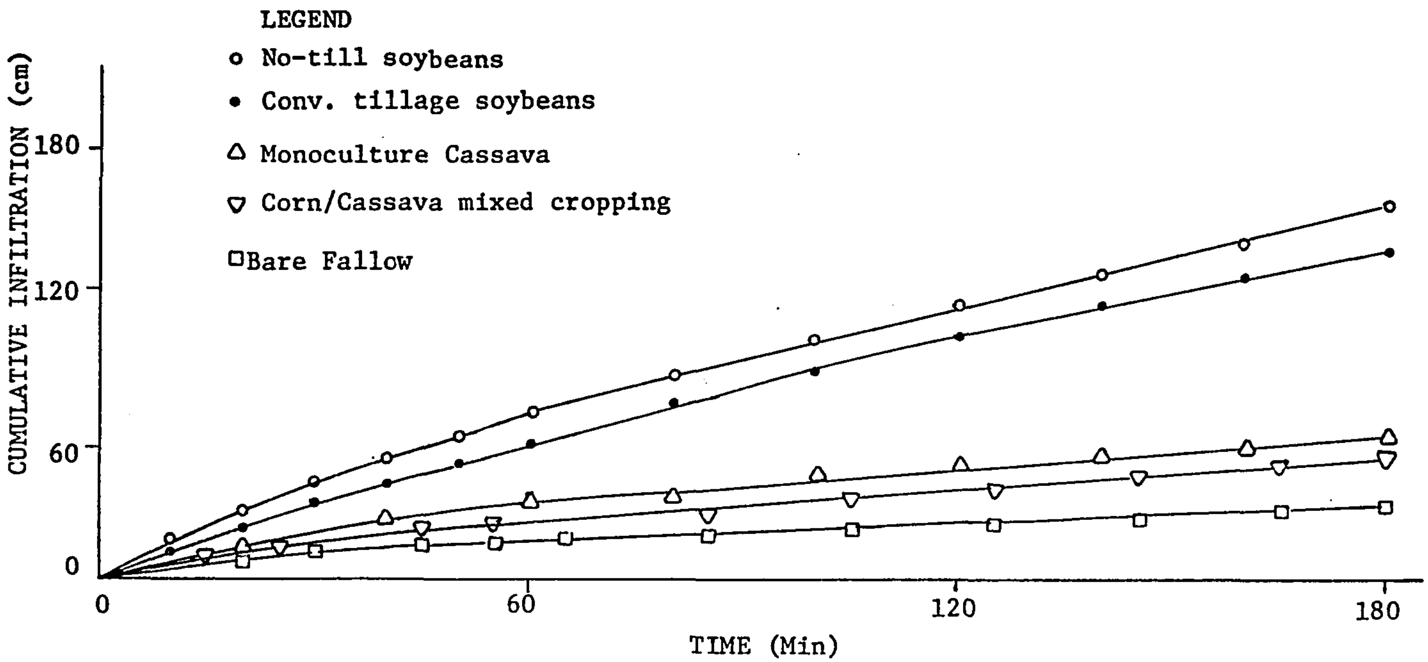


Figure 13. Infiltration characteristics of soil as influenced by tillage and cropping treatments on 5% slope

