A COMPARISON BETWEEN CONSERVATION AND CONVENTIONAL TILLAGE SYSTEMS FOR MAIZE PRODUCTION

by

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DECLARATION

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

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ABSTRACT

The experiment entitled "A Comparison Between Conservation and Conventional Tillage Systems For Maize Production" was conducted at Kabete (Nairobi, Kenya) during the short rainy season of 1989/90. A 3x2 factorial experiment consisting of three tillage treatments (no-tillage, minimum tillage and conventional tillage) with two methods of weed control (manual weed control and chemical weed control) was used for the experiment. All treatments were replicated three times on a randomized complete block design.

The results showed that the highest draught and fuel requirements were obtained from the conventional tillage treatment; the lowest were from the no-tillage treatment, while minimum tillage was intermediate. As compared to conventional tillage, minimum tillage and no-tillage saved 47.4% and 59.6% per hectare in draught requirements respectively. Moreover, minimum tillage saved 50.3% and no-tillage saved 78.2% of fuel per hectare as compared to conventional tillage. The different tillage systems, when tested for both draught and fuel requirements, showed highly significant differences.

The most rapid emergence of maize seedlings, as indicated by emergence rate index, was obtained from the minimum tillage treatment where weeds were controlled with chemicals and the slowest was from the conventional tillage treatment where weeds were also controlled with chemicals. There was, however, statistically no significant tillage effect and no significant weed control methods effect on emergence rate.

The results indicated the longest maize plant growth was for minimum tillage treatment where weeds were controlled with chemicals, while the shortest maize plant growth was observed in the no-tillage treatment where weeds were controlled manually. However, there was no significant difference among tillage systems for length of plant growth.

The minimum tillage with manual weed control plot had the highest yield and the no-tillage with manual weed control plot had the lowest yield. However, when tested for statistical difference, tillage systems did not significantly affect yield.

The greatest residue mass production was achieved from the conventional tillage with manual weed control treatment while the lowest was from the no-tillage with manual weed control treatment. Analysis of variance indicated a significant difference at 5% level among tillage systems, while there was no significant difference between weed control methods and no interaction between tillage systems and weed control methods on residue production.

The result from economic analysis showed that the minimum tillage treatment where weeds were manually controlled was most profitable as compared to all the other treatments.

The results of the experiment strongly indicate that the minimum tillage with manual weed control system should be employed by farmers in the area during the short rains, as it has been found to perform better than the other systems. However, it is recommended that further investigations be carried out to substantiate the result obtained during the short rains and to see whether they also apply to the long rains.

1. INTRODUCTION

The use of fire and the development of agriculture are the two innovations that form the basis of civilization. Agriculture is a relatively recent innovation when considered in relation to human history, because man has been a mere collector of food for the greatest part of his existence. The first production of food by crop cultivation and actual domestication dates back 7000 to 10000 years, to the Neolithic Age (Janick *et al.*, 1981). This means, tillage has existed since man domesticated plants. Domestication of plants allowed man to begin farming and to be not totally dependent upon his skills and strength as a hunter to survive. As man became civilized, he found ways to make his work easier; the forked sticks and sharp stones were gradually improved. During World War I and II, with shortages of labour and demand for agricultural products, farm mechanization accelerated. Work horses were replaced by tractors, which continuously increased in power (Siemens, 1989).

Now-a-days, many researchers realize that the number of field operations involved in producing maximum yield have created several problems; such as soil erosion, soil compaction, high power and labour requirement, pollution, etc. Consequently, they have come to the conclusion that the number of field operations should be reduced which will lead to the required result. Hence, they developed a new concept called conservation farming.

Conservation farming is a world wide trend which was started over thirty years ago. It was first started in USA and, later in Canada and Australia, and is now a common practice in many parts of the world; It has been the single most important agricultural development during the 1980's. Reduced tillage is seen as a long term method of stabilizing soil and crop production, as well as a method of controlling costs while gradually increasing yields.

Now, many farmers are using different forms of reduced tillage. For instance, according to Dickey *et al.* (1987), adoption of conservation tillage throughout central United States has increased steadily from 1973 to 1981. The number of minimum tillage hectares increased by 125% and that of no-tillage planting by 78%. The area planted with conventional tillage increased just by only 1% during the same period. Minimum tillage and no-till accounted for 18% of the total number of tilled hectares in the United States in 1973. In 1981, these systems accounted for 32%. Farmers were using conservation tillage methods on about 31% of US crop land in the year 1987.

Most of the developing countries are currently faced with the problem of large populations, limited land, limited capital, and low levels of production and productivity in agriculture. All of these lead to a generally low standard of living. So, in the process of agricultural development, the basic problem that has to be tackled is the low agricultural productivity. Therefore, it is advantageous to increase the productivity of the land while minimizing inputs. Interest in and the use of no-tillage has increased considerably in the last few years, because in the production of crops, it has been realized that tillage is one of the heaviest consumers of energy.

As opposed to the above mentioned developed countries, very little has been done in Africa regarding the usage of conservation farming. This is mainly due to the fact that in Africa, development along the lines of conservation farming started only about ten years ago. However, in spite of the relatively short time span, a tremendous amount of development has been done in Kenya (plate 1 & 2) and South Africa; Ethiopia and Zimbabwe being in the early stages of the process towards development.

The concept of conservation farming in Kenya started about ten years ago, but was seriously adopted within the last three to five years in some parts of the country. It was estimated that about 70,000 hectares are currently under some form of minimum tillage, taking the amount of Roundup (Glyphosate) herbicide used as a yardstick (Keighley, per. comm., 1990).

It is crucial to have a clear explanation of what is meant by conservation tillage.

