EVALUATION OF THE EFFECT OF SURFACE SOIL REMOVAL ON THE GROWTH OF WHEAT

by

Hilda Muthoni Mukui

BSc. (Hons) Agriculture, Post Graduate Diploma in Soil Conservation

University of Nairobi

A Thesis submitted in Partial Fulfilment of the requirements for the degree of Master of science in Land and Water Management of the

UNIVERSITY OF NAIROBI

January, 1991

DECLARATION

I hereby declare that this thesis is my original work and has not been submitted for a degree course in any other University.

.... 22/1/91

HILDA MUTHONI MUKUI DATE

This thesis has been submitted for Examination with our approval

....

DR A. M KILEWE PROF. D.B. THOMAS

KARI, MUGUGA AGRIC. ENG. DEPT

22/1/91 22/1/91

DATE DATE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

DEDICATION

This work has been dedicated to my dear husband, Mukui and my children Grace and Ruth, for their sacrifice, love and encouragement throughout the course of my study.

ACKNOWLEDGEMENT

very grateful to the Swedish International Development Agency who sponsored me for this course through the Ministry of ulture.

ncere thanks and gratitude go to my supervisors Prof. D. B. of Agricultural Engineering Department, University of Nairobi, r. A. M. Kilewe of Kenya Agricultural Research Institute - n, for the invaluable guidance and encouragement throughout rse of this study.

lso grateful to Dr. Oggema, former Director of Plant Breeding h Station, Njoro and the staff of Plant Breeding Station for kindly g me to use the facilities which were necessary for my work.

t not least I am grateful to the Technicians in the Department of tural Engineering of University of Nairobi, the ladies who in typing this work and all those others who assisted me in one he other in accomplishing this study. To them all I say, Thank much!

ABSTRACT

The study was conducted at the National Plant breeding Research Station in Njoro. The main objectives of the study were to evaluate the effect of surface soil removal on the growth of wheat, and to determine whether chemical fertilizers can restore the growth of wheat on the desurfaced soil.

Three different soil types were used. These were Luvisol, Nitosol and Andosol collected respectively from Katumani Research Station, Kabete Campus and Plant Breeding Station, Njoro. The soils were taken from different depths in the soil profile placed in pots in a raised cage and tested by growing wheat both with and without fertilizer.

The performance of the wheat was monitored by taking the measurements of maximum height, number of tillers, weight of straw, length of ears, weight of ears, weight of grains, weight of dry roots. The data collected was then analysed statistically. The results showed that surface soil removal decreased yield in all the parameters that were measured. The greater the depth of surface soil removal the higher the reduction in yield. However the impact of removing the first 10cm of topsoil had a more serious effect on yield than the removal of 40cm of topsoil in terms of decrease per cm of topsoil removed.

When fertilizer was added at recommended and double the recommended rates there was a general increase in all the parameters. The increase depended on the level of fertilizer, the depth of topsoil removal and the soil type. The increase in yield was different in different parameters, with wheat straw being the least affected while grain weight was most affected. Addition of fertilizer at double the

recommended rate, after 10cm of topsoil removal raised yields in almost all aspects to that of the control except grain weight and weight of ears. However at 40 cm of topsoil removal parameters such as grain weight, number of grains and weight of ear attained only 84.0, 97.1 and 85.1% respectively as compared with the control.

Thus addition of chemical fertilizer may not compensate for loss in productivity in desired parameters such as grain weight which are important in food production.

CHAPTER I

1.0 INTRODUCTION

1.1 The Importance of Soil Erosion

There are two major forms of the soil erosion, geological and accelerated erosion. Geological erosion, in the broadest sense, is a normal process representing erosion of land in its natural environment without the influence of man. It has been going on since the time continents emerged from the sea. Geological erosion is caused mainly by the action of wind and water, temperature variation, gravity and glaciers. Geological erosion has contributed to the formation of our soils and their distribution on the surface of the earth. It has been responsible for the wearing away of hills and mountains and it is the cause of present land surface features. Geological erosion includes soil forming as well soil eroding processes which maintain the soil in a favourable balance, suitable for the growth of most plants.

Accelerated erosion on the other hand is soil loss in excess of geological erosion. It is usually a more rapid process that is largely induced by such human practices as forest clearing, raising crops, and domesticated animals, mining and construction. The forces involved in accelerated erosion are

(a) attacking forces which remove and transport the soil particles and

(b) resisting forces which retard erosion.

Soil erosion is the washing away of the fertile top-soil from one place to another by action of water, or in the case of wind, by blowing away from one place to another. The erosion by water process begins when raindrops strike the surface of the soil and break down clods and aggregates. It is a three phase process consisting of detachment, transportation and deposition of the soil material. The severity of erosion depends on various factors such as the amount of rain, vegetation cover, topography, land use and the type of soil.

Soil erosion has been accelerated by man through the action of burning, cultivation and overgrazing. All these factors expose soil to the direct action of rainwater and wind. The energy of the raindrops causes detachment of the soil particles. As run-off accumulates on the soil surface it gathers enough energy to transport the detached soil particles. As run-off moves it makes rills by scouring action and these rills may increase and develop into gullies.

When vegetation cover is wholly or partly removed, particularly from sloping lands, rainwater runs off more rapidly and in increased volume. In this way soil erosion causes damage to soil and to any vegetation that may be left. Floods occur more frequently and with greater severity.

Eventually as the vicious cycle of erosion proceeds, less water percolates into the soil to feed the underground supplies. Springs, marshes and streams dry up more quickly and this leads to further degradation. As soil becomes depleted by water erosion people attempt to move to other more productive lands. Eventually when there is no land available, they are forced to adapt themselves to smaller amounts of food which require harder work and more expensive inputs to produce.

Vast improvements have been made in the science of crop production during the past 50 years. Inorganic fertilizing materials have improved in content and availability of nutrients and physical properties. Rates of fertilizers application have been increased enormously in many areas and the number of farmers using fertilizers has increased many times over. Better adapted and high yielding varieties of crops have been made available; better materials and equipment for control of insect pests and diseases have been developed. These and other related developments would have brought about large increases in crop production per hectare, if the fertility of soil had been maintained.

Erosion reduces soil productivity slowly such that the reduction may not be recognised until land is no longer economically suitable for growing crops. The difficulty of detecting soil productivity losses is compounded by the non-linear nature of the erosion process. Erosion generally increases run-off because of the reduced infiltration. Increased run-off reduces available soil water and this affects plant growth which means less residue and therefore less soil cover and increased erosion. The process thus advances exponentially if it is not detected early and controlled properly. Restoration of severely eroded soils is generally difficult and costly because subsoil conditions such as poor aeration, low organic matter, or lack of available nutrients, often restrict crop growth.

1.2 Significance of the study

The population of Kenya is expected to reach thirty-five million in the year 2000 if the present rate of growth of 3.8% does not change. (Republic of Kenya, 1986). The country's food production must therefore increase at the same rate or higher to maintain the same food supply/population ratio we have today. At the same time that increased food production is needed, thousands of hectares of land are being subjected to major soil erosion losses. This combination of events lead to the conclusion that losses in soil productivity due to erosion will not permit maintenance of the current levels of agricultural production unless we reverse the situation by engaging in adaptive research that is concerned with the care and maintenance of our soil resources.

In areas where the population per unit of agricultural land is already high and still increasing at a rapid rate the problem of increasing food supply at a sufficient rate becomes increasingly difficult. Although population control is the job of population experts it is inseparably interwined with our food production problem.

Already land resources in some parts of Kenya have been abused to such a degree as to limit severely their options for future productive use. The economic and social costs of soil erosion are substantial. Lower agricultural productivity resulting from soil misuse will lead to scarcity of low cost food, which will lead in turn to further misuse of already cultivated land and exploitation of other land more vulnerable to erosion.

Although soil erosion is a pressing agricultural problem presenting a major threat to all facets of agricultural production, the relationship between erosion and soil productivity is not adequately defined, and selection of management strategies to optimise present and future crop production is difficult. Poor decisions can easily result in loss of soil and associated vegetation, or under utilization of the soil resources, either of which will cause loss of income to the farmer and food supply to the nation. There is therefore a need to assess the effects of erosion on soil productivity for the major soil types in Kenya.

1.3 Objectives

The objectives of the study were:-

a) To evaluate the effect of surface soil removal on the growth of wheat and

b) To determine whether addition of chemical fertilizer can restore the growth of wheat on desurfaced soil.

The study was conducted at The National Plant Breeding Station in Njoro. Three soil types were used. These were Luvisol, Nitosol and Andosol collected respectively from Katumani Dryland Farming Research Centre, College of Agriculture and Veterinary services (Kabete Campus) and the National Plant Breeding Station Njoro.

Soil samples were taken from different depths in the soil profile, placed in pots in a green house, and tested by growing wheat both with and without fertilizer.

The next chapter reviews the literature on soil erosion and productivity. This is followed by chapters dealing with methodology and experimental results. The findings are then discussed and the thesis ends with conclusions and recommendations.

CHAPTER II

2.0 LITERATURE REVIEW

2.1 Introduction

Erosion causes a physical loss of the upper layer or top soil which is the most important part necessary for growth of healthy plants. Once the top layer has been lost, it has for all practical purposes gone for good. (F.A.O, 1976). In broader terms soil erosion does not only refer to the removal, transportation and net loss of soil, but also refers to other forms of soil degradation such as breaking down of the soil structure and the sealing of the surface, washing down of clays and colloids to lower horizons and leaching of soluble plant nutrients by rain and runoff.

Different soils erode differently under the same climate. This is because of different aggregate stability which is as a result of parent material, the nature of their structure, texture and the amount of organic matter. Soils with good structure are not as easily eroded as those without.

Soils with high clay content are not as easily eroded compared to those with high sand content. However, once both have been eroded, the clay particles are more easily transported than sand particles because they are small and light while sand particles are heavy and not easily transported. (Wenner, 1981).

The effect of soil erosion on soil productivity has serious implications for the farming community, particularly in the area of crop and livestock production.

It is the aim of every farmer and government to increase food production, but unfortunately if soil is left to erode continously the desired goals cannot be attained because soil erosion lowers the capacity of a soil to produce high yields. Studies in U.S.A show that productivity can approach to zero in some severely eroded areas (Bennett, 1939, Krauss and Allmaras, 1982).

Soil productivity has been defined as 'the capacity of a soil in its normal environment to produce a particular plant or sequence of plants under a specified management system' (Soil Science Society of America, 1975). Thus productivity is a measure of the production potential of a soil system that allows accumulation of energy in the form of vegetation. The best estimator of productivity is yield in terms of grain or total biomass. However productivity is more than yield assessment because it includes the potential for future production which cannot be assessed by a historical crop yield.

The relationship between soil erosion and soil productivity has not been well defined (Langdale *et al.*, 1981). In the absence of a defined relationship it is difficult to justify the enormous amounts of money spent on soil erosion research and control by various organisations and governments. It is even more difficult to select management strategies to maximise long term crop production. Poor decisions can easily result in serious damage to soil resources. Poor decisions can also lead to under-utilization of soil resource and loss of income to the producers and loss of food or fibre to the consumers. (National Soil Erosion - Soil Productivity Research Planning Committee, 1981). The following is a review of the ways in which soil erosion lowers productivity.

2.2 Effect of Erosion on Soils

As soil changes and nutrients diminish, the potential for erosion increases. This forms a vicious cycle in that further erosion induces further decline in productivity and the problem becomes self perpetuating. Moldenhauer (1971) sees erosion as having two major effects on soil and that one is irreversible and one is reversible. Yield potential is irreversibly reduced by erosion but on the other hand loss of nitrogen and phosphorus and some minor elements can be compensated for by additional fertilizer. However, the long term effects on the soil in its natural nutrient balance, structure, water holding properties and the ability to produce crops will be detrimental. This is often so for major tropical soils. Experiments at Saria Research Station, Upper Volta, conclusively showed that degradation caused harm to soil that could not be made up for by mineral fertilizer alone. Mulching and manuring in addition were necessary (Couprie *et al*, 1984). The degree of the effect depends on the soil type, climate, inputs, crop types and level of management. The main effects of soil erosion on loss of productivity are the change in water holding characteristics and the change in nutrient status.

2.2.1 Loss of water holding capacity

Loss of soil water holding capacity is one of the main reasons for low productivity of most eroded soils. The water storage capacity of most plants is small relative to water loss and uptake by the process of evapotranspiration (Hsiao *et al.*, 1980) and therefore any water stress will have a relatively quick response. Erosion affects the water holding components such as organic matter and clay particles. The erosion process is selective and therefore it nearly always removes the fine particles and leaves the coarse sand which has little ability to retain water.

Erosion also reduces the depth of the root zone and if subsoil is toxic to roots or has high density or poor aeration, it will retard root development. Many studies have conclusively shown that root growth is severely limited by high bulk density. Most often a soil with high bulk density is compacted . A compacted soil has low organic matter, reduced infiltration and hence less plant available water. Soils of this type have low productivity because root development is impeded (Taylor et al., 1980) as reported by Stocking (1984).

