TILLAGE PRACTICES AND DRAFT POWER REQUIREMENTS FOR SOIL MOISTURE CONSERVATION OF A HARD SETTING SOIL.

By

GITAU AYUB NJOROGE BSc. Ag. Eng. (Egerton Univ. 1990)

Thesis submitted to the Department of Agricultural Engineering, UNIVERSITY OF NAIROBI, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING**.

UNIVERSITY OF NAIROBI

1995

DEDICATION

I dedicate this thesis to my wife Veronicah and son Gitau (Jr) for their love and patience during the busy periods when they needed my presence.

DECLARATION

I, GITAU AYUB NJOROGE, hereby declare that, this thesis is my original work and has not been presented for a degree in any other University.

1/11/96

GITAU, A.N. DATE

This thesis has been submitted with our approval as University Supervisors.

4th NOVEMBER 1996

KAUMBUTHO, P.G. DATE

1.11.96

BIAMAH, E.K. DATE

ACKNOWLEDGEMENTS

I am very grateful to my project supervisors, Dr. Kaumbutho, P.G. and Mr. Biamah, E.K., for their valuable advice and material assistance. I would also like to express my gratitude to Dr. Owende P.M. for his assistance in the thesis correction. Special thanks go to the Swedish Agency for Research Cooperation with Developing Countries (SAREC) for the scholarship and to members of staff of the Department of Agricultural Engineering for their cooperation and invaluable assistance.

Lastly, I wish to thank everyone else that contributed in one way or the other to the successful completion of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

ABBREVIATIONS

CI	Cone Index
ERI	Emergence Rate Index
SR'93	Short rains season, 1993
DMR	Duncans' Multiple Range Test
LR'94	Long rains season, 1994
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
FAO	Food and Agriculture Organisation of the United States
ILCA	International Livestock Centre for Africa
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USDA	United States Department of Agriculture
pH	Negative Logarithm to the base 10 of Hydrogen ion concentration
ca	Circa
ppm	Parts per million

ABSTRACT

Field experiments were conducted to study the draft power requirement of four tillage operations and their effect on moisture conservation in a *Luvisol* soil. The experimental sites were located in Iiuni in Machakos District (Kenya), a region with semi-arid type of climate. The experiments were conducted during the short rain season of 1993 and the long rain season of 1994 in Randomized Complete Block experimental design with three and four replications respectively. The treatments were; deep mouldboard tillage (DTM) to 17 cm, shallow mouldboard tillage (STM) to 11 cm, deep cultivator tillage (DTC) to 10 cm, shallow cultivator tillage (STC) to 7 cm and no-till (NT). A pair of oxen provided the draft power.

Soil moisture, bulk density, penetration resistance and crop height were monitored throughout the crop growing period of a Maize (*Zea Mays*) crop. The Maize crop was harvested at the end of the crop growing period so that grain and dry matter yield comparisons could be made.

It was found that, the draft power requirement was significantly different ($p = 0.05$) between the shallow and deep tillage treatments in both experimental seasons. During the short rain season, DTM had the highest draft power requirements of 1.00 kW followed by DTC (0.85 kW), STC (0.78 kW) and STM (0.67 kW). In the long rain season, draft power requirements were highest for DTC (0.96 kW) followed by DTM (0.91 kW), and STC and STM (0.77 kW) each. Higher draft power requirement for DTM was as a result of the corresponding higher depth of tillage (17 cm). High draft power requirement for DTC was due to the higher depth (10 cm) of tillage and probably higher weight of equipment (39 kg) as compared to 32 kg for the mouldboard plough.

Available soil moisture was not significantly different between all treatments from the vegetative to pollination stages of the crop. Changes in bulk density and penetration resistance (before and after tillage) were significantly different ($p = 0.001$ and $p = 0.05$) between the mouldboard and cultivator tillage treatments, for the short and long rain seasons respectively. The high surface roughness for the DTM treatment probably increased surface depressional water storage and thus increased the time available for infiltration, therefore more water was stored in the profile. Low available soil moisture for the NT treatment was

due to the low surface roughness which led to the development of a dense crust over the entire soil surface resulting in surface runoff water losses.

Crop yields were not significantly different ($P = 0.05$) between all treatments during both seasons. During the short rain season DTM had the highest grain yield (1632 kg/ha) followed by STC (1398 kg/ha), STM (1328 kg/ha), DTC (1319 kg/ha) and NT (1126 kg/ha). DTM had the highest dry matter yield (4974 kg/ha) followed by STM (4435 kg/ha), DTC (4291 kg/ha), STC (4278 kg/ha) and NT (3508 kg/ha). During the long rain season, STC had the highest grain yield of 1320 kg/ha followed by DTM (1234 kg/ha), NT (1119 kg/ha), DTC (1106 kg/ha) and STM (947 kg/ha). Dry matter yield was highest for DTM (3925 kg/ha) followed by STC (3474 kg/ha), NT (2850 kg/ha), DTC (2613 kg/ha) and STM (2499 kg/ha).

Overall, deep tillage with the mouldboard should be recommended for the short rain season as the results indicate a higher crop yield. This may also imply that surface roughness is the single most important condition determining moisture availability for crop growth under the conditions of the experiments. The corresponding draft requirements for DTM could probably be lowered if tillage was performed immediately after the long rain season when the soil moisture conditions are favourable. Shallow tillage with the cultivator could also be used in the long rain season without any adverse effects on soil properties and crop yields.

1 INTRODUCTION

1.1 General Background.

Tillage practices in semi-arid environments have been well documented in literature and there is evidence that simple low draft traction ploughs, like the wooden "Ard", have been in use since Sumerian times, ca 3500 B.C.(Henderson and Siddique, 1969; Amon, 1972; Phillips and Young, 1973; Wolf and Luth, 1977; cited by Willcocks, 1981).

Tillage practices within the semi-arid regions vary considerably and they are determined by such factors as soil type and rainfall distribution over the year. About half of these soils have been described as "clod-forming" (Wolf and Luth, 1977) because when dry they become hard and large clods are produced if the soil is ploughed under these dry conditions. Effective tillage is therefore critically dependent upon the soil moisture content and available draft power. The strength characteristics of these soils are such that dry seedbed preparation is mostly difficult and expensive (in terms of implement life and draft requirements from the animals). The optimum range of soil moisture for tillage is limited as the water holding capacity of semi-arid sandy soils is low (Willcocks, 1980).

Limited capital in developing countries severely limits the choice of inputs, especially at the small land-holder level. For this reason, it is important that an understanding of potentially usable tillage systems and their effects on soil properties be developed prior to investing large sums of capital for the purchase of tillage implements. Only then can tillage systems be selected to give the appropriate balance between sustainable yields, minimized costs, soil deterioration and optimized energy use.

Tillage or soil surface management to prepare a desired seedbed, is a major input in agricultural production. It is a labour-intensive activity in low-resource agriculture on small holder farms, and a capital and energy-intensive activity in large-scale mechanized farming. Judiciously used, tillage can be a powerful tool to alleviate some soil-related constraints to crop production e.g. compaction, crusting, low infiltration, poor drainage, unfavourable soil moisture and temperature regimes, disposal of undesirable biomass and pest management. Improperly used, tillage can lead to deterioration of soil structure, reduced infiltration, accelerated runoff and erosion and consequential degradation of soil and the environment.

Tillage determines the extent to which soil and water can be conserved by its effect (at the time of seedbed preparation) on resulting surface roughness, mulch retained on the surface, aggregate size and stability. Conservation of moisture is of utmost importance in arid and semi-arid areas as a means of ensuring crop production and controlling erosion by rain and wind. This could be achieved by; increasing infiltration, reducing evaporation, weed control, terracing, and strip cropping (Muchiri and Gichuki, 1981).

Crop response to the tillage system is hard to predict (Lal et al., 1990). Crop yield depends on a range of associated practices such as drainage method, planting date, variety selection, cropping geometry, plant population, type of fertilizer, and time and mode of its application, pest control, cropping systems and type of equipment. Above all, crop growth and yield in relation to tillage are significantly influenced by antecedent soil moisture and climate.

1.2 Uniqueness of the Study.

Arid and semi-arid lands of Kenya make about 80 percent of total land area. As population rises movement is into these areas and here farm sizes get smaller and call for specialized tillage methods and implements.

In these semi-arid areas, which offer potential for increased production, suitable technologies need to be tested under farmers conditions before being ready for dissemination.

Crop production in semi-arid areas is limited by inadequate and poorly distributed rainfall and low soil fertility. In the later case, an analysis of soil has revealed that most of the soils in semi-arid areas of the Eastern Province, Kenya are deficient in Nitrogen, Phosphorus, Copper and Zinc, and are also low in organic matter content (Ikombo, 1983). Under these conditions, the maintenance and improvement of soil fertility becomes fundamental in all agronomic practices. An effective method for maintaining soil fertility could be the use of inorganic fertilizer. However, the current prices of imported inorganic fertilizers are beyond the economic capability of subsistence farmers in question and crop yields obtained cannot pay for the fertilizer.

In addition to increasing crop yields, tillage methods must also facilitate soil and water conservation, improve root system development, maintain a favourable level of soil organic matter content and reverse degradation trends in the soil life support processes.

In dry years, crops grown on *Luvisols* (dominant soil type in the study area) often suffer from water stress. This stress is more serious where shallow cultivation has led to a concentration of roots near the surface. Cultivation to allow for deep root penetration is severely restricted by high draft power requirements. Upon drying, even tilled topsoil can become too hard for germinating seeds to emerge.

In semi-arid areas of Kenya, the two major tillage objectives are to increase the amount of effective annual rainfall (through increased surface roughness, surface storage and enhanced infiltration) and to generally reduce the draft power requirements (by identification of appropriate tillage implements).

Research suggests that compacted subsoil and/or poor top soil water holding capacity, both typical features of sandy soils, make some primary cultivation necessary in order to create a sufficiently deep root proliferation zone and thus increase water availability (Vogel, 1993).

This study attempts to evaluate the performance of a set of tillage practices on infiltration and subsequent moisture conservation. The evaluation was carried out by monitoring animal draft power requirements, soil macro-structure, moisture retention and crop performance.

1.3 Objectives and Scope of the Study.

1.3.1 Objectives of the Study

The overall objective of this study was to establish the draft power requirements and influence of a set of tillage practices on soil physical properties and moisture conservation of a hard setting semi-arid soil.

The specific objectives were to;

a) determine the draft power requirements of two implements (Bukura Mark II mouldboard and cultivator) during primary tillage operations.

b) report on the effect of tillage depth on moisture retention, of a hard setting soil under the different tillage practices.

c) determine the effect of the different tillage practices on soil macrostructure and moisture conservation.

d) monitor crop performance (seedling emergence and crop height) and yield for the different tillage practices during the crop growth periods.

e) determine the appropriateness of the tillage practices to the prevailing soil conditions.

1.3.2 Scope of the Study

This study attempted to evaluate the effects of deep and shallow tillage with a mouldboard plough, deep and shallow tillage with a cultivator and no-tillage on soil and water conservation and subsequent crop performance and yield of a hard setting soil. The prime mover was a pair of oxen which provided the draft required to till the soil.

The focus of this research was on climate, soil and draft power as they influence tillage and moisture conservation in crop production. Pre- and post-tillage soil physical properties (soil moisture, bulk density, soil strength and soil surface roughness) were monitored so that changes in soil conditions resulting from tillage could be evaluated. In-field measurements were made of the draft requirements of mouldboard and cultivator tillage implements.

During the short rains season (1993) less data on soil moisture was obtained over the season. It was expected that moisture data collected at the emergence, tasselling and harvesting stages would be adequate to describe soil moisture storage under the different tillage practices. But during the long rains season (1994), more data on soil moisture was collected so as to include the vegetative and maturity stages which are also critical stages of maize crop development.

2 REVIEW OF LITERATURE

2.1 Mechanization.

2.1.1 General background

While in the whole world there may be as many as 400 million draft animals (Ramaswamy, 1981), in Africa the total figure is only in the order of 10 to 17 million (ILCA, 1981; Anderson, 1984). Of these animals, 6 million are found in Ethiopia, where almost all the farmers in the highlands use draft oxen (Anderson, 1984).

FAO, (1984) suggested safe average draft and power outputs for a pair of bullocks (see Table 2.1). It is observed that the draft power and performance of the animals is directly proportional to the weight of the animals. The draft power requirements depends upon the soil conditions, the field operation and the type of implement. Similar findings were reported by other workers (FAO, 1972; Crossley and Kilgour, 1983; Schmitz et al., 1991). For horses and cattle 10 % to 14 % of the body weight was mentioned as equivalent to the draft with a daily work time of 5 to 6 hours. Donkeys and mules achieved better results, with high values often being recorded (up to 23 % of their weight).

In the semi-arid tropics, the power availability at the farm level is an important factor limiting crop production. Giles (1975) estimated agricultural power by source and geographical regions as shown on Table 2.2. He suggested that a minimum of 0.37 kW per hectare is required for high yields.

Table 2.1 Suggested Draft and Power output (FAO, 1984).

Bullock pair weight (kg)	Average speed (m s^{-1})	Average safe draft (kN)		Power output (kW)	
		27°c	34°c	27°c	34°c
500	0.8	.50	.40	0.43	0.35
600	0.8	.60	.50	0.52	0.43
700	1	.67	.57	0.68	0.58
800	1	.75	.65	0.77	0.67
900	1	.83	.72	0.85	0.73
1000	1	.90	.80	0.92	0.77

Table 2.2 Agricultural Power by source and geographical region (Giles, 1975).

Region	Total (kW/ha)	% of available power / ha		
		Man	Animal	Engine
Asia	0.16	26	51	23
Africa	0.08	35	7	58
Latin America	0.19	9	20	71
Total %		24	26	50

2.1.2 Mechanization status in Kenya

The relative importance of the various forms of mechanization, especially in land preparation is currently not precisely known in Kenya. However, by early 1980s, Muchiri and Gichuki (1981) reported that, in Kenya 3.4 per cent of the cultivated area was prepared by tractors, 12.2 per cent by oxen and 84.4 per cent by hand. It is therefore clear that in small landholder level, the dominant equipment for land preparation is the hoe, using human labour.

According to Muchiri and Gichuki (1992) and Kahumbura (1994), tractor mechanization has had very little impact on smallholder farmers in the semi-arid areas. This is mainly attributed to logistic problems of ploughing small and dispersed farm units, steep slopes, maintenance problems, lack of spare parts and the sharp increases in the prices of tractors and fuel. Thus tractor mechanization is becoming increasingly expensive for smallholder farmers, resulting in late ploughing and planting which translates into a substantial reduction in crop yield or even crop failure. Other problems that plague tractor mechanization include:

(1) Lack of competent management and strict supervision,

(2) Inadequate workshop and repair facilities,

(3) Lack of skilled and responsible operators, and

(4) Unavailability of cash and credit when needed.

The Kenya Government Development Plan, sessional paper No.1 of 1986, noted that ox-drawn equipment reduced land preparation time to less than 40% of that required with hand tools and markedly expanded the area planted, increasing yields to land and labour. According to the paper, development and use of improved ox-drawn equipment (however) required efforts in research, manufacture, marketing and extension.

In areas where animals are used for cultivation the efficiency of work is much better than in areas where hand tools are dominant. Previous studies have reported that a man using a hand hoe is only capable of managing efficiently about one fifth of a hectare, while when using a pair of oxen the efficiency can be increased 15 times. It was further observed that, hand tool mechanization is constrained by labour shortage during peak periods (primary tillage and weeding), high energy requirements, associated drudgery and unavailability of appropriate tools.

The use of animal power, which is to a very large extent a renewable energy source will in future continue to be of enormous importance for many agricultural holdings in Africa and its significance will probably increase still further (Munzinger, 1982). This hypothesis is supported in particular by the worldwide escalating prices of fossil fuel. The resultant increase in the cost of conventional types of energy is already having disastrous consequences for some African countries. Animal traction mechanization therefore offers a good alternative where land is available to support draft animals.

2.1.3 Draft Animal use in Kenya

Animal traction is used in all countries of East Africa, but there are great differences between and within countries in the extent of use. For example, ox-cultivation was introduced in Kenya about 70 years ago. But for an overall figure of 12 per cent of all farmers using a total of 700,000 working animals (mainly Zebu oxen) most are derived from some areas, such as Machakos where more than 80 per cent of farmers use draft animals (Rukandema, 1984; Starkey, 1986).

2.1.3.1 Available tillage implements

In Kenya the most widely used animal-drawn tillage equipment is the victory mouldboard plough. It is generally manufactured locally and when made from good quality steel it is light and popular with farmers. The implement requires high draft power, particularly when the soil are dry and hard. The high draft requirement cannot easily be supplied by a pair of oxen that are not physically fit after the long drought.

Research and development programmes have continued to acquire "improved" animal-drawn implements. The bukura toolbar was recently designed to operate with a pair of working oxen. The major development breakthrough (with the toolbar) was its durability, simplicity, versatility and ease of local fabrication. It can work with minimum adjustments and such adjustments as is required can be made without the need for special tools. The demanding work of hitching on or disengaging different attachments has been totally eliminated by devising a hole and simple pin clip system on the multi-purpose toolbar.

Table 2.3 shows the percentage of farmers owning various implements in Machakos District. From this data Machakos area can be characterised as advanced in draft animal use, especially in the ploughing operations.

Table 2.3 Possession of various Implements (Rukandema, 1984).

Implement	% farmers possessing
Ox-plough	78
Ox-cart	26
Wheelbarrow	7
At least one hoe	96

Absence of reliable support services can be a major constraint to profitable employment of draft animals. The farmers employing draft animals need to be assured of a reliable source of harness and other animal traction equipment. The repair services need to be available at the village level. According to Onyango (1988), efforts have been directed at establishing production units and a supply network equipment with the relevant repair skills in Kenya.

2.1.3.2 Tillage using Draft Animals

At present most draft cattle are only used for ploughing, an operation frequently restricted to two months periods each year. As the ownership of draft animals necessitates investments both in time and resources throughout the year, the lack of regular employment has major implications both for overall farm profitability and the standard of training of the animals. Therefore there is need to fully employ draft animals in the weeding operation.

While weeding implements are available in Kenya, it is likely that less than 5 per cent of farmers who plough with animals use tines. Farmers have modified their ploughs for inter-row weeding by removing the mouldboard and thus using the share. In Machakos District, land is not limiting. Use of draft animal power, mainly for land preparation raises the cultivated hectarage to about 3 hectares, at which point the high labour demand for the weeding operation limits further land use (Rukandema, 1984).

The relative labour requirement of various crop production operations is as shown on Table 2.4, whereby the operation requiring the most labour input is weeding. The high labour demand of the weeding operation calls for the use of field cultivators.

Table 2.4 Labour Requirement of various crop production operations (Rukandema, 1984).

Operation	% of total labour inputs
Land preparation / planting	23.6
Weeding	48.8
Harvesting	20.9
Others (e.g. manure application)	6.7
Total	100

Population pressure means that there is a need for measures to intensify agricultural production and the spread of the use of draft animals, in combination with suitable implements. These must be regarded as an entirely suitable form of modernization. Furthermore animal power is the only economically practical form of mechanization in semi-arid areas of Kenya.

2.2 Draft Power Requirements for Tillage Operations.

Animal draft and power requirements of tillage tools are an important consideration in selecting tillage systems. Quantitative data on power requirements of reduced tillage equipment and on the effects of tillage on soil and plant characteristics are needed as a means of understanding problems associated with adopting conservation tillage in semi-arid environments.

2.2.1 Draft and Speed of Tillage

Because soil physical condition varies both spatially and temporally, methods which sense the condition in real-time are desirable (Young et al., 1988).

The draft of a tillage tool, the force which opposes the forward movement of a tillage tool, is not constant. Instead, it is cyclic in nature because of the development of major shear failures in the soil (Osman, 1964).

It is well documented (Gill and Vanden Berg, 1968; Young et al., 1988) that the mean draft varies with changes in soil conditions. However, the mean draft by itself probably does not characterize all dynamic properties of the soil. It is not uncommon for a tool to have the same mean draft in two different soil types yet, visual observations verify that the soils are failing differently. The mean draft represents the average soil resistance and not the total dynamic response of the soil.

In tillage, it is the combined integrated effect of structure, material properties and any other pertinent characteristics which affect the dynamic behaviour of soil. The mean draft is an indication of the average dynamic strength of the soil, whereas the residual draft is indicative of the intensity of the changes in soil strength which occur as a soil yields, fails and moves.

Tool surface area, lift angle, depth and soil condition undoubtedly influence the magnitude of the speed effect of chisel-type of implements. In some cases a linear relation between draft and speed can be assumed over a limited range of speed. Under normal soil conditions, the movement of soil on the mouldboard is due to the resistance of the soil ahead of the plough, and the average speed of movement of the soil across the mouldboard would be expected to approximate that of the plough.

The draft of tillage varies widely under different conditions, being affected by such factors as the soil type and condition, operating speed, plough bottom shape, friction characteristics of the soil engaging surfaces, share sharpness and shape, depth of tillage, width of furrow slice, type of attachment and adjustments of the implement and attachments.

Other pertinent soil factors include the degree of compaction, the previous tillage treatment and the type or absence of cover crop. Soil types and conditions are by far the most important factors contributing to variations in draft. Soil moisture content is an important factor in both draft and quality of work.

Summers et al. (1986) found out that, draft was a linear function of speed for chisel type of implements, disks and sweep ploughs and a quadratic function of speed for the mouldboard ploughs. Draft was directly proportional to depth of tillage for all implements.

Collins (1920) as cited by Bernacki (1972) found that draft requirements for mouldboard plough were influenced by the following factors according to the given percentages.

Weight - 18%
Turning - 34%
Cutting - 48%

It was also found out that in sandy loam soils, the effects of the share sharpness on the draft were negligible, while on blue grass sod there was an increase of 14% due to share dullness.

Goryachkin (1927) found out that the ploughing speed was proportional to the bottom resistance. According to Kepner et al. (1987) increased forward speed increased the draft with most tillage implements, mainly because of the more rapid acceleration of any soil that is moved appreciably. Soil acceleration increases draft for at least two reasons - first, because acceleration forces increase the normal load on soil engaging surfaces, thereby increasing the frictional resistance, and second, because of the kinetic energy imparted on the soil.

2.2.2 Depth and Width of Cut

Depending upon the tillage implement considered, draft may be a function of ground speed, depth of operation, mass of the implement and/or width of the implement (Smith, 1992).

Most available evidence indicates that the specific draft of a plough generally decreases as the depth is increased to some optimum depth/width ratio and then increases as the depth is increased further. The initial decrease of specific draft with increased depth is logical because the total force for cutting the bottom of the furrow slice should be independent of depth. The increase in specific draft beyond the optimum depth is probably due in part to choking of the thick furrow slice in the curvature of the mouldboard (Kepner et al., 1987).

Goryachkin (1927) found out that the specific draft of furrow slice was more dependent on the depth than on the width of cut and that the resistance also depended on the type of plough bottom. The friction between the furrow slice, the share and the mouldboard was important and contributed as much as 40% of the bottom resistance.

Implement draft is primarily a function of ploughing depth for the soil moisture existing at the time of study. Campbell and Phene (1977) observed that deep tillage benefits crop production in soils with an impermeable layer in the root zone, for both wet and dry conditions by improving internal drainage and increasing rooting depth. The ideal tillage depth (for dry or wet conditions) may be a compromise. To arrive at an intelligent compromise, research is needed on draft power requirements and crop returns for different practices.

Clear benefits from deep tillage (20-30 cm) have been recorded from a tillage experiment conducted at ICRISAT Sahelian Centre where in addition to high crop yields, deep tillage was effective in reducing runoff and soil loss (Laryea et al., 1991). Deep tillage is strongly recommended for cambic Arenosols and Luvisols of the Sahelian region. Deep tillage helped to overcome the low porosity and hardening of the soil after rains and permitted root proliferation and exploitation of soil water and nutrients at deep horizons of the soil profile, thereby producing higher yields. It has been suggested that the benefits of deep tillage are gained only with soils with a poor structure, having a sandy texture and less than 20% clay content.

However, the increase in soil porosity and water infiltration after deep tillage is not maintained for long. The combination of high intensity rainfall and exposure of the soil surface results in the formation of soil crusts and compaction, thereby reducing water infiltration and hence, increasing water runoff and soil erosion (Hulugalle and Maurya, 1991). But owing to deeper root penetration, soil profiles with a loosened plough pan (a situation which will only exist for a few years) usually have smaller moisture deficit than soils with compacted plough pans.

2.2.3 Energy Use and Efficiency

Tool forces and change in soil conditions are the two basic aspects of tillage-tool performances. The tool should accomplish the necessary soil manipulation with a minimum of energy input, and the final soil condition must be acceptable when compared with the desired conditions.

The amount of energy required to produce a given degree of pulverization depends primarily upon the soil strength and the energy utilization efficiency of the implement. Soil strength is related to the nature of the soil and its physical condition. Clay soils have higher break-up energy requirements than sandy soils or loams. Climate, cropping practices, cultural practices, and other factors, influence the physical condition. For a given soil, energy requirements increases with bulk density (Kepner et al., 1987).

Willcocks (1981) in a study in Botswana observed that the mouldboard plough required the highest energy per hectare 105 MJ/ha with the lowest work rate of 0.4 ha/h. The chisel plough had a similar power requirement to the mouldboard plough (11 kW) but, due to its greater working width and smaller effective working depth, less energy was required per ha (74 MJ/ha). The sweep required the least energy per hectare, but the loosening of the soil was minimal as penetration in these hard soils was difficult and the implement frequently became blocked with crop residue trash. The net energy demands of the mouldboard and chisel plough relative to the soils were about the same 42 and 38 kJ/m^3

respectively.

Hadas and Wolf (1983) investigated the energy efficiency in tilling air dry soils using various types of ploughs. A clear cut relationship between the final soil condition and the energy efficiency could not be found. Some of the ploughs improved their efficiency with increasing ploughing speed. Some had no change in their efficiency with increasing operation speed while others actually showed a decline in their efficiency with increased ploughing speed. These inconsistencies could be attributed to plough size and geometry differences. Gill and Vanden Berg (1968) found that the efficiency of ploughs decreased with increased ploughing speed. Both groups of researchers used the "Drop Shattle" technique attributed by Marshall and Quirk (1950) to obtain energy required to reduce the soil clods to smaller sizes.

2.3 <u>Effects of Tillage on Soil Productivity</u>.

2.3.1 Compaction, Bulk Density and Mechanical Impedance

Soil strength usually increases with an increase in bulk density or with the drying of cohesive soil (Chaudhary et al., 1985).

Soil compaction is defined as the compression of unsaturated soil due to a reduction of air filled pore space without any change in mass wetness.

High mechanical strength in cultivated soils develops because;

a) the soil has been compacted due to forces applied during traction or tillage,

b) particle aggregation has been partially lost by excessive tillage or organic matter losses,

c) soil cohesion has been increased by loss of soil water (Bowen, 1982).

Soil compaction can be caused by animal trampling, natural cementation, and pressure and deformation resulting from tillage or trafficability (Threadgill, 1982). Tillage is widely recognized as the most controllable factor in the reduction of soil compaction.

Effects of soil compaction on soil physical properties are characterized by; a decrease in air-filled porosity, degradation of soil aggregates and an increase in the friction of soil to roots.

Depending upon the degree of soil compaction, these effects may or may not be harmful to plants. Air-filled porosity of less than 10% when the soil moisture is at field capacity can be expected to restrict root growth and subsequent crop development (Vomocil and Flocker, 1961). Restricted root growth could be due to inadequate Oxygen supply, limited rate of water supply to roots and excessive mechanical impedance (penetration resistance) of soil to roots. When air filled pore space is reduced beyond a critical limit, diffusion of Oxygen or Carbon dioxide between the soil and the atmosphere cannot be maintained at a rate suitable for biological activities.

The detrimental effects of soil compaction include; restriction of root development, nutrient movement, water movement and oxygen availability, which often result in reduced yields of both agronomic and horticultural crops (Threadgill, 1982).

It is important to realize that the bulk density on a particular field site varies for reasons other than those due to tillage operations. According to Cassel (1984), soil bulk density undergoes temporal variation after tillage operations. For instance, bulk density of the zero to 10 cm depth of a freshly tilled soil may increase soon thereafter due to slumping during periods of excessive wetness and to soil settling in response to desiccation and/or the kinetic energy associated with rain drop impact. With time, bulk density at this same depth may decrease in response to the loosening action exerted by roots or insects activity. At high bulk density, poor aeration and high mechanical impedance may limit root penetration.

Mechanical impedance is mostly equated to the mechanical resistance of the soil to a penetrometer. Mechanical impedance data can be expressed in terms of a cone index (CI) which is defined as the force required to push a metal cone into the soil divided by the basal area of the cone. Mechanical impedance is related to clay mineralogy and to soil physical properties such as bulk density, texture, structure, water content and percentage of organic matter. Tillage operations alter mechanical impedance primarily by effecting changes in bulk density, structure and water content.

