DEVELOPMENT OF CROP FUNCTIONS FOR ESTIMATING CROP AND SOIL MANAGEMENT FACTORS OF THE UNIVERSAL SOIL LOSS EQUATION FOR SOIL EROSION PREDICTION UNDER TANZANIAN CONDITIONS

BY

CHRISTIAN ALPHONCE MGINA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENGINEERING) OF SOKOINE UNIVERSITY OF AGRICULTURE

2000

ABSTRACT

One of the appropriate tools for predicting soil erosion in planning for soil conservation measures is by the application of soil erosion predictive equations or models. Although many equations do exist for use in soil erosion prediction, they cannot be directly applied to Tanzanian conditions since their developments were done in conditions different from the ones existing in Tanzania. Therefore, it is increasingly acknowledged that such equations are inapplicable for use in predicting soil erosion for Tanzanian conditions.

This study was conducted at SUA farm runoff plots with the aim of developing crop functions, as useful data in estimating the crop and soil management factor, C, of the USLE or its revised version (The RUSLE) for its adaptation for use under Tanzanian conditions.

Crop height development and canopy curves for maize and sorghum crops were developed using the data collected during the 1998 season and functions relating crop height and crop canopy cover with yield for a three year period (1994, 1995 and 1998) were developed. All the equations developed gave relatively high coefficients of determination (0.72 - 0.99) which were significant at the 95 % level ($\alpha = 0.05$). The equations developed show that there exists a relationship between crop canopy cover and crop height with yield for both maize and sorghum crops (equations 4.4 to 4.6).

Moreover, there exists a relationship between maximum crop height attained by each crop with the final crop canopy cover (equations 4.8 and 4.9).

The predicted seasonal crop and soil management factor, C for 1998 season was estimated using the sub-factor method. The predicted and measured C factor values for maize crop for the 1998 season were 0.147 and 0.086, respectively. For sorghum crop, the values obtained were 0.158 and 0.100, respectively (Table 4.3).

Also, a crop development curve was estimated from the developed functions relating yield and crop growth parameters (canopy cover and crop height) and the average curve which related the crop development ratios to crop growth period ratios. This curve was used to estimate the long term C factor value. From the growth curve, the value of 0.136 was estimated (Table 4.4). This value was reasonable when compared to the estimated C factor values for individual years. This suggests that the method can be used to establish average crop growth curves in terms of height and cover for any given crop yield level useful in predicting the crop and soil management factor, C. However, prediction of the crop and soil management factor, C, is appropriate provided that sufficient data bank is available. Thus, research to collect such information is required if soil loss prediction equations are to be locally applicable for their use for practical soil conservation planning in Tanzania.

DECLARATION

I, MGINA, CHRISTIAN ALPHONCE, hereby declare to the Senate of the Sokoine University of Agriculture, Morogoro, Tanzania, that the work presented here is my own, and has not been submitted for a higher degree in any other university.

Date....20.06.2000 Signature........................

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ACKNOWLEDGEMENTS

I am indebted to Dr. M. Mulengera for his tireless guidance and assistance throughout the study period which finally made this study successful. I am also indebted to all members of the teaching staff of the Agricultural Engineering Department and all workers of the department for their assistance during my stay at the department.

This research study could not have been done without being financed. I would like to express my sincere thanks to SACCAR/GTZ for financing the study.

Lastly but not least I would like to express my gratitude and appreciation to all my course mates for their encouragement during the study period. Special thanks should go to Mr. Francis Wikedzi, Malogo Kongola, Steven Nindi and Adam Njovu for their brotherly closeness both academically and socially.

DEDICATION

This work is dedicated to my beloved mother, **MAMA CASSIANA NDOMBA**, who brought me to this mother Earth and sent me to school.

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LIST OF ABBREVIATIONS

USLE	Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
EI_{30}	Rainfall erosivity index
E	Rainfall kinetic energy
CM	Plot cropped with maize
CS	Plot cropped with sorghum
BP	Bare fallow plot
SNV	Plot with semi-natural vegetation
CC	Canopy cover sub-factor
C	Crop and soil management factor
SR	Surface roughness sub-factor
PLU	Prior land use sub-factor
REC	Sub-factor for reconsolidation
ETo	Potential evapotranspiration
ETcrop	Crop evapotranspiration
ETact.	Actual evapotranspiration

CHAPTER 1

1 INTRODUCTION

1.1 Background information

Soil erosion is a widespread problem facing the agricultural sector in Tanzania (Rapp, 1975). Soil erosion by both water and wind have been reported to be active in Tanzania, the later being prominent in areas with semi-arid climate (Mulengera, 1996). Accelerated soil erosion have lowered the productivity of many soils in Tanzania leaving the affected areas unsuitable for agricultural activities (Rapp, 1975). Erosion of soil removes the productive top soil which contains finer particles with high content of organic matter and nitrogen thereby, reducing soil depth and consequently the rooting depth of plants (Nelson and Sommer, 1984). Soil erosion affects the structure of soil resulting in reduced infiltration of that particular soil. The reduced infiltration capacity of the soil in turn promotes runoff which is effective in removing applied inorganic nutrients dissolved in runoff water or attached to the cation exchange of clays and organic matter (Foth, 1984).

Soil erosion happens due to inappropriate land use practices. The increased population density, overgrazing, expansion of agricultural activities into marginal areas and intensification of agricultural activities on unsuitable areas have resulted in increased runoff and soil loss (FAO, 1974). Many mountainous areas with dense population and high intensive farming systems and those areas with semi-arid climate characterized by sparse vegetation cover and long dry spells have been prone to erosion (Rapp, 1975; Ngalesoni, 1996). Agricultural and economic activities performed in these areas such as bad cultivation practices on steep slopes, tree falling for firewood, charcoal and construction materials have resulted in alarming deforestation and consequently soil erosion (Larson et al., 1983; Ngalesoni, 1996).

In planning for soil conservation measures, the basic systems of soil management such as proper tillage practices, crop rotation, lime and fertilizer application, strip cropping, terracing, contouring and other practices are important so as to control runoff and soil loss. Conservation practices aim at minimizing erosion and other forms of land degradation by utilizing the land in accordance with its capabilities, applying restoration measures where the land has been damaged and preventing further damage to happen as well as combining sound methods to obtain satisfactory production on sustained way (Moldenhauer and Foster, 1981).

Effective planning of soil conservation requires appropriate tools for predicting soil erosion (Mulengera, 1996). One of these tools is the application of predictive equations or models. Soil erosion predictive equations or models can be used as predictive tools for assessing soil loss for conservation planning. Also, they can be used to tell where and when erosion is occurring, thus helping the conservation planners target efforts to reduce erosion (Nearing et al., 1994). The application of models requires evaluation of the factors affecting soil erosion such as rainfall erosivity, soil erodibility, topographic factors, crop and land management parameters as their essential inputs. The most widely used models are those based upon statistical inferences of observed and response data such as the Universal Soil Loss Equation (Wischmeir and Smith, 1978).

The Universal Soil Loss Equation (USLE) or its revised version (the RUSLE) (Wischmeier and Smith, 1978, Renard et al., 1994) is an empirical equation widely used for soil loss prediction. The use of the USLE/RUSLE model for predicting soil erosion in Tanzania is limited because not all the factors of the equation are directly applicable to Tanzanian conditions (Lal, 1990; Mulengera, 1996). Critical factors of the USLE/RUSLE which have been shown to give inappropriate values when transferred to conditions different from where they were developed include the soil erodibility and the crop and soil management factors (Ngatunga et al., 1984; Lal, 1990; Mulengera, 1996). Following these shortcomings, the application of the USLE/RUSLE in Tanzania requires modification of the above mentioned factors by developing site specific methods for the determination of the parameters.

The present study was conducted at the runoff plot site situated at Sokoine University of Agriculture (SUA) farm where three previous researchers conducted soil erosion studies for four previous seasons. The study involved in developing crop functions useful in determining the canopy cover sub-factor of the crop and soil management factor of the USLE model for soil erosion prediction under Tanzanian conditions.

1.2 Study Objectives

This study was performed with an overall objective of developing crop functions useful in estimating the crop and soil management factor values of the USLE/RUSLE for use in predicting soil erosion under Tanzanian conditions. The specific objectives of the study were:

1. To develop crop growth curves for estimation of canopy cover and crop heights.
2. To develop crop canopy cover-crop height-yield relationships/equations.
3. To estimate the crop and soil management factor, C.

CHAPTER 2

2 LITERATURE REVIEW

2.1 What is Soil Erosion

Soil erosion is the physical removal of top soil by various agents such as falling raindrops, water flowing through and over the soil profile, wind velocity and gravitational pull (Lal, 1990). The removal of soil materials involves the detachment and transport of soil particles, the process which is common for removing and transporting insoluble soil materials. The removal of soluble materials is caused by both surface and subsurface flow of water (Morgan, 1988). Soil erosion processes have adverse effects on agricultural as well as range lands. Their effects are not only felt in deteriorating the quality of the cropping and grazing lands but also they can cause a great damage to the ecology of water resources. Some of these damages include siltation of reservoirs and rivers which can result in reduced capacity, flood hazards creation, water pollution, destruction of infrastructures, canals and reservoirs (Morgan, 1986).

Soil erosion can be classified into two types, natural and accelerated soil erosion. Natural erosion also referred to as geological or normal erosion is caused by the forces of nature in soil formation and slope evolution process which maintain the soil in a favourable balance (Watson, 1965). This kind of soil erosion does not severely affect the soil and the environment (Hudson, 1981; Morgan, 1986). Erosion becomes a problem when the process is accelerated by human activities therefore bringing imbalance between the soil forming and soil eroding process (Kirby,1980).

Accelerated soil erosion is caused by primary agents of erosion, namely water and wind (Hudson, 1981; Schwab et al., 1981). Wind is the most active erosive agent in arid and semi-arid regions where the soil is often dry with sparse or completely no vegetation. In humid regions where rainfall is in excess of the infiltration capacity of the soil, water plays a big role as an agent of erosion. Soil erosion by water can be classified into rainsplash, overland or sheet erosion, rill erosion, gully erosion and other minor forms such as stream bank erosion and piping. Splash erosion results from detachment and movement of soil particles due to the impact of raindrops on soil surface. Splash erosion may be insignificant on soils protected with vegetation or plant residues, however, it may result into a severe erosion on sloping land where more soil particles are splashed down-hill than up-hill (Schwab et al., 1981). Sheet erosion is probably the most severe form of soil erosion because it removes a thin and relatively uniform layer of soil particles from the soil surface after the soil particles have been detached by the impact of falling raindrops (Kohnke and Bertrand, 1959). Rill erosion comprises the removal of soil particles from small but well defined channels resulting from the concentration of surface flow. When rill erosion continues without being disturbed by normal tillage operations then gully erosion occurs (Lal, 1990). Gully erosion is channel erosion which washes so deep into the soil therefore causing mass movement of soil materials (Temple and Rapp, 1973).

As explained earlier in the introduction, the problem of soil erosion arises due to inappropriate utilization of land and natural resources found on land. The removal of vegetation cover by overgrazing, cultivation and construction works expose bare soil to direct action of raindrops. The action of raindrop impact on soil causes detachment and dispersion of soil particles which seal the soil pores in so doing promoting runoff volume that washes away the soil particles. When this happens, it results in a considerable reduction in the permeability of the newly exposed soil surface, reduced water retention and removal of top soil (Greenland, 1977). Schwab et al. (1981) suggested that the most effective way of controlling soil erosion is by maintaining surface cover and reducing the gradient of surfaces over which water flows.

2.2 Factors Affecting Soil Erosion

The major variables that influence soil erosion by water include climate, soil, vegetation and topography (Lal, 1990). Specifically, the factors that affect the magnitude of soil erosion by water include the rainfall erosivity, soil erodibility, land form and soil surface management (Morgan, 1986).

2.2.1 Rainfall erosivity

Rainfall erosivity is the potential power of rain to cause erosion through the double effect of rainfall splash detaching soil particles and the total amount of rainfall supplying water to overland flow to transport detached soil particles (Stocking et al., 1988).

Erosivity of rain is a function of its intensity and duration, mass, diameter and velocity of the raindrops (Morgan,1986).

Soil erosion is associated with the amount of rainfall, i.e. more rain produces more erosion and vice versa, however, in statistical terms the correlation between rainfall amount and soil erosion is poor (Hudson, 1995) since the same amount of rain can on different occasion result in widely differing amount of soil erosion. The importance of rainfall amount in soil erosion is governing the overall water balance and the relative proportions of rainfall that becomes runoff. Apart from rainfall amount. soil erosion is affected by rainfall characteristics such as the intensity distribution. energy load and its seasonal variability (Kirkby, 1980). Rainfall intensity distribution during a storm affects erosion by altering the amount and rate of overland flow.

In rainfall erosivity calculations, rainfall intensity is regarded as a potential parameter of particular importance since apart from rainfall amount it is the only feature which is frequently recorded at conventional meteorological stations (Hudson, 1995). Regardless of the relative extent of various phases of the erosion process, it may be stated that rainfall intensity is the most important factor governing soil erosion by water (Zachar, 1982). Rainfall amount falling over short duration results in more erosion than when it is distributed over a long period of time, falling gently with low intensity. High rainfall intensity is related both to large drop sizes and high number of drops falling per unit area per unit time, thus, the higher the intensity, the higher the kinetic energy, velocity, momentum or the ability to cause soil erosion. That is why tropical rains with higher intensities than temperate rains, mostly falling in form of convection storms are more erosive (Hudson, 1981; Morgan, 1986). Although the kinetic energy is generally accepted to be a driving force of erosion process, dropsize distribution useful in their calculation is difficult to measure (Hudson, 1981; Lal, 1990). Following these difficulties, empirical equations have been developed relating intensity and kinetic energy or momentum. Researchers such as Wishmeier and Smith (1978), Hudson (1965) and Kinnel (1981) respectively developed the following equations relating rainfall intensity to kinetic energy (Lal, 1990):

$$E = 0.119 + 0.0873\log_{10}I \quad \text{...} (2.1)$$

$$E = 0.298 - 1.275/I \quad \text{...} (2.2)$$

$$E = 0.2983\ (1 - e^{-(0.0477I - 0.112)}) \quad \text{...} (2.3)$$

Where:

E = Kinetic energy (MJ/ha-mm)

I = Rainfall intensity (mm/h)

e = base of natural logarithm.

Basing on the above empirical equations, the kinetic energy of a storm can be calculated by analyzing a trace of rainfall from a recording gauge and then dividing the storm into small time increments of uniform intensity. For each period of known rainfall intensity, the kinetic energy of the rain is computed by one of the equations given above and then multiplied by the amount of the rainfall received so as to obtain the kinetic energy for that period of time. Kinetic energy values obtained for all the time periods are summed together to obtain the total kinetic energy of the storm.

Experiments by various researchers on rainfall erosivity have shown that neither the rainfall amount nor the intensity of rainfall are highly correlated to soil loss (Stocking and Elwell, 1973). This can be explained by the fact that soil loss is a function of rainfall energy which detaches soil particles and runoff energy which is responsible for transporting soil particles by taking the advantage of slope gradient. Through multiple regression, Wischmeier et al. (1958) found that a compound index of kinetic energy and the maximum 30-minute rainfall intensity gave a good estimation of soil loss. The index was termed as the erosivity index. The erosivity index (R) is a product of the kinetic energy of the storm (E) and the maximum 30-minute rainfall intensity (I_{30}). The term I_{30} is computed as twice the greatest amount of rain falling in any 30 consecutive minutes. According to Wischmeier and smith (1978), the product (EI_{30}) is the measure of the manner in which energy and intensity are combined in a storm and defines the combined effects of raindrop impact and runoff turbulence to transport soil particles from the field.

In several studies in the tropics, the EI_{30} index has been found to be less effective as a measure of rainfall erosivity. Hudson (1981) working in Zimbabwe developed KE>25 index as an alternative erosivity index by summing the kinetic energy received in time increments when rainfall intensity equals 25mm/h or greater. This index provided a better correlation to soil loss than the EI_{30} for Zimbabwe. Based on soil erosion-rainfall records at Ibadan, Nigeria, Lal (1976) reported that soil loss from small plots had a better correlation with the product of total rainfall amount (A) and a peak storm intensity (I_m) than either the EI_{30} or KE>25 index. This led to the development of the AI_m index. Although the EI_{30} index has not yet been universally accepted as a measure of erosivity, it remains to be a widely used erosivity estimator (Mulengera, 1996).

2.2.2 Soil erodibility

Erodibility defines the resistance of the soil to both detachment and transport. Erodibility of the soil depends on the factors like topographic position, slope steepness and the amount of disturbance created by man (Morgan, 1986). Apart from these factors, soil erodibility is strongly affected by soil properties. Soil erodibility varies with soil texture, structure, aggregate stability, shear strength, infiltration capacity, organic and chemical content (Morgan, 1986).