Soil erosion brings high strength soil close to the surface and thus limits the rooting zone. It further helps to compact the surface soil and retard root development. It is therefore difficult to isolate the contraints of available water from that of mechanical impedence.

The evidence of the importance of available water capacity has been shown in U.S.A. by Thomas and Casell (1979) where they demonstrated a close relationship between soil depth, available water capacity (AWC) and dry matter production on a sandy loam with a shallow fragipan horizon.

Table 2.1: Effect of soil depth on productivity of dry matter and available water capacity

Soil depth (cm)	Production of dry matter kg/ha	Available water capacity (mm)
26	5902	32
39	7397	52
45	9135	64

Source: Thomas and Cassell (1979)

In Southern Bavaria, Becher (1983), found a lower maize yield on an eroded soil with an available water capacity of 50mm compared with a loess soil with 200mm of available water. In two years of relatively high rainfall, yields were similar on the two soils. This demonstrates the limiting role of water availability.

2.2.2 Loss of plant nutrients

Early studies on the effect of erosion on productivity centered on the diminishing supply of nutrients particularly nitrogen. This is because most of the plant available nitrogen is concentrated in the 10-30 cm of the surface soil. Also 50% of the plant available phosphorus is usually in the organic form (Black and Siddoway, 1966). Many longterm studies in the U.S.A (Adams, 1949) showed that yields of row crops declined drastically on all soils as surface soil was lost by erosion, except where soil nutrients, organic matter and occasionally water was added. Engelstrad and Shrader (1961) found that nitrogen application allowed a top soil and a sub-soil to yield similar amounts of maize.

However, on many occasions the findings of Bachelder and Jones (1972) would be true, that lime, mulch and irrigation are necesary to restore yields on eroded soil to the same level as its uneroded equivalent. Although fertilizer can partially compensate for low crop yields on exposed subsoils, production costs are certainly increased.

It should be noted that the nutrients limiting productivity vary according to soil type and the degree of erosion. Low phosphorous and potassium contribute to yield decline in Eastern U.S (Thomas and Cassell, 1979) and low nitrogen and phosphrous in Texas (Eck *et al.*, 1965).

The problem becomes even worse if the subsoil contains more clay than topsoil which is a common occurence. Clay tends to transform applied phosphorous quickly into forms which are not readily available to plants.

Loss in nutrients as a result of erosion has been written about and discussed by many researchers. The most telling evidence on this has been through the nutrient enrichment ratio. That is the ratio of the concentration of fertility related nutrients in the eroded soil to that in the parent soil. In almost all cases, the eroded soil has more nutrients than the parent soil. The enrichment ratio tends to decline as soil fertility declines (Lal, 1976) and as soil losses get greater (Massey and Jackson, 1952). Under certain circumstances the concentration of some elements of soil fertility in the eroded sediments can be at least ten times than in the original soil.

Generally after only slight erosion, application of nitrogen restores yield while after moderate erosion application of nitrogen can only bring production back to a maximum of 90% (Downer *et al*, 1981, Free, 1960, and Trustrum *et al.*, 1983). Table 2.2 shows the enrichment ratios as reported by various authors.

Table 2.2 Enrichment ratios; concentration of nutrients in eroded sediment compared to concentration in original soil.

Enrichment Ratios				
O.M	**Total N**	**Avail. P**	**Ex.K**	**Source**
-	-	3.3	4.7	Rogers, 194
3.9	4.2	-	-	Kinsklanch et al., 1942
2.1	2.7	3.4	-	Massey, Jackson 1952
1.1	1.1	2.2	6.7	Massey et al., 1953
-	-	-	12.6	Stoltenberg, White, 1953
2.0	2.1	2.4	-	Hudson, Jackson, 1959
2.4	1.6	5.8	1.7	Lal 1979
1.5	-	1.9	1.8	Ketchson, Webber, 1978

Source: Stocking (1984)

From the table above the nutrients from the eroded soil are higher than in soil left behind in all cases.

2.2.3 Non-uniform removal of soil within a field

Erosion does not occur uniformly across a field simply because of the non-uniform topography and run-off flow network. Selecting management strategies to maximise production is almost impossible in fields with various degrees of erosion since farms are farmed as units. Fertilizer application is normally applied uniformly across a field. Application is therefore appropriate in some parts while it is not in others, hence optimum production cannot be achieved in all areas. The same argument goes for use of herbicide.

The performance of herbicides depends on the soil organic matter content, pH and the cation exchange capacity. In a non-uniformly eroded field one rate of herbicide application may kill weeds and damage the crops in one part of the field but not effectively control weeds in another part of the field.

2.2.4 Exposure of subsoil

Because of the non-linear advance of erosion, subsoils are being exposed at an accelerated rate in many places. Once cultivation starts erosion exposes subsoils within a few years. This is particularly so on steep slopes where soil conservation measures are not observed strictly. The exposed subsoils may increase erosion on adjacent areas of a field. When a clay or a sodium saturated subsoil is exposed, infiltration declines while run-off increases and therefore erosion accelerates on adjacent downslope soils.

Also ridges and knolls of exposed calcium carbonate provides readily movable soil materials for wind erosion. In both cases lack of sufficient crop residue compounds the problem.

2.2.5 Effect on farm operations

Non-uniform erosion in fields also affects the timing of farming operations. Proper timing is important especially when it comes to the time of planting because productivity can be affected.Timeliness in planting is closely correlated with yields. Akehurst and Screedharan (1965) in an experiment in Tanzania showed that the best yields are obtained by planting as soon as the rains start. In Kenya (Dowker, 1964) found a yield loss of 5% per day delay. Often clay subsoils which are exposed by erosion are too wet when the rest of the field is suitable for farming operations. This forces the farmer to either avoid them or wait until they are dry enough to permit tillage. In either way the yield per unit area will be affected. Non-uniform erosion also affects tillage effectiveness and causes inconsistent seedbeds which lead to variations in seedling emergence and poor stands.

2.2.6 Energy requirements for tillage

Energy requirements are also greater in non-uniformly eroded soils. Tilling a subsoil often requires more power than tilling a topsoil. Additional energy is also required for filling and smoothening gullies. If gullies are neglected they cut across the fields and make row lengths shorter, thus reducing farming efficiency.

2.2.7 Degradation of soil structure

Soil erodibility is increased by degradation of soil structure. Surface sealing and crusting reduce seedling emergence and lower infiltration. Reduced infiltration provides less opportunity for soil water storage. This can affect the healthy growth of plants due to water stress, and finally lead to low productivity.

2.2.8 Difficulties of restoration of productivity

Another characteristic of the erosion productivity problem is the difficulty in restoring productivity of severely eroded soils. Restoration is generally difficult and costly because subsoil conditions often inhibit crop growth. These conditions include poor aeration, low organic matter, lack of exchangeable or soluble nutrients and calcium

Plate - 1 A crusted soil (Katumani Luvisol)

The photo was taken after the straw was cut off at the base

Plate - 2 Surface sealing on Katumani Luvisol carbonate, high soluble aluminium, gravel and high bulk density. Although productivity can be restored partly by adding organic matter and fertilizer, such additions may not be economical in marginal areas because of low rainfall.

Other effects of erosion induced loss in productivity on soil include:

- puddling and sealing of the soil surface
- loss in soil structure
- loss in organic matter
- compaction and high bulk density
- increased aridity of the soil
- salinity and alkalinity

2.3 Effect of erosion on yields

Erosion reduces productivity very slowly such that the reduction may not be easily recognised until land is no longer economically suitable for growing crops. Further improved technology, such as improved seed, fertilizer types and rates, often masks the reduction in productivity as shown by Krauss and Allmaras, (1981). Also Langdale and Shrader (1981) found that on deep, medium textured, soils only addition of nitrogen and phosphorus and occasionally micro-nutrients are necessary to produce crop yields. Where fertilizer is used it is difficult to detect loss in productivity. Most evidence of the erosion productivity relationship comes in the form of reduced yields. Most of the research work was done in U.S.A and half the experiment were on artificial desurfacing.

As reported by the National Soil Erosion - Soil Productivity Planning Committee (1981) the rates of yield decline range from 20% to100%. Borst *et al* (1945) observed a 96% decline in maize yield on a Ohio podzollic silt loam after 15cm of natural soil loss over 9 years. Lathan (1940) found that for cotton the A-horizon of a soil was three times as productive as the B-horizon. In another study the A:B ratio was found to be 1.6 Adams, (1949). The table below shows the incremental decline in Kg/ha per cm of soil lost assuming a linear relationship.

Table 2.3 Incremental Yield decline; Some U.S. data

Crop	**Yield decline** Kg/ha/cm soil loss	**Source**
Maize	76-124	Smith et al 1945 Smith 1946
"	55	Hendrickson, 1948
"	50-250	Uhland, 1949
"	30-90	Van Doren &Bartelli,1956
"	50-175	Stallings, 1957
"	268	Stallings 1957
"	100	Piemental et al, 1976
"	147	Langdale et al, 1979
"	188	Hagen & Dyke, 1980
Wheat	21-42	Stallings, 1957
"	40	Piemental et al 1976
"	54	Krauss & Allmaras 1982

Source: Stocking (1984)

In all cases, it is clear that the effect of soil erosion on productivity can be seen in reduction of yield for every small amount of soil lost. Again the decline will depend on the soil type and other management factors.

The yield decline per cm of soil lost in natural erosion and artificial desurfacing is very different. Lal, (1983) showed that one cm of natural erosion reduced maize yield by more than 90% while the equivalent reduction by artificial desurfacing always under estimates yield decline, sometimes even by a factor of 10, (Stocking 1985).

2.4 Measurement of the impact of erosion on productivity

There are various methods of measuring the impact of erosion on productivity. Most of them have been outlined by Stocking (1985) in his research design for erosion induced loss in productivity. They are as follows;

2.4.1 Use of existing experimental data

In many countries a lot of experiments have been done on soil loss and runoff. The data from these experiments may reveal useful information on productivity losses due to erosion if carefully scrutinised by an experienced researcher.

Problems may be encountered in using existing data because the experiments were not designed to generate soil loss/yield data and therefore there may have been poor control of variables and no specific base line condition on which yield decline can be inferred.

However, some of the following forms of information may be available which can be useful in giving some insight to trends in productivity as one commences a research programme.

- crop yield information

- standard treatments and erosion history
- nutrient and O.M in eroded soil as compared to non-eroded soil - enrichment ratio
- changes in soil erodibility between years
- soil texture and aggregate stability
- comparative drought stress between plots
- yield and leaf area index can provide worthwhile information on growth curve for the growing season.

The above analysis can provide a useful starting point for research investigations though it may not be adequate or comprehensive.

2.4.2 Use of existing experimental data with additional standard treament

Old runoff and soil loss plots with a known history of erosion can be subjected to a standard cropping treatment in order to compare responses. This would have the advantage of obtaining results quickly with little marginal costs. However, there may be difficulties in comparing what is likely to have been complicated by disruption of experimental programmes and complicated erosion histories and different management standards and crops.

All the same this approach would be a worthwhile interim measure especially where existing soil loss plot experiments are finishing.

2.4.3 New field experiments using natural rainfall

This approach would ideally be the best but unfortunately runoff and soil loss experiments designed for investigating erosion productivity relationship would require a minimum of 10 years which is an unacceptable delay.

2.4.4 Field experiment using simulated rainfall

Rainfall simulation is one way of speeding the natural process of erosion and has the advantages of flexibility and production of precise qantities of erosion. However, simulators have problems such as mentioned below;

- to produce rainfall over an area sizeable enough to generate runoff and infiltration characteristics close to reality would require equipment that is large, cumbersome and expensive.
- large simulators give an uneven pattern of rainfall.
- simulated rainfall does not always give the drop size and energy characteristics of natural rainfall. The resultant erosion, the proportion of colloids removed, breakdown of aggregates and surface crusting may be different from that which would have occured under natural rainfall.
- rainfall simulators are costly to make and need considerable maintenance and large quantities of water.

Nevertheless this method should not be ruled out because some rainfall simulators may be suitable where the necessary facilities and experience in use of simulation is available.

2.4.5 Artificial desurfacing

Artificial removal of layers of soil followed by comparative crop growth and yield trials is the most common research approach for erosion productivity investigation.

The method is most appealing because it is quick, easy to operate, requires no erosion monitoring device and could be operated anywhere. The disadvantage of this method is that many researchers tend to automatically assume that one centimeter of soil removed by artificially removed soil is equal to one centimeter removed by natural rainfalls. At least some 4 studies have confirmed that artificial desurfacing always under estimates yield decline sometimes by a factors of 10. This is because erosion occurring naturally is selective of finer and more fertile particles which in the case of a soil with an appreciable sand fraction would severely under estimate the removal of nutrients.

Other methods include:

- Green house and lab studies and
- On-farm experiment

All the methods listed above have their own advantages in one way or another. Some are time and money saving while others take long but give quality and accurate information on soil erosion - soil productivity relationship. The author chose artificial desurfacing because it was time saving.