Agricultural production systems may adversely affect soil physical properties which in turn may result in a decline in crop productivity. Pea plant emergence, vigour and plant growth are sensitive to soil compaction. Taylor et al. (1981) showed that increasing soil bulk density from 1000 to 1500 kg m^{-3} reduced pea yield in a clay loam soil. Pikul et al. (1993) reported that both soil strength and air filled porosity can affect primary root elongation in peas.

For proper interpretation, Cone Index data must be accompanied with the corresponding soil moisture and bulk density data collected near the point of Cone Index measurements. Cassel (1984) working on a clay soil in England, showed that within 5 weeks after planting in each of 4 years, no-tilled soil was more compact as indicated by both bulk density and penetration resistance measurement. There was no evidence of restricted root growth during early seedling emergence.

Soil compaction is generally viewed as being a cause of reduced plant activity (Gaultney et al., 1980). Willcocks (1981) and Threadgill (1982) indicated that Cone Index values greater than 2.11 MPa frequently reduce crop yields and values above 1.41 MPa restrict root growth. Although there is some disagreement regarding the precise limits of root growth (Busscher and Sojka, 1987), most literature show that root growth is restricted beyond 1.5 MPa as measured by a flat-tipped penetrometer. Based upon generally accepted Cone Index values for restricting root growth, the slot planter tillage system maintained only 22% of the soil profile suitable for root growth whereas the mouldboard plough tillage systems maintained 61% of the profile at soil strength less than restricting levels (Threadgill, 1982).

One approach for eliminating high soil strength involves managing the soil moisture. The problem of root restriction due to high soil strength could be avoided by conserving soil moisture, by timing planting so that early root growth occurred when the subsoil was moist. Overcoming soil strength limitations for the dense coastal plain soils by maintaining high water contents risked restricting oxygen availability (Campbell and Phene, 1977). Subsoiling promoted deeper and earlier root penetration allowing more efficient use of nutrients. Weill et al. (1990) showed that bulk density of the top 30 cm was greater in a sandy loam and clay soil for zero tillage as compared with conventional and reduced tillage. Agenbag and Maree (1991) while working on a shallow stony soil reported a significant increase in cone resistance in the upper soil profile as a result of no-till in comparison with tine and conventional tillage treatments.

According to Maurya (1986) when no-till plots were compared with conventionally tilled plots there was a significant difference in the physical properties of the soil. The no-till plots with residue had a higher organic matter content and a higher porosity in the surface soil horizon than had the tilled plots. Also infiltration rates were higher in the no-till with residue by 50% but lower in the no-till no-residue plots. Research has shown that tillage practices and frequency affect porosity of the 15-30 cm soil layer and that the more intensive the tillage, the lower the porosity (Agboola, 1981).

Laryea, et al. (1991) reported a decrease in bulk density from 1440 to 1110 kg m^{-3} (under conventional tillage) of the upper soil layer. Chaudhary et al. (1985) reported that loosening of soil by tillage decreased soil bulk density and soil strength. However, the decrease in bulk density was only of the order of 100 kg m^{-3} as compared to a 10-fold decrease in soil strength. This was associated with the fact that bulk density is only related to the total porosity of the soil, while soil strength is a composite property related to many factors

such as size and continuity of pores, rigidity of soil, displaceability of particles and number of particle-to-particle contacts. Evidently therefore, disturbance by subsoiling reduced soil strength (as measured by impedance to penetration) by effecting changes in these factors without causing material changes in bulk density. Better root growth and plant water status with deep tillage resulted in better crop growth and higher yield.

The following equation was used in the determination of penetration resistance (in situ testing penetrometers);

$$CR = I*(CS/AC) \qquad (1)$$

where;

CR = Cone resistance (N/cm^2)

I = Impression on the scale (cm)

CS = Spring constant (N/cm)

AC = Area of cone (cm^2)

2.3.2 Soil Structure and Erosion

The physical properties of soil affect its infiltration capacity and the extent to which it can be dispersed and transported. Those properties that influence erosion include soil structure, organic matter, moisture content, and density or compaction, as well as chemical and biological characteristics of the soil.

Soil structure refers to the gross arrangement of soil particles into aggregates. A soil may have either a simple or a compound structure, their particles aggregate or bond together. Good soil structure is very important for agricultural soils. Highly aggregated soils are well aerated, have a higher water holding capacity because of the increased volume of the soil pore space, and are resistant to surface puddling or crusting.

The size, distribution and stability of aggregates in tilled soil and the roughness of the soil surface following tillage operations are important aspects of soil structure which directly influence a range of other soil properties and processes including erosion by wind. Unstable aggregates or a high proportion of small particles at the soil surface increases susceptibility to surface crust formation. Soils with low random surface roughness can have dense surface crusts develop over the entire surface, while in more uneven surface, crusts form mainly in surface depressions (Larson, 1962).

Many researchers investigated the effect of tillage practices on soil structure to identify any resulting differences in soil structural condition and to investigate the relationships between such differences and the soil type, management systems and other crop requirements.

Landon (1991) has given the ratings of P, N and C in the soil (see Table 2.5).

Table 2.5 Rating of Soil Phosphorous, Nitrogen and Carbon (Landon,1991).

-General interpretation of available phosphorus determined by olsen's method for maize, whose pH range is 6-7.5, for optimal crop growth.

Indicative available P values (ppm)

Deficient	Questionable	Adequate
<4	5-7	>8

-Broad ratings of nitrogen and organic matter.

N-content Kjeldahl method (% of soil by wt.)	Rating
>1.0	very high
0.5-1.0	high
0.2-0.5	medium
0.1-0.2	low
<0.1	very low

-Organic matter content

Walkley-Black method (% of soil wt.)	Rating
>10	very high
5-10	high
2-5	medium

1-2	low
< 1	very low

Under zero-tillage, the size of the aggregates is considerably larger, whereas the aggregate size distribution is more homogeneous, especially the small aggregates with diameter of less than 0.3 mm disappear (Boone, 1976). It was also hypothesized that aggregates persist longer under zero-tillage than in a ploughed soil because ploughing and seed-bed preparation always destroy and deform aggregates to a certain extent. Osborne et al. (1978) observed some significant deterioration in soil structure as cultivation intensified. Lale (1978) also reported that structural conditions of soil under no-tillage improved with time, provided there was an adequate amount of residue mulch on the surface and compacting wheel traffic was limited to non-destructive levels.

Soil erosion is the removal of surface material by wind or water. It is a hazard traditionally associated with agriculture in tropical semi-arid areas. Moreover, erosion is increasingly being recognized as a hazard in temperate countries as well. During rainstorms, raindrops disperse, compact and transport soil particles. Often, a seal develops on the surface and where soils, such as *Luvisols*, have crusting properties, crusts form. Soil surface crusting is a special phenomenon of physical soil degradation. It results from non soil loss processes such as soil compaction, breakdown and dispersion of soil aggregates and physical translocation of fine soil particles. Its significance however, has been obscured by more conspicuous soil loss processes such as, rill erosion, gully erosion and mass movements.

It is important that tillage systems enhance infiltration and reduce evaporation and run-off as much as possible. Conditions that promote rapid infiltration are; large pores that are open to the soil surface and remain open during intensive rain storms, and conditions that increase the length of time the water remains on the soil surface (Denton and Cassel, 1989). Work on a chromic *Luvisol* at Katumani (Njihia, 1975) revealed that bare soil had strong sealing properties whereas soils covered by grass pastures had no sealing effect. At the same site, it was found that maize stover mulch was effective in dissipating the kinetic energy of the raindrops and thus reducing its erosive power. Similarly, maize stover mulch was sufficiently effective in controlling runoff through increased surface water storage. The storage increased the time available for infiltration. Maize stover also helped minimize evaporation and surface sealing and crusting.

Crop residue mulches provided by proper no-till practices are effective ways for improving soil moisture conditions and enhancing crop production levels. But though mulching is beneficial in most semi-arid areas, it is not practical to recommend it to farmers because it has alternative uses as fodder for animals, fuel and fencing which often take first priority. Animals are often allowed to roam freely in the field after crops have been harvested and consequently residue left over is consumed by these animals. It is these factors that led Kilewe (1987) to conclude that mulching is not a feasible recommendation in the semi-arid areas of Eastern Kenya. Therefore, there is need to explore other alternative methods of conserving soil and water in these areas.

Wischmeier (1973) reported that mixing corn residues into the soil each year by ploughing compared to removal of stover at harvest resulted in a 40% reduction in runoff. The conclusion was based on a study of 678 plot-years of data for corn systems.

Water erosion will not occur on a cropped field if each rain drop that falls can be cushioned and not permitted to strike the soil, then infiltrate into the soil surface and percolate to the ground water table. We know this does not happen on cropland, because complete crop cover cannot be maintained throughout the year. In addition, rain often falls faster than the soil can absorb it. But, if the water that runs off the surface can be slowed to a non erosive velocity in addition to having mulch on the surface, then erosion caused by water on cropland can be significantly reduced. Soil loss data from a very fine sandy-loam soil showed, a 60 minute storm, soil loss of 8.4, 2.0 and 26.4 t/ha for till planted, no-till and conventional tillage respectively. Infiltration rates were 2.3, 2.7 and 2.8 cm per hour for till planted, no-till and conventional tillage respectively. Therefore, some significant difference in soil loss between the tillage systems was observed but hardly any difference was observed in infiltration (Hayes, 1982).

The erosive power of rainfall is highest and most damaging when the protective cover of vegetation is removed exposing bare soil to the destructive forces of high intensity raindrop and running water. Retained stubble, as in a zero tillage field, reduces the impact of high intensity rainfall and the undisturbed standing stubble gives maximum protection against soil erosion (Facer, 1989). According to Christensen and Norris (1983), 19.3 t/ha soil loss was obtained for conventional tillage, while the same loss was 2.7 t/ha for no-till in 1973 in Mississippi under soya beans.

2.3.3 Soil Surface Roughness and Soil Moisture

Kuipers (1957) was the first to quantify soil roughness by using a relief meter with 20 pins located at 10 cm intervals to take soil elevation or profile measurements. The relief meter was read 20 times on each plot for a total of 400 observations. Kuipers defined soil surface roughness as;

$$SR = 100\log_{10}S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where,

R = Soil surface roughness and

S = Standard deviation of the heights in cm.

Burwell et al. (1963) used the term random roughness to describe the variations in elevations that occur at random on the soil surface. In contrast, roughness attributed to tillage tool marks and wheel tracks create oriented roughness.

Soil microrelief refers to the description of peaks and valleys, inclusive of the clods, created after the passage of a tillage tool. Several types of analyses have been suggested (Allmaras et al., 1967; Freebairn and Gupta, 1990) to summarize microrelief data as one or two indices. All indices are a statistical measure of the randomness in the point heights taken over the tilled surfaces. In addition to the differences in aggregate size distribution between different tillage systems, the depth of tillage is another important variable affecting the microrelief of the tilled surface. According to Logan et al. (1991), the greater variation in microrelief at higher depths of tillage is caused by an increased volume of soil disturbed during tillage but not by the presence of large soil aggregates.

Soil surface roughness affects infiltration, the storage of water in depressions on the soil surface, runoff, evaporation, penetration resistance, organic matter and other processes. Roughness after tillage or cultivation is affected by soil factors such as soil type, soil aggregation, soil moisture and others.

The study of roughness has not received the attention it deserves, because of the difficulty of describing the configuration of the soil surface adequately (Romkens and Wangs, 1985).

Soil moisture, one of the most important properties, affects soil surface roughness not only directly but also indirectly, by influencing other soil properties which in turn affect roughness. Allmaras et al. (1967) found that random roughness was greatest at low soil moisture and decreased as soil moisture continued to increase. Bulk density, soil texture (clay content) and aggregate size also affected soil surface roughness. As the bulk density of a sandy loam, a silty clay loam and a clay soil increased, the percentage of clods having diameters greater than 6.4 mm also increased (Lehrsch et al., 1987). It was also found that clay content increased clod strength. Aggregate size as usually observed has been noted to be approximately proportional to random roughness.

As earlier observed, one of the most common ways to quantify soil surface roughness is to compute the standard deviation of sampled height measurements (Kuipers, 1957). The calculation of descriptive statistical parameters such as standard deviation, implies the assumption of normally distributed values of the height measurements. Bertuzzi et al. (1990), stated that the logarithmic conversion of data improves their distribution. But according to Currence and Lovely (1970) such conversion was not necessary. It was also observed that the assumption of normally distributed data was invalid for some data sets, even after logarithmic conversion.

According to Zobeck and Onstad (1987), although some soils appeared quite smooth, most soils contain small surface depressions or roughness. Soil microrelief is the result of tillage and can have considerable impact on the rate and amount of erosion. Soils with higher microrelief will often maintain higher infiltration rates than smooth soils because dense crusts tend to form mainly in the depressions of uneven soils and over the entire surface of smooth soils (Larson, 1962). Rough soils are generally more porous than smooth soils, contributing to the increased infiltration rates. Many studies have related soil roughness to porosity. Soils with high infiltration rates will have less runoff and erosion than soils with low infiltration rates.

Larson (1964) included microrelief as one of the critical factors for evaluating tillage requirements for corn, noting the importance of depressional storage differences due to tillage. Rough soil surfaces temporarily store more water in surface depressions than smooth soils. Increasing the volume of surface storage increases sediment trapping and reduces movement in runoff and subsequently reduces erosion (Cogo et al., 1983). It was further noted that, increasing surface roughness also decreased the velocity of runoff, and thus reduced soil detachment and transport. In general, depressional storage decreases with decreasing soil roughness and increasing slope (Onstad, 1984).

Zobeck and Onstad (1987) further observed that, soil surface roughness is also associated with other soil properties or processes such as aggregate size distribution, soil thermal properties and energy balance, solar radiation reflection, evaporation and soil-air exchange. Soil surface microrelief is reduced by surface smoothing and residue burying operations such as discing, harrowing, cultivating and land levelling. In addition, raindrop impact, soil freezing and thawing and erosion can further reduce roughness.

Tillage roughens the surface and creates depressions for temporary water storage, thereby providing more time for infiltration. This results in reduced water flow and particle transport, thus minimizing erosion. Onchere (1977), in an infiltration study at Kitale, found that bare fallow, minimum tillage and conventional tillage operations of an orthic *Luvisol*

(FAO/UNESCO classification) at a slope of 3%, significantly improved infiltration and other soil properties. It was observed that the method of seedbed preparation significantly influenced the pore size, distribution and density, moisture holding capacity, bulk density, and surface sealing and crusting properties of the soil. Whereas the coarse seedbed had no crusted soil surface, the other seedbeds showed some crusting.

Stein et al. (1982) in a tillage study observed that due to the increased tillage-induced surface roughness (for a mouldboard plough), transport capacity, as seen in flow velocity measurements, was reduced in comparison to the relatively smooth, bare ridge-till plots. The mouldboard treatment surface was initially rough enough to create considerable surface storage and to expose a large surface area to rain, allowing a greater amount of infiltration in the dry run. But as the run sequence progressed, clods were broken down and total surface area reduced, so that infiltration was negligible for the wet and very wet runs.

Easily compactible soils of the arid and semi-arid regions require mechanical loosening to alleviate soil compaction, increase infiltration capacity, conserve soil moisture in the root zone, increase deep root system development, and decrease risks of soil erosion by wind and water. Lal (1991) reported that, soil inversion and deep ploughing may increase plant available water reserves and increase crop yields. For soils of arid and semi-arid regions, ploughing has been shown to increase porosity and root growth, and improve crop yields in structurally inactive soils. However, ploughing brings about only a transient improvement in soil structure, and follow-up restorative measures are necessary for long-lasting effects.

According to Biamah et al.(1992), in marginal rainfall areas of eastern Africa, recurrent low soil moisture conditions have been attributed to low infiltration of rain water (owing to soil surface sealing and crusting properties) and low organic matter content of top soils. It was further observed that rainfall impact causes surface sealing and crusting of bare soils resulting in very high runoff water losses. It is this runoff water that must be harvested and conserved in the soil to sustain crop growth. This calls for appropriate tillage practices that not only improve rain penetration but also conserve adequate soil moisture for plant growth.

Kilewe (1987), in a soil runoff study in Machakos, observed that due to the high sand content and insufficient water retaining capillary pores as well as the high soil and surface temperatures prevalent in the semi-arid region, much of the water held in the soil profile was lost to downward drainage and evaporation at a fast rate.

Availability of soil water in the B horizons can be increased by subsoiling, a practice that lowers both mechanical impedance and bulk density within and near the subsoiler slit. Root density below the pan is also increased, allowing increased exploitation of subsoil water (Ewing et al., 1991).

Available water content (AWC) is defined as the volume of water retained between field capacity (FC) and permanent wilting point (PWP). FC describes the maximum water content that the soil will hold following free drainage. It represents the condition of each individual soil after the large pores have drained freely under gravity. For medium textured soils a FC moisture content corresponding to -0.33 bar potential (-33kPa, 330 cm water or pF 2.5) is used. PWP arbitrary describes the soil moisture content at which the leaves of sunflower plants wilt permanently i.e. they do not recover their turgor if subsequently placed in a saturated atmosphere. PWP is represented by the moisture content at -15 bar water potential (pF 4.2 or 15000 cm of water).

Phillips et al. (1980) reported that, except for a few unusual situations, soil moisture is always higher under no-till than under conventional tillage. This was attributed to reduction of evaporation losses due to the mulch on the surface. Alegre et al. (1991) while monitoring soil moisture conditions observed that plant-available moisture was consistently highest under no-till and least under conventional tillage.

In a tillage study at Katumani, Machakos, M'Arimi (1978) found that minimum tillage, conventional tillage and tied ridging operations on a sandy clay soil (Chromic *Luvisol*, FAO/UNESCO classification) broke the soil surface crust and improved infiltrability and moisture storage of the soil. Higher soil moisture contents were obtained under tied ridges when compared with the other tillage methods. Minimum tillage stored the least amount of soil moisture.

2.4 Cropping Systems.

Crop performance and yield are significantly influenced by the amount of rainfall and its distribution throughout the rains season. As a result of inherent soil moisture deficits in the study area, the period of cropping is limited to the rains season. Furthermore, timeliness of operations in rainfed agriculture in the semi-arid areas is of paramount importance in order to make proper use of soil moisture.

The mixture of crops (common in the study area) consists of high water crops (maize and sorghum) and short duration low water crops (beans and cowpeas). Cowpeas and beans mitigate against complete crop failure when the season is poor. Maize and sorghum give relatively high yields when the season is favourable.

The most important crops are the early maturing Katumani maize and bulrush millet (3 months duration). Sorghum is common in the lower and drier areas. Pigeon peas of about 240 days duration, cowpeas and beans (at higher altitudes) are the most important legumes. Annual cash crops are not well developed. They include cotton, tobacco and sunflower.

There are two cropping seasons per year. The most reliable one (short rains season) begins in late October or early November with reasonable chance of rain upto December and sometimes in January. The other (long rains season) begins in late March or early April but rainfall in May is unreliable and in June is usually absent. In each season, maize, millet, cowpeas and beans are planted but frequently fail (Fisher, 1978). Pigeon peas, cotton and long duration sorghum are generally planted in October or November, since they require more than one season to mature (thus escaping the dry spell between June and October).

2.5 Effects of Tillage on Crop Productivity.

2.5.1 Seedling Emergence and Crop Height

Rapid drying of hardsetting soils frequently results in poor seedling emergence. Therefore, prediction of seedling response to seedbed strength requires an understanding of the manner in which soil strength develops during drying. According to Weaich et al. (1992) penetration resistance is an empirical estimate of the cavity expansion pressure required of the emerging seedling and soil strength is a key impediment to seedling emergence in hardsetting soils. Collapse of aggregate structure upon settling creates a more homogeneous soil matrix which when followed by drying, leads to a hardset soil matrix which may impede pre-emergent shoot growth.

Final emergence is a critical measure of performance in a crop production system and is an indication of the ability to successfully plant in a specific tillage system.

The success or failure of a crop production system is often dependent on the seedbed environment created by climate, previous tillage, and by planting and tillage equipment at seeding (Wilkins et al., 1982).

Any tillage system to be adopted by a farm must prove its ability to allow seeds to effectively germinate and emerge. Many researchers have compared different tillage systems for their effect on seedling emergence. Stand counts provide a measure of the number of seeds that successfully germinate and emerge. Stand counts, taken periodically during the emergence process and expressed as rate of emergence, gives an indication of the amount of plant stress imposed by the seedbed. Stress delays emergence or slows the rate of emergence.

Studies have shown that emergence, yield and other crop performance criteria of corn grown in conservation tillage can equal more intensive tillage systems (Smith and Yonts, 1989).

Erbach (1982) used an Emergence Rate Index (ERI) to compare plant emergence rates among tillage systems. The most rapid emergence, as indicated by ERI for maize following soya beans, was obtained with till planting and the slowest was with Autumn mouldboard ploughing. The ERI for soya beans following maize was significantly greater for till planting than for the other systems. The following equation , which was used by Erbach (1982), was used in the study for the determination of ERI;

$$ERI = \sum_{n = first}^{Last} \left[\frac{(\%n - \%(n-1)}{n} \right] \quad \text{...(3)}$$

Where;

%n = Percentage of seedlings emerged on day n,

%(n-1) = Percentage of seedlings emerged on day n-1,

n = number of days after planting,

first = number of days after planting that the first seedling emerged (1st counting day),

Last = number of days after planting when emergence was established as complete (last counting day).

Work carried out by Gera-work (1991) while growing maize in Kabete, under three tillage systems (no-till, minimum tillage and conventional tillage) revealed that the conventional tillage system had the highest ERI while the no-till system had the lowest.

According to Smith and Yonts (1989) rotary tillage provided a higher final emergence than minimum or conventional tillage systems and minimum tillage had the lowest emergence. Final sugarbeet emergence of 60% or lower in conventional tillage systems was observed. Important factors observed were soil temperature, soil moisture and planting depth.

Unreliable emergence both as delayed emergence and reduced plant population is a problem associated with corn production under conservation tillage (Hayloe et al., 1993).

It was observed that on average, conventional tillage practices required 11.7 days to achieve 50% emergence followed by chisel ploughing with 12.2 days and no-till with 14.2 days. Ridge and no-till treatments required an average of approximately 2 more days to achieve 50% emergence than did the conventional and chisel tillage treatments.

Vogel (1993) observed that besides tillage, seasonal rainfall pattern and the Year times site interaction had highly significant effects on maize production. Crop yields were poor for the no-till plots due to emergence and establishment problems. Mouldboard ploughing yielded the best. Stibbe and Terpstra (1982) reported that percentage of emerged seedlings and increase in plant height and dry matter yield during early growth decreased highly with increasing penetration resistance.

Initial adoption of conservation tillage was impeded primarily by problems associated with root penetration of the dense E soils horizons (Campbell et al., 1974). Poor corn yield in conservation tillage plots was attributed by Sojka et al.(1991) to erratic emergence and slow early season growth. In their study, stand count of conservation tillage 7 days after planting was half that of conventional tillage, and although counts were not statistically different by 17 days after planting, plant size of conservation tillage plants remained smaller and variable in size. Late-emerged conservation tillage plants remained stunted but continued to grow, although ultimately producing little or no grain. These retarded corn plants, robbed water and nutrients from their productive neighbours and were termed "corn weeds".

Gera-work (1991) reported that minimum tillage systems, both with chemical and manual weed control, maintained nearly the same height and had the tallest plants of all treatments, followed by conventional tillage systems. The no-till manual weed control treatment had the shortest, followed by no-till chemical weed control. Generally crop height corresponded to the crop yield with the treatments showing the tallest plants having the highest dry matter yield.

2.5.2 Crop Yield

The main objectives of farming is increasing the productivity of the land, i.e. to get maximum output (yield) per unit of input. Increased yields have been attributed to those cultural practices that decrease soil strength and increase the extent of root exploration (Busscher and Sojka, 1987).

According to Figueroa and Mburu (1983), in areas of low rainfall, where a growing season is short, timely planting is crucial, as late planting may cause a large reduction in yield or even crop failure. This means that land preparation has often to be carried out before the onset of rain, when the soil is still dry and hard.

Research experience showed that, when reduced tillage is compared with conventional mouldboard ploughing, reduced tillage can increase, decrease or have no effect on crop yield (Agenbag and Maree, 1991). These differences in yield responses to tillage systems are often related to soil properties. Santos and Brian (1986) reported that the superior relative yield under zero-tillage management of a highly compacted plot is attributed to the higher organic matter content restored in the soil. Improved yields under zero-tillage can also be attributed to the establishment of the necessary network of continuous micropores for root development through proper soil aeration and better water availability. But lower yields have been reported to occur with no-till system in semi-arid tropics (Hulugalle and Maurya, 1991). Some probable reasons are, the absence or low amount of residue mulch, high soil compaction, the presence of harmful soil insects in crop residues, the creation of stable pores by tillage in soils of high organic matter and silt and fine sand contents. Unavailability of crop residues is a major impediment to the adoption of no-till.

According to Unger et al. (1991) corn yields increased with depth of tillage on sandy soils, with the effect being greatest on soils having the lowest water holding capacity.

Larson and Osborne (1982) reported that, on experimental plots in Ohio and Virginia , no-tillage planting of corn following a row crop in clay loam to clay soils produced lower yields than the Autumn-ploughed conventional tillage systems. No-till had approximately equal yields with conventional tillage on clay loam to clay soils following sod. They concluded that the apparent interaction between soil type and previous crop should be examined to establish major causes of variations in yield difference between tillage treatments.

McGregor and Greer (1982) observed that, with corn grown for silage and grain on erosion plots and small watersheds, crop yields from the no-till and reduced till systems compared favourably with those from conventional tillage. Average grain yield during 1975 through 1977 from no-till and reduced till plots were about 1 and 11% greater, respectively, than those from conventional-till plots. The crop production from these no-till and reduced-till cropping practices is encouraging noting that acceptance of conservation tillage systems requires crop yields equal or nearly equal to conventional tillage yields.

Erbach (1982) reported that the Autumn mouldboard plough system had the highest 5 year average yield for continuous corn production. The tillage systems did not significantly affect yields of corn.

Yoo et al. (1989) observed that, with conservation tillage systems, cotton yields were poor than for the conventional tillage systems, under the drought conditions.

A study carried out in Embu (rain 1081 mm) by Ngugi and Michieka (1986), on conventional tillage and two-minimum tillage operations (strip and spot tillage) showed that conventional tillage had the best crop performance and yield when compared with the other tillage methods during both rains seasons (short and long rains). Conventional ploughing decreased root restriction and thus increased rooting depth (for more nutrients and water uptake).

In Kalalu, Laikipia, Gicheru (1990) monitored the effects of conventional tillage, tied ridging and crop residue mulching on soil moisture conservation under marginal rainfall (750 mm) conditions. The experiment was carried out on a clay soil (ferric-Acrisols, FAO/UNESCO classification) at a slope of 2%. This study showed that crop residue mulching (despite lagging behind in seedling emergence) did conserve more moisture and had the best crop (maize and beans) performance and yield when compared with the other two tillage practices. The tied ridged plots had the lowest amount of soil moisture and hence the poorest crop performance and yield, owing to no-runoff to impound and high evaporation water losses from increased soil surface area.

Huxley (1979) at Morogoro, monitored the effects of zero (minimum) tillage, mulching and conventional tillage on crop production. The results showed that maize yields obtained from zero-tillage were about 65-75% of those from conventional tillage. The incorporation of mulch increased maize yields by 18-54%. Generally grass mulch was more effective in conserving soil moisture and increasing crop yields than woody mulch.

A study of 4 summer fallow methods of producing winter wheat showed a wide variation in energy requirements, but crop yields were nearly equal regardless of production method (Smith, 1992).

Most contradictory findings are from people dealing with tillage in dry regions. Hakimi and Kachru (1976) reported that the lowest yield of barley crops responding to different tillage treatments was observed under a no-till system. Stobbe (1989) observed also a more stunted growth of cotton plants and an earlier ripening of bolls (for harvesting) when grown on a minimum tilled, medium textured soil than when grown on a deeper tilled soil.

Willcocks (1979), from his research in Botswana, observed that crop yields under semi-arid conditions without mulch are positively related to the degree of soil loosening to a given depth. From this study, sorghum yields were positively correlated with effective reduction in bulk density upto 25 cm depth. This shows that soil bulk density values should be given their due weight in any cultural practice. Moreover, it was observed that yields from no-till farming are unlikely to be as high as those from deep tillage if the porosity of the soil is too low for the effective development of crop roots.

According to Nelson (1976) well drained loams and sandy soils are best adapted to no-till while fine textured (silty-clay-loams, clay-loams and clay) dark coloured soils and soils with poor drainage are not well adapted to no-till.

From the crop production point of view, the Machakos area is classified as one of the low potential areas of Kenya. From 1954 to 1973, rainfall per season ranged between

250 and 400 mm, which is considered marginal. The rainfall duration in each season was less than 60 days. Maize yield in the area ranged between 240 and 750 Kg/ha under the conditions of the long rains of 1977 when the precipitation was exceptionally high (Nadar, 1983) for Katumani composite B.

Work done in Kenya (Michieka, 1985; Njogu, 1981) have shown comparable yields under minimum tillage compared to conventional tillage. During a dry season, Michieka (1985) got satisfactory yields from maize under minimum tillage whereas maize under conventional tillage failed to give a crop. The minimum tillage treatments conserved the little moisture available (due to less soil disturbances). Soil inversion and increased surface area in the conventional tilled plots resulted in most of the water being lost through evaporation.