Soil texture is an important factor influencing erodibility through its effects on both the detachment and transport processes, and the ease with which the soil can be dispersed. While large soil particles resist transportation of fine soil particles provide resistance to detachment due to their cementing effects (Morgan, 1986). Soil structure affects soil's resistance to erosion depending on the way it influences resistance to soil dispersion by water by binding together the soil particles and allowing the transmission of water through the profile due to the presence of relative proportions of macro and micro pores (Lal, 1990). Organic matter and clay minerals influence the soil structural stability. It has been found that soils with high organic matter content are less susceptible to erosion than those with low organic matter. This is because soils with high organic matter have high water retention capacity, therefore reduced rainfall erosive potential (Mulengera, 1996).

Direct measurements of soil erodibility using natural rainfall is costly to perform and requires a considerable time and equipment. Thus, relating a few measured soil erodibility values to soil properties affecting soil erodibility have been used (Morgan, 1988; Lal, 1990). Wischmeier et al. (1971) developed a nomograph of soil erodibility values based on the following soil parameters: silt plus very fine sand, organic matter content, soil structure and soil permeability. Since a limited number of soils were used in preparing the nomograph, consequently the K values from the nomograph are unrealistic and cannot be used in the tropics (Ngatunga et al., 1984; Mtakwa et al., 1987; Lal, 1990).

2.2.3 Topographic factor

The topographic factor represents the combined effect of slope length and slope steepness. The degree of slope, the slope length and the shape of the slope affect soil erosion by affecting rainfall splash and the transport capacity of runoff. Erosive power of rainfall increases with the increase of slope steepness (Foth, 1984). The amount and velocity of overland flow is also influenced by the shape of the slope. Meyer et al. (1975) have shown that convex slopes increase erosion while concave slopes experience reduced soil loss with respect to uniform slope gradient.

2.2.4 The vegetation cover

Vegetation cover has a great influence in soil erosion control. Vegetation cover protects soil against rain splash by intercepting the raindrops so that their kinetic energy is dissipated by the plants rather than impacting the soil. On the other hand, low level cover on the ground reduce the ease with which water can pass through therefore encouraging deposition of eroded materials (Cogo et al. 1984).

Many field experiments have been conducted to investigate the effect of canopy and ground cover on erosion. Hudson and Jackson (1959) found that the mean soil loss over a ten year period was 126.6 kg/m^2 for the bare plot and 0.9 kg/m^2 for the plot covered by the mosquito gauze. Hudson (1981) working at the Henderson Research Station in Zimbabwe found that in the period of 1953-56 mean annual soil loss from bare ground was 4.63 kg/m^2 compared to 0.04 kg/m^2 from the ground with a dense cover of *digitaria.*

In similar research, Purwanto (1992) working on the effect of different land cover systems in Java, Indonesia, found that the rate of soil erosion under the forest stand was 0.07 1 t/ha/year when compared to soil loss rates of 22.3 t/ha/year and 5.8 t/ha/year from bare land and the land under annual crops.

The effect of plant cover in controlling soil erosion depends on some factors like the type of the canopy, the density of the ground cover and the root density. Apart from these factors, the height of the canopy is important. Foster et al. (1988) found that runoff and soil loss decreased with increased ground and canopy cover but increased with increased height. This was attributed to the intercepted raindrops that coalesced in the leaves to form larger raindrops with substantial high amount of terminal velocity upon falling (Morgan, 1986).

Other plant characteristics apart from the percentage canopy cover and the canopy height which provide protective effect to the soil include the leaf foliage and root growth characteristics (Morgan, 1988; Dissmeyer, 1982). Plant roots play an important role in controlling soil erosion by holding together soil particles therefore improving soil structure.

2.2.5 Soil surface management

Soil surface management has influence on the amount of soil erosion which occurs under given conditions. Different land tillage management have different effects on soil erosion. Generally, smooth land tillage management is more erosive than conservation tillage (Cogo et al., 1984). Conservation tillage which leaves the tilth of soil surface cloddy and with a crop residue cover has shown to result in soil surface that resist crusting. This promotes high infiltration rates compared to highly pulverized soil surface (Lal, 1990). Practices like no tillage have been found to increase the percentage of water stable aggregates in the soil compared with disc cultivation and ploughing (Morgan, 1988). Soil erosion is also influenced by the direction of ploughing operations in relation to land slope. Normally, high amount of soil erosion is produced when the land is ploughed up and down the slope than when the same land is ploughed across the slope.

Normal crop and soil management practices are not always enough to prevent excessive soil loss. Special support practices are sometimes needed to provide more protection to soil (Troeh et al., 1980). The most important of these support practices are the contour tillage, strip cropping and terracing with vegetated water ways (Wischmeier and Smith, 1978; Troeh et al., 1980). Contour cultivation reduces soil erosion during low to moderate intensity rainstorms however, it is seldom effective against severe storms. Experiments indicate that contouring is most effective on middle range slopes from 2 to 7 percent and less effective on flatter and steeper slopes (Wischmeier and Smith, 1978; Hudson, 1981). Ridging of the soil is an important cultivation practice in many parts of Africa. In Tanzania, different forms of ridges and other practices are found depending on the traditional agricultural systems practiced by certain tribes. A good example of this is the Matengo pits (*Ngoro*) which are effective in reducing soil loss in cultivated mountainous areas of Mbinga district in Ruvuma region, Southern Tanzania (Msanya et al., 1995).

2.3 Soil Erosion and Conservation in Tanzania

Soil erosion has been recognized and reported to happen in Tanzania as far back as the late 19th century. Authors like Berry and Townshend (1973), Kullayar and Parkers (1973) reported on the existence of soil erosion and the conservation measures carried out by a number of tribes on agricultural lands back in the 18th and 19th centuries. By 1920, soil erosion was recognized as a serious problem particularly on the wetter, densely populated and highly mountainous areas of Usambara, Kilimanjaro, Meru, Uluguru and the Southern highlands due to forest clearing brought about by the practice of shifting cultivation (Temple, 1973). Soil erosion during those times was also reported to occur even in drier, gentle slopping plateau of central Tanzania (Watson, 1973). Gillman (1930) pointed out that areas like Kondoa in Dodoma region and other areas in Singida, Tabora and Shinyanga regions were typical areas of advanced soil erosion in semi-arid areas.

The colonial government started conservation schemes such as those in Uluguru mountains, the Uluguru forest conservation scheme and others in other parts of the country. As a result of the efforts by the colonial government, conservation schemes were widespread in Tanzania in 1940s. Great emphasis of early colonial soil conservation schemes were tree planting and forest conservation to minimize soil erosion. Experiments on demonstration of structural measures of controlling soil erosion like contour bunds, bench terracing, tie ridging, large scale burning prevention, land use schemes and agricultural demonstration plots were introduced (Temple, 1973; Watson, 1973). Different research stations were established during those times for soil erosion and conservation research. The establishment of Ukiriguru Agricultural Research Station for determination of cotton yield on various land management and the start of the experiments on gathering quantitative data on runoff and soil loss at Mpwapwa in 1933 with the aim of obtaining data on runoff and soil loss in semi-arid areas of Tanzania are some of the examples. However, the data collected from the research stations were few and inadequate to provide a general picture of soil erosion in the areas (Kauzeni et al., 1987).

Most of the schemes started by colonial government for soil conservation were however abandoned in the 1950s because of a number of factors. Some of the factors included poor performance of established schemes caused by the shortage of trained technical staff and the fact that conservation was a political issue (Berry and Townshend, 1973).

Widespread measures of soil conservation were introduced after independence in the five year plan of 1969 to 1974 following the severity of soil erosion in areas like Kondoa in Dodoma region and Uluguru mountains in Morogoro region. In the plan a national soil conservation project known as Hifadhi Ardhi Dodoma (HADO) was established in 1973 (Mbegu and Mlende, 1983) followed by the introduction of the national afforestation campaign in 1980s. Although all these measures have been taken in soil conservation, they have so far failed to produce fruitful results, therefore leaving soil erosion and land degradation to be severe problems in Tanzania (Mulengera, 1996).

2.4 Soil Erosion Prediction

The purpose of soil conservation is to obtain maximum sustained level of production from a given area of land while maintaining soil loss below threshold level which permits the natural rate of soil formation to keep pace with soil erosion (Maene and Sulaiman, 1980). This can be done by selecting appropriate strategies for soil conservation. Rate of soil erosion depends on a complex interrelationship between erosivity of rainfall and runoff and the vulnerability of soil to detachment by erosive forces (Ulsaker and Onstad, 1984). The complexity of soil erosion system with its numerous interacting factors require the most promising approach for developing a predictive procedure that gives the relation between the interacting factors and soil loss. Therefore, planning for conservation requires a predictive method which is applicable under a wide range of conditions. Among the methods applied in predicting soil erosion include the application of several predictive equations or models which are based on defining important factors which can be related to the measurements of soil loss. The first equation for predicting soil erosion was proposed by Baver (1933). Hudson (1961) suggested an equation similar to the universal soil loss equation during the time when existing erosion prediction equations were being reviewed. Presently, a number of equations for predicting soil erosion exist. However, the most widely applied equation is the Universal Soil Loss Equation or its revised version (RUSLE) (Wischmeier and Smith, 1978: Renard et al., 1991). In USLE the annual soil loss is correlated with rainfall erosivity, soil erodibility, length and steepness of the slope, crop and soil management and soil conservation practices. The USLE is expressed (Wischmeier and Smith, 1978) as:

$$A = R * K * L * S * C * P \qquad (2.4)$$

Where:

A = Predicted soil loss (t/ha-yr)

R = Annual rainfall erosivity index (MJ-mm/ha-h-yr)

K = Soil erodibility factor (t-ha-h/ha-MJ-mm)

L = Slope length factor

S = Slope steepness factor

C = Crop and land management factor

P = Support practice factor

The USLE was primarily developed to calculate soil loss from farm lands. However, since its development it has been modified and used extensively in USA and other parts of the world to predict soil loss from grazing lands and construction sites (Morgan, 1988; Lal, 1990). The problems of using the USLE in other regions with conditions different from where it was developed have been recognized by several researchers.

Elwell (1978) working in Zimbabwe found that the USLE mispredicted soil loss even after careful calibration. This led to the development of soil erosion prediction model widely used in Zimbabwe. The model known as Soil Loss Estimation Method for Southern Africa (SLEMSA) resembles the USLE, however, it considers the erosivity, erodibility and crop cover and management factors differently.

Apart from empirical models, sound physically based erosion prediction models exist. Their practical use is still limited because they require extensive analysis of the current knowledge of soil erosion science for their refinement and they also still need improved data base (Morgan, 1994). Furthermore, the research required for improving and making the physically-based models practical cannot be made by most of the developing countries like Tanzania (Mulengera, 1996). Therefore, the only alternative is the adaptation of the USLE and / or the SLEMSA model.

2.5 Evaluation of USLE Factor Values

2.5.1 Introduction

As it was stated earlier in chapter one that the application of the USLE or its revised version (RUSLE) for predicting soil erosion in tropical regions, Tanzania in particular has shown to give problems (Ngatunga et al., 1984; Mulengera, 1996). The use of the USLE for Tanzanian conditions requires evaluation and modifications of some of the factors of the equation to suit the prevailing local conditions. In achieving this, my study mainly involved in developing crop functions useful in estimating the crop and soil management factor, C, of the USLE under Tanzanian conditions. In this work, other sub-factor values will be used as suggested by previous researchers (Wischmeier and Smith, 1978; Dissmeyer, 1982) since it was not a scope of this research to work on them.

2.5.2 Crop and soil management factor

The crop and soil management factor in the USLE or RUSLE measures the effect of crop and soil management on soil's resistance to erosion and the effect of plant cover, roots and their residues on eroding power of rainfall (Mulengera, 1996). It is the ratio of soil loss from an area with specific cover and management to that from an identical area in tilled continuous fallow condition (Renard et al., 1994). How much soil loss from cropped field compared to fallow depends on the particular combinations of cover, crop sequence and management practices. It also depends on a particular stage of growth and development of vegetal cover at the time of the rain. The correspondence of periods of expected highly erosive rainfall with periods of good or poor plant cover differs between regions or locations. Hence the C value for a particular cropping system will not be the same in all parts of the country. Deriving the C values for a given locality requires knowledge of how the erosive rain in that locality is distributed throughout the year and how much protection is given to soil from growing plants, crop residues and how much protection the selected management practices provide at the time when erosive rains are occuring.

The crop and soil management factor is the most important USLE/RUSLE factor because it represents conditions that can most easily be managed to control soil erosion. Lal (1990) found that research results obtained from a range of soils and climatic conditions indicated that the best method of soil control is good crop and soil management. The empirically determined crop and soil management factor (Wischmeier and Smith, 1978) uses factors from tables of values obtained from field studies based on local agricultural systems and management in USA. These values are not directly applicable to the tropics (Elwell, 1978; Lal, 1990). The use of these values to untested areas can be done by separating their total influence into the effects of sub-factor values (Wishmeier and Smith, 1978; Dissmeyer, 1982). Recent revisions of the USLE (the RUSLE) use a sub-factor method to compute the crop and soil management factor (Renard et al., 1994) as a function of four sub-factors given as:

$$C = CC * SR * SC * PLU \qquad \text{..(2.5)}$$

Where:

C = Cover and management factor

CC = Canopy cover sub-factor

SC = Surface or ground cover sub-factor

SR = Surface roughness sub-factor

PLU = Prior land use sub-factor

As it can be seen from equation 2.5 that the value of C on a particular field is determined by many variables. Major variables include crop canopy, residue mulch, incorporated residues, tillage, land use residual and other interactions. Each of these effects may be treated as a sub-factor whose numerical value is the ratio of soil loss with the effect to the corresponding loss without it (Wischmeier and Smith, 1978; Renard et al., 1994). The C factor is the product of all the contributing sub-factors.

(i) Canopy cover sub-factor

The role of canopy cover in soil loss estimation is in rainfall interception before reaching the soil surface. Rainfall interception assists in reducing the kinetic energy of raindrops striking the soil surface, in so doing reducing soil loss (Elwell, 1978; Morgan, 1986). The effectiveness of canopy cover in soil erosion protection depends on the type of the canopy, the density of the cover and the height of the canopy. Assuming that the fraction of rainfall intercepted by the canopy was equal to the fraction of land surface covered by canopy and that the rainfall intercepted by the canopy reached the ground as 2.5mm diameter drops, Wischmeier (1975) derived an equation and from the equation, he constructed curves for estimating canopy cover effects on reducing rainfall erosive potential (Figure 4.15, Appendix 3). The equation developed by Wischmeier (1975) is:

$$CC = 1 - [(Et - Eh) / Et] * Fc \qquad (2.6)$$

Where:

E_t = Total kinetic energy of rain

E_h = Kinetic energy of rain dropping from canopy at a given effective canopy height, which equals to 0.6 of the total height of the crop.

F_c = Fraction of surface covered by crop canopy.

Since the effective height of plant will vary with plant characteristics, rainfall interception values will differ from one type of plant to another depending on their growth characteristics.

Ghebreiyessus and Gregory (1987) suggest that there is a relationship between canopy cover-time of development-height of canopy and yield. It is the aim of this research work to investigate the practical use of the suggested relationship by developing canopy cover-height of canopy-yield functions/curves for maize and sorghum by performing regression analysis. The functions obtained from the analysis will be used together with equation 2.6 or Figure 4.15 (in Appendix 3) to develop canopy cover sub-factor values over the growing season for maize and sorghum crops using my own data and data from earlier researchers. This can help to eliminate the necessity of conducting field measurements whenever the canopy cover sub-factor is to be estimated.

(ii) Surface roughness sub-factor

Random roughness of the soil surface can be used to predict the effect of surface roughness on soil erosion. A number of researchers have shown that there exist a relation between rainfall and surface roughness change (Dexter, 1977; Römkens and Wang, 1987; Zobeck and Onstad, 1987; Mwendera, 1992). These findings suggest that change of surface roughness with rainfall can be modeled using either kinetic energy or cumulative rainfall (Mwendera, 1992; Mulengera, 1996). The change of roughness in relation to rainfall event has been found to be in the form of:

$$RR = ae^{-bc} \qquad (2.7)$$

Where:

RR = Ratio of measured random roughness to initial random roughness

a and b = Constants

c = Cumulative rainfall or kinetic energy

e = Natural logarithm

In addition, the curves obtained have been shown to be variable in shape, exhibiting high variability in a and b constants. These variations have been attributed to the fact that the equations depend on a number of factors such as the nature of surface roughness, the soil type, reconsolidation, soil moisture, rainfall characteristics, previous management history and soil aggregation (Zobeck and Onstad, 1987). Surface roughness affects soil erosion by reducing both the speed and amount of runoff water. This happens when runoff water is retained in depressions created by rough surfaces, thus reducing its erosive force and promoting deposition of eroded soil particles carried by runoff water. Generally, rougher surfaces are resistant to soil erosion than smoother ones. Surface roughness offer protection to soil loss in so doing affecting the C values. Rough soil surfaces give small soil loss ratios compared to smoother surfaces.