CHAPTER III

3.0 MATERIALS AND METHODS

3.1 Source of soils

The study was conducted at the National Plant Breeding Station (N.P.B.S) Njoro using three different soil types. The soil types included Luvisol, Nitosol and Andosol collected from Katumani National Dryland Farming Research Centre, Machakos (K.N.D.F.R.C), College of Agriculture and Veterinary Sciences, Kabete (C.A.V.S) and National Plant Breeding station, Njoro (N.P.B.S) respectively.

The KNDFRC is about 10 km South of Machakos town on the Machakos Konza road and about 80 km to the east of Nairobi. It has Centre Co-ordinates of 37^0 17' East 01^0 35' South with an altitude of about 1600 m above the sea level. The centre lies in the agro-climatic zone IV. It experiences a bimodal rainfall ranging between 500 to 800 mm annually. The rainfall is monsoonal in character with the short rains approaching from the north and the long rains from the south. The onset of the short rains is in the latter half of October or early November, with the peak ranfall in the latter month tapering off in December. The long rains on the other hand arrive in the last half of March or early April with the peak occuring in the month of April.

The C.A.V.S Kabete campus is about 12 km North-West of Nairobi. It is situated at longitude 36^0 44' East and latitude1^0 15' South and at an elevation of 1940 meters above sea level. The college lies in the agroclimatic zone III. The area experiences a bimodal rainfall with a mean annual rainfall of approximately 1006 mm.

The NPBS is about 2km South West of Njoro town and about 18km South-West of Nakuru town. It is situated at longitude 35^0 56 'East and latitude 0^0 21' South with an altitude of 2164 meters above sea level. The centre lies in the agro climatic zone III with an average annual rainfall of about 938 mm.

3.2 Soil characteristics

3.2.1 The Katumani Luvisol

The soils at Katumani National Dryland Farming Research Centre (KNDFRC) is classified as ferral chromic Luvisol based on the F.A.O/U.NE.S.C.O system (Mbuvi and Van de Weg, 1975; Gicheru and Ita, 1987). These soils are moderately deep to deep, well drained, dark reddish brown sandy clay loam, tending to sandy clay at the lower horizons (Kilewe and Ulsaker, 1984). They tend to harden when dry but are very friable when wet and have a petroplinthite (gravel) horizon that occurs about 100 to 120cm deep (Marimi, 1977).

The surface horizon is weakly to well developed with low to high amounts of organic matter, low medium to fertility and moisture storage capacity. The sub horizon is well developed with concentration of clay. These soils have a high degradation hazard even under natural conditions. They normally develop a surface seal which lowers infiltration and enhances run-off and erosion.

3.2.2 The Kabete Nitosol

The soils at the College of Agriculture and Veterinary Sciences C.A.V.S, Kabete campus have been described as humic Nitosol by Gachene (1989). These soils are deep well drained, dark reddish brown clay overlying dark red clay. They have deep argillic B-horizon. Both topsoil and subsoil are well developed with a marked structural stability. The organic matter content and soil fertility range from low to high. The soils are porous throughout and have a moderate to high moisture storage capacity. These soils have a low to moderate degradation hazard under natural conditions. They have a good structure which enhances infiltration and hence moderate runoff and erosion.

3.2.3 The Njoro Andosol

The soils at NPBS Njoro have been described by Siderius and Muchena (1977) as mollic Andosols according to FAO/UNESCO (1974) and as typic eutradept according to the USDA taxonomy (1975). These soils are well drained deep medium to fine texured. The surface horizon is normally well developed with medium to high amount of organic matter, fertility, and moisture storage capacity. The subsurface horizon is weakly developed, with favourable structure, fertility and moisture storage capacity. These soils have a low to moderate degradation hazard. The good infiltration gives them low degradation hazard due to water erosion. They are however prone to wind erosion when exposed and are also very susceptable to degradation by mass movement.

3.3 Soil Sampling

The soil samples used in this study were collected from a cropland site on each of the three soil types described in section 3.2. At each site, sub samples were taken at 0, 10, and 40cm depths, from four representative sampling areas that formed the corners of a 5m by 5m square. The sub samples were then mixed thoroughly in a sack and labelled clearly.

The first sample (0 cm) consisted of the top soil collected from the four representative sampling areas. Soil was then removed from the four sampling areas, to a depth of 10cm. The second sample (10 cm) was then collected as described above. The soil was again removed from the four sampling areas to a depth of 40 cm. The third sample (40 cm) was then collected as before. This sampling procedure was repeated for all the three soil types.

3.4 Preparation of the Soil Samples in Pots

Each soil sample was thoroughly mixed and then put in pots of about 20cm. diameter and 25 cm. depth. The pots were filled with soil upto about 24cm. This corresponded to about 5.5 kgs of soil per pot. The pots were planted with ten seeds each, and after germination they were thinned to five plants from which data on various aspects of plant growth such as height, tillering capacity, grain weight etc was collected.

Each of the soil depths had 9 pots giving a total of 27 pots per soil and 81 pots for the whole study. The pots were clearly labelled identifying the soil type, depth, replicate, and fertilizer rate.

3.5 Experiment design

The experimental design of this study involved simulations of soil erosion by artificial removal of 0, 10, and 40cm of top soil. These are referred to as D_0, D_{10} and D_{40} respectively in the text and form the main treatments. The sub-treaments included no fertilizer, application of the recommended rate of fertilizer and application of double recommended rate of fertilizer. These are referred to as F_0, F_1 and F_2 in the text. The treatments were combined in a completely randomised design, replicated 3 times.

Table 3.1 Experimental design for one of the soil types

Depth of soil desurfaced cm	F ertilizer Rates F_0	F_I	F_2
D_0	D_0 F_0 x 3	D_0 F_1 x 3	D_0 F_2 x 3
D_{10}	D_{10} F_0 x 3	D_{10} F_1 x 3	D_{10} F_2 x 3
D_{40}	D_{40} F_0 x 3	D_{40} F_1 x 3	D_{40} F_2 x 3

The experiment was set up in a cage with a raised platform. The walls of the cage were enclosed with wire mesh to keep off the birds and other intruders. The roof of the cage was made of translucent roofing sheets so as to allow sufficient light for normal plant growth. All the pots were arranged on large metal trays with ballast and placed on top of the platform according to the fertilizer treatment. The pots were watered through capillary action by flooding the metal trays with water to a depth of 5cm. This was expected to minimise the loss of fertilizer through leaching. The frequency of watering depended on plant requirements at different stages of growth and the prevailing weather conditions.

3.6 Fertilizer application

The fertilizer used in this study was Diammonium phosphate, DAP (11:46;0) which is recommended for wheat at the rate 130 kg per hectare. The amount applied in pots was calculated on weight basis which assumes that the recommended rate is applied on 2,000,000 kg of soil within the plough layer. The calculation could also have been done on area basis but the former was adopted because that is what the other researchers in agronomy use in that research center. Thus all the pots with fertilizer treatment at the recommended rate of application were given 0.36g, and all the pots with double the recommended rate of fertilizer were given 0.72g.

Since these amounts were so little, the fertilizer was first made into powder form using a pestle and mortar. The powder was then weighed into blotting papers on a very sensitive electrical balance and then dusted on the respective pots.

3.7 Seeding and disease control

The variety of wheat chosen for this study was Kenya Kwale because it has good resistance to most of the wheat diseases such as stem rust, stripe rust and leaf rust. The seeds used were first tested for germination which was found to be 85%. The seeds were then dusted with copper oxychloride at a rate of 1kg per 100kg of seeds. This is a

Plate - 3 View of the cage

The cage was covered with wire mesh and roofing material is transparent

Plate - 4 Wheat growing in the cage

The pots were arranged on metal trays with ballast - variation in growth is due to different experimental treatment common practice in areas where copper is deficient. Ten seeds were planted in each pot. These were later thinned to five plants from which data was collected on a weekly basis. The plants were sprayed fortnightly with an insecticide Rogor E40 at the rate of 1.5 ml per litre of water in order to protect the plants from barley yellow dwarf virus (BYDV) disease that is common to wheat and barley and is transmitted by aphids.

3.8 Data collection

Data on germination, tillering and height was collected with the latter two being done on a weekly basis. The height of the plants was measured by taking the length of the longest leaf among the main shoot and its tillers from the base of the plant. After heading, the height of the longest head, up to the tip of the ear if longer than the flag leaf, was taken to represent the height.

The length and width of the flag leaf was taken immediately after heading. The crop was monitored on a weekly basis until it was mature. After maturity, harvesting was done and the following data was recorded:-

a) Number of tillers plus shoots with heads per treatment
b) Number of ears per treatment
c) Average length of ears per treatment
d) Total weight of ears per treatment
e) Total weight of grains per treatment
f) Total weight of straw per treatment
g) Total weight of straw plus ears per treatment
h) Total weight of dry roots per treatment

To get the weight of straw, the shoots were cut at the base for each treatment and weighed. In order to get the weight of the root, the pots were then soaked with water. Using a hose pipe and a big sieve and small water containers the roots were washed. First the main root together with the bigger lateral roots were taken from the pots and placed in a sieve and sprayed with a jet of water from the hose pipe. Care was taken to ensure that even the smallest roots which broke were retained in the sieve as much as possible. For the remaining small roots in the pots, the soil in the pots was mixed with water and stirred and then sieved. This was repeated many times until all the soil was washed away and all the roots retained in the sieve. The roots were then dried and weighed.

CHAPTER IV

4.0 RESULTS AND DISCUSSION

This chapter presents the results and discussion of the effect of soil desurfacing for both with and without application of fertilizer, on the growth of wheat. The parameters used to measure the growth of wheat included height, tillering, length of ears, weight of ears number of grains produced, grain weight, straw weight, root weight and above ground biomass.

4.1 The effect of top soil removal and the application of different rates of fertilizers on the development of wheat on three different soil types

4.1.1 Wheat growth rate

Table 4.1(a) shows the effect of removal of various depths of topsoil and the application of different rates of fertilizers on the growth rate of wheat on Luvisol, Nitosol, and Andosol. The removal of 40 cm of topsoil without application of fertilizer caused very slow growth rate on all the three soil types as shown on Table 4.1(a) However, the application of the recommended and double the recommended rates of fertilizers increased the growth rate of wheat by varying degrees on all the three soil types. In general the growth rate of wheat followed a similar trend for all the different depths of topsoil removal and fertilizer application rates on all the soil types.

Plate – 5 A pot with five plants

Plate – 6 Effect of depth of top soil removal on growth of wheat

NOTICE: The effect of different depths of top soil removal on the growth of wheat when no fertilizer was applied.

Plate - 7 Effect of fertilizer on growth of wheat

Notice the effect of different rates of fertilizer application on growth of wheat at 40 cm depth of topsoil removal

TABLE 4.1a: The effect of depth of topsoil removal on the maximum height of wheat on three different soil types

Depth of topsoil removal (cm)	Luvisol		Nitosol		Andosol	
	cm	% of control	cm	% of control	cm	% of control
0	73.5	100	70.3	100	71.6	100
10	67.0	91.1	69.1	98.3	66.4	92.7
40	63.5	86.3	57.9	82.3	57.9	81.0

(Figures on the above table show the interaction of depth and soil type taking the effect of fertilizer to be constant).

Table 4.1a shows the effect of depth of topsoil removal on maximum height of wheat for Luvisol, Nitosol and Andosol. The highest maximum height of wheat after removal of zero and 40 cm of topsoil was achieved on Luvisol followed by Andosol and Nitosol. However, Nitosol produced the highest maximum height of wheat after removal of 10 cm of topsoil followed closely by Luvisol and Andosol.

Removal of 10 cm of topsoil caused a reduction in the maximum height of 6.5, 1.2 and 5.2 cm in Luvisol, Nitosol and Andosol respectively. This was equivalent to a reduction of 0.7, 0.1 and 0.5 cm per cm of topsoil removed on the Luvisol, Nitosol and Andosol respectively. On the other hand removal of 40 cm of topsoil caused a reduction of 10.0, 12.4 and 13.6 cm in Luvisol, Nitosol and Andosol respectively. This corresponded to a reduction of 0.3 cm per cm of topsoil removed on all the three soil types.

Removal of 10 cm of topsoil caused the highest reduction on the maximum height on wheat.

Table 4.1b: The effect of application of different rates of fertilizers on the maximum height of wheat on three different soil types

Rates of fertilizer application	Luvisol cm	Luvisol % of control	Nitosol cm	Nitosol % of control	Andosol cm	Andosol % of control
F_0	55.8	100	51.8	100	58.0	100
F_1	71.3	127.9	70.3	135.7	64.4	111.1
F_2	76.9	137.9	75.3	145.4	73.6	126.9

(Figures on the above table show the interaction of fertilizer rates and soil types taking effect of depth to be constant).

Table 4.1b shows the effect of fertilizer application on the maximum height of wheat for Luvisol, Nitosol and Andosol on all soil depths. When there was no fertilizer applied wheat grown on Andosol attained a greater height than that grown on the other soil types. Application of fertilizer at the recommended rate increased maximum height by 15.6, 18.5 and 6.4 cm for Luvisol, Nitosol and Andosol respectively. This corresponds to a percentage increase of 28, 36 and 11 over the maximum height attained with no fertilizer application.