However, none of the studies conducted so far have recommended optimal tillage operations for semi-arid conditions in Kenya.

Draft power requirements under different soil physical properties (soil moisture, bulk density, soil strength) and soil surface roughness created are essential components of the tillage practices under test. Tillage could allow deep root penetration thus avoiding water stress due to root concentration on the surface. A rough soil surface (created through tillage) also minimises the chance of formation of a dense crust (common in *luvisols* under semi-arid environments) thus allowing water infiltration and gaseous exchange. The final yield is a critical measure of performance in a crop production system and is an indication of the ability to successfully plant in a specific tillage system. A combined analysis of draft power requirements, soil physical properties, crop response to treatments and yield (under a hard setting soil) would give a base to identification of the most appropriate tillage practice(s) for a semi-arid environment, under the prevailing soil conditions influenced by the seasonal rainfall pattern.

3 MATERIALS AND METHODOLOGY

3.1 Research Study Area.

The research study area was in Iiuni Watershed, Kalama Location, Machakos. The watershed is about 40 km South-east of Machakos Town, Kenya. It is at an elevation of 1554-1932 m above sea level. The watershed area is approximately 11 km^2 (Thomas et al., 1981).

The climate of this area is semi-arid with some poor rainfall distribution. The area has bimodal rainfall (see Figure 1.1) ranging between 450 and 1120 mm annually and split almost equally between the long rains (March-May) and the short rains (October-December) with an annual mean of 850 mm (16-year record). The rainfall is intense and of short duration. Under these conditions, crops have to be planted immediately after the onset of the rains to be able to maximize on available soil moisture.

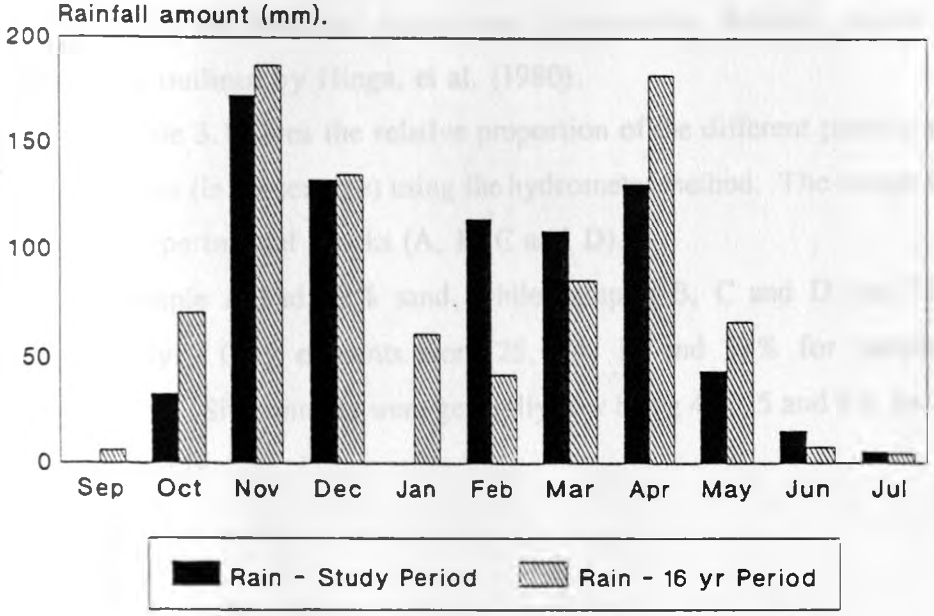


Figure 3.1. Monthly rainfall distribution of Iiuni watershed, Machakos.

Detailed profile description and soil classification from six pits representing different land use types in the watershed have been given by Barber and Thomas (1979). They found two of the pits to have luvisols, three to have ferralsols and one pit on the old colluvial footslopes to have a fluvisol. The upland soils had developed mainly from pre-cambrian basement system rocks consisting of gneiss and schists (Thomas et al., 1981). The upland soils were well drained, red-to-brown in colour with sandy clay loams to sandy clay top soil becoming fine textured with depth. Many of the soils in Iiuni were characterized by weak soil structures with a strong tendency to surface sealing. If left bare, the soils showed a pronounced tendency to seal and crust under rainfall impact.

3.2 Characterization of soils at the experimental site.

Augering were made randomly at the experimental site and five soil samples taken from each block to a maximum depth of 30 cm, using the traverse method. The soil texture was examined (using hydrometer method) from the soil samples obtained.

Five soil samples were taken to depths of 30 cm from each block for fertility analyses after harvesting the crop during the long rains season, 1994. Laboratory soil analysis were conducted at the National Agricultural Laboratories, Kabete, Nairobi and the method of analysis is outlined by Hinga, et al. (1980).

Table 3.1 gives the relative proportion of the different particle sizes which made up the soil mass (in percentage) using the hydrometer method. The samples were obtained from the four experimental blocks (A, B, C and D).

Sample A had 72% sand, while samples B, C and D had 74%, 82% and 63% respectively. Clay contents were 25, 24, 13 and 31% for samples A, B, C and D respectively. Silt contents were generally low being 4, 2, 5 and 6% for samples A, B, C and D respectively.

Table 3.1 Soil Particle Size Distribution (Hydrometer method).

Particle size classification (%)	Sample A	Sample B	Sample C	Sample D
Sand	71.7	74.2	82.2	63.2
Clay	24.5	23.7	12.7	30.7
Silt	3.8	2.1	5.1	6.1
Texture	SCL	SCL	SL	SCL

SCL = Sandy Clay Loam, SL = Sandy Loam (USDA soil classification system).

Note: Sampling involved 5 samples collected by traverse method per block and mixed thoroughly.

Table 3.2 Soil Chemical Characteristics of the Experimental Site.

Block	Depth (cm)	pH	N (%)	P (ppm)	C (%)	C/N ratio
A	0-30	6.1	0.08	4	1.38	10.0
B	0-30	6.1	0.11	19	2.44	12.9
C[1]	0-30	7.5	0.14	23	2.18	9.1
C[2]	0-30	7.0	0.06	24	0.88	8.5
D	0-30	7.0	0.17	14	3.06	10.5

[1] and [2] represents regions of Block C showing better crop performance (middle of block) and stunted crop growth (ends of block) respectively.

3.3 Experimental Materials and Equipment.

3.3.1 Manure and Seed

Commercially available Katumani maize (Composite B) seed was planted. This variety is the most widely grown in semi-arid Machakos District. Farmyard manure (mixture of cow-dung and grass/crop straw) was added as a soil amendment in all plots.

3.3.2 Cone Penetrometer

An Eijkelkamp (Netherlands) analogue cone penetrometer was used in this study. This instrument measured the penetration resistance, of the surface layer, by means of a calibrated compression spring. The instrument was pushed vertically and readings were taken upto 12 cm depth (the maximum depth for the penetrometer). Penetration resistance measurements were carried out on the same day moisture samples were obtained.

There were two cone types (0.25 and 0.5 cm^2) and three kinds of compression springs (50, 100, and 150 N). A particular combination of a cone and a compression spring could be selected depending on the penetration resistance to be expected.

A slip ring on a graduated scale was taken along as the spring was compressed, so it indicated the maximum compression measured. Using spring constants and cone areas, the compression could be translated into penetration resistance (see Appendix 11).

3.3.3 Relief Meter

The microrelief-meter used in this study was essentially a modified version of the one designed by Kuipers (1957). The equipment consisted of a 120 by 25.5 cm mainframe made by joining 5 cm wide and 2 cm thick aluminium bars (see Plate 3). Across the middle of the frame was a hollow needle locking bar. Both the frame and the bar had twenty needle holes which were drilled through them for height measuring needles to slide in. At the corners of the frame were fixed two base plates for supporting the frame. The needles were held in position by the locking bar, which in turn was controlled by means of a locking knob and tube.

The foot of each needle had two small rings placed a distance of 2 cm apart. The lower ring prevented penetration into the soil and the upper one prevented dirt which stuck to the foot of the needle from getting into the frame. For transport the needles were bolted back into position and the equipment lifted.

3.3.4 Tillage Implements

Two, animal drawn, tillage implements were used, the Bukura Mark II mouldboard plough and a cultivator. The multipurpose toolbar (to which the implements were attached) was pulled by the animals by means of a chain hooked to the yoke (see Plate 1).

The cultivator used had five, 5 cm wide tines placed 9 cm apart (see Plate 2). The middle tine was 45 cm ahead of the others along the direction of travel. The use of this implement caused little soil disturbance.

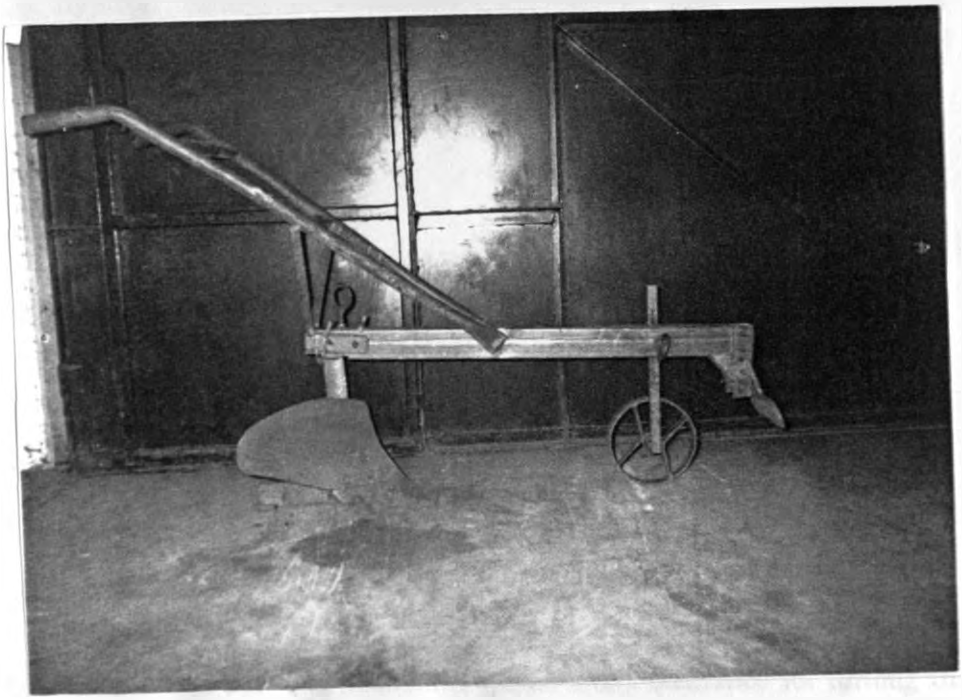


Plate 1. The Multipurpose Toolbar Attachment.

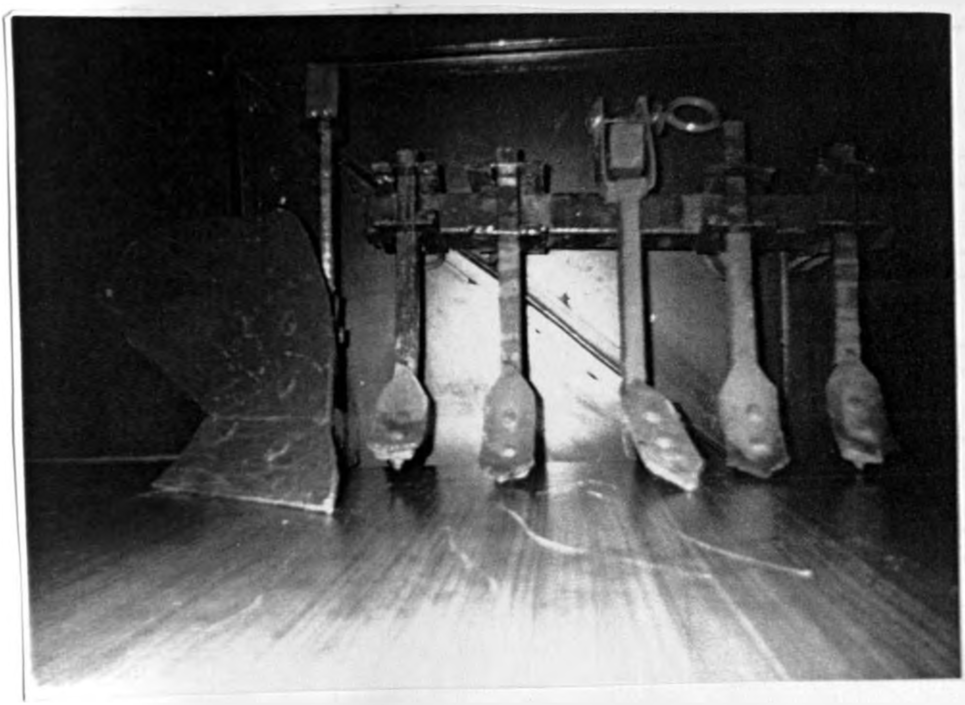


Plate 2. The Detachable Mouldboard Plough and Cultivator Units.

3.4 Experimental Layout and Design.

Experimental Layout

The experimental layout had; each plot with an area of 60 m^2 (3 by 20 m), a boundary of one metre between treatments (plots) and a clearance for turning of at least 4 m. The largest side of the plots was laid out across the slope. The average gradient of the experimental site was 4%.

The following was the layout of experimental plots at Iiuni site;

Short rains, 1993 Season	Block A Average slope=7%	STM	NT	DTC	DTM	STC
	Block B Average slope=6%	DTM	STC	STM	NT	DTC
	Block C Average slope=2%	STM	DTC	NT	STC	DTM
Long rains, 1994 Season	Block A Average slope=7%	DTC	STM	STC	NT	DTM
	Block B Average slope=6%	STM	STC	DTM	DTC	NT
	Block C Average slope=2%	NT	DTM	STC	DTC	STM
	Block D Average slope=2%	DTM	STC	DTC	STM	NT

Where;

NT = No-till
DTM = Deep mouldboard tillage
STM = Shallow mouldboard tillage
DTC = Deep cultivator tillage
STC = Shallow cultivator tillage

Soil analysis carried out at the end of the long rains season (1994) indicated that the soil pH varied from slightly acidic to slightly alkaline (pH 6.1 - 7.5). Available phosphorus (P) was adequate (14 - 25 ppm) except in block A which had an inadequate amount (4 ppm).

Nitrogen (N) levels were low (0.06 - 0.17 %), probably because microbial activity was considerably reduced by prevalent low pH values. Organic matter content (C) was moderate (2.13 - 3.06%) except in blocks A and C^2, which had 1.38 and 0.88% respectively (see Table 3.2).

Experimental Design.

The experimental design was a randomized complete block design with 3 and 4 replications (for short, 1993 and long, 1994 rains seasons respectively). The statistical model was used in evaluating five tillage treatments. Treatment means were compared using the Duncans' multiple-range test. The Duncans' multiple range test allowed multiple comparisons to be made between treatment means with a single least significant difference (lsd) value.

The treatments were as follows;

NT - No-till with the only soil disturbance being in digging holes for planting. Planting was done manually by dropping the seeds on the dug holes and covering them to approximately 5 cm deep.

DTM - Preplant tillage was mouldboard ploughing to an average depth of about 17 cm (this was referred to as deep mouldboard tillage).

STM - Preplant tillage was mouldboard ploughing to an average depth of about 11 cm (this was referred to as shallow mouldboard tillage).

DTC - Preplant tillage was cultivating to an average depth of about 10 cm (this was referred to as deep cultivator tillage).

STC - Preplant tillage was cultivating to an average depth of about 7 cm (this was referred to as shallow cultivator tillage)

3.5 Treatments.

3.5.1. No - Till

After land clearing, the residue was left on the surface as mulch. Planting was done manually at the recommended rates, for Katumani maize seed, with manure application. All surfaces remained undisturbed except at the holes where seeds were sown. Weed control was achieved by use of a flat jembe so that weeds were cut and left on the surface with minimal soil disturbance.

3.5.2 Cultivator - Tillage

After land clearing, residue was left on the surface and tillage done using the cultivator. The depth of tillage was controlled by use of the gauge wheel and hitching point adjustment, to achieve deep tillage (10 cm) and shallow tillage (7 cm) for each replication. The depth control was not very accurate but relative depths were performed from which deep and shallow tillage were obtained. Planting was done at the recommended rates, for Katumani maize seed, with application of manure in the planting holes. Thereafter weeding and cultivation were done manually using a hoe with minimal soil disturbance. Weeding was done three times at intervals of about 3 weeks.

3.5.3 Mouldboard - Tillage

For the mouldboard tillage treatments, the plots were cleared and mouldboard ploughed to average depths of 11 and 17 cm, shallow and deep tillage respectively. Planting was done manually on the dug holes with manure application. Weed control was done by use of a hoe. Weeding was done 3 times at intervals of about three weeks.

3.6 Experimental Procedure.

3.6.1 In-field Measurements

The effective total period of the experiment was 6 months divided into two experimental phases of 3 months each. The phases were short rains season, 1993 and long rains season, 1994.

In each phase the operations performed were; seedbed preparation, planting and weeding. Draft requirements, seedling emergence, plant height and crop yield were monitored. Soil properties determined included soil moisture, bulk density, surface roughness and soil strength.

To obtain the initial soil conditions soil samples (for moisture content and bulk density) were collected at the time of penetration resistance measurements, for a depth of up to 30 cm prior to seedbed preparation. Three samples were collected per plot and average obtained.

Draft measurements, using a hydraulic dynamometer, was accomplished during seedbed preparation. Immediately after seedbed preparation, surface roughness was taken before other factors that could influence the roughness set in. Before the first weeding, during the long rains season (1994), surface roughness readings were again obtained to evaluate the effect of rainfall on the microrelief created by tillage. The relief meter was placed horizontally during measurement by means of a spirit level attached at the top centre of the frame. When the bar holding the needles was loosened, all the needles slid down till they touched the surface. Each observation gave 20 readings from the 20 needles. On a slope the board was placed parallel to the soil surface.

Seeding was done at a spacing of 90 cm between the rows and 30 cm within the row giving a population of approximately 37,037 plants per hectare for all plots. Two seeds were planted per hill and thinned to one plant two weeks after germination. The number of seedlings in each row was recorded daily as the seedlings were emerging, starting with the day of first emergence to the day when the emergence was established as complete.

Weed control in all plots was carried out with a hand hoe, except in no-till plots where a flat jembe was used in order to reduce the soil disturbance to a minimum. Planting was at approximately 5 cm depth for all treatments.

The early maturing stress torrelant Katumani maize seed was grown during all the seasons and approximately 7 tonnes/ha of farm yard manure added.

Post-tillage soil physical conditions (bulk density, soil moisture and penetration resistance) were then measured to determine any changes that had occurred following tillage. Readings for the penetration resistance were taken in the row at a depth of 12 cm. Samples for soil moisture and bulk density were also obtained in the row near the points of penetration resistance readings at different crop stages over the cropping periods.

Plant height measurements were taken 30 days after planting and the measurements repeated every month until harvesting.

Maize was harvested at the end of the crop growing periods so that grain and dry matter yield comparisons could be made.

3.6.2 Calibration of Dynamometer

This was done for the short, 1993 and long, 1994 rains seasons before the start of land preparation. A 200 kg dial scale dynamometer was used to calibrate the hydraulic dynamometer. The sensor of the hydraulic dynamometer was connected in series with the dial dynamometer. Tractor weight provided resistance to the tensile load, which was applied through the hoist.

The dial dynamometer was loaded at intervals of 20 kg by pulling on one of the chains of the hoist and corresponding hydraulic dynamometer readings noted. The whole procedure of loading and unloading was repeated four times. The loading and unloading values of the hydraulic dynamometer for the same value of dial dynamometer were different because of hysteresis. To account for this, the averages of corresponding loading and unloading values were used to make the calibration curves. Results were as shown in Figures 3.2 and 3.3. The X-axis has hydraulic dynamometer readings plotted against dial dynamometer readings (reference load).

The calibration curves showed that there were some differences in the calibration equations each time the dynamometer was calibrated, hence the need to recalibrate. Otherwise the percentage error due to non calibration would have been significant. This could have had an appreciable effect on the draft obtained and hence on the conclusion.

The source of error in dynamometer is predominantly due to hysteresis. This is especially so if the dynamometer is not allowed sufficient time to settle and if it measures loads near its limit. As a result, permanent deformation could occur in the dynamometer parts necessitating continuous calibration and recalibration.

The dynamometer that was used had a hydraulic sensor. Some small quantities of fluid were noticed to be leaking out of the sensor, this was another reason which necessitated dynamometer recalibration. Ideally the calibration should have been done on a daily basis, but this was not practical. The compromise of calibrating once per season was adopted.

The recording hydraulic dynamometer was calibrated against a dial scale dynamometer.

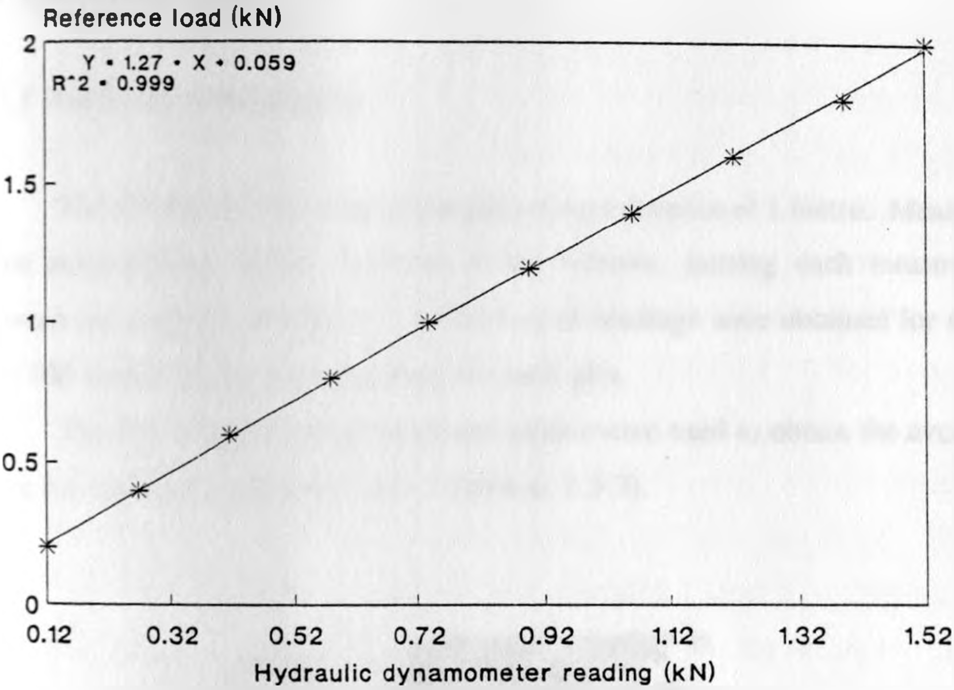


Figure 3.2 Dynamometer Calibration Curve for the short rains, 1993.

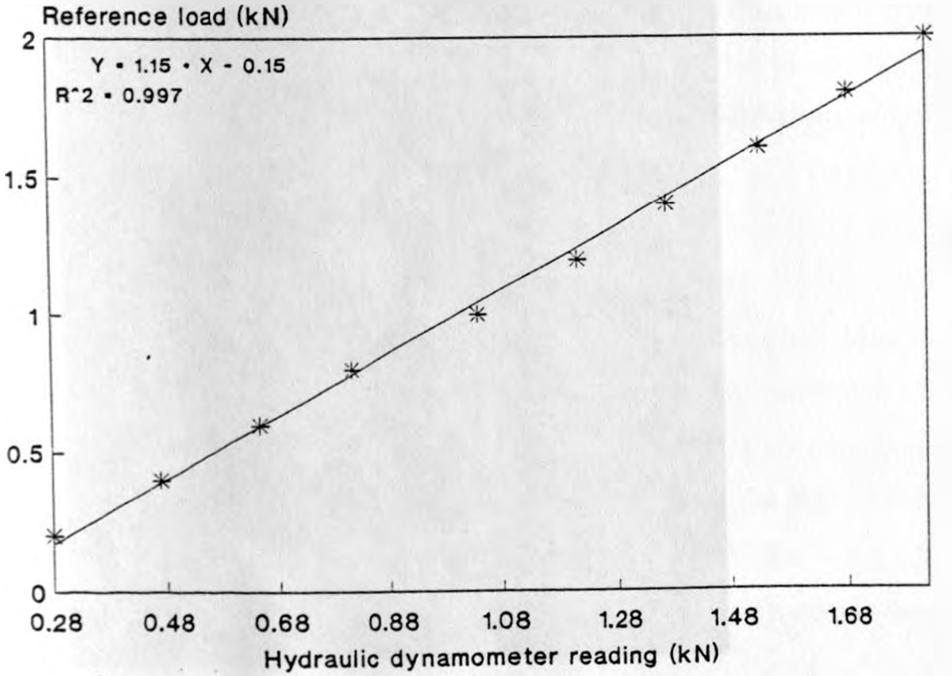


Figure 3.3 Dynamometer Calibration Curve for the long rains, 1994.

3.7 Collection of Data.

3.7.1 Soil Surface Roughness

The relief meter recorded 20 heights along a distance of 1 metre. Measurements were made perpendicular to the direction of the furrows, starting each measurement exactly between two furrows (see Plate 3). Five sets of readings were obtained for each treatment, thus 100 height values were obtained for each plot.

The five sets of surface roughness values were used to obtain the average roughness value for each plot, using equation 2 (section 2.3.3).

Plate 3. Micro-structure Measurement using the Relief Meter.

3.7.2 Soil Moisture, Bulk Density and Penetration Resistance

Soil samples for bulk density and moisture were obtained at depths of upto 30 cm (approximate rooting depth for Katumani maize - composite B). Three soil samples were obtained for every plot at each sampling interval and average got. The ring for obtaining the sample was driven into the soil up to the intended cutting depth. The sample was then removed, trimmed and covered by the plastic lids to prevent moisture loss. Samples were weighed using an electronic balance and dried in the oven at 105 ^{0}C for 24 hours.
Available water content (AWC) is the volume of water retained between field capacity (FC) and permanent wilting point (PWP). FC was determined using pressure plates as moisture content correponding to -0.33 bar potential (-33kPa, 330 cm water or pF 2.5). PWP was taken as the moisture content at -15 bar water potential (pF 4.2 or 15000 cm of water). Samples (5 for each FC and PWP) for pF test were placed under the pressure plates for 24 hours. Moisture contents were determined and averages obtained.

Soil moisture was obtained as the ratio of weight of water to weight of solids and then converted to volumetric basis to obtain millimetres of water for the 30 cm soil depth. Bulk density was determined as the ratio of solids to total volume of soil sample.

A hand held cone penetrometer was pushed into the soil at a relatively constant rate (approximately 2 cm s^{-1}) and Equation 1 (section 2.3.1) employed to calculate the penetration resistance. Five set of values were obtained per interval per plot and average got.

3.7.3 Width and Depth of Cut

Pegs were placed on each side of block directly opposite each other in line with the tillage direction. The pegs were used as reference points while measuring the width tilled.

After opening the first furrow (lead furrow), a tape measure was placed between the opposite pegs across the block and the distance between the furrow edge and the pegs on one side noted. After each consecutive run, this distance was recorded. The width tilled was then obtained by subtracting two consecutive readings from every point and average obtained from five width values.

Operating depth was controlled by adjusting the multipurpose tool-bar gauge wheel and the hitch point. It was measured at the same opposite pegs as the width. Operating depth was measured by inserting a steel tape measure into the tilled furrow until the hard surface at the bottom of the trench was felt. Then a straight edge was positioned on the original field surface adjacent to the tillage pans and forced through the mould of soil thrown up by the implement. Distance from the intersection point of the straight edge and the tape measure, down to the bottom of the trench was taken as the tillage depth. Five readings were obtained for each furrow and an average computed.

3.7.4 Draft and Velocity

A recording hydraulic dynamometer was used for draft measurements, from which a dynamogram (graphical representation of draft over time for a given run) was obtained. The dynamometer had provision for placement on the beam of the toolbar and was held firmly in position.

The dynamometer was switched on as soon as the animals started working and switched off at the end of a 20 m run. Allowance was made for stabilisation at the start and end of the run. Allowance of 2.5 m distance was kept on both sides. From the data collected (from the dynamogram) for each furrow an average draft was obtained. Draft requirements for the tillage practices were obtained from the averages of the draft values for four runs made.

The operating speed (ground speed) was evaluated by measuring the time taken to travel over the distance of 20 m. Each run was timed with a stop-watch.

Draft power values were computed as the product of speed of operation and the draft.

3.7.5 Seedling Emergence and Crop Height

The tillage systems were compared for their effect on seedling emergence using an Emergence Rate Index (ERI), obtained using Equation 3 (section 2.5.1). Emergence rate index was determined (for each tillage practice) from the average value of the three and four different plots, for the short, 1993 and long, 1994 rains seasons respectively.

Since the number of rows in each plot were three, crop height measurements were carried out from the middle row and average height for each plot recorded (see Plate 4).