A number of researchers have come up with different techniques for estimating surface roughness (Kuipers, 1957; Dexter, 1977; Wischmeier and Smith, 1978; Dissmeyer, 1982; Römkens and Wang, 1987; Zobeck and Onstad, 1987). Wischmeier and Smith (1978) developed the coefficients for surface roughness from the USLE soil loss ratios and Wischmeier's (1973) analysis of conservation tillage system. In their development, the ratio of soil loss for the fallow plot to that for the seedbed plot was a measure of the effect of surface roughness. Dissmeyer (1982) developed surface roughness values for different surface roughness conditions (Figure 4.14, Appendix 3). These techniques for estimating surface roughness were also applied in this research work.

(iii) Ground cover sub-factor

Ground or surface cover is the term of the sub-factors having the greatest effects on soil erosion. As it is used in the USLE or its revised version (the RUSLE), surface cover reflects residue mulches from close growing vegetation covering the soil surface. Surface cover or mulches are more effective in controlling soil erosion than equivalent percentages of canopy cover. Mulches intercept falling raindrops so near the surface that the drops regain no fall velocity. In some research studies, a 50 percent cover reduced soil loss by about 65 percent while in other studies a 50 percent cover reduced soil loss by 95 percent (Renard et al., 1991). Also, mulches obstruct runoff flow and thereby reduce its velocity and transport capacity (Wischmeier and Smith, 1978). The surface cover sub-factor can be estimated using the relation (Renard et al., 1994):

$$SC = e^{-ab} \quad \text{..} (2.8)$$

Where:

SC = ground or surface cover sub-factor
a = coefficient
b = fraction of land surface covered by mulch or crop residue

The effect of surface cover on agricultural soils can also be given by the Wischmeier's (1975) mulch effect curve. Dissmeyer (1982) incorporated some modifications to Wischmeier's (1975) curve for estimation of surface cover sub-factor for forest lands.

(iv) Prior land use sub-factor

The prior land use sub-factor includes the effects of plant roots, long term plant residues incorporated by ploughing, changes in soil structure, detachability, organic matter content and soil reconsolidation (Dissmeyer, 1982). Factors have been developed due to reconsolidation, organic matter content and residue effect to form the prior land use sub-factors (Wischmeier and Smith, 1978; Dissmeyer, 1982). The developed factors are used together with other factors to estimate the C factor value.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 The Study Area

3.1.1 Location

The experimental site is located at Sokoine University of Agriculture farm about one kilometer north-west of the University main gate. The area is representative of the agro-climatic conditions and major soils found in Morogoro region. The SUA farm is situated west of Morogoro town at about latitude 6 °50'S and longitude 37° 39' E. The farm lies close to the foot of Uluguru mountains at an elevation of about 500 m above sea level (Sampson and Wright, 1964).

3.1.2 Climate

The study area has a sub-humid tropical climate with total annual rainfall of about 800 to 900 mm. The rainfall pattern is bimodal with short rains starting in October and ending in mid February followed by long rains starting in late February and ending in May (Mulengera and Ngobei, 1990). The mean monthly temperature vary from about 21°C in June and July to 26°C in November to February. Mean monthly maximum temperature vary from about 27.5°C during the coldest months to 32°C during the hottest months.

The mean minimum monthly temperature ranges from about 15°C during the coldest months to 21.5°C during the hottest months (Kaaya, 1989).

3.1.3 Geomorphology and soils

The study area exhibit a gentle geomorphic feature with an average land slope of about 3%. Soils found in the SUA farm are mainly Acrisols, Ferrasols and Luvisols with moderate to low cation exchange capacities (Sampson and Wright, 1964). According to soil survey and crop production suitability assessment done by Kaaya (1989), the area falls under moderately suitable class with fertility, moisture availability and erosion hazards as subclass limitations.

3.1.4 Vegetation and land use

The natural vegetation of the area is the miombo woodland dominated by the *Brachystegia species*. The main crops grown in the area are maize, sorghum and cowpeas. Land preparation for tillage is normally done before the onset of the rains. Some cultivation operations are done in October during short rains or *Vuli*, however, the main tillage operations are performed during long rains or *Masika*, the period which starts in January and sometimes up to March in case of delayed rains.

3.2 Experimental set-up and data collection

The preparations of the experimental site started in February, 1998. These included the general cleaning of the site and minor repairing of already established runoff plots and sediment collection system. The runoff plots dimensions were in accordance to the Universal Soil Loss Equation standard plot (i. e. they were 22.1 m long and 4.5 m wide). The plots were large enough to represent the combined process of rill and interrill erosion, and they were sufficiently wide to minimize border effects. The runoff plots had borders on their upper and lateral sides. Borders were of corrugated iron sheets, buried to a depth of 20 cm and protruding 10 cm above the ground. These prevented water entry into the plots from surrounding areas thus making each plot a complete drainage area. Each runoff plot was attached to a runoff and sediment collection system at the lower side. The collection system consisted of a collection channel and two concrete tanks, with the capacity of 1.0 m^3 each. The first tank to receive runoff from the runoff plot had a multi-slot divisor with nine slots. Water with suspended sediments therefore passed from the central groove to the second tank. That is, the second collecting tank was able to accumulate 1/ 9 of the runoff water and suspension from the first tank.

3.2.1 Experimental procedures

The experimental runoff plots layout was a randomized block design (RBD) which was laid out during the three previous studies (Figure 3.1) with the following treatments: plots cropped with maize, plots cropped with sorghum, plots under semi-natural vegetation and bare plots. There were twelve plots in total. of which four plots were planted with maize, four other plots with sorghum, two plots were under semi-natural vegetation and the remaining two plots were kept bare.

At the experimental site, two types of rain gauges were installed: a standard non-recording rain gauge and an autographic recording rain gauge. While the autographic recording rain gauge provided continuous measurements of rainfall intensity, the readings from the standard non-recording rain gauge verified the daily accumulated rainfall. Although at the beginning there was a problem of pointers and proper recording charts for the rain gauge, the problem was solved by the help from University of Dar-Es-Salaam meteorological station.

3.2.2 Treatments and agronomic practices.

Tillage operations were done in March, 1998 on plots which required tillage as a treatment. Cultivation up and down the slope using a disc plough was carried out on all plots with the exception of the plots under semi-natural vegetation. The corrugated iron sheets bordering the plots on both the upper and lateral sides were removed prior to land tillage and their replacement was done soon after ploughing. Worn out and torn corrugated iron sheets were replaced by new ones. Bare fallow plots were hoed by using a hand hoe to break any clods remaining and then they were raked up and down the slope after repositioning of the corrugated iron sheets around the ploughed plots. Other field operations such as planting, weeding and fertilizer application were performed manually.

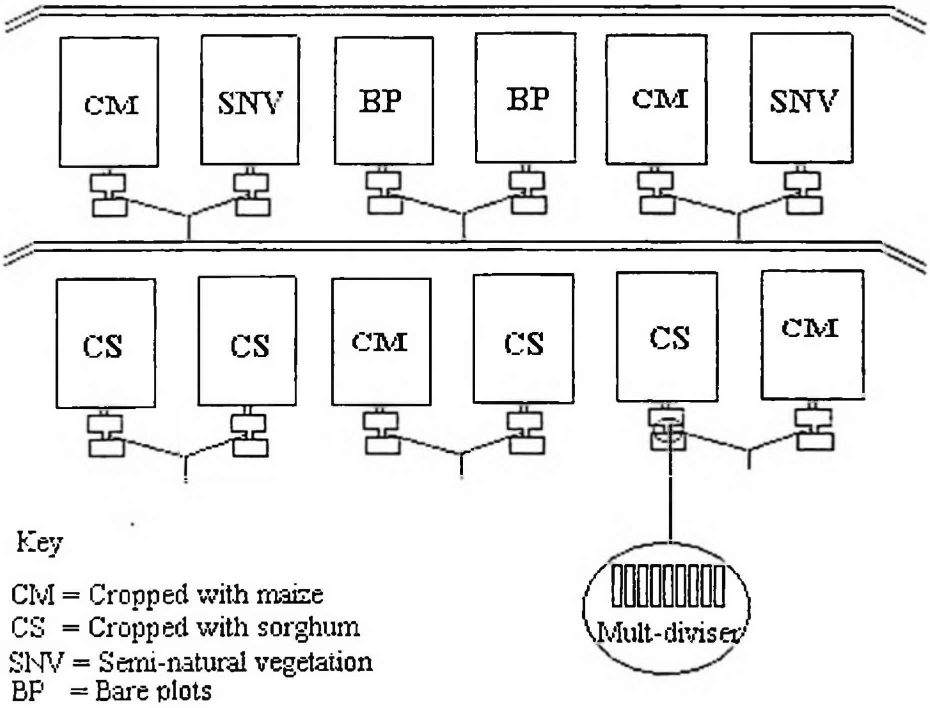

Figure 3.1: **Layout of the plots at the study site.**

Maize (*Zea mays*) *Staha* variety recommended for Morogoro region was planted in rows running up and down the slope with inter-line and inter-plant spacing of 90 cm and 30 cm respectively. Also, sorghum *Tegemeo* variety recommended for semi-arid climate was planted in the same manner with inter-line and inter-plant spacing of 80 cm and 30 cm respectively. Maize plots were planted on 29/03/1998 and sorghum plots were planted on 30/03/1998. Germination was about 100% but rodents pulled off some of the newly germinated seedlings. Since transplanting was not possible for maize seedlings as it is for the case of sorghum, replanting was done where seedlings were missing. Although reseeding operation was done for those holes without seedlings, still rodents pulled some of the newly germinated seeds thus, reducing the plant population in some of the plots.

Thinning operation was performed when the crop attained a height of about 15cm, leaving each hole with one seedling for both maize and sorghum crops. Hand hoe weeding was carried out once during the growing season. To ensure that plots were free from weeds during the growing season, hand pulling of weeds was done. Hand pulling was also performed several times on the bare plots to keep them free from weeds since the rate of weed growth was high during the growing period.

Fertilizer was applied as recommended for Morogoro region at a rate of 50 kg/ha of NPK at planting and 160 kg/ha of CAN after the first weeding (Mowo et al. 1993). Stalk borers were common pests which mainly affected sorghum during the 5th and 6th weeks of the growing period. Chlorpyrifos (diethly-trchloro-2-pyridyl) insecticide was applied at a recommended concentration to control the pests. Only one application was found to be satisfactory.

Grain yield was determined by harvesting all crop stands within the plot. Harvesting started by cutting the maize stalk flush with the soil surface, then maize cobs were hand peeled, air dried for some days and then shelled. Dry shelled grains were weighed and their yield per harvest plot area was determined. Data recorded included sun-dried weight of shelled crops for each plot and their corresponding oven-dried weights. Similar procedure was applied in harvesting and determining the weight of sorghum crop. These yield data together with yield data from previous researchers were employed in developing canopy cover-yield curves.

Runoff plots were managed by myself and one labourer who guarded the plots during the day and assisted with data collection. Hired labour was frequently sought when field activities exceeded our ability. There were also two night guards who kept a constant eye during the night since the site lies in an isolated area, a little bit far from residential areas.

3.2.3 Rainfall volume and intensity measurements.

The amount of rainfall was measured using both the standard rain gauge and an automatic rainfall recording gauge installed at the runoff plot site. Rainfall intensity was computed using the results from the recording rain gauge charts. Since the rain gauge chart used was that which operates for 24 hours, the total rainfall was divided into uniform intensity ranges of 15 minutes.

3.2.4 Runoff and soil loss measurements.

Runoff and soil loss from the entire plot were collected through the collection channel towards the collection tanks at the lower end of each runoff plot. The collection channel was connected to the collection tank by a buried plastic pipe. Runoff and soil loss data were collected and measured after every rainfall storm whenever it was possible. Runoff volume was measured by using a graduated wooden ruler. Soil loss was measured after collecting the sediments settled down the bottom of the concrete tanks. Desludging of the tanks started in the mornings following rainfall event. A flocculating agent (Calcium chloride) was added to the runoff suspension so as to aid fast settling of the sediments in the collected runoff, and then clear water was carefully drawn off the tanks using small containers leaving behind wet soil. Wet soil was carefully removed from the tanks and put into plastic containers, air dried at the plot site by spreading them on the plastic sheets and then weighed. Sub samples were taken from air dried sediments for determination of oven dried weight at 105°C for 24 hours for the calculation of the oven-dried soil losses from the plots. The dry weight of each soil sample was determined by subtracting a known weight of the metal containers from the total weight of the metal container plus dried soil. This weight was then correlated to the original weight of sun dried soil collected from concrete tanks to obtain total dry soil weight for the entire plot.

3.2.5 Measurements of canopy cover and crop height.

Canopy cover and crop height development were measured on three sub-areas of 1.0 m^2 in each of the plots with maize and sorghum crops. The sub-areas in cropped plots were randomly determined by assigning numbers on the crop lines and then the table of random numbers (Chatfield, 1991) were used to obtain the line numbers on which the sub-areas would be located. Then the numbers ranging from zero to the length of the plots were randomly obtained for each line from the table of random numbers to locate the exact position where the sub-area would be located.

Measurements of canopy cover and crop height development were conducted after every ten days but sometimes field conditions hindered this exercise. The canopy cover was determined by the use of a quadrant sighting frame . The frame consisted of a horizontal wooden bar having 10 small holes drilled at regular intervals of 10 cm along it so that an observer may peer through the hole and see the small area of the ground. The frame was four-legged and had to be leveled and firmly pushed into the ground. Leveling was done using a spirit bubble. An observer simply records the presence or absence of a leaf covering the ground. A hole observation was regarded to have vegetation cover only and only if half or more of it was occupied by the leaf and none if less than half of the hole was occupied. One hundred observations were made for each sub-area making a total of 300 observations per plot. The average of the sights gave the average canopy cover in percentage of the plot at a given period. In addition to the quadrant sighting frame, the mirror sighting frame was employed when the crops grew tall, therefore making the quadrant sighting frame unsuitable for canopy cover measurements.

Measurements of crop height development were taken from the surface of the ground to the top bending leaf using a steel tape attached to the wooden bar. Crop height measurements were taken from the plants found in the sub-areas throughout the growing season. The average heights of crops for each sub-area was found and then the average height of crops from the sub-areas for each plot were summed, divided by the number of sub-areas per plot to get the average height of crops in the plot.

3.3 Data analyses

Data analyses were done both manually and with the aid of computers. Microsoft Excel program was used for statistical analyses in determination of crop development-canopy cover-yield relationships.

Rainfall intensity data from rainfall charts were used to calculate kinetic energy using the equation 2.3 proposed by Kinnel (1981) for tropical storms and rainfall erosivity (EI_{30}) values for SUA farm during the study period. The Charts analyzed were those for erosive storms. The 30-minute maximum intensity of rainfall (I_{30}) was obtained from the automatic rain gauge charts by taking the greatest amount of rainfall in any 30-minutes of the storm. The intensity of rainfall was obtained by doubling the 30-minutes maximum intensity.

The soil loss data collected from bare plots, plots under maize, sorghum and semi-natural vegetation during the research period were used to calculate the observed C factor values for each treatment (Table 4.11 in Appendix 4). The sum of the C factor values for each treatment gave the C factor for 1998 season.

Data on canopy cover and crop height development for maize and sorghum crops collected during the study period were summed and their average values were determined. Also, yields for both maize and sorghum crops during the study period were determined. Other data on canopy cover, crop height development and yield were obtained from previous researchers (Mulengera, 1996; Shayo, 1997; Rushomesa, 1998). The measured data for canopy cover and crop height development for maize and sorghum crops were used to develop canopy cover and crop height development curves for 1998 season. These figures were then used with Figure 4.15 (Appendix 3) abstracted from Dissmeyer (1982) to obtain canopy cover sub-factor values which were then multiplied with other sub-factors (Section 2.5.2) to give the estimated C factor values for maize and sorghum crops for given rainfall storm events during the growing season. The estimated seasonal C factor values were calculated by multiplying the estimated storm-based C factors with their respective rainfall erosivity distribution ratios.

Available data for maximum canopy cover and maximum crop height attained by each crop from each year (1994, 1995 and 1998) were regressed against their respective yields to obtain equations for predicting maximum canopy cover and maximum crop height for any given yield level. Yield and canopy cover data for 1996 and 1997 were not included in the analysis because crop height data not corrected.

