EFFECT OF MULCH TYPE, MULCH RATE AND SLOPE ON SOIL LOSS, RUNOFF AND INFILTRATION UNDER SIMULATED RAINFALL FOR TWO AGRICULTURAL SOILS IN GHANA

by

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DECLARATION

I hereby declare that this work is my own work towards the Master of Science (Agricultural Machinery Engineering) and that, to the best of my knowledge, it contains no material previously published by another person nor materials which have been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

To study the effect of mulch type, mulch rate and slope on soil loss, runoff and infiltration of some agricultural soils in the Ashanti Region of Ghana, soil loss experiments were conducted. A rainfall simulator was developed to measure soil loss, runoff and infiltration for two agricultural soils. The average drop size was 1.49 mm. The unit provided mean velocity of *7.5 m/s*, which is *83%* of terminal velocity of natural rain, given kinetic energy of 4.91×10^{-5} *Joules.* The effectiveness of using maize stover *(*Zea mayz *L.), Rice straw (*Oryza sativa *L.),* Elephant grass *(*Pennisetum purpureum*), and* Cyperus haspan *L.,* as mulching materials were evaluated using the rainfall simulator which was set at rainfall intensities typical of the tropics. Soil samples, from two sites at KNUST *(Anwomaso Research Farm) and Kotei (a suburb of KNUST)* representing the main agricultural soils in the area were collected, placed at four different slopes, and covered with different rates of mulch materials. The surface runoff, soil loss, and infiltration were measured under each condition. The results with cyperus haspan compared favourably with elephant grass, which also compared favourably with results from rice straw and the rice straw also compared favourably with results from the maize stover. This finding confirms results from previous researchers. Runoff and soil loss decreased as mulch rate increases and increases with slope. It was determined that the mulch rate and field slope at which runoff and infiltration become equal were *2.25 t/ha and 3.14%* respectively. Soil bulk density for the Anwomaso soil *(sandy clay loam)* increases linearly with increasing mulch cover and that of the Kotei soil (*sandy loam*) increases slightly, plateau and then decreases with increasing mulch cover.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The rate of infiltration of water into the soil depends on the intensity and duration of the rainfall, slope of the field, nature of the soil surfaces and physical characteristics of the soil according to Adekalu *et al* (2006). Rainfall simulations are widely used to help understand the effects of soil properties under various conditions (Covert, and Jordan, 2009). The designed rainfall simulator is inexpensive, portable and easily operated by two people. Many rainfall simulators are designed with the nozzle at a height of 3 m to replicate the velocity and kinetic energy of natural rain (Meyer and Harmon 1979; Commandeur and Wass 1994; Humphry *et al*. 2002).

1.2 Mulching

Returning crop residues to the soil improves soil quality and productivity through their favourable effects on soil properties (Lal and Stewart, 1995). Favourable effects of residue mulching on soil organic carbon (SOC), water retention and percent water-stable aggregates have been reported for the surface layer (Duiker and Lal, 1999). Application of crop residue mulches increases SOC content (Havlin *et al*., 1990; Saroa and Lal, 2003). Conservation of soil moisture is one of the major advantages of mulch farming system. Mulching protects the soil from water erosion by reducing the rain drop impact. A partial covering of mulch residue on the soil can strongly affect runoff dynamics, and reduce runoff amount (Findeling *et al*., 2003; Rees *et al*., 2002). Straw mulch is known to increase soil moisture storage (Ji and Unger, 2001).

Crop residues at the soil surface shade the soil and serve as a vapour barrier against moisture losses from the soil, slow surface runoff and increase infiltration. Rathore *et al*. (1998) observed that more water was conserved in the soil profile during the early growth period with straw mulch than without it. Subsequent uptake of conserved soil moisture moderated plant water status, soil temperature and soil mechanical resistance, leading to better root growth and higher grain yields.

Crop residues on the soil surface decrease soil erosion, increase soil organic matter, and improve soil quality (Lal et al., 1999). Thus, management of crop residues is seen as an integral part of many conservation tillage systems. To study the effect of mulch rate, mulch type, field slope, and rainfall duration on runoff, soil erosion and infiltration rate for two agricultural soils in Ghana, an effective but simple rainfall simulator was constructed.

1.3 Problem Statement

Erosion usually occurs due to transport by wind, water, or ice grid by down-slope creep of soil and other material under the force of gravity (Zhang *et al.*, 2008). Erosion is a natural process, but it has been increased dramatically by human land use, especially industrial agriculture, deforestation, and urban sprawl (Renard *et al*., 1997). Land that is used for conservational agriculture generally experiences a significantly greater rate of erosion than that of land under natural vegetation, or land used for sustainable agricultural practices. The poor protection offered against rainfall impact by a sparse crop cover is a major factor contributing to severe splash erosion, which is a major process in providing detached soil particles for transport by overland flow Quansah, (1981). This is particularly true if conventional tillage is used, which reduces vegetation cover on the surface of the soil and disturbs both soil structure and plant roots that would otherwise hold the soil in place. However, improved land use practices can limit agricultural soil loss, using farming techniques such as, conservation agriculture including mulching the surface of the soil, minimum tillage and crop rotation.

Crop residues, however, have numerous competing uses (e.g. fodder, fuel and construction material). Similarly, costs are incurred in its application and these increase with mulch level (Mulumba and Lal, (2007). It is based on the problems associated with soil loss that the required mulch type, mulch cover and slope of the farming field need to be determined. This, in effect, reduces surface runoff and increases infiltration of water into the soil and also reduces the depletion of water within the root zone.

1.4 Objective

To determine the effect of mulch types, mulch rates and slope on runoff, infiltration and soil loss under simulated rainfall for two agricultural soils in Ghana.

1.4.1 Specific objectives

The specific objectives were to:

1. construct a rainfall simulator to simulate local rainfall conditions
2. Determine the effect of mulch type on runoff, infiltration and soil loss
3. Determine the effect mulch rate on runoff, infiltration and soil loss
4. Determine the effect slope on runoff, infiltration and soil loss and
5. Determine the effect mulch rate on soil bulk density.

CHAPTER TWO

LITERATURE REVIEW

2.1 Rainfall Simulators

The primary purpose of a rainfall simulator is to simulate natural rainfall accurately and precisely. Rainfall simulations are used to help us understand the effects of rainfall on soil properties under various conditions (Blanquies *et al*., 2003).

Simulators can be separated into two main groups: drop-forming and pressurized nozzle simulators (Thomas and El Swaify, 1989: Cited by Blanquies *et al*., 2003). Drop-forming simulators are impractical for field use since they require such a huge distance (10 m) to reach terminal velocity (Grierson and Oades, 1977). The drop-forming simulators do not produce a distribution of drops unless a variety of drop - forming sized tubes are used. Another disadvantage of the drop forming simulators is their limited application to small plots (Bubenzer, 1979b). Several points of raindrop production must be closely packed to create an intense enough downpour.

Pressurized nozzle simulators on the other hand are suited for a variety of uses. They can be used in the field and their intensities can be varied more than the drop forming type (Grierson and Oades, 1977). Since drops exiting the nozzles have an initial velocity greater than zero due to the pressure driving them out, a shorter fall distance is required to reach terminal velocity. Nozzle intensities vary with orifice diameter, the hydraulic pressure on the nozzle, and the spacing of the nozzle (Blanquies *et al*., 2003).

2.2 Simulating Rainfall

Rainfall is complex, with interactions among properties (drop size, drop velocity, etc.) and large climatic variation based on topography and marine influences. Properly simulated rainfall requires several criteria such as:

1. Drop size distribution near to natural rainfall (Bubenzer, 1979a).

2. Drop impact velocity near natural rainfall of terminal velocity (Laws, 1941); Gunn and Kinzer, 1949)

3. Uniform rainfall intensity and random drop size distribution (Laws and Parsons, 1943)

4. Uniform rainfall application over the entire test plot

5. Vertical angle of impact and

6. Reproducible storm patterns of significant duration and intensity (Moore *et al*., 1983).

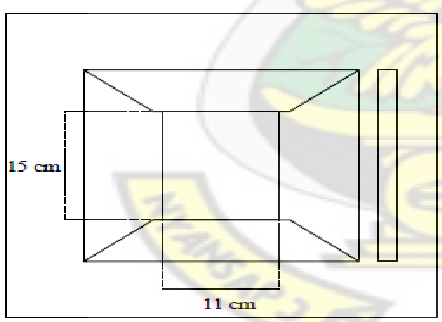
Drop size distribution, impact velocity and reproducible storm patterns must be met to simulate the kinetic energy of rainfall (Meyer and Harmon, 1979).

Kinetic energy (KE $=\frac{m}{2}V^2$) is a single measure of the rainfall used to correlate natural storms and simulator settings. Drop size distribution depends on many storm characteristics, especially rainfall intensity. Drop size distribution varies with intensity (from less than 1 mm to about 7 mm), increasing with the intensity to 2.25 mm median drop size for high intensity storms (Laws and Parsons, 1943). Most design standards were based on Laws and Parson's (1943) studies.

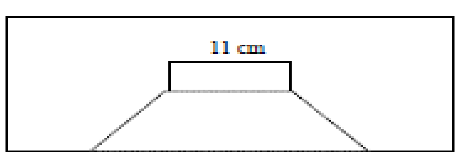
2.3 The Norton Simulator

The Norton Ladder Type Rainfall Simulator is a spray boom that oscillates across a test plot at varying speeds to produce variable intensity storms. Boxes around each nozzle regulate the spray for proper nozzle overlap and swath width. A clutch brake starts and stops the boom as regulated by a signal from the control box. A small gear motor drives the clutch brake and the boom. The four nozzles are supplied with water in sets of two; each set of nozzles has its own hose and pressure gauge to adjust for differences in elevation, hose orientation, etc. The rainfall simulator uses a Spraying systems Veejet 80100 nozzle.

The pressure range of the nozzle is quite large, from 34 to 3400 kPa (5 to 500 psi) yielding flow rates of 13.2 to 132 Litres per minute (3.5 to35 gpm). A pressure of 41 kPa (6 psi) produces drop size and intensity similar to natural rainfall (Bubenzer, 1979a).



Overhead View



Side View

Figure 1: Spray Box

2.4 Covert and Jordan's Portable Rainfall Simulator

2.4.1 The Covert and Jordan's Portable Rainfall Simulator Design

The simulator design described here was based on the pressurised nozzle-type simulator developed by Humphry *et al*., (2002). It was altered to fit the specific requirements of a study into the effect of rainfall on runoff and soil erodibility in different wildfire burn severity conditions. This simulator was used in studies meant to understand the role of the forest floor in water storage and erosion response in south-eastern British Columbia. The simulator needed to produce constant, high-intensity, simulated rainfall for 20-minute intervals, be operated by a 2-person crew on steep forested slopes, and be portable and inexpensive. The simulator consists of an extendible tripod base that supports a single, fixed spray nozzle above the plot (Figure 2). A small fire pump was used to draw water from a collapsible, 273-L still-well water bladder to supply constant pressure to the nozzle.

The tripod base is constructed of three dry-wall support rods (Task Quick Support Rod) extendable to 3.3 m with flat articulated feet that can be spiked into the ground for stability. The upper portion is a rigid frame of three 38-mm angle aluminium leg extensions (1 m long) supporting a 30-cm square, 19-mm plywood top. The leg extensions ensure the nozzle reaches 3 m high when positioned on a slope up to 60%. The simulator used a single nozzle (Spraying Systems 1/2HH-30WSQ) to deliver simulated rain over a 1-m^2 plot. Due to the limited water storage capacity of the Covert and Jordan's simulator, the nozzle is slightly smaller than the nozzle used by Humphry *et al*., (2002). A level and a hook for a plumb bob were attached to the nozzle for levelling and centring the nozzle over the plot.

The simulator generated results that were useful in understanding runoff and sediment production on bare and different mulched rate surfaces.

Figure 2: Rainfall simulator on a 50% slope (source: Covert and Jordan, 2009)

This simulator achieved medium drop size of 1.4mm. The velocity for the median drop size was estimated at approximately 6.9 m/s. This velocity was 7% higher than the terminal velocity of the drops measured by Epema and Riezebos (1983). Drops greater than 3 mm fell at approximately 75% of terminal velocity. Epema and Riezebos (1983) found that drops greater than 3 mm require a fall distance of approximately 13 m to reach terminal velocity, which is difficult to achieve with Covert and Jordan's; however, only 6% of drops generated by this simulator were greater than 3 mm.

2.5 A Portable Drop Former Rainfall Simulator

This type of simulator (Figure 3) was constructed with a 12 mm thick Perspex, for application to an area not exceeding 400 x 400 mm. Water to the closed simulator chamber was supplied from a reservoir by means of a peristaltic pump. The rainfall simulator uses 0.8 mm external diameter hypodermic needles in a 20 x 20 mm square array, with drops falling from the tips at essentially zero velocity. The unit was hoisted to a height of 6 m and produced average drop size of 2.89 mm, intensity up to 575 mm/h, and drop velocity of 7.9 m/s, which is 90% of terminal velocity of natural rain.

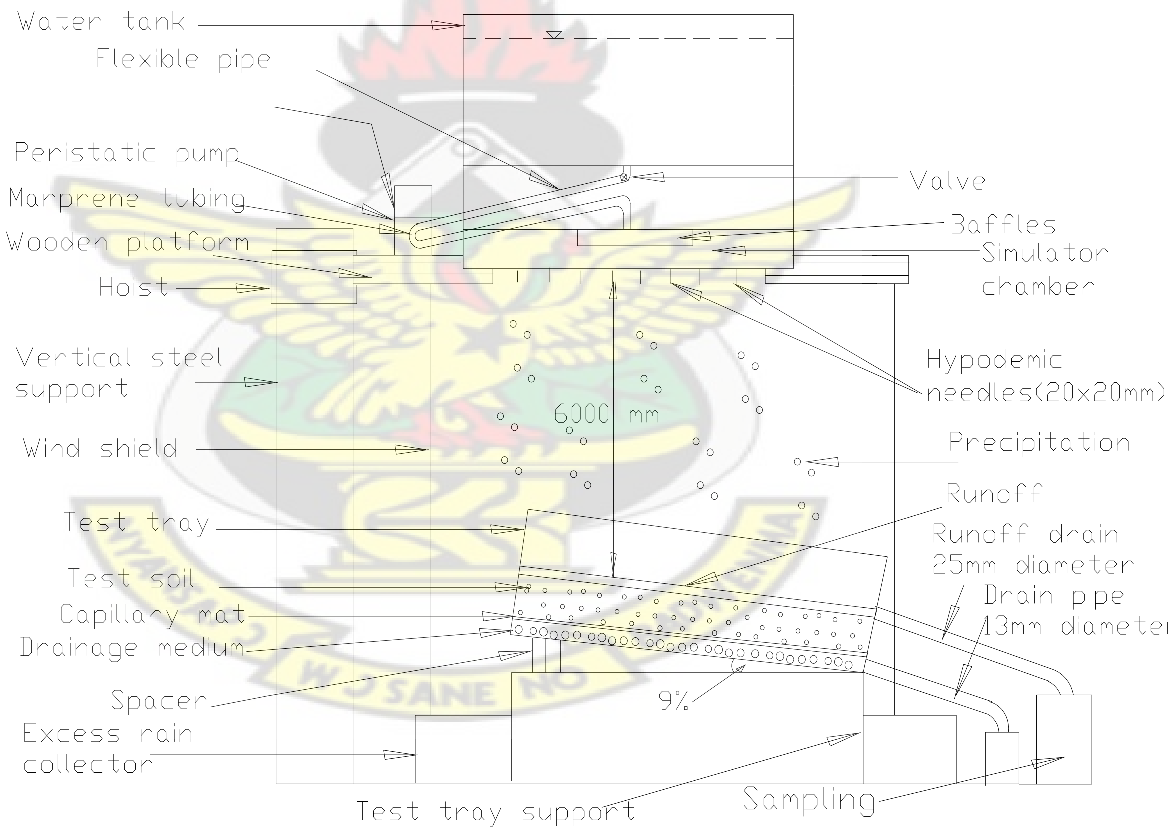


Figure 3: Schematic of the Portable Drop Former Rainfall Simulator with test tray

(Source: Kyei-Baffour, 2004)

2.6 Advantages of Rainfall simulators

The main advantages are:

- The ability to take many measurements quickly without having to wait for natural rain.
- To be able to work with constant controlled rain, thereby eliminating the erratic and unpredictable variability of natural rain.
- It is usually quicker and simpler to set up a simulator over existing cropping treatments than to establish the treatments on runoff plots.

2.7 Disadvantages of Rainfall simulators

It is cheap and simple to use a small simulator which rains onto a test plot of only a few square metres, but simulators to cover field plots of say 100 m^2 are large, expensive and cumbersome.

Measurements of runoff and erosion from simulator tests on small plots cannot be extrapolated to field conditions. They are best restricted to comparisons, such as which of three cropping treatments suffers least erosion under the specific conditions of the simulator test, or the comparison of relative values of erodibility of different soil types.

Simulators are likely to be affected by wind, but having to erect windshields (Hudson, 1993).

2.8 Drop size and terminal velocity

Raindrop size and velocity can have a significant impact on the rate and amount of erosion that can occur at a site, particularly for non-vegetated conditions (Sawatsky, 1996). Drop size distribution, impact velocity and reproducible storm patterns must be met to simulate the kinetic energy of rainfall (Blanquies et al., 2003).

2.8.1 Drop sizes

Thus, gravitational force leads growing cloud droplets to fall as precipitation particles (Humphry et al 2002). Drop diameters ranges from less than 1 mm (usually considered the threshold size separating cloud droplets, which are suspended in the air indefinitely, from falling precipitation drops) to 7 mm (usually considered the maximum drop diameter).

2.8.2 Drop velocities

The gravitational force on a drop is offset by the frictional resistance of the air. As a particle is accelerated downward by gravity, its motion is increasingly retarded by the growing frictional force. Its final velocity is called fall speed, which range from 6.5 m/s for the smallest raindrops to over 9 m/s for the largest raindrops (Blanquies, 2003).