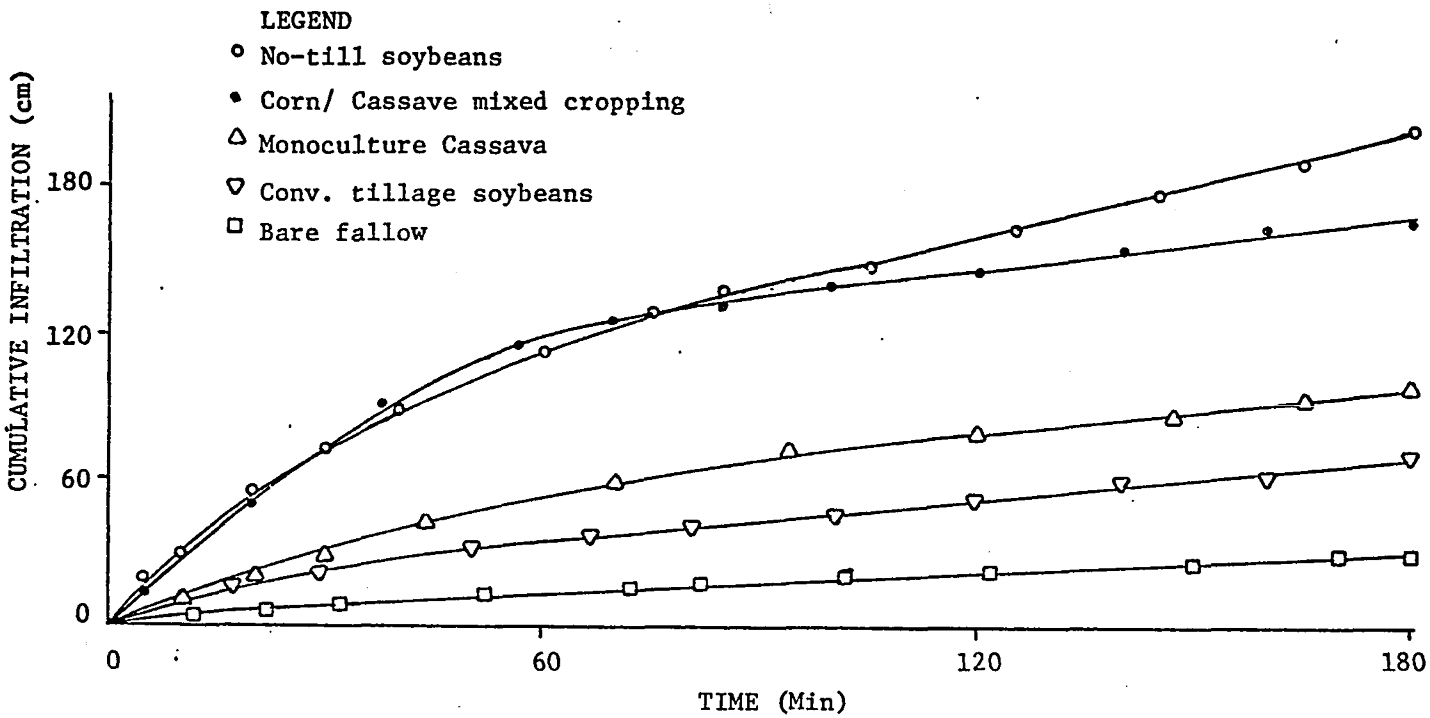


Figure 14. Infiltration characteristics of soil as influenced by tillage and cropping treatments on 10% slope

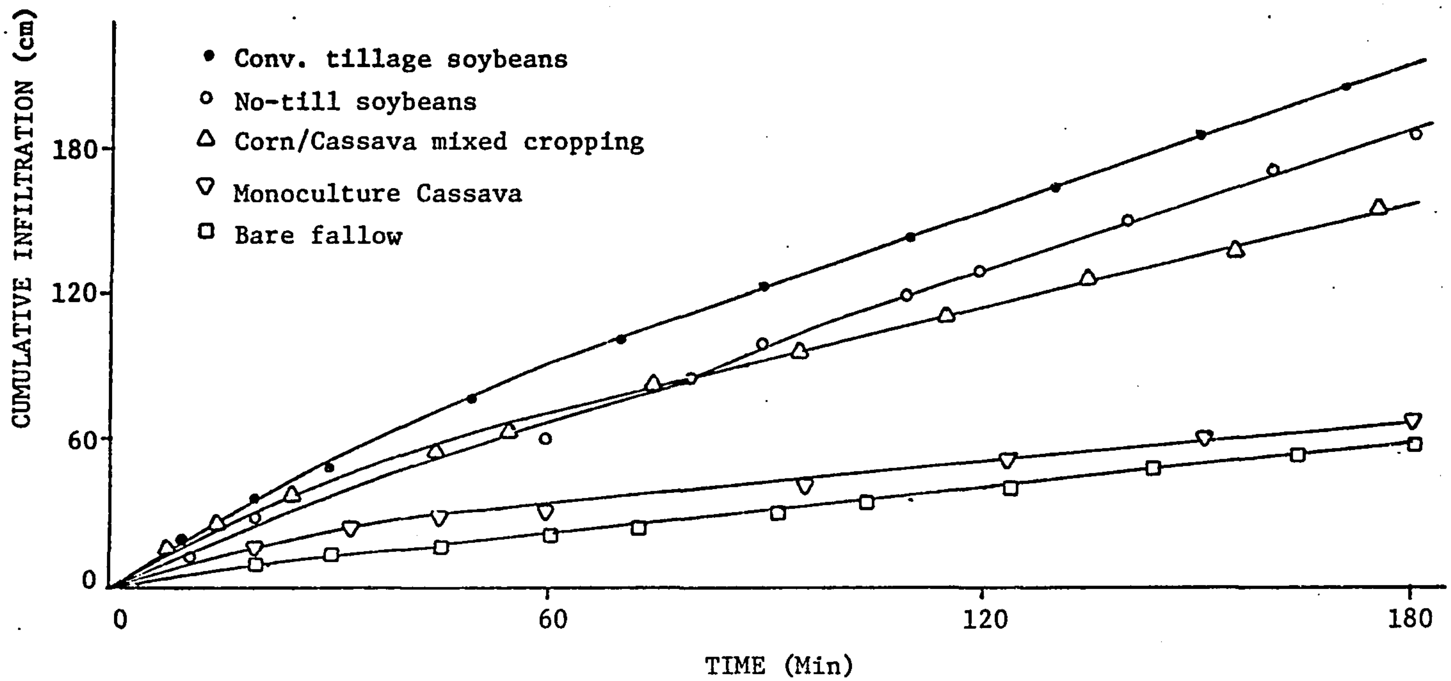


Figure 15. Infiltration characteristics of soil as influenced by tillage and cropping treatments on 15% slope