Crop development curves (canopy cover and crop height) for maize crop were plotted for years under consideration. From the curves, a crop growth curve resulting from rainfall distribution pattern similar to that for average long term rainfall distribution was considered as an average curve. From the average curve, growing crop canopy cover to maximum crop cover ratios and growing crop height to maximum crop height ratios were plotted against crop growth period ratios to obtain a curve representing the variation of canopy cover and crop height ratios with crop growth period ratios. This curve can was to determine the long term soil and crop management factors.

In estimating the USLE's crop and soil management factor using the sub-factor method, not all the sub-factor values discussed in section 2.5.2 have established methods of their estimation. In many cases, the estimation of such values is based on subjective judgement especially when considering the farming system which has not been evaluated through runoff plot studies. During the research period, the surface roughness sub-factor was estimated using Figure 4.14 (Appendix 3) developed from table values of soil loss ratios (Wischmeier and Smith, 1978) which resulted from subjective analysis of conservation tillage by Wischmeier (1973) abstracted from Dissmeyer (1982). The effect of prior land use binding sub-factors for this study were estimated based on subjective judgements as explained in section 4.4. The canopy cover sub-factor was estimated using the growth curves (Figures 4.1 and 4.2) and Figure 4.15 (Appendix 3) abstracted from Dissmeyer (1982). The crop and soil management factor value for individual soil loss events was a product of the sub-factors discussed above.

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 Rainfall Energy, Erosivity and Soil loss

The total amount of rainfall recorded at the runoff plot site during the study period (late March to early June, 1998) was 339.75 mm, out of which 240.5 mm (71 percent) were erosive rainstorms. The highest rainfall amount recorded was 58 mm which fell on 17/04/1998, with a duration of two hours.

Table 4.1 shows the rainfall energies and erosivity values calculated from 1998 season rainfall data. During the research period, the highest recorded kinetic energy of rainfall (E) and erosivity (EI_{30}) for the runoff plot site were 1006.84 J/m^2 and 332.26 Mjmm/ha-h, respectively. The total rainfall energy and erosivity were about 5007 J/m^2 and 1228 Mjmm/ha-h, respectively.

The amount of soil loss recorded during the research period were 0.14 t/ha for plots under semi-natural vegetation, 0.68 t/ha for plots under maize, 0.79 t/ha for plots under sorghum and 7.93 t/ha was for bare plots resulted from total erosivity value of 1228.00 MJmm/ha-h. Similar trends were obtained from previous researchers where Mulengera (1996) obtained soil loss of 12.974 t/ha from bare plots, 0.907 t/ha from plots under maize and 0.496 t/ha from the plots under semi-natural vegetation resulted from a total erosivity of 1012.95 MJmm/ha-h.

It can be seen that, for each rainfall event, bare plots registered the highest total soil loss followed by the plots under sorghum crop, the plots under maize and lastly the plots under semi-natural vegetation which registered the least soil loss. This is in agreement with the previous researchers at the site (Mulengera, 1996; Ngalesoni, 1996; Shayo, 1997: Rushomesa, 1998) who obtained similar trends.

4.1.1 Rainfall amount and soil loss

During 1998 season, rainfall amount did not always give a good relationship with soil loss (Table 4.1). There were some instances where relatively small amount of rainfall produced high amount of soil loss and vice versa. This may have been brought about by moisture saturation in the soil and the action of rodents, burrowing animals and insects. When simple linear regression was used to fit rainfall amount to soil loss for 1998 rainfall amount and soil loss data for bare plots, rainfall amount proved to have a poor relationship with soil loss with $r^2 = 0.52$. Similar results were reported by Foster et al. (1982) who found that r^2 ranged between 0.11 to 0.53. Ngalesoni (1996) working at the same site found a very poor relationship between rainfall amount and soil loss with $r^2 = 0.1$.

Table 4.1: Rainfall energy, erosivity values and soil loss for runoff plots at SUA farm.

Date	Rainfall (mm)	E (J/m^2)	EI$_{30}$ (MJmm/ha-h)	Soil loss (t/ha) CMP	CSP	SNV	BP
09.04.98	24.00	242.09	25.42	0.02	0.03	0.01	0.28
10.04.98	26.75	550.24	187.08	0.05	0.06	0.02	1.60
11.04.98	20.25	146.12	14.61	0.03	0.02	0.01	0.20
12.04.98	12.00	251.88	52.89	0.03	0.04	0.00	0.54
15.04.98	11.75	201.03	32.65	0.02	0.03	0.00	0.32
17.04.98	58.00	1006.84	332.26	0.32	0.35	0.06	2.41
25.04.98	55.50	788.48	157.70	0.08	0.09	0.02	1.10
29.04.98	34.50	388.79	85.53	0.04	0.05	0.01	0.49
30.04.98	15.00	123.57	9.90	0.01	0.02	0.00	0.05
02.05.98	28.50	416.82	108.37	0.03	0.04	0.01	0.42
03.05.98	25.75	290.20	37.73	0.02	0.02	0.00	0.08
05.05.98	18.25	485.59	169.96	0.03	0.04	0.01	0.42
12.05.98	9.50	115.76	13.89	0.00	0.00	0.00	0.02
Total	339.75	5007.41	1228.00	0.68	0.79	0.14	7.93

CMP = plots cropped with maize

CSP = plots cropped with sorghum

BP = bare plots

SNV = plots with semi-natural vegetation

The relationship between rainfall amount and soil loss for 1998 season was expressed as:

$Y = 0.034x - 0.248\ (r^2 = 0.52)$...................................(4.1)

Where:

Y = Soil loss (t/ha)

x = Rainfall amount (mm)

4.1.2 Rainfall erosivity and soil loss

For 1998 season a compound erosivity index (EI_{30}) gave a good relationship with soil loss for bare plots. Generally, storms with high EI_{30} values resulted in relatively high soil loss. The results for linear regression analysis indicated that there was a good relationship between EI_{30} index and soil loss at SUA Farm runoff plots with the coefficient of determination (r^2) of 0.85. Ngalesoni (1996) in a similar analysis had r^2 ranging from 0.44 to 0.92. Salako et al. (1991) also found a good relationship between the parameters in a similar study in Southern Nigeria. The relationship between soil loss and EI_{30} for 1998 season was given by:

$SL = 0.0068EI_{30} - 0.03\ (r^2 = 0.85)$...........................(4.2)

Where:

SL = Soil loss (t/ha)

EI_{30} = Rainfall erosivity index (MJmm/ha-h)

4.1.3 Rainfall amount and EI_{30} erosivity index

The relationship between rainfall amount and EI_{30} index for 1998 season was relatively weak with $r^2 = 0.56$. As it is seen from Table 4.1, there were many instances where high amount of rainfall produced small EI_{30} values. This was due to the fact that rainfall erosivity depends on the intensity of rainfall. Low erosivity values were recorded because most of the rainfall received at the site had low intensity. However, good relationship was found between monthly rainfall amount and monthly EI_{30} for a five year rainfall data (1994-1998) with the coefficient of determination of 0.86. In a similar study, Nyenza (1995) found a good correlation between monthly rainfall amount and monthly EI_{30} for Morogoro with $r^2 = 0.85$. The relationship between monthly rainfall amount and monthly EI_{30} was:

$$EI_{30} = 0.84RA - 3.4 \; (r^2 = 0.86) \ldots\ldots (4.3)$$

Where:

RA = Monthly rainfall amount (mm)

EI_{30} = Rainfall erosivity index (MJmm/ha-h)

4.2 Crops Development, Canopy Cover and Crop Yields

Figures 4.1, 4.2 and Table 4.2 below show the results for crop development, canopy cover measurements and yield records of maize and sorghum crops planted at the experimental site for 1998 *masika* season. From Figure 4.1 it is seen that the final height of maize crop was 258.3 cm. This height is the highest to be recorded since the start of the experiments at the site back in 1994. This is explained by the fact that apart from timely weeding and fertilizer application, soil moisture was available throughout the growing season due to the availability of rainfall. The highest canopy cover recorded for maize crop at the site was 65 percent. For sorghum crop, the highest crop height recorded during the study period was 148.5 cm and the final canopy cover recorded was 58 percent. These high values of crop height and canopy cover were achieved due to a good stand of the crops in response to improved management conditions and the availability of rainfall during the growing period.

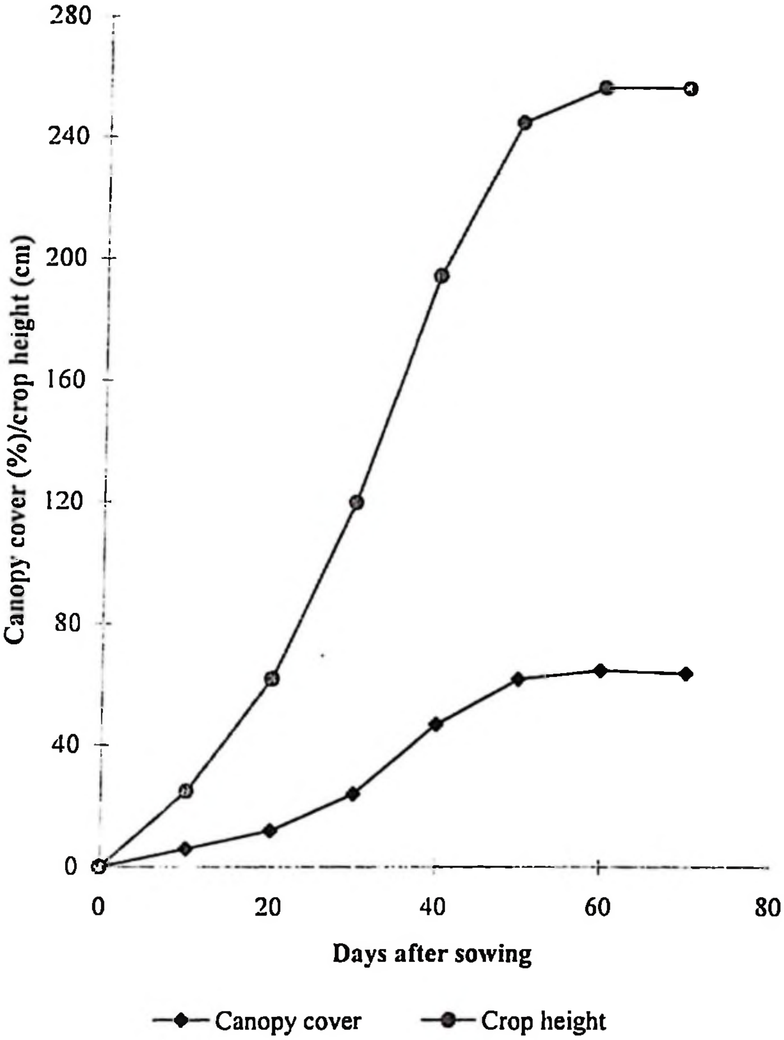

Figure 4.1: Crop height and canopy cover development for maize at SUA Farm runoff plots for 1998 season.

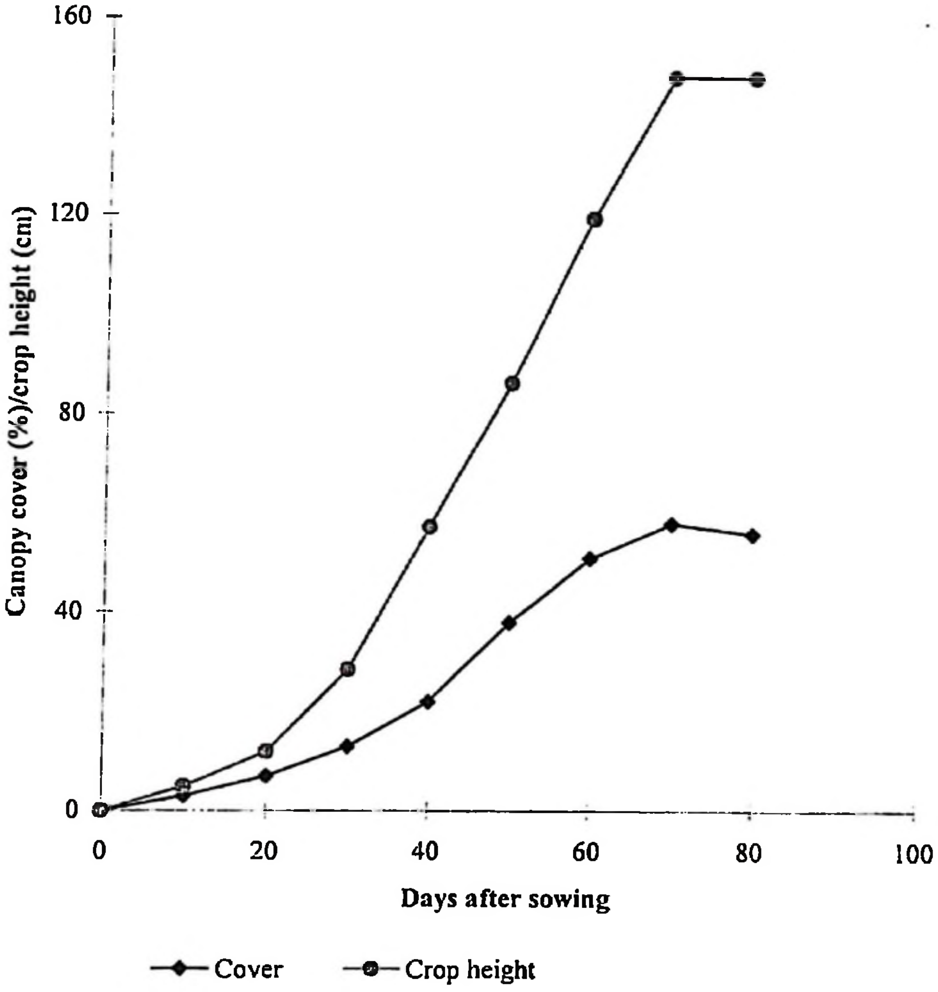

Figure 4.2: Crop height and canopy cover development for sorghum crop at SUA Farm runoff plots for 1998 season.

Although the crop stand at the site was generally good for 1998 season, the yields recorded especially for maize crop were lower than expected. The yields were 2786 kg/ha and 2725 kg/ha for sun-dried and oven-dried weights of maize crop, respectively. The yields for sorghum crop were 1681 kg/ha for sun-dried and 1612 kg/ha for oven-dried crop.

Table 4.2: Crop yields at runoff plots-SUA farm for 1998 season

Crop	Yield (t/ha)	
	Sun-dried	Oven-dried
Maize	2.786	2.725
Sorghum	1.681	1.612

Low maize yield for 1998 season was recorded because of the absence of rainfall during flowering period, the condition which existed for almost two weeks which affected the process of seed formation. Furthermore, some maize cobs especially those which fell down due to strong winds were destroyed by termites therefore reducing the yield of the crop.

4.3 Development of Crop Height and Crop Canopy Functions

The relationship between the canopy cover and yield for the period of three years (1994, 1995 and 1998) for both maize and sorghum crops is shown in Figures 4.3 and 4.4, respectively. Analysis shows that the relationship between yield and canopy cover for both crops is linear. The final canopy cover for both crops increases with the increase in yield as it is seen from Figures 4.3 and 4.4. In a similar study, Ghebreiyessus and Gregory (1987) found that there was a steady increase of canopy cover with dry matter accumulation. Also, Elwell and Stocking (1976) reported that the mean seasonal cover for maize, tobacco and cotton crops increased with yield. Similar results were reported by Wischmeier and Smith (1978). The equations representing the relationship between yield and canopy cover for maize and sorghum crops are respectively given as:

$$Y_m = 0.1054x_m - 223.10 \ (r^2 = 0.86) \ldots\ldots\ldots\ldots (4.4)$$

$$Y_s = 0.032x_s + 7.86 \ (r^2 = 0.95) \ldots\ldots\ldots\ldots (4.5)$$

Where:

Y_m = final or maximum canopy cover attained by maize crop (%).

Y_s = final or maximum canopy cover attained by sorghum crop (%).

x_m and x_s = maize and sorghum yields (kg/ha) respectively.

Figures 4.5 and 4.6 show the relationship between yield and crop height for a three year period (1994, 1995 and 1998) for maize and sorghum crops. Like canopy cover, crop height for both maize and sorghum crop increases with the increase in yield. In a similar study, Ghebreiyessus and Gregory (1987) found a steady increase in height with dry matter accumulation. Also, Mulengera (1996) who did his research at the SUA farm runoff plots found that the final height for maize crop increased from 224 cm to 242 cm with the increase in yield from 2664.7 kg/ha to 2714 kg/ha. The linear relationship between crop height and yield for maize and sorghum crops is respectively represented by the following equations:

$Y_m = 0.56x_m - 1277.87$ ($r^2 = 0.84$)................................(4.6)

$Y_s = 0.052x_s + 61.06$ ($r^2 = 0.72$)..................................(4.7)

Where:

Y_m and Y_s = maximum crop height attained by maize and sorghum crops (cm) respectively.