The addition of fertilizer at double the recommended rate caused a further increase in maximum height for all the soils. The increases were 21.1, 23.5 and 15.6 cm for Luvisol, Nitosol and Andosol respectively. This corresponds to 38%, 45% and 27% above the control. The Nitosol therefore responded better to the two fertilizer application rates followed by Luvisol and Andosol.

Table 4.1c: The effect of different rates of fertilizer application after different depths of topsoil removal on maximum height of wheat

Depth of topsoil removal (CM)	F_0		F_1		F_2	
	cm	%	cm	%	cm	%
0	66.1	100	72.1	109	76.1	115
10	59.7	90.3	68.8	104.1	75.2	113.6
40	39.7	60.0	65.1	98.8	74.5	88.7

SE = 1.39 LSD = (P=0.05) = 3.95 for tables 4.1a, 4.1b and 4.1c

The figures on the above table show interaction of fertilizer and depth while the effect of soil type is held constant. Tble 4.1c shows the effect of depth of topsoil removal and fertilizer application rates on the maximum height of wheat. Removal of 10 cm. and 40 cm. of soil reduced height by 6.4 cm and 26.4 cm. respectively. However on addition of fertilizer at the recommended and double the recommended rates, wheat height increased by 6.0 cm and 9.9 respectively at zero depth of topsoil removal, 9.1 and 15.5 at 10 cm depth of topsoil removal and 25.4 and 34.8 cm. at 40 cm. topsoil removal. Thus there was a significant increase at P=(0.05) level caused by fertilizer application. The F1 and F2 treatments produced maximum wheat height after removal of 10 cm of topsoil that was higher than that attained with no topsoil removal and no fertilizer application. At 40 cm depth of topsoil removal, the double rate of recommended fertilizer could not restore height. The increase in height was only upto 89% of the normal soil.

4.1.2 The tillering capacity of wheat

Table 4.2a shows the effect of depth of topsoil removed on the production of tillers by wheat on Luvisol, Nitosol and Andosol. As the depth of topsoil removed increased, the number of tillers decreased in all the soils. When the three soils are compared the Luvisol had a higher number of tillers followed by Andosol and Nitosol at all levels of topsoil removal. The removal of 10 cm of topsoil has a more serious impact in reducing the number of tillers in Luvisol than in the other two soils. The percentage reduction of tillers for the three soils after the removal of 10 cm of topsoil was 13.9%, 1.8% and 9% for Luvisol, Nitosol and Andosol respectively using the 0 cm removal of topsoil as a control. On the other hand, removal of 40cm of topsoil reduced the number of tillers by 25%, 21% and 28 % for Luvisol, Nitosol and Andosol respectively. The tillering capacity of wheat on each soil was significantly different (P = 0.05) at all levels of topsoil removed.

Table 4.2a; The effect of topsoil removal on tillering capacity of wheat on three different soil types

Depth of topsoil removal (cm)	Luvisol		Nitosol		Andosol	
	No. tillers	%	No. tillers	%	No. tillers	%
0	6.4(40)[c]	100	5.2(24)[c]	100	5.9(35)[c]	100
10	5.5(30)[b]	87.1	5.2(28)[b]	99.2	5.4(28)[b]	91.5
40	4.8(16)[a]	75.0	4.1(21)[a]	79.2	3.7(14)[a]	72.0

NB: The figures in the brackets are actual while those not in brackets were transformed before the analysis of variance was done.

Table 4.2b: The effect of fertilizer application on tillering capacity of wheat on three different soil types

Rates of fertilizer application	Luvisol		Nitosol		Andosol	
	No.tillers	%	No. tillers	%	No.tillers	%
(F0)	4.7 (23)[a]	100	3.1(9)[a]	100	4.3(19)[a]	100
(F1)	5.8 (33)[b]	123.7	5.5(26)[b]	179.7	5.2(27)[b]	121.5
(F2)	6.2 (29)[c]	132.5	6.0(39)[b]	194.7	5.6(31)[b]	130.3

Table 4.2c: The effect of topsoil removal and application of different rates of fertilizer on tillering capacity on all soils

Depth of topsoil removal (cm)	F0		F1		F2	
	No.tillers	%	No. tillers	%	No. tillers	%
0	5.1 (27)[c]	100	6.1 (32)[b]	117.8	6.3 (39)[b]	81.1
10	4.3 (18)[b]	82.8	5:6 (30)[b]	108.6	6.2 (27)[b]	120.8
40	2.6 (6)[a]	50.9	4.8 (23)[a]	94.2	5.2 (21)[a]	100.7

SE = 0.19 LSD (P = 0.05)= 0.53 for tables 4.2a, 4.2b, and 4.2c

* Figures in brackets were transformed for analysis

Table 4.2b and figure 4.2b shows the effect of adding fertilizer at zero rate, the recommended rate and double recommended rate on the tillering capacity of wheat on the Luvisol, Nitosol and Andosol with no topsoil removed. Taking zero rate as a control, addition of fertilizer at the recommended rate increased the number of tillers by 24%, 80% and 22% for Luvisol, Nitosol and Andosol respectively. Doubling the recommended rate of fertilizer increased the tillering capacity of wheat by 33%, 95% and 30 % for the Luvisol, Nitosol and Andosol respectively. Therefore, the Nitosol showed a higher response followed by Luvisol and Andosol at both rates of fertilizer application. Doubling the recommended rate of fertilizer nearly doubled the tillering capacity of wheat. However the Luvisol gave a higher tillering capacity of wheat at all the fertilizer rates than the other two soils. The tillering capacity of wheat on the Luvisol was significantly (P= 0.05) different at all rates of fertilizer application. The application of the recommended and doubled the recommended rates of fertilizer however, did not produce significantly (P=0.05) different tillering capacity on the Nitosol and Andosol.

The effect of topsoil removal and application of different rates of fertilizer on tillering capacity of wheat on all soils is show on table 4.2c. Using the combination of zero cm of topsoil removal and zero rate of fertilizer application as control, the recommended and double the recommended rate of fertilizer increased the number of tillers by 17.8% and 23% respectively. The two levels of fertilizer application increased the number of tillers from 83% to 109% and 121%. However at the depth 40 cm of topsoil removal the two levels of fertilizer application increased the number from 51% to 92% and 100.1% thus the reduction from 100% to 51% made by the removal of 40 cm of topsoil cannot be restored by the application of fertilizer at the recommended rate but, could be restored by application of fertilizer at double the recommended rate.

4.2 The effect of topsoil removal and the application of different rates of fertilizers on wheat ear production

4.2.1 Wheat ear length

The depth of topsoil removal in the absence of fertilizer caused a significant (P= 0.05) difference in the length of wheat ears as shown by table 4.3a. The length of wheat ears decreased with the increase in depth of topsoil removed in all the soil types. The reduction caused by the removal of 10 cm of the topsoil was about 5% for all the soil types. Removal of 40 cm of topsoil, however, caused a 13%, 25% and 20% reduction in ear length in Luvisol, Nitosol and Andosol respectively.

Comparison of the three soil types showed that the Luvisol had longer ears at all depths of topsoil removed followed by Nitosol and Andosol. However Nitosol showed the highest percentage decline in ear length as a result of removal of 40 cm of topsoil. This was followed by Andosol and Luvisol.

Table 4.3b shows the effect of fertilizer application on length of ears. Application of fertilizer at the recommended rate gave significant (P= 0.05) increase in the length of ears as compared to zero rate of fertilizer application on all the soils. But application of double the recommended rate of fertilizer caused significant (P= 0.05) difference on Andosol only. When the three soils are compared there was not much difference in the length of ears.

Table 4.3c shows the effect of adding fertilizer after different depths of topsoil are removed. Without any addition of fertilizer, removal of 10 and 40 cm of topsoil caused a reduction of 14 and 46% on length of ears. Addition of fertilizer at the recommended and double recommended rates, however increased the length of ears at 10 cm depth of topsoil removal to only 99% and 105%. This was a reasonable increase since the length of ears cannot increase indefinitely. The impact of fertilizer at the recommended and at double the recommended rates was greatest at the depth of 40 cm of topsoil removal where the percentage increase was from 54% to 90% and 54 to 104% respectively.

Table 4.3a: The effect of depth of topsoil removal on length of wheat ears on three different soil type

Depth of topsoil removal (cm)	Luvisol Length cm	%	Nitosol Length cm	%	Andosol Length cm	%
0	8.78 c	100	8.82 c	100	8.35 c	100
10	8.29 b	94.4	8.38 b	95.0	7.90 b	94.6
40	7.60 a	86.6	6.64 a	75.3	6.68 a	80.0

Table 4.3b: The effect of the application of different rates of fertilizers on the length of wheat ears on 3 different soil types

Rates of fertilizer application	Luvisol Length cm	%	Nitosol Length cm	%	Andosol Length cm	%
F0	6.99 a	100	6.41 a	100	6.90 a	100
F1	8.67 b	124.0	8.55 b	133.4	7.41 b	107.4
F2	9.02 b	129.0	8.88 b	138.5	8.61 c	124.8

Table 4.3c: The effect of different rates of fertilizer application after different depths of topsoil removal on the length of wheat ears

Depth of Topsoil Removal	F0 Length cm	F0 %	F1 Length cm	F1 %	F2 Length cm	F2 %
0	8.46 c	100	8.66 c	102.4	8.83 a	104.4
10	7.29 b	86.2	8.37 b	98.9	8.92 a	105.4
40	4.55 a	53.8	7.60 a	89.8	8.76 a	103.5

4.2.2 Wheat ear weight

The effect of depth of topsoil removal as can be seen on table 4.4a shows that as the depth increased the weight of ears decreased. The removal of 10 cm of soil caused a reduction of 38%, 25% and 36% on Luvisol, Nitosol and Andosol respectively. The removal of 40 cm of topsoil, however, caused a reduction of 46%, 54% and 58% respectively. This implies that the removal of the top 10 cm of soil caused a more serious effect on weight of ears than removal of the next 30 cm of soil from 10-40 cm. When the three soils were compared the Luvisol had higher ear weights followed by Nitosol and Andosol at all depths of topsoil removal.

Table 4.4b shows the effect of fertilizer application on the weight of ears for the three soils. Again the Luvisol had higher weight followed by Nitosol and Andosol at all rates of fertilizer application. Considering zero rate of fertilizer application as the control, the application of the recommended rate of fertilizer caused an increase of 46% to 43% to 21% for Luvisol, Nitosol and Andosol respectively. On the other hand the application of the double recommended rate caused an increase of 86.5%, 90.5% and 54.4% respectively. Thus the Nitosol had better response to fertilizer application for both rates followed by Luvisol and Andosol.

Table 4.4c shows the effect of topsoil removal and the application of different rates of fertilizer on wheat ear weight. Taking D0F0 as the control, removal of 10 and 40 cm of soil reduced the weight of ears by 44% and 81% respectively. This means that with severe erosion, the harvest obtained is only 19% of what could have been obtained if there was no erosion. However when fertilizer is applied at the recommended rate the percentage increase at both 10 cm and 40 cm depth of topsoil removal was only upto 73% and 58%, of the control. On the other hand application of fertilizer at double the recommended rate increased ear weight upto 99% and 85% of the control. Thus even the addition of the double the recommended rate of fertilizer could not quite restore productivity after removal of 40 cm of topsoil to that attained with no topsoil removed.

Table 4.4a: The effect of depth of topsoil removal on the weight of wheat ears on 3 different soil types

Depth of topsoil removal (cm)	Luvisol		Nitosol		Andosol	
	wt (g)	%	wt (g)	%	wt (g)	%
0	18.38 c	100	16.94 c	100	14.0 c	100
10	11.52 b	62.7	12.77 b	75.4	9.01 b	64.4
40	9.89 a	53.8	7.85 a	46.3	5.90 a	42.1

Table 4.4b: The effect different rates of fertilizers application on the weight of wheat ears on 3 different soil types

Rates of fertilizer application	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
F0	9.21 a	100	8.67 a	100	7.67 a	100
F1	13.40 b	145.5	12.37 b	143	9.40 b	122.5
F2	17.18 c	186.5	16.52 c	190.5	11.84 c	154.4

TABLE 4.4c: The effect of different rates of fertilizer application after different depths of topsoil removal on the weight of wheat ears

Depth of topsoil removal (cm)	F0 wt (g)	%	F1 wt (g)	%	F2 wt (g)	%
0	14.59 c	100	16.04 c	109.9	18.69 c	128.1
10	8.17 b	56.00	10.69 b	73.3	14.45 b	99.0
40	2.80 a	19.2	8.44 a	58.0	12.41 a	85.1

S.E.= 0.4 LSD (p = 0.05) = 1.15

4.3 The effect of topsoil removal and the application of different rates of fertilizers on wheat yields

4.3.1 Number of wheat grains

Table 4.5a shows the effect of different depths of topsoil removal of on the number of wheat grains. At zero and 40 cm depth of topsoil removal the Luvisol had the highest number of wheat grains followed by Nitosol and Andosol. But at 10 cm depth of topsoil removal the Nitosol had the highest number followed by Luvisol and lastly Andosol. Thus when the 3 soils are compared the Luvisol seemed to be more productive followed by Nitosol and then Andosol. However, looking at the impact of topsoil removal, the percentage reduction caused by removal of 10 cm of topsoil was greater in Luvisol followed by Andosol and Nitosol. The actual percentage reduction in wheat grains was 35%, 31% and 17% for Luvisol, Andosol and Nitosol respectively. The percentage reduction after removal of 40 cm of topsoil was 42%, 45% and 52% for Luvisol, Nitosol and Andosol respectively. This shows that the removal of 10 cm of topsoil caused a sharper decline in the number of grains than removal of the next 10 - 40 cm of topsoil. The top 10 cm of the three soils is very crucial in terms of their productivity. Although the Luvisol had the highest number of grains it was affected more by removal of topsoil than the other two soil types. This could be attributed to the generally low fertility and organic matter content in the lower horizons of the Luvisol.