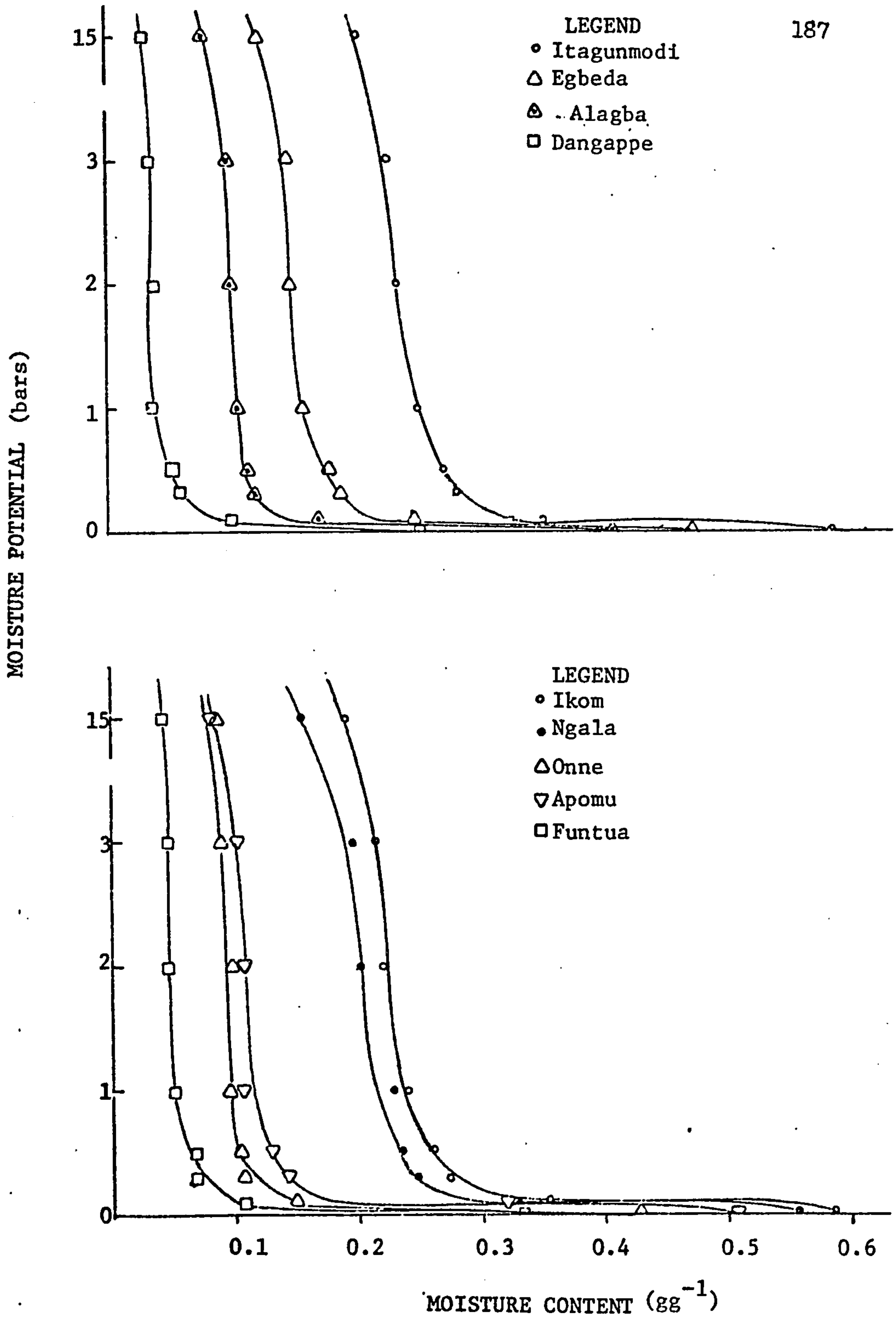


Figure 16. Moisture retention characteristics of surface horizon soils

TABLE 12

SOIL LOSS (G/PLOT)[1] FROM LABORATORY MICROPLOTS
UNDER DIFFERENT TREATMENT COMBINATIONS

Soil Type	Treatment Combinations[2]											
	$S_1I_1A_1$	$S_1I_1A_2$	$S_1I_1A_3$	$S_1I_2A_1$	$S_1I_2A_2$	$S_1I_2A_3$	$S_2I_1A_1$	$S_2I_1A_2$	$S_2I_1A_3$	$S_2I_2A_1$	$S_2I_2A_2$	$S_2I_2A_3$
Ngala	96.6	230.2	335.1	405.9	739.0	954.0	139.4	486.5	847.6	262.1	581.1	1061.7
Funtua	43.9	153.4	219.7	240.7	472.1	913.4	143.3	215.0	334.0	334.2	720.1	635.5
Dangappe	54.4	60.8	94.7	133.6	413.3	576.4	221.6	335.8	429.9	354.0	716.4	823.3
Apomu	7.0	7.5	15.5	69.7	214.5	247.4	108.1	201.5	370.8	278.3	519.1	976.7
Egbeda	40.8	41.3	135.6	111.5	295.8	395.4	54.2	67.7	83.8	126.2	389.0	526.0
Onne	0.0	0.0	0.0	0.0	0.0	0.0	46.4	155.5	191.4	116.1	315.5	386.3
Itagunmodi	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.5	7.5	8.2	12.1	18.1
Alagba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ikom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[1]Average of 2 replications.