X_m and x_s = maize and sorghum crops yield (kg/ha) respectively.

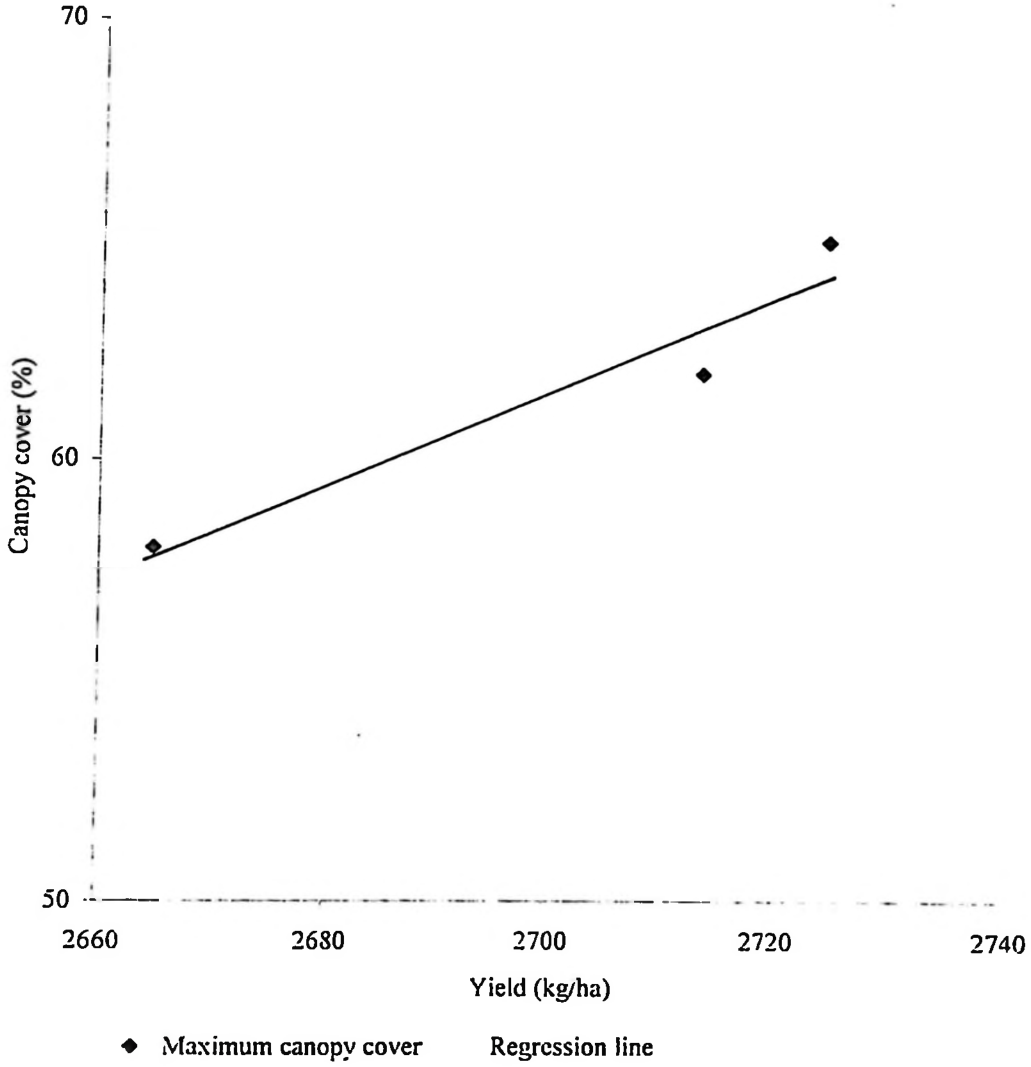

Figure 4.3: Relationship between yield and canopy cover for maize crop for a three year period (1994, 1995 and1998) at SUA farm.

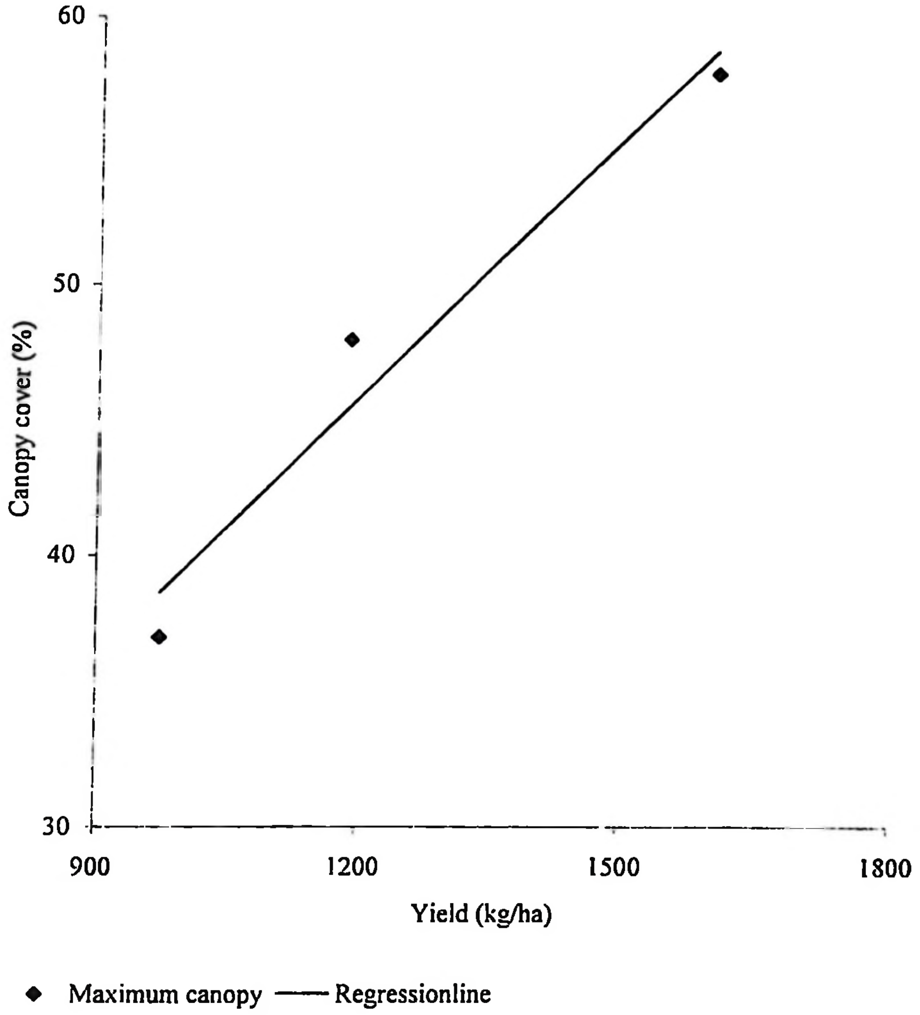

Figure 4.4: Relationship between yield and canopy cover for sorghum crop for a three year period (1994, 1995 and 1998).

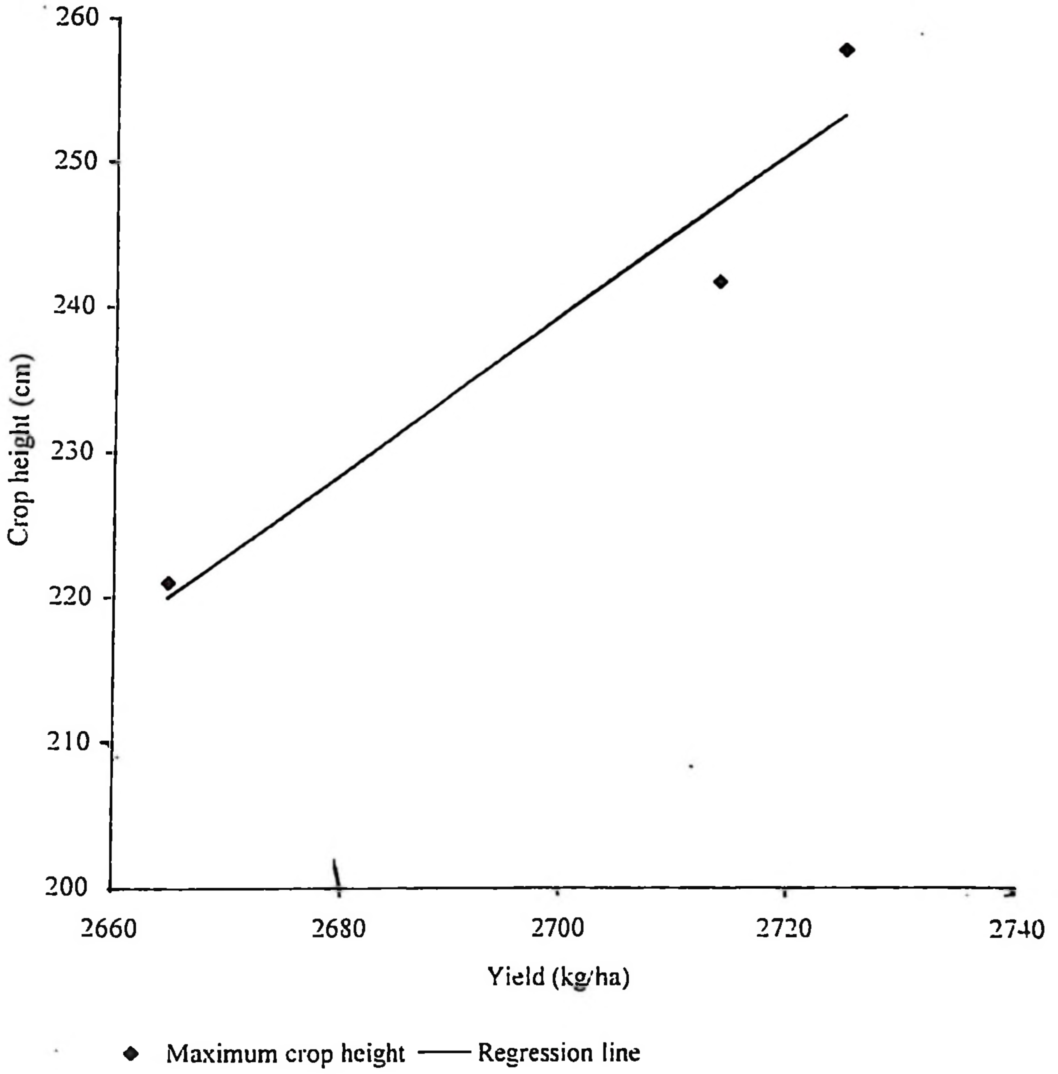

Figure 4.5: Relationship between yield and canopy height for maize crop for a three year period (1994, 1995 and 1998) at SUA farm.

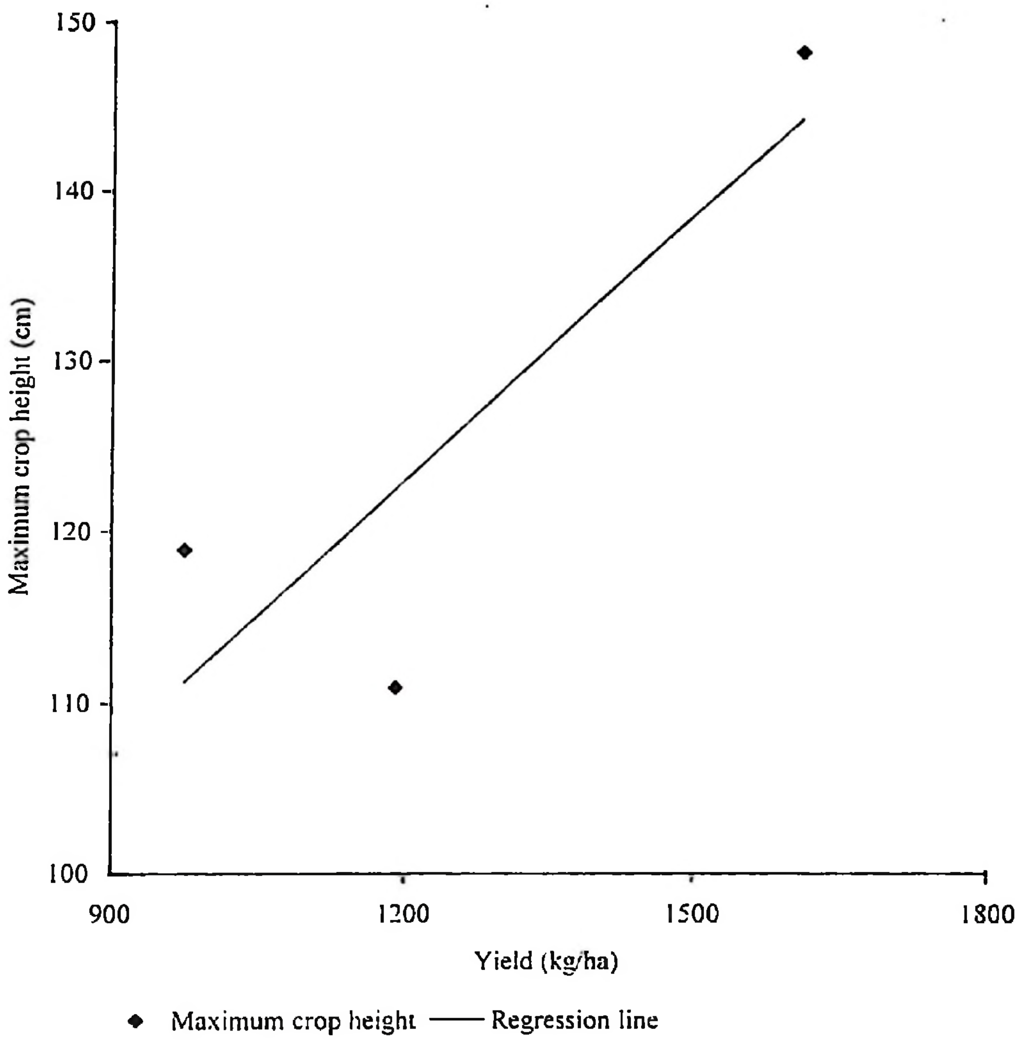

Figure 4.6: Relationship between yield and canopy height for sorghum crop for a three year period (1994, 1995 and 1998).

The maximum crop height attained by each crop at the runoff plot site was found to be proportional to the final canopy cover attained by those crops. For a three year period, the increase of the final canopy cover was associated with the increase of the crop height for both crops, maize and sorghum. Figures 4.7 and 4.8 and equations 4.8 and 4.9 below show the linear relationship between crop height and canopy cover for maize and sorghum crops, respectively.

$Y_m = 4.21x_m - 22.21$ ($r^2 = 0.99$)..................................(4.8)

$Y_s = 1.37x_s + 60.90$ ($r^2 = 0.72$)..................................(4.9)

Where:

Y_m and Y_s = maximum height (cm) for maize and sorghum crops respectively.

X_m and x_s = maize and sorghum crop canopy cover (%) respectively.