Tillage: Is the act or practice of cultivating land or soil manipulation of any kind. Houghton and Charman (1986) diffined different tillage systems as follows:

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.

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.

No-tillage (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.

Conventional tillage: is a tillage system using cultivation as the major means of seedbed preparation and weed control, and traditionally used for a given crop in a given geographical area. Typically includes a sequence of soil workings, 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.

Plate 1 The Ndume air seeder used for wheat no-tillage planting

Plate 2 Wheat no-tillage field at Kisima farm, Kenya

1.1 *OBJECTIVES*

Despite the fact that conservation tillage is quite popular in some parts of the world, it is realized that not many studies have been done regarding the performance of different tillage systems, their potential use and suitability with respect to different climatic conditions, soil types, slopes, farmer's level of income, etc. Hence, it is recommendable that tillage systems be investigated with respect to the above described areas. Therefore, the objectives of this experiment were:

1. To investigate the draught and fuel requirement for three different tillage systems (No-tillage, Minimum tillage, and Conventional tillage)
2. To determine the effect of the tillage systems, tested with two methods of weed control, on the growth of maize crop.
3. To determine the effect of the tillage systems, tested with two methods of weed control, on maize yield and residue mass production.
4. To establish the extent of changes in certain physical and chemical soil properties brought about by the employment of the different tillage systems.

5. To determine the cost-effectiveness of the different tillage systems.
6. To determine the most appropriate tillage system for adoption by area farmers (see section 3.1).

This thesis describes an investigation carried out to determine the effects of different tillage systems on the factors mentioned in the above objectives. The reasons of the study were: (1) Due to the fact that developing countries are stricken with innumerable problems' one of which being the extremely low agricultural productivity, it seemed relevant to study the impact of different tillage systems on productivity. (2) The author hopes that the result of this study will be of help to farmers; that it will give them an idea about adopting different tillage systems for greater productivity with minimum inputs.

The present study was undertaken at Kabete (Nairobi, Kenya) in 1989/90 growing season. The next chapter provides a review of literature on the effects different tillage systems have on the various factors affecting production. It is followed by chapters giving details of the methodology used and the results obtained. Finally a discussion of the result is presented and the thesis ends with conclusion and recommendation for future work.

2. LITERATURE REVIEW

2.1 *EFFECTS OF TILLAGE ON SOIL EROSION*

Soil erosion is the removal of surface material by wind or water. It is a hazard traditionally associated with agriculture in tropical and semi-arid areas. Moreover, erosion is increasingly being recognized as a hazard in temperate countries as well.

The rapid erosion of soil by wind and water has been a problem since man began cultivating the land. The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation and this, in turn, requires a thorough understanding of the processes of erosion (Morgan, 1986).

2.1.1 Soil erosion by water

Soil erosion by water is most active where rainfall can't infiltrate the soil, but flows over the surface, and is able to carry soil materials away through the hydraulic force of its flow. At the same time, it's only in contact with the surface soil for an hour or two, and not for the several days needed to pick up an appreciable amount of dissolved material (Kirkby, 1980).

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 doesn't happen on crop land, because complete crop cover can't 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 most preventing rain drops from striking the soil, then erosion caused by water on cropland can be greatly reduced. Soil loss and infiltration data from Bridge Port very fine sandy-loam soil (North Platte, Nebraska) show, 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. So, a great difference in soil loss between the tillage systems was observed but hardly no difference in infiltration between the tillage systems (Hayes, 1982)

The amount of cover required for effective erosion control varies but the standard established by the Soil Conservation Society of America (1985) calls for at least 30 percent of the soil surface being covered with residue after planting. Research results show that with 30% residue cover, soil erosion is reduced by about 60% when compared to the erosion with no cover (Siemens, 1986). Erosion comparisons of different tillage systems (mouldboard plough, chisel plough, disc or no-till) were made by Siemens and Oschwald (1978) using a rainfall simulator, on Catlin silt-loam soil with a slope of 4%, for maize and soybean. The result showed that with conservation tillage the amount of soil erosion is significantly less than with conventional tillage. Soil erosion was greater after soybean than after maize because maize residues cover more of the soil than soybean residues (cited by Siemens, 1986).

The erosive power of rainfall is greatest and most damaging when the protective cover of vegetation is removed exposing bare soil to the destructive forces of high intensity rain drops 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 Mc

Gregor *et al.*(1975) 19.3 t/ha sediment loss was obtained for conventional tillage, while the same loss was 2.7 t/ha for no-till in 1973 at Mississippi under soybeans (cited by Christensen and Norris, 1983)

2.1.2 Soil erosion by wind

Soil erosion by wind, like erosion by water, relies on the force which the fluid (in this case air) can exert on soil particles. For any fluid, this force depends to some extent on the roughness of the surface, but for wind, roughness plays a particular critical role because of the low density and hence transport capacity of air. Where the surface is very rough, with for example, plants or large stones which cannot be lifted by the wind, then the wind speed near the surface is low, and little erosion takes place. Any relatively smooth surface, like a bare field, is however, susceptible to wind erosion, and the risk is increased where the soil contains appreciable amounts of clay and silt-sized materials, which settle out of the air only slowly once they have been picked up. Soil particles that are 0.84 of a millimetre in diameter or smaller are considered to be erodible by wind. Therefore, the smaller soil particles are more erodible. Wind erosion can occur when the wind velocity exceeds

12.87 km/h at the soil surface. Hence, wind erosion can be stopped by slowing the wind at the soil surface to less than 12.87 km/h or by causing an increase in the size of soil aggregates or groups of soil particles to greater than 0.84 mm in diameter, which will make them too big to be transported by the wind (Hayes, 1982).