The effect of adding fertilizer at zero, recommended and double the recommended, rate on the three soil types is shown on table 4.5b. Addition of fertilizer at the recommended rate had significant (P=0.05) effect on Luvisol and Nitosol where the percentage increases were 51.4%

and 57.3% respectively. However, addition of fertilizer at the same rate did not cause a significant (P=0.05) increase on the number of wheat, grains on the Andosol. The addition of fertilizer at double the recommended rate caused a significant (P = 0.05) increase on all the three soil types. The actual percentage increases were 99%, 110% and 45% for Luvisol, Nitosol and Andosol respectively. The greatest impact of addition of double the recommended rate was on Nitosol where the numbers were doubled followed by Luvisol where the numbers were also almost doubled. The least impact was observed on Andosol where there was an increase of only 45%.

Table 4.5c shows the interaction of fertilizer and depth of topsoil removal on the average number of wheat grains. The addition of fertilizer at the recommended and double the recommended rate increased the average number of wheat grains by 8% and 32% at the zero depth of topsoil removal respectively. On the other hand, removal of 10 cm and 40 cm of topsoil caused a decline of 41% and 79% respectively. However addition of fertilizer at the recommended and double the recommended rates increased the average number of wheat grains to 81% and 106% respectively. At 40 cm depth of topsoil removed the percentage increases were 66% and 97% respectively. Thus even double the recommended rate of fertilizer could not raise the average number of wheat grains to that attained from the zero depth of topsoil removed with zero fertilizer rate. Furthermore the average maximum number obtained by double rate of fertilizer at 40 cm depth of topsoil removed was only 74% of what would have been obtained if the same fertilizer was added to a soil with no topsoil removed. As shown in Table 4.5c, the average number of wheat grains obtained with zero depth of topsoil removal and zero fertilizer rate. D0F0, D0F1, D10F2 and D40 F2 are very close. This implies that a severely eroded soil requires heavy fertilizer application (which is costly) only to bring yields to what could have been obtained without fertilizer application on uneroded soil. Cost would have been minimal had the soil erosion been controlled. Therefore if the loss of topsoil through soil erosion is prevented then productivity of soil could be maintained at a high level and only minimum fertilizer inputs would be required to increase the yields.

Table 4.5a: The effect of depth of topsoil removal on the average number of wheat grains on three different soil types

Depth of topsoil removal (cm)	Luvisol No.	Luvisol %	Nitosol No.	Nitosol %	Andosol No.	Andosol %
0	309.1 [b]	100	280.6 [c]	100	228.6 [c]	100
10	200.6 [a]	64.9	233.9 [b]	83.4	157.1 [b]	68.7
40	180.2 [a]	58.3	153.8 [a]	54.8	109.4 [a]	47.9

Table 4.5b: The effect of application of different rates of fertilizers on the average number of wheat grains on three different soil types

Rates of fertilizer application	Luvisol No	%	Nitosol No.	%	Andosol No.	%
F0	153.3 [a]	100	142.9 [a]	100	138.4 [a]	100
F1	232.1 [b]	151.4	224.8 [b]	157.3	156.4 [a]	113.0
F2	304.4 [c]	198.6	300.6 [c]	1210.4	200.2 [b]	144.7

Table 4.5c: The effect of application of fertilizers after different depths of topsoil removal on the average number of wheat grains

Depth of topsoil removal (cm)	F0 No.	%	F1 No.	%	F2 No.	%
0	240.8 [c]	100	260.3 [c]	108.1	317.1 [b]	131.7
10	143.3 [b]	59.5	193.9 [b]	80.5	254.3 [a]	105.6
40	56.6 [a]	21.0	159.1 [a]	66.4	233.8 [a]	97.1

S.E. = 8.34 LSD (P = 0.05) = 23.7

4.3.2 Weight of wheat grain

Table 4.6a shows the effect of topsoil removal on the weight of grains for the three soils. At zero depth of topsoil removal the value of wheat grain weight for Luvisol was higher than that of Nitosol which was followed by Andosol. After 10 cm.of topsoil removal the grain weight for Luvisol and Andosol was reduced to 62% and 63% respectively while that of Nitosol was reduced to 74%. Thus the effect of removal of 10 cm of topsoil was more in Luvisol and Andosol than it was in Nitosol.

The effect of removal of 40 cm of topsoil reduced the weight of wheat grains to 53%, 46% and 41% for Luvisol, Nitosol and Andosol respectively. There was significant (P=0.05) reduction in weight of grains at both 10 cm and 40 cm depths of topsoil removal.

Table 4.6b shows the effect of fertilizer application on grain weight for the three soils. Again the Luvisol had a higher grain weight at all levels of topsoil removal. Nitosol had also values higher than those of Andosol. In all the soils fertilizer applied at the recommended rate increased weight of grain by 48%, 43% and 26% for Luvisol, Nitosol and Andosol respectively. Thus at this rate the response of Luvisol and Nitosol was high and almost the same. On the other hand, the Andosol showed a lower response to fertilizer application.

At the double rate of fertiizer application the weight of wheat grains increased by 88%, 84% and 55% for Luvisol, Nitosol and Andosol respectively. Again the response of Andosol to fertilizer application was much lower than the other two soil types . The differences in weight brought about by different rates of fertilizer was significant (P=0.05) in all soils.

Table 4.6c shows the effect of different rates of fertilizer application and depth of topsoil removal on the weight of grain. Taking zero depth of topsoil removal and zero rate of fertilizer application as the control 10 cm and 40 cm depth of topsoil removal caused a reduction of grain weight from 100% to 55% and 18% respectively. This implies that if there was erosion which caused 10 cm and 40 cm depth of soil to be washed away then the effect of that on yield would be a reduction of 45% and 82% respectively. However, since artificial topsoil removal is known to under estimate the effect of erosion by a factor of about 10, it can be assumed that the actual effect in this case would be a reduction from 100% to 6% and 2% respectively at 10 cm and 40 cm of real erosion. Thus if erosion is allowed to continue and become severe, the crop yield would be drastically reduced to levels that are not even worth the efforts involved in farming.

On application of fertilizer at the recommended rate, the grain weight increased from 100% to 111%, 55% to 67% and 18% to 57% for the zero, 10 and 40 cm of topsoil removal respectively.

Thus at 10 cm depth of topsoil removal normal rate of fertilizer application could restore grain yield of wheat only from 55% to 67% and at 40 cm depth of topsoil removal the fertilizer application could restore yield from 18% to 57% . Thus the recommended rate of fertilizer is not able to restore yields on eroded soils. When fertilizer was applied at double the recommended rate the increase in grain weight was from 55% to 96% and 18% to 84% for 10 and 40 cm depth respectively. Thus even when twice as much fertilizer (which would be very expensive) was applied the grain weight could not be restored even to the yield level of the control. This means that if erosion was controlled inputs would be as good as or even better than when double rate of fertilizer is applied on severely eroded soils.

Table 4.6a: The effect topsoil removal on weight of grain for three soil types

Depth of topsoil removal (cm)	Luvisol wt (g)	Luvisol %	Nitosol wt (g)	Nitosol %	Andosol wt (g)	Andosol %
0	12.92 c	100	11.80 c	100	9.82 c	100
10	8.05 b	62.3	8.75 b	74.2	6.27 b	62.8
40	6.87 a	53.2	5.42 a	45.9	4.03 a	41.0

Table 4.6b: The effect of application of fertilizer on grain weight for three soil types

Rates of fertilizer application	Luvisol wt (g)	Luvisol %	Nitosol wt (g)	Nitosol %	Andosol wt (g)	Andosol %
F0	6.39 a	100	6.08 a	100	5.28 a	100
F1	9.48 b	148.4	8.69 b	142.9	6.64 b	125.8
F2	11.98 c	187.5	11.19 c	184.0	8.20 c	155.3

Table 4.6c: The effect of application of fertilizer on grain weight at different levels of topsoil removal

Depth of topsoil removal	F0 wt (g)	F0 %	F1 wt (g)	F1 %	F2 wt (g)	F2 %
0	10.23 c	100	11.35 c	110.9	12.96 c	126.7
10	5.65 b	55.2	7.60 b	67.0	9.82 b	96.0
40	1.87 a	18.3	5.85 a	57.2	8.59 a	84.0

S.E = 0.58 LSD (P = 0.05) = 1.01

4.4 The effect of topsoil removal and the application of different rate of fertiizers on residue production

4.4.1 Weight of straw

The effect removal of 10 cm of topsoil caused a reduction of 35%, 18% and 34% of straw weight on Luvisol, Nitosol and Andosol respectively . Thus the impact was more on Luvisol and Andosol than on Nitosol. On the other hand removal of 40 cm of topsoil caused a reduction of 37% and 43% and 56% on Luvisol, Nitosol and Andosol respectively. Hence the impact of 40 cm depth of topsoil removal was greatest on Andosol followed by Nitosol and lastly Luvisol. Generally the impact of topsoil removal had less effect on Luvisol than Nitosol and Andosol as indicated on table 4.7a.

Table 4.7b shows the effect of fertilizer application on the Luvisol, Nitosol and Andosol. Taking zero rate of fertilizer as the control, addition of fertilizer at the recommended rate caused an increase of 59%, 141% and 41% on Luvisol, Nitosol and Andosol respectively on straw weight. Before fertilizer was added, Nitosol had the lowest value but after addition of fertilizer the value more than doubled. On application of double the recommended rate the weight of straw doubled on Luvisol, tripled on Nitosol and increased by 75% on Andosol. Thus the response of Andosol to fertilizer application was rather poor compared to the other two soils.

The effect of different rates of fertilizer on different depths of topsoil removal is shown on table 4.7c. As the depth of topsoil removal increased, the weight of straw decreased at all rates of fertilizer application. Addition of fertilizer at both recommended and double the recommended rate caused the straw weight to increase to 95 and 124% of the control at 10 cm depth of topsoil removal. But at 40 cm depth of topsoil removal the increase was only upto 81% and 113% of the control. In this case the recommended rate could not compensate for 40 cm depth removal or fully restore the loss of productivity. However, double the recommended rate more than fully compensated for the effect of 40 cm depth of topsoil removal.

Table 4.7a: The effect different depths of topsoil removal on straw weight on Luvisol, Nitosol and Andosol

Depth of topsoil removal (cm)	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
0	18.09 b	100	14.57 c	100	14.47 c	100
10	11.78 a	65.1	11.90 b	81.7	9.57 b	66.1
40	11.33 a	62.6	8.34 a	57.2	6.26 a	43.6

Table 4.7b: The effect of different rates of fertilizer application on wheat straw weight for Luvisol, Nitosol and Andosol

Rates of fertilizer application	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
F0	8.85 a	100	5.36 a	100	7.28 a	100
F1	14.11 b	159.4	12.89 b	240.5	10.28 b	141.2
F2	18.25 c	205	16.56 c	309	12.75 c	175.3

Table 4.7c: The effect of different rates of fertilizer application on wheat straw weight at different depths of topsoil removal

Depth of topsoil removal (cm)	F0 wt (g)	F0 %	F1 wt (g)	F1 %	F2 wt (g)	F2 %
0	12.04 c	100	16.04 c	133.2	19.05 c	158.2
10	6.86 b	57	11.49 b	95.4	14.90 b	122.8
40	2.57 a	21.3	9.75 a	81.0	13.6 a	113.0

S.E.= 0.24 L.S.D.(P = 0.05) = 0.67

4.4.2 Weight of roots

As in the other cases discussed above the weight of roots decreased with increase in the depth of topsoil removal but increased with the increase in levels of fertilizer application in all the soil. However the responses to the depth of topsoil removal and fertilizer rates was different in different soils as can be seen from table 4.8a, b and c.

Table 4.8a shows the effect of depth of top soil removal on the weight of roots for Luvisol, Nitosol and Andosol. When the soils were compared at the same depths of topsoil removal, the Luvisol had a higher value for root weight than Nitosol and Andosol. As the depth of topsoil removal increased the weight of roots decreased for all the soils. However the impact of 10 cm of topsoil removed was more on Luvisol than on Nitosol and Andosol.

The effect of different rates of fertilizer application on the weight of roots for the 3 soil types is shown in table 4.8b. At both the recommended and double recommended rate there was substantial increase in the weight of roots. The greatest response was in Luvisol followed by Nitosol and lastly Andosol.