[2]S_1 = 5% slope; S_2 = 10% slope; I_1 = 12.5 cm/hr; I_s = 17.5 cm/hr rainfall intensity; A_1 = 2.1 cm; A_2 = 4.2 cm; A_3 = 6.3 cm rainfall amount.

TABLE 13

RUNOFF (%)[1] FROM LABORATORY MICROPLOTS UNDER DIFFERENT TREATMENT COMBINATIONS

Soil Type	Treatment Combinations[2]											
	$S_1I_1A_1$	$S_1I_1A_2$	$S_1I_1A_3$	$S_1I_2A_1$	$S_1I_2A_2$	$S_1I_2A_3$	$S_2I_1A_1$	$S_2I_1A_2$	$S_2I_1A_3$	$S_2I_2A_1$	$S_2I_2A_2$	$S_2I_2A_3$
Ngala	79	89	89	95	98	98	87	86	83	96	92	95
Funtua	63	72	70	77	78	91	84	75	81	79	97	88
Dangappe	53	59	57	46	69	71	71	76	74	85	82	78
Apomu	23	42	57	40	56	45	66	66	61	62	79	79
Egbeda	65	63	59	66	79	80	79	80	76	86	98	85
Onne	0	0	0	0	0	0	22	42	35	31	47	44
Itagunmodi	0	0	0	0	0	0	22	40	44	22	28	40
Alagba	0	0	0	0	0	0	0	0	0	0	0	0
Ikom	0	0	0	0	0	0	0	0	0	0	0	0

[1] Average of 2 replications.

[2] S_1 = 5%; S_2 = 10% slope; I_1 = 12.5%; I_2 = 17.5 cm/hr rainfall intensity; A_1 = 2.1%; A_2 = 4.2%; A_3 = 6.3 cm rainfall amount.

BIBLIOGRAPHY

1. Ahmad, N., and E. Breckner. (1974). Soil erosion on three Tobago soils. Trop. Agri. 51(2):313-324.

2. Andrews, D. J. (1970). Relay and intercropping with sorghum at Samaru. Proc. seminar on intercropping, Ford Foundation/IITA/IRAT, Ibadan, Nigeria.

3. American Society for Testing and Materials. (1972). ASTM Standards, part 4. Philadelphia, Pa.

4. Atals, O., and V. G. Plank. (1953). Measuring rain with radar. J. Meteorol. 10:291-295.

5. Bates, J. A. R. (1960). Studies on a Nigerian forest soil. I. The distribution of organic matter in the profile and in various soil fractions. J. Soil Sci. 11(2):246-256.

6. Baver, L. D. (1938). Ewald Wollny - A pioneer in soil and water conservation research. Proc. Soil Sci. Soc. Amer. 3:330-333.

7. Baver, L. D. (1972). Soil Physics. 3rd ed. John Wiley and Sons, Inc., New York.

8. Bennett, H. H. (1926). Some comparisons of the properties of humid-tropical and humid-temperate American soils, with special reference to indicated relations between chemical and physical properties. Soil Sci. 21:349-375.

9. Bentley, W. A. (1904). Studies of rain drops and raindrop phenomena. Monthly Weather Review 32:450-456.

10. Berger, J. M. (1964). Profils culturaux dans le centre de la Cote d'Ivoire. Cah. ORSTOM, Ser. Pedol. 2(1):41-69.

11. Bertoni, J., W. E. Larson, and W. D. Shrader. (1958). Determination of infiltration rates on Marshall silt loam from runoff and rainfall records. Proc. Soil Sci. Soc. Amer. 22:571-574.

12. Bertrand, A. R., and J. F. Parr. (1961). Design and operation of Purdue sprinkling infiltrometer. Purdue Agr. Exp. Sta. Bul. 723, Purdue University, W. Lafayette, Ind. 16 pp.

13. Blanchard, D. C. (1950). Beharior of water drops at terminal velocity. Trans. Am. Geophys. Union 31:836-842.

14. Borst, H. L., and R. Woodburn. (1942). The effect of mulching and methods of cultivation on runoff and erosion from Muskingum silt loam. Agric. Eng. 23:19-22.