A report from Wisconsin indicates that, in one single dust storm 30 cm of top soil was deposited in some areas. Young (1982) and Hayes (1982) also suggested that wind erosion can be eliminated by adopting minimum tillage practices which leave the proper quantity of residue on the soil surface.

The effectiveness of any tillage method for controlling erosion ultimately depends upon the amount of crop residue left on the soil surface. The greatest reduction in erosion comes between 0 and 20 percent cover. A 65 percent reduction in soil loss was achieved with 20 percent ground cover (Moldenhauer et al, 1983).

Recommended minimum levels of small grain residues required to curtail wind erosion are 1000, 1500 and 2000 kg/ha on loam, clay and coarse-textured soils respectively. And 800 to 1700 kg/ha to control water erosion on gentle to moderate field slopes (Saskatchcuean Agriculture, 1988). Zero tillage fallow and seeding consistently resulted (significant in most years) in a lower erodibilty index than conventional and minimum tillage-practices on the silt-loam measured after either fallow or harvest.

A combination of fewer tillage operations and the use of wide blade cultivator to prepare the minimum tillage fallow resulted in significantly less wind erodible aggregates than for conventional fallow after four years of study on the same soil. On all soil textures, zero tillage maintained better aggregation (significant in most years) compared to minimum tillage practices. However, both the sandy-loam and clay soils were more prone to soil drifting after fallow or harvest than the silt-loam soil (Tessier et al., 1989).

2.2 *EFFECTS OF TILLAGE ON SOIL COMPACTION:*

The compaction of soil can be defined as an increase in its dry density, and the closer packing of solid particles or reduction in porosity. Soil compaction can be caused naturally by rainfall impact, soaking, internal water tension etc, and artificially under the down-ward forces of foot traffic and machines. Compactive forces are usually of short duration in the case of moving vehicles (McKyes, 1985). Continuous cultivation, particularly with larger and faster equipment, causes compaction of the soil at the surface and also at subsoil depths. A "plough plan" forms in some soils just below the cultivated layer reducing root penetration and water movement. Compaction can also occur deeper in the soil due to the traffic of heavy tractors and equipment. These deeper compacted layers of soil reduce the volume of soil explored by crop roots for moisture and nutrients (Monosanto Australia Limited, 1987). It is evident that the number of times that a load is repeated affects not only the magnitude of change in soil density, but also the volume of soil which is affected. Some 85% of the deep compaction occurs upon the first traffic pass. After 10 and 15 passes of the tractor and sprayer, the volume of compacted soil was seen to be progressively deeper and wider than after one or five passes (Gill and Reaves, 1956; Raghavan et al., 1970; cited by McKyes, 1985).

The compaction process reduces the total pore space in the soil and particularly the proportion of large pores. The large pores are the ones that drain most quickly after the soil has been saturated, and they provide most of the oxygen supply for roots (Denton and Cassel, 1989).

Both the mechanical and the hydraulic properties of compacted soil have an effect on the rate at which plant roots can grow to a certain depth in a soil, and on the flow and availability of water and nutrients for plant use. This fact has been quite obvious in numerous comparative observations.

As cited by McKyes, (1985), Taylor *et al.* (1966) indicated that the number of roots penetrating the soil was reduced drastically as the penetration resistance approached 2 MPa pressure. When soils were compacted to more than 2 MPa resistance, virtually no roots were able to grow. Similarly, Raghavan *et al.* (1989) indicated that the heaviest compaction treatment (15 Tractor passes) decreased the maximum depth of rooting by one half, and the depth of dense roots about one third of that in un-compacted soil. This effect had the net result of considerably reducing the growth and yields of the silage maize compared to un-compacted plots in the same field.

Soil compaction, mainly caused by wheel traffic and tillage operations, has recently become more apparent and growers are expressing a greater concern over compaction effects on field crops. It has often been asserted that conservation tillage reduce soil compaction. Fewer trips are usually made across the fields, and the tillage equipment may be lighter. With less tillage there is less disruption of the natural soil structure, resulting in more durable aggregates with greater bearing strength. With any conservation tillage system there is less disruption of wheel tracks and of other compacted soil zones near the surface, and with no-till planting there is no disruption of compacted soil at all (Denton and Cassel, 1989). A conservation tillage system such as light, once-over discing may result in a compacted zone in the lower half of the plough layer.

Schuller (1989) reported that reduced tillage had much less traffic as expected, and as machine working widths increased the tracked area decreased. Moreover he noted that the traffic intensity for the no-till is one half the intensity for the plough system while the chisel and till plant are intermediate.

Hakansson *et al.* (1989) reported that although wheel traffic may be semi-random in modern farming practices, the total area covered by the tractor drive wheels alone is about two times the total field area during one season for conventionally tilled crops such as small·grains, maize, soybean and cotton. When the front tractor wheels and harvester wheels are included this becomes 3.5 to 4 times the field area (Cited by Schuller, 1989).

Studies conducted on many different soils in Tennessee, Georgia, North Carolina and several mid-western states have generally shown that soils farmed with non-till system are more compacted in the plough layer than with conventional tillage. In Georgia, a study involving no-till soybeans double cropped with wheat showed serious compaction in the lower part of the plough layer due to the discing used to prepare the wheat seedbed (Denton and Cassel, 1989). Moreover, Stobbe (1989) indicated that the top 15 cm of soil under zero tillage is more compacted than soils under conventional tillage.

The increased awareness of soil compaction has stimulated the introduction of improved tillage implements such as inter-row sub-soilers and a substantial adoption of these implements by agricultural producers. The more recent emphasis on reduced tillage systems which leave crop residues on the soil surface has increased interest in slot planters and other reduced tillage devices.

Coupled with this revolution in tillage systems is the recognition that although appropriate primary tillage systems can be used to reduce soil compaction, wheel and implement traffic during and after primary tillage can recreate a compacted situation where conventional wheel spacing is used (Threadgill, 1984).