2.9. Soil erosion

Soil erosion, a geophysical process involving the detachment, transport and deposition of soil materials, is one of the most serious eco-problems in many parts of the world, and has put great pressures on the earth surface and its environment (Diodato, 2006; Chen *et al*., 2007; Zhang *et al*., 2008). Soil erosion is a naturally occurring process involving the mobilisation and deposition of soil particles, mainly by water and air. Soil erosion is a feature of any natural ecosystem, the rate at which it is taking place has been significantly accelerated by anthropogenic influences,

2.10. Causes of soil erosion

The causes of erosion can loosely be grouped into two main categories: inappropriate cropping or livestock regimes, and bad management practices: Growing crops on inappropriate land. In many areas, it is possible to identify cropping regimes that are inappropriate for the types of soil and topography present.

2.10.1. Growing maize on steep sided slopes

Maize can often be found growing on steeply sided slopes adjacent to water courses. Given the fact that maize tends to be harvested in June, it is often the case that harvesting takes place in wet conditions which leads to problems with soil compaction and an associated increase in run-off and soil mobilisation. Once maize is harvested, fields of bare soil are often left exposed to July and August rainfall events which can result in extremely high rates of erosion taking place, (Inman 2006).


Figure 4*:* Maize stubble on a steep slope with bare soil exposed.

2.10.2 Animal production on inappropriate land

Inappropriate positioning of livestock production activities can also cause soil erosion. Outdoor pig farming, whilst favourable from an animal welfare perspective, has been found to produce high levels of soil erosion, given the fact that pigs often expose soil to rainfall events due to their characteristic 'rooting' of the land. If land used for pig production is on sloping land, the impacts of soil loss on surrounding water courses can be dramatic (Inman 2006).

Figure 5: Exposed soil on an outdoor pig unit

2.10.3 Degradation of river banks by stock

An increasing proportion of soil entering water courses in recent years has been caused by livestock denuding river banks of vegetation, thus making the banks susceptible to erosion during high water or flood conditions. Grazing animals also enter watercourses to drink during which they often destroy the bank structure.

Figure 6: Bank erosion caused by dairy cow

2.10.4. Lack of ground cover

Modern farming systems have increasingly favoured gully erosion. If crops are not planted early enough after ploughing, they would not establish sufficient crop cover to protect the soil from erosion by heavy rainfall events. This situation would result in gully erosion.

Figure 7: Gully erosion on arable land.

2.11. Effects of soil erosion

The effects of soil erosion can be sub-divided into on-farm and off-farm impacts. On-farm impacts are predominantly borne by the farmer and are essentially related to loss of production capacity. As soil erosion takes place, the ability for cereal crops and grass to flourish is reduced which, in turn, has a direct impact on the productivity of the land (Inman 2006).

2.11.1. Damage to roads and footpaths.

When significant quantities of soil are eroded from agricultural land, roads and footpaths can become blocked which has a negative impact on motorists and walkers. Soil deposition on roads can induce traffic accidents due to the creation of slippery surfaces and can also increase localised flooding when drains become blocked by excessive sediment loads.

Figure 8: Soil movement from field to public highway

2.11.2. Contamination of drinking water

Soil erosion has a significant effect on the quality of potable drinking water supplies. Not only do suspended sediments affect the taste of water but the associated phosphate loads also have to be removed by water companies to provide drinking water fit for human consumption.

Figure 9: Heavy sediment loads after a rainfall event

2.12 Effect of mulch rate on bulk density

Mulching effects on soil bulk density are often variable (Mulumba and Lal, 2007). While some researchers have observed reduced soil bulk density under mulch (Unger and Jones, 1998), others have observed increased bulk density (Bottenberg *et al*., 1999) and yet others noted no mulch effect on bulk density (Blevin *et al*., 1983; Acosta *et al*., 1999; Duiker and Lal, 1999): cited by Mulumba and Lal, (2007). The effects of mulching on bulk density may vary due to soil type, antecedent soil properties, type of mulch, climate and land use. Although the beneficial effects of mulching are known, there are instances when its availability is limited. Crop residues have numerous competing uses (e.g. fodder, fuel and construction material). Similarly, costs are incurred in its application and these increase with mulch level.

2.13 The Revised Universal Soil Loss Equation

The revised universal soil loss equation (RUSLE) has widely been used for predicting annual average soil loss for specific areas. In this equation, soil loss A is defined as a product of rainfall–runoff erosivity factor R, soil erodibility factor **K,** slope steepness factor **S**, slope length factor L, cover management factor C, and support practice factor P (Renard *et al*., 1997); cited by Wang, *et al*., 2002. i.e.: A=RKSLCP (1)

Modelling soil erosion is very complicated because the soil loss is determined not only by its multiple factors, but also by the interactions between the factors and the inputs from other systems. For example, the soil erodibility factor K depends on soil structure, permeability, organic matter, percent sand and so on. Errors from the factors and inputs propagate and accumulate through the entire system of soil loss (Renard *et al*., 1997). Furthermore, soil loss varies in both space and time because of the heterogeneity of the factors at different space and time scales (Wu and Loucks, 1995; Marceau and Hay, 1999; Wu, 1999). Aggregating the estimates of soil loss from minimum measurement units to a region or from short term to long term, may also lead to error propagation (Wu, 1999).

2.14 Soil Erodibility

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil (Wall *et al*., 2003; El-Swaify and Dangler, 1977). Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils (Wall *et al*., 2003).

Although soil resistance to erosion depends partially on topographic position, slope steepness and the amount of soil disturbance, the properties of soil are the most important determinants (Morgan, 1995). Erodibility is influenced by soil properties including texture, organic matter, structural stability, clay mineralogy and chemical constituent (Lal, 1994; Morgan, 1995).

Soil texture, the relative proportion of various mineral particles, is important in determining erodibility. The risk of erosion increases if soil contains a greater amount of silt and very fine sand. These are the most erodible particles, since they are more easily detached and transported than sand and clay particles. Sandy soils have lower run off rates and are easily detached, but is less transported; clay soils usually form stable aggregate with organic matter and thus protect them from detachment and transport.

Organic matter consists of plant and animal litter in various stages of decomposition. It helps in binding soil particles together, improving soil structure, and increasing the soil's permeability and water-holding capacity. Soils with organic matter are less susceptible to erosion and more fertile than soils without organic matter.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The experiment was conducted at the Department of Agricultural Engineering at the Kwame Nkrumah University of Science and Technology, Kumasi, which is located at latitude 6°41'56.75''N, longitude 1°31'25.85''W at an altitude of 274 m above sea level. Average maximum and minimum temperature is about 31°C and 23°C respectively. The rainfall distribution has bimodal nature with the first and second rainfall during April to July and August to October respectively.

The gross annual rainfall of Kumasi recorded over 55 years is around 1488.92mm. The area has uniformly high mean temperature values between 24-27°C occurring from December to mid-March for Kumasi, monthly means of 24°C at Kumasi. The highest relative humidity prevalent in the area occurs in the morning with values of 90% in July-September and 78% in January-February. The relative humidity is usually around 50% at mid-day

3.2 Rainfall Simulator Design

The designed simulator consists of a telescopic/extendible four legged base that supports a fixed spray boom above the plot (Figure 11). A small pump (0.37 kW, 3.8 N/m^2) was used to draw water from a 5000 litres galvanized steel water tank to supply constant pressure to the boom.

The spray boom was made from a 12.7 mm internal diameter and 2.5 m long PVC pipe. Five (5) strips of lines 5 mm apart were drawn along the surface of the boom. This surface formed a sector which subtends an angle of 180^0 at the centre of the boom. A 0.5 mm drill was used to create orifices along those strips of lines at 20 mm equidistance spacing.

The main frame onto which the boom was fixed on was 100 x 50 cm rectangular section constructed from 25 x 25 mm angle iron and had provision for rod and sockets joints at the four corners at an angle of 15^0 to the vertical to accommodate the legs. The stand was made up of four (15 x 15 mm and 3.4 m long) rectangular pipes having iron rod base extension (12.5 mm diameter and 75 cm long) to ensure that the boom reaches 3 m heights and levels when positioned on a slope up to 30 %. Many rainfall simulators are designed with the nozzle at a height of 3 m to replicate the velocity and kinetic energy of natural rain (Meyer and Harmon 1979; Commandeur and Wass 1994; Humphry *et al*., 2002).

An adjustable valve at the base of the simulator, along with a pressure gauge at the outlet of the pump were used to achieve the desired nozzle pressure (3.8 N/m^2). A level and a hook for a plumb bob were attached to the nozzle for levelling and centring the boom over the plot.

The height was set by adjusting and positioning the legs so that the hanging plumb bob touched the centre of the plot when the level bubble was centred.

A 0.37 kW single phase electric pump delivered water from the 5000 litres galvanized steel tank to the simulator through 12.7 mm internal diameter pipe to the boom (Figure 11).

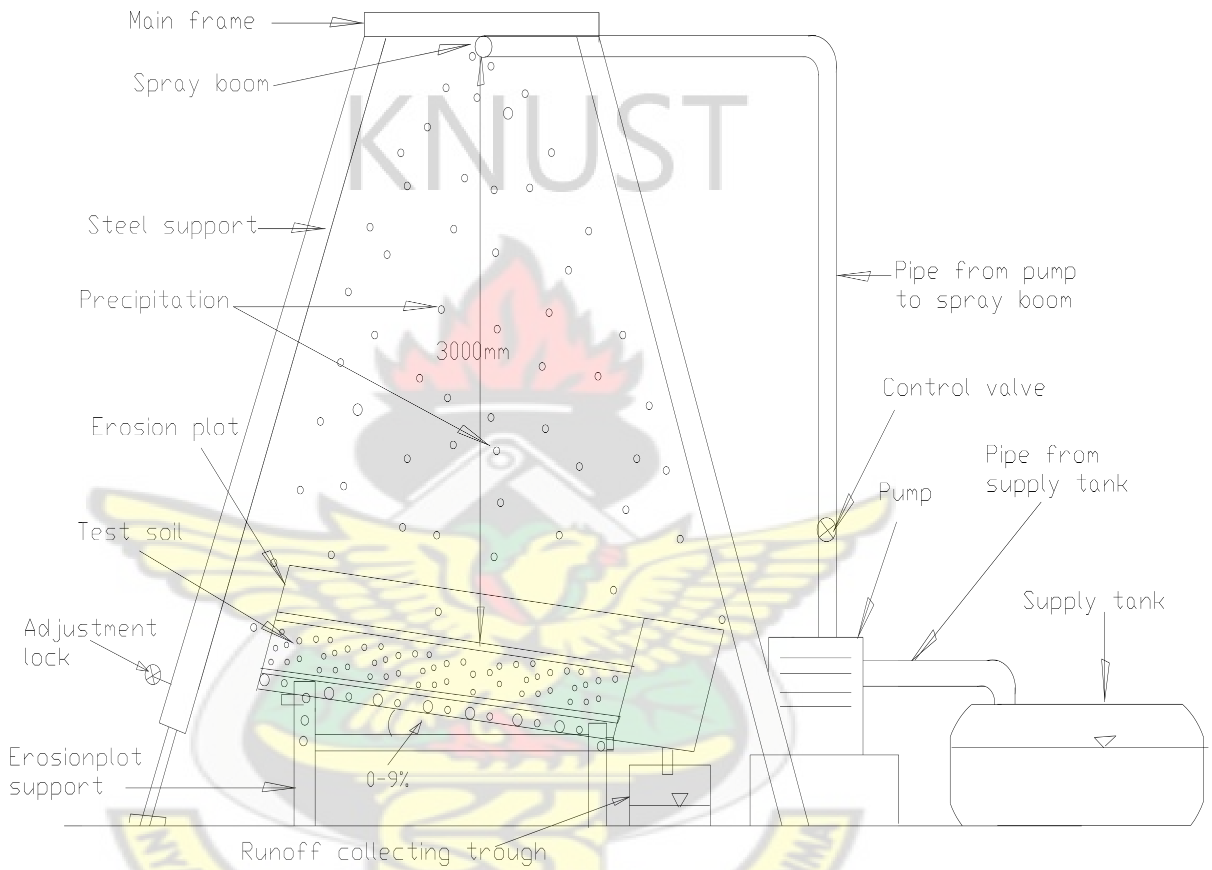


Figure 10: Schematic diagram of the rainfall simulator with erosion plots arrangement

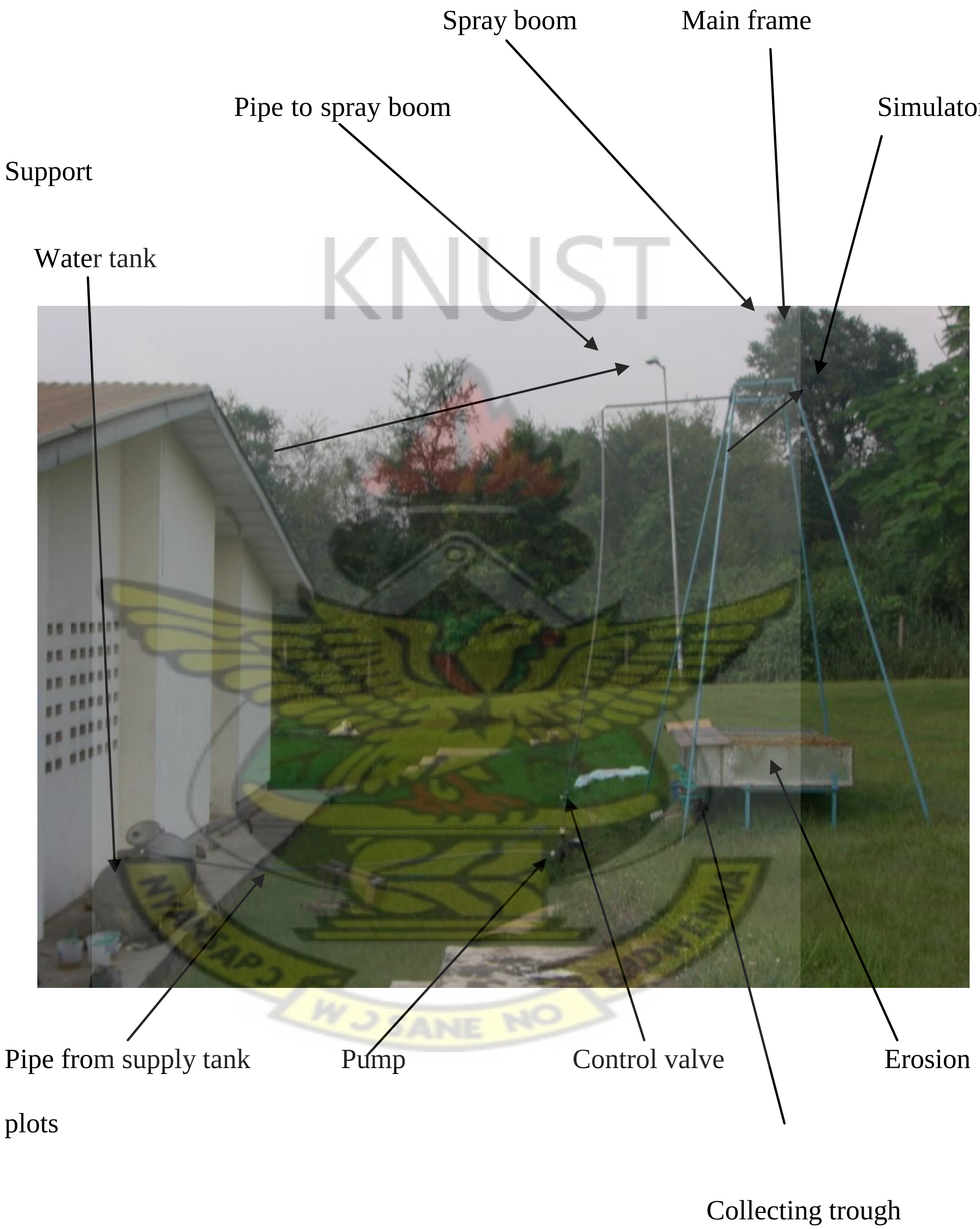


Figure 11: The complete set up for the experiment (Author's experimental set-up)

3.3 Intensity Calibration

The intensity of the simulated rainfall was measured by using TRU-CHEK (TRU-200) type of rain gauge. Rainfall intensity was measured by the rain gauge placed vertically in the central portion of the plot. The pump and pressure at the nozzle were set to the desired level for one minute. The water collected was poured into a measuring cylinder to determine the rainfall amount and hence the intensity. If the intensity was undesirable, the pressure was adjusted and the calibration re-run until the desired intensity for the simulation was reached. The rainfall was simulated for 3 runs with the rain gauge placed at three different positions, each lasting for 1 minute. The measured value of rainfall amount was thus the average of these values.

3.4 Discharge Calibration

For the calibration of discharge, a 0.5-m^2 waterproof tray was placed over the erosion plot's border to catch the rainfall and to keep the plot dry during calibration. The pump at the water tank and pressure at the nozzle were set to the desired intensity level for one minute. The water captured in the tray was measured in a 1000-ml graduated cylinder to determine the resulting rainfall amount. After calibration, the plot cover was removed, the timer started, and the valve was opened to start the simulation.

3.5 Drop sizes and velocity Determination

A thin layer of Cassava flour, and Wheat flour were each spread on separate trays and passed speedily through the rain shower. The raindrops were assumed equivalent in size to the raindrops received in the flour layer. The flour was dried and the pellets separated according to their size ranges using a nest of sieves. The pellets on each sieve were then counted and the weight calculated using density formula in equation one below. The size of raindrops was calculated from the size of pellets.

The velocity of the drop was measured using a stop watch to time a drop from the time it leaves the orifice to the time it terminates at the surface of the soil. This timing was done repeatedly for five times by three people and the averages taken. The velocity was calculated by dividing the distance between the boom and the surface of the soil by the recorded time.

$D = \frac{M_d}{V_d}$ ……………………………………………………………………………………..…….**1**

Where: D = density of water in kg/m^3*,*

M_d = *mass of the drop in kg and*

V_d = *volume of the drop in m*^{3}*,*

$V_d = \frac{1}{6}\pi d^3$ *(m*^{3}*)* ……………………………………………………………………………….… ***2***

Where, d = mean diameter of the rain drops.