15. Borst, H. L., A. G. McCall, and F. G. Bell. (1945). Investigations in erosion control and reclamation of eroded land at the Northwest Appalachian Conserv. Exp. Sta. U. S. Dept. Agri. Gech. Bul. 888.

16. Bosazza, V. L. (1953). On erodibility of soils. Afrigan Soils 2:337.

17. Bouyoucos, G. J. (1935). The clay ratio of a criterion of susceptiblity of soils to erosion. J. Am. Soc. Agron. 27:738-741.

18. Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. Agron. J. 54:464-465.

19. Boyd, J. R. (1922). Physical properties of sub-grade materials. Am. Soc. Testing Mater., Proc. 22:337-355.

20. Briggs, L. J., and J. W. McLane. (1907). The moisture equivalent of soils. U.S.D.A. Bur. Soil Bul. No. 45:1-23.

21. Browning, G. M., C. L. Parish, and J.A. Glass. (1947). A method for determining the use and limiation of rotation and conservation practices in control of soil erosion in Iowa. Amer. Soc. Agron. Jour. 39:65-73.

22. Bruce-Okine, E., and R. Lal. (1975). Soil erodibility as determined by raindrop technique. Soil Sci. 11(2);149-157.

23. Bryan, R. B. (1969). The development, use and efficiency of indices of soil erodibility. Geoderma 2:5-26.

24. Bryan, R. B. (1970). Improved rainfall simulator for use in erosion research. Canadian J. Earth Sciences 7:1552.

25. Burwell, R. E., R. R. Allmaras, and L. L. Sloneker. (1966). Structural alteration of soil surfaces by tillage and rainfall J. Soil Water Conserv. 21:61-63.

26. Carter, C. E., and J. D. Greer, H. L. Braud, and J. M. Floyd. (1974). Raindrop characteristics in South Central U.S. Trans. ASAE 17(6):1033-1037.

27. Chalk, A.T. (1963). Soil conservation in northern Nigeria and a suggested programme. USAID Rep. C-34.

28. Chibber, R. K., P. C. Ghosh, and K.V.S. Satyanarayanna. (1961). Studies on the physical properties of some of the Himachal Pradesh soils formed on different parent materials in relation to their erodibility. Indian Soc. Soil Sci. Jour. 9:187-192.

29. Dangler, E. W., S. A. El-Swaify, L. R. Ahuja, and A. P. Barnett. (1976). Erodiblity of selected Hawaii soils by rainfall simulation. U. S. Dept. Agr., ARS No. W-35, 113 pp.

30. Duley, F. L. (1926). The loss of soluble salts in runoff water. Soil Sci. 21:401-409.

31. Duley, F. L., and O. E. Hays. (1932). Effect of degree of slope on runoff and soil erosion. J. Agr. Res. 45:349-360.

32. Duley, F. L., and L. L. Kelly. (1939). Effect of soil type, slope, and surface conditions on intake of water. Nebraska Agri. Sta. Res. Bul. 112, 16 pp.

33. Ellison, W. D. (1945). Some effect of raindrops and surface-flow on soil erosion and infiltration. Amer. Geophys. Union Trans. 26:415-429.

34. El-Swaify, S. A., and W. W. Emerson. (1975). Changes in the physical properties of soil clays due to precipitated aluminum and iron hydroxides. 1. Swelling and aggregate stability. Proc. Soil Sci. Soc. Amer. 39(6):1056-1063.

35. Elwell, H. A., and M. A. Stocking. (1973). Prediction of subtropical storm losses from field plot studies. Agri. Meteorol. 12:193-201.

36. Elwell, H. A., and M. A. Stocking. (1976). Vegetal cover to estimate soil erosion hazard in Rhodesia. Geoderma 15(1): 61.70.

37. FAO (1965). Agricultural development in Nigeria, 1965-80. FAO, Rome.

38. Fournier, F. (1960). Climat et Erosion. Paris: Presses Universitaires de France.

39. Fournier, F. (1967). Research in soil erosion and soil conservation in Africa. African soils 12(1):53-96.

40. Gard, L. E., and C. A. Van Doren (1950). Soil losses as affected by cover, rainfall and slope. Proc. Soil Sci. Soc. Amer. 14:374-378.

41. Gerdel, R. W. (1937). Reciprocal relationships of texture, structure and erosion. Proc. Soil Sci. Soc. Amer. 2:537-545.

42. Gleason, C. H. (1957). Reconnaissance methods of measuring erosion. Jour. Soil and Water Conserv. 12:105-107.

43. Greenland, D. J. (1975). Bringing the green revolution to the shifting cultivator. Science. 190:841.

44. Gunn, R. and G. D. Kinzer. (1949). Terminal velocity of water droplets in stagnat air. Jour. Meteorol. 6:243-248.

45. Haan, C. T. (1971). Movement of pesticides by runoff and erosion. Trans. ASAE. 14(3):445-447, 449.

46. Hall, M. J. (1970). Use of the stain method in determining the drop-size distributions of coarse liquid sprays. Trans. ASAE. 13(1):33-37, 41.