Soil compaction has often been used or understood to have bad connotations; however, not all compaction is bad. There are times where seed-bed compaction is needed to improve soil-seed contact. It is important to note that such seedbed compactions are temporal in the seeding zone and not irreversible into the subsoil. Thus, it is necessary to differentiate good or acceptable compaction from harmful or excessive compaction (Gupta and Allmaras, 1987).

Francis, Cameron and Swift (1987) reported that, in their sixth year of a tillage trial, the bulk density of the direct drilling soil was greater than the conventional cultivation soil throughout the equivalent depth of cultivation, although this trend was reversed at 250-350 mm depth. In contrast, soil strength as determined by cone-penetrometer resistance was almost significantly greater in direct drilling than conventional cultivation soil at all times and depth of measurement.

Threadgill (1984) reported that, on his study conducted over a 4 years period on a Tifton sandy-loam soil, based upon generally accepted cone index values for restricting root growth (1500 kPa); the slot-planter tillage system maintained only 22 per cent of the soil profile suitable for root growth whereas the mouldboard plough tillage system maintained 61 per cent of the profile at soil strengths less than restricting levels.

Voorhees and Lindstorm (1984) investigated long-term effects of tillage method on soil tilth independent of wheel traffic compaction on a Nicollet silt clay loam soil and reported that mouldboard ploughing produced a more porous soil in the 0 to 15 cm depth than did conservation tillage during the first and second year, but gradually in 3 to 4 years, conservation tillage produced a higher porosity than did ploughing. Moreover, a similar effect was measured in the 15 to 30 cm layer, but about 7 years of conservation tillage was needed to produce a soil with a porosity equal to that of ploughing.

2.3 *EFFECTS OF TILLAGE ON SOIL TEMPERATURE.*

From the moment when seed is sown, the growth of a crop plant is influenced by the temperature of the soil. Provided the soil is moist, temperature is the determinant environmental factor which determines when germination will occur. Thereafter, temperature controls the rate of seedling growth as far as the structure and nutrient status of the soil allow roots to develop vigorously (Monteith, 1979). Janick et al. (1981) indicated that most plants will not live if soil temperature exceeds 54^0c or is below about 5^0c.

Many researchers have given emphasis to investigate how temperature is affected by tillage practices. As quoted by Young (1982), Cook summarized the temperature effect of no-tillage as, during the few days immediately after planting maize, soil temperatures should be about 10^0c as much as possible to assure a high percentage of seed germination. Soil temperature at the 5.1cm depth (the usual depth of maize seed) rises during the day time due to sunshine directly on the soil. Soil temperature falls at night because no sunshine is received and heat which was stored by the soil during the day may be back-radiated at night.

Hayes (1982) described soil temperature after planting as influenced by tillage practices and mentioned that soil temperature in the fall ploughed plots was highest (average 18.7^0C); till plant ridged next (17.5^0C); chisel plough (17.4^0C); and non till (16.1^0C) due to the amount of surface residue, soil surface configuration, and soil water content differences.

Ojeniji and Dexter (1979) described that, although the mean temperature in the different tillage treatments did not differ significantly there were difference in the daily temperature ranges. They also summarized that soil structure had no effect on mean soil temperature, but had significant correlation with daily temperature range and maximum temperature gradient in tilled soil.

Aston and Fischer (1986) reported that generally, the soil temperatures of the conventionally cultivated treatment were warmer during the day and cooler during the night than the direct drilled treatment.

2.4 *EFFECTS OF TILLAGE ON SOIL STRUCTURE*

Soil structure refers to the gross arrangement of the soil particles into aggregates. A soil may have either a simple or a compound structure. Most agricultural soils have 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 high water holding capacity because of the increased volume of the soil pore space, and are resistant to surface puddling or crusting.

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 crop requirements.

Under zero-tillage the size of the aggregates is considerably larger, whereas the aggregate size distribution is more homogenous. Especially the small aggregate with a diameter smaller than 0.3 mm disappear (Boone *et al.*, 1976). They 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. In the second place, the difference in displacement between two neighbouring soil particles can be longer by the compacting and smearing action of wheels in a loosened soil than in an already compacted soil.

Osborne *et al.* (1978) indicated significant deterioration in soil structure as cultivation intensified. Lale (1978) also reported that the structural conditions of soil under no-tillage improve with time, provided there is an adequate amount of residue mulch on the surface and compacting wheel traffic is limited to non-destructive levels.

2.5 *EFFECTS OF TILLAGE ON SOIL MOISTURE*

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 intense rain storms, and conditions that increase the length of time the water remains on the soil surface (Denton and Cassel, 1989).

Studies of the effect of conservation tillage on plant available soil water have produced variable results. Francis *et al.* (1987) reported that there were no significant differences in the rate of infiltration at any time between direct drilled and conventionally cultivated soils. Tollner and Hargrove (1982) observed that the top soil in the conventional tillage treatment held more water than did the no-till treatment at a suction of 800 cm or less. At a suction of 3000 cm or higher they observed no difference. It is also worth noting that the no-till treatment had higher values of residual moisture and infiltration rates which is contrary to other reports.

Crop residue mulches provided by proper no-tillage practices are an effective way to improve soil water conditions and enhance crop production levels. Under Canadian conditions, Negi *et al.* (1980) observed that the amount of water available to plants at 0.30m depth was twice as large in the subsoiled and roto-tilled plots as in the compacted-untilled, ploughed and chiselled plots. Tessier *et al.* (1989) reported that conservation tillage improved soil water availability throughout the fallow periods, likely via a combination of lower evaporative losses, faster redistribution of soil water influxes, and better over winter precipitation conservation efficiency.