Table 4.8c shows the effect of different rates of fertilizer application on weight of roots at different depths of topsoil removal.
Once again considering zero depth of topsoil removal and zero rate of fertilizer application as the control, the removal of 10 cm and 40 cm of topsoil reduced the weight of roots from 100% to 57% and 19% respectively. Addition of fertilizer at recommended rate and double the recommended rate increased weight of roots 95% and 119% respectively at 10 cm depth of topsoil removal. At the depth of 40 cm the same rates of fertilizer caused an increase of 81% and 105%. Thus the recommended rate of fertilizer application could not restore weight of roots to that of the control. But application of the double recommended rate restored weight of roots by increasing it to 119% and 105% at 10 cm and 40 cm of topsoil removal respectively.

TABLE 4.8a: The effect of depth of topsoil removal on the weight of roots for Luvisol, Nitosol and Andosol

Depth of topsoil removal (cm)	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
0	8.28 b	100	5.49 c	100	5.52 c	100
10	5.24 a	63.3	4.70 b	85.6	4.06 b	73.6
40	4.73 a	57.1	3.31 a	60.3	2.50 a	45.3

TABLE 4.8b: The effect of different rates of fertilizer application on the weight of roots for Luvisol, Nitosol and Andosol

Rates of fertilizer application	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
F0	3.86 a	100	2.12 a	100	3.11 a	100
F1	5.83 b	151	5.56 b	262.3	4.07 b	130.9
F2	8.56 c	221.8	5.83 b	274.4	4.89 b	157.2

TABLE 4.8c: The effect of different rates of fertilizer application on the weight of roots at different depths of topsoil removal

Depth of topsoil removal	F0 wt (g)	% (g)	F1 wt (g)	%	F2 wt	-%
0	5.16 c	100	6.41 b	124.2	7.72 b	149.6
10	2.95 b	57.2	4.89 a	94.8	6.15 a	119.2
40	0.97 a	18.8	4.16 a	80.6	5.40 a	104.7

S.E. = 0.39 LSD (P = 0.05) = 0.90

4.5 The effect of topsoil removal and application of fertilizer on the biomas above soil surface

Table 4.9a shows the effect of depth of topsoil removal on the weight of the total biomass above the soil surface on the three soils. The weight of the biomass above the soil surface was obtained from the addition of ear and straw weight.

As the depth of topsoil removal increased, the weight of total biomass decreased on all the three soils. At the same levels of topsoil removal the weight of biomass above surface was higher for the Luvisol except a the depth of 10 cm where it was almost the same with Nitosol. At all levels Andosol had the least weight. For example at the depth of 40 cm the Andosol was only 57% of Luvisol. This implies that the Andosol would be greatly affected by severe erosion.

Table 4.9b shows the effect of different rates of fertilizer application on the weight of the biomass above the soil surface.

When the three soils were compared the Luvisol had the highest yields followed by Nitosol and Andosol. The response to fertilizer was best in Nitosol where the weight increased by 75% and 129% at the application of the recommended and double the recommended rate respectively. The other soils showed similar responses.

TABLE 4.9a: The effect of depth of topsoil removal on the weight of biomass above the soil surface for Luvisol, Nitosol and Andosol

Depth of topsoil removal (cm)	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
0	36.5 b	100	31.5 c	100	28.5 c	100
10	23.3 a	63.9	24.7 b	78.3	18.6 b	65.3
40	21.2 a	58.2	16.6 a	52.7	12.2 a	42.7

TABLE 4.9b: The effect of different rates of fertilizer application on the weight of biomass above the soil surface for Luvisol, Nitosol and Andosol

Rates of fertilizer application	Luvisol wt (g)	%	Nitosol wt (g)	%	Andosol wt (g)	%
F0	18.16a	100	14.4 a	100	14.95 a	100
F1	27.5b	152.3	25.3 b	175.1	24.2 b	161.5
F2	35.4 c	196.2	33.1 c	229.3	31.0 c	207.6

TABLE 4.9 c: The effect of different rates of fertilizer application on different depths of topsoil removal on above surface biomass of wheat

Depth of topsoil removal	F0 wt (g)	F0 %	F1 wt (g)	F1 %	F2 wt (g)	F2 %
0	26.6 a	100	32.1 a	120.4	37.7 a	141.7
10	15.0 b	56.4	22.2 b	83.2	29.4 b	110.2
40	5.8 c	21.7	18.2 c	68.3	26.0 c	97.7

SE = 0.85 LSD = 2.41 (P = 0.05) for tables 4.9a, 4.9b and 4.9c

From table 4.9c topsoil removal to 10 cm depth and 40 cm depth reduced weight to 56% and 22% respectively. Considering zero depth and zero fertilizer level to be the control, addition of fertilizer at the recommended rate increased weight to 83% and 68% at 10 cm and 40 cm depth of topsoil removal respectively. On the other hand application of fertilizer at double rate increased weight of biomass above the surface to 100% for 10 cm depth and 98% for 40 cm depth of topsoil removal. Thus even after doubling the rate of fertilizer the yields of soil desurfaced at 40 cm cannot be restored to normal. Moreover the application of the same rate would have caused an increase of 42% on soil that is not desurfaced.

CHAPTER V

5.0 SUMMARY AND CONCLUSIONS

The following is the summary and conclusion of the the results obtained from the study.

5.1 Summary

5.1.1 The effect of topsoil removal on loss of production in various aspects of wheat plants

The effect of 10 cm. removal of topsoil on the three soil types had a depressing effect on all the parameters of wheat crop which were recorded. The percentage reductions were greatest on weight of ears, weight of grains, number of grains and weight of straw. The range was from 14.4% to 37.7% on all the soils as reduction in yield of grain is very high because it means for instance where the average yield of wheat is 1,800 kg. per ha., the reduction per hectare would range from 260 kg. to 680 kg. Bearing in mind that artificial removal of soil underrates actual erosion by 4-10 times, the reductions would even be higher if real erosion had occurred to a depth of 10 cm.

Compared with the removal of 10 cm.of soil removal of 40 cm. had a more depressing effect on all aspects of wheat growth , but the trend was the same. The fall in production ranged from 30% to 59% in all the soils. Thus in some cases the yields reduced to almost 40%. Although the effect of 40 cm topsoil removal is apparently high, it is interesting to note that it is not a multiple of the effect of 10 cm. topsoil removal The loss in production per cm of soil removed is much greater when 10 cm. of soil is removed than when 40 cm is removed. This is in conformity with what has been accepted over the years that the topsoil is the most fertile and most important part of the soil profile.

When each soil is considered on its own, the Katumani Luvisol was more affected because the reduction ranged from 35% to 38% in all the four parameters named above. It was followed by Andosol whose range was 26% to 37% and finally by Nitosol whose range was from 14% to 25%.

The different degrees of effect on different soils shows that the productivity of different soils is affected differently by erosion. This must be due to inherent soil characteristics in each soil. Looking at the other parameters of wheat crops, that is maximum height, tillering capacity and length of ears, the effect of removing 10 cm. of topsoil in all the three soil types was not as much as the effect on those parameters mentioned earlier. The range was from 1% to 9%. Again the effect was more on Luvisol followed by Andosol and lastly Nitosol.

The application of the recommended rate of fertilizer increased production in all barameters of the wheat crop and in all soils. The highest impact was in weight of roots and weight of straw, where the increases were 162% and 141% respectively. These two parameters are basically vegetative, but when it comes to grain weight which is the most important in food production, the increase ranged from 25% to 48%. Therefore although addition of fertilizer can increase yield, it may not do so to the desired extent, as in this case where an increase in straw weight was 141% of the control while the increase in grain weight was only 43%.

When each soil is considered on it own, there was better response on Nitosol whose range was 33% to 162% on all parameters followed by Luvisol whose range was 24% to 59% and lastly Andosol whose range was 7% to 41%.
Here again it is clearly seen that different soils respond differently to fertilizer application. The response is probably not just because of fertilizer but it could be as a result of other factors. For instance the Andosol in Njoro region are known to be deficient of copper and possibly even after dressing the seeds with copper it was not sufficient. Application of double the recommended rate of fertilizer raised production in all parameters of the wheat crop. In all cases the increases were higher than those attained by application of the recommended rate of fertilizer. The trend closely followed what has been discussed above for application of the recommended rate.

The effect of removing 10 cm. of topsoil without addition of any fertilizer had a marked reduction on production in various aspects of wheat. The impact ranged from 10% to 45%. The most affected aspects were grain weight, weight of ears straw weight and weight of roots. The least affected parameters were maximum height, tillering capacity and the length of ears.The impact of removing 40 cm. of topsoil without addition of fertilizer was more serious than removal of 10 cm.of topsoil. In the former, loss of yield ranged from 40% to 82%. These results indicate that if erosion was to continue at high rates and farmers cannot afford to apply fertilizers, the yields would continue to decline so drastically to such levels that it would no longer be worth while to farm.

Assuming 40 cm. of topsoil removal to be a case of severe erosion as sometimes happens in gully erosion, wastelands or bad lands, then farming cannot even be thought of because no economic yields could be obtained on such lands. Furthermore the effect of such erosion would depend on the soil profile in question. Where the soil profiles are deep one can still farm with extra inputs and harvest something substantial, but in case of shallow soils crop yields can decrease to zero.

5.1.2 The effect of chemical fertilizer application in restoring production in various aspects of wheat plants

The effect of adding the normal rate of recommended fertilizer increased yields on all parameters of wheat taking zero rate of fertilizer and zero depth topsoil removal (Do Fo) as the control. Addition of fertilizer at the recommended rate increased production by a range of 102% to 133% while addition of double the recommended increased production by a range of 104% to 158% in all parameters respectively and in all soils.

As mentioned earlier removal of 10 cm. of topsoil decreased production in all aspects. However when fertilizer was added at the normal rate of recommendation after 10 cm. of topsoil had been removed, the production increased in the range of 67% to 109% of the control. This implies that addition of fertilizer at the recommended rate was not sufficient to raise production where 10 cm. of topsoil had been removed to that where there was no soil removed and no fertilizer applied. When all parameters are looked into separately only tillering capacity and maximum height managed to attain the value of the control. All the others were below and grain weight which is important in crop production, was the least having attained only 67% of the control.

Addition of fertilizer at double the recommended rate raised production at 10 cm depth of topsoil removed and the range was 96% to 123% in all parameters. In this case yield in almost all parameters attained the level of the control and even went higher except grain weight and weight of ears which increased upto 96% and 99% respectively.

At 40 cm. depth of topsoil removal addition of fertilizer at the recommended rate increased wheat growth in all parameters and the range was 57% to 99%

Application of double the recommended fertilizer at 40 cm depth of topsoil removal had an effect of increasing production in the range of 84% to 113% in all aspects. However parameters such as grain weight, number of grains and weight of ears attained only 84% to 97% and 85% to respectively, as compared with the control.

Thus addition of fertilizer on severely eroded soil at the normal rates of recommendation cannot give yield levels that can be obtained if such soils were not eroded. Such soils require heavier doses such as double rate or even more, but even then one is not sure of attaining high yields in the desired parameters. For instance it is a well known fact that too much fertilizer in form of nitrogen increases vegetative growth at the expense of grain weight. Secondly chemical fertilizer has a cost element, therefore the more it is applied the higher the cost of production. Not every farmer can afford to buy it in the first place and the economic returns may not warrant the use of high rates of fertilizer on severely eroded soil. It is clearly essential to adopt farming practises that will minimise the hazard of erosion.

5.1.3 Impact on the present farming methods in Kenya

The loss of soil productivity due to erosion has serious implications in a developing country like Kenya. First of all, the arable land is only about 18% of the country. The population is increasing at a fast rate, and the demand for food both for local consumption and export is high. This can only be attained through intensive farming on productive soils whose productivity is well maintained.

Most of the farm holdings are small in size and are farmed by peasant farmers. In most cases, these farmers cannot afford to buy chemical fertilizers to be applied on food crops. The few who can afford apply it on cash crops which earn them more money. The question of adding chemical fertilizers to restore soil productivity on eroded soils is not a practical solution in developing countries. As shown from the experiment, losses in production due to artificial topsoil removal are high, yet this underrates real erosion by 4-10 times as mentioned earlier. This means real erosion is causing great losses in the productive capacity of our soils on the cultivated and grazing lands where soil conservation is not strictly observed.

At the moment there are no practical alternative ways of maintaining soil fertility under the present farming system. Therefore soil conservation should be done by all means possible, so that soil productivity can be maintained not only for present but also for future sustained production.

5.2 Conclusions

- Soil erosion as simulated by artificial removal of a 0, 10 and 40cm of topsoil lowered the productivity of the soils that were looked into.

- The severity on the loss in productivity depended on the depth of topsoil removed. This implies that severe soil erosion causes severe loss in soil productivity.

- The loss in soil productivity was indicated by low grain yield and low production in other aspects of wheat plants that were looked into, such as straw weight, above the surface biomass etc.

- Removal of the first 10cm of topsoil had a more serious impact in reducing production per cm of soil removed than removal of 40cm of soil.