Plate 4. Crop Height Measurements at the Experimental Site during the long rains, 1994.

3.7.6 Crop Yield

Harvesting of test crops during the short, 1993 and long, 1994 rains seasons were carried out in February, 1994 and in June, 1994 respectively. The harvested maize was stalked until the shelling moisture content was attained, then moisture content was determined for each block (using representative grain samples) with a portable moisture meter. The grain moisture content was then adjusted to 13.5 % (w/w, wet basis). Thus, the grain yields were reported on a 13.5 % (w/w, wet basis) which is the equilibrium storage moisture content for maize. After shelling, the yield from each plot was obtained by weighing on an electronic balance (Fortec CR-107) and the weights recorded in kilograms per hectare.

The dry matter yield was obtained from the maize stover and cobs from each plot. It was obtained by weighing them on a 50 kg spring balance and recording the mass in kilograms per hectare. Maize stover weight measurements were made in the field.

4. RESULTS AND DISCUSSION

4.1 Implement Performance.

The results on implement performance was in draft power (kW) requirements. During the short rain season (1993), deep mouldboard tillage (DTM) had the highest average draft power requirements of 1.00 kW followed by deep cultivator tillage (DTC) (0.85 kW) and shallow cultivator tillage (STC) (0.78 kW). Shallow mouldboard tillage (STM) had the lowest power requirements of 0.67 kW (see Table 4.1 and Fig. 4.1). During the long rains season (1994), average power requirements were highest for DTC with a value of 0.96 kW (Table 4.2) followed by DTM (0.91 kW), STC and STM (0.77 kW).

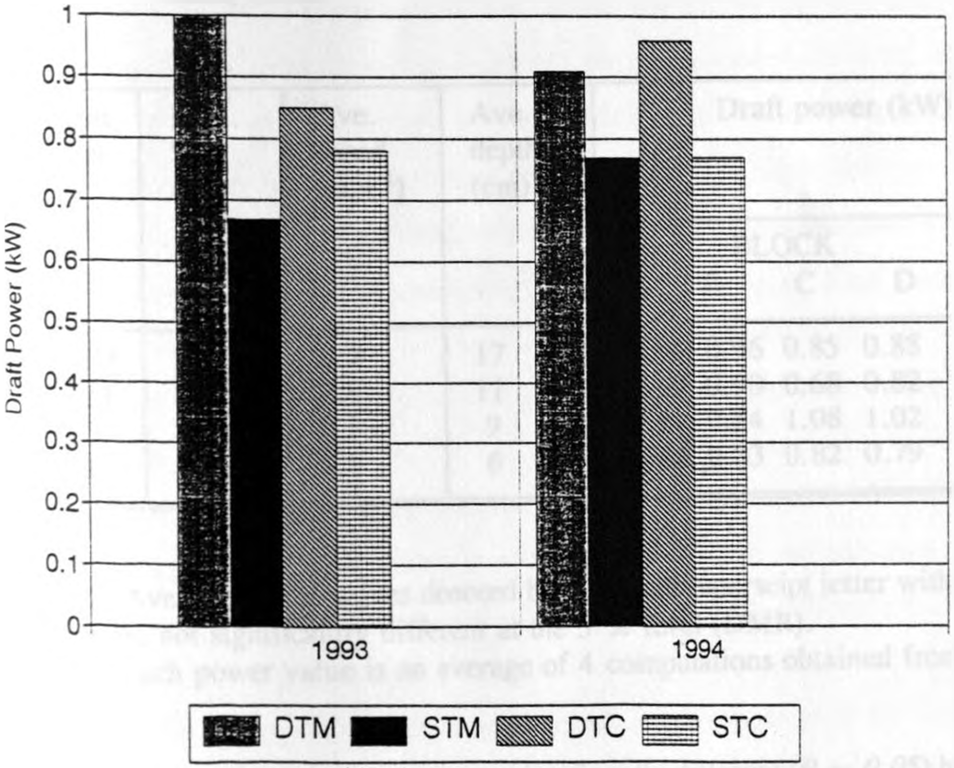


Figure 4.1 **Draft power requirements of the different treatments during the SR'93 and LR'94 seasons.**

Table 4.1 Draft power requirements of the different Implements for the short rains, 1993.

Treatrement	Impl. Wt. (kg)	Average speed (m s^{-1})	Ave. depth (cm)	Draft Power (kW)			Ave. Power
				BLOCK A	B	C	
DTM	32	0.8	17	1.03	0.93	1.03	1.00^{a}
STM	32	0.9	10	0.69	0.69	0.64	0.67^{c}
DTC	39	0.8	11	0.83	0.73	1.00	0.85^{ab}
STC	39	0.8	8	0.84	0.78	0.72	0.78^{bc}

Table 4.2 Draft power requirements of the different Implements for the long rains, 1994.

Treatment	Impl. Wt. (kg)	Ave. speed (m s^{-1})	Ave. depth (cm)	Draft power (kW)				Ave. Power
				BLOCK A	B	C	D	
DTM	32	0.7	17	0.96	0.96	0.85	0.88	0.9^{ab}
STM	32	0.8	11	0.69	0.90	0.68	0.82	0.77^{b}
DTC	39	0.8	9	0.91	0.84	1.08	1.02	0.96^{a}
STC	39	0.8	6	0.65	0.83	0.82	0.79	0.77^{b}

Note: - Average power values denoted by the same superscipt letter within the same column are not significantly different at the 5 % level (DMR).
- Each power value is an average of 4 computations obtained from 4 furrows.

The power requirements were significantly different ($P = 0.05$) between shallow and deep tillage treatments for both rain seasons (see Appendix 1). The deep tillage treatments like the shallow tillage treatments had similar power requirements (based on the DMR test). The general trend showed an increase in power requirements with increasing depth of tillage for the implements. Overall, DTM showed the highest draft power requirement while STM showed the lowest.

The high draft power requirements (at low depth of tillage) for the cultivator could be associated with its greater weight of 39 kg as compared to the weight of the mouldboard of 32 kg. Again the loosening of the soil with the cultivator was minimal as penetration in these hard soils was difficult and the implement frequently became blocked with trash. Collins (1920) cited by Bernacki (1972) showed that implement weight contributed to as much as 20% to increase in draft requirements. Summers et al. (1986) and Smith (1992) observed that draft requirements increased with increasing depth of tillage and width of cut of the implement.

Draft power requirements were relatively similar between the two seasons. DTM had lower power requirements in the LR'94 season possibly due to the residual tillage effects from the SR'93 season and also the rain had started (erratic showers in February) at the time of land preparation for LR'94 season. This made the soils less hard which may explain the resulting low draft power requirements. STM, for LR'94 season, showed increased power requirements due to the the high depth (11 cm) as compared to depth of 10 cm for SR'93. DTC and STC showed increased power requirements in LR'94 season at lower depths due to blockage by trash which increased draft and impaired implement penetration. The speed of operation was maintained relatively constant over the seasons and between implements.

Generally the draft power requirements were higher than those reported by other scientists elsewhere. Most likely, the hard soils and weight of the multipurpose toolbar contributed to higher draft power requirements and especially during deep tillage which resulted in animal fatigue.

Since the performance of these implements was evaluated under similar conditions between the two seasons (surface soil conditions, draft animal used and soil types) any differences in the performances was taken to be due to the differences in the implements and the monitored depth of tillage.

Although the STM had the lowest draft power requirements it is important to note that the depths attained with the DTM were high and therefore contributed to the relatively high draft power.

4.2 Soil Response to Treatments.

4.2.1 Bulk Density and Penetration Resistance

The bulk density profile is shown, for block A, in Figure 4.2. For bulk density data and Figures see Appendix 2.

Soil bulk density and penetration resistance tended to increase under low soil moisture conditions and to decrease under high soil moisture (after a rainstorm) showing that soil moisture had a high influence on both bulk density and penetration resistance. High bulk density and penetration resistance are known to impede root growth leading to poor water and nutrient extraction from deep soil horizons. They also lead to inadequate aeration and subsequently to poor crop performance.

From Figure 4.2, over the SR'93 season STC showed highest bulk density profile followed by DTC, DTM, NT and STM respectively. For the LR'94 season, NT showed highest bulk density profile followed by DTM, STC, STM and DTC respectively.

During the LR'94 season the lower bulk densities compared to the SR'94 season, could be due to the higher water storage and residue tillage effects from the previous season. Furthermore tillage in the LR'94 season was performed immediately after harvesting the previous crop. The high initial bulk densities for the SR'93 season were attributed to the dry spell (April to October) which increased soil cohesion through loss of soil water. Initially after tillage and wetting by the rains the bulk densities decreased and did not increase to the initial levels even after the recompaction by rain drop impact and surface crusting. It was observed that profile bulk densities were highly dependent on the initial bulk densities.

Soil bulk densities greater than 1600 kg m^{-3}, for sandy and loamy soils, have been reported to show restricted root growth (Willcocks, 1981; Landon, 1991). The values for bulk density obtained in all the treatments, during the crop growing periods, were lower than those reported to restrict root growth.

Although cases of restricted root growth could not be completely quantified, plots (e.g. no-till) showing lower rooting depths were found to have shorter plant height and lower dry matter yield.

For the SR'93 season the highest average decrease in bulk density after the tillage

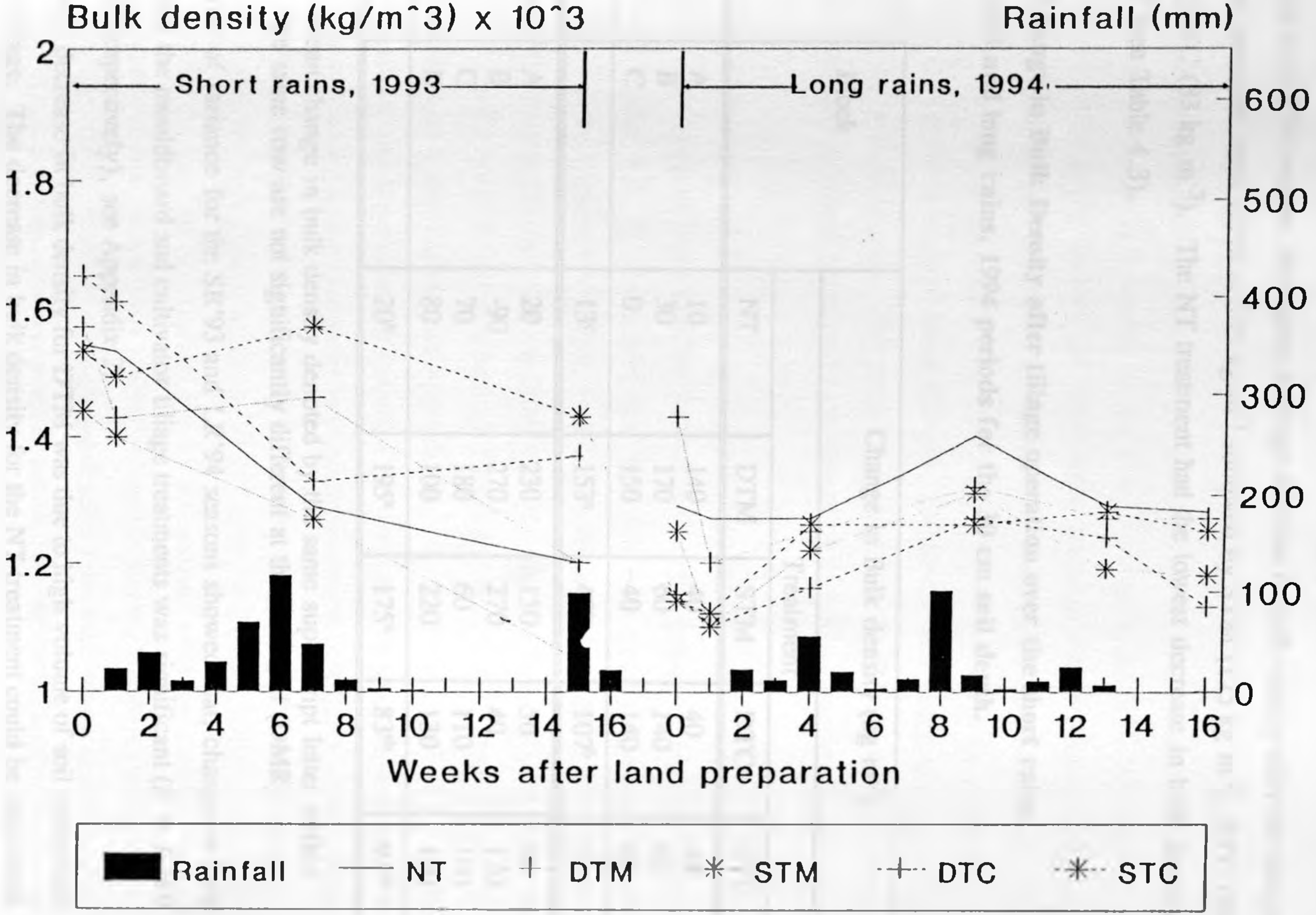


Fig. 4.2 Variation of Bulk Density for the treatments at 30 cm soil depth for block A during the short rains, 1993 and long rains, 1994 seasons.

operation was obtained from DTM, an average figure of 153 kg m^{-3} followed by DTC (107 kg m^{-3}), STC (53 kg m^{-3}), STM (47 kg m^{-3}) and NT (13 kg m^{-3}).

During the LR'94 season, the highest average decrease in bulk density after the tillage operation was obtained from DTM of 195 kg m^{-3} followed by STM (175 kg m^{-3}), STC (93 kg m^{-3}) and DTC (83 kg m^{-3}). The NT treatment had the lowest decrease in bulk density of 20 kg m^{-3} (see Table 4.3).

Table 4.3 Change in Bulk Density after tillage operation over the short rains, 1993 and long rains, 1994 periods for the 30 cm soil depth.

Year	Block	Change in Bulk density (kg m^{-3})				
		Treatment				
		NT	DTM	STM	DTC	STC
Short rains, 1993	A	10	140	40	40	40
	B	30	170	60	140	60
	C	0	150	40	140	60
Average		13^{c}	153^{a}	47^{c}	107^{b}	53^{c}
Long rains, 1994	A	20	230	150	50	20
	B	-90	270	270	40	130
	C	70	180	60	110	100
	D	80	100	220	130	120
Average		20^{b}	195^{a}	175^{a}	83^{ab}	93^{ab}

Note: Mean change in bulk density denoted by the same superscript letter within the same row are not significantly different at the 5% level (DMR).

Analysis of variance for the SR'93 and LR'94 seasons showed that, change in bulk density between the mouldboard and cultivator tillage treatments was significant (*$P = 0.001$ and $P = 0.05$* respectively), see Appendix 2.

The high decrease in bulk density for DTM was due to high volume of soil pulverised through deep tillage. The decrease in bulk density for the NT treatment could be associated with the rainfall which increased the water storage in the profile and thus decreased the bulk density. The low decrease in bulk density for the STM, during the short rains (1993) could not be quantified but probably the rain drop impact compacted the otherwise loose soil.

In the LR'94 season DTC and STC had relatively low and similar decrease in bulk density. The difference in depths attained for these treatments was not high and the cultivator left some areas untilled (between the tines). Whenever such areas were sampled the decrease in bulk density would be low.

The decrease in bulk density was attributed to the rain and tillage practice. The tillage practice increased the soil moisture storage, loosened the soils and thus decreased the bulk density. The decrease in bulk density of the tilled layer appeared to be temporary, as by the end of the crop growing seasons (14 weeks after planting) the favourable effects of tillage had disappeared as soil cohesion had increased. Recompaction of the previously loosened soil by the rain drop impact and resettling of the soil mass in response to desiccation were the probable cause of these changes. Otherwise weed control on all tilled plots was carried out with hand hoes. This suggested a high degree of instability of the soil aggregates and probably the large pores readily collapsed as the soil was wetted by the rain.

The penetration resistance values were obtained from the surface layer 0-12 cm deep. Figure 4.3 show the variation in penetration resistance over the crop growing periods for block B. From Figure 4.3, It is observed that over the crop growing period the NT treatment maintained the highest penetration resistance profile while DTM had the lowest profile. The other treatments were intermediate with the profiles being inconsistent, but generally DTC had a higher penetration resistance profile followed by STC and STM. For penetration resistance data and Figures see Appendix 3.

An increase in soil compaction as indicated by resistance to penetration can lower crop yields because the depth of root penetration and proliferation is reduced. Cone Index values greater than 2.0 MPa have been reported to reduce crop yields and values above 1.5 MPa frequently restricted root growth (Gaultney et al., 1980; Willcocks, 1981; Threadgill, 1982; Busscher and Sojka, 1987). During the SR'93 season, only the no-till plot had penetration resistance values greater than 1.5 MPa which is known to restrict root growth, at about the tasselling stage. Probably the high penetration resistance values restricted root growth and proliferation and thus the lower yield obtained from the no-till treatment. In the LR'94 season at about the tasselling stage all treatments showed penetration resistance values greater than the root growth restricting level. Yields in the LR'94 season were lower than for the SR'93 season. Probably the high penetration resistance values observed at about the tasselling stage (7th week) contributed to the lower yields during the long rains season, 1994.

For the SR'93 season, DTM had the highest decrease in penetration resistance of 1.69 MPa followed by STM (1.16 MPa), DTC (0.94 MPa), STC (0.80 MPa) and NT (0.02 MPa). During the LR'94, DTM had the highest decrease in penetration resistance of 0.57 MPa followed by STM (0.47 MPa), DTC (0.38 MPa) and STC (0.28 MPa). The NT treatment had the lowest decrease in penetration resistance of 0.01 MPa (see Table 4.4).

Table 4.4 **Change in Penetration Resistance after the tillage operation for the different treatments over the short rains, 1993 and long rains, 1994 periods for the 12 cm soil depth.**

Year	Block	Change in Penetration resistance (MPa)				
		Treatment				
		NT	DTM	STM	DTC	STC
Short rains 1993	A B C	0 0.05 0.01	1.37 1.88 1.82	1.19 1.53 0.76	0.74 0.86 1.22	0.51 0.97 0.92
Average		0.02^{c}	1.69^{a}	1.16^{b}	0.94^{b}	0.80^{b}
Long rains 1994	A B C D	0.05 -0.01 0.01 0	0.57 0.04 0.67 0.99	0.43 0.57 0.34 0.54	0.46 0.16 0.59 0.32	0.07 0.42 0.08 0.54
Average		0.01^{b}	0.57^{a}	0.47^{a}	0.38^{a}	0.28^{ab}

Note: Mean change in penetration resistance denoted by the same superscript letter within the same row are not significantly different at the 5% level (DMR).

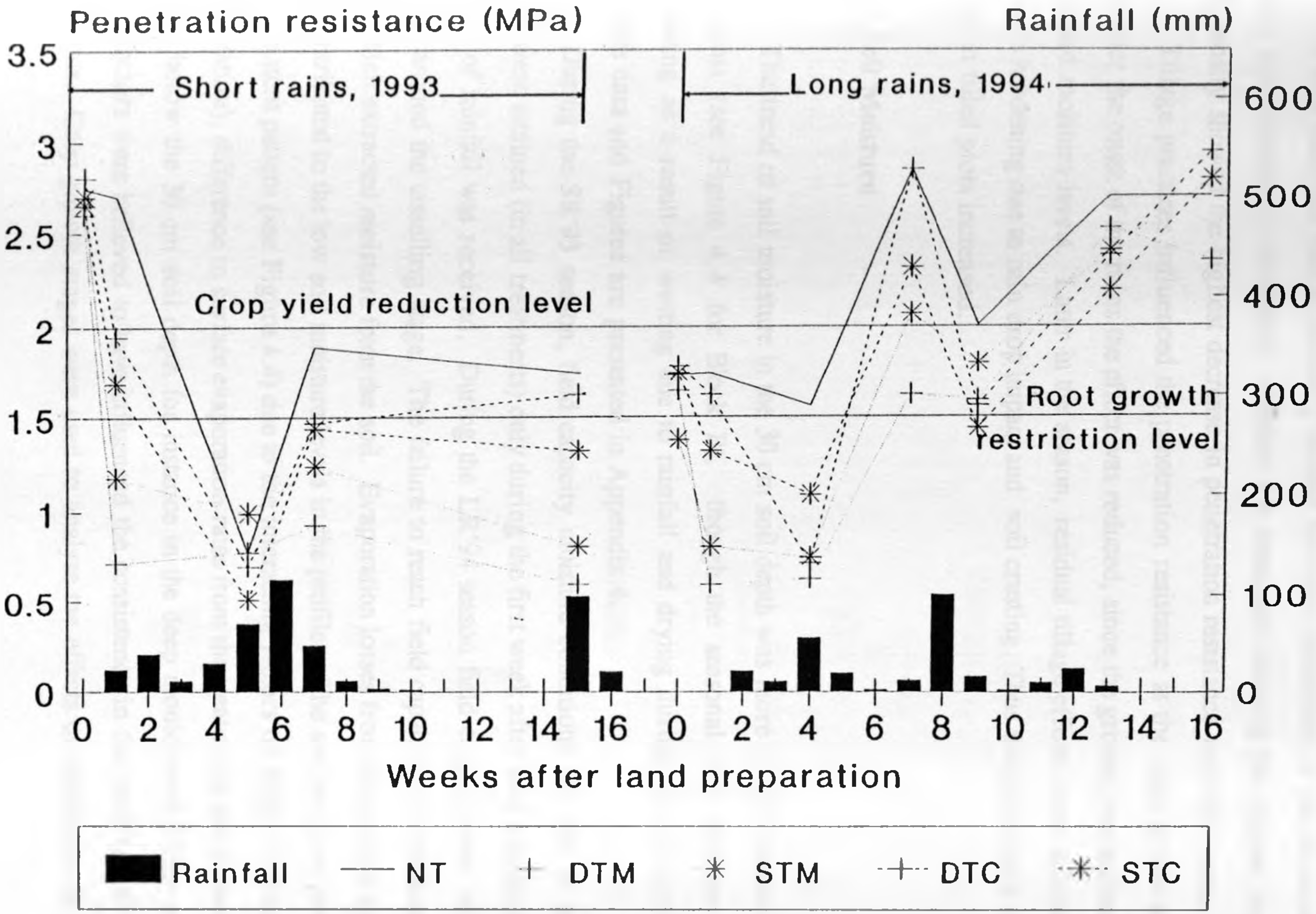


Fig. 4.3 Variation of Penetration Resistance for the treatments at 12 cm soil depth for block B during the short rains, 1993 and long rains, 1994 seasons.

During the SR'93 and LR'94 seasons, change in penetration resistance between treatments was significant (P = 0.001 and P = 0.05 respectively), see Appendix 3.

It was observed that a similarity existed between treatments in the decrease in bulk density and penetration resistance, whereby the treatment showing the highest decrease in bulk density showed the highest decrease in penetration resistance and vice versa.

Tillage practices influenced the penetration resistance at the start of the season but soon after the onset of the rains the effect was reduced, since the ground was softened by the increased moisture levels. Later in the season, residual tillage effects were minimal due to the soils hardening due to rain drop impact and soil crusting. Thus the penetration resistance values in tilled plots increased.

4.2.2 Soil Moisture

The trend of soil moisture in the 30 cm soil depth was more or less similar under all treatments (see Figure 4.4 for Block B), though the seasonal soil moisture kept on fluctuating as a result of wetting due to rainfall and drying during the dry spells. Soil moisture data and Figures are presented in Appendix 4.

During the SR'93 season, field capacity moisture conditions (65 mm in the 30 cm depth) were attained (in all treatments) only during the first week after land preparation when 35 mm of rainfall was received. During the LR'94 season field capacity was not attained until at around the tasselling stage. The failure to reach field capacity was attributed to the crop which extracted moisture from the soil. Evaporation losses from the surface could have also contributed to the low soil moisture levels in the profiles. The soil moisture profiles had no consistent pattern (see Figure 4.4) due to the interacting factors of; crop (which extracted soil moisture), difference in surface evaporation rates from the treatments and probable water storage below the 30 cm soil depth for instance in the deep mouldboard tillage treatment. These factors were believed to have influenced the consistency in the profiles soil moisture conditions. Crop growth stages were used to analyse the effects of treatments on moisture storage.

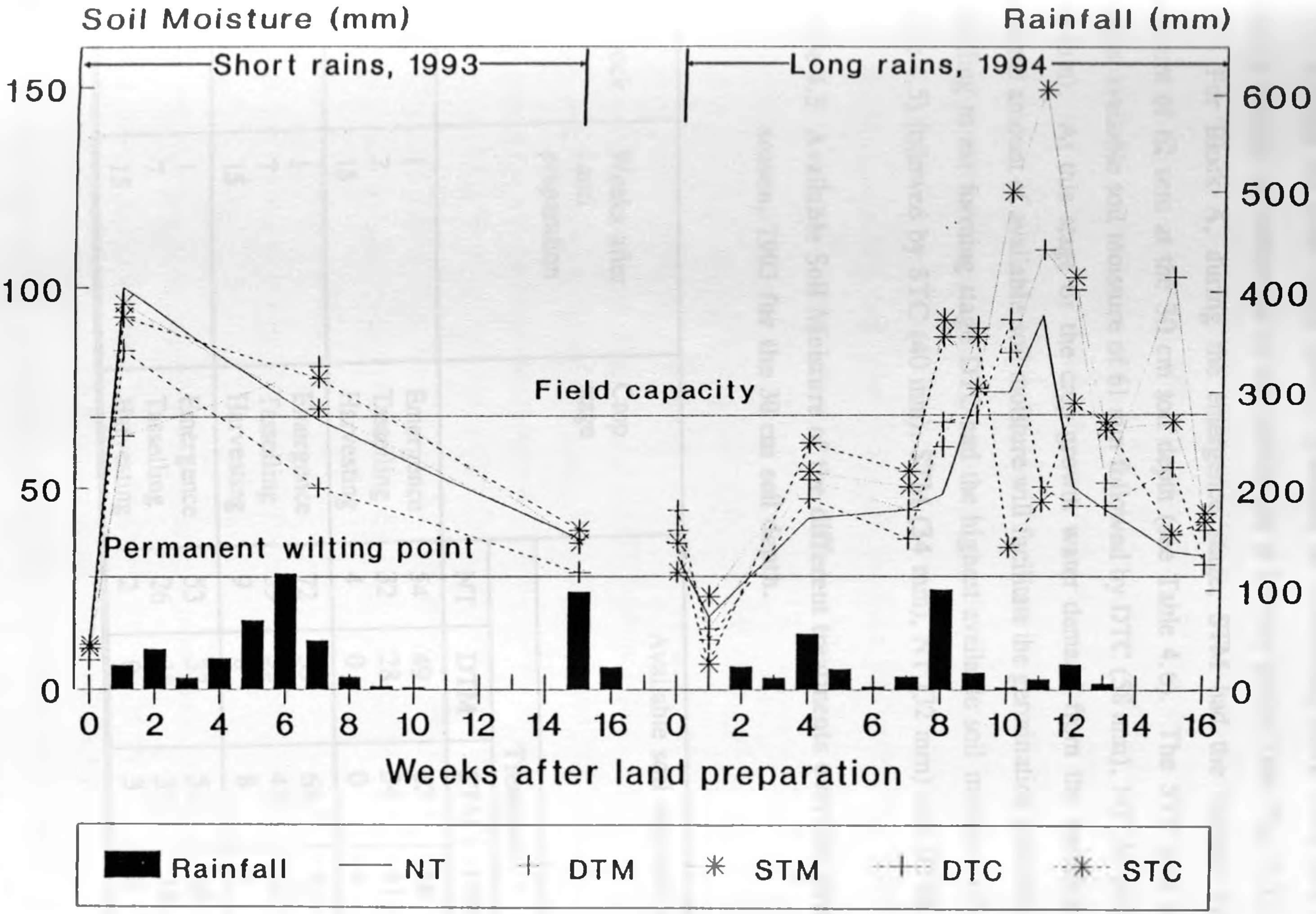


Fig. 4.4 Variation of Soil Moisture for the treatments at 30 cm soil depth for block B during the short rains, 1993 and long rains, 1994 seasons.

Short rains, 1993

During the short rains period (October to December) there were low amounts of monthly rainfall as compared to the rainfall for a 16-year period (see Fig. 3.1).

For Block A, during the emergence stage, STM had the highest available soil moisture of 62 mm at the 30 cm soil depth (see Table 4.6). The STC plot had the next highest available soil moisture of 61 mm followed by DTC (58 mm), NT (54 mm) and DTM (49 mm). At this stage of the crop growth water demand from the seedling is low. A minimal amount of available soil moisture will facilitate the germination process. During the tasselling to ear forming stage DTC had the highest available soil moisture of 41 mm (see Table 4.5) followed by STC (40 mm), STM (34 mm), NT (32 mm) and DTM (28 mm).

Table 4.5 Available Soil Moisture of the different treatments over the short rains season, 1993 for the 30 cm soil depth.