2.6 *EFFECTS OF TILLAGE ON PLANT EMERGENCE*

Any tillage system to be adopted by farms must proof its ability to allow seeds an effective germination and emergence. Many researchers compared different tillage system for their effect towards seedling emergence.

Erbach (1982) used an Emergence Rate Index (ERI) to compare plant emergence rates among the tillage systems. He reported that the most rapid emergence, as indicated by ERI for maize following soybeans, was obtained with till planting and the slowest was with fall mouldboard ploughing. The ERI for soybeans following maize was significantly greater for till plant than for the other systems.

Francis *et al.* (1987) reported that the direct drilled soil had a significantly greater plant emergence count than conventionally cultivated soil. They attributed this to the 16 mm of rainfall which occurred two days following drilling, causing break down of the less stable surface soil aggregates and crusting in the cultivated treatment. In contrary, Huxley (1980) reported that, in comparing the effects over time of zero and conventional hoe-tillage (when combined with different inputs of fertilizer on a highly-weathered oxysol) maize emergence was slightly poorer on untilled plots compared with tilled plots.

2.7 *EFFECTS OF TILLAGE ON WEED CONTROL.*

Weed control has been one of the most expensive, yet least successful steps in production of all crops. Largely because of weeds, many systems of costly and excessive tillage have been developed over the decades.

A 1984 survey in Indiana found that farmers obtained adequate weed control 87 % of the time with conventional tillage, 65 % of the time with reduced tillage, and 42 % of the time with no-till (Koskinen and Whorter, 1986).

Stobbe (1989) reported that, weed population is usually lower under zero-tillage than conventional or minimum tillage (77, 158 and 134 weeds/m^2, respectively). Lale (1979), cited by Stobbe (1989), reported that in Nigeria under zero tillage weed growth was greatly reduced compared to conventional tillage. In contrary, Huxley in his first year of the experiment at

Morogoro, Tanzania got more weeds in uncultivated plots than in cultivated ones.

2.8 *EFFECTS OF TILLAGE ON SOIL MICROBES*

The numbers, types and activities of soil micro organisms are important to the productivity of soil through their regulatory effect on soil Carbon (C) and Nitrogen (N) levels. Doran (1980), cited by Dick (1984), has reported that microbial numbers in the 0 to 7.5 cm surface increment of no-till soil were significantly higher than in the surface increment of ploughed soils.

Linn and Doran (1984) investigated aerobic and anaerobic microbial populations in the no-till and ploughed soils at six locations across the U.S. They reported that numbers of aerobic and anaerobic microorganisms in surface (0-75 mm) no-till soils averaged 1.35 to 1.41 and 1.27 to 1.31 times greater, respectively, than in surface ploughed soils. Deeper in the soil (75-300 mm), however, aerobic microbial populations were significantly greater in conventionally tilled soils. In contrast, below 150 mm, the numbers of anaerobic microorganism differed little between tillage treatments. In no-till soils, however, these organisms were found to comprise a greater proportion of the total bacterial population than in conventionally tilled soils.

2.9 *EFFECTS OF TILLAGE ON NUTRIENTS AVAILABILITY*

Plant growth is dependent on the availability of essential nutrients, which are ultimately supplied to the plant cell from the soil. Many researchers investigated how tillage systems affect the availability of nutrients.

Loch and Coughlan (1984) measured soil chemical and physical properties of a black cracking clay soil after five years under a zero tillage and stubble retention trial. They reported that stubble retention slightly increased the organic carbon content in the 0-10 cm layer, and the dispersion ratio in the 0-4 cm layer. Stubble retention increased dry aggregate size in the 0-4 cm layer of the zero tilled treatment, apparently due to a reduction in the rate of drying of the surface after rain.

The phosphorous and potassium concentrations in the 0 to 7.5 cm soil layer, for a continuous-maize study tended to be greater for conservation tillage systems than for mouldboard plough systems. Much of the increase in nutrient concentration with conservation tillage occurred during the first 2 years of maize production (Erbach, 1982).

McDowell *et al.* (1980) investigated no-till soybeans and maize grown on highly erodible loessial soils in northern Mississippi and got a result of total (solution plus sediment) nitrogen and phosphorous losses in 1973 from no-till soybeans as 4.7 kg/h and 2.8 kg/ha, respectively, as compared with 46.4 kg/h and 17.6 kg/ha from conventional till. No-till effectively reduced soil and associated plant nutrient losses, but increased solution P concentrations and losses in run-off.

Laflen and Tabatabai (1984) evaluated the effect of different tillages for continuous row cropping for maize-soybean rotations on the losses of NH_4-N, and No_3-N and PO_4-P in run-off and total N and total P in sediment at two sites in Iowa by using simulated rainfall, and they reported that concentrations of NH_4-N, NO_3 -N, and PO_4 -P in run-off water and, in general concentration of total N and total P in the sediment fraction increased following the order of tillage practices, plough < chisel < no-till. However, because more N and P was lost in eroded soil than in water and because erosion is in the reverse order, losses of nutrients were on the order, plough > Chisel > no-till.

2.10 *MACHINERY INVESTMENT*

Presently, machinery-related expenditures may be the greatest single item in a farm's production cost, and there exists a potentially great opportunity to improve the profits of a farm by employing some management technique and hence reducing machinery costs. Optimum farm machinery management occurs when the economic performance of the total machine system has been maximized (Hunt, 1983). No-tillage offers an opportunity for more intensive land use, a reduction in machinery investment and repairs and a need for less fuel and labour thus increasing the farmers net returns (Hayes, 1981).