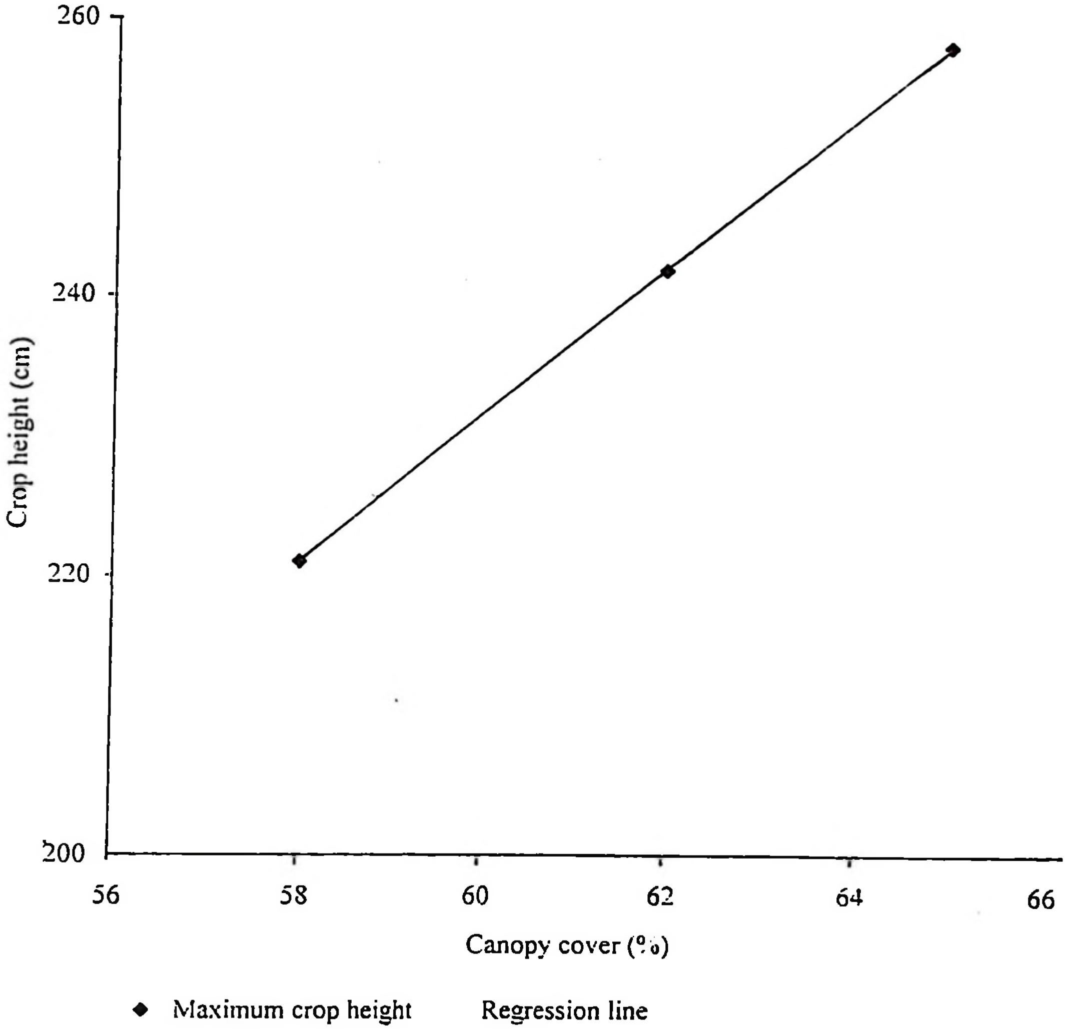

Figure 4.7: Relationship between crop height and canopy cover for maize crop for a three year period (1994, 1995 and 1998) at SUA farm.

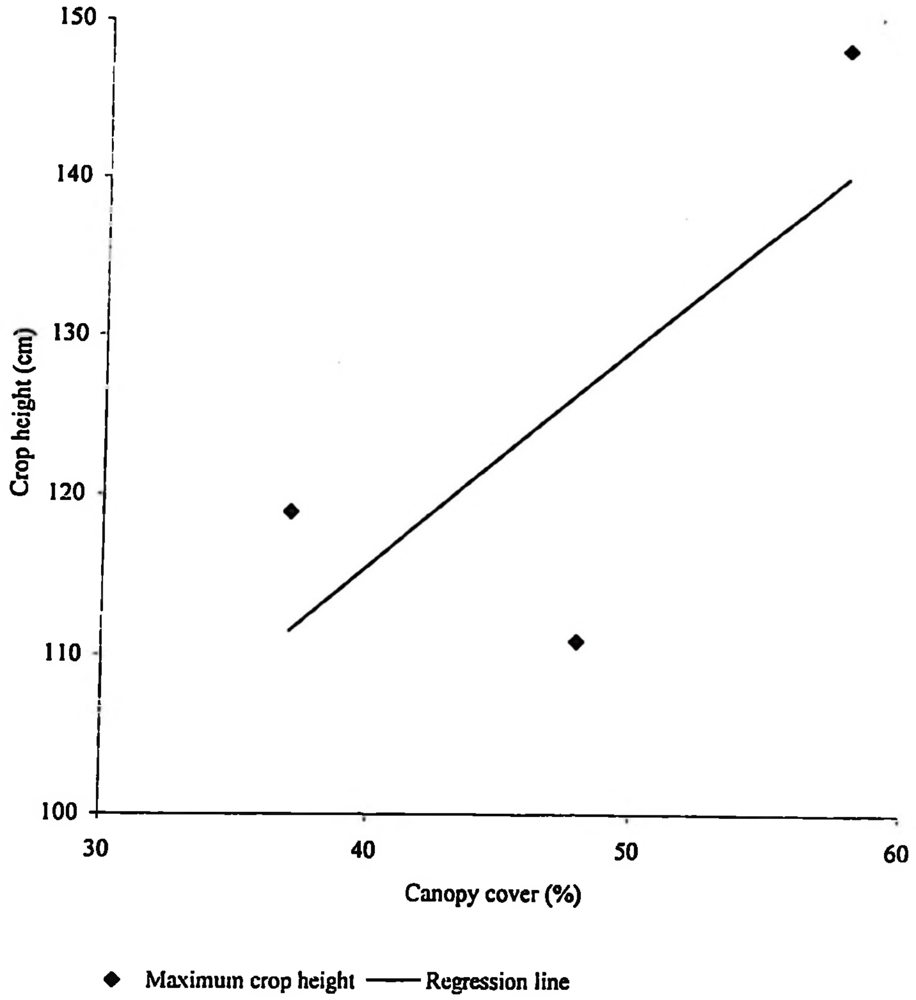

Figure 4.8: Relationship between crop height and canopy cover for sorghum crop for a three year period (1994, 1995 and 1998).

Figures 4.9 and 4.10 show the curves for crop growth development (canopy cover and crop heights) for maize crop at SUA farm runoff plots for a three year period (1994,1995 and 1998). As it is seen, the curves exhibit similar shapes, however, the slopes of the curves given differ slightly. A 1994 growth curve (for both canopy cover and crop height development) had a better early growth in early days of crop growth. However, the growth rate slowed down from the 30th day since sowing to the end of the growing period resulting in low final canopy cover and crop height. This was due to moisture stress the crops experienced during the mid to the end of the growing season as it is seen from Figure 4.17 (Appendix 5) showing the rainfall and ETo distribution for the year 1994. The unavailability of sufficient moisture caused a reduction in vegetative growth hence the canopy cover, crop height and final yield. In 1995, the crops had a good growth throughout the growing period. The crop which was sown in March while moisture was available, continued to get enough moisture through rainfall which was available most of the times during the growing period. Also, the evaporation rates during the growing period were low which reduced the loss of moisture and therefore making it available for plants (Figure 4.18). All these conditions gave rise to a higher final canopy cover, crop height and yield for 1995 season compared to 1994 season. A 1998 growth curve had a slowed down crop development at the early days of crop growth but it picked up from the 35th day and it slowed down at the end of the growing period. The slowed down growth happened because the crops received high amount of rainfall which caused water logging condition at the site at early days of crop growth. This condition slowed down early canopy cover and crop height development. However, when rainfall amount decreased the crops attained a fast development in canopy cover and crop height (see Figure 4.19).

As it is seen from crop development curves, it is not easy to get a curve which can be used for estimating the average long term crop and soil management factor, C, because the rate of crop development is affected by many soil physical, chemical and biological factors and the availability of moisture (which varies year to year due to variability of rainfall distribution). However, in attempt to help local farmers in planning for long term soil erosion control, the estimation of local C factor values is important so that farmers can be advised on appropriate soil and crop management practices which would be taken in order to minimise soil erosion and therefore obtain high yields. The difficulty of estimating average long term C factor values shows that there is a need to have sufficient data bank of the crop development parameters, i.e. canopy cover, heights and yields to be able to have reasonable estimates of the factor for various field conditions, even in the same environmental locality. To investigate how long term average crop development curves together with long term erosivity can determine the C factor values in a given locality, careful consideration of the behaviour of each of the three growth curves plotted (Figures 4.9 and 4.10) in relation to long term rainfall and actual evapotranspiration distribution (Figures 4.17-4.19, Appendix 5) was done. Investigation of the 1994-1998 rainfall seasons showed that the 1995 rainfall distribution pattern was close to the long term average rainfall distribution pattern at SUA farm, therefore, the 1995 crop development curves were taken as representative of average crop development curves where other curves can be developed based on crop yield levels of a particular farmer. The curve to predict canopy cover and crop height for sorghum crop was not developed because the data considered were from two different locations with different rainfall distribution patterns therefore, different soil moisture regime.

Figure 4.11 shows the canopy cover-crop height ratio against crop growth period ratio developed from a 1995 crop development curve as representative of average long term crop development curve. Figure 4.11 was constructed by plotting the graphs of the growing crop cover to maximum crop cover and the growing crop height to maximum crop height ratios versus crop growth period to crop maturity period ratio This figure can be used to predict long term values for canopy cover and crop height for any given crop yields of a particular field. As an example, the crop cover-yield (Fig. 4.3) and crop height-yield (Fig. 4.5) curves (see Eqs. 4.4 and 4.6) for 1995 were used to predict the maximum canopy cover and maximum crop height attained by the crop to crop maturity period. The values obtained were multiplied by their respective canopy cover and crop height ratios from the curves in Figure 4.11 to develop the estimated long term crop cover and height development curves as it is seen in Figure 4.12. The estimated long term canopy cover and crop height curves from Figure 4.12 were used together with Figure 4.15 to estimate the long term canopy cover sub-factor.

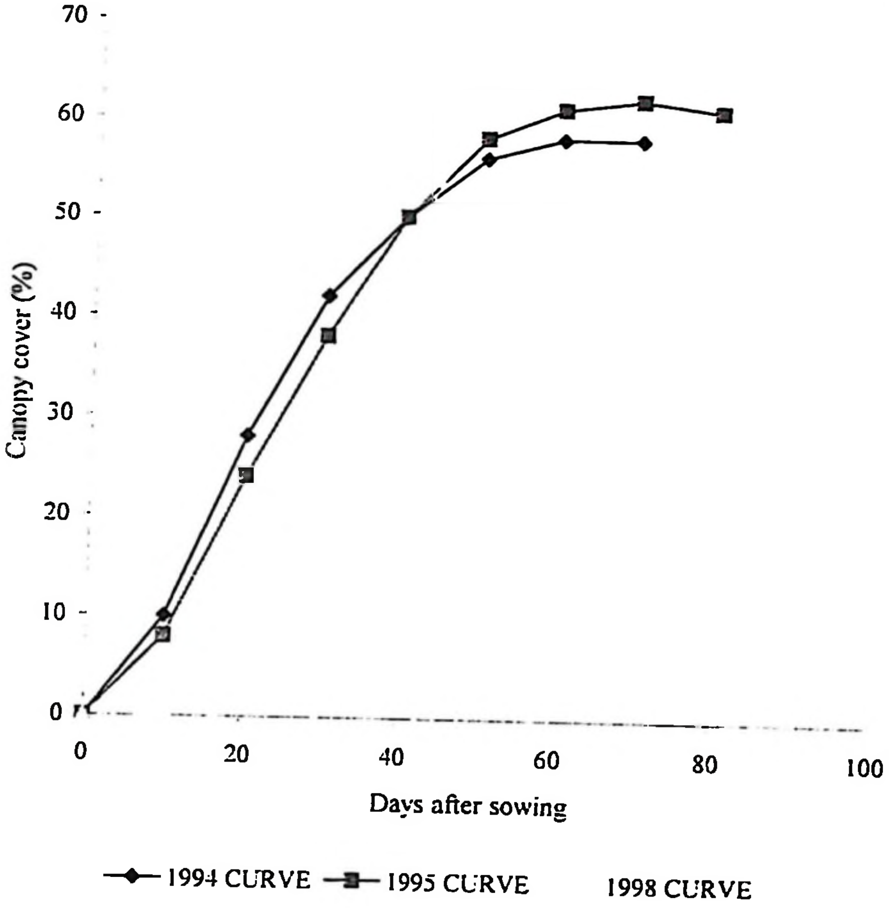

Figure 4.9: Canopy cover curves for maize crops for a three year period (1994, 1995 and 1998) at SUA farm runoff plots.

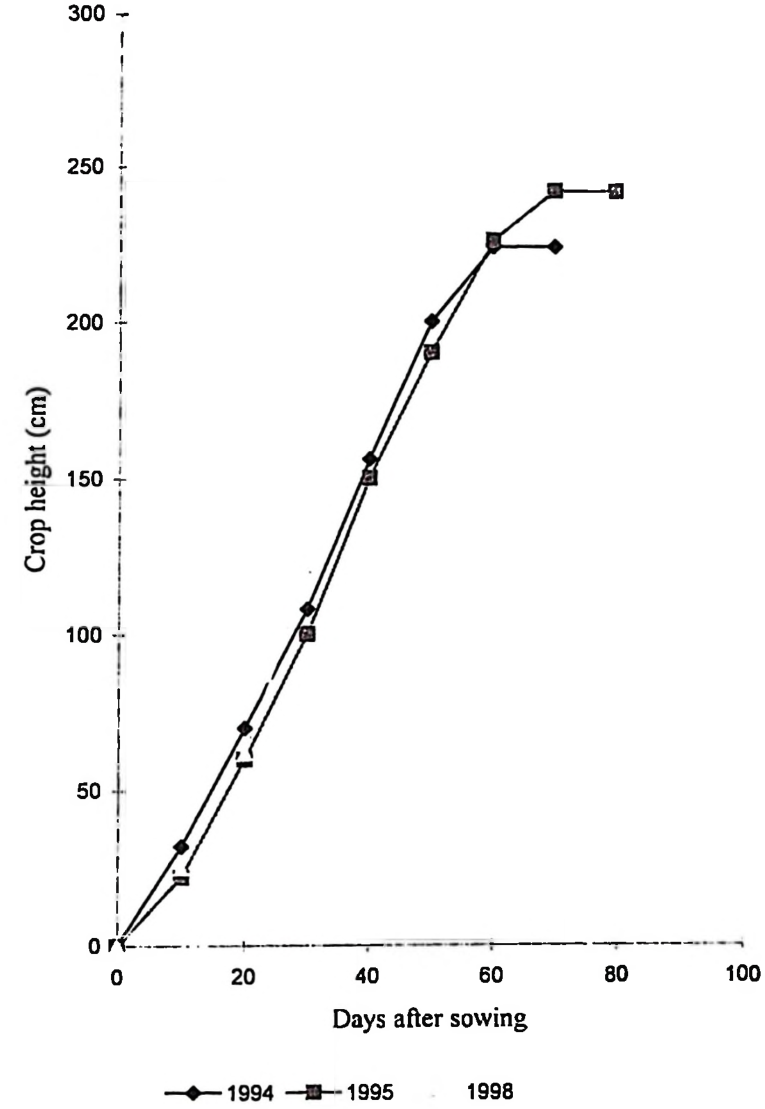

Figure 4.10: Crop height curves for maize crop for a three year period (1994, 1995 and 1998) at SUA farm runoff plots.

The canopy cover sub-factor estimated was multiplied by other sub-factors and the long term seasonal rainfall erosivity distribution ratios for SUA farm runoff plots to obtain the long term predicted seasonal C value (Table 4.14 in Appendix 4).

The predicted growth curve from predicted canopy cover and crop height values for maize crop from Figure (4.11) have similar shape to the actual growth curve developed from measured canopy cover and crop height values for 1995 season (Figure 4.12). Although this method looks promising, its suitability for estimating long term crop development curves from yield information can only be acertained only if enough data bank is used to test it.

4.4 Determination of the USLE's Crop and Soil Management Factor

Determination of the crop and soil management factor of the USLE through the sub-factor method is not common in the tropics (Mulengera. 1996). Not all the sub-factor values required for the determination of the C values have established methods of estimation, even in USA where the sub-factor method has been developed.

In estimating the crop and soil management factor, C, for runoff plots under both maize and sorghum crops using the sub-factor method, the prior land use, surface roughness and canopy cover sub-factors were considered.

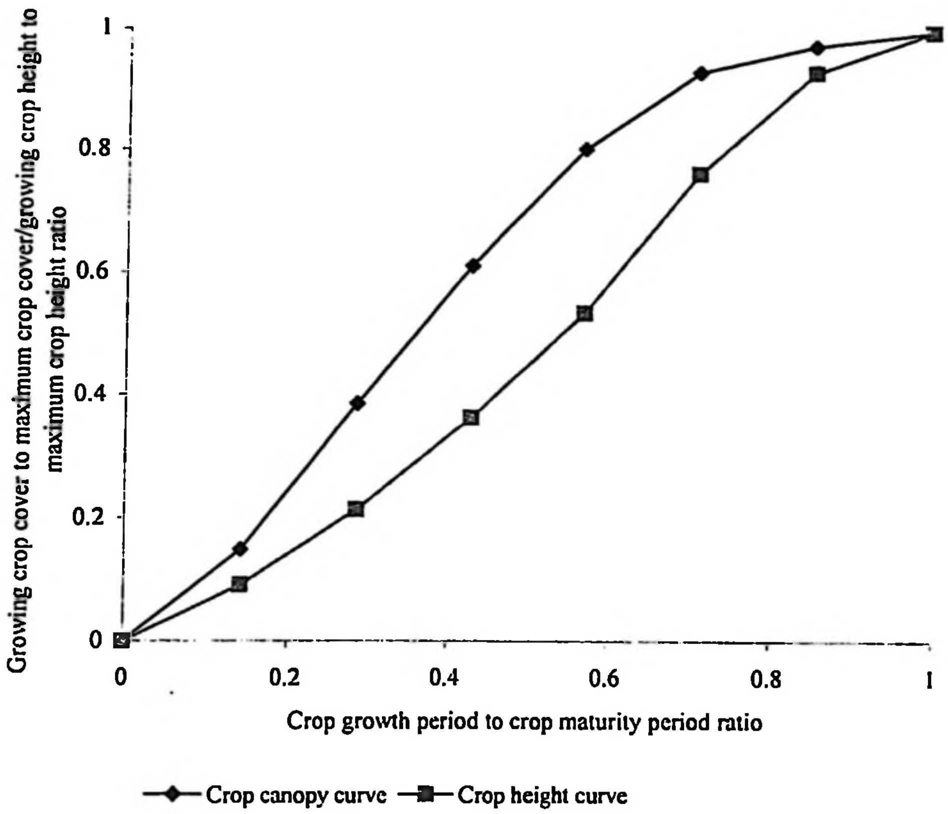

Figure 4.11: Growing crop to maximum crop cover/growing crop height to maximum crop height ratios.