Block	Weeks after Land preparation	Crop stage	Available soil moisture (mm)				
			Treatment				
			NT	DTM	STM	DTC	STC
A	1	Emergence	54	49	62	58	61
	7	Tasselling	32	28	34	41	40
	15	Harvesting	4	0	0	4	0
B	1	Emergence	72	35	68	57	65
	7	Tasselling	39	53	42	22	50
	15	Harvesting	9	8	8	1	11
C	1	Emergence	53	33	51	48	49
	7	Tasselling	26	38	31	38	30
	15	Harvesting	2	0	3	0	0

The crop in the DTM plot performed better as compared to the other treatments. This shows that most of the water was utilised by the crop and thus the reason for the low available soil moisture. The crop in STM performed poorly although the available moisture was high. Soil fertility was a probable reason for the poor yield. The relatively high available soil moisture for the DTC and STC plots was attributed to the low soil disturbance, Otherwise the yield from this plots were also high. Surface crust for the NT plot led to water runoff and thus the subsequently low available soil moisture and crop yield.

For Block B, at emergence stage, NT had the highest available soil moisture of 72 mm followed by STM (68 mm), STC (65 mm), DTC (57 mm) and DTM (35 mm). During the tasselling and ear forming stages, DTM had the highest available soil moisture of 53 mm followed by STC (50 mm), STM (42 mm), NT (39 mm) and DTC (22 mm). The soil moisture profile for the DTM plot was high due to the high depth of tillage which resulted in high surface roughness for depressional water storage and infiltration. The yield from this plot was also high. The STM plot had relatively low available soil moisture but the yield was high, showing that most of the soil moisture was extracted by the crop. The relatively low soil moisture for the DTC plot could be due to high evaporation water losses which led to poor crop yield.

For Block C, during emergence stage, the NT plot had the highest available soil moisture of 53 mm followed by STM (51 mm), STC (49 mm), DTC (48 mm) and DTM (33 mm). During the tasselling stage DTM and DTC had the highest available soil moisture of 38 mm each followed by STM (31 mm), STC (30 mm) and NT (26 mm). During the emergence stage soil moisture might have infiltrated beyond the 30 cm soil depth in the tilled plots and thus the lower amounts of available soil moisture. Similar observations were made in Block B. Soil moisture in the STC and STM plots were low but the crop yield was high. Probably most of water was extracted by the crop. The DTM and DTC plots had high available soil moisture which shows that moisture storage was enhanced by deep tillage. The NT plot had the lowest available soil moisture due to runoff water losses over the crusted soil surface.

The difference in available soil moisture at emergence was significant ($P = 0.05$) between blocks and treatments. Using the DMR test, the STM, NT, STC and DTC plots were found to have similar and high available soil moisture values. The DTM plot had low available soil moisture. Through deep tillage, with the mouldboard, most of the water might have infiltrated below the 30 cm soil depth explaining the reason for low available soil moisture, at the emergence stage. Blocks A and B had high available soil moisture than block C. Blocks A and B had the same soil type (sandy clay loam) while block C had a sandy loam soil with a high sand content. Probably the difference in soil texture contributed to the difference in available soil moisture whereby water from block C might have infiltrated deep into the profile. At the tasselling stage no significant difference was observed between treatments. The crop height in the plots was generally uniform and probably the reason for no difference in available soil moisture at the tasselling stage (see Appendix 4).

Long rains, 1994

During the long rains period (March to May), there were low amounts of monthly rainfall as compared to the rainfall for a 16-year period, except for the month of March.

Four weeks after planting, there was available soil moisture in all the treatments at the 30 cm soil depth.

For Block A, during the vegetative stage the STM plot had the highest available soil moisture of 30 mm followed by DTM (17 mm), DTC (14 mm), NT (12 mm). The STC plot had the lowest available soil moisture of 8 mm (see Table 4.6). During the tasselling and ear forming stage, DTM had the highest available soil moisture of 20 mm followed by STC (18 mm), STM (16 mm), DTC (14 mm) and NT (10 mm). From pollination to maturity STC had the highest available soil moisture (261 mm) followed by NT (213 mm), DTM (203 mm), DTC (200 mm) and STM (158 mm).

High water demand by the maize crop occurs from vegetative to maturity stage (Nadar, 1983). During this period the STC plot maintained the highest available moisture of 287 mm followed by DTM (240 mm), NT (235 mm), DTC (228 mm) and STM (204 mm).

The high amount of available soil moisture conserved in STC was associated with low soil disturbance during the tillage operation. The treatment had the highest crop yield showing that shallow tillage with the cultivator helped in conserving more soil moisture. The crop in the DTM and NT plots performed well showing that the conserved moisture was extracted by the crop, therefore explaining the reason for the relatively low amount of available soil moisture. The DTC and STM plots had low available soil moisture and yield compared to the other treatments. The plots were laid out at a raised part in the block and probably the water that infiltrated was lost through sub-surface flow down the slope. The slope for this block was 7 %. The crop yield in this block was low compared to the other blocks. Fertility analysis showed that the soil was deficient in organic matter, in the block,

Table 4.6 Available soil moisture of the different treatments over the long rains, 1994 season for the 30 cm soil depth.

Block	Weeks after Land preparation	Crop stage	Available soil moisture (mm)				
			Treatment				
			NT	DTM	STM	DTC	STC
A	1	Emergence	2	9	5	0	0
	4	Vegetative	12	17	30	14	8
	7	Tasselling	10	20	16	14	18
	8-13	Pollination-Maturity	213	203	158	200	261
	15	Harvesting	26	9	16	37	32
Total	4-13		235	240	204	228	287
B	1	Emergence	0	0	0	0	0
	4	Vegetative	14	24	26	19	33
	7	Tasselling	16	16	22	9	26
	8-13	Pollination-Maturity	215	325	437	198	226
	15	Harvesting	11	85	53	30	23
Total	4-13		245	365	485	226	285
C	1	Emergence	0	0	0	0	0
	4	Vegetative	16	14	26	28	4
	7	Tasselling	9	11	1	13	7
	8-13	Pollination-Maturity	167	244	142	295	259
	15	Harvesting	8	4	0	2	29
Total	4-13		192	269	169	336	270
D	1	Emergence	10	9	4	0	25
	4	Vegetative	27	40	24	22	34
	7	Tasselling	23	18	17	19	23
	8-13	Pollination-Maturity	218	266	226	242	212
	15	Harvesting	49	32	25	86	55
Total	4-13		268	324	267	283	269

thus explaining the reason for the relatively poor yield (for fertility analysis see Table 3.2).

For Block B, during the vegetative stage the STC plot had the highest available soil moisture of 33 mm at the 30 cm soil depth. This was followed by STM (26 mm), DTM (24 mm), DTC (19 mm) and NT (14 mm). During the tasselling and ear forming stage STC had the highest available soil moisture of 26 mm followed by STM (22 mm), NT and DTM (16 mm each) and DTC (9 mm). During the pollination to maturity stage STM had the highest available soil moisture of 437 mm followed by DTM (325 mm), STC (226 mm), NT (215 mm) and DTC (198 mm). During the vegetative to maturity period STM had the highest available soil moisture of 485 mm followed by DTM (365 mm), STC (285 mm), NT (245 mm) and DTC (226 mm).

The ploughing depth for STM was about 11 cm and probably the low rainfall that fell was retained in the 30 cm soil profile and was available to the crop which performed relatively well as compared to the other treatments in this block. For the DTM plot it was possible that water infiltrated beyond the 30 cm soil depth but was available to the crop as observed in the good crop performance (dry matter yield). The relatively high grain yield on the STC plot showed that most of the available soil moisture was extracted by the crop explaining the reason for the low available soil moisture. The NT and DTC plots had low available soil moisture and dry matter yield. For the NT plot the hard soil surface impaired the infiltration process and increased water runoff. The cause of the low soil moisture for the DTC plot was not well established. Evaporation water losses from this plot was a probable explanation to the low soil moisture and subsequently poor crop yield.

For Block C, during the vegetative stage DTC had the highest available soil moisture of 28 mm followed by STM (26 mm), NT (16 mm), DTM (14 mm) and STC (4 mm). During the tasselling and ear forming stage, DTC had the highest available soil moisture of 13 mm followed by DTM (11 mm), NT (9 mm), STC (7 mm) and STM (1 mm). During the pollination to maturity stage DTC had the highest available soil moisture of 295 mm followed by STC (259 mm), DTM (244 mm), NT (167 mm) and STM (142 mm). During the vegetative to maturity period DTC had the highest available soil moisture of 336 mm followed by STC (270 mm), DTM (269 mm), NT (192 mm) and STM (169 mm).

The crop in the DTC plot performed poorly and stunted growth was observed showing that the crop did not extract most of the water from the soil and thus the relatively high soil moisture retained in the soil. The cause of the relatively poor crop performance was not well established. The STC plot had high soil moisture, the soil was least disturbed and thus evaporation losses could have been minimised. In the DTM plot, the low moisture contents showed that the crop extracted most of the moisture from the soil as observed from the good crop performance. The NT plot had low available soil moisture showing that the crusted soil surface encouraged runoff water losses. The STM plot had the lowest available soil moisture. The cause of the low soil moisture was not well established but probably evaporation water losses were high due to the pulverised soil surface. Furthermore the crop in this plot performed poorly.

For Block D, during the vegetative stage, DTM had the highest available soil moisture of 40 mm followed by STC (34 mm), NT (27 mm), STM (24 mm) and DTC (22 mm). During the tasselling and ear forming stage STC and NT had the highest amount of available soil moisture of 23 mm each followed by DTC (19 mm), DTM (18 mm) and STM (17 mm). During the pollination to maturity stage DTM had the highest available soil moisture of 266 mm followed by DTC (242 mm), STM (226 mm), NT (218 mm) and STC (212 mm). During the vegetative to maturity period DTM had the highest available soil moisture of 324 mm followed by DTC (283 mm), STC (269 mm), NT (268 mm) and STM (267 mm). The high surface roughness for the DTM plot increased surface depressional water storage and thus increased the time available for infiltration, therefore more water was stored in the profile. The DTC plot stored high amount of water due to minimal soil disturbance and therefore evaporation losses were low. The STC plot had lower available moisture compared to the DTM and DTC plots although the crop performance in STC was better than in the later treatments. This shows that the crop in STC could extract more moisture from the soil leading to the low available soil moisture in the profile. The NT plot had low soil moisture and relatively poor yield. Low available soil moisture was stored in the profile due to the low random surface roughness which led to the development of a dense surface crust resulting in surface runoff water losses. The STM plot had low available soil moisture probably due to evaporation water losses from the originally pulverised shallow surface. The yield from this plot was low compared to the other plots. The crop in this block performed better as compared to the other blocks explaining the reason for the relatively lower available soil moisture.

During the vegetative, tasselling and pollination stages there were no significant differences in available soil moisture between all treatments (see Appendix 4). During the vegetative to maturity stage (4th to 13th week) there was no significant difference in available soil moisture between treatments. The crop, from different treatments, extracted water from the soil at differing rates and therefore the crop performance between these treatments varied. These indicated that, there was a difference in available soil moisture stored in the profiles, for different treatments, which the crop could extract. Therefore the amount left in the profile was not significant. During the tasselling stage there was a significant difference ($P = 0.05$) in available soil moisture among blocks. Blocks A, B and D had high amounts of available soil moisture than block C. As stated earlier, probably the difference in soil texture contributed to the difference in available soil moisture, in which case due to the high sand content in block C water might have infiltrated deep into the profile. The crop yield from block C was lower than for block D, but higher than that from blocks B and A.

4.2.3 Surface Roughness

The results from the SR'93 season showed that deep mouldboard tillage had the highest average surface roughness, with a value of 49. The no-till plot had the lowest surface roughness, with a value of 4 (for surface roughness computation see Appendix 12).

During the LR'94 season deep mouldboard tillage maintained the highest roughness value of 49. The no-till plot had the lowest value of 9.

The no-till plots were expected to have the lowest surface roughness since no tillage operations were performed. Deep mouldboard tillage, due to its greater depth of tillage, produced bigger clods and disturbed the soil more and hence the higher value of surface roughness obtained. High surface roughness increased surface water storage (through surface ponding), reduced rainfall impact and enhanced water infiltration or evaporation (through greater surface area). Deep mouldboard tillage showed good crop performance. Shallow mouldboard tillage, deep and shallow cultivator tillage treatments had similar surface roughness values (by DMR test). The depths attained between these treatments (STM, DTC and STC) were not different and therefore the similarity in surface roughness. The no-till treatments, with the lowest surface roughness, had the poorest crop performance (in terms of height and dry matter yield). Rough soils are generally more porous than smooth soils and therefore shows increased infiltration rates. This results in reduced surface water flow,

Table 4.7 Surface Roughness of the different treatments over the short rains, 1993 and long rains, 1994 periods.

Block	Surface roughness				
	Treatment				
	NT	DTM	STM	DTC	STC
A	2.46	48.54	32.40	25.64	16.56
B	8.54	49.58	40.82	28.02	21.02
C	1.01	47.76	38.14	21.46	21.14
Average[1]	4.00^{e}	48.60^{a}	37.12^{b}	25.04^{c}	19.57^{d}
A	16.06	63.20	23.56	42.48	13.84
B	8.77	44.34	33.22	28.02	33.62
C	6.30	44.22	46.48	44.74	32.36
D	6.60	43.08	38.94	30.48	34.36
Average[2]	9.45^{c}	48.71^{a}	35.55^{ab}	36.43^{ab}	28.60^{b}
A	12.95	26.72	26.28	29.04	19.96
B	7.10	21.50	22.62	29.82	28.14
C	4.99	23.02	22.78	30.10	24.72
D	9.47	14.04	17.72	28.92	31.98
Average[3]	8.63^{c}	21.32^{b}	22.35^{b}	29.47^{a}	26.20^{ab}

Note: Mean surface roughness values denoted by the same superscript letter within the same row are not significantly different at the 5 % level (DMR).

[1], [2] and [3] represents Surface roughness values for the short rains season (1993), long rains season (1994) and one month after land preparation during the long rains (1994) season respectively.

increased sediment trapping and reduced particle transport thus minimising erosion.

The difference in roughness values between all treatments were significant ($P = 0.001$) during the SR'93 season (see Appendix 5). During the LR'94 season, the difference in surface roughness between all treatments was also significant ($P = 0.01$).

Previous work by Stein et al. (1982) showed that the mouldboard treatments surface was initially rough enough to create considerable surface storage and to expose large surface areas to rain, allowing a greater amount of infiltration in the dry run. But as the run sequence progressed, clods were broken down and total surface area reduced, so that infiltration was low for the wet runs. It has been observed that 70 per cent of the erosive storms in the study area occur in the first month of the rainfall season, when no annual crop can provide efficient leaf cover (Fisher, 1978). Hence it is important to emphasize on mechanical measures for soil and water conservation during this period.

Soil surface roughness measurements carried out during the LR'94 season, one month after land preparation were reduced by rainfall. But the surface roughness was still significantly different (*P = 0.001*) between treatments. Although the surface roughness was reduced by the rain drop impact, infiltration or evaporation had already taken place during the erosive storms. This clearly shows the benefit of creating an initially rough surface before the onset of the rains.

4.3 Crop Performance and Yield.

4.3.1 Seedling Emergence

Table 4.8 shows the emergence rate indices for the different treatments. Figures 4.5 and 4.6 show the seedlings emerged for the SR'93 and LR'94 periods respectively.

During the SR'93 season, the most rapid seedling emergence as indicated by emergence rate index, for maize tested under different tillage systems was obtained with the DTM plot with a value of 11.94 followed by STC (11.80), STM (11.66), DTC (11.60) and NT (11.45). During the LR'94 season, the STC plot had the most rapid emergence of 8.69 followed by DTM (8.24), NT (7.88), DTC (7.00) and STM (6.94).

During SR'93 and LR'94 seasons, there were no significant differences in ERI between all treatments (see Appendix 6). All planting operations involved digging holes, manure dropping, planting and covering the seeds. Thus the tillage practices did not significantly influence emergence. Furthermore at emergence stage a minimal amount of available soil moisture was found to facilitate the emergence process.

Emergence rate indices for LR'94 season were generally low (5-11) as compared with those of the SR'93 season (10-13) since after planting there was a dry spell of about one

Table 4.8 Emergence Rate Index of maize as influenced by tillage practices over the short rains, 1993 and long rains, 1994 periods.

Year	Block	Emergence rate index				
		Treatment				
		NT	DTM	STM	DTC	STC
Short rains, 1993	A	10.91	12.17	10.20	11.41	12.14
	B	11.31	12.57	12.42	10.97	10.76
	C	12.14	11.07	12.37	12.41	12.49
Average		11.45^a	11.94^a	11.66^a	11.60^a	11.80^a
Long rains, 1994	A	6.48	7.18	5.42	5.05	5.97
	B	6.14	6.26	7.44	5.03	8.14
	C	8.30	9.20	5.07	7.54	9.97
	D	10.58	10.31	9.84	10.36	10.66
Average		7.88^a	8.24^a	6.94^a	7.00^a	8.69^a

Note: Average ERI values denoted by the same superscript letter within the same row are not significantly different at the 5% level (DMR).

week and hence some seeds did not get enough moisture for germination. Stress delays emergence or slows the rate of emergence. It was observed that most of the seeds germinated two weeks later when rains resumed and moisture was adequate for germination. Probably the poor germination contributed to the relatively poor crop yield, during the long rains season. Poor corn yield in conservation tillage plots was attributed to erratic emergence and slow early season growth (Sojka et al., 1991).

For the SR'93 and LR'94 seasons there was a correlation between plant emergence (by ERI) and crop yield with treatments showing the highest ERI having the highest crop yield and vice versa. This compares well with other scientists findings.

Emergence rate indices were significantly different ($P = 0.001$) between block D and the other blocks (A, B and C) during the LR'94 season. Treatments in block D had available soil moisture at the emergence stage while in the other blocks there was hardly any available soil moisture for the treatments. This contributed to the difference in ERI between blocks.

locks C and B, and B and A had similar emergence rate indices based on the DMR test.

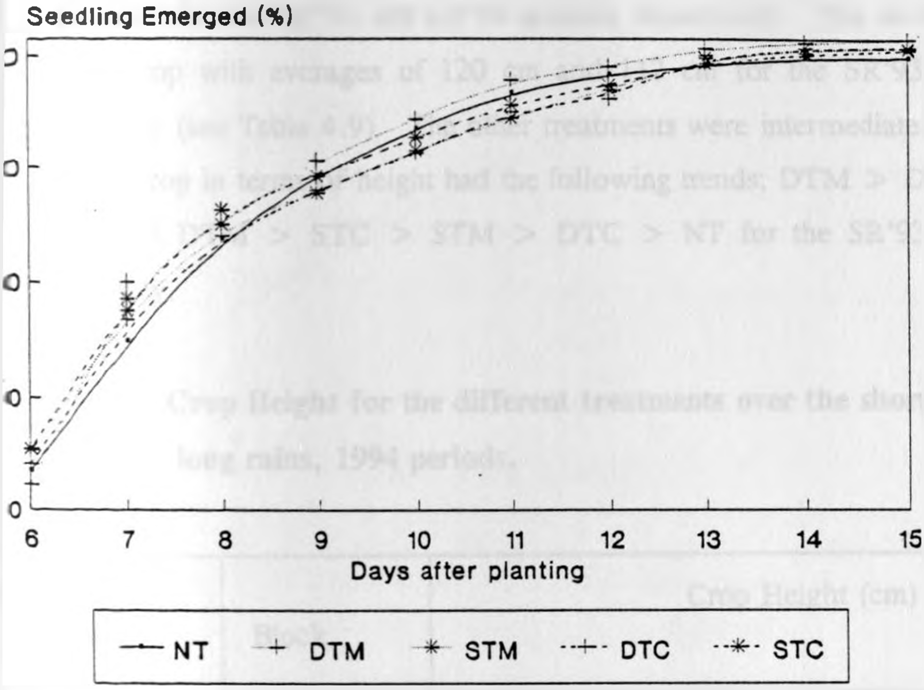


Figure 4.5 Seedling emergence for the treatments during the short rains, 1993 season.

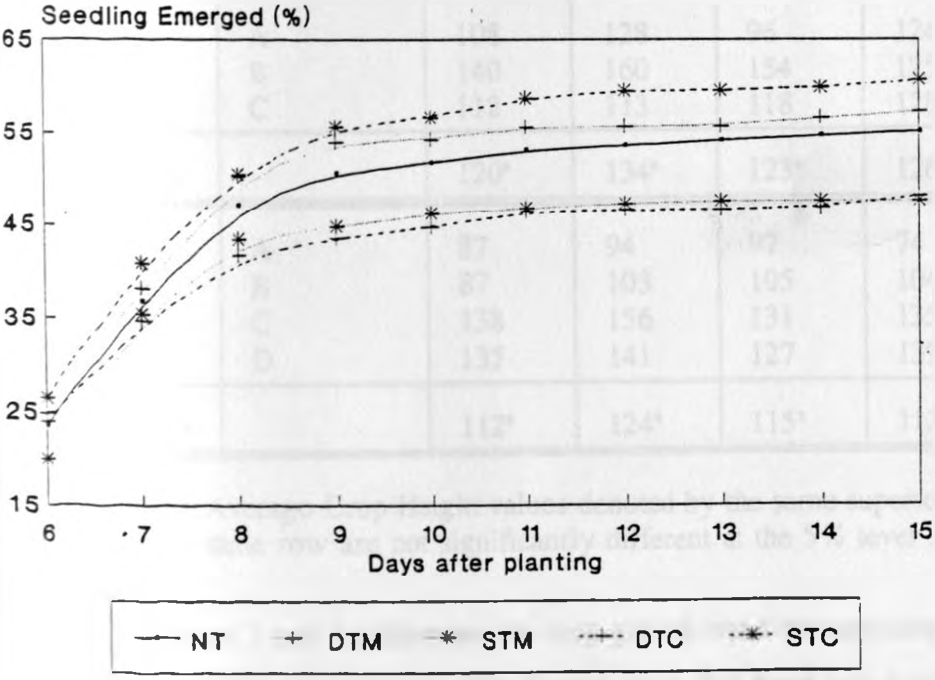


Figure 4.6 Seedling emergence for the treatments during the short rains, 1994 season.

4.3.2. Crop Height

Deep mouldboard tillage had the tallest crop with averages over the season of 134 cm and 124 cm for the SR'93 and LR'94 seasons respectively. The no-till treatment had the shortest crop with averages of 120 cm and 112 cm for the SR'93 and LR'94 seasons respectively (see Table 4.9). The other treatments were intermediate in which the growth of maize crop in terms of height had the following trends; DTM > DTC > STC > STM > NT and DTM > STC > STM > DTC > NT for the SR'93 and LR'94 seasons respectively.

Table 4.9 Crop Height for the different treatments over the short rains, 1993 and long rains, 1994 periods.

Year	Block	Crop Height (cm)				
		Treatment				
		NT	DTM	STM	DTC	STC
Short rains, 1993	A	108	128	96	124	115
	B	140	160	154	125	132
	C	112	113	118	128	123
Average		120^{a}	134^{a}	123^{a}	126^{a}	123^{a}
Long rains, 1994	A	87	94	97	74	83
	B	87	103	105	104	95
	C	138	156	131	135	136
	D	135	141	127	139	159
Average		112^{a}	124^{a}	115^{a}	113^{a}	118^{a}

Note: Average Crop Height values denoted by the same superscript letter within the same row are not significantly different at the 5% level (DMR).

Figures 4.7 and 4.8 illustrate the crop growth trend through time for the two periods (SR'93 and LR'94) respectively. The figures show that there was a uniform trend of crop

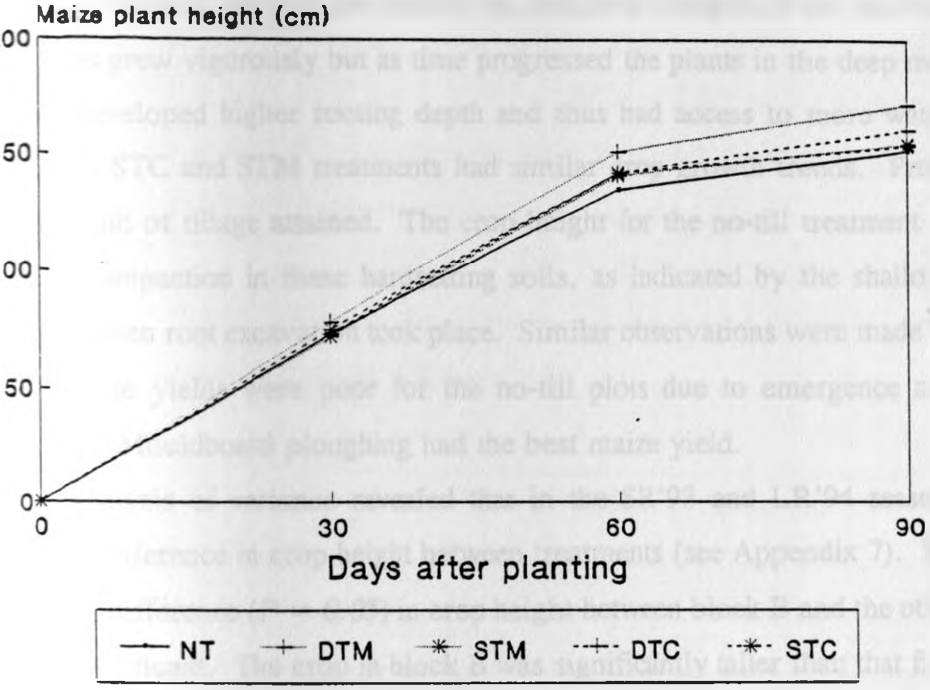


Figure 4.7 Maize crop height for the treatments during the short rains, 1993 season.

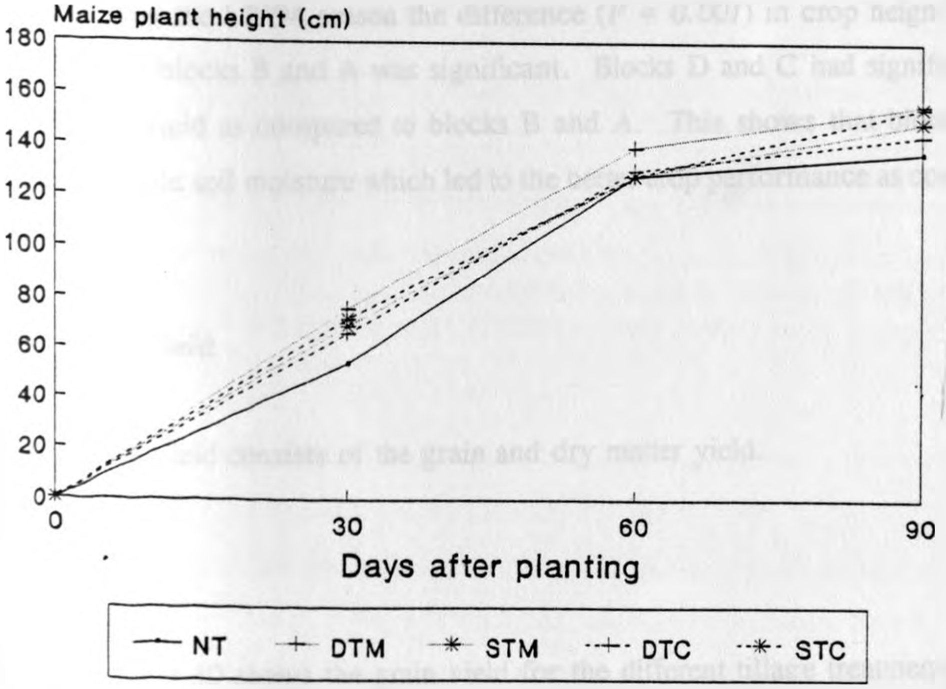


Figure 4.8 Maize crop height for the treatments during the short rains, 1993 season.

height for all treatments until one month after planting, but the trend changed from then until harvest. Probably, early in the seasons the available nitrogen in the soil was high so plants in all plots grew vigorously but as time progressed the plants in the deep mouldboard tillage practice developed higher rooting depth and thus had access to more water and nutrients. The DTC, STC and STM treatments had similar crop growth trends. Probably due to the similar depth of tillage attained. The crop height for the no-till treatment was short due to the high compaction in these hardsetting soils, as indicated by the shallow rooting depths observed when root excavation took place. Similar observations were made by Vogel (1993), where maize yields were poor for the no-till plots due to emergence and establishment problems. Mouldboard ploughing had the best maize yield.

Analysis of variance revealed that in the SR'93 and LR'94 seasons there was no statistical difference in crop height between treatments (see Appendix 7). During the SR'93 season the difference ($P = 0.05$) in crop height between block B and the other blocks (B and A) was significant. The crop in block B was significantly taller than that from blocks C and A. Dry matter yield from the plots in block B was high as compared to that in blocks C and A. This shows that the soil moisture available to the crop in block B was high and therefore led to the better crop height performance as compared to blocks C and A.

During the LR'94 season the difference ($P = 0.001$) in crop height between blocks D and C and blocks B and A was significant. Blocks D and C had significantly taller and higher crop yield as compared to blocks B and A. This shows that blocks D and C had higher available soil moisture which led to the better crop performance as compared to blocks B and A.

4.3.3 Crop Yield

Crop yield consists of the grain and dry matter yield.

Grain Yield

Table 4.10 shows the grain yield for the different tillage treatments during the two periods (SR'93 and LR'94).