There is a decrease in resources required for producing a crop under zero tillage compared to conventional tillage. Large reductions in fuel, oil and machinery repair makes zero tillage a very attractive option for countries whose foreign exchange earnings are low. Zentner and Lindwall (1978) compared tillage systems for their resource requirement and table 1 shows their result as quoted by Stobbe (1989).

Happar and Henderson (1985) reported that for seed-bed preparation the highest draught per unit was observed with a disk plough operating at a 25 cm depth. The lowest draught at this depth was that of the Zahle plough and no power was used for seed-bed preparation in the no-till treatment. The least amount of fuel used was in the no-till while the greatest amount was for Zahle plough at 25 cm depth (59 lit/ha).

Fuel consumption for tillage and seeding was determined for three tillage systems in Manitoba, Canada. When comparing the fuel for establishing the crop, zero tillage was 5 times more efficient than when the land was ploughed with a mouldboard plough, and 3.3 times more efficient than when a chisel plough was used (Townsend, 1979; Cited by Stobbe, 1989).

Table 2 analyzed by Mathews (1975) of the U.K. National Institute of Agricultural Engineering, illustrates the energy requirements of some conventional and reduced cultivation techniques for cereal growing. Apart from the reduced number of passes required by the tractor and reduction in labour hours/ha, the most significant reduction is in the energy requirement for planting the crop to almost one tenth that of conventional ploughing and harrowing. Moreover, studies in U.K. show that labour requirements for seeding crops were 5.2, 3.7 and 1.0 man-hours/ha for ploughing, reduced cultivation, and zero tillage, respectively (Butterworth, 1980; Cited by Stobbe, 1989).

Fuel use depends on the specific field operations, as well as the soil resistance. With this information, one can estimate the energy requirements of specific tillage systems; using a conventional tillage system (including discing stalks, mouldboard ploughing, discing, applying ammonium nitrate, field cultivating, planting, and cultivating) would require 56.2 litres of diesel fuel per hectare. A chisel tillage system including chisel ploughing, and cultivating would require 38.8 litres of diesel fuel per hectare. The no-till system (shredding stalks, applying liquid nitrogen, and no-till planting) would use 16.3 litres per hectare (Christensen and Norris, 1983).

Due to the advantages of no-tillage systems over conventional tillage systems, farmers may need to replace their conventional systems with no-tillage systems. But a question may arise from farmers as to when to replace their systems with no-tillage. Rowshan, Royblack, and Alan Rotz (1985) recommended to replace the conventional mouldboard plough tillage/planting system to no-tillage system if:

> "The current repairs plus change in salvage value of the conventional tillage/planting system plus change in the value of land,
>
> Exceeds:
>
> Interest on the salvage value of the conventional tillage/planting system plus annual ownership and repair cost on the no-tillage system minus net annual operating cost gains.

otherwise, keep the conventional system for an additional year."

Table 1 Resource requirements for zero tillage as percentage of conventional tillage (Stobbe, 1989).

	Rotation	
Resource	wheat fallow	wheat-wheat fallow
Labour	71.7	79.7
Fuel and oil	57.9	71.9
Machine repairs	52.9	62.7
Total	80.7	83.7

Table 2 Energy requirement of some traditional and reduced cultivation treatments for cereals (Mathews, 1975).

Treatment	Number passes	Energy MJ/ha	Labour hours/ha
Mouldboard plough, disk-harrow twice and drill	4	300	4.0
Shallow (10cm) ploughing and combined rotary-harrow-drill	2	180	1.6
Rotary digger and combined rotary harrow-drill	2	180	1.6
Herbicide and direct-drilling	2	35	0.7

2.11 *EFFECTS OF TILLAGE ON YIELD*

The main objective of farming is increasing the productivity of the land, i.e., to get the maximum output (yield) per unit of input. Yields with conservation tillage are greater, less, or about the same as with conventional tillage, depending upon the particular circumstances.

Many researchers have evidence that minimum or no-till systems produce higher yields than conventional ones. Langdale and Wilson (1987) reported that grain sorghum responded significantly to minimum tillage, yielding an average of 0.31 and 0.50 Mg/ha more grain than the average for the conventional tillage (4.58 Mg/ha) and no-tillage (4.39 Mg/ha) treatments. Mc Gregor and Greer (1982) investigated no-till and reduced till maize for silage and grain on erosion plots and small water-sheds at Holly Springs, Mississippi. Their result shows that, the crop yields from the no-till and reduced till systems compared favourably with those from conventional tillage.

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-tillage system. Stobbe *et al.* (1977) 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.

Erbach (1982) reported the effects of tillage system and year on yield of maize in the continuous-maize study near Ames, IOWA, as follows. The conventional fall mouldboard plough system had the greatest average yield. The fall chisel plough system had the lowest average yield for the 5 years because of the low yield in 1975 caused by a poor stand. The yields from the no-tillage systems also were low, averaging about 11 percent below the yield from the fall mouldboard plough system.

Willcocks (1979) indicated, from his research in Botswana, that crop yields under semi-arid conditions without mulch are positively related to the degree of soil loosening to a given depth. He also stated that Sorghum yields are positively correlated with effective reduction in bulk density to 250 mm depth. This shows that soil bulk density values should be given their due weight in any cultural practices. Moreover, he mentioned that yields from no-tillage farming are unlikely to be as high as the deep tillage if the porosity of the soil is too low for the effective development of crop roots.

According to Nelson *et al*. (1976) over 20234 hectares of no-till maize were grown in Michigan in the year 1975 and there have been both successes and failures. The experiment suggests that top management is required for success. Well-drained loams and sandy loams are best adopted to no-till while fine textured (silty-clay-loams, clay-loams and clay) dark coloured soils, and soils with poor drainage are not well adopted to no-till.