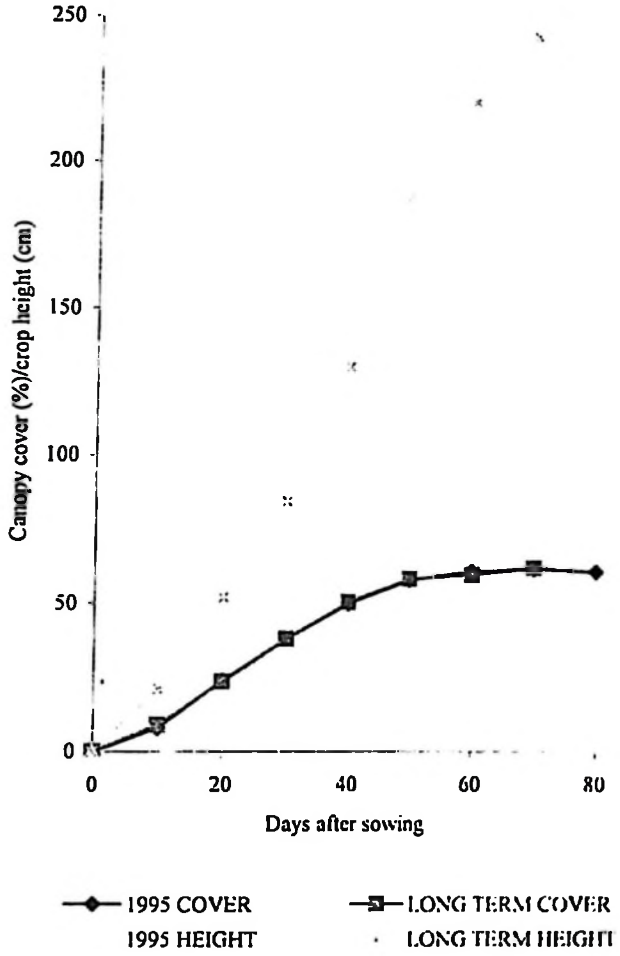

Figure4.12: Actual (1995) and long term predicted crop development curves.

As part of the prior land use sub-factor, maize stalks left into the field after harvesting and the weeds established after the previous season harvest were considered. The remains of maize stalks left in the field after the previous season harvest and the weeds which were already established at the end of the 1997 season were incorporated into the soil during tillage operation for 1998 season. Although no measurements were made it was assumed from visual observations and from previous researchers (Mulengera, 1996) that just before tillage, the weeds had attained a cover value greater than 80%. To take into account for soil loss reduction by the residue effects of weeds and maize stalks incorporated into the soil during conventional seedbed preparation, the soil loss reduction factor read from Table 5 (Wischmeier and Smith, 1978) line no. 91 for conventional seedbed was 0.36. This value was maintained constant because insufficient moisture was available for rapid decomposition.

As stated above, maize stalk remains from the previous season and weeds infested the site before tillage for the 1998 season. Tillage operations incorporated these residues into the soil and left the soil surface with soil clods of about 150 mm diameter with soil loss reduction factor of about 0.5, based on Figure 4.14 (Appendix. 3) abstracted from Dissmeyer (1982). Because the intensity of most rainfall storms which fell after tillage were low and the binding effects of soils and tilled vegetation, tillage aggregates did not break down, instead they formed relatively stable aggregates. Due to this reason, the surface roughness factor given above was maintained until the end of the rainy season.

The canopy cover for both maize and sorghum crops were estimated from their respective crop development curves (Figures 4.1 and 4.2). Long term canopy cover were estimated from the long term growth curves developed (Figure 4.12). The cover values obtained were then used in Figure 4.15 (Appendix 3) to obtain the canopy cover sub-factors.

The runoff plots at SUA farm have been continuously tilled since 1994. Due to this, the soil had no time to reconsolidate therefore the factor for reconsolidation selected from Figure 4.16 abstracted from Dissmeyer (1982) was 1.0. Because the growing season for maize and sorghum crops is shorter than a year, this value was maintained constant for the rest of the season.

The product of the sub-factors obtained (surface roughness, canopy cover, reconsolidation, prior land use) for the given conditions gave the crop and soil management factor values which were then multiplied by their respective rainfall erosivity fractions of the total recorded rainfall erosivity to obtain the estimated seasonal crop and soil management factor, C as given in Table 4.3 below.

Table 4.3: Measured and predicted crop and soil management factors for runoff plots at SUA farm for 1998 season.

Crop	Crop and soil management factor, C	
	Measured	Predicted
Maize	0.086	0.147
Sorghum	0.100	0.158

From Table 4.3 above, it is seen that the predicted crop and soil management factors are reasonable and comparable to those obtained by Mulengera (1996) who did his research at the same site although they are not the same. This happens because the observed soil loss ratios for given conditions are subject to variation from one year to another due to the influence of unpredictable random variables and experimental errors (Wischmeier and Smith, 1978). According to Wischmeier and Smith (1978) the estimated and measured values cannot always be the same, since the sub-factor values estimated from established averages like the table values can differ considerably from short term observations. Therefore, due to the variations of the measured crop and soil management factors, there is a need to have long term measurements of crop cover development for different crops to establish the actual trends of the crop and soil management factor values.

Table 4.4 shows the seasonal measured and predicted C factor values for 1994/95 and 1998 and the long term predicted C factor value at SUA farm runoff plots. As it was mentioned earlier, the measured and predicted seasonal C factor values were calculated from soil loss data collected during the study period, seasonal cover and heights of the crop and their corresponding seasonal rainfall erosivity values. The long term predicted seasonal C factor value (Table 4.14 in Appendix 4) was calculated from average long term cover and height curve, (Figure 4.12) and the average long term rainfall erosivity distribution (Figure 4.20, Appendix 5).

Table 4.4: Seasonal measured, predicted and long term C factor values for maize crop at SUA farm runoff plots.

	C values	
Year	Measured	Predicted
1994/95	0.071	0.139
1998	0.086	0.147
Long term	-	0.136

As it is shown (Table 4.4), the long term predicted C factor value is not far from the predicted C values for individual years. It lies between the seasonal measured and predicted C values for individual years. This suggests that the method relating crop yields to cover and height to predict the crop and soil management factor, C, is appropriate provided that sufficient data bank is available. Thus, research to collect such information is vital if soil loss prediction equations are to be locally applicable for their use for practical soil conservation planning in Tanzania.

CHAPTER 5

5 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and Conclusion

Soil erosion is a widespread problem facing the agricultural sector of many countries including Tanzania. In Tanzania, soil erosion is severe in central semi-arid regions. Although the problem of soil erosion is serious in many parts of Tanzania, for the time being there exist no locally adapted equations for predicting soil loss. There exists a number of equations for predicting soil erosion ranging from empirical to physically based ones which have been developed in temperate regions, it has been shown that these equations cannot be applied or directly transferred to conditions different from where they were developed, therefore, they are inappropriate for use in tropical regions, Tanzania being inclusive (Mulengera, 1996). Moreover, physically based models require data, financial and technical resources which is scarce or totally unavailable in countries like Tanzania. For the case of developed empirical models, they have shown to give unrealistic values when applied in tropical regions. Hence, their application in tropical regions requires modifications of those factors which give unrealistic values (Mulengera and Payton, 1997). This research work involved development of crop functions useful in predicting the crop and soil management factor of the widely used soil erosion predictive equation (the USLE or its revised version, the RUSLE) through the sub-factor method. The crop and soil management factor obtained through the sub-factor method of the

USLE (Wischmeier and Smith, 1978) gave reasonable values for the given short period of the research.

5.2 Recommendations

Based on the findings of this study and from previous researchers it is therefore recommended that:

- For effective soil conservation in Tanzania a wide use of soil erosion predictive equations such as the USLE requires further and long time research on soil erosion-crop cover-yield relationships for different crops and soil management conditions to collect enough data needed for estimating the crop and soil management factor.

- Research to develop locally applicable equations for estimating rainfall erosivity from widely available rainfall records.

- Research on the relation between crop development and moisture availability in the soil throughout the growing season is required in order to test the suitability of developed curves in estimating the C factor values of the crops under consideration.

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APPENDICES

Appendix 1: Rainfall Erosivities and Soil Losses

Appendix 1.1: Rainfall erosivities and soil losses for 1997 season.

	Total energy	EI_{30}	Average soil loss (t/ha)		
Date	(MJ/ha)	(MJmm/ha-h)	BP	CM	SNV
22.3.97	2.358	24.53	0.329	0.054	0.021
24.3.97	3.841	28.42	0.036	0.011	0.007
25.3.97	2.257	20.32	0.157	0.029	0.007
27.3.97	1.152	8.75	0.043	0.011	0.006
31.3.97	2.806	55.0	0.264	0.039	0.007
03.4.97	5.887	247.26	0.865	0.139	0.022
06.4.97	2.380	30.94	0.045	0.019	0.008
08.4.97	6.944	201.37	0.742	0.208	0.004
09.4.97	12.153	656.25	2.873	0.493	0.031
11.4.97	1.164	12.10	0.232	0.132	0.007
12.4.97	1.670	43.43	1.005	0.273	0.017
13.4.97	1.201	8.41	0.119	0.181	0.009
14.4.97	3.071	71.85	0.546	0.186	0.009
28.4.97	0.987	4.15	0.019	0..008	0.003
29.4.97	11.071	520.31	0.013	0.006	0.003
Total	58.942	1933.09	7.288	1.789	0.161

Appendix 1.2: Rainfall erosivities and soil losses for 1998 season.

Date	Rainfall (mm)	E (J/m^2)	EI$_{30}$ (MJmm/ha-h)	Soil loss (t/ha) CMP	CSP	SNV	BP
09.04.98	24.00	242.09	25.42	0.02	0.03	0.01	0.28
10.04.98	26.75	550.24	187.08	0.05	0.06	0.02	1.60
11.04.98	20.25	146.12	14.61	0.03	0.02	0.01	0.20
12.04.98	12.00	251.88	52.89	0.03	0.04	0.00	0.54
15.04.98	11.75	201.03	32.65	0.02	0.03	0.00	0.32
17.04.98	58.00	1006.84	332.26	0.32	0.35	0.06	2.41
25.04.98	55.50	788.48	157.70	0.08	0.09	0.02	1.10
29.04.98	34.50	388.79	85.53	0.04	0.05	0.01	0.49
30.04.98	15.00	123.57	9.90	0.01	0.02	0.00	0.05
02.05.98	28.50	416.82	108.37	0.03	0.04	0.01	0.42
03.05.98	25.75	290.20	37.73	0.02	0.02	0.00	0.08
05.05.98	18.25	485.59	169.96	0.03	0.04	0.01	0.42
12.05.98	9.50	115.76	13.89	0.00	0.00	0.00	0.02
Total	339.75	5007.41	1228.00	0.68	0.79	0.14	7.93

APPENDIX 2: Canopy Cover and Crop Height Developments.

Appendix 2.1: Canopy cover development for maize crop for 1996 season.

Days after sowing	Canopy cover (%)
10	4
20	10
30	23
40	39
50	54
60	59
70	63

Source: Shayo (1997).

Appendix 2.2: Canopy cover development for maize crop for 1997 season.

Days after sowing	Canopy cover (%)
10	5
20	11
30	23
40	40
50	52
60	59
70	65

Source: Rushomesa (1998).

Appendix 2.3: Crop height and canopy cover development for maize crop for 1998 season.

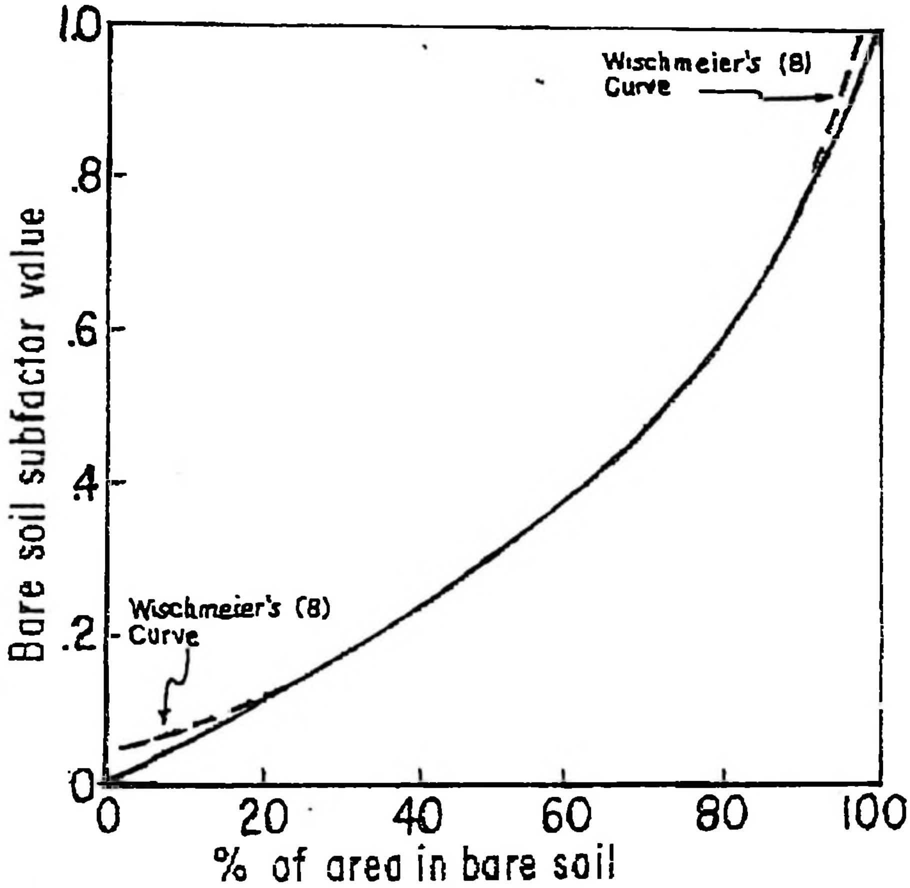
Days after sowing	Canopy cover (%)	Crop height (cm)
10	6	25
20	12	62
30	22	120
40	47	195
50	62	245.6
60	65	258.3
70	64	258.3

Appendix 2.4: Crop height and canopy cover development for sorghum crop for 1998 season.