The kinetic energy of the drop KE = $\frac{m}{2}V^2$ *(Joules)* ………………………………………….……….…***3***

Where m = average mass of the rain drops, and

V = average velocity of the rain drops in m/s.

3.6 Runoff, Soil Loss and Infiltration Rate Determination

Samples from each soil were collected from the upper 30 cm of uncultivated land from two locations in the Ashanti Region of Ghana. The samples for each soil type were bulked to give a composite. All soils had been under bush fallow for at least one year prior to being sampled. The physico-chemical properties of the soils were determined. Initially the iron oxide in the soil was removed by centrifuging with citrate-bicarbonate, peroxide, sodium dithionite and saturated sodium chloride until a clear centrifugation was obtained prior to analysis (Gee and Bauder, 1986). The soils were sun-dried to moisture content of 8% (dry basis), and large clods were reduced to smaller fractions. The soils were then passed through a No. 10 sieve, with an apparent opening size of 2 mm. A portion of the soils was further dried for mechanical analysis. The developed rainfall simulator similar to the one described in Figure 12 by Covert and Jordan (2009) was used in the laboratory to simulate up to 100 mm/h rainfall intensity, which is typical of the tropics.

Figure 12: Covert and Jordan’s Rainfall simulator on a 50% slope

3.7. Experimental design

The experiment used a 2 x 4 x 4 x 4 x 4 factorial design with four independent variables (four of four levels each, and the other of two levels).

The independent variables and their levels were:

Soil types; Kotei series, and Anwomaso series,

Slope; 0%, 3%, 6% and 9%,

Rainfall duration; 15, 30, 45 and 60 minutes,

*Mulch type: Rice straw (*Oryza sativa *L.), Elephant grass (*Pennisetum purpureum*),*

*Maize Stover (*Zea mayz *L.) and* Cyperus haspan *L.,*

Percent ground cover by mulch; 0%, 30%, 60% and 90%.

The zero percent mulch cover served as the control experiment. This gave 512 experimental runs and there were five replicates of each run. The dependent variables were surface runoff, soil loss, and apparent cumulative infiltration. The amount of grass mulch needed for a given mulch cover was estimated using the following equation derived by Gregory (1982): Cited by Adekalu *et al*., (2006).

$$MR = -\frac{ln\,(1-MC)}{A_m}$$

Where *MR* is the mulch rate in tons/ha, *MC* is the fraction of ground cover by mulch, and A_m is the area covered per unit mass of the mulch type. The A_m value of 0.38 derived by Ozara (1992); Cited by Adekalu *et al*., (2006) for grass was used. This gave mulch application rate of 0.94, 2.41, 6.06 t/ha for 30%, 60%, and 90% mulch cover, respectively. This formula was used for all the mulch types used in the work.

Boxes measuring 1.0 m x 0.5 m · 0.3 m (length x width x height) were developed and used to expose the soils to the simulated rain. Sieve sizes of 2 mm were used to cover the bottom of the box to allow free drainage of water. New mulch material was applied to the soil surface after each rainfall duration. The soils were compacted to a bulk density of 1.33 Mg/ m^3 for the Kotei series and 1.39 Mg/m^3 for the Anwomaso series, and left for one (1) day for the gravitational water to drain out. This was done to simulate field conditions because in Ghana mulching is applied after ploughing, which is done after the first few rains.

After each experimental run, 200 ml of the thoroughly mixed runoff water from each plot was put into weighted containers. The samples were then placed in an oven at a temperature of 105^0 for 24 h to dry. The dried samples plus container were reweighed and the weight of the empty container subtracted to determine the mass of the sediment in the 200 ml. The total soil loss was determined in proportion to the total runoff for each experimental run.

The volume of water infiltrated was calculated as the difference between the volume of water simulated onto the plot area and the runoff volume.

3.8 Statistical Analysis

The statistical tool used for all the analyses was SPSS version 17, UK at 0.05 significance level.

Univariate analysis of variance was performed on the data from the two soils to determine if there were any significant differences between the treatments and their interactions for the soil loss, runoff and infiltration.

Probability density functions at full factorial were performed on the data to determine the mean effect of the treatments and their interactions.

Regression was performed on the data for each soil to determine the equations for the soil loss, runoff and infiltration.

CHAPTER FOUR

RESULTS AND DISCUSSION

This graph (Figure 13) was obtained from the drop sizes that were determined from the rainfall simulator. From Figure 13, the bars in the blue colour were obtained from the drops that were determined with the wheat flour and those obtained from the cassava flour are in deep brown.

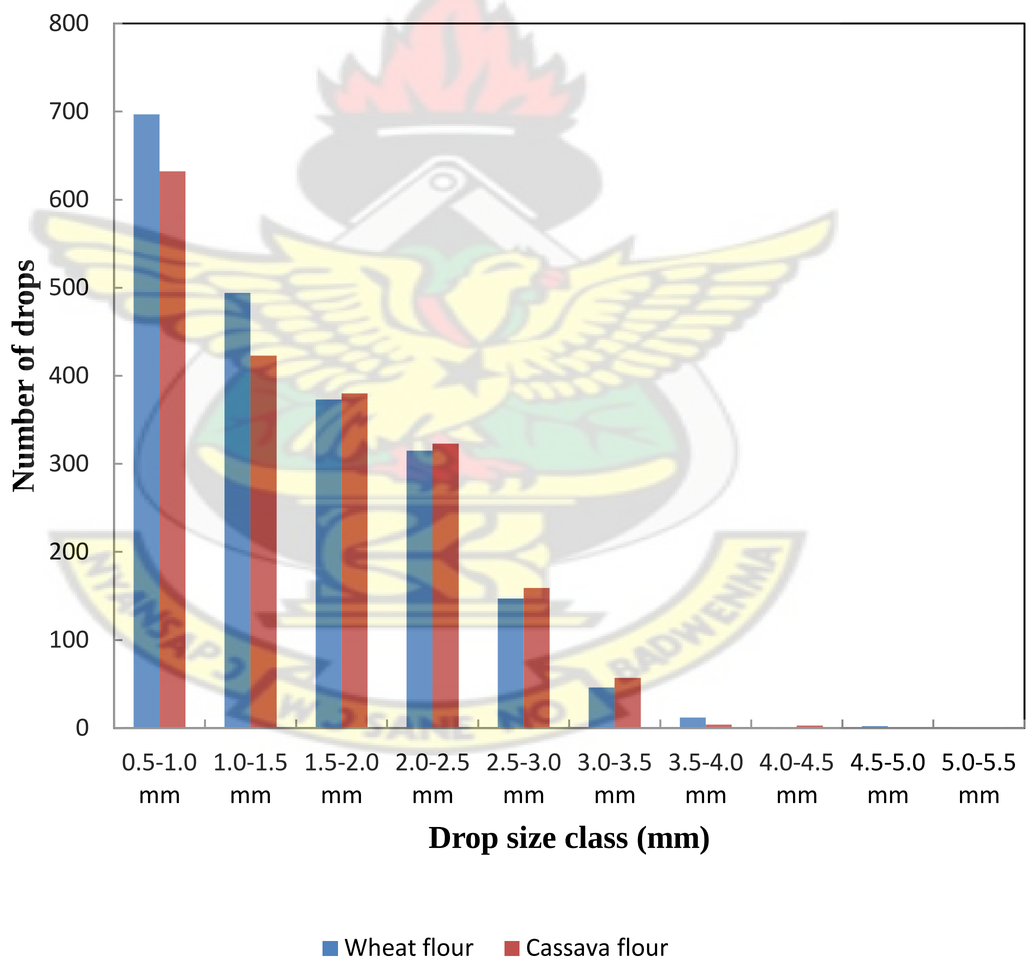


Figure 13: Graph of drop sizes against the number of drops obtained from cassava and wheat flours

4.1. Mean drop size, velocity and kinetic energy from the simulator

The simulator achieved mean drop sizes of 1.54 mm and 1.49 mm from cassava and wheat flours respectively.

The drops were 0.14 mm and 0.09 mm higher than that reported by Covert and Jordan (2009) who used similar simulator at the same height and achieved mean drop size of

1.4 mm. The mean velocity of the drops was 7.5 m/s which is 8.6% higher than was reported by Covert and Jordan (2009) with a mean velocity of 6.9 m/s. The mean velocity achieved 83% of the terminal velocity of natural rainfall of 9 m/s.

Table 1: Average drop size, mass and kinetic energy obtained from Cassava and Wheat flours

S/N	Flour material	Mean drop size (mm)	Mean mass (g)	Mean kinetic energy (Joules)
1	Cassava flour	1.5388 (0.0456)	0.001908	5.3665×10^{-5}
2	Wheat flour	1.4940(0.0450)	0.007460	4.9106×10^{-5}

The drops obtained from cassava and wheat flours achieved mean kinetic energies of 5.3665×10^{-5} Joules and 4.9106×10^{-5} Joules respectively. These kinetic energies are within the required values for the drops obtained.

The measured mean mass of the drops obtained from cassava and wheat flours re also 1.908 x 10 -3 g and 7.46 x 10 -3 g respectively. These values are also within the required weights for the drops obtained.

Drops greater than 3 mm require a fall distance of approximately 13 m to reach terminal velocity (Epema and Riezebos (1983). This was difficult to achieve with the drops that were bigger than 3mm; however, only 3% of drops generated by this simulator were greater than 3 mm (Appendix 1c).

The drop sizes were within the range of drops measured from natural rainfall of less than 1 mm to 7 mm Blanquies, 2003. This meant that the drops produced by this simulator could cause the necessary downpour to detach soil particles for transport.

4.2 Physico-Chemical Properties of the Top Soils

Soil series	Iorizon (cm)	pH H_{20}	Org. C %	Total N %	Org. M %	Exchangeable cation				T.E.B	Exch. A Al+H	E.C.E.C /me/100 g	Base Salt %	Mechanical Analysis			Texture	FAO Classification, 1998
						Ca	Mg	K	Na					Sand	Silt	Clay		
Anwomaso	0 - 30	4.78	0.47	0.05	0.81	2.67	2.67	0.24	0.64	6.22	0.80	7.02	88.60	57.98	19.98	22.04	Sandy Clay Loam	Acrisol
Kotei	0 - 30	6.07	0.53	0.05	0.91	2.94	0.67	0.19	0.24	4.00	0.10	4.10	97.56	71.30	24.68	4.02	Sandy Loam	Acrisol

The textural class indicates that the percentage of silt particles in the Anwomaso soil was almost 18% higher than the Kotei soil. The percentage of sand particles in the Kotei soil was also about 14% higher than the Anwomaso soil. Combining the silt and clay particles for each soil, Anwomaso soil had 42.02% and Kotei soil had 28.7%. During rainfall event, silt and clay particles are easily transported by runoff water. This resulted in higher soil loss value for the Anwomaso soil.

Table 2: Analysis of variance for soil loss, runoff and infiltration data generated in the rainfall simulator

Sources	DF	F-value		
		Soil loss	Runoff	Infiltration
Soil type	1	23880^{**}	1685^{*}	1419^{*}
Mulch type	3	5079^{**}	574.2^{*}	659.8^{*}
Mulch rate	3	91500^{**}	20160^{**}	20930^{**}
Rainfall duration	3	52510^{**}	71450^{**}	44470^{**}
Slope	3	26360^{**}	9013^{**}	9109^{**}
Soil type ^{x} Mulch type	3	186.2^{ns}	55.5^{ns}	22.9^{ns}
Soil type ^{x} mulch rate	3	3417^{*}	1240^{*}	1042^{*}
Soil type ^{x} Rainfall duration	3	1333^{*}	456.4^{*}	216.6^{*}
Soil type ^{x} Slope	3	651.7^{*}	616.6^{*}	471.7^{*}
Mulch type ^{x} mulch rate	9	120.8^{ns}	19.9^{ns}	42.2^{ns}
Mulch type ^{x} Rainfall duration	9	170.4^{ns}	36.3^{ns}	107.8^{ns}
Mulch type ^{x} Slope	9	142.4^{ns}	74.6^{ns}	74.1^{ns}
Mulch rate ^{x} Rainfall duration	9	4161^{*}	1339^{*}	1520^{*}
Mulch rate ^{x} Slope	9	1395^{*}	248.0^{*}	288.5^{*}
Rainfall duration ^{x} Slope	9	260.5^{*}	623.9^{*}	708.3^{*}
Soil type ^{x} Mulch type ^{x} mulch rate	9	38.5^{ns}	10.4^{ns}	9.4^{ns}
Soil type ^{x} Mulch type ^{x} Rainfall duration	9	228.7^{ns}	38.0^{ns}	69.2^{ns}
Soil type ^{x} Mulch type ^{x} Slope	9	232.2^{ns}	23.3^{ns}	30.7^{ns}
Soil type ^{x} mulch rate ^{x} Rainfall duration	9	155.7^{ns}	133.4^{ns}	88.6^{ns}
Soil type ^{x} mulch rate ^{x} Slope	9	147.9^{ns}	65.4^{ns}	65.7^{ns}
Soil type ^{x} Rainfall duration ^{x} Slope	9	127.3^{ns}	98.4^{ns}	84^{ns}
Mulch ^{x} mulch rate ^{x} Rainfall duration	27	85.0^{ns}	5.5^{ns}	28.5^{ns}
Mulch ^{x} mulch rate ^{x} Slope	27	28.7^{ns}	14.6^{ns}	25.1^{ns}
Mulch type ^{x} Rainfall duration ^{x} Slope	27	168.1^{ns}	35.8^{ns}	77.6^{ns}
Mulch rate ^{x} Rainfall duration ^{x} Slope	27	98.8^{ns}	16.8^{ns}	34.8^{ns}
Soil type ^{x} Mulch type ^{x} mulch rate ^{x} Rainfall duration	*27*	57.8^{ns}	7.1^{ns}	13.1^{ns}
Soil type ^{x} Mulch type ^{x} mulch rate ^{x} Slope	27	32.9^{ns}	16.8^{ns}	29.9^{ns}
Soil type ^{x} Mulch type ^{x} Rainfall duration ^{x} Slope	27	160.3^{ns}	16.1^{ns}	61.5^{ns}
Soil type ^{x} mulch rate ^{x} Rainfall duration ^{x} Slope	27	82.2^{ns}	16.7^{ns}	19.5^{ns}
Mulch ^{x} mulch rate ^{x} Rainfall duration ^{x} Slope	81	50.9^{ns}	8.1^{ns}	21.5^{ns}
Soil type ^{x} Mulch type ^{x} mulch rate ^{x} Rainfall duration ^{x} Slope	81	39.3^{ns}	5.9^{ns}	22.9^{ns}
Error	1			
Total	512			
Corrected Total	511			

Key: * = significant at $P \leq 0.05$; ** = significant at $P \leq 0.01$;

*** = significant at $P \leq 0.001$; ns = not significant; ^{x} = interaction

4.3. Interactions between variables (Table 2)

On the effect of soil type, slope, rainfall duration, mulch type and mulch rate on soil loss, runoff and infiltration; there were two star significant differences ($P \leq 0.01$) dependent variables except for soil type and mulch type on runoff and infiltration where there was one star significant difference ($P \leq 0.05$).

Interactions between two variables: there were one star significant differences ($P \leq 0.05$) for soil type ^{x} mulch rate, soil type ^{x} rainfall duration, soil type ^{x} slope, mulch rate ^{x} rainfall duration, mulch rate ^{x} slope, and rainfall duration ^{x} slope in the soil loss, runoff and infiltration. There were no significant difference ($P \geq 0.05$) for soil type ^{x} mulch type, mulch type ^{x} mulch rate, mulch type ^{x} rainfall duration, and mulch type ^{x} slope for all the response variables.

Interactions involving three or more variables: there were no significant difference ($P \geq 0.05$) for all the interactions This means that as the number of interaction increases the significant differences decreases from ($P \leq 0.01$) to ($P \leq 0.05$).

Where there was no significant difference ($P \geq 0.05$) for soil loss, it was also not significant ($P \geq 0.05$) for runoff and infiltration. Where variables interactions was significant ($P \leq 0.05$) for soil loss, it was also significant for runoff and infiltration. This confirms findings by Adekalu, (2006) that where there was no significant difference ($P \geq 0.05$) for soil loss, it was also not significant ($P \geq 0.05$) for runoff and where variables interactions was significant ($P \leq 0.05$) for soil loss, it was also significant for runoff.

4.4 Mulch types and percentage reduction of soil loss

With reference to figure 14, mulching the soil surface with 0.94 t/ha of mulch, the percentage reduction of soil losses were 29%, 37%, 40% and 42% for maize stover, rice straw, elephant grass and lawn grass respectively as compared to their respective no mulch surfaces.

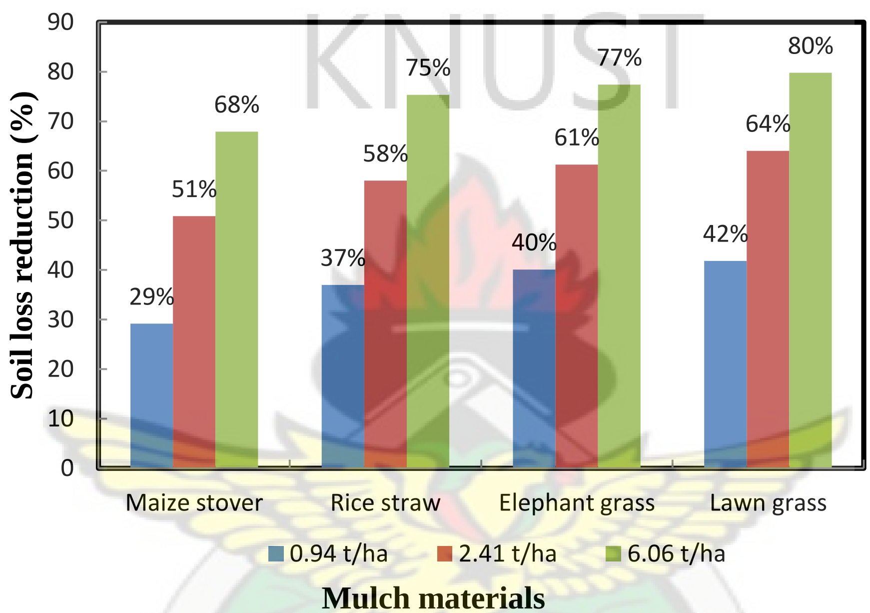


Figure 14: Graph of percentage soil loss reduction (for all soils, mulch rates, slopes and durations) as affected by the mulch materials

Mulching the soil surface with 2.41 t/ha of mulch, the percentage reduction of soil losses were 51%, 58%, 61% and 64% for maize stover, rice straw, elephant grass and lawn grass respectively as compared to their respective no mulch surfaces.