Henery and Van Doren (1985) reported that there is no significant yield differences between the no-till and deep parplow treatments. Tessier *et al.* (1989) reported that despite benefits of erosion protection and enhanced soil water reserve, zero-tillage practices failed to consistently out-yield conventionally grown spring and autumn wheat. Crop yields with zero-tillage seeding of wheat on stubble and chemical fallow were generally equal to and in a few years greater than when seeding after stubble tillage or tilled fallow. On a silt-loam, wheat sown on minimum tillage fallow resulted in comparable grain yields in three of six years and lower yields in three more years, relative to conventional fallow.

3.0 MATERIALS AND METHODS

3.1 *THE SITE*

The study was conducted at Kabete (Nairobi, Kenya), located at an altitude of 1930 meters above sea level, having coordinates of 01 degree 15 minutes South and 36 degree 44 minutes East. The soil at the site is classified as Eutric nitosol and the climate is known as semi-humid (Sombroek *et al.*, 1982).

Mean annual rainfall as computed from 18 years of rainfall data was 1024 mm with a bimodal distribution (Nurzefa, 1989). There are two distinct seasons: the long rains, March to May, and the short rains, mid October to December.

3.2 *PAST CROPPING HISTORY OF THE SITE*

It was not possible to get a long history of the past about the site. However, the land-use of the experimental site starting from 1984 to 1989 was shown in table 3 below.

Table 3 Past cropping history of the experimental site

Year	Season	Land use system
1984	Long rains	Fallow
	Short rains	Potato, Research
1985	Long rains	Bean, Research
	Short rains	Maize, Herbicide/minimum tillage research
1986	Long rains	Maize, Aphid research
	Short rains	Cowpea and Bean, research
1987	Long rains	Potato, research
	Short rains	Pigeon pea, Research
1988	Long rains	Pigeon pea, Research
	Short rains	pigeon pea, Research
1989	long rains	Maize, Research
	Short rains	Maize, tillage system comparison

Source: Mr. F. K. Njoroge, Assistant farm manager

3.3 *THE EXPERIMENT*

The study was carried-out in a 3x2 factorial experiment; consisting of three treatments with two levels of weed control. All treatments were replicated three times on a randomized complete block design. Maize (Katumani composite) was used for all treatments. It is an early maturing variety which takes about 115-

120 days from planting to maturity (M'Arimi, 1977). Fertilizer (DAP) was applied in a single dose during planting. The crops were managed according to the recommended practices for the area. Planting was done after the short rain started (November 4, 1989). The maize seed was spaced at 80 cm between rows and 30 cm between plants, giving an expected population of 41625 per hectare.

3.3.1 Treatment description

3.3.1.1 *No-tillage*

After the land was cleared, planting was accomplished by using a two unit conventional maize planter with stub runner furrow opener and fertilizer attachment. The planter had two modified tines attached to the front of the frame of the planter to open a furrow wide enough`for the stub runner. The planter dropped the seed into the furrow and then covered the seeds (plate 3). The tine dimension was 2 mm at the lower end and 80 mm at the upper end; this facilitated easy furrow opening and covering for the planter. All surface area of the land remained undisturbed, except the furrow line where the seeds were sown (plate 4).

Plate 3 Conventional maize planter used for no-tillage planting

Plate 4 No-tillage plot after planting

3.3.1.2 *Minimum tillage*

Following clearing, the plots were cultivated twice by using a spring loaded tined harrow to an average depth of 15 cm in the same direction. The implement (tined harrow) consisted of two ranks; four tines at the front and five tines at the back, and a total width of 210 cm and a space of 23 cm between tines (plate 5). After cultivation, planting was done by using the same planter described in the no-till treatment above with front tines. Even though the land was disturbed in this treatment, the soil was not over turned. Hence most of the weeds and the previous residues were exposed to the surface to act as a mulch or cover (plate 6).

3.3.1.3 *Conventional tillage*

For the conventional tillage system, the Plots were cleared and mouldboard ploughed to an average depth of 20 cm using a two bottom mouldboard plough (Plate 7). Here most of the weeds and bushes found on the surface were buried (plate 8). The land was then cultivated by using an offset disk harrow with two ranks and a total of 16 disks (plate 9). Planting was done by using the conventional maize planter described in the no-till treatment above without front tines.

Plate 5 Tined harrow used for minimum tillage plots

Plate 6 Minimum tillage plot after planting

Plate 7 The two bottom mouldboard plough used for the conventional tillage treatments

Plate 8 Conventional tillage treatment plots, across photograph.

3.3.2. Level of weed control description

The three treatments described above were tested with two methods of weed control (chemical weed control and manual weed control).

3.3.2.1 *Chemical weed control*

Weeds in all the three treatments were controlled by using herbicides. The minimum and no-tillage treatments were sprayed with Round up (41.0% Isopropylamine salt of glyphosate), a foliar applied herbicide for the control of annual and perennial weeds, the day after planting, to control weeds as per recommendation. Spraying was done manually by knapsack sprayer (plate 10). The rate of application was 3 lit/ha in 200 lit/ha of water. The conventional tillage treatments were sprayed with Lasso+Atrazine, flowable, (27.2% Alachlor [2-chloro-2'6'-diethyl-N-(Methoxymethyl) acetanilide] and 15.5% Atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine]) a pre-emergence residual herbicide, particularly effective against annual grass weeds, on the same date at a rate of 2.5 lit/ha in 200lit/ha of water. Lasso+Atrazine was sprayed for the second time between rows at a rate of 2 lit/ha to all the three treatments, in order to control weeds that emerged after the first spraying was done. Spraying was done on the same day for all treatments.

Plate 9 The offset disk harrow used for conventional tillage treatments

3.3.2.2 *Manual weed control*

The three tillage treatments were also tested under manual weed control using three different hand tools that were assumed appropriate for the tillage treatments, as described below.