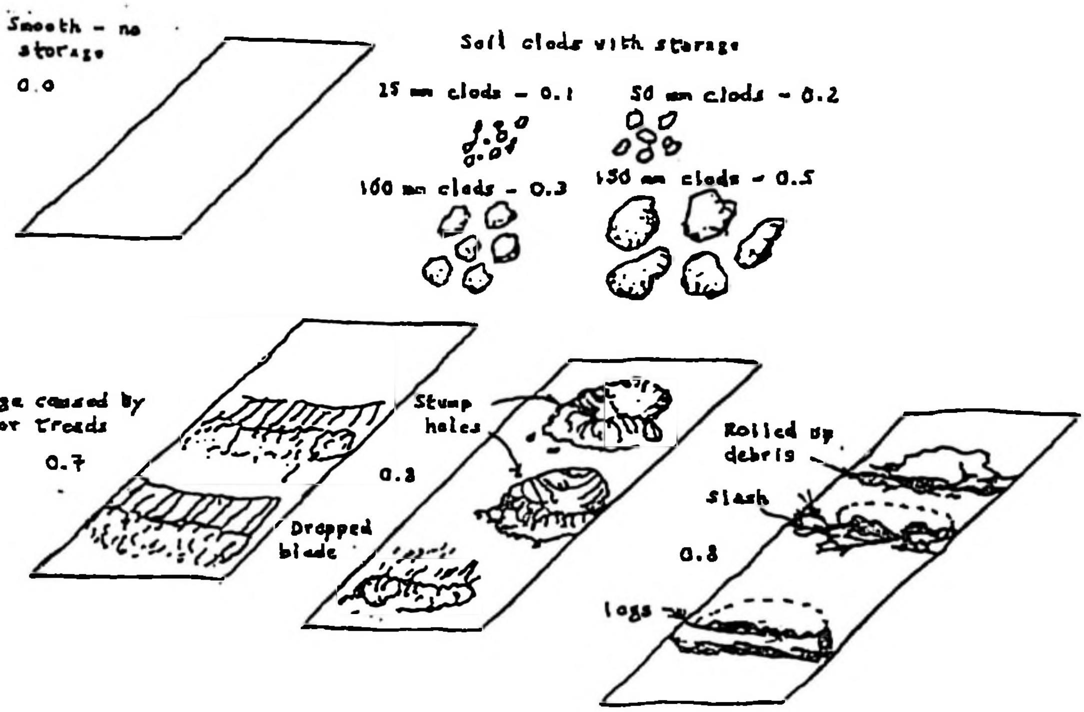
Days after sowing	Canopy cover (%)	Crop height (cm)
10	3	5
20	7	12
30	13	28.5
40	22	57.3
50	38	86.4
60	51	119.6
70	58	148.5
80	56	148.5

APPENDIX 3: Figures for Estimation of the Crop and Soil Management Factor, C.

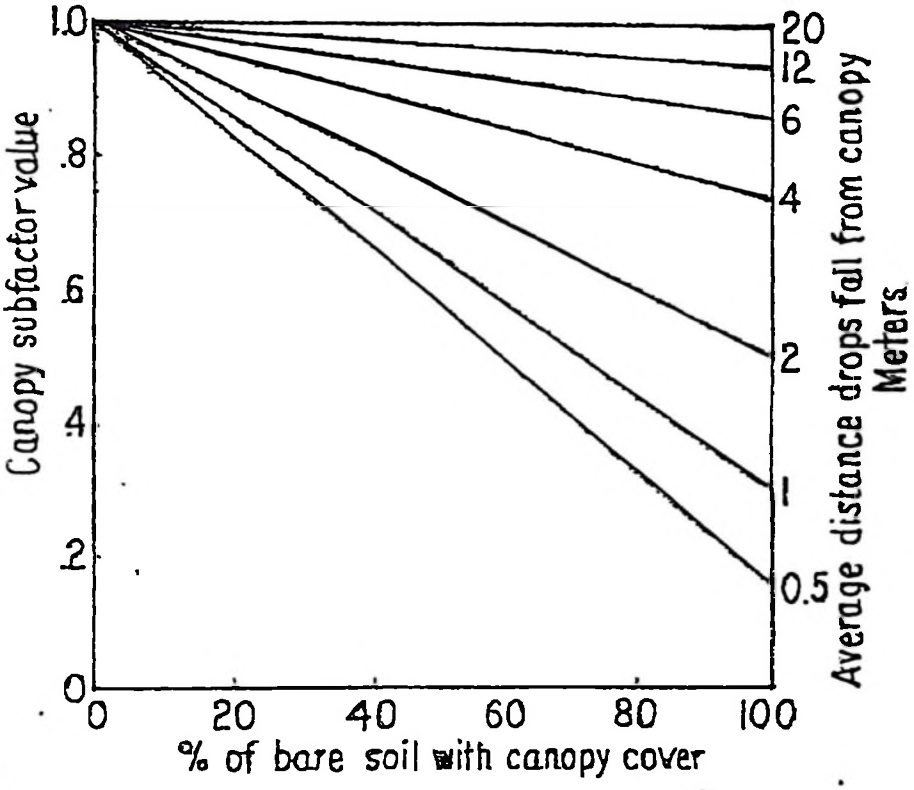
Appendix 3.1: Figure for estimation of ground cover sub factor(Source: Dissmeyer, 1982).



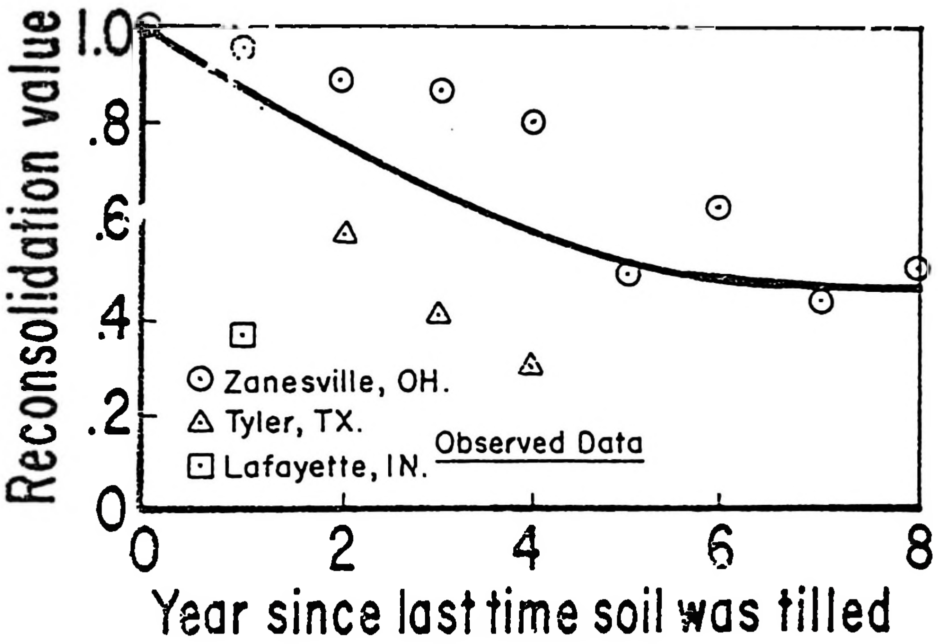
Appendix 3.2: Figure for estimation of surface roughness sub-factor (Source:Dissmeyer, 1982).



Appendix 3.3: Figure for estimation of canopy cover sub-factor (Source: Dissmeyer, 1982).



Appendix 3.4: Figure for estimation of the sub-factor for soil reconsodilation (Source: Dissmeyer,1982).



APPENDIX 4: Rainfall erosivity distribution, measured and predicted C factor values.

Appendix 4.1: Rainfall erosivity distribution and measured C values for 1998 season.

Date	EI_{30} ratio	Measured C factor values		
		CM	CS	SNV
09.04.1998	0.021	0.0015	0.0022	0.0007
10.04.1998	0.152	0.0047	0.0057	0.0019
11.04.1998	0.012	0.0018	0.0018	0.0006
12.04.1998	0.043	0.0024	0.0032	0.0000
15.04.1998	0.027	0.0016	0.0025	0.0000
17.04.1998	0.270	0.0350	0.0390	0.0067
25.04.1998	0.128	0.0090	0.0093	0.0023
29.04.1998	0.070	0.0057	0.0071	0.0014
30.04.1998	0.008	0.0016	0.0032	0.0000
02.05.1998	0.088	0.0063	0.0084	0.0021
03.05.1998	0.031	0.0077	0.0077	0.0000
05.05.1998	0.138	0.0098	0.0099	0.0019
12.05.1998	0.011	0.0000	0.0000	0.0000
Total	1.000	0.0860	0.099	0.0176

Appendix 4.2: Rainfall erosivity distribution and predicted C values for maize crop for 1998 season.

Rainfall event day	SR	PLU	CC	EI_{30}	C
09.04.98	0.50	0.36	0.895	0.021	0.0034
10.04.98	0.50	0.36	0.895	0.152	0.0245
11.04.98	0.50	0.36	0.894	0.012	0.0019
12.04.98	0.50	0.36	0.884	0.043	0.0068
15.04.98	0.50	0.36	0.883	0.027	0.0043
17.04.98	0.50	0.36	0.878	0.271	0.0428
25.04.98	0.50	0.36	0.847	0.128	0.0195
29.04.98	0.50	0.36	0.789	0.069	0.0095
30.04.98	0.50	0.36	0.789	0.008	0.0011
02.05.98	0.50	0.36	0.778	0.085	0.0119
03.05.98	0.50	0.36	0.747	0.031	0.0042
05.05.98	0.50	0.36	0.736	0.136	0.018
12.05.98	0.50	0.36	0.724	0.011	0.0014
Total				1.000	0.147

Appendix 4.3: Rainfall erosivity distribution and predicted C values for sorghum crop for 1998 season.

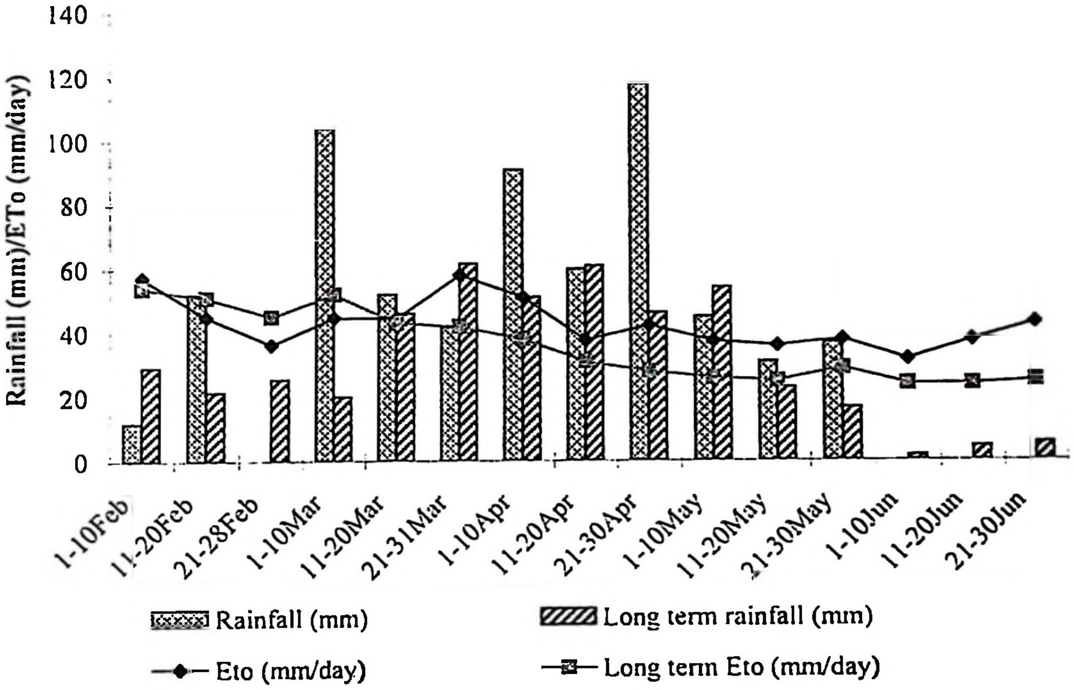
Rainfall event day	SR	PLU	CC	EI_{30}	C
09.04.98	0.50	0.36	0.958	0.021	0.0036
10.04.98	0.50	0.36	0.958	0.152	0.0262
11.04.98	0.50	0.36	0.947	0.012	0.0020
12.04.98	0.50	0.36	0.936	0.043	0.0072
15.04.98	0.50	0.36	0.921	0.027	0.0045
17.04.98	0.50	0.36	0.916	0.271	0.0447
25.04.98	0.50	0.36	0.858	0.128	0.0198
29.04.98	0.50	0.36	0.842	0.069	0.0104
30.04.98	0.50	0.36	0.837	0.008	0.0012
02.05.98	0.50	0.36	0.832	0.085	0.0127
03.05.98	0.50	0.36	0.826	0.031	0.0046
05.05.98	0.50	0.36	0.821	0.136	0.0200
12.05.98	0.50	0.36	0.736	0.011	0.0014
Total				1.000	0.158

Appendix 4.4: Long term rainfall erosivity distribution and predicted C factor values.

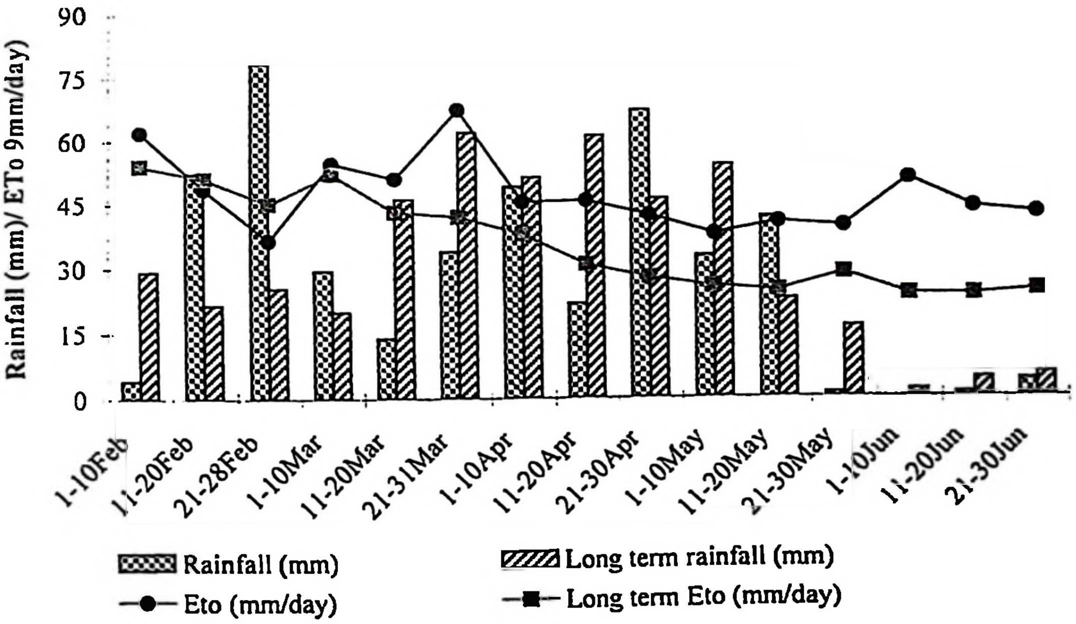
Growth period intervals (days)	SR	PLU	CC	EI_{30}	C
1 - 15 March	0.50	0.36	0.847	0.286	0.0436
16 - 31 March	0.50	0.36	0.726	0.343	0.0448
1 - 15 April	0.50	0.36	0.695	0.179	0.0224
16 - 30 April	0.50	0.36	0.726	0.171	0.0224
1 - 15 May	0.50	0.36	0.726	0.021	0.0027
				1.000	0.1360

APPENDIX 5: Rainfall, ETo and EI_{30} distribution figures

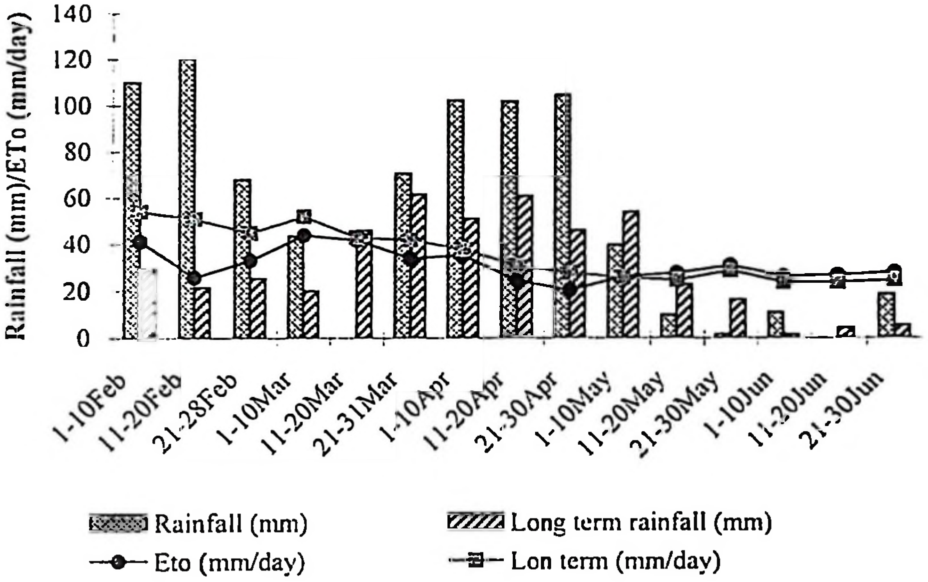
Appendix 5.1: Rainfall and ETo distribution for 1994 for SUA farm runoff plots.



Appendix 5.2: Rainfall and ETo distribtion for 1995 for SUA farm runoff plots.



Appendix 5.3: Rainfall and ETo distribution for 1998 for SUA farm runoff plots



Appendix 5.4: Long term cumulative erosivity distribution for SUA farm.