Mulching the soil surface with 6.1t/ha of mulch, the percentage reduction of soil losses were 68%, 75%, 77% and 80% for maize stover, rice straw, elephant grass and lawn grass respectively as compared to their respective no mulch surfaces. The average mulch rate of 5t/ha for rice straw reduced soil loss by 89% which is close to Meyer *et* *al*., (1970) cited by Adekalu *et al*., (2006) that application of 5t/ha of rice straw mulch reduces soil loss by 95%. The difference in the reduction may be due to differences in the nature of the soil surfaces, bulk density and the slopes at which the experiments were conducted.

This means that lawn grass may be a better mulch material than elephant grass, rice straw and maize stover. Elephant grass is also better than rice straw which agrees with Adekalu *et al*., (2006) who used similar application rates of elephant grass and compared it with rice straw application done by Lal (1979). Although lawn grass proved to be a better mulch material than elephant grass, farmers in Ghana may prefer the elephant grass to the lawn grass because it is easier to harvest, common and close to their farms.

4.5 Slope against soil loss, runoff and infiltration

Mean soil loss, runoff and infiltration values (average for all soils, mulch types, Mulch rates and durations) as affected by slope were plotted as shown in Figure 15.

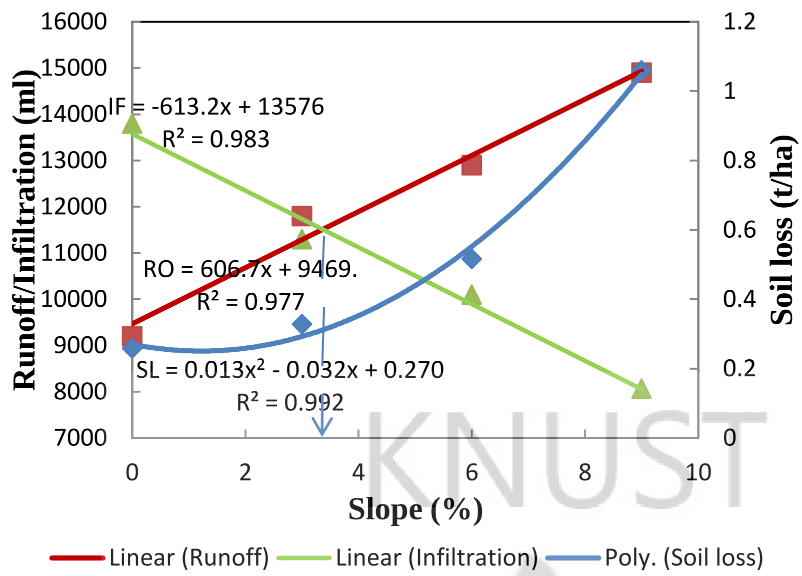


Figure 15: Graph of mean soil loss, runoff and infiltration (for all soils, mulch rates, mulch types and durations) as affected by the slopes.

The effect of slope on soil loss, runoff and infiltration (average for all soils, mulch types, mulch rates and durations) are shown in Figure 15. From the graph in Figure 15, it can be deduced that soil loss and runoff increase with increase in slope but infiltration decreases with increasing slope. It was observed from the graph that the increase in soil loss from 0% slope to the 3.4% slope where runoff and infiltration intersect was small. It however, increased sharply after the 3.4% slope where runoff increases more than infiltration.

From calculation in Appendix 5, the field slope at which runoff and infiltration become equal is **3.36 %, w**hich agrees with Lay (2010) who used an irrigation system design to prove that slopes in excess of 3% are not recommended, unless the field is planted to a permanent sod-forming crop or unless other means of erosion control are used.

4.6 Mulch rate and surface runoff

The effect of mulch cover on runoff losses for the different soils and slopes is shown in Table 3. The results were averaged over all the rainfall durations and mulch types.

Table 3: Surface runoff (%) from two Ghanaian soils as affected by mulch rate and slope (average for all mulch type, and rainfall duration)

Soil series	**Slope (%)**	**Mulch rate (%)**			
		0	**30**	**60**	**90**
Kotei	0	48(±4)	43(±5)	38(±4)	31(±3)
	3	71(±2)	61(±5)	54(±7)	38(±5)
	6	74(±5)	63(±6)	53(±8)	39(±9)
	9	79(±5)	68(±8)	60(±7)	51(±5)
Awomaso	0	56(±3)	45(±5)	33(±3)	21(±4)
	3	65(±4)	55(±7)	38(±8)	21(±7)
	6	78(±6)	66(±8)	45(±9)	22(±5)
	9	83(±8)	72(±9)	64(±10)	40(±11)

Standard deviation values are in brackets

The correlation between runoff and slope was positive. Mean runoff losses were 39%, 50%, 55%, and 65% for 0%, 3%, 6%, and 9% slopes respectively. Also the mean runoff losses were 69%, 59%, 48% and 33% for 0%, 30%, 60% and 90% ground cover of mulch, respectively.

4.7 Mulch rate and infiltration

The influence of mulch rate and slope on infiltration is shown in Table 6. The result indicates that the percentage of water infiltrated into the soil decreased with increasing slope and increased with increasing level of mulch cover. At 0% and 30% mulch cover, the percentage infiltration is higher in the Kotei soil than the Anwomaso soil for all the slopes except at 3% slope. Also at 60 and 90% mulch rates, the percentage infiltration for the Anwomaso soil was higher at all slopes, except with 60 mulch rate at 9 % slope.

Table 4: Cumulative infiltration (%) from two Ghanaian soils as affected by mulch rate and slope (average for all mulch type, and rainfall duration)

Soil series	**Slope (%)**	**Mulch rate (%)**			
		0	**30**	**60**	**90**
Kotei	0	52(±4)	57(±5)	62(±4)	69(±3)
	3	29(±2)	39(±5)	44(±8)	62(±5)
	6	26(±5)	37(±6)	46((8)	61(±9)
	9	21(±5)	32(±8)	40(±7)	49(±5)
Awomaso	0	44(±3)	55(±5)	67(±3)	79(±4)
	3	35(±4)	45(±7)	62(±8)	79(±7)
	6	22(±6)	34(±8)	55(±9)	78(±5)
	9	17(±8)	28(±9)	36(±11)	60(±11)

Standard deviation values are in brackets

4.8 Mulch cover against soil loss, runoff and infiltration

Mean soil loss, runoff and infiltration values (average for all soil, mulch type, slope and duration) as affected by mulch rate were plotted as shown in Figure 16. The analysis of variance in Table 3 shows that there was significant interaction between mulch rate and all other variables for soil loss. The effect of mulch rate on soil loss, runoff and infiltration (average for all soils, mulch types, slope and durations) are shown in Figure 16. For runoff, there was no significant difference between mulch rate and mulch type and for combinations that involved more than two variables.

From the graph in Figure 16, it can be proved that soil loss and runoff decrease with increase in mulch rate. Infiltration however, increases with increasing mulch rate. The mulch cover at which runoff and infiltration become equal is **2.25 t/ha** (57.4 %) ground cover.

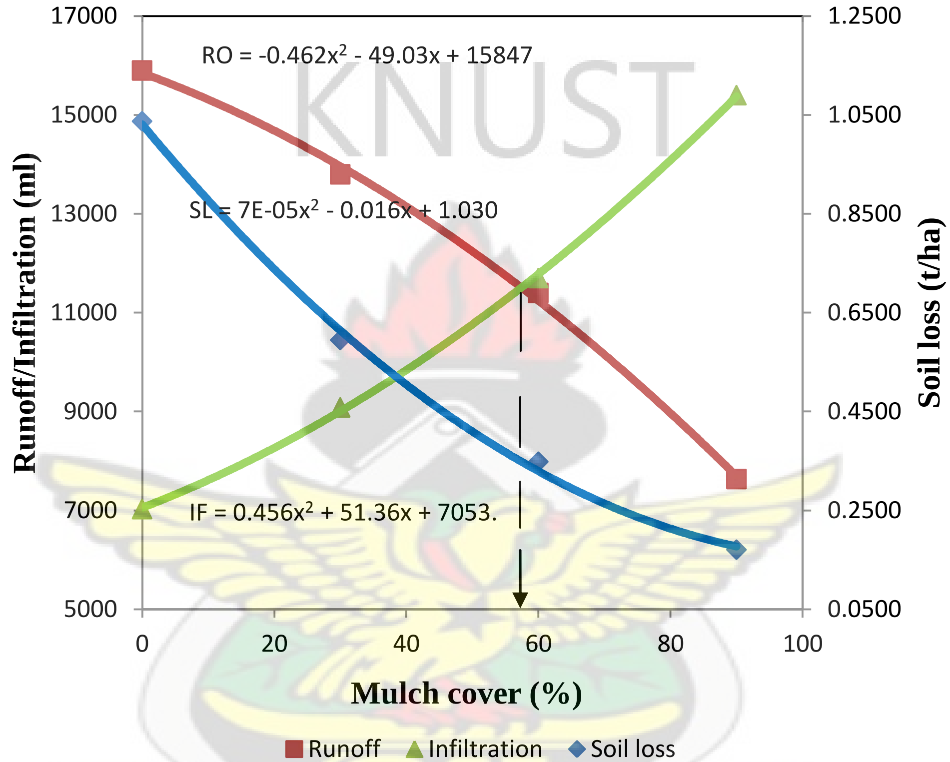


Figure 16: Graph of mean soil loss, runoff and infiltration (for all soils, mulch types, slope and durations) as affected by the mulch cover.

4.9 Soil loss and slope

The values for plotting this graph can be found in Appendices 7 and 11. The averages of the mean and standard deviation values from the two soils were used.

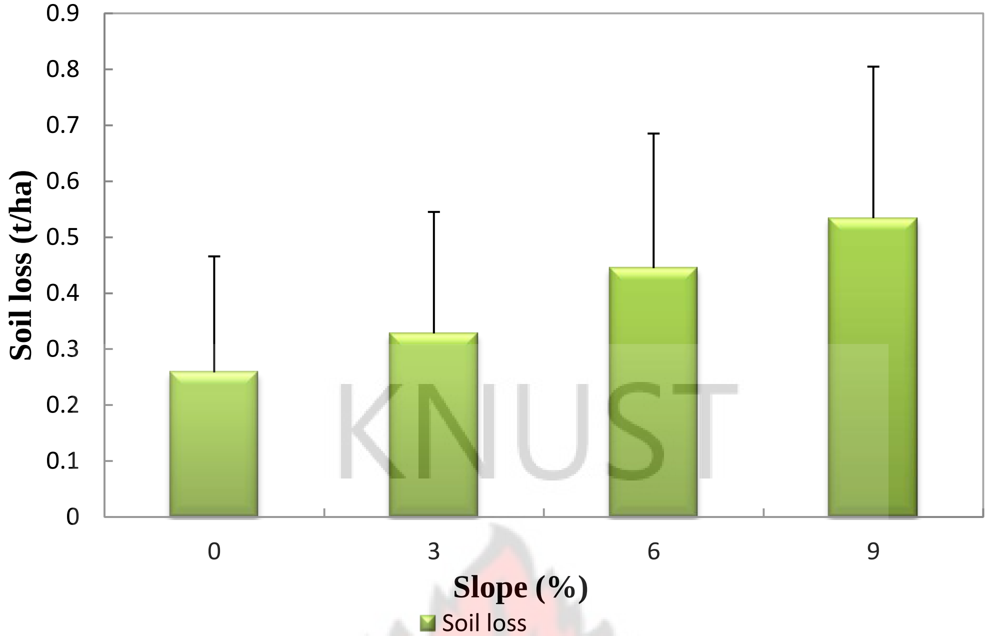


Figure 17: Mean soil loss Kotei and Anwomaso soils (average for all mulch types, mulch rate and rainfall durations) as affected by slope

Figure 17 shows that soil loss increases with increasing field slope. The length of the error bar is an indication that the level of variability in the data was high.

4.10 Slope against runoff and infiltration

The value for plotting this graph can be found in Appendix 7 and 11. Averages of the mean and standard deviation values from the two soils were used.

Figure 18 shows that runoff increases with increasing slope but the infiltration decreases with increasing slope. It was observed that at 0% slope, the infiltration was higher than the runoff.

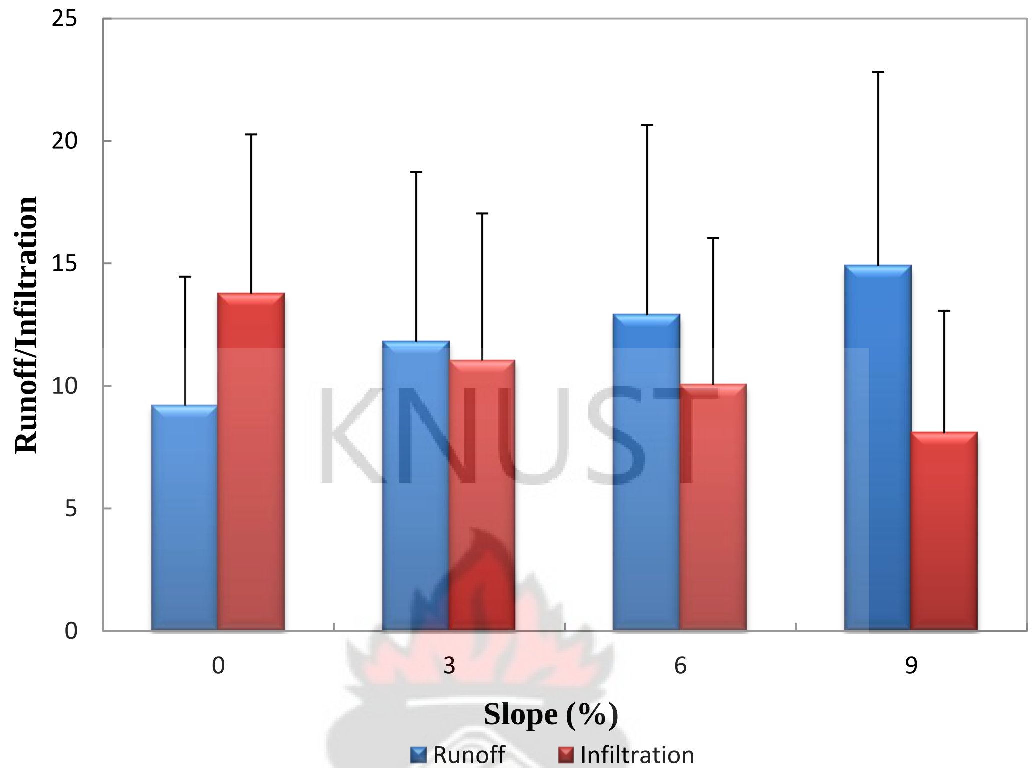


Figure 18: Mean runoff and infiltration for the Kotei soil (average for all mulch types, mulch rate and rainfall durations) as affected by the slope.

At 3% slope, runoff and infiltration almost closed up. This was because the increasing slope was getting closer to 3.4%, the slope at which runoff and infiltration equalled (Figure 15). The length of the error bar is an indication that the level of variability in the data for the runoff was slightly higher than that of the infiltration.

4.11 Soil loss against rainfall duration

The values for plotting this graph can be found in Appendix 8 and 12. Averages of the mean and standard deviation values from the two soils were used.

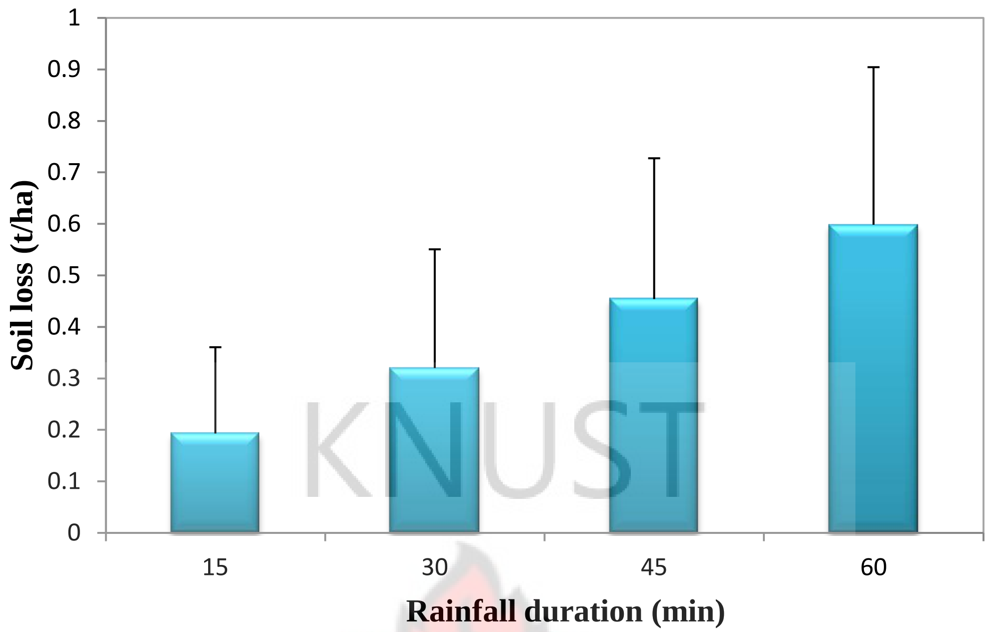


Figure 19: Mean runoff and infiltration for the Kotei soil (average for all mulch types, mulch rate and slope) as affected by rainfall durations

From Figure 19, it was observed that the soil loss increases with increasing rainfall duration. The error bar indicated that the variability in the data were also increased with increasing rainfall duration.