47. Harpstead, M. I. (1973). The classification of some Nigerian soils. Soil Sci. 116:437-443.

48. Harrold, L. L. (1960). The watershed hydrology of plow-plant corn. J. Soil Water Conserv. 15(4):183-184.

49. Harrold, L. L., and W. M. Edwards. (1972). A severe rainstorm test of no-till corn. J. Soil Water Conserv. 27(1):30.

50. Haynes, J. L. (1948). Interception of rainfall by vegetative canopy. U. S. Dept. Agri. Soil Conserv. Ser. Mimeo Rept. 2668.

51. Hays, O. E. (1961). No-tillage methods reduce erosion and runoff. J. Soil and Water Conserv. 16:172-175.

52. Horner, W.W., and L. C. Lloyd. (1940). Infiltration-capacity as determined from the study of an 18-month record at Edwardsville, Illinois. Trans. Am. Geophys. Union 21:522-541.

53. Hoyt, G. D. (1975). Movement of manure and fertilizer forms of nitrogen from soils under various conditions of simulated rainfall, cover, and slope. M.Sci. Thesis, The Ohio State University.

54. Hudson, N. W. (1957). Erosion control research-Progress report on experiments at Henderson Research Station, 1953-56. Rhod. Agri. J., 54:297-323.

55. Hudson, N. W. (1963). Raindrop size distribution in high intensity storms. Rhodesion J. Agric. Res. 1(1):6-11.

56. Hudson, N. W. (1964). The flour pellet method for measuring the size of raindrops. Res. Bul. No. 4, Dept. of Conserv., Salisbury, Rhodesia.

57. Hudson, N. W. (1965). The influence of rainfall on the mechanics of soil erosion. M.Sci. Thesis, University of Cape Town.

58. Hudson, N. W. (1971). Soil Conservation. Cornell University Press, Ithaca, N. Y., 320 pp.

59. Hudson, N. W. and D. C. Jackson. (1959). Results obtained in the measurement of erosion and runoff in Southern Rhodesia. Paper presented in Third Inter-African Soils Conf., Dalaba, 1959.

60. Jones, J. N., Jr., J. E. Moody, G. M. Shear, W.W. Moschler, and J. H. Lillard. (1968). The no-tillage system for corn. Agron. J. 60:17-20.

61. Kannegieter, A. (1967). Zero cultivation and other methods of reclaiming Pueraria fallowed land for crop production in the forest zone of Ghana. Trop. Agri. 123:1-2.

62. Kowal, J. M., W. Kijewski, and A. H. Kassam. (1975). A simple device for analysing the energy load and intensity of rainstorms. Agri. Met. 12:271-280.

63. Lal, R. (1973). Soil erosion and shifting cultivations. FAO/SIDA regional seminar on shifting cultivation and soil conservation in Africa. Ibadan, Nigeria, July 2-21, 1973.

64. Lal, R. (1974). No-tillage effects on soil properties and maize production in Western Nigeria. Soil Sci. 40(2):321-331.

65. Lal, R. (1975). Role of mulching techniques in tropical soil and water management. Tech. Bul. No. 1, IITA, Ibadan, Nigeria.

66. Lal, R. (1976). Soil erosion problems on an alfisol in Western Nigeria and their control. IITA Monograph No. 1. 208 pp.

67. Lawes, D. A. (1961). Rainfall conservation and the yield of cotton in Northern Nigeria. Emp. J. Expl. Agric. 29:307-313.

68. Laws, J. O. (1941). Measurement of the fall-velocity of water-drops and raindrops. Trans. Am. Geophys. Union 22:709-721.

69. Laws, J. O., and D. A. Parsons. (1943). The relation of rain-drop size to intensity. Trans. Am. Geophys. Union 24:452-460.

70. Lawson, T. L. (1975). IITA Weather Data. 1975 IITA Annual Report.

71. Lugo-Lopez, M. A. and J. Juarez Jr., (1954). Evaluation of the effects of organic matter and other soil characteristics upon the aggregate stability of some tropical soils. J. Agr. Univ. Puerto Rico. 43:268-272.

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

73. Marshall, J. S., and W. Palmer. (1948). Distribution of rain-drops with size. J. Meteorol. 5:165-166.

74. Mason, B. J., and R. Ramamadham. (1953). A photoelectric rain-drop spectrometer. Q.U.R. Meteorol. Soc. 79:490-495.

75. McCalla, T. M. (1944). Waterdrop method of determining stability of soil structure. Soil Sci. 58:117-121.

76. Meyer, L. D., and J. V. Mannering. (1961). Minimum tillage for corn: its effect on infiltration and erosion. Agr. Eng. 42:72-76.

77. Meyer, L. D., and E. J. Monke. (1965). Mechanics of soil erosion by rainfall and overland flow. Trans. ASAE 8:572-578.