Deep mouldboard tillage and shallow cultivator tillage had the highest grain yields of

1632 and 1320 kg/ha for the SR'93 and LR'94 seasons respectively. The no-till and the shallow mouldboard tillage systems had the lowest grain yields of 1126 and 947 kg/ha, for the SR'93 and LR'94 seasons respectively. The average grain yields had the following trends; DTM > STC > STM > DTC > NT and STC > DTM > NT > DTC > STM for the SR'93 and LR'94 seasons respectively Figures 4.9 and 4.10 show the crop yield from different treatments, for the two periods (SR'93 and LR'94).

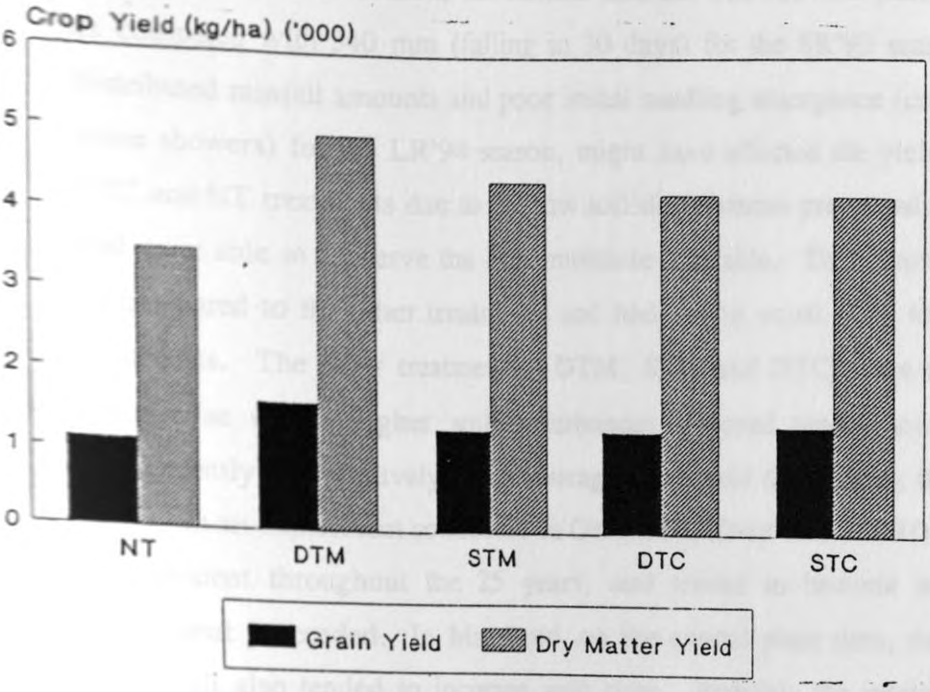
Table 4.10 Grain Yield for the different treatments over the short rains, 1993 and long rains, 1994 periods.

Block	Grain yield (kg ha^{-1})				
	Treatment				
	NT	DTM	STM	DTC	STC
A	878	1524	470	1117	1399
B	1092	2284	1902	1034	788
C	1407	1088	1611	1806	2008
Average[1]	1126^a	1632^a	1328^a	1319^a	1398^a
A	430	471	260	103	477
B	855	827	1095	722	939
C	1649	1973	1142	1575	1669
D	1540	1663	1290	2025	2194
Average[2]	1119^a	1234^a	947^a	1106^a	1320^a

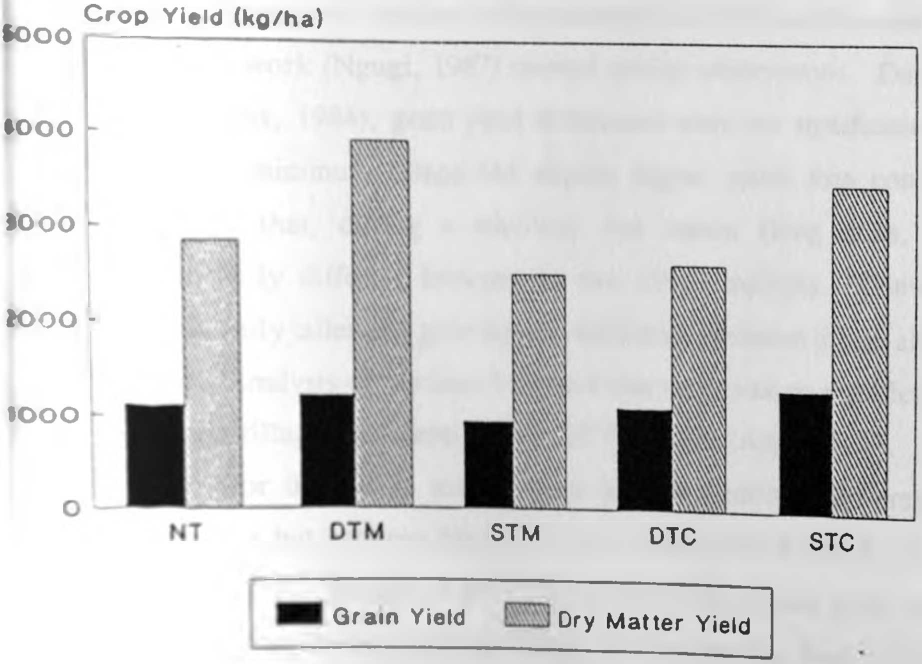
Note: Mean grain yield values denoted by the same superscript letter within the same row are not significantly different at the 5 % level (DMR).

[1] and [2] = Mean yield for the short (1993) and long (1994) rains seasons respectively.

In the SR'93 season no-till plots had low crop yields. This was attributed to the higher soil strengths as indicated by resistance to penetration. DTM had high crop yield due to high depth to which water could infiltrate and the large storage profile. Probably, roots penetrated deeper due to lower soil strengths, and most likely were able to use more nutrients and water from deeper zones. Average crop yield from STM, DTC and STC treatments were almost equal. Probably the relatively similar depth of tillage contributed to the



gure 4.9 Crop yield from different tillage treatments for the short rains, 1993 season.



gure 4.10 Crop yield from different tillage treatments for the short rains, 1994 season.

similarity in crop yield. Crop yields from no-till farming are unlikely to be as high as for deep tillage if the porosity of the soil is too low for effective development of crop roots.

In the LR'94 season, the rainfall amount was 300 mm (falling in 32 days) as compared with 340 mm (falling in 30 days) for the SR'93 season. The lower, poorly distributed rainfall amounts and poor initial seedling emergence (caused by a dry spell after some showers) for the LR'94 season, might have affected the yield in all treatments. The STC and NT treatments due to the low soil disturbances prevented evaporation water losses and were able to conserve the little moisture available. They showed improved crop yield as compared to the other treatments and had almost equal yield to the same SR'93 season treatments. The other treatments (DTM, STM and DTC) were affected by the moisture deficit due to the higher soil disturbances imposed (under low rainfall amounts) and consequently had relatively lower average crop yield than during the SR'93 season.

In an experiment conducted in Ohio USA (Dick et al., 1991), the advantage of no-till was evident throughout the 25 years, and tended to become more pronounced as the experiment proceeded. In Maryland, on the coastal plain sites, the maize yield advantage for no-till also tended to increase with time. Probably the relatively better yields in the LR'94 season, for no-till, could have the same bearing.

During the LR'94 season (after randomization),the NT and STC plots seemed to have taken advantage of the low soil moisture while DTM was favoured by relatively wet seasons. Previous work (Ngugi, 1987) showed similar observations. During a relatively dry season (short rains, 1984), grain yield differences were not significant between tillage treatments although minimum tillage had slightly higher yields than conventional tillage. He also observed that, during a relatively wet season (long rains, 1985), plant vigour was significantly different between the two tillage methods. Conventional tillage maize was significantly taller and gave higher yields than minimum tillage although the differences were small. Analysis of variance indicated that there was no significant difference in grain yield between tillage treatments for the SR'93 season (Appendix 8).

For the LR'94 season, there was no significant difference in grain yield between treatments but between blocks D and C and blocks B and A the difference was significant ($P = 0.001$). Blocks D and C had significantly higher grain yields than blocks B and A. Block A had the lowest grain yield. This shows that Blocks D (SCL soil) and C (SL soil) had higher soil moisture available to the crop and therefore the crop performed better than in blocks B and A (SCL soils). Seedling emergence was also significantly higher in blocks D and C as compared to blocks B and A, which most likely contributed to the difference in grain yield between the blocks.

Dry Matter Yield

The dry matter yield was estimated from material collected after harvest and the weight of cobs obtained after shelling. The highest dry matter yield was obtained from DTM with values of 4974 and 3925 kg/ha for the SR'93 and LR'94 seasons respectively. The lowest dry matter yield was from the NT (3508 kg/ha) and STM (2499 kg/ha) for the SR'93 and LR'94 seasons respectively (see Table 4.11). The dry matter yield tended to decrease in the following order; DTM > STM > DTC > STC > NT and DTM > STC > NT > DTC > STM for the SR'93 and LR'94 seasons respectively.

Table 4.11 Dry Matter Yield for the different treatments over the short rains, 1993 and long rains, 1994 periods.

Block	Dry matter Yield (kg/ha)				
	Treatment				
	NT	DTM	STM	DTC	STC
A	3397	4601	2539	3985	3585
B	3728	7177	6035	3224	4397
C	3399	3177	4732	5663	4851
Average[1]	3508^{a}	4974^{a}	4435^{a}	4291^{a}	4278^{a}
A	1428	1386	942	775	1515
B	1411	2638	2974	1416	2534
C	4702	6385	3113	3664	4016
D	3857	5290	2967	4595	5829
Average[2]	2850^{ab}	3925^{a}	2499^{b}	2613^{ab}	3474^{ab}

Note: Mean dry matter yield values denoted by the same superscript letter within the same row are not significantly different at 5 % level (DMR).

[1] and [2] represents the average dry matter yield for the SR'93 and LR'94 seasons respectively.

The general trend in grain yield followed that of dry matter yield during the crop growing periods. Thus the treatments with deeper rooting characteristics had relatively better dry matter yield, most likely because of adequate nutrients and water from deeper zones for crop use. Clearly, deep root penetration improved crop water availability and increased potential nutrient uptake. Analysis of variance was carried out and the result indicated that there was no significant difference (in DMY) between treatments. For the LR'94 season, results from the analysis of variance showed that there was no significant difference in dry matter yield between treatments, but the difference was significant ($P = 0.001$) between blocks D and C and blocks B and A (see Appendix 8). Blocks D and C had significantly higher dry matter yields than blocks B and A. Probably, the relatively better seedling emergence and available soil moisture influenced the plant stand in blocks D and C and thus the higher dry matter yield.

Sojka et al. (1991) observed that maize yield produced did not differ significantly among implements despite producing differences in the overall profile soil strength. The yield did, however, drop in proportion to mean profile soil strength.

Thus although there was a wide variation in draft power requirements, crop yields were nearly equal statistically regardless of tillage method. Similar observations were made by Smith and Fornstrum (1980).

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion.

Draft power requirements

Draft power requirements were evaluated for the different tillage operations. Overall, deep mouldboard tillage required the highest draft power followed by deep cultivator tillage and shallow cultivator tillage. Shallow moudboard tillage had the lowest draft power requirements.

The high draft power requirements for deep mouldboard tillage , compared to the other treatments, was as a result of the high depth (average of 17 cm) of tillage and mass of soil moved. Deep cultivator tillage (average depth 10 cm) had higher draft power requirements, compared to shallow cultivator tillage (average depth 7 cm), due to the relatively high depth of tillage. The comparatively high draft power requirements, at low depth of tillage, for the cultivator tratments was associated with implement blockage by trash during tillage and probably by its greater weight of 39 kg as compared to the weight of the mouldboard of 32 kg. From a draft power requirements viewpoint shallow mouldboard tillage had the best performance.

Soil moisture and tillage depth

Available soil moisture for different treatments were obtained at different growth stages during the crop growing periods. Overall, deep mouldboard tillage treatment conserved the highest available soil moisture followed by shallow mouldboard tillage, shallow cultivator tillage and deep cultivator tillage. The no-till treatment had the lowest available soil moisture during the crop growing periods.

The high surface roughness for the DTM treatment increased surface depressional water storage and thus increased the time available for infiltration therefore more water was stored in the profile. The relatively lower available soil moisture for the STM treatment was due to evaporation water losses from the pulverised soil surface layer, through shallow tillage. Probably deep cultivator tillage lead to higher moisture losses through evaporation as compared to shallow cultivator tillage where surface disturbance was minimal. But generally the relatively rough soil surface, for the cultivator treatments, reduced runoff water losses as observed in high soil moisture as compared to the NT treatment. Low available soil moisture for the NT treatment was due to the low surface roughness which led to the development of a dense crust over the entire soil surface resulting in surface runoff water losses.

There was no significant difference in available soil moisture between all treatments from the vegetative to pollination crop growth stages. This was attributed to the crop which extracted soil moisture at different rates depending on the tillage practice.

The beneficial effects of tillage, which resulted in initial decrease in soil strength (through increased porosity) and increased soil moisture storage, may have disappeared by the end of the cropping periods. During the seasons, residual tillage effects were minimal due to soil hardening after rain drop impact, relatively low soil moisture levels and soil surface crusting. Thus the soil strength values in tilled plots increased. Using accepted criteria that cone index values above 2.0 MPa reduce crop growth and those above 1.5 MPa restrict root growth (Willcocks, 1981), it is evident that the tillage implements significantly reduced soil compaction. High soil strength for the no-till plots may have reduced crop vigour and yield.

Crop performance and Yield

For the conventional tillage practices; deep and shallow mouldboard tillage, deep mouldboard tillage performed better than shallow mouldboard tillage in terms of soil moisture storage, seedling emergence, crop height and yield. This was attributed to the high depth of tillage which resulted in high surface roughness for depressionsl water storage and infiltration. Shallow and deep cultivator tillage treatments were considered as the conservation tillage practices. The Shallow cultivator tillage treatment performed better than the deep cultivator tillage treatment in terms of soil moisture storage, seedling emergence, crop height and yield. Probably due to the less soil disturbance moisture loss through evaporation was minimised for shallow cultivator tillage. The no-till treatment showed poor crop performance, since low soil moisture was stored in the profile due to the low surface roughness which led to the development of a dense surface crust resulting in surface runoff water losses. Overall the crop in deep mouldboard tillage treatment had the best performance in terms of moisture extraction and subsequent crop performance.

There was a correlation between crop performance and yield, with treatments showing the highest seedling emergence giving the highest grain yield and treatments having the tallest crop height giving the highest dry matter yield and vice versa. The crop yield remained constant for no-till and shallow cultivator tillage over both rain seasons, showing that the crop was not highly affected by the relatively lower rainfall in the long rains season. There was no significant difference in crop yield between treatments. According to Logan et al. (1991) crop yields under conservation tillage are initially depressed compared with conventional tillage. It was observed that whenever conservation tillage was applicable there seemed to be a transition period of 3 to 5 years or longer for crop yield to stabilize. Probably the relatively better crop yields in the LR'94 season for no-till and shallow cultivator tillage had the same bearing whereby the yields were stabilising.

Overall conclusion.

On the basis of draft power requirements, soil physical properties, crop performance and yield the following inferences were made;

- Deep tillage with the mouldboard should be carried out during the short rains season.
- Shallow tillage with the cultivator should be carried out during the long rains season.

5.2 Recommendation.

1. New strategies should be developed to improve the exploitation of draft power and the following areas should be considered;

- Selection and training of draft animals, in order to get animals that are strong enough to provide the draft levels needed, otherwise during deep tillage animal draft was limited.
- Design and development of suitable animal drawn implements, in order to match animal and implement otherwise the implements used were heavy for the animals which

contributed to the high draft requirement which the animals hardly provided during deep tillage.

2. At the start of the short rains season, the draft animals are generally weak and the soils are hard after a 6 month dry period. Therefore deep ploughing (with a mouldboard plough) could be carried out immediately after the long rains when the animals are strong and the prevailing moisture conditions are favourable. Under these conditions, the animal draft power requirements could be relatively low when compared to tillage under dry soil conditions. During the long rains season, tillage intensity could be reduced to the level of shallow tillage with the cultivator without any adverse effect on soil properties and crop yield.

3. For minimum tillage system (cultivator) to be adopted, incentives should be provided (intially) to small scale farmers, since they usually operate at subsistence level and consequently have very little risk absorbing capacity. In addition, farmers are usually responsive to new technology if they are convinced of its benefit. Furthermore, the use of the cultivator has received little farmers acceptance with good results, as evidenced over the LR'94 season for STC.

4. Further research should be carried out for a longer period, for a better and conclusive result. Emphasize being on DTM and STC practices, which were found to have the best performance, over the short and long rains respectively.

APPENDICES

Note: ns = Not significant,
*= Significant at the *p=0.05* level,
**= Significant at the *P=0.01* level,
***= Significant at the *P=0.001* level.

Appendix 1: Analysis of Variance of draft Power Requirements for the Treatments, using Randomised Complete Block Design.

(a) Short rains, 1993.

Source	SS	df	MS	F	P
Blocks	0.011	2	0.006	0.814	.487 ns
Main Effects					
treatments	0.166	3	0.055	7.988	.016 *
Error	0.042	6	0.007		
Total	0.219	11			

cv = 10.1 %

(b) Long rains, 1994.

Source	SS	df	MS	F	P
Blocks	0.016	3	0.005	0.582	.642 ns
Main Effects					
treatments	0.114	3	0.038	4.117	.043 *
Error	0.083	9	0.009		
Total	0.213	15			

cv = 11.2 %

Appendix 2: Bulk Density Data and Analysis of Variance of Change in Bulk Density for the Treatments, using Randomised Complete Block Design.

(a) Bulk density data for the short rains (1993) for the 30 cm soil depth

Block	Weeks after Land preparation	Bulk density (kg m^{-3})				
		Treatment				
		NT	DTM	STM	DTC	STC
A	0	1540	1570	1440	1650	1530
	1	1530	1430	1400	1610	1490
	7	1290	1460	1270	1330	1570
	15	1200	1200	1050	1370	1430
B	0	1450	1550	1470	1610	1620
	1	1420	1380	1410	1470	1560
	7	1310	1190	1270	1420	1250
	15	1390	1130	1330	1260	1330
C	0	1630	1710	1650	1720	1610
	1	1630	1560	1610	1580	1550
	7	1470	1660	1480	1580	1490
	15	1420	1390	1310	1450	1370

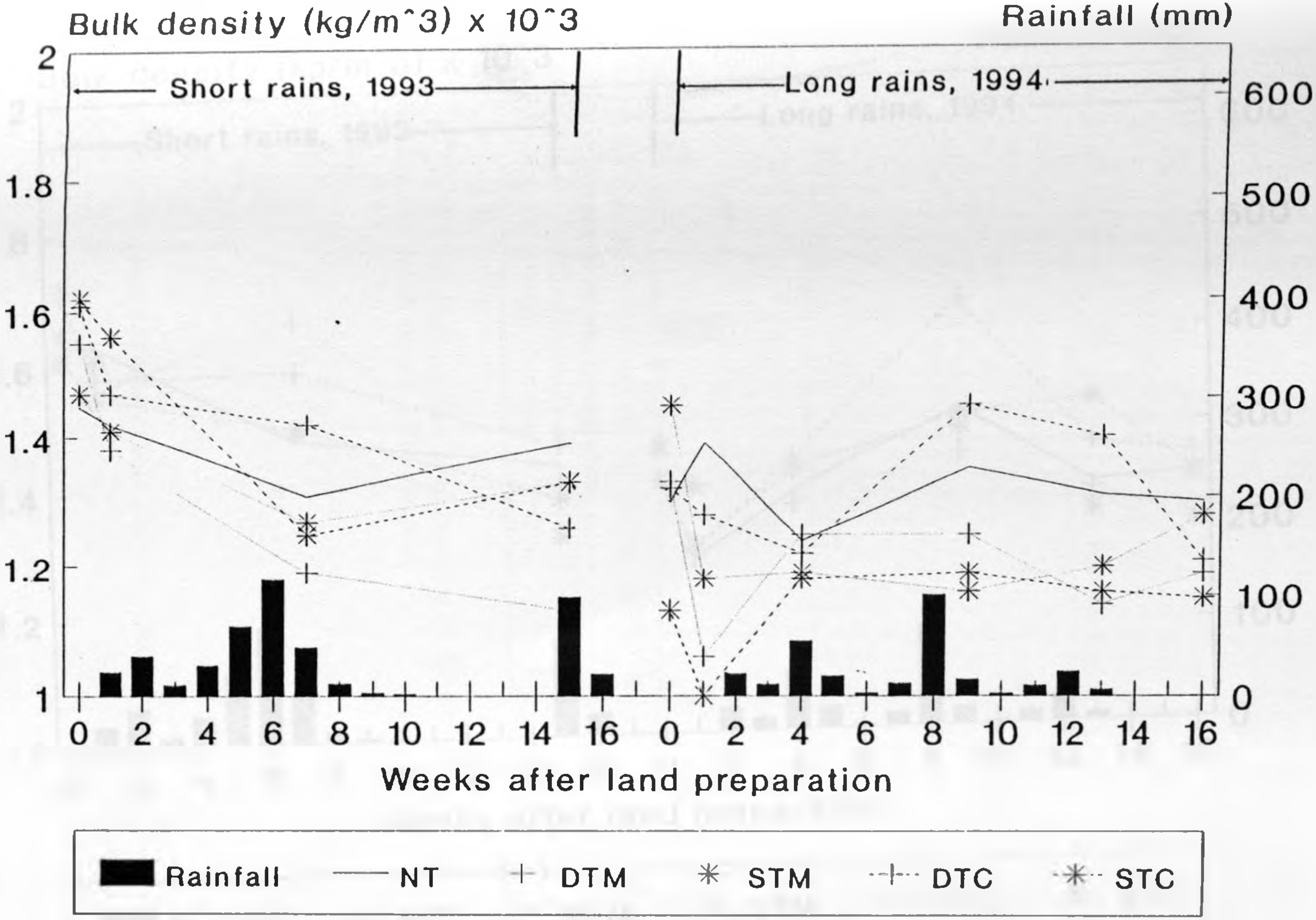
(b) Bulk density data for the long rains season (1994) for the 30 cm soil depth.

Block	Weeks after Land preparation	Bulk density (kg m^{-3}) Treatment NT	DTM	STM	DTC	STC
A	0	1290	1430	1250	1150	1140
	1	1270	1200	1100	1100	1120
	4	1270	1250	1220	1160	1260
	9	1400	1320	1310	1270	1260
	13	1290	1270	1190	1240	1280
	16	1280	1270	1180	1130	1250
B	0	1300	1330	1450	1320	1130
	1	1390	1060	1180	1280	1000
	4	1240	1250	1190	1220	1180
	9	1350	1250	1160	1450	1190
	13	1310	1140	1200	1400	1160
	16	1300	1190	1280	1210	1150
C	0	1340	1450	1440	1390	1390
	1	1270	1270	1380	1280	1290
	4	1370	1350	1410	1420	1400
	9	1490	1420	1460	1660	1480
	13	1370	1360	1330	1430	1500
	16	1380	1310	1310	1410	1380
D	0	1140	1100	1180	1120	1110
	1	1060	1000	960	990	990
	4	1100	1020	1120	1040	1060
	9	1080	1240	1140	1180	1130
	13	1090	1010	950	1100	1120
	16	1090	1080	1050	1130	1020

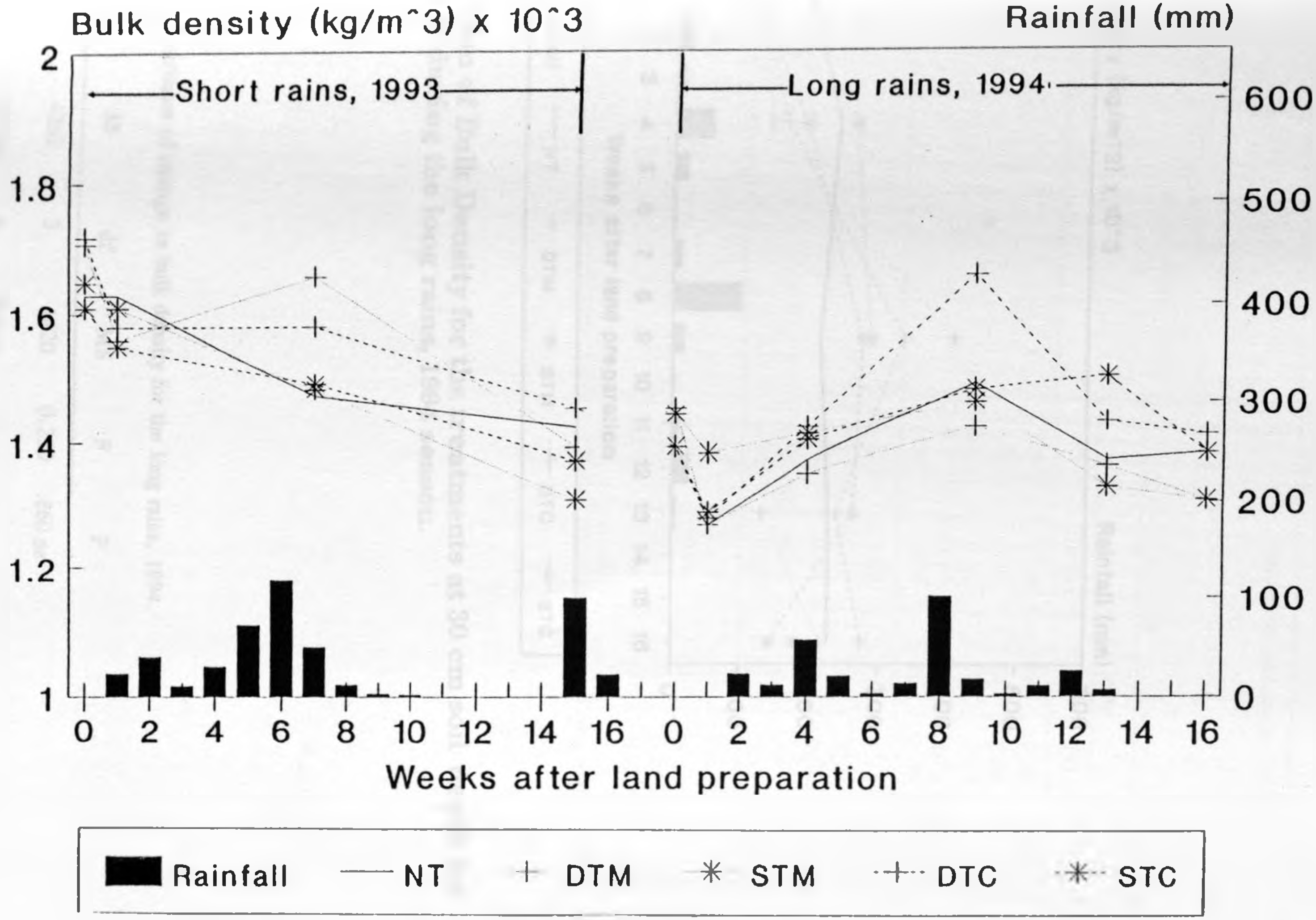
(c) Analysis of variance of change in bulk density for the short rains, 1993.

Source	SS	df	MS	F	P
Blocks	3693	2	1847	3.327	.089 ns
Main Effects					
treatment	36640	4	9160	16.505	.001 ***
Error	4440	8	555		
Total	44773	14			

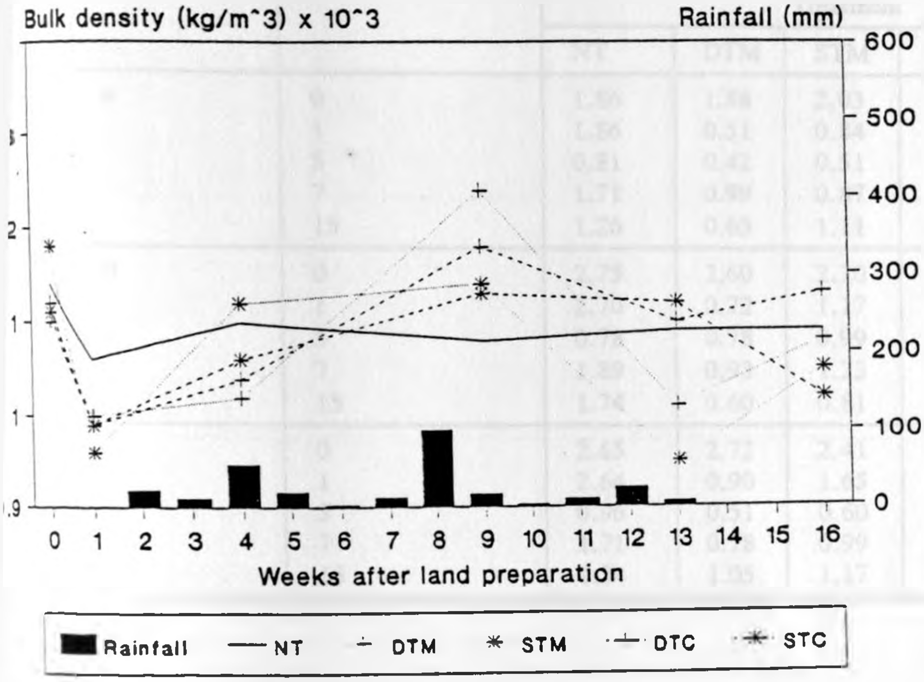
cv = 31.6%



(d) Variation of Bulk Density for the treatments at 30 cm soil depth for block B during the short rains, 1993 and long rains, 1994 seasons.