4.12 Rainfall duration against runoff and infiltration

The value for plotting this graph was obtained from appendices 8 and 12. Averages of the mean and standard deviation values from the two soils were used.

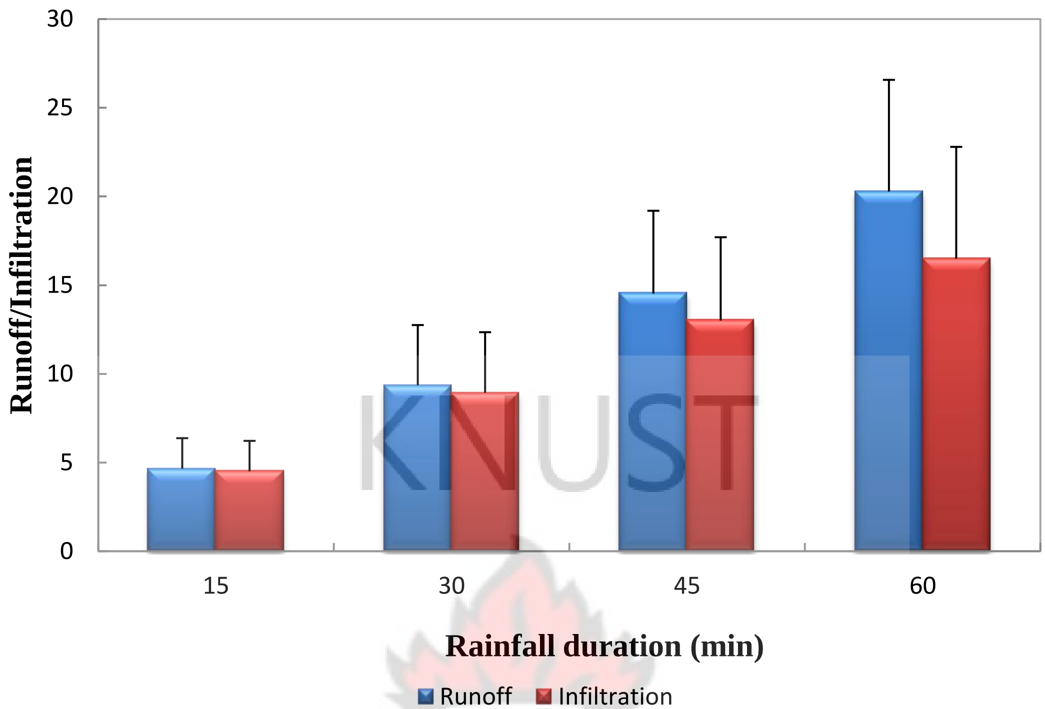


Figure 20: Mean runoff and infiltration for the Kotei soil Anwomaso soil (average for all mulch types, mulch rate and slope) as affected rainfall duration

According to Figure 20, both runoff and infiltration increase with increasing rainfall duration. It was observed that runoff was slightly higher than infiltration for the 15 and 30 minutes rainfall duration respectively. The increase in runoff over the infiltration was more pronounced at the 45 and 60 minutes rainfall durations. This may be due to the saturation of the soil after 30 minutes of rainfall duration.

4.13 Soil loss and mulch rate

The values for plotting this graph can be found in Appendices 10 and 14. The mean and standard deviation values were used for the graph and error bars respectively.

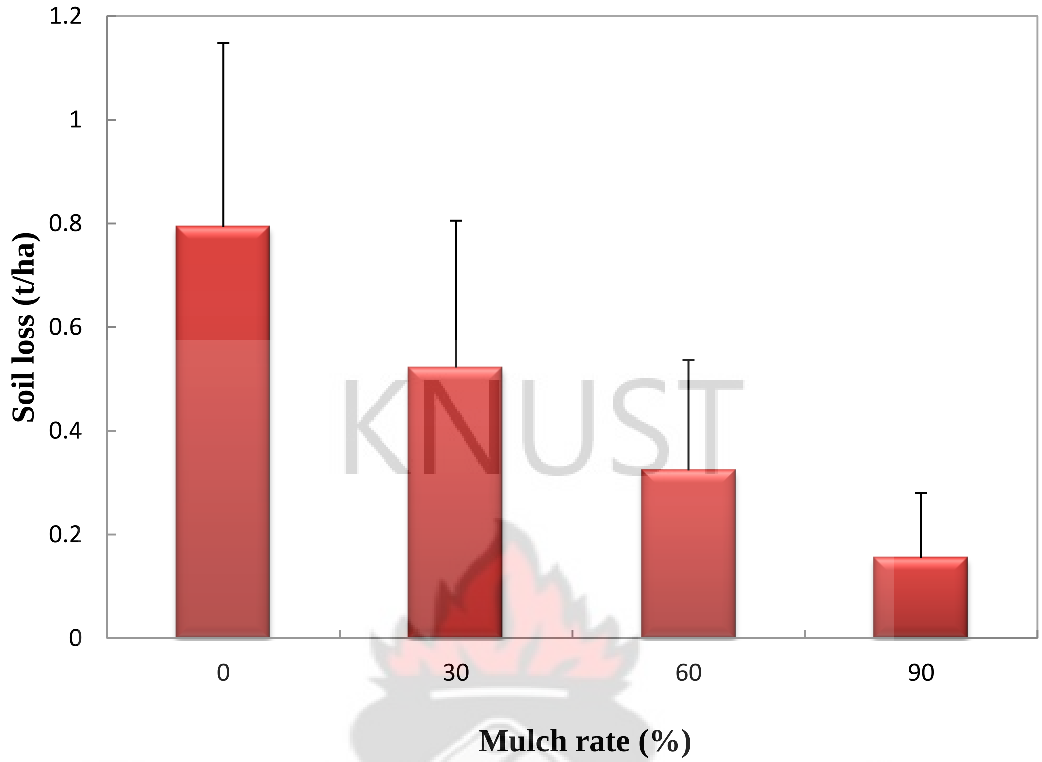


Figure 21: Mean soil loss for the Kotei and Anwomaso soils (average for all mulch types, slopes and rainfall durations) as affected by mulch rate (%)

Figure 21 shows that soil loss decreases with increasing mulch rate. The lengths of the error bars are indications that the level of variability in the data also decreases with increasing mulch cover. This was as a result of the mulch cover preventing the rain drops from getting direct contact with the soil to cause detachment of the soil particles for transport.

4.14 Mulch rate against runoff and infiltration

The values for plotting this graph can be found in Appendices 10 and 14. The mean and standard deviation values can be were used for the graph and error bars respectively.

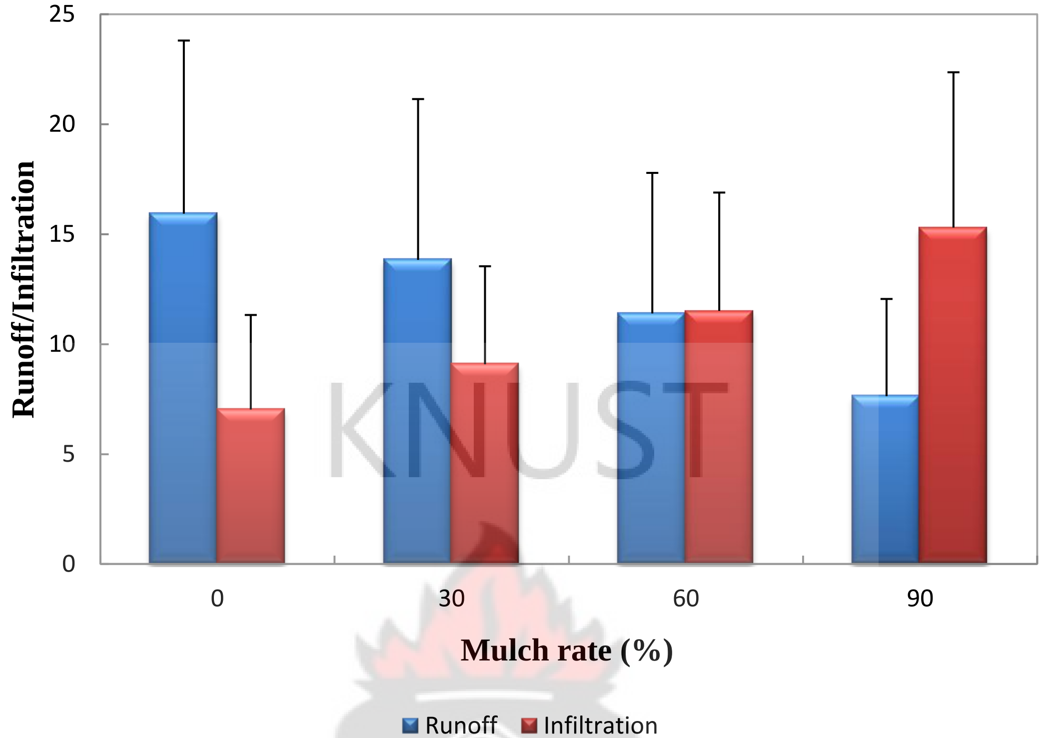


Figure 22: Mean runoff and infiltration for the Kotei and Anwomaso soil (average for all mulch types, slopes and rainfall durations) as affected by mulch rate (%)

Figure 22 is a graph of mulch rate against runoff and infiltration. It shows that runoff decreases with increasing mulch cover and the rate of infiltration of water into the soil increases with increasing mulch cover. The difference between runoff and infiltration was more pronounced at 0% mulch cover with the runoff being high. This difference reduced with increasing mulch cover until about 58 % mulch rate where it was almost equal. This situation confirms the earlier finding in Figure 16 that the mulch rate at which runoff and infiltration become equal is 57.4 % or 2.25 t/ha.

4.15 Mulch types against runoff and infiltration

The value for plotting this graph can be found in Appendices 9 and 13. The mean and standard deviation values average were used. Figure 24 indicates the effect of mulch type on runoff and infiltration.

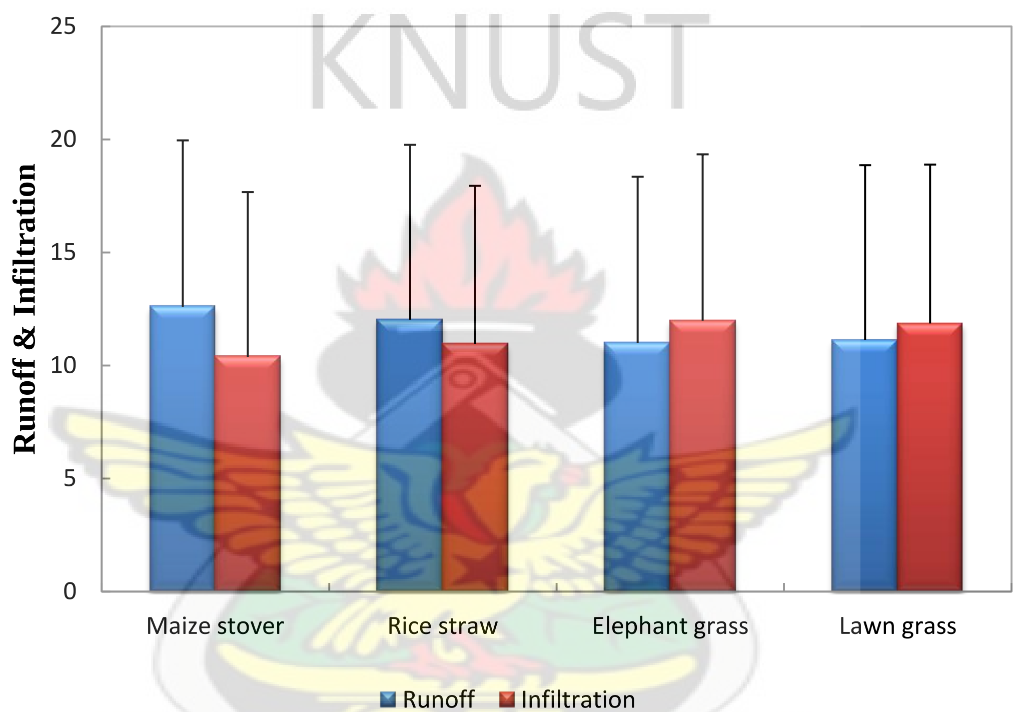


Figure 23: Mean soil loss Kotei soil and Anwomaso soil (average for all mulch rate, slope and rainfall durations) as affected by mulch type.

From Fig. 23, the mean effect of mulching with lawn grass (*Cyperus haspan*) on the reduction of runoff was more effective followed by the elephant grass and the rice straw with the maize stover providing the least.

4.16. Equations from statistical analysis results

The computed response models for soil loss (SL) for Kotei (K) and Anwomaso (A) soils are as follows:

$$SL_K\,(t/ha) = 1.44\ x\ 10^{-1} - 1.99\ x\ 10^{-2}\ Mt + 1.68\ x\ 10^{-2}\ Sp - 4.79\ x\ 10^{-3}\ Mr + 1.01\ x\ 10^{-2}\ Rd\ (R = 0.841)$$

$$SL_A\,(t/ha) = 4.14\ x\ 10^{-1} - 6.03\ x\ 10^{-2}\ Mt + 4.61\ x\ 10^{-2}\ Sp - 7.05\ x\ 10^{-3}\ Mr + 7.88\ x\ 10^{-3}\ Rd\ (R = 0.832)$$

The computed response models for surface runoff (RO) for Kotei and Anwomaso soils are as follows:

$$RO_K\,(ml) = 2.37\ x\ 10^{-1} - 2.76\ x\ 10^{-1}M_t + 5.29\ x\ 10^{-1}S_p - 6.87\ x\ 10^{-1}M_r + 3.70\ x\ 10^{-1}R_d\ (R = 0.933)$$

$$RO_A\,(ml) = 2.70\ x\ 10^{-1} - 4.32\ x\ 10^{-1}M_t + 6.83\ x\ 10^{-1}S_p - 1.13\ x\ 10^{-1}M_r + 3.22\ x\ 10^{-1}R_d\ (R = 0.870)$$

The computed response models for infiltration (IF) for Kotei and Anwomaso soils are as follows:

$$IF_K\,(ml) = -2.42\ x\ 10^{-1} + 2.44\ x\ 10^{-1}\ Mt - 5.23\ x\ 10^{-1}\ Sp + 6.82\ x\ 10^{-2}\ Mr + 2.42\ x\ 10^{-1}\ Rd\ (R = 0.871)$$

$$IF_A\,(ml) = -2.71\ x\ 10^{-1} + 4.34\ x\ 10^{-1}\ Mt - 6.83\ x\ 10^{-1}\ Sp + 1.13\ x\ 10^{-2}\ Mr + 2.90\ x\ 10^{-1}\ Rd\ (R = 0.855)$$

Where *SL* is the soil loss in tonnes per hectare (t/ha), *RO* is the surface runoff (*Lt)*, *IF* is the infiltration of water into the soil, M_T is the mulch type, S_P is the field slope in percent (%), M_R is the mulch rate in percent (%), R_D is the rainfall duration and R is the regression coefficient.

These equations take into account the contribution of all independent variables (slopes, mulch rates, mulch types and rainfall duration) to predict the dependent variables (soil loss, runoff and infiltration).

4.17 Bulk density and mulch rate

From Figure 24, the mean bulk density of the Anwomaso soil which is a sandy clay loam increases with increasing much cover which confirms the finding of Bottenberg *et al*., (1999), who observed increased bulk density with increase in mulch cover. The Kotei soil however, produced bulk densities that increase, plateau and then decreases. Bulk density was not directly influenced by the mulch rate which also confirms finding by Acosta *et al*., (1999); Duiker and Lal, (1999) that there is no mulch effect on bulk density.

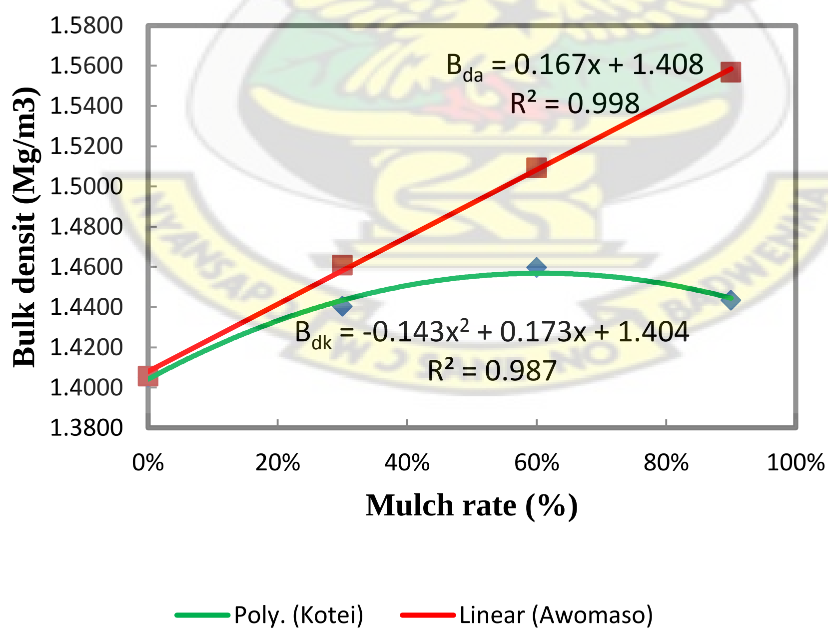


Figure 24: Graph of mean bulk density (for all mulch type, slope and durations) as affected by the mulch cover.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

- The designed rainfall simulator is simple, very economical to construct and easy to operate by two people in the laboratory. It is able to supply constant precipitation at intensities of up to 600 mm/h. The mean drop size (1.49 – 1.52 mm) was also within the acceptable limits of natural raindrops of less than 1 mm to 7mm. The mean drop size used to determine the velocity was reliable because only 3% of the drops were greater than 3mm which could not achieve terminal velocity at the 3 m height.