78. Middleton, H. E. (1930). Properties of soil which influence soil erosion. U.S. Dept. Agr. Tech. Bul. No. 178 16 pp.

79. Miller, M. F., and H. H. Krusekopf. (1932). The influence of systems of cropping and methods of culture on surface runoff and soil erosion. Missouri Agr. Exp. Sta. Res. Bul. 177.

80. Moldenhauer, W. C., W. H. Wischmeier, and D. T. Parker. (1967). The influence of crop management on runoff, erosion and soil properties of a Marshall silty clay loam. Proc. Soil Sci. Soc. Amer. 31:541-546.

81. Monnier, G. (1965). Effect of organic matter on soil structural stability. Africian soils. 10:29-42.

82. Moormann, F. R., R. Lal and A.S.R. Juo. (1975). The soils of IITA. IITA Tech. Bul. 3, Ibadan, Nigeria.

83. Muller, J., and O. DeBilerling. (1953). Les methods culturales indigenes sur les sols equatoriaux de plateau. I.N.E.A.C. Belge Bull. Inform. 2:21-30.

84. Munn, D. A., E. O. McLean, A. Ramizez, and T. J. Logan (1973). Effects of soil cover, slope and rainfall factors on soil and phosphorus movement under simulated rainfall conditions. Proc. Soil Sci. Soc. Amer. 37:428-431.

85. Musgrave, G. W. (1935). Some relationships between slope-length, surface-runoff and silt-load of surface-runoff. Trans. Amer. Geophy. Union, 16:472-478.

86. Musgrave, G. W. (1947). The quantitative evaluation of factors in water erosion-A first approximation. J. Scoil Water Conserv. 2:133-138.

87. Mutchler, C. K. (1967). Parameters for describing raindrop splash. Agric. Eng. 22(3):91-94.

88. Neal, J. H. (1938). The effect of the degree of slope and rainfall characteristics on runoff and soil erosion. Missouri Agr. Exp. Sta. Res. Bul. No. 280.

89. Neal, J. H. and L. D. Baver. (1937). Measuring impact of raindrops. J. Am. Soc. Agron. 29:708-709.

90. Norman, D.W. (1970). Intercropping. Proc. Seminar on inter-cropping. Ford Foundation IITA/IRAT, Ibadan, Nigeria.

91. Ofomata, G.E.K. (1964). Soil erosion in the Enugu region of Nigeria. African soils 9(2):289-348.

92. Parr, J. F., and A. R. Bertrand. (1960). Water infiltration into soils. Adv. Agron. 12:311-358.

93. Pereira, H. C., and P. A. Jones (1954). A tillage study in Kenya. II. The effects of tillage practices on structure of soil. Empire J. Exp. Agr. 23:323-331.

94. Platt, B. S. (1965). Tables of representative values of foods commonly used in tropical countries. Medical Res. Council Special Report Series No. 253, U. K.

95. Robinson, A. R. (1971). Sedimentation, our greatest pollutant. Agri. Eng. 52(1):26.

96. Rogers, J. S., L. C. Johnson, D. M. A. Jones, and B. A. Jones, Jr. (1967). Sources of error in calculating the kinetic energy of rainfall. J. Soil and Water Conserv. 22(4): 140-143.

97. Roose, E. J. (1967). Ten years of erosion and runoff records in Senegal. Agron. Trop., 22:123-152.

98. Rose, C.W. (1958). Effects of rainfall and soil factors on soil detachment and the role of water penetration into soils. Ph.D. thesis, University of London, London.

99. Rose, C. W. (1960). Soil detachment caused by rainfall. Soil Sci. 89(4):28-35.

100. Screenivas, S. L., J. R. Johnston, and H. O. Hill. (1947). Some relationship of vegetation and soil detachment in erosion process. Proc. Soil Sci. Soc. Amer. 12:471-474.

101. Service, J., A. J. Barr, and J. H. Goodnight. (1972). A user's guide to the statistical analysis system. North Carolina State Univ., Raleigh, N.C.

102. Shear, G. M., and W. W. Moshler. (1969). Continuous corn by the no-tillage and conventional tillage methods: A six-year comparison. Agron, Jour. 61:524-526.

103. Smith, D. D. (1941). Interpretation of soil conservation data for field use. Agric. Eng. 22:173-175.

104. Smith, R. M., and C. F. Cernuda. (1951). Some applications of water drop stability testing to tropical soils of Puerto Rico. Soil Sci. 71:337-345.

105. Smith, D. D., and W. H. Wischmeier. (1957). Factors affecting sheet and till erosion. Trans. Am. Geophys. Union, 38:889-896.

106. Smith, D. D., D. M. Whitt, A. N. Zingg, A. G. McCall, and F. G. Bell. (1945). Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conser. Exp. Station, Bethany, Mo., U.S.D.A. Tech. Bull. 883.

107. Smyth, A. J., and R. F. Montgomery. (1962). Soils and land use in Central Western Nigeria. Govt. Printer, Ibadan, Nigeria.