(e) Variation of Bulk Density for the treatments at 30 cm soil depth for block C during the short rains, 1993 and long rains, 1994 seasons.



(f) **Variation of Bulk Density for the treatments at 30 cm soil depth for block D during the long rains, 1994 season.**

(g) Analysis of variance of change in bulk density for the long rains, 1994.

Source	SS	df	MS	F	P
Blocks	4260	3	1420	0.250	.860 ns
Main Effects					
treatment	82270	4	20568	3.614	.037 *
Error	68290	12	56910		
Total	154820	19			

cv = 66.8%

Appendix 3: Penetration Resistance Data and Analysis of Variance of Change in penetration Resistance for the Treatments, using Randomised Complete Block Design.

(a) Penetration resistance data for the short rains (1993) and irrigation (1994) for the 30 cm soil depth.

Block	Weeks after Land preparation	Penetration resistance (MPa)				
		Treatment				
		NT	DTM	STM	DTC	STC
A	0	1.86	1.88	2.03	1.79	1.83
	1	1.86	0.51	0.84	1.05	1.32
	5	0.81	0.42	0.51	0.72	0.63
	7	1.71	0.99	0.87	1.23	0.96
	15	1.26	0.63	1.11	0.54	1.08
B	0	2.75	2.60	2.70	2.81	2.65
	1	2.70	0.72	1.17	1.95	1.68
	5	0.78	0.78	0.99	0.70	0.51
	7	1.89	0.93	1.23	1.47	1.44
	15	1.74	0.60	0.81	1.62	1.32
C	0	2.65	2.72	2.41	2.75	2.63
	1	2.64	0.90	1.65	1.53	1.71
	5	0.96	0.51	0.60	0.54	0.69
	7	1.71	0.78	0.99	0.93	1.32
	15	1.74	1.05	1.17	0.90	1.26

b) Penetration resistance data for the long rains, 1994.

Block	Weeks after Land preparation	Penetration resistance (MPa)				
		Treatment				
		NT	DTM	STM	DTC	STC
A	0	1.31	1.20	1.54	1.30	1.82
	1	1.26	0.63	1.11	0.84	1.75
	4	1.11	0.42	1.11	0.54	1.08
	7	2.82	1.80	2.43	1.74	2.52
	9	1.35	0.99	1.62	1.59	1.47
	13	2.66	2.19	2.67	2.25	2.64
	16	3.00	2.82	2.82	2.79	3.00
B	0	1.73	1.64	1.38	1.78	1.74
	1	1.74	0.60	0.81	1.62	1.32
	4	1.56	0.63	0.75	0.72	1.08
	7	2.85	1.62	2.07	2.85	2.31
	9	2.01	1.59	1.80	1.56	1.44
	13	2.70	2.52	2.40	2.37	2.19
	16	2.70	2.34	2.79	2.94	2.79
C	0	1.75	1.72	1.51	1.49	1.34
	1	1.74	1.05	1.17	0.90	1.26
	4	1.23	0.60	0.84	0.69	1.05
	7	2.88	2.37	2.46	1.74	2.67
	9	1.32	1.08	1.53	0.93	1.38
	13	2.34	1.74	2.04	1.89	1.86
	16	3.00	2.64	2.88	2.97	2.73
D	0	1.41	1.44	1.53	1.55	1.50
	1	1.41	0.45	0.99	1.23	0.96
	4	1.53	0.48	1.23	0.90	0.93
	7	2.52	1.92	1.83	2.10	2.07
	9	1.32	0.54	1.11	1.59	1.35
	13	2.31	1.35	1.86	2.10	2.28
	16	2.85	1.89	2.46	2.85	2.73

(c) Analysis of variance of change in penetration resistance for the short rains, 1993.

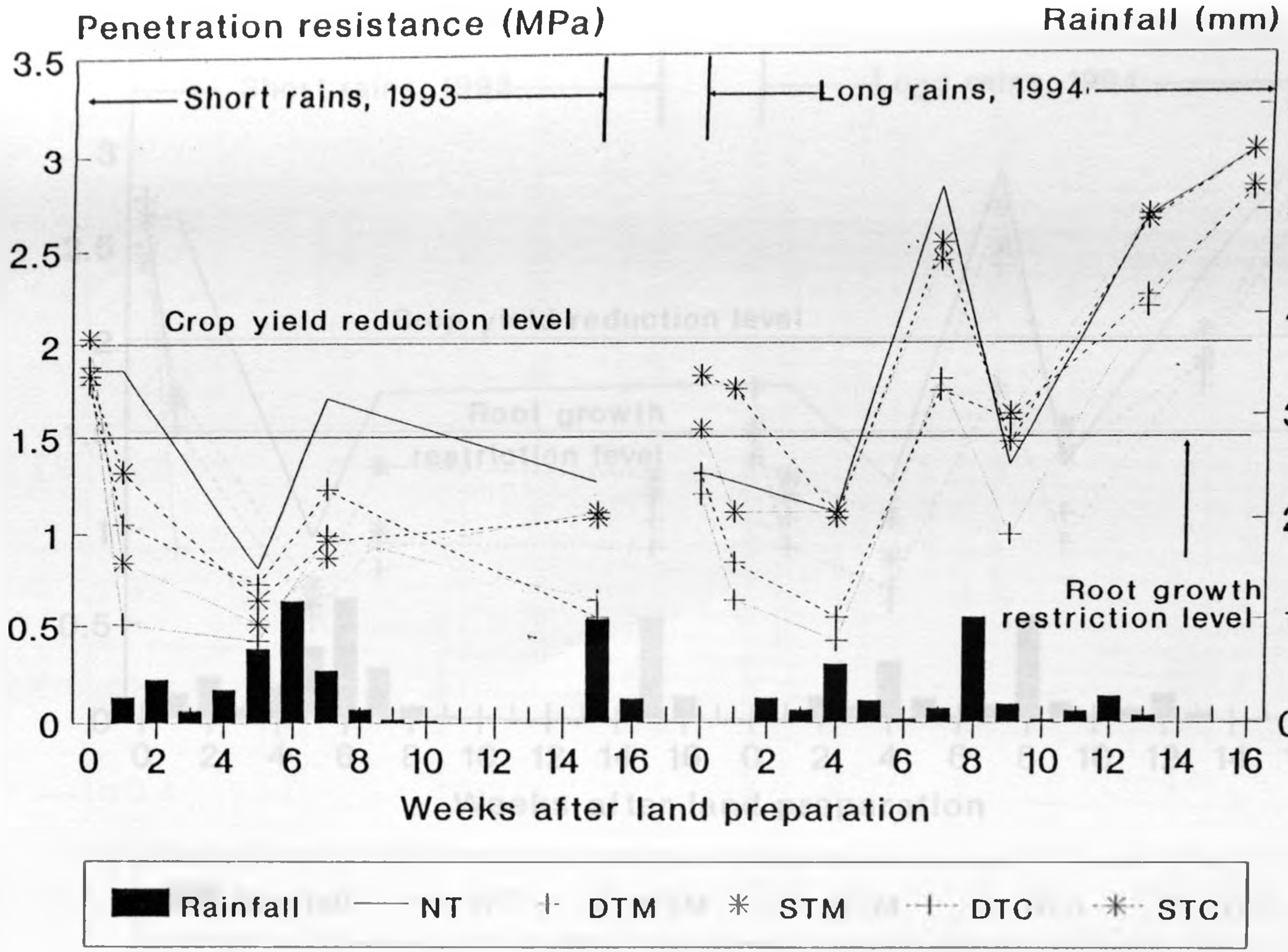
Source	SS	df	MS	F	P
Blocks	0.223	2	0.112	1.848	.219 ns
Main Effects					
treatment	4.426	4	1.106	18.310	.000 ***
Error	0.483	8	0.060		
Total	5.132	14			

cv = 26.7%

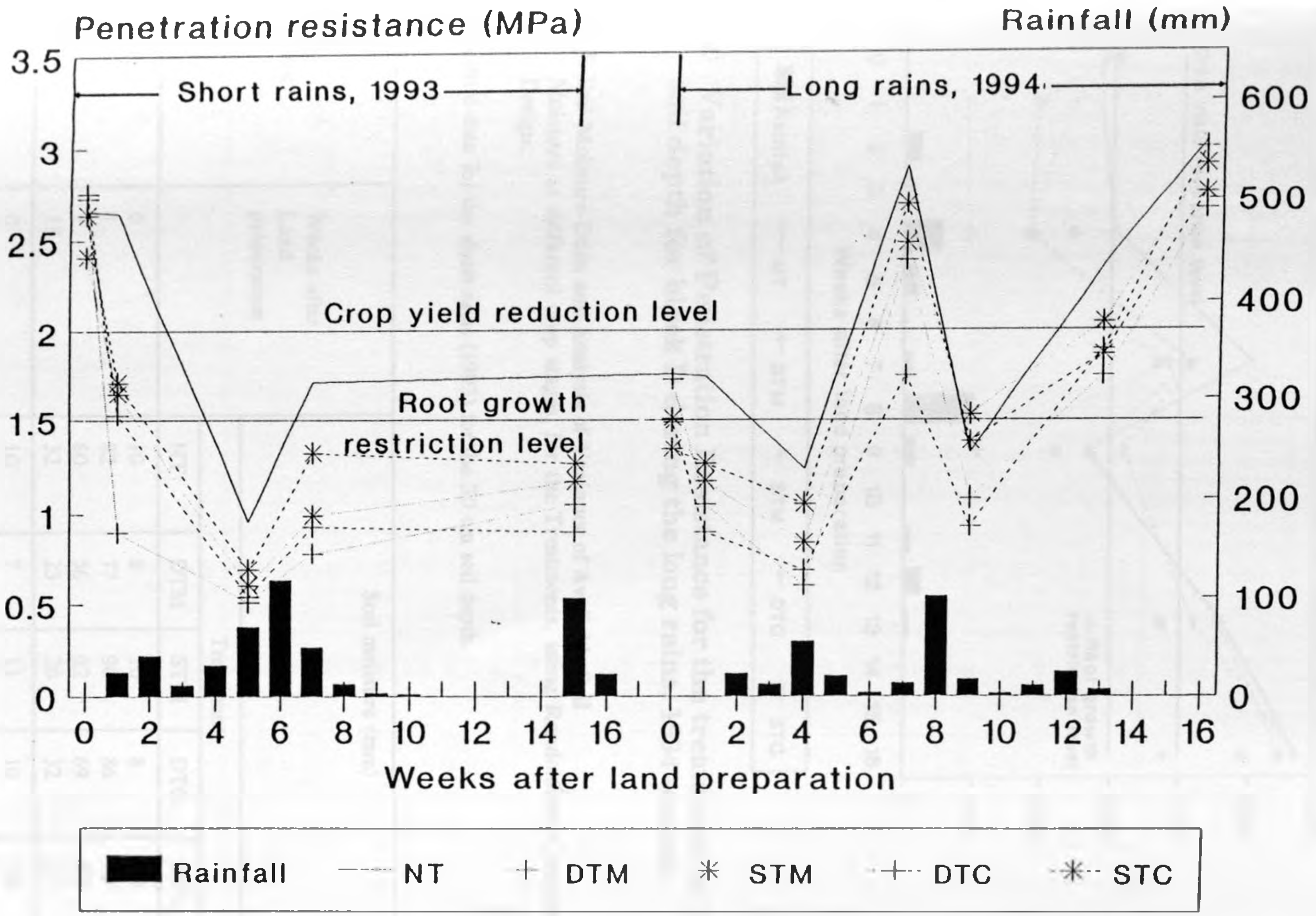
(d) Analysis of variance of change in penetration resistance for the long rains, 1994.

Source	SS	df	MS	F	P
Blocks	0.152	3	0.051	0.975	.437 ns
Main Effects					
treatment	0.726	4	0.182	3.490	.041 *
Error	0.624	12	0.052		
Total	1.502	19			

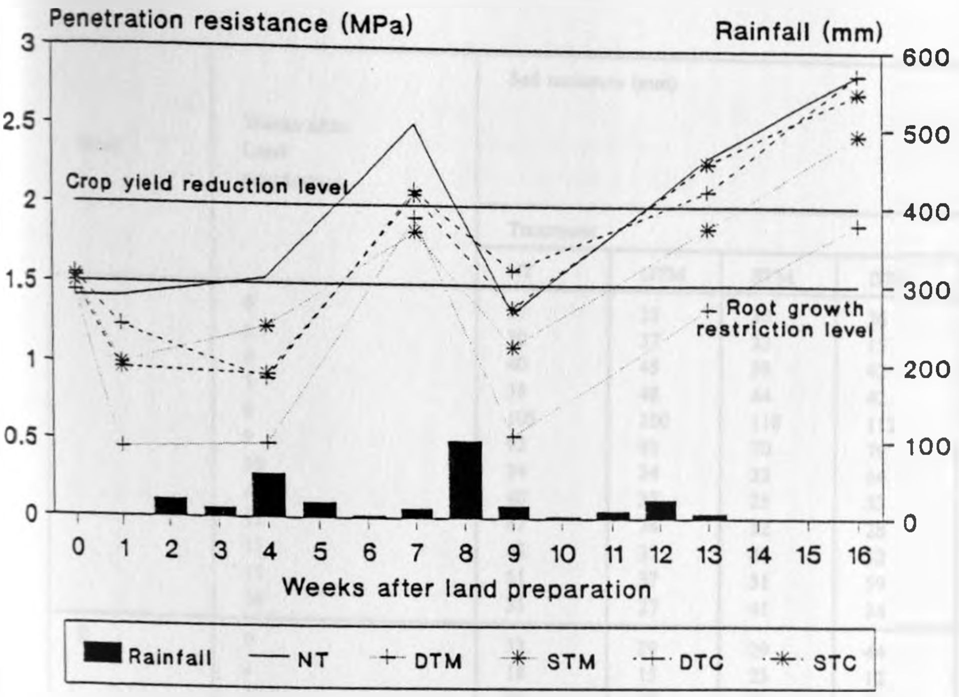
cv = 66.7%



(c) Variation of Penetration Resistance for the treatments at 12 cm soil depth for block A during the short rains, 1993 and long rains, 1994 seasons.



(f) Variation of Penetration Resistance for the treatments at 12 cm soil depth for block C during the short rains, 1993 and long rains, 1994 seasons.



(g) Variation of Penetration Resistance for the treatments at 12 cm soil depth for block D during the long rains, 1994 season.

Appendix 4: Soil Moisture Data and Analysis of Variance of Available Soil Moisture at different crop stages, for the Treatments, using Randomised Complete Block Design.

(a) Soil moisture data for the short rains (1993) for the 30 cm soil depth.

Block	Weeks after Land preparation	Soil moisture (mm)				
		Treatment				
		NT	DTM	STM	DTC	STC
A	0 1 7 15	10 82 60 32	8 77 56 23	10 90 62 26	8 86 69 32	10 89 68 21
B	0 1 7 15	10 100 67 37	7 63 81 36	11 96 70 36	10 85 50 29	10 93 78 39
C	0 1 7 15	9 81 54 30	8 61 66 20	10 79 59 31	9 76 66 28	7 77 58 27

(b) Soil moisture data for the long rains (1994) for the 30 cm soil depth.

Block	Weeks after Land preparation	Soil moisture (mm)				
		Treatment				
		NT	DTM	STM	DTC	STC
A	0	27	21	38	26	26
	1	30	37	33	15	24
	4	40	45	58	42	36
	7	38	48	44	42	46
	8	105	100	118	112	121
	9	92	91	70	79	68
	10	34	34	33	64	77
	11	40	35	25	33	56
	12	67	74	32	28	57
	13	43	37	48	52	50
	15	51	37	31	59	54
	16	31	27	41	34	34
B	0	33	39	29	44	36
	1	18	15	23	12	6
	4	42	52	54	47	61
	7	44	44	50	37	54
	8	48	60	92	66	88
	9	74	90	75	68	88
	10	74	84	123	92	35
	11	93	109	149	50	46
	12	50	99	102	45	71
	13	44	51	64	45	66
	15	34	102	66	55	38
	16	33	39	43	31	41
C	0	29	28	18	20	43
	1	17	18	27	14	8
	4	44	42	54	56	32
	7	37	39	29	41	35
	8	73	95	77	83	145
	9	63	58	54	65	80
	10	51	31	34	51	29
	11	52	58	32	82	50
	12	57	123	78	134	77
	13	39	47	35	48	46
	15	34	31	28	25	55
	16	30	29	24	30	30
D	0	22	21	17	25	42
	1	38	37	32	14	53
	4	55	68	52	50	62
	7	51	46	45	47	51
	8	80	59	57	120	108
	9	75	102	74	69	76
	10	64	68	53	38	42
	11	45	51	66	45	46
	12	57	94	85	74	47
	13	65	60	59	64	61
	15	57	43	40	86	63
	16	48	45	41	56	48

Analysis of variance of available soil moisture for the short rains, 1993.

(i) Available soil moisture at the emergence stage.

ource	SS	df	MS	F	P
locks	442.533	2	221.267	6.186	.024 *
ain Effects					
eatment	946.667	4	236.667	6.617	.012 *
rror	286.133	8	35.767		
otal	1675.333	14			

v = 12.9%

(ii) Block effect, at the emergence stage, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	B	59	a
2	A	57	a
3	C	47	b

(iii) Available soil moisture at the tasselling stage.

Source	SS	df	MS	F	P
Blocks	196.933	2	98.467	1.162	.361 ns
Main Effects					
treatment	144.267	4	36.067	0.426	.787 ns
Error	677.733	8	84.717		
Total	1018.933	14			

cv = 25.3%

(d) Analysis of variance of available soil moisture for the long rains, 1994.

(i) Available soil moisture at the vegetative stage.

Source	SS	df	MS	F	P
Blocks	542.8	3	180.933	2.458	.113 ns
Main Effects					
treatment	206.8	4	51.700	0.702	.605 ns
Error	883.2	12	73.600		
Total	1632.8	19			

cv = 39.7%

(ii) Available soil moisture at the tasselling stage.

urce	SS	df	MS	F	P
ocks	394.0	3	131.333	5.599	.012 *
ain Effects					
eatment	63.3	4	15.825	0.675	.622 ns
rror	281.5	12	23.458		
otal	738.8	19			

v = 31.5%

(iii) Block effect, at the tasselling stage, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	D	20	a
2	B	18	a
3	A	16	a
4	C	8	b

(iv) Available soil moisture at the pollination stage.

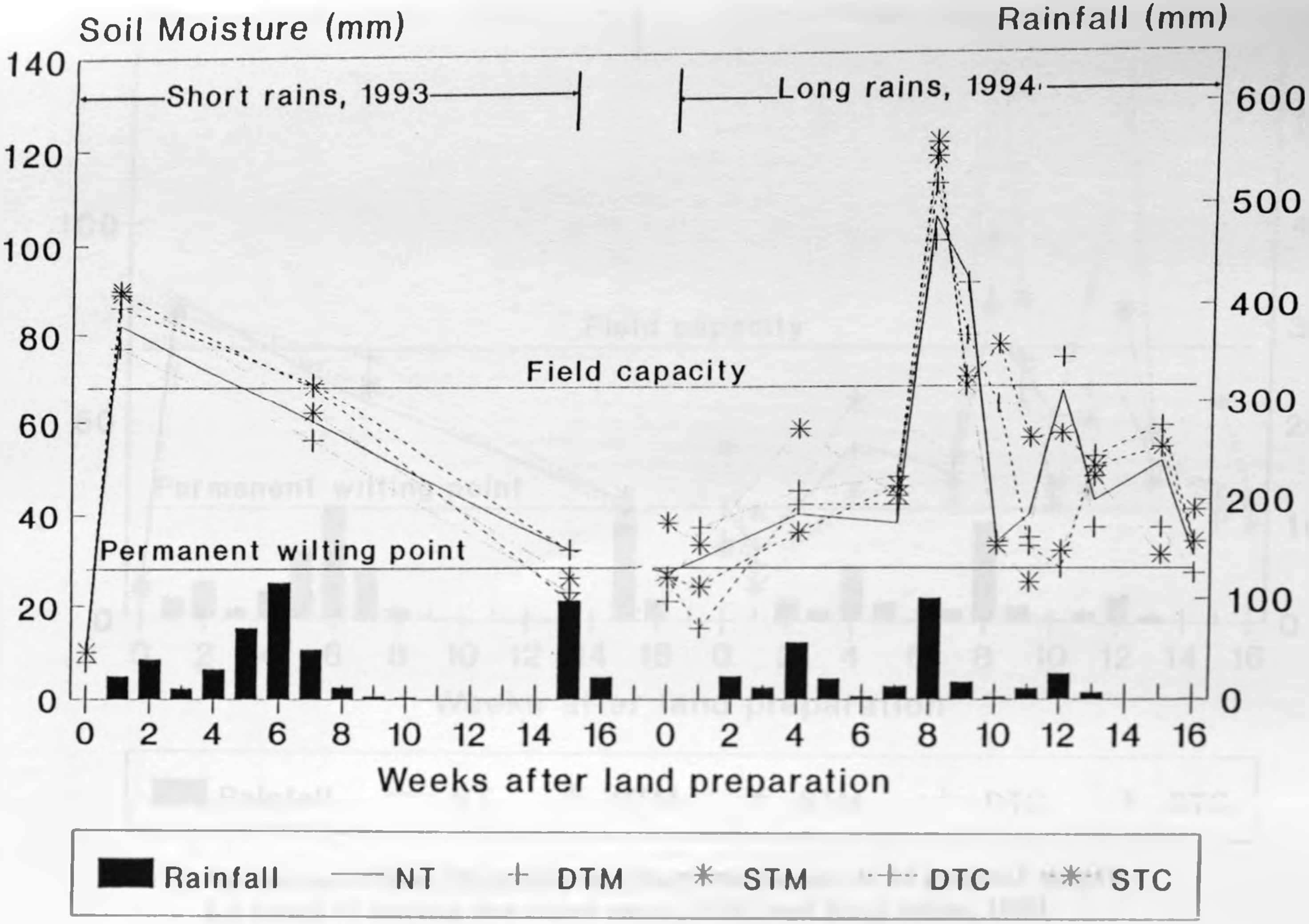
Source	SS	df	MS	F	P
Blocks	14968.95	3	4989.650	1.038	.411 ns
Main Effects					
treatment	6747.70	4	1686.925	0.351	.839 ns
Error	57686.30	12	4807.192		
Total	79402.95	19			

cv = 29.4%

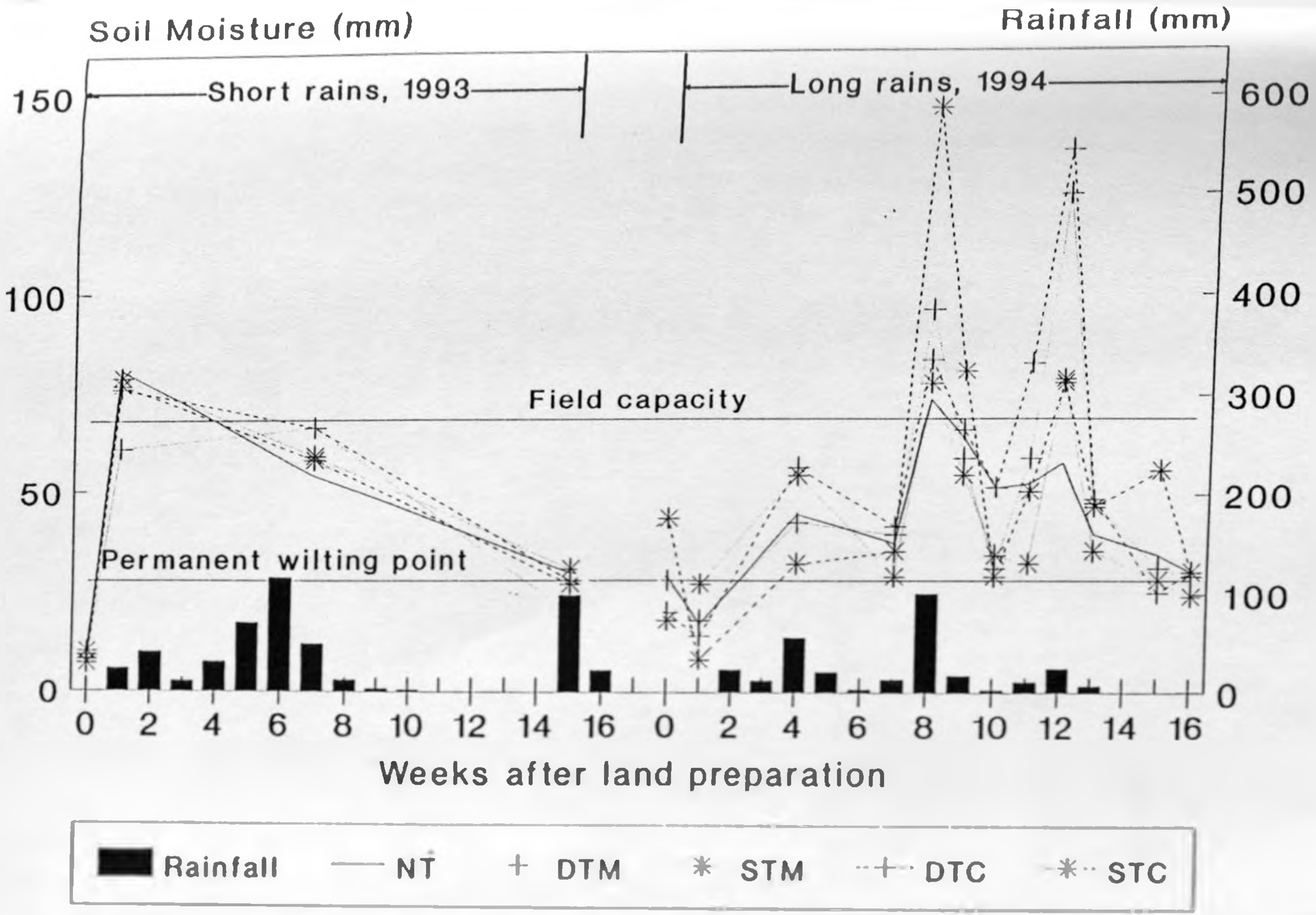
(v) Available soil moisture from the vegetative to maturity stage.

Source	SS	df	MS	F	P
Blocks	21207.4	3	7069.117	1.415	.287 ns
Main Effects					
treatment	9029.3	4	2257.325	0.452	.770 ns
Error	59963.9	12	4996.992		
Total	90200.6	19			

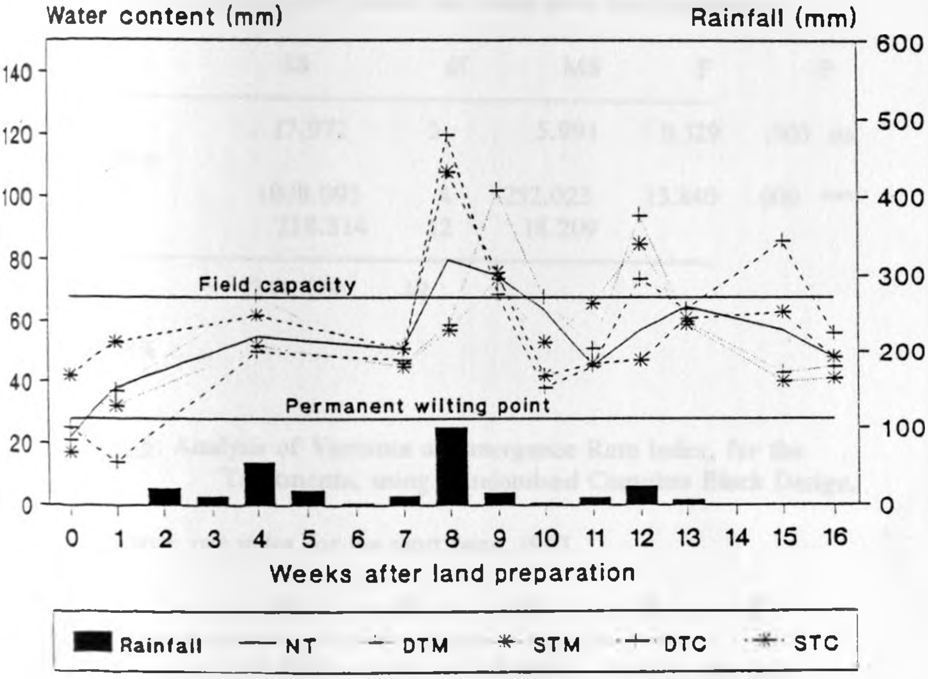
cv = 26%



(e) Variation of soil moisture for the treatments at 30 cm soil depth for block A during the short rains, 1993 and long rains, 1994 seasons.



(f) Variation of Soil Moisture for the treatments at 30 cm soil depth for block C during the short rains, 1993 and long rains, 1994 seasons.