- When soil cover was increased with mulch materials such as *Pennisetum purpureum* and *Cyperus haspan* from 57.4% to 95% it decreased runoff and soil loss and increased infiltration for the slopes tested. The *Cyperus haspan* grass proved to be the best mulch material among the four tested, but farmers in Ghana will however, prefer the elephant grass (*Pennisetum purpureum*) because it is easy to harvest, common and close to their farms. It is also economical since it grows naturally on uncultivated and fallow lands.

- The influence of the treatments on soil loss was highest for mulch rate, mulch type, slope and rainfall durations and these were highly contributed by the mulch rate followed by the slope and then rainfall duration. On the issue of runoff, the influence of the treatments was highly contributed by the slope followed by mulch rate. For the infiltration, the influence of the treatments was highly contributed by the slope followed by mulch rate. This means that mulch rate and slope if managed well can increase infiltration of water into the soil, reduce runoff, soil loss and conserve plant nutrient in the soil.

- Mulching increased infiltration greatly on the Kotei soil at the lower slopes of 0% 3% but it was less than the Anwomaso soil at the higher slope of 6% and 9%. This means that increasing mulch rate at the tested higher slopes will reduce surface runoff and increase soil infiltration thereby increasing soil moisture content and conserve soil nutrient for crop cultivation in the minor farming season where rainfall is not regular and insufficient.

- The differences in soil loss, runoff and cumulative infiltration for the two soils may be due to their differences in texture and organic matter content.

- The maximum slope at which runoff and soil loss can be brought to their barest minimum is 3.4 %.

- The mulch cover at which runoff and infiltration become equal was determined to be **2.25 t/ha** (57.4 % ground cover). Therefore mulch application should be 2.25 t/ha and above to ensure maximum infiltration of water into the soil and protection of the soil to avoid depletion of soil nutrients.

5.2. RECOMENDATION

Further research work should be conducted into the effect of mulch rate on bulk density for agricultural soils from other areas in Ghana.

Further research work should also be conducted on other mulch materials in order to discover other best material for mulching locally to reduce pressure on the already known ones.

Research should also be conducted into the decomposition rate of these mulch materials and their propagation.

Farmers should be sensitized on the use of the lawn grass (Cyperus haspan) as mulch material.

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APPENDICES

APPENDIX 1a: Calculation of terminal velocity and kinetic energy of drops

Distance moved by drops, $d_p = 3$ m

Time taken for the drops to reach terminal velocity, t = 0.40 seconds

Therefore average velocity of drops, $V_L = \frac{\text{distance}}{\text{time}}$..4.1

Velocity, $V_L = \frac{3.0}{0.40}$ = **7.5 m/s**

Average drop size is given by $D_m = \frac{\varepsilon f x}{\varepsilon f}$ (mm).. 4.2

Average drop size from cassava flour, $D_{mc} = \frac{3050}{1982}$ = **1.5388 mm**

Volume of drop $V_d = \frac{4}{3}\pi r^3$ (m^3)..4.3

Where π = 3.142 and r = radius of the sphere since rain drops are assumed to be spherical in shape.

But radius, $r = \frac{d}{2}$

Volume of drop; $V_d = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3 = \frac{4}{3}\pi\left(\frac{1}{8}\right) d^3$

Therefore $V_d = \frac{1}{6}\pi d^3$ 4.4

So $V_d = \frac{1}{6} x\ 3.142\ (0.0015388)^3$ = **1.9081×10^{-9} m^3**

Density of water $D_m = \frac{m}{v}$

Where m is the mass of water (1000 kg/m^3) and v is the volume of water (rain drops).

Therefore average mass of rain drops m = D_m x v

....4.5

And mass m = 1000 kg/m^3 x 1.9081 x 10^{-9} m^3

m = **1.9081 x 10^{-6} kg**

The mean kinetic energy of the drops, $KE = \frac{1}{2}$

mv^2..4.6

Where m is the average mass of drops and V is the mean velocity of drops.

Therefore $KE = \frac{1}{2}(0.0000019081)\ x\ 7.5^2$ = **5.3665 x 10^{-5} Joules**

APPENDIX 1b: Calculation of terminal velocity and kinetic energy of drops using Wheat flour

From equation 4.1 in Appendix 4, average drop velocity, V_L = **7.5 m/s**

Using equation 4.2 from Appendix 4 and values in Appendix 2, Average drop size from wheat flour, $D_{mc} = \frac{3119.5}{2088}$ = **1.494 mm**

Using equation 4.4 in Appendix 4 average volume of drops V_d =

$\frac{1}{6}\ x\ 3.142(0.001494)^3$

So V_d = **<u>1.746 x 10^{-9} m^3</u>**

Using equation 4.5 in Appendix 4, average mass m = 1000 kg/m^3 x 1.746 x 10^{-9} m^3

m = **<u>1.746 x 10^{-6} kg</u>**

Using equation 4.6 in Appendix 4, $KE = \frac{1}{2}\,(0.000001746)\ x\ 7.5^2$ = **<u>4.9106 x 10^{-5} Joules</u>**

APPENDIX 1c: Determination of percentage drops greater than 3 mm

	Cassava flour	Wheat flour	Mean
Total drops	1982	2088	2035
Total drops < 3 mm	1917	2026	1971.5
% of drops < 3 mm			**96.9 %**
Total drops > 3 mm	65	62	63.5
% of drops > 3 mm			**3.1 %**

APPENDIX 2: Analysis of Variance between soil loss and all independent variables

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Corrected Model	52.042[a]	510	.102	1.349E3	.022
Intercept	78.764	1	78.764	1.041E6	.001
Slope	5.982	3	1.994	2.636E4	.005
Rainfall	11.915	3	3.972	5.251E4	.003
Mulch	1.153	3	.384	5.079E3	.010
Mulch rate	20.764	3	6.921	9.150E4	.002
Soil type	1.806	1	1.806	2.388E4	.004
Slope * Rainfall	.177	9	.020	260.455	.048
Slope * Mulch	.301	9	.033	142.351	.087
Slope * mulch rate	.950	9	.106	1.395E3	.021
Slope * Soil type	1.441	3	.480	651.687	.029
Rainfall * Mulch	.116	9	.013	170.401	.059
Rainfall * mulch rate	2.833	9	.315	4.161E3	.012
Rainfall * Soil type	.303	3	.101	1.333E3	.020
Mulch * mulch rate	.082	9	.009	120.847	.070
Mulch * Soil type	.226	3	.075	186.248	.073
Mulch rate * Soil type	.775	3	.258	3.417E3	.013
Slope * Rainfall * Mulch	.380	27	.014	186.138	.058
Slope * Rainfall * mulch rate	.202	27	.007	98.830	.079
Slope * Rainfall * Soil type	.223	9	.025	327.260	.043
Slope * Mulch * mulch rate	.059	27	.002	28.733	.147
Slope * Mulch * Soil type	.158	9	.018	232.196	.051
Slope * mulch rate * Soil type	.237	9	.026	347.966	.042
Rainfall * Mulch * mulch rate	.174	27	.006	85.023	.086
Rainfall * Mulch * Soil type	.156	9	.017	228.666	.051
Rainfall * mulch rate * Soil type	.106	9	.012	155.700	.062
Mulch * mulch rate * Soil type	.026	9	.003	38.510	.124
Slope * Rainfall * Mulch * mulch rate	.312	81	.004	50.947	.111
Slope * Rainfall * Mulch * Soil type	.327	27	.012	160.306	.062
Slope * Rainfall * mulch rate * Soil type	.168	27	.006	82.205	.087
Slope * Mulch * mulch rate * Soil type	.067	27	.002	32.919	.137
Rainfall * Mulch * mulch rate * Soil type	.118	27	.004	57.797	.104
Slope * Rainfall * Mulch * mulch rate * Soil type	.238	80	.003	39.257	.126
Error	7.565E-5	1	7.565E-5		
Total	131.114	512			
Corrected Total	52.042	511			

a. R Squared = 1.000 (Adjusted R Squared = .999)

APPENDIX 3: Analysis of Variance between runoff and all independent variables

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.753E10[a]	510	5.399E7	674.870	.031
Intercept	7.591E10	1	7.591E10	9.489E5	.001
Slope	2.163E9	3	7.210E8	9.013E3	.008
Mulch	1.378E8	3	4.594E7	574.192	.031
Rainfall	1.715E10	3	5.716E9	7.145E4	.003
Mulch rate	4.838E9	3	1.613E9	2.016E4	.005
Soil type	1.348E8	1	1.348E8	1.685E3	.016
Slope * Mulch	5.375E7	9	5971684.351	74.646	.090
Slope * Rainfall	4.492E8	9	4.991E7	623.867	.031
Slope * mulch rate	1.786E8	9	1.984E7	247.992	.049
Slope * Soil type	1.480E8	3	4.933E7	616.582	.030
Mulch * Rainfall	2.614E7	9	2904129.991	36.302	.128
Mulch * mulch rate	1.435E7	9	1593924.971	19.924	.172
Mulch * Soil type	1.332E7	3	4441369.180	55.517	.098
Rainfall * mulch rate	9.643E8	9	1.071E8	1.339E3	.021
Rainfall * Soil type	1.095E8	3	3.651E7	456.405	.034
Mulch rate * Soil type	2.976E8	3	9.921E7	1.240E3	.021
Slope * Mulch * Rainfall	7.733E7	27	2863958.286	35.799	.131
Slope * Mulch * mulch rate	3.160E7	27	1170339.698	14.629	.204
Slope * Mulch * Soil type	1.678E7	9	1864917.261	23.311	.159
Slope * Rainfall * mulch rate	3.637E7	27	1346958.953	16.837	.191
Slope * Rainfall * Soil type	7.086E7	9	7873053.351	98.413	.078
Slope * mulch rate * Soil type	4.711E7	9	5234396.198	65.430	.096
Mulch * Rainfall * mulch rate	1.182E7	27	437799.079	5.472	.328
Mulch * Rainfall * Soil type	2.736E7	9	3040399.687	38.005	.125
Mulch * mulch rate * Soil type	7520998.676	9	835666.520	10.446	.236
Rainfall * mulch rate * Soil type	9.606E7	9	1.067E7	133.414	.067
Slope * Mulch * Rainfall * mulch rate	5.265E7	81	650038.502	8.125	.273
Slope * Mulch * Rainfall * Soil type	3.484E7	27	1290371.312	16.130	.195
Slope * Mulch * mulch rate * Soil type	3.621E7	27	1341163.585	16.765	.191
Slope * Rainfall * mulch rate * Soil type	3.604E7	27	1334750.712	16.684	.192
Mulch * Rainfall * mulch rate * Soil type	1.526E7	27	565108.403	7.064	.290
Slope * Mulch * Rainfall * mulch rate * Soil type	3.786E7	80	473215.612	5.915	.318
Error	80000.000	1	80000.000		
Total	1.037E11	512			
Corrected Total	2.753E10	511			

a. R Squared = 1.000 (Adjusted R Squared = .999)

APPENDIX 4: Analysis of Variance between infiltration and all independent variables

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.178E10[a]	510	4.271E7	533.879	.035
Intercept	5.966E10	1	5.966E10	7.458E5	.001
Slope	2.186E9	3	7.287E8	9.109E3	.008
Mulch	1.584E8	3	5.279E7	659.827	.029
Mulch rate	5.022E9	3	1.674E9	2.093E4	.005
Soil type	1.135E8	1	1.135E8	1.419E3	.017
Rainfall	1.067E10	3	3.558E9	4.447E4	.003
Slope * Mulch	5.336E7	9	5929079.778	74.113	.090
Slope * mulch rate	2.077E8	9	2.308E7	288.455	.046
Slope * Soil type	1.132E8	3	3.773E7	471.657	.034
Slope * Rainfall	5.100E8	9	5.666E7	708.307	.029
Mulch * mulch rate	3.038E7	9	3375868.358	42.198	.119
Mulch * Soil type	5494491.104	3	1831497.035	22.894	.152
Mulch * Rainfall	7.761E7	9	8623486.383	107.794	.075
Mulch rate * Soil type	2.501E8	3	8.335E7	1.042E3	.023
Mulch rate * Rainfall	1.094E9	9	1.216E8	1.520E3	.020
Soil type * Rainfall	5.198E7	3	1.733E7	216.590	.050
Slope * Mulch * mulch rate	5.420E7	27	2007365.584	25.092	.157
Slope * Mulch * Soil type	2.209E7	9	2454382.786	30.680	.139
Slope * Mulch * Rainfall	1.677E8	27	6211162.516	77.640	.090
Slope * mulch rate * Soil type	4.729E7	9	5254376.695	65.680	.095
Slope * mulch rate * Rainfall	7.512E7	27	2782305.422	34.779	.133
Slope * Soil type * Rainfall	6.046E7	9	6717682.378	83.971	.085
Mulch * mulch rate * Soil type	6757304.607	9	750811.623	9.385	.248
Mulch * mulch rate * Rainfall	6.152E7	27	2278554.092	28.482	.147
Mulch * Soil type * Rainfall	4.985E7	9	5538719.734	69.234	.093
Mulch rate * Soil type * Rainfall	6.376E7	9	7084129.507	88.552	.082
Slope * Mulch * mulch rate * Soil type	6.454E7	27	2390206.423	29.878	.144
Slope * Mulch * mulch rate * Rainfall	1.393E8	81	1720358.056	21.504	.170
Slope * Mulch * Soil type * Rainfall	1.329E8	27	4922228.834	61.528	.100
Slope * mulch rate * Soil type * Rainfall	4.204E7	27	1557198.965	19.465	.178
Mulch * mulch rate * Soil type * Rainfall	2.834E7	27	1049449.073	13.118	.215
Slope * Mulch * mulch rate * Soil type * Rainfall	1.462E8	80	1828044.743	22.851	.165
Error	80000.000	1	80000.000		
Total	8.156E10	512			
Corrected Total	2.178E10	511			

a. R Squared = 1.000 (Adjusted R Squared = .998)

APPENDIX 5: Determination of the value of field slope at which runoff is equal to infiltration.

From figure 15:

Runoff, RO = 606.7 x + 9469……………………………………………………………………6.1

Infiltration, IF= - 613.2x + 13576…………………………………………………………………6.2

For intersection; runoff = infiltration

Therefore, 606.7 x + 9469 = - 613.2x + 13576

Which implies that, 606.7 x + 613.2x = 13576 – 9469.. …………………………………………6.3

1219.9 x = 4107……………………………………………………………………6.4

$x = \frac{4107}{1219.9}$, $\boldsymbol{x}$ **= 3.36 %**

Therefore the slope at which runoff and infiltration become equal is **3.36 %**

APPENDIX 6: Determination of the value of mulch rate at which runoff is equal to infiltration

From figure 4.3: Runoff = $-0.462x^2 - 49.03x + 15847$ 7.1

Infiltration = $0.456x^2 + 51.36x + 7053$ 7.2

For intersection; runoff = infiltration

Therefore, $-0.462x^2 - 49.03x + 15847 = 0.456x^2 + 51.36x + 7053$

And $0.918x^2 + 100.39x - 8794 = 0$ 7.3

Where a = 0.918, b = 100.39, c = - 8794

From the quadratic equation, $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$; therefore

$$x = \frac{-100.39 \pm \sqrt{100.39^2 - 4(-8794 * 0.918)}}{2(0.918)}$$

Therefore, $x = \frac{-100.39 \pm \sqrt{10078.1521 + 32291.568}}{1.836}$

$$x = \frac{-100.39 + 205.84}{1.836} \text{ or } \frac{-100.39 - 205.84}{1.836}$$

It implies that x = 57.43 % and - 166.79 %

Since there is no negative mulch rate, x = **57.43 %**

Using Gregory's formula, MR = $\frac{-\ln(1 - MC)}{A}$ where MR = mulch rate in t/ha, MC = percentage mulch cover and A = area covered per unit mass of the mulch type.

Therefore, MR = $\frac{-\ln(1 - 0.5743)}{0.38}$ = **2.25 t/ha.**

APPENDIX 7: Means Tables=Soil loss Runoff Infiltration by Slope

/Cells Mean Count Standard Deviation.

Report on Soil Loss Runoff Infiltration * Slope (Kotei soil)

Slope (%)		Runoff	Soil loss	Infitration
0	Mean	9.54981	.257017	1.34189E1
	N	64	64	64
	Std. Deviation	5.344174E0	.2089252	5.708906E0
3	Mean	1.31647E1	.308636	9.56109
	N	64	64	64
	Std. Deviation	7.226070E0	.2476663	4.913985E0
6	Mean	1.33876E1	.363723	9.50911
	N	64	64	64
	Std. Deviation	7.324983E0	.2883178	4.997880E0
9	Mean	1.47657E1	.406764	8.20548
	N	64	64	64
	Std. Deviation	7.452801E0	.2849336	4.367987E0
Total	Mean	1.27169E1	.334035	1.01737E1
	N	256	256	256
	Std. Deviation	7.118241E0	.2640701	5.359413E0

APPENDIX 8: Means Tables=Soil loss Runoff Infiltration by Rainfall duration,

/Cells Mean Count Standard Deviation.

Report on Soil Loss Runoff Infiltration * Rainfall duration (Kotei soil)

Rainfall duration		Runoff	Soil loss	Infitration
15	Mean	4.90363	.132237	4.26637
	N	64	64	64
	Std. Deviation	1.603746E0	.0887530	1.597012E0
30	Mean	9.43791	.229337	8.79460
	N	64	64	64
	Std. Deviation	2.756949E0	.1265403	2.802779E0
45	Mean	1.49603E1	.389126	1.24662E1
	N	64	64	64
	Std. Deviation	3.712285E0	.2190115	3.761575E0
60	Mean	2.15659E1	.585441	1.51674E1
	N	64	64	64
	Std. Deviation	4.851543E0	.3010007	4.863209E0
Total	Mean	1.27169E1	.334035	1.01737E1
	N	256	256	256
	Std. Deviation	7.118241E0	.2640701	5.359413E0

APPENDIX 9: Means Tables=Soil loss Runoff Infiltration by Mulch type, /Cells Mean Count Standard Deviation.