108. Soil Survey Staff. (1975). Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agric. Handbook 436. U.S. Govt. Printing Press Office, Washington, D. C.

109. Stallings, J. H. (1957). Soil Conservation. Prentice-Hall, Eaglewood Cliffs, New Jersey.

110. Steele, W. M. (1972). Cowpeas in Nigeria. Ph.D. Thesis, Reading University.

111. Taylor, R. E., and O. E. Hays. (1960). Agron. Abstr., Amer. Soc. Agron. p. 41. Reported in D. D. Smith and W. H. Wischmeier (1962). Rainfall Erosion. Adv. Agron. 109-146.

112. Triplett, G. B., Jr., D. M. Van Doren, Jr., and S. W. Bone. (1973). An evaluation of Ohio soils in relation to no-tillage corn production. Ohio Agric. Res. and Dev. Center Res. Bul. 1068:1-20.

113. Uhland, R. E. (1949). Crop yields lowered by erosion. U. S. Dept. of Agric. Soil Conserv. Serv. Tech. paper No. 75.

114. Van Bavel, C. H. M. (1950). Mean weight diameter of soil aggregates as a statistical index of aggregation. Proc. Soil Sci. Soc. Amer. 14:20-23.

115. Van Doren, C. A., and L. J. Bartelli. (1956). A method of forcasting soil loss. Agric. Eng. 37:335-341.

116. Verney, R., and P. Williame. (1965). Results of studies of erosion on experimental plots in Dahomey, Proc. OAU/STRC Symp. on the maintanance and improvement of soil fertility. Khartoum.

117. Wallis, J. R., and L. J. Stevan. (1961). Erodibility of some California wildland soils related to their metallic cation exchange capacity. J. Geophys. Res. 66:1225-1230.

118. Wiesner, J. (1895). Bietraege Zur Kenntniss, des tropiregens, K. Akad. Will., Math-Naturw. Kless, Sitzber, 104:1397-1434.

119. Wilding, L. P., L. R. Drees, N. E. Smeck, and G. F. Hall. (1971). Mineral and elemental composition of Wisconsin-age till deposits in West-Central Ohio. Till/A Symposium, Ed. R. P. Goldthwait. The Ohio State University Press, Columbus, Ohio.

120. Wilkinson, G. E. (1975). Rainfall characteristics and soil erosion in rainforest area of Western Niger. Expl. Agric. 11(4):247-255.

121. Wilkinson, G. E., and P. O. Aina. (1976). Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping. Geoderma 15(1):51-59.

122. Williams, M. A. (1969). Prediction of rainfall splash erosion in the seasonally wet tropics. Nature, Lond. 222, 763.

123. Wilm, H. G. (1943). The application and measurement of artificial rainfall on types FA and F infiltrometers. Trans. Amer. Geophys. Union. 24:480-487.

124. Wischmeier, W. H. (1959). A rainfall erosion index for a universal soil-loss equation. Proc. Soil Sci. Soc. Amer. 23:246=249.

125. Wischmerie, W. H. (1960). Cropping management factor evaluations for a universal soil-loss equation. Proc. Soil Sci. Soc. Amer. 24:322-326.

126. Wischmeier, W. H. (1962). Storms and soil conservation. J. Soil and Water Conserv. 17(2):55-59.

127. Wischmeier, W. H. (1966). Relation of field-plot runoff to management and physical factors. Proc. Soil Sci. Soc. Amer. 30:272-277.

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

129. Wischmeier, W. H., and D. D. Smith. (1958). Rainfall energy and its relationship to soil loss. Trans. Am. Geophys. Union 39:285-291.

130. Wischmeier, W. H., and D. D. Smith (1965). Predicting rainfall-erosion losses from cropland East of the Rocky Mountains. Agric. Handbook No. 282, ARS U.S. Dept. of Agric.

131. Wischmeier, W. H., D. D. Smith, and R. E. Uhland. (1958). Evaluation of factors in soil loss equation. Agric. Eng. 39:458-462.

132. Wollny, E. (1877). Der einfluss der pflanzendecke und beschattung auf die physikalischen eigenschaften und die fruchtbarkeit des bodens. Berlin. 197 pp.

133. Woodruff, C. M. (1947). Erosion in relation to rainfall, crop cover and slope on a greenhouse plot. Proc. Soil Sci. Soc. Amer. 12:475-478.

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

135. Yoder, R. E. (1936). A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28:337-351.

136. Young, R. A., and R. E. Burwell. (1972). Prediction of runoff and erosion from natural rainfall using a rainfall simulator. Proc. Soil Sci. Soc. Amer. 36:827-830.

137. Young, R. A., and C. K. Mutcher. (1969). Soil movement on irregular slopes. Water Resources Res. 5:1084-1089.

138. Zingg, A. W. (1940). Degree and length of land slope at it affects soil loss in runoff. J. Amer. Soc. Ag. Eng. 21:59-64.