(g) **Variation of Soil Moisture for the treatments at 30 cm soil depth for block D during the long rains, 1994 season.**

Appendix 5: Analysis of Variance of Soil Surface Roughness, for the Treatments, using Randomised Complete Block Design.

(a) Short rains, 1993

Source	SS	df	MS	F	P
Blocks	95.681	3	31.894	1.972	.172 ns
Main Effects					
treatments	4070.929	4	1017.732	62.937	.000 ***
Error	194.049	12	16.171		
Total	4360.659	19			

cv = 14.5%

(b) Long rains, 1994

Source	SS	df	MS	F	P
Blocks	75.577	3	25.192	0.287	.834 ns
Main Effects					
treatments	3328.034	4	832.009	9.489	.001 **
Error	1052.187	12	87.682		
Total	4455.799	19			

cv = 29.5%

(c) Long rains, 1994, taken one month after land preparation.

Source	SS	df	MS	F	P
Blocks	17.972	3	5.991	0.329	.805 ns
Main Effects					
treatments	1008.093	4	252.023	13.840	.000 ***
Error	218.514	12	18.209		
Total	1244.579	19			

cv = 19.8%

Appendix 6: Analysis of Variance of Emergence Rate Index, for the Treatments, using Randomised Complete Block Design.

(a) Emergence rate index for the short rains, 1993.

Source	SS	df	MS	F	P
Blocks	1.384	2	0.692	0.841	.466 ns
Main Effects					
treatment	0.413	4	0.103	0.125	.969 ns
Error	6.585	8	0.823		
Total	8.382	14			

cv = 7.7%

(b) (i) Emergence rate index for the long rains, 1994.

Source	SS	df	MS	F	P
Blocks	55.708	3	18.569	15.975	.000 ***
Main Effects					
treatment	9.398	4	2.350	2.021	.155 ns
Error	13.949	12	1.162		
Total	79.054	19			

cv = 13.9%

(ii) Block effect, for ERI, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	D	10.35	a
2	C	8.02	b
3	B	6.60	bc
4	A	6.02	c

Appendix 7: Analysis of Variance of Crop Height for the Treatments, using Randomised Complete Block Design .

(a) (i) Crop height for the short rains, 1993.

Source	SS	df	MS	F	P
Blocks	2254.533	2	1127.267	6.563	.0216 *
Main Effects					
treatment	326.267	4	81.567	0.475	.754 ns
Error	1374.133	8	171.767		
Total	3954.933	14			

cv = 10.5%

(ii) Block effect, for crop height, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	B	142	a
2	C	119	b
3	A	114	b

(b) (i) Crop height for the long rains, 1994.

Source	SS	df	MS	F	P
Blocks	11301.8	3	3767.267	39.287	.000 ***
Main Effects					
treatment	355.7	4	88.925	0.927	.480 ns
Error	1150.7	12	95.892		
Total	12808.2	19			

cv = 8.4%

(ii) Block effect, for crop height, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	D	140	a
2	C	139	a
3	B	99	b
4	A	87	b

Appendix 8: Analysis of Variance of Crop Yield, for the Treatments, using Randomised Complete Block Design.

(a) Crop yield for the short rains, 1993.

(i) Grain yield

Source	SS	df	MS	F	P
Blocks	667624.533	2	333812.267	1.087	.382 ns
Main Effects					
treatments	399271.733	4	99817.933	0.325	.854 ns
Error	2455827.467	8	306978.433		
Total	3522723.733	14			

cv = 40.7 %

(ii) Dry matter yield.

Source	SS	df	MS	F	P
Blocks	4192893.733	2	2096446.867	1.164	.360 ns
Main Effects					
treatments	3299846.267	4	824961.567	0.458	.765 ns
Error	14404878.933	8	1800609.867		
Total	21897618.933	14			

cv = 31.2 %

(b) Crop yield for the long rains, 1994.

(i) Grain yield

Source	SS	df	MS	F	P
Blocks	6332576.550	3	2110858.850	33.462	.000 ***
Main Effects					
treatments	319506.700	4	79876.675	1.266	.336 ns
Error	756979.700	12	63081.642		
Total	7409062.950	19			

cv = 21.9 %

(ii) Block effect, for grain yield, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	D	1742	a
2	C	1602	a
3	B	888	b
4	A	348	c

(iii) Dry matter yield.

Source	SS	df	MS	F	P	
Blocks	40006089.400	3	13335363.100	19.517	.000	***
Main Effects						
treatments	5909440.800	4	1477360.200	2.162	.135	ns
Error	8199322.400	12	683276.900			
Total	54114852.600	19				

cv = 26.9%

(iv) Block effect, for dry matter yield, by the DMR test.

Rank	Block	Mean	Non-significant ranges
1	D	4508	a
2	C	4376	a
3	B	2195	b
4	A	1209	b

Appendix 9: Definition of Tillage Terms

Tillage is the act or practice of cultivating land or any soil manipulation that changes soil condition. Most often machines are used to apply forces to the soil to effect this changes. Houghton and charman (1986) defined different tillage systems as follows:

Conventional tillage is any tillage system using cultivation as the major means of seedbed preparation and weed control, and is traditionally used for a given crop in a given geographical area. Typically includes a sequence of soil working, such as ploughing, discing and harrowing to produce a fine seedbed, and also the removal of most of the plant residue from the previous crop. In this context the terms cultivation and tillage are synonymous, with emphasis on soil preparation.

Conservation tillage is a tillage system that creates a suitable environment for growing a crop and that conserves soil, water and energy resources. The essential elements of such a system are reduction in the intensity of tillage and retention of plant residues (up to 30 % residue left on the surface).

Minimum tillage is a general term describing a conservation tillage system in which the crop is grown with the fewest possible tillage operations. Herbicides and / or grazing may be used for fallow weed control (it involves reducing tillage to only those operations that are timely and essential to producing the crop and avoiding damage to the soil).

No-till (zero-tillage) is a minimum tillage practice in which the crop is sown directly into a soil not tilled since the harvest of the previous crop. Weed control is achieved by the use of herbicides and stubble is retained for erosion control. It is typically practised in arable areas where fallowing is important.

Tillage Systems as Applied in Semi-arid Areas, Kenya.

In Conventional tillage, farmers use oxen or hand hoes to break the land upto a maximum depth of 20 cm often leaving large soil clods on the surface. Often conventional tillage involves primary tillage operations with no secondary tillage until weed control.

Minimum tillage operations often involve strip tillage (narrow strips of 20 cm width cut along the planting rows) or spot-tillage (where planting holes of sizes 10x10 cm are made using hand hoes). Crop residues are either placed on the soil surface or incorporated into the soil as a means of supplementing organic matter deficiencies and improving the water holding capacities of soils.

Appendix 10: Sample Calculation to Determine Emergence Rate Index.

Example: Data for deep tillage mouldboard for irrigation, 1994.

Day after planting	6	7	8	9	10	11	12	13	14	15
Population count (%)	20.1	53.6	68.3	74.5	83.5	85.6	88.1	92.8	93.9	93.0

Using equation 3,

$$ERI = \frac{20.1-0}{6} + \frac{53.6-20.1}{7} + \frac{68.3-53.6}{8} + \frac{74.5-68.3}{9} + \frac{83.5-74.5}{10}$$

$$+ \frac{85.6-83.5}{11} + \frac{88.1-85.6}{12} + \frac{92.8-88.1}{13} + \frac{93.9-92.8}{14} + \frac{93.9-93.9}{15}$$

$$= 3.35 + 4.79 + 1.84 + 0.69 + 0.9 + 0.19 + 0.21 + 0.36 + 0.08 + 0$$

$$= 12.41$$

Appendix 11: Sample Calculation to Determine Penetration Resistance.

Example: Data for no-till treatment for the LR'94 season, before the onset of the rains.

Impression on the scale = 8.0 cm
Spring constant = 15.0 N cm^{-1}
Cone Area = 0.50 cm^2

Using equation 1 (Netherlands, In situ testing penetrometers)

$$\text{Cone Resistance} = 8.0 * \frac{15}{0.50}$$

$$= 240\ Ncm^{-2}$$

$$= 2.4\ MPa.$$

Appendix 12: Sample height figures in centimetres for surface roughness (for deep desi plough)

Station	Figures
1.	20 16 14 6 10 15 17 20 12 13 16 16 17 14 16 14 15 16 13 17
2.	17 14 15 6 4 15 18 21 15 10 14 12 13 13 10 12 17 20 20 24
3.	19 14 19 19 20 22 21 17 16 17 18 18 18 16 13 10 14 20 14 18
4.	16 15 9 14 16 19 12 12 15 18 18 20 19 12 13 17 20 19 18 16
5.	16 17 16 19 14 12 11 17 15 18 17 17 16 12 18 18 12 10 8 11

Sample calculation of surface roughness using height figures above:

Surface roughness, $R = 100\log_{10}S$, where S = Starndard deviation of the height figures for each setting (station) of the reliefmeter.

For station 1, $S = 3.183$

$$R = 100\log_{10}3.183$$
$$= 50.3$$

Similarly for stations, 2, 3, 4 and 5 the surface roughness values are 69.2, 47.4, 49.3 and 50.6 respectively.

Average surface roughness for plough is;

$$\frac{50.3 + 69.2 + 47.4 + 49.3 + 50.6}{5}$$
$$= 53.36$$

REFERENCES.

Agboola, A.A., (1981). The effects of different soil tillage and management practices on the physical and chemical properties of soil and maize yield in a rainforest zone of Western Nigeria, Agron. J., 73:247-251.

Agenbag, G.A. and Maree, P.C.J., (1991). Effect of tillage on some soil properties, plant development and yield of spring wheat (Trificum aestium L.) in stony soil. Soil Tillage Res., 21:97-112.

Alegre, J.C., Cassel, D.K. and Amezquita, E., (1991). Tillage systems and soil properties in Latin America. Soil tillage Res., 20:147-163.

Allmaras, R.R., Burwell, R.E. and Holt, R.F., (1967). Plow-layer porosity and surface roughness tillage as affected by initial porosity and soil moisture at tillage time. Soil Sci. Soc. Am. Proc., 31:550-556.

Anderson, F.M., (1984). Draught animal power in Africa: An overview. pp. 60-66. In: Animal energy in Agriculture in Africa and Asia. Animal production and health paper 42, FAO, Rome, Italy. 143p (E,F).

Barber, R.G. and Thomas,D.B., (1979). Measurements of soil loss and runoff from simulated rainstorms at Kabete, Katumani and Iiuni. Paper presented to the third annual general meeting of the soil science society of E. Africa. Muguga, Kenya. July 25-27, 1979.

Bernacki, H., (1972). Agricultural machines, theory and construction. Vol.1. Scientific Publications Foreign Cooperation Centre of the Central Institute for Scientific, Technical and Economic Information. Warsaw, Poland.

Bertuzzi, P., Rauws, G. and Courault, D., (1990). Testing roughness indices to estimate soil surface roughness changes due to simulated rainfall. Soil Tillage Res., 17:87-99.

Biamah, E.K., Gichuki, F.N. and Kaumbutho, P.G., (1992). Tillage methods and soil and water conservation in Eastern Africa. Soil Tillage Res., 27:105-123.

Boone, F.R., (1976). Some influence of zero-tillage on the structure and stability of a fine textured river Levee soil. Neth. J. Agric. Sci. 24:105-119.

Bowen, H.D., (1982). Alleviating mechanical impedance. In: Modifying the Root Environment to Reduce Crop Stress. ASAE Monograph No.4, ASAE, St. Joseph, MI 49085.

Burwell, R.E., Allmaras, R.R. and Amemiya, M., (1963). A field measurement of total porosity and surface microrelief of soils. Soil Sci. Soc. Am. Proc., 27:697-700.

Busscher, W.J. and Sojka, R.E., (1987). Enhancement of subsoiling effect on soil strength by conservation tillage. Transaction of the ASAE, 30:888-892.

Campbell, R.B., Reicosky, D.C. and Doty, C.W., (1974). Physical properties and tillage of Palendults in the Southeastern Coastal Plain. J. Soil Water Conserv., 29:220-224.

Campbell, R.B. and Phene, C.J., (1977). Tillage, matric potential oxygen and millet yield relations in a layered soil. Trans. ASAE 20(2):271-275.

Cassel, D.K., (1984). Tillage effects on soil bulk density and mechanical impedance. Soil phy. Pro. & Proc. (Am. So. Ag. Sc. 44:45-68).

Chaudhary, M.R., Gajri, P.R., Prihar, S.S. and Khera, R., (1985). Effect of deep tillage on soil physical properties and maize yields on coarse textured soils. Soil Tillage Res., 6:31-44.

Christensen, L.A., and Norris, P.E., (1983). A comparison of Tillage systems for reducing soil erosion and water pollution. National Technical Information service, Washington, D.C.

Cogo, N.P., Moldenhaver, W.C. and Foster, G.R., (1983). Effect of crop residue, tillage-induced roughness and runoff velocity on size distribution of eroded soil aggregates. Soil Sci. Soc. Am., 47:1005-1008.

Crossley, P. and Kilgour J., (1983). Small farm mechanization for developing countries. A Wiley-inter science publication John Wiley and sons. 57-183.

Currence, H.D. and Lovely, W.G., (1970). The analysis of soil surface roughness. Trans. Am. Soc. Agric. Eng., 13:710-714.

Denton, H.P., and Cassel, D.K., (1989). Conservation tillage and soil physical properties. Conservation tillage for crop production in North Carolina. The North Carolina Agriculture extension service., AG-407, 16-19.

Dick, W.A., McCoy, E.L., Edwards, W.M., and Lal, R., (1991). Continous application of no-till to Ohio soils. Agro. J., 83:65-73.

Erbach, D.C., (1982). Tillage for continous corn and corn-soyabean rotation. Transactions of ASAE, 906-911.

Ewing, R.P., Wagger, M.G. and Denton, H.P., (1991). Tillage and cover crop management effects on soil water and corn yield. Published in Soil Sci. Soc. Am. J. 55: 1081-1085.

Facer, S., (1989). Conservation tillage systems in Australia. Paper presented at farmers day at Kisima Farm, Kenya, 1989.

Figueroa, R.E. and Mburu, J.K., (1983). Development of the Bukura mark II plough. E. Afr. Agric. For. J. 44: 275-295.

Fisher, **N.M., (1978).** Cropping systems for soil conservation. Department of Crop Science, University of Nairobi, Internal Report.

FAO, **(1972).** The employment of draught animals in Agriculture. FAO, Rome, Italy.

FAO, **(1984).** Animal energy in Agriculture in Africa and Asia. 8-20pp.

Freebairn, D.M. and Gupta, S.C., (1990). Microrelief, rainfall and cover effects on infiltration. Soil Tillage Res., 16:307-327.

Gaultney, L., Krutz, G.W., Steinhardt, G.C. and Liljedah,J.B., (1980). Effects of subsoil compaction on corn yield in Indiana. ASAE Paper No.80-1011. St. Joseph, MI.

Gera-work, G.G., (1991). A comparison between conservation and conventional tillage systems for maize production. Unpublished MSc. Thesis, Univer-sity of Nairobi.

Gicheru, P.T., (1990). The effects of tillage and residue mulching on soil moisture conservation in Laikipia, Kenya. Unpublished MSc. Thesis, University of Nairobi, Kenya.

Giles, **G.W., (1975).** The re-orientation of agricultural mechanization for the developing countries, policies and attitude for action programmes. Report of experts panel, FAO, Rome, 4-7 February.

Gill, **R.W. and Vanden Berg, G.E., (1968).** Soil dynamics in tillage and traction. Agricultural Research Service, USDA.

Government of Kenya, (1986). Economic management for renewed growth. Sessional paper No.1 of 1986. Government of Kenya, Government printers, Nairobi.

Goryachkin, V.P., (1927). Theory of plow. Moskava.

Hadas A., and Wolf D., (1983). Energy efficiency in tilling dry soils. Soil and tillage Research, 3(1):47-59. Elsevier Science publishers B.V., Amsterdam, The Netherlands.

Hakimi, A.M., and Kachru, R.P., (1976). Response of barley crop to different tillage treatments on calcareous soil. J. Agric. Eng. Res. 21, 399-403.

Hayes, W.A., (1982). Minimum Tillage Farming. No-Till farmer, MC. Brookefield, Wisconsin.

Hayloe, H.N., Dwyer, L.M., Balchin, D. and Culley, J.L.B., (1993). Tillage effects on corn emergence rates. Soil Tillage Res., 26:45-53.

Hinga, G., Muchena, F.N. and Njihia, C.M., (1980). Physical and chemical methods of soil analysis. National Agricultural Laboratories, Nairobi, Kenya.

Houghton, P.D. and Charman, P.E.V., (1986). Glossary terms in soil conservation. Soil conservation service of Northern South West. Published by the soil conservation service of Northern South West.

Hulugalle, N.R. and Maurya, P.R., (1991). Tillage systems for the West African semi-arid Tropics. Soil Tillage Res., 20:187-199.

Huxley, P.A., (1979). Zero tillage at Morogoro, Tanzania. In: R., Lal(Ed), soil tillage and crop production. IITA, Ibadan, Nigeria.

Ikombo, B.M., (1983). Effects of Farmyard manure and Fertilizers on maize in semi-arid areas of Eastern Kenya. A comparison. E. Afr. Agric. For. J. 44:266-274.

ILCA, (1981). Animal traction in sub-saharan Africa. ILCA, Bulletin 14, International livestock centre for Africa, Addis Ababa, Ethiopia. 17p (E,F).

Kahumbura, J.M., (1994). Tillage and weed control in medium potential lands in Kenya. In: Improving Animal Traction Technology. P.Starkey, E.Emmanuel and J.Stares (Eds.).

Kepner, R.A., Bainer, R and Barger, E.L., (1987). Principles of farm machinery. Third Edition. CBS Publishers and distributors. 136-208.

Kilewe, A.M., (1987). Soil and water management. National Research priorities. Soil and water conservation in Kenya. Proceedings of the third National Workshop Kabete, Nairobi, 16-19 Sep.1986. Department of Agric. Engineering, University of Nairobi and SIDA. 539-552.

Kuipers, H., (1957). A relief-meter for soil cultivation studies. Neth. J. Agric. Sci., 5:255-262.

Lal, R., Eckert, D.J., Fansey, N.R. and Edwards, W.M., (1990). Conservation tillage in sustainable agriculture. In sustainable agricultural systems. Ed. Clive A. Edwards, Rattan Lal, and Gar House: Soil and water conservation society. 203-224.

Lal, R., (1991). Tillage and agricultural sustainability. Soil Tillage Res., 20:133-146.

Lale, R., (1978). Influence of tillage methods and residue mulches on soil structure and infiltration rate: Modification of soil structure. A wiley-Inter Science Publication. John Wiley and Sons. 393-402.

Landon, J.R. (Editor), (1991). Booker Tropical soil manual. A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agri. international Ltd., Longman Inc., New York, 40-120pp.

Larson, W.E., (1962). Tillage requirements for corn. J.Soil and water conserv., 17:3-7.

Larson, W.E., (1964). Soil parameters for evaluating tillage needs and operations. Soil Sci. Soc. Am. Proc., 28:118-122.

Larson, W.E. and Osborne G.J., (1982). Tillage accomplishments and potential. In:Am S. Sc. So. 677 South Segre road, Madison, Wisconsin 53711 USA. 44:1-12.

Laryea, K.B., Pathak, P. and Klaij, M.C., (1991). Tillage systems and soils in the semi-arid tropics. Soil Tillage Res., 20:201-218.

Lehrsch, G.A., Whisler, F.D. and Romkens, M.J.M., (1987). Soil surface roughness as influenced by selected soil physical properties. Soil Tillage Res., 10:197-212.

Logan, T.J., Lal, R., and Dick, W.A., (1991). Tillage systems and soil properties in North America. Soil Tillage Res., 20:241-270.

M'Arimi, A.M., (1978). The effects of tillage method and cropping systems for conserving rainwater in a semi arid area of Eastern Kenya. In: soil and water conservation in Kenya, Occasional paper No. 27, University of Nairobi.

Maurya, P.R., (1986). Effects of tillage and residue management on maize and wheat yield and on physical properties of an irrigated sandy loam soil in Northern Nigeria. Soil tillage Res., 8:161-170.

McGregor, K.C., and Greer, J.D., (1982). Erosion control with no-till and reduced till corn for silage and grain. Transaction of the ASAE :154-159.

Michieka, R.W., (1985). Research on maize production under minimum tillage. A preamble. Proceedings of the tenth Weed Science Society of East Africa.

Moreno F., Martin-Arada J., Konstankiemicz K. and Gomez-Rojas F., (1985). Changes in soil physical and mechanical properties due to transformation from dry farming (olives) to irrigation (wheat and sunflower annual crops). Soil Tillage Res., 7:75-84.

Muchiri, G. and Gichuki, F.N., (1981). Conservation tillage in semi-arid areas of Kenya. Soil and water conservation in Kenya. Proceedings of the Second National Workshop. Nairobi, March 10-13, 1982. Published by Ins. Dev. stu. and Fac. Agric., University of Nairobi.

Muchiri, G. and Gichuki, F.N., (1992). Conservation tillage for smallholders in semi-arid areas of Kenya. In proceedings of the National Agricultural

Mechanisation Strategy (NAMS). Feb. 26-28th, 1992, Masinga, Kenya.

Munzinger, P., (1982). Animal traction in Africa. Microfiche. Published by German technical co-operation.

Nadar, H.M., (1983). Matching Rainfall Patterns and Maize Growth stages under Machakos Area Conditions. In: E. Afri.Agric. For. J. 44:52-56.

Nelson, L.V , (1976). No-till corn: 1, Guidelines, M.S.U. Crop Ext.. Serv. Ext. Bulletin. E-904.

Ngugi, M.N. and Michieka, R.W., (1986). Current findings on conservation tillage in a medium potential area of Kenya. In: D.B. Thomas, E.K. Biamah, A.M. Kilewe, L. Lundgren and B.O. Mochoge (Eds.), Soil and water conservation in Kenya. Proceedings of Third National Workshop, University of Nairobi, Kenya.

Ngugi, M.N., (1987). The effect of tillage methods and subsequent weed control on maize. Unpublished Msc. Thesis. University of Nairobi, Kenya.

Njihia, C.N., (1975). Effect of tie-ridges, stover mulch and farmyard manure on moisture conservation in a medium area, Katumani, long rains, 1975.

Njogu, N., (1981). Experiences with zero-tillage for small scale farms in Kitale. Proceedings of the 8th East Africa weed science society conference, Nairobi. 145-155.

Onchere, J., (1977). Infiltration rates and related soil properties as influenced by seedbed preparation and time of the year. Unpublished MSc. thesis, University of Nairobi, Kenya.

Onstad, C.A., (1984). Depressional storage on tilled soil surfaces. Transactions of ASAE, 27: 729-732.

Onyango, S.O., (1988). Reducing present constraints to the use of animal power in Kenya. In Animal traction for agricultural development. Pg 455-460.

Osborne, G.J., Powell, D.L. and Matthews, P.G., (1978). Value and measurement of soil structure under system of reduced and conventional cultivation. Modification of soil structure. A Wiley-Inter Science publication John Wiley and Sons. 379-385.

Osman, M.S., (1964). The mechanics of soil cutting blades. J. Agric. Engineering Res. 9(4): 313-328.

Phillips, R.E., Blenns, R.L., Thomas, G.W., Foye, W.W. and Phillips, S.H.,(1980). No-tillage agriculture Science, 208:1108-1113.

Pikur, Jr. J.L., Ramig R.E. and Wilkins, D.E., (1993). Soil properties and crop yield among four tillage systems in wheat-pea rotation. Soil Tillage Res., 26:151-162.

Ramaswamy, N.S., (1981). Report on draught animal power prepared by FAO. India. 173 p.(E). (Mimeo).

Romkens, M.J.M., and Wangs, J.Y., (1985). Soil roughness changes of tillage systems from rainfall. ASAE paper No.85-2048, ASAE, St. Joseph, MI 49085.

Rukandema, M., (1984). Farming systems of semi-arid Eastern Kenya: a comparison. E.Afr. Agric. For. J.44:422-435.

Santos, G.C. and Brian, G.S., (1986). An animal drawn disk harrow for developing countries. ASAE paper NO.86-5502, ASAE, st. Joseph, MI 49085-9659.

Schimtz, H., Sommer M. and Watter S., (1991). Animal traction in rainfed agriculture in Africa and South America. Published by Vieweg and Sohn.

Smith, J.A. and Fornstrum J.K., (1980). Energy requirements of selected dryland wheat cropping systems. ASAE Transactions 23:822-825.

Smith, J.A. and Yonts, C.D., (1989). Final emergence of corn, sugarbeets and edible beans in three tillage systems. Transactions of ASAE 5(1) : 29-34.

Smith, L.A., (1992). Energy requirements for selected crop production implements. Soil tillage Res., 25:281-299.

Sojka, R.E., Karlen, D.L. and Busscher, W.J., (1991). A conservation tillage research update from the coastal plain soil and water conservation research centre of South Carolina: A review of previous research. Soil Tillage Res., 21:361-376.

Starkey, P., (1986). The introduction, intensification and diversification of the use of animal power in West African farming systems. In: Animal power in farming systems.

Stein, O.R., Neibling, W.H., Logan, T.J. and Moldenhaver, W.C.,(1982). Runoff ad soil loss as influenced by tillage and residue cover. Soil Sci. Soc. Am. J. 50:1527-1531.

Stibbe, E. and Terpstra, R., (1982). Effect of penetration resistance on emergence and early growth of silage corn in a laboratory experiment with sandy soil. Soil Tillage Res., 2:143-153.

Stobbe, E.H., (1989). Conservation tillage. Department of Plant Science, University of Manitoba, Winnipeg, Canada R3T. 2N2. Paper presented during farmers day at Kisima, Kenya.

Summers, J.D., Khalilian, A. and Batchelder, D.G., (1986). Draft Relationships for primary Tillage in Oklahoma soils. Transaction of the ASAE 29:37-39.

Taylor, F., Raghavan, G.S.V., Vigier, B., Mckyes, E. and Gauthier, L., (1981). Effect of compaction and root rot disease on development and yield of peas. Am. Soc. Agric. Eng. Paper No. Nar-81-302, ASAE. St. Joseph, MI.

Thomas, D.B., Edward, K.A., Barber, R.G., and Hogg, I.G.G., (1981). Runoff, erosion and conservation in a representative catchment in Machakos District, Kenya. In: Tropical Agricultural Hydrology, John Wiley and Sons Ltd.

Threadgill, E.D., (1982). Residual tillage effects as determined by cone index. Transactions of the ASAE. 25(4): 859-867.

Unger, P.W., Stewart, B.A., Parr, J.F. and Singh, R.P., (1991). Crop residue management and tillage methods for conserving soil and water in semi-arid tropics. Soil Tillage Res., 20:219-240.

Vogel, H., (1993). Tillage effects on maize yield, rooting depth and soil water content on sandy soils in Zimbabwe. Field crops Res., 33:367-384.

Vomocil, J.A. and Flocker, W.J., (1961). Effect of soil compaction on tomato and potato yield. Am. So. Ag. Sc. 44:1-19. 677 South Segoe road. Madson Wisconsin 53711.

Weaich, K., Cass, A. and Briston, K.L., (1992). Use of a penetration resistance characteristic to predict soil strength development during drying. Soil Tillage Res., 25:149-166.

Weill, A.N., Mehnys, G.R. and Mckyes, E., (1990). Effect of tillage reduction and fertilizer type in soil properties during corn production. Soil tillage Res. 17:63-76.

Wilkins, D.E., Klepper, B. and Rickman, R.W., (1982). Effect of tillage on wheat tillering. ASAE Paper No. 821512, St.Joseph, Michigan 49085.

Willcocks, T.J., (1979). Semi-arid tillage research in Botswana. Paper presented at the "Appropriate Technology for Tillage Workshop" Zaria, Nigeria 16-20 January, 1979.

Willcocks, T.J., (1980). Semi-arid tillage studies. In:Final Scientific Report of Dryland Farming Research Scheme Phase II, Vol. 1. Overseas Development Administration, London, 156PP.

Willcocks, T.J., (1981). Tillage of clod-forming sandy loam soils in the semi-arid climate of Botswana. Soil Tillage Res., 1:323-350.

Wischmeier, W.H., (1973). Conservation tillage to control water erosion. In Proceedings of the National Conservation Tillage Conference, 133-144. Ankeny, IA: Soil Conservation Soc. of America.

Wolf, D. and Luth, H.J., (1977). Tillage Equipment for clod-forming soils. Am. Soc. Agric. Eng. Paper No. 77-008, 8pp.

Yoo, K.H., Touchton, J.T., and Walker, R.H., (1989). Effect of conservation Tillage systems on cotton, surface runoff and its quality. J. Agric. Eng. Res. 44:289-299.

Young, S.C., Johnson, C.E., Schoger, R.L., (1988). Quantifying soil physical condition for tillage control application. ASAE Transactions 662-667.

Zobeck, T.M., and Onstad, C.A., (1987). Tillage and rainfall effects on random roughness. A review. Soil tillage Res., 9:1-20.