Report on Soil Loss Runoff Infiltration * Mulch Type (Kotei Soil)

Mulch type		**Runoff**	**Soil loss**	**Infitration**
Rice straw	Mean	1.28403E1	.342684	1.01316E1
	N	64	64	64
	Std. Deviation	7.174876E0	.2768685	5.153646E0
Maize stover	Mean	1.32770E1	.379922	9.69172
	N	64	64	64
	Std. Deviation	7.128098E0	.2585243	5.477355E0
Elephant grass	Mean	1.25606E1	.314166	1.00924E1
	N	64	64	64
	Std. Deviation	7.244833E0	.2621352	5.310442E0
Lawn grass	Mean	1.21898E1	.299369	1.07789E1
	N	64	64	64
	Std. Deviation	7.047892E0	.2573132	5.557171E0
Total	Mean	1.27169E1	.334035	1.01737E1
	N	256	256	256
	Std. Deviation	7.118241E0	.2640701	5.359413E0

APPENDIX 10: Means Tables=Soil loss Runoff Infiltration by mulch rate, /Cells Mean Count Standard Deviation.

Report Soil Loss Runoff Infiltration * Mulch Rate (Kotei soil)

Mulch rate		Runoff	Soil loss	Infitration
0	Mean	1.56532E1	.582132	7.29540
	N	64	64	64
	Std. Deviation	7.773915E0	.3143862	4.192123E0
30	Mean	1.37286E1	.367439	9.13168
	N	64	64	64
	Std. Deviation	7.178504E0	.2136633	4.256803E0
60	Mean	1.21923E1	.242097	1.06590E1
	N	64	64	64
	Std. Deviation	6.699934E0	.1437476	4.731651E0
90	Mean	9.29369	.144472	1.36085E1
	N	64	64	64
	Std. Deviation	5.123838E0	.0913508	6.036091E0
Total	Mean	1.27169E1	.334035	1.01737E1
	N	256	256	256
	Std. Deviation	7.118241E0	.2640701	5.359413E0

APPENDIX 11: Means Tables=Soil loss Runoff Infiltration by Slope, /Cells Mean Count Standard Deviation.

Report on Runoff Soil loss Infiltration * Slope (Anwomaso soil)

Slope		Soil loss	Runoff	Infiltration
0	Mean	.259784	8.848469E0	1.412028E1
	N	64	64	64
	Std. Deviation	.2258616	5.1820649E0	7.2862545E0
3	Mean	.347500	1.045234E1	1.251644E1
	N	64	64	64
	Std. Deviation	2.6666667E-1	6.6290569E0	7.0915321E0
6	Mean	.525781	1.238403E1	1.058336E1
	N	64	64	64
	Std. Deviation	3.9279950E-1	8.1865479E0	7.1081782E0
9	Mean	.661562	1.503297E1	7.930234
	N	64	64	64
	Std. Deviation	3.4929507E-1	8.3883747E0	5.6417026E0
Total	Mean	.448657	1.167945E1	1.128758E1
	N	256	256	256
	Std. Deviation	3.5046374E-1	7.5345792E0	7.1577711E0

APPENDIX 12: Means Tables=Soil loss Runoff Infiltration by Rainfall duration, /Cells Mean Count Standard Deviation.

*Report on Soil Loss Runoff Infiltration * Rainfall duration (Anwomaso soil)*

Rainfall duration		Soil loss	Runoff	Infiltration
15	Mean	.253581	4.425156E0	4.760930
	N	64	64	64
	Std. Deviation	.2463628	1.8281667E0	1.8262748E0
30	Mean	.410763	9.290187E0	9.079156
	N	64	64	64
	Std. Deviation	3.3454763E-1	4.0202820E0	4.0274500E0
45	Mean	.518964	1.404656E1	1.351613E1
	N	64	64	64
	Std. Deviation	3.4367246E-1	5.6299937E0	5.6299632E0
60	Mean	.611320	1.895591E1	1.779409E1
	N	64	64	64
	Std. Deviation	3.6660926E-1	7.7357926E0	7.7357926E0
Total	Mean	.448657	1.167945E1	1.128758E1
	N	256	256	256
	Std. Deviation	3.5046374E-1	7.5345792E0	7.1577711E0

APPENDIX 13: Means Tables=Soil loss Runoff Infiltration by Mulch type, /Cells Mean Count Standard Deviation.

Report on Soil Loss Runoff Infiltration * Mulch Type (Anwomaso soil)

Mulch type		Soil loss	Runoff	Infiltration
Rice straw	Mean	.522552	1.202078E1	1.094084E1
	N	64	64	64
	Std. Deviation	.3864076	7.3601129E0	7.2841866E0
Maize stover	Mean	.515247	1.259234E1	1.037647E1
	N	64	64	64
	Std. Deviation	3.4137542E-1	7.7356877E0	7.0017987E0
Elephant grass	Mean	.395344	1.099062E1	1.197820E1
	N	64	64	64
	Std. Deviation	3.2347729E-1	7.3554327E0	7.3564460E0
Lawn grass	Mean	.361486	1.111406E1	1.185481E1
	N	64	64	64
	Std. Deviation	3.2558263E-1	7.7392918E0	7.0282125E0
Total	Mean	.448657	1.167945E1	1.128758E1
	N	256	256	256
	Std. Deviation	3.5046374E-1	7.5345792E0	7.1577711E0

APPENDIX 14: Means Tables=Soil loss Runoff Infiltration by mulch rate, /Cells Mean Count Standard Deviation .

*Report Soil Loss Runoff Infiltration * Mulch Rate (Kotei soil)*

Mulch rate		Soil loss	Runoff	Infiltration
0	Mean	.793764	1.620953E1	6.759273
	N	64	64	64
	Std. Deviation	.3547105	7.9657910E0	4.4024093E0
30	Mean	.522252	1.393238E1	9.036352
	N	64	64	64
	Std. Deviation	2.8326659E-1	7.4411146E0	4.6554756E0
60	Mean	.323738	1.059888E1	1.236439E1
	N	64	64	64
	Std. Deviation	2.1276478E-1	6.0788922E0	6.3856655E0
90	Mean	.154875	5.977031E0	1.699030E1
	N	64	64	64
	Std. Deviation	1.2568978E-1	3.7124649E0	8.0838377E0
Total	Mean	.448657	1.167945E1	1.128758E1
	N	256	256	256
	Std. Deviation	3.5046374E-1	7.5345792E0	7.1577711E0

APPENDIX 15: Means Tables=Soil loss Runoff Infiltration by soil type, /Cells Mean Count Standard Deviation.

Soil loss Runoff Infiltration * Soil type

Soil type		Soil loss	Runoff	Infiltration
Kotei	Mean	.333645	1.27E4	1.017E4
	N	256	256	256
	Std. Deviation	.2629049	7.118E3	5.3593E3
Anwomaso	Mean	.452329	1.17E4	8121.643
	N	256	256	256
	Std. Deviation	.3576251	7.535E3	8.2751E3
Total	Mean	.392987	1.22E4	9147.771
	N	512	512	512
	Std. Deviation	.3191284	7.341E3	7.0398E3

APPENDIX 16: Regression Analysis for the soil loss equation: Kotei soil

Regression Analysis: SL versus Mt, Sp, Mr, Rd

The regression equation is
SL = 0.144 - 0.0199 Mt + 0.0168 Sp - 0.00479 Mr + 0.0101 Rd

Predictor	Coef	SE Coef	T	P
Constant	0.14363	0.02529	5.68	0.000
Mt	-0.019877	0.005921	-3.36	0.001
Sp	0.016821	0.001980	8.50	0.000
Mr	-0.0047913	0.0001980	-24.20	0.000
Rd	0.0101356	0.0003960	25.60	0.000

S = 0.106249   R-Sq = 84.1%   R-Sq(adj) = 83.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	14.9487	3.7372	331.05	0.000
Residual Error	251	2.8335	0.0113		
Total	255	17.7822			

APPENDIX 17: Regression Analysis for runoff equation-Kotei soil

Regression Analysis: RO versus Mt, Sp, Mr, Rd

The regression equation is
RO = 0.237 - 0.276 Mt + 0.529 Sp - 0.0687 Mr + 0.370 Rd

Predictor	Coef	SE Coef	T	P
Constant	0.2367	0.4431	0.53	0.594
Mt	-0.2761	0.1038	-2.66	0.008
Sp	0.52916	0.03470	15.25	0.000
Mr	-0.068674	0.003470	-19.79	0.000
Rd	0.370148	0.006939	53.34	0.000

S = 1.86193   R-Sq = 93.3%   R-Sq(adj) = 93.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	12050.5	3012.6	868.99	0.000
Residual Error	251	870.2	3.5		
Total	255	12920.7			

APPENDIX 18: Regression Analysis for the infiltration equation- Kotei soil

Regression Analysis: IF versus Mt, Sp, Mr, Rd

The regression equation is
IF = - 0.242 + 0.244 Mt - 0.523 Sp + 0.0682 Mr + 0.242 Rd

Predictor	Coef	SE Coef	T	P
Constant	-0.2420	0.4613	-0.52	0.600
Mt	0.2440	0.1080	2.26	0.025
Sp	-0.52321	0.03611	-14.49	0.000
Mr	0.068184	0.003612	18.88	0.000
Rd	0.242422	0.007223	33.56	0.000

S = 1.93812   R-Sq = 87.1%   R-Sq(adj) = 86.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	6381.6	1595.4	424.73	0.000
Residual Error	251	942.8	3.8		
Total	255	7324.4			

APPENDIX 19: Regression Analysis for the soil loss equation: Awomaso soil

Regression Analysis: SL versus Sp, Rd, Mt, Mr

The regression equation is
SL = 0.414 + 0.0461 Sp + 0.00788 Rd - 0.0603 Mt - 0.00705 Mr

Predictor	Coef	SE Coef	T	P
Constant	0.41381	0.03453	11.98	0.000
Sp	0.046121	0.002694	17.12	0.000
Rd	0.0078761	0.0005388	14.62	0.000
Mt	-0.060311	0.008083	-7.46	0.000
Mr	-0.0070506	0.0002694	-26.17	0.000

S = 0.144586   R-Sq = 83.2%   R-Sq(adj) = 83.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	26.0734	6.5183	311.81	0.000
Residual Error	251	5.2472	0.0209		
Total	255	31.3206			

APPENDIX 20: Regression Analysis for the runoff equation: Awomaso soil

Regression Analysis: RO versus Sp, Rd, Mt, Mr

The regression equation is
RO = 2.70 + 0.683 Sp + 0.322 Rd - 0.432 Mt - 0.113 Mr

Predictor	Coef	SE Coef	T	P
Constant	2.7046	0.6549	4.13	0.000
Sp	0.68284	0.05110	13.36	0.000
Rd	0.32232	0.01022	31.54	0.000
Mt	-0.4322	0.1533	-2.82	0.005
Mr	-0.113437	0.005110	-22.20	0.000

S = 2.74222   R-Sq = 87.0%   R-Sq(adj) = 86.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	12588.9	3147.2	418.53	0.000
Residual Error	251	1887.5	7.5		
Total	255	14476.3			

APPENDIX 21: Regression Analysis for the infiltration equation: Awomaso soil

Regression Analysis: IF versus Sp, Rd, Mt, Mr

The regression equation is

IF = - 2.71 - 0.683 Sp + 0.290 Rd + 0.434 Mt + 0.113 Mr

Predictor	Coef	SE Coef	T	P
Constant	-2.7101	0.6553	-4.14	0.000
Sp	-0.68344	0.05113	-13.37	0.000
Rd	0.29024	0.01023	28.38	0.000
Mt	0.4344	0.1534	2.83	0.005
Mr	0.113404	0.005113	22.18	0.000

S = 2.74395   R-Sq = 85.5%   R-Sq(adj) = 85.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	11174.7	2793.7	371.04	0.000
Residual Error	251	1889.8	7.5		
Total	255	13064.6			

APPENDIX 22: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	0	15	0	60	40
Rice straw	0	30	0	53	47
Rice straw	0	45	0	57	43
Rice straw	0	60	0	52	48
Maize stover	0	15	0	58	42
Maize stover	0	30	0	54	46
Maize stover	0	45	0	58	42
Maize stover	0	60	0	54	46
Elephant grass	0	15	0	59	41
Elephant grass	0	30	0	55	45
Elephant grass	0	45	0	57	43
Elephant grass	0	60	0	52	48
Lawn grass	0	15	0	56	44
Lawn grass	0	30	0	61	39
Lawn grass	0	45	0	57	43
Lawn grass	0	60	0	51	49
Mean				**56**	**44**
Standard deviation				**3**	**3**

APPENDIX 23: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	3	15	0	66	34
Rice straw	3	30	0	69	31
Rice straw	3	45	0	66	34
Rice straw	3	60	0	68	32
Maize stover	3	15	0	65	35
Maize stover	3	30	0	61	39
Maize stover	3	45	0	64	36
Maize stover	3	60	0	63	37
Elephant grass	3	15	0	68	32
Elephant grass	3	30	0	63	37
Elephant grass	3	45	0	62	38
Elephant grass	3	60	0	64	36
Lawn grass	3	15	0	54	46
Lawn grass	3	30	0	70	30
Lawn grass	3	45	0	69	31
Lawn grass	3	60	0	67	33
Mean				**65**	**35**
Standard deviation				**4**	**4**

APPENDIX 24: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	*Slope (%)*	**Rainfall duration** *(minutes)*	**Mulch rate** *(%)*	**Runoff** *(%)*	**Infiltration** *(%)*
Rice straw	6	15	0	81	19
Rice straw	6	30	0	86	14
Rice straw	6	45	0	80	20
Rice straw	6	60	0	74	26
Maize stover	6	15	0	81	19
Maize stover	6	30	0	88	12
Maize stover	6	45	0	87	13
Maize stover	6	60	0	82	18
Elephant grass	6	15	0	70	30
Elephant grass	6	30	0	71	29
Elephant grass	6	45	0	78	22
Elephant grass	6	60	0	77	23
Lawn grass	6	15	0	68	32
Lawn grass	6	30	0	71	29
Lawn grass	6	45	0	73	27
Lawn grass	6	60	0	73	27
Mean				**78**	**22**
Standard deviation				**6**	**6**

APPENDIX 25: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	9	15	0	88	12
Rice straw	9	30	0	86	14
Rice straw	9	45	0	70	30
Rice straw	9	60	0	87	13
Maize stover	9	15	0	81	19
Maize stover	9	30	0	97	3
Maize stover	9	45	0	92	8
Maize stover	9	60	0	91	9
Elephant grass	9	15	0	77	23
Elephant grass	9	30	0	81	19
Elephant grass	9	45	0	83	17
Elephant grass	9	60	0	83	17
Lawn grass	9	15	0	74	26
Lawn grass	9	30	0	71	29
Lawn grass	9	45	0	87	13
Lawn grass	9	60	0	85	15
Mean				**83**	**17**
Standard deviation				**8**	**8**

APPENDIX 26: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	0	15	30	48	52
Rice straw	0	30	30	42	58
Rice straw	0	45	30	46	54
Rice straw	0	60	30	49	51
Maize stover	0	15	30	50	50
Maize stover	0	30	30	44	56
Maize stover	0	45	30	48	52
Maize stover	0	60	30	51	49
Elephant grass	0	15	30	47	53
Elephant grass	0	30	30	36	64
Elephant grass	0	45	30	46	54
Elephant grass	0	60	30	48	52
Lawn grass	0	15	30	42	58
Lawn grass	0	30	30	35	65
Lawn grass	0	45	30	39	61
Lawn grass	0	60	30	47	53
Mean				**45**	**55**
Standard deviation				**5**	**5**

APPENDIX 27: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	3	15	30	58	42
Rice straw	3	30	30	54	46
Rice straw	3	45	30	60	40
Rice straw	3	60	30	60	40
Maize stover	3	15	30	49	51
Maize stover	3	30	30	47	53
Maize stover	3	45	30	51	49
Maize stover	3	60	30	55	45
Elephant grass	3	15	30	56	44
Elephant grass	3	30	30	55	45
Elephant grass	3	45	30	51	49
Elephant grass	3	60	30	55	45
Lawn grass	3	15	30	37	63
Lawn grass	3	30	30	64	36
Lawn grass	3	45	30	65	35
Lawn grass	3	60	30	64	36
Mean				**55**	**45**
Standard deviation				**7**	**7**

APPENDIX 28: Surface runoff (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	6	15	30	54	46
Rice straw	6	30	30	76	24
Rice straw	6	45	30	71	29
Rice straw	6	60	30	70	30
Maize stover	6	15	30	64	36
Maize stover	6	30	30	73	27
Maize stover	6	45	30	76	24
Maize stover	6	60	30	75	25
Elephant grass	6	15	30	53	47
Elephant grass	6	30	30	59	41
Elephant grass	6	45	30	66	34
Elephant grass	6	60	30	71	29
Lawn grass	6	15	30	55	45
Lawn grass	6	30	30	60	40
Lawn grass	6	45	30	61	39
Lawn grass	6	60	30	65	35
Mean				**66**	**34**
Standard deviation				**8**	**8**

APPENDIX 29: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	9	15	30	79	21
Rice straw	9	30	30	82	18
Rice straw	9	45	30	64	36
Rice straw	9	60	30	80	20
Maize stover	9	15	30	73	27
Maize stover	9	30	30	92	8
Maize stover	9	45	30	75	25
Maize stover	9	60	30	76	24
Elephant grass	9	15	30	57	43
Elephant grass	9	30	30	60	40
Elephant grass	9	45	30	74	26
Elephant grass	9	60	30	73	27
Lawn grass	9	15	30	62	38
Lawn grass	9	30	30	60	40
Lawn grass	9	45	30	73	27
Lawn grass	9	60	30	73	27
Mean				**72**	**28**
Standard deviation				**9**	**9**