This confirms that topsoil is the most fertilie and most important part of a soil profile which is necessary for healthy growth of plants.

- Uneroded soils often give higher figures for production than eroded soil . This was confirmed by the fact that treatments that had zero depth of topsoil removal had higher figures for production than those which has 10 and 40cm depth of topsoil removal when all were given the same treatment. Thus if soil erosion can be controlled more food can be produced while less is spent on chemical fertilizer input.

- The effect of soil erosion on the productivity of different soil types was different. This was indicated by difference in production in different soils after they were given same treatment. The Katumani Luvisol seemed to be more affected by erosion than Andosol and Nitosol.

- Addition of chemical fertiliser increased production on both eroded and non-eroded soils, however increases on the non-eroded soils are much higher than on eroded soils.

- At 10cm. depth of topsoil removal, addition of chemical fertilizer at the recommended rate increased production to almost the same level as the control.

- When double the recommended rate of fertilizer was applied at 10cm depth of topsoil removal, production was restored to over and above that of the control except for grain weight and weight of ears. This implies that chemical fertilizers can almost restore productivity on soils that are not severely eroded. However grain weight which is the most important aspect of production had the least response to fertilizer application.

- At 40cm. depth of topsoil removal which represented severely eroded soils, addition of fertilizer at the recommended rate did not raise production to that of the control in any of the aspects. But when fertilizer was added at double the recommended rate, production in some aspects such as straw weight, increased to that of the control. Again grain weight had the least response. Thus addition of chemical fertilizers which is expensive to ordinary farmers does not always restore productivity of severely eroded soils. Soil erosion should be controlled by all means available in order to sustain productivity.

CHAPTER VI

6.0 RECOMMENDATIONS

- The effect of soil erosion on soil productivity should be assessed for major soils in Kenya through setting up experiments in various parts of the country.

- Soil erosion rates in tonnes per year for different soils, slopes and land use systems should be assessed because this can indicate how fast soil is getting lost and hence loss in productivity.

- At the moment the available data on soil loss is mainly from temperate countries and on slopes of about 9% or slightly higher. In Kenya cultivation is done upto 55% and sometimes beyond. The erosion in these areas must be many times greater than those under mechanised farming in temperate conditions. Therefore assessment of soil loss in these areas should be done as a matter of urgency.

- More research work should be conducted to look into the effects of soil erosion on productivity on newly opened agricultural land, to find out the actual loss in yield due to erosion as opposed to depletion of nutrients by removal of the crop.

- An experiment like the one which was done in this study should be repeated by an interested individual or institution with experimental plots set on the ground on different soil types in order to find out the impact of real erosion as opposed to artificial desurfacing. Although this would take a long time, the results would be worthwhile.

- While waiting for the research findings, which might take many years, soils particularly in cultivated and grazing lands should be managed in the best way possible using the already available knowledge. Agricultural land use as stipulated in the Agricultural Act should be strictly observed for the sake of sustaining present and future food production.

- The extension staff should create more awareness to the farmers about other effects of soil erosion on loss of soil productivity apart from annual soil loss and loss of plant nutrients. Increased awareness on hazards of soil erosion such as destruction of soil structures, increased bulk density, low infiltration rate and reduction of water holding capacity can motivate farmers to take soil conservation measures more seriously.

REFERENCES

Adams W.E. (1949)

Loss of topsoil reduces crop yields. J. Soil Water Conservation 4(3): 130

Akehurst B.C., and Screedharan A. (1965)

Time of planting - a brief review of experimental work in Tanganyika 1952 - 62 E. Afr. Agric. For. J. 30 189-201

Batchelder, A.B., and Jones J.N. (1972)

Soil Management factors and growth of Zea Mays on topsoil and exposed subsoil. Agron. J.64(5): 648-652

Becher, H.H. (1983)

Crop yield reduction due to reduced water caused by water erosion. Paper to Malama 83 Honolulu as reported by Stocking A.M. 1984.

Bennett, H.H. (1939)

Soil Conservation McGraw - Hill, New York

Black A.L., and Siddoway F.H. (1966)

Influence of tillage and wheat straw residue management on soil properties in the great plains. J. Soil and Water Cons. 34 (5): 220-223

Borst et al.(1945)

Investigations in erosion control and reclamation of Appalachian conservation experimental station, Zanesville, Ohio, 1934-42 USDA Tech. Bull No. 888 Washington D.C

Couprie, F., Gibbon D., and Nweke F.I. (1984)

Farming systems research in SAFGRAD Project in West Africa as reported by Stocking (1984).

Dowker, B.D. (1964)

A note on the reduction in yield of Taboran maize by planting. E. Afric. Agric. J. 19: 30-31

Eck, H.V., Hauser, V.L., and Ford, R.H. (1965)

Fertilizer needs for restoring productivity on pullman silty loam after various depths of soil removal. Soil Sci. Soc. Amer. Proc 29(2): 209-213

Eck, H.V., (1968)

Effect of topsoil removal on N-supplying ability of Pullman silty clay loams. Soil Sci. Soc. Amer. Proc. 32(5): 686-691

Engelstrad, O.P., and Shrader, W.D. (1961)

The effect of surface soil thickness on corn yields as determined by an experiment using normal surface soil and artificially exposed subsoil. Soil Soc. Amer. Proc. 25(6): 494-497

F. A. O. (1976)

Soils bulletin No. 30, F.A.O., Rome

F. A. O. (1977)

Guidelines for soil profile description, FAO, Rome

F.A. O./UNESCO (1974)

Soil map of the world vol.1 Legend UNESCO Paris

Free, G.R. (1960)

Research tells how much soil we can afford to lose. Crops and soils 12:21 as reported by Stocking (1984).

Gachene, C.K.K., (1989)

Soils of the Erosion Research farm. Kabete Campus

Gicheru, P.T. and Ita, B.N. (1987)

Detailed soil survey of the Katumani National Dryland Farming Research Station farms. Detailed soil survey report No. D43, Kenya Soil Survey.

Hsiao, T.C., O'Toole, J.C. and Tomar, V.S. (1980)

Water stress as a constraint to crop production in the tropics in IRRI, pp 339-369 as reported by Stocking (1984)

Kilewe, A.M., and Ulsaker, L.G. (1984)

Soil erosion a threat to land resources. E. Afr. Agric. For. J. 44: 203-29 (Special issue)

Krauss, H.A., and Allmaras, R.R. (1982)

Technology masks the effects of soil erosion on wheat yields - a case study in Whiteman county Washington In Determinants of soil loss tolerance publ. No. 45 Amer. Soc Agron. Madison Wisconsin

Lal, R (1976)

Erosion on Alfisols in Western Nigeria. IV. Nutrient element losses in runoff and eroded sediments. Geoderma 16:403-417

Lal, R. (1983)

Soil erosion caused productivity decline in soils of the humid tropics. Soil Taxonomy News 5: 4-5

Langdale, G.W and Shrader, W.D. (1982)

Soil erosion effects on soil productivity of cultivated cropland. In Determinants of soil loss tolerance publ. No. 45, Amer. Soc. Agron. Madison Wisconsin

Marimi, A.P.M. (1977)

The effect of certain tillage methods in cropping systems for conserving rainfall in a semi-arid area of Eastern Kenya. In Soil and Water Conservation in Kenya. Report of a workshop. University of Nairobi 21-23rd Sep. 1977 IDS Occassional Paper No. 27 pp 74-86

Massey, H.F and Jackson, M.L. (1952)

Selective erosion of soil fertility constitutents. Soil Sci Soc Amer. Proc. 16: 353-356

Moldenhauer, W. C. (1971)

On site consequences and control. USDA - ARS Corn Belt Branch, Ames, Iowa as reported by Stocking (1984)

Mbuvi, J.P., and Van de Weg R.F. (1975)

Some preliminary notes on the soils of Katumani, Kampi ya Mawe, Embu and Murinduko Agricultural Research Stations. Report No. P 25, Kenya Soil Survey

National Soil Erosion - Soil Productivity Planning Committee 1981.
Soil erosion effects on soil productivity; a research perspective J. Soil Water Conservation 36(2) :82-90

Power, J.F., Sandoval, F.M., Ries, R. E. and Merrill, S.D. (1981)
Effects of topsoil and subsoil thickness on soil water content and crop production on a disturbed soil. Soil Sci. Soc. Amer. J. 45(1): 124-129

Republic of Kenya, (1986)
Sessional Paper No. 4 on food policy, Govt. Printers

Siderius, W. and Muchena, F.N. (1977)
Soils and environmental conditions of Agricultural Research Stations in Kenya. Misc. Soil Paper No., Kenya Soil Survey

Stocking A. M. (1984)
Erosion and soil productivity: A review. F.A.O., Rome

Stocking A.M. (1985)
Erosion - induced loss in soil productivity. A research design. Consultants' working Paper No. 2, F.A.O., Rome

Thomas, D.J. and Cassell D.K. (1979)
Land forming Atlantic Coastal Plains. Crop yield relationship to soil physical and chemical properties. J. Soil Water Cons. 30: (1) 20-24

Trustrum, N. A., Lambert, M.G. and Thomas V.J. (1983)
The impact of soil slip erosion on hill county pasture production in New Zealand. Paper to Malama Aina 83 Honolulu Hawaii

Wenner, C.G (1981)

Soil Conservation in Kenya especially on small scale farming in high potential areas using labour intensive methods, Ministry of Agriculture, Nairobi.

Soil Science Society of America (1975)

Glossary of soil science terms, Madison Wisconsin.

Latham, E.E. (1940)

Relative productivity of the A-horizon on the Cecil sandy loam and the Band C Horizons exposed by erosion J. Amer. Soc. Agron 32: 950-954.

APPENDIX I

The following is a profile description of the soil sampling site at Katumani as described by Gicheru and Ita (1978)

i) General Sampling Site Information

Soil Classification:	Chromic luvisol
Parent Materical:	Undifferentiated quartzo-feldspathic gneisses
Physiography:·	Upland
Relief Macro:	Gently undulating to undulating
Slope gradient:	2 - 3%
Vegetation/land use:	Cultivation

ii) Profile Decription

Ap 0-14cm: Dark red (2.5YR 3/3 dry) dusky red (2.5 YR 3/2 moist). clay; porous massive, breaking into weak, fine to medium sub-angular block; hard when dry, friable when moist, sticky and plastic when wet; many very fine to fine pores; many very fine to fine roots; clear and smooth transition to:

Bt1 14-76 cm: Red (2.5 YR 4/6 dry), dark reddish brown (2.5 YR 3/4 moist); clay; porous massive, breaking into weak, medium sub-angular blocky slightly hard to hard when dry, friable when moist, sticky and plastic when wet, many fine to fine pores; common very fine to fine roots; gradual and smooth transition to;

Bt2 76-126: Dark red (10YR 3/4 moist); clay; porous massive, breaking into weak, medium.sub-angular blocky; hard when dry, friable when moist sticky and plastic when wet; worm channels and krotovinas;

APPENDIX II

The following is the profile description of the sampling site at Kabete campus as described by Gachene (1989).

i) General sampling site information

Soil classification	humic Nitosols
Parent material	Nairobi trachytes
Physiograpy	Upland
Relief	Hilly;
Slope gradient	16 - 30%
Drainage class	well drained

ii Profile Description

Ah 0 - 20cm	Dark reddish brown (2.5YR 3/4 moist) clay loam; moderate very fine and fine crumbs and moderate fine and medium subangular blocky; friable when moist, sticky and plastic when wet; many very fine, fine and medium pores; common very fine, few coarse roots; gradual and smooth transition to;

ABh 20-40cm	Dark reddish brown (2.5YRs. 5/4, moist); clay; moderate, medium, subangular blocky; friable when moist, sticky and plastic when wet; many very fine and fine, common medium pores; common very fine, few coarse roots; clear and smooth transition to;
Bt1 40-60cm	Dusky red (7.5R3/4, moist); clay; moderate, medium, subtangular blocky; friable when moist, sticky and plastic when wet; patchy thin clay cutans,many very fine and fine pores very few very coarse roots; clear and smooth transition to:

Bt2 60-85cm	Dusky red (7.5R3/4, moist) clay; moderate, medium, subangular blocky breaking into moderate, fine, angular blocky; friable when moist, sticky and plastic when wet; broken thin clay cutans; many very fine and fine pores; many very fine and fine roots; gradual and smooth transition to:
Bt3 85-150cm	Dark red (7.5R3/6-3/8, moist); clay; weak to moderate, fine and medium, angular blocky; friable when moist, sticky and plastic when wet; continous moderate clay cutans; many very fine and fine pores; very few very fine roots; gradual and smooth transition to:
Bt4 150-170cm	Same as horizon Bt3

APPENDIX III

The following is the profile description of the sampling site at Njoro as described by Siderius and Muchena (1977).

i) General Site Information

Soil Classification; Mollic Andosol
Physiography; Flat to almost flat volcanic plain
Drainage; Well drained

Profile Description

Horizon	Depth(cm)	Description
Ap	0-25	Very dark brown (10YR 2/2) moist, clay loam, weak fine subangular blocky breaking to weak fine crumb; slightly hard when dry, friable when moist, sticky and plastic when wet; many fine and medium roots; many fine and medium pores, diffuse smooth boundary to;
AB	25-50	Very dark brown (10YR 2/2 and 7.5YR 2/2) clay; weak fine subangular blocky consistence roots and pores as Ap; ph 6.0; diffuse smooth boundary to;

B21	50 - 70	Dark reddish brown (5YR 2/2 and 5YR 2.5/2) clay, but more than in horizons above; weak fine and medium subangular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; many fine and common medium roots; many fine pores; many pyroxenes (mainly augite) and some volcanic glass; gradual smooth boundary to
B22	70-100	Dark reddish brown (5YR 3/2) clay; weak fine and very fine subangular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; slightly smeary; common fine roots; abrupt weavy boundary to;
C	100+	consolidated tuff.