APPENDIX 30: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	0	15	60	36	64
Rice straw	0	30	60	32	68
Rice straw	0	45	60	34	66
Rice straw	0	60	60	34	66
Maize stover	0	15	60	39	61
Maize stover	0	30	60	35	65
Maize stover	0	45	60	35	65
Maize stover	0	60	60	36	64
Elephant grass	0	15	60	36	64
Elephant grass	0	30	60	31	69
Elephant grass	0	45	60	34	66
Elephant grass	0	60	60	33	67
Lawn grass	0	15	60	26	74
Lawn grass	0	30	60	30	70
Lawn grass	0	45	60	32	68
Lawn grass	0	60	60	29	71
Mean				**33**	**67**
Standard deviation				**3**	**3**

APPENDIX 31: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	3	15	60	48	52
Rice straw	3	30	60	47	53
Rice straw	3	45	60	33	67
Rice straw	3	60	60	35	65
Maize stover	3	15	60	39	61
Maize stover	3	30	60	38	62
Maize stover	3	45	60	40	60
Maize stover	3	60	60	41	59
Elephant grass	3	15	60	38	62
Elephant grass	3	30	60	37	63
Elephant grass	3	45	60	36	64
Elephant grass	3	60	60	32	68
Lawn grass	3	15	60	15	85
Lawn grass	3	30	60	38	62
Lawn grass	3	45	60	53	47
Lawn grass	3	60	60	44	56
Mean				38	62
Standard deviation				8	8

APPENDIX 32: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	6	15	60	36	64
Rice straw	6	30	60	55	45
Rice straw	6	45	60	52	48
Rice straw	6	60	60	52	48
Maize stover	6	15	60	51	49
Maize stover	6	30	60	55	45
Maize stover	6	45	60	58	42
Maize stover	6	60	60	59	41
Elephant grass	6	15	60	36	64
Elephant grass	6	30	60	41	59
Elephant grass	6	45	60	40	60
Elephant grass	6	60	60	39	61
Lawn grass	6	15	60	40	60
Lawn grass	6	30	60	39	61
Lawn grass	6	45	60	40	60
Lawn grass	6	60	60	54	46
Mean				**45**	**55**
Standard deviation				**9**	**9**

APPENDIX 33: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	9	15	60	76	24
Rice straw	9	30	60	77	21
Rice straw	9	45	60	58	42
Rice straw	9	60	60	74	26
Maize stover	9	15	60	64	36
Maize stover	9	30	60	83	17
Maize stover	9	45	60	66	34
Maize stover	9	60	60	68	32
Elephant grass	9	15	60	50	50
Elephant grass	9	30	60	51	49
Elephant grass	9	45	60	66	34
Elephant grass	9	60	60	59	41
Lawn grass	9	15	60	50	50
Lawn grass	9	30	60	52	48
Lawn grass	9	45	60	62	38
Lawn grass	9	60	60	64	36
Mean				64	36
Standard deviation				10	11

APPENDIX 34: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	0	15	90	25	75
Rice straw	0	30	90	23	77
Rice straw	0	45	90	25	75
Rice straw	0	60	90	18	82
Maize stover	0	15	90	25	75
Maize stover	0	30	90	24	76
Maize stover	0	45	90	27	73
Maize stover	0	60	90	21	79
Elephant grass	0	15	90	23	77
Elephant grass	0	30	90	22	78
Elephant grass	0	45	90	24	76
Elephant grass	0	60	90	16	84
Lawn grass	0	15	90	19	81
Lawn grass	0	30	90	15	85
Lawn grass	0	45	90	22	78
Lawn grass	0	60	90	15	85
Mean				**21**	**79**
Standard deviation				**4**	**4**

APPENDIX 35: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	3	15	90	18	82
Rice straw	3	30	90	37	63
Rice straw	3	45	90	19	81
Rice straw	3	60	90	24	76
Maize stover	3	15	90	27	73
Maize stover	3	30	90	25	75
Maize stover	3	45	90	30	70
Maize stover	3	60	90	25	75
Elephant grass	3	15	90	18	82
Elephant grass	3	30	90	18	82
Elephant grass	3	45	90	18	82
Elephant grass	3	60	90	22	78
Lawn grass	3	15	90	10	90
Lawn grass	3	30	90	13	87
Lawn grass	3	45	90	18	82
Lawn grass	3	60	90	14	86
Mean				**21**	**79**
Standard deviation				**7**	**7**

APPENDIX 36: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	6	15	90	23	76
Rice straw	6	30	90	25	75
Rice straw	6	45	90	25	75
Rice straw	6	60	90	25	75
Maize stover	6	15	90	24	76
Maize stover	6	30	90	25	75
Maize stover	6	45	90	25	75
Maize stover	6	60	90	27	73
Elephant grass	6	15	90	16	84
Elephant grass	6	30	90	14	86
Elephant grass	6	45	90	13	87
Elephant grass	6	60	90	21	79
Lawn grass	6	15	90	18	82
Lawn grass	6	30	90	17	83
Lawn grass	6	45	90	28	72
Lawn grass	6	60	90	24	76
Mean				**22**	**78**
Standard deviation				**5**	**5**

APPENDIX 37: Surface runoff/Infiltration (%) from Anwomaso soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration (minutes)	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice straw	9	15	90	56	44
Rice straw	9	30	90	51	49
Rice straw	9	45	90	31	69
Rice straw	9	60	90	37	63
Maize stover	9	15	90	47	53
Maize stover	9	30	90	56	44
Maize stover	9	45	90	52	48
Maize stover	9	60	90	50	50
Elephant grass	9	15	90	37	63
Elephant grass	9	30	90	35	65
Elephant grass	9	45	90	34	66
Elephant grass	9	60	90	36	64
Lawn grass	9	15	90	23	77
Lawn grass	9	30	90	21	79
Lawn grass	9	45	90	35	65
Lawn grass	9	60	90	41	59
Mean				**40**	**60**
Standard deviation				**11**	**11**

APPENDIX 38: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	0	15	0	48	52
Rice Straw	0	30	0	46	54
Rice Straw	0	45	0	48	52
Rice Straw	0	60	0	54	46
Maize Stover	0	15	0	45	55
Maize Stover	0	30	0	46	54
Maize Stover	0	45	0	48	52
Maize Stover	0	60	0	54	46
Elephant Grass	0	15	0	43	57
Elephant Grass	0	30	0	45	55
Elephant Grass	0	45	0	47	53
Elephant Grass	0	60	0	54	46
Landscape Grass	0	15	0	41	59
Landscape Grass	0	30	0	45	55
Landscape Grass	0	45	0	48	52
Landscape Grass	0	60	0	54	46
Mean				**48**	**52**
Standard deviation				**4**	**4**

APPENDIX 39: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	3	15	0	70	30
Rice Straw	3	30	0	71	29
Rice Straw	3	45	0	68	32
Rice Straw	3	60	0	73	27
Maize Stover	3	15	0	70	30
Maize Stover	3	30	0	73	27
Maize Stover	3	45	0	69	31
Maize Stover	3	60	0	71	29
Elephant Grass	3	15	0	75	25
Elephant Grass	3	30	0	73	27
Elephant Grass	3	45	0	71	28
Elephant Grass	3	60	0	73	27
Lawn Grass	3	15	0	69	31
Lawn Grass	3	30	0	72	28
Lawn Grass	3	45	0	71	29
Lawn Grass	3	60	0	69	31
Mean				**71**	**29**
Standard deviation				**2**	**2**

APPENDIX 40: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	6	15	0	71	31
Rice Straw	6	30	0	72	28
Rice Straw	6	45	0	69	30
Rice Straw	6	60	0	75	25
Maize Stover	6	15	0	76	24
Maize Stover	6	30	0	81	19
Maize Stover	6	45	0	80	20
Maize Stover	6	60	0	81	19
Elephant Grass	6	15	0	70	31
Elephant Grass	6	30	0	72	24
Elephant Grass	6	45	0	73	27
Elephant Grass	6	60	0	71	29
Landscape Grass	6	15	0	82	18
Landscape Grass	6	30	0	70	30
Landscape Grass	6	45	0	72	28
Landscape Grass	6	60	0	70	30
Mean				**74**	**26**
Standard deviation				**5**	**5**

APPENDIX 41: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	9	15	0	87	14
Rice Straw	9	30	0	75	26
Rice Straw	9	45	0	75	25
Rice Straw	9	60	0	80	20
Maize Stover	9	15	0	85	15
Maize Stover	9	30	0	85	15
Maize Stover	9	45	0	80	20
Maize Stover	9	60	0	80	20
Elephant Grass	9	15	0	84	16
Elephant Grass	9	30	0	70	30
Elephant Grass	9	45	0	74	26
Elephant Grass	9	60	0	80	20
Landscape Grass	9	15	0	83	17
Landscape Grass	9	30	0	69	31
Landscape Grass	9	45	0	74	26
Landscape Grass	9	60	0	79	21
Mean				**79**	**21**
Standard deviation				**5**	**5**

APPENDIX 42: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	0	15	30	39	61
Rice Straw	0	30	30	42	58
Rice Straw	0	45	30	43	57
Rice Straw	0	60	30	52	48
Maize Stover	0	15	30	40	60
Maize Stover	0	30	30	42	58
Maize Stover	0	45	30	43	57
Maize Stover	0	60	30	53	47
Elephant Grass	0	15	30	39	61
Elephant Grass	0	30	30	41	59
Elephant Grass	0	45	30	42	58
Elephant Grass	0	60	30	51	49
Landscape Grass	0	15	30	37	63
Landscape Grass	0	30	30	40	60
Landscape Grass	0	45	30	41	59
Landscape Grass	0	60	30	51	49
Mean				**43**	**57**
Standard deviation				**5**	**5**

APPENDIX 43: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	3	15	30	59	41
Rice Straw	3	30	30	56	44
Rice Straw	3	45	30	63	37
Rice Straw	3	60	30	66	34
Maize Stover	3	15	30	64	36
Maize Stover	3	30	30	62	38
Maize Stover	3	45	30	65	35
Maize Stover	3	60	30	67	33
Elephant Grass	3	15	30	57	37
Elephant Grass	3	30	30	56	32
Elephant Grass	3	45	30	63	30
Elephant Grass	3	60	30	66	34
Lawn Grass	3	15	30	52	48
Lawn Grass	3	30	30	56	44
Lawn Grass	3	45	30	62	38
Lawn Grass	3	60	30	66	34
Mean				**61**	**37**
Standard deviation				**5**	**5**

APPENDIX 44: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	6	15	30	60	41
Rice Straw	6	30	30	58	42
Rice Straw	6	45	30	64	37
Rice Straw	6	60	30	69	31
Maize Stover	6	15	30	67	33
Maize Stover	6	30	30	65	35
Maize Stover	6	45	30	65	35
Maize Stover	6	60	30	66	34
Elephant Grass	6	15	30	53	47
Elephant Grass	6	30	30	57	35
Elephant Grass	6	45	30	63	35
Elephant Grass	6	60	30	68	32
Landscape Grass	6	15	30	71	29
Landscape Grass	6	30	30	53	47
Landscape Grass	6	45	30	58	42
Landscape Grass	6	60	30	66	34
Mean				**63**	**37**
Standard deviation				**6**	**6**

APPENDIX 45: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	9	15	30	76	25
Rice Straw	9	30	30	59	41
Rice Straw	9	45	30	65	35
Rice Straw	9	60	30	71	28
Maize Stover	9	15	30	76	24
Maize Stover	9	30	30	80	20
Maize Stover	9	45	30	65	35
Maize Stover	9	60	30	72	28
Elephant Grass	9	15	30	73	27
Elephant Grass	9	30	30	54	46
Elephant Grass	9	45	30	64	36
Elephant Grass	9	60	30	71	29
Landscape Grass	9	15	30	73	27
Landscape Grass	9	30	30	53	47
Landscape Grass	9	45	30	63	37
Landscape Grass	9	60	30	69	31
Mean				**68**	**32**
Standard deviation				**8**	**8**

APPENDIX 46: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	0	15	60	33	67
Rice Straw	0	30	60	39	61
Rice Straw	0	45	60	39	61
Rice Straw	0	60	60	44	56
Maize Stover	0	15	60	34	66
Maize Stover	0	30	60	40	60
Maize Stover	0	45	60	40	60
Maize Stover	0	60	60	45	55
Elephant Grass	0	15	60	33	67
Elephant Grass	0	30	60	38	62
Elephant Grass	0	45	60	38	62
Elephant Grass	0	60	60	44	56
Landscape Grass	0	15	60	32	68
Landscape Grass	0	30	60	37	63
Landscape Grass	0	45	60	37	63
Landscape Grass	0	60	60	43	57
Mean				**38**	**62**
Standard deviation				**4**	**4**

APPENDIX 47: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	3	15	60	46	54
Rice Straw	3	30	60	50	50
Rice Straw	3	45	60	57	43
Rice Straw	3	60	60	63	37
Maize Stover	3	15	60	53	47
Maize Stover	3	30	60	50	50
Maize Stover	3	45	60	60	40
Maize Stover	3	60	60	63	37
Elephant Grass	3	15	60	50	39
Elephant Grass	3	30	60	49	36
Elephant Grass	3	45	60	57	36
Elephant Grass	3	60	60	62	38
Lawn Grass	3	15	60	39	61
Lawn Grass	3	30	60	48	52
Lawn Grass	3	45	60	56	44
Lawn Grass	3	60	60	61	39
Mean				**54**	**44**
Standard deviation				**7**	**8**

APPENDIX 48: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	6	15	60	48	54
Rice Straw	6	30	60	51	49
Rice Straw	6	45	60	58	42
Rice Straw	6	60	60	63	36
Maize Stover	6	15	60	55	45
Maize Stover	6	30	60	56	44
Maize Stover	6	45	60	57	43
Maize Stover	6	60	60	54	46
Elephant Grass	6	15	60	37	63
Elephant Grass	6	30	60	52	44
Elephant Grass	6	45	60	58	38
Elephant Grass	6	60	60	63	37
Landscape Grass	6	15	60	55	45
Landscape Grass	6	30	60	48	52
Landscape Grass	6	45	60	37	63
Landscape Grass	6	60	60	58	42
Mean				**53**	**46**
Standard deviation				**8**	**8**

APPENDIX 49: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	9	15	60	68	32
Rice Straw	9	30	60	52	49
Rice Straw	9	45	60	59	41
Rice Straw	9	60	60	66	34
Maize Stover	9	15	60	67	33
Maize Stover	9	30	60	68	32
Maize Stover	9	45	60	56	44
Maize Stover	9	60	60	67	33
Elephant Grass	9	15	60	64	36
Elephant Grass	9	30	60	48	52
Elephant Grass	9	45	60	56	44
Elephant Grass	9	60	60	66	34
Landscape Grass	9	15	60	61	39
Landscape Grass	9	30	60	46	54
Landscape Grass	9	45	60	56	44
Landscape Grass	9	60	60	65	35
Mean				**60**	**40**
Standard deviation				**7**	**7**

APPENDIX 50: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	0	15	90	27	73
Rice Straw	0	30	90	32	68
Rice Straw	0	45	90	31	69
Rice Straw	0	60	90	33	67
Maize Stover	0	15	90	30	70
Maize Stover	0	30	90	35	65
Maize Stover	0	45	90	31	69
Maize Stover	0	60	90	34	66
Elephant Grass	0	15	90	27	73
Elephant Grass	0	30	90	30	70
Elephant Grass	0	45	90	30	70
Elephant Grass	0	60	90	33	67
Landscape Grass	0	15	90	26	74
Landscape Grass	0	30	90	29	71
Landscape Grass	0	45	90	29	71
Landscape Grass	0	60	90	32	68
Mean				**31**	**69**
Standard deviation				**3**	**3**

APPENDIX 51: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	3	15	90	37	63
Rice Straw	3	30	90	32	68
Rice Straw	3	45	90	44	56
Rice Straw	3	60	90	44	56
Maize Stover	3	15	90	40	60
Maize Stover	3	30	90	38	62
Maize Stover	3	45	90	38	62
Maize Stover	3	60	90	43	57
Elephant Grass	3	15	90	37	61
Elephant Grass	3	30	90	32	57
Elephant Grass	3	45	90	42	50
Elephant Grass	3	60	90	43	57
Lawn Grass	3	15	90	31	69
Lawn Grass	3	30	90	34	66
Lawn Grass	3	45	90	32	68
Lawn Grass	3	60	90	37	63
Mean				**38**	**61**
Standard deviation				**5**	**5**

APPENDIX 52: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	6	15	90	39	59
Rice Straw	6	30	90	36	66
Rice Straw	6	45	90	47	53
Rice Straw	6	60	90	44	55
Maize Stover	6	15	90	44	56
Maize Stover	6	30	90	48	52
Maize Stover	6	45	90	50	50
Maize Stover	6	60	90	46	54
Elephant Grass	6	15	90	22	78
Elephant Grass	6	30	90	22	78
Elephant Grass	6	45	90	45	55
Landscape Grass	6	60	90	41	59
Landscape Grass	6	15	90	33	67
Landscape Grass	6	30	90	22	78
Landscape Grass	6	45	90	42	58
Landscape Grass	6	60	90	40	60
Mean				**39**	**61**
Standard deviation				**9**	**9**

APPENDIX 53: Surface runoff/Infiltration (%) from Kotei soil as affected by all mulch materials (average for all rainfall duration)

Mulch type	Slope (%)	Rainfall duration minutes	Mulch rate (%)	Runoff (%)	Infiltration (%)
Rice Straw	9	15	90	55	46
Rice Straw	9	30	90	44	56
Rice Straw	9	45	90	51	49
Rice Straw	9	60	90	55	45
Maize Stover	9	15	90	53	47
Maize Stover	9	30	90	58	42
Maize Stover	9	45	90	51	49
Maize Stover	9	60	90	55	45
Elephant Grass	9	15	90	52	48
Elephant Grass	9	30	90	43	57
Elephant Grass	9	45	90	49	51
Elephant Grass	9	60	90	53	47
Landscape Grass	9	15	90	51	49
Landscape Grass	9	30	90	42	58
Landscape Grass	9	45	90	48	52
Landscape Grass	9	60	90	52	48
Mean				**51**	**49**
Standard deviation				**5**	**5**