APPENDIX IV

The following tables show raw data for 81 pots for all the nine aspects that were recorded in the experiments.

Table 1: Data on maximum height of wheat plants for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	70.06	67.76	70.94
	D0F1	70.16	75.26	76.44
	D0F2	75.50	75.96	79.82
	D10F0	58.14	62.20	58.64
	D10F1	67.60	67.94	73.24
	D10F2	70.70	75.88	68.38
	D40F0	38.88	47.12	28.20
	D40F1	68.42	74.10	68.78
	D40F2	78.30	82.14	85.28
NITOSOL	D0F0	61.00	64.06	60.26
	D0F1	73.52	70.02	75.50
	D0F2	63.24	75.86	78.52
	D10F0	59.92	59.62	58.22
	D10F1	67.18	72.48	76.76
	D10F2	76.08	78.14	84.58
	D40F0	31.50	30.94	40.56
	D40F1	62.16	64.54	70.28
	D40F2	69.26	73.18	78.76
ANDOSOL	D0F0	64.24	69.72	67.22
	D0F1	69.56	66.54	71.77
	D0F2	73.14	80.20	82.22
	D10F0	58.22	59.30	63.22
	D10F1	64.40	66.72	63.02
	D10F2	73.42	70.88	78.56
	D40F0	47.64	48.02	44.40
	D40F1	51.44	61.08	65.24
	D40F2	66.80	67.98	69.18

Table 2: Data on maximum number of tillers for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1		R2		R3	
LUVISOL	D0F0	34	(5.92)	38	(6.24)	38	(6.24)
	D0F1	44	(6.71)	41	(6.48)	38	(6.24)
	D0F2	47	(6.93)	40	(6.40)	36	(6.08)
	D10F0	27	(5.29)	28	(5.39)	23	(4.90)
	D10F1	31	(5.66)	28	(5.39)	28	(5.39)
	D10F2	35	(6.00)	31	(5.66)	37	(6.16)
	D40F0	7	(2.83)	7	(2.83)	5	(2.45)
	D40F1	25	(5.10)	36	(6.08)	25	(5.10)
	D40F2	35	(6.00)	39	(6.32)	38	(6.24)
NITOSOL	D0F0	9	(3.16)	11	(3.46)	14	(3.87)
	D0F1	38	(6.24)	30	(5.57)	28	(5.39)
	D0F2	32	(5.74)	46	(6.86)	42	(6.56)
	D10F0	7	(2.83)	11	(3.46)	8	(3.00)
	D10F1	29	5.48)	32	(5.74)	37	(6.16)
	D10F2	39	(6.32)	45	(6.78)	45	(6.78)
	D40F0	7	(2.83)	6	(2.45)	5	(2.45)
	D40F1	21	(4.69)	18	(4.36)	33	(5.83)
	D40F2	36	(6.08)	32	(5.74)	32	(5.74)
ANDOSOL	D0F0	34	(5.92)	25	(5.10)	39	(6.32)
	D0F1	33	(5.83)	34	(5.92)	37	(6.16)
	D0F2	37	(6.16)	33	(5.83)	41	(6.48)
	D10F0	17	(4.12)	22	(4.79)	20	(5.58)
	D10F1	32	(5.54)	30	(5.57)	25	(5.10)
	D10F2	37	(6.16)	38	(6.24)	33	(5.83)
	D40F0	5	(2.45)	7	(2.82)	5	(2.45)
	D40F1	13	(3.74)	16	(4.12)	20	(4.58)
	D40F2	19	(4.47)	19	(4.47)	20	(4.58)

NB. The figures in brackets were transformed for analysis

Table 3: Data on length of wheat ears (cm) for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	8.79	8.4	9.38
	D0F1	8.53	9.11	9.00
	D0F2	8.39	8.35	9.11
	D10F0	7.80	7.62	7.06
	D10F1	9.00	8.13	7.90
	D10F2	9.57	9.11	8.44
	D40F0	4.54	6.00	3.28
	D40F1	9.12	8.66	8.59
	D40F2	9.04	9.86	9.27
NITOSOL	D0F0	8.47	8.43	7.67
	D0F1	8.95	9.46	9.38
	D0F2	8.99	9.29	8.72
	D10F0	7.38	7.24	7.38
	D10F1	9.03	8.85	9.15
	D10F2	8.60	8.83	8.95
	D40F0	3.54	3.46	4.12
	D40F1	7.14	7.22	7.77
	D40F2	9.13	8.25	9.12
ANDOSOL	D0F0	7.93	8.38	8.72
	D0F1	8.66	7.10	7.77
	D0F2	9.06	8.82	8.70
	D10F0	7.38	6.87	6.86
	D10F1	8.28	7.66	7.30
	D10F2	9.00	8.92	8.84
	D40F0	5.36	5.40	5.24
	D40F1	6.42	6.80	6.68
	D40F2	8.66	7.88	7.65

Table 4: Data on Weight of wheat ears (gm) for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	15.08	14.10	21.80
	D0F1	16.64	18.11	17.22
	D0F2	17.13	21.77	23.54
	D10F0	8.26	7.51	8.42
	D10F1	10.21	10.95	11.80
	D10F2	17.04	14.39	15.12
	D40F0	2.70	4.43	0.61
	D40F1	11.40	13.29	10.95
	D40F2	14.74	15.74	15.18
NITOSOL	D0F0	13.24	15.84	14.96
	D0F1	15.20	17.84	17.65
	D0F2	20.06	18.39	19.27
	D10F0	9.56	8.91	8.47
	D10F1	12.50	12.44	12.56
	D10F2	16.76	17.03	16.73
	D40F0	1.88	2.15	3.01
	D40F1	8.03	7.03	8.09
	D40F2	13.79	13.77	12.93
ANDOSOL	D0F0	12.62	11.51	12.18
	D0F1	13.87	13.75	14.06
	D0F2	15.97	17.37	14.69
	D10F0	7.68	7.85	6.85
	D10F1	8.95	8.42	8.35
	D10F2	10.94	10.89	11.19
	D40F0	3.49	3.86	3.03
	D40F1	5.09	5.58	6.50
	D40F2	8.85	8.12	8.58

Table 5: Data on number of wheat grains (nos.) for nine treatments on three different soil types

Type of Soil	Treatments	Replicates R1	R2	R3
LUVISOL	D0F0	242	238	380
	D0F1	289	286	273
	D0F2	315	357	402
	D10F0	142	135	132
	D10F1	181	200	202
	D10F2	292	298	223
	D40F0	42	61	8
	D40F1	220	230	208
	D40F2	286	291	276
NITOSOL	D0F0	203	246	214
	D0F1	283	283	314
	D0F2	344	308	330
	D10F0	174	165	157
	D10F1	234	233	228
	D10F2	309	307	298
	D40F0	35	33	59
	D40F1	154	146	148
	D40F2	267	256	286
ANDOSOL	D0F0	228	208	208
	D0F1	143	234	238
	D0F2	272	280	246
	D10F0	133	131	121
	D10F1	172	148	147
	D10F2	192	189	181
	D40F0	67	80	70
	D40F1	93	110	123
	D40F2	145	147	150

Table 6: Data on weight of wheat grains (gm) for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	10.38	10.17	15.41
	D0F1	11.80	12.57	12.31
	D0F2	10.97	15.91	16.80
	D10F0	5.48	5.34	5.69
	D10F1	7.20	8.05	8.36
	D10F2	12.38	9.76	10.17
	D40F0	1.77	2.92	0.31
	D40F1	8.09	9.32	7.59
	D40F2	10.57	10.71	10.55
NITOSOL	D0F0	8.93	11.46	10.20
	D0F1	10.79	12.70	12.34
	D0F2	14.18	12.75	12.82
	D10F0	6.92	6.35	5.93
	D10F1	8.86	8.95	8.87
	D10F2	9.46	11.91	11.51
	D40F0	1.26	1.49	2.19
	D40F1	5.37	4.70	5.64
	D40F2	9.44	9.59	9.08
ANDOSOL	D0F0	8.83	8.15	8.51
	D0F1	9.89	9.84	9.95
	D0F2	11.25	11.64	10.32
	D10F0	5.13	5.21	4.79
	D10F1	6.46	5.92	5.75
	D10F2	7.71	7.49	8.00
	D40F0	2.25	2.58	2.08
	D40F1	3.42	3.94	4.60
	D40F2	5.93	5.56	5.88

Tab le 7: Data on weight of wheat straw (gm) for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	14.51	12.60	18.29
	D0F1	15.60	17.30	19.20
	D0F2	19.00	20.40	25.92
	D10F0	7.92	7.90	8.40
	D10F1	10.25	11.73	13.50
	D10F2	15.36	15.00	16.00
	D40F0	4.10	4.20	1.70
	D40F1	11.56	14.29	13.56
	D40F2	15.82	18.42	18.30
NITOSOL	D0F0	9.40	8.86	8.50
	D0F1	15.97	16.10	17.60
	D0F2	15.00	18.70	21.00
	D10F0	5.50	6.00	5.40
	D10F1	12.10	13.17	13.60
	D10F2	16.55	17.10	17.70
	D40F0	1.20	1.50	1.87
	D40F1	9.60	8.60	9.30
	D40F2	14.50	13.30	15.20
ANDOSOL	D0F0	12.33	11.43	12.42
	D0F1	13.50	13.81	15.30
	D0F2	15.78	19.93	15.70
	D10F0	6.40	7.88	6.37
	D10F1	10.17	9.50	9.37
	D10F2	11.70	12.70	12.00
	D40F0	2.90	3.20	2.50
	D40F1	5.87	6.39	8.62
	D40F2	9.00	9.00	8.90

Table 8: Data on weight of wheat roots (gm) for nine treatments on three different soil types

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	7.08	5.93	8.19
	D0F1	6.76	7.88	8.46
	D0F2	8.16	13.49	8.54
	D10F0	3.28	3.92	3.39
	D10F1	4.59	4.72	4.57
	D10F2	7.75	6.06	8.84
	D40F0	3.74	6.65	5.06
	D40F2	6.47	9.46	8.23
NITOSOL	D0F0	3.29	3.22	3.53
	D0F1	7.81	5.96	6.05
	D0F2	5.88	7.26	6.43
	D10F0	2.39	2.33	1.97
	D10F1	4.85	5.25	6.37
	D10F2	6.85	6.09	6.17
	D40F0	0.58	0.66	1.11
	D40F1	4.51	4.95	4.27
	D40F2	4.43	4.56	4.71
ANDOSOL	D0F0	4.80	4.73	5.69
	D0F1	3.50	5.39	5.87
	D0F2	5.48	7.91	6.32
	D10F0	2.99	3.38	2.93
	D10F1	4.74	4.88	4.00
	D10F2	4.04	4.95	4.62
	D40F0	1.14	1.29	1.04
	D40F1	2.56	2.40	3.32
	D40F2	3.88	3.57	3.25

**Table 9: Data on the weight of above the surface biomass (gm) of wheat for
nine treatments on three different soil types**

Type of soil	Treatment	Replicates R1	R2	R3
LUVISOL	D0F0	29.59	26.70	40.09
	D0F1	32.24	35.41	36.42
	D0F2	36.13	42.17	49.46
	D10F0	16.18	15.41	16.82
	D10F1	20.46	22.68	25.30
	D10F2	32.40	29.39	31.12
	D40F0	6.80	8.63	2.31
	D40F1	22.96	27.58	24.51
	D40F2	30.56	34.16	33.48
NITOSOL	D0F0	22.64	24.70	23.46
	D0F1	31.17	33.94	35.25
	D0F2	35.06	37.09	40.27
	D10F0	15.06	14.91	13.87
	D10F1	24.60	25.61	26.16
	D10F2	33.31	34.13	34.43
	D40F0	3.08	3.65	8.53
	D40F1	17.63	15.63	17.39
	D40F2	28.29	27.07	28.13
ANDOSOL	D0F0	24.95	22.94	24.65
	D0F1	27.37	27.56	29.36
	D0F2	31.75	37.30	30.39
	D10F0	14.08	15.73	13.22
	D10F1	19.12	17.92	17.72
	D10F2	22.64	23.59	23.19
	D40F0	6.39	7.06	5.53
	D40F1	10.96	11.97	15.12
	D40F2	17.85	17.12	17.48