Plate 10 Spraying herbicide to control weeds from chemical treated plots

No-tillage, manual weed control:

In this treatment the control of weeds was done manually using a sickle (plate 11) so that the weeds could be cut and left on the surface as a mulch without disturbing the soil (plate 12). Weeding was done each time the weeds had germinated and were convenient to handle and could be cut by the Sickle. In addition, a little cultivation using forked jembe, hoe, (plate 11) was performed along the furrow since the lines were already disturbed.

Minimum tillage, manual weed control:

Here the control of weeds was done by using forked jembe (plate 11) so that each time the weeds germinated they could be uprooted and left on the surface as mulch without over turning the soil too much.

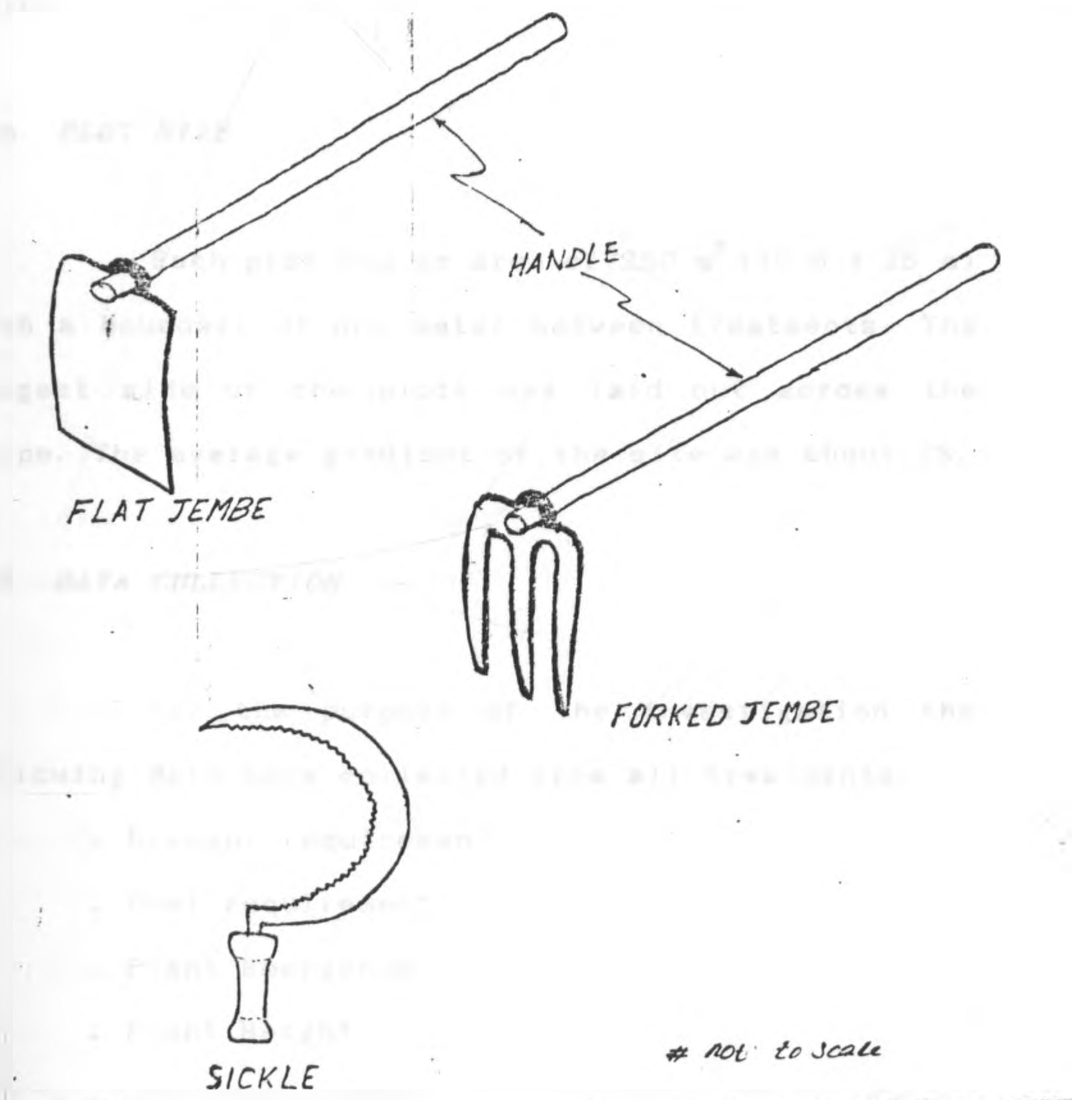


Plate 11 Hand tools used to control weeds from manual weed control treatment plots

Conventional tillage, manual weed control:

The control of weeds on the conventionally tilled plots was accomplished by using a flat jembe (plate 11). Plots were thoroughly cultivated and the weeds uprooted. All the weeds were taken out of the plots, leaving no weed on the surface to act as a mulch.

3.4 *PLOT SIZE*

Each plot had an area of 250 m^2 (10 m x 25 m) with a boundary of one meter between treatments. The longest side of the plots was laid out across the slope. The average gradient of the site was about 2%.

3.5 *DATA COLLECTION*

For the purpose of the investigation the following data were collected from all treatments:

. Draught requirement

. Fuel requirement

. Plant Emergence

. Plant Height

. Moisture Content

. Labour requirement

- Nutrient availability
- Yield
- Residue mass production

3.5.1 Methods of data collection

The data for the above variables were collected for all treatments from each plot as follows:

3.5.1.1 *Draught requirement*

The draught requirement was approximated for each treatment. For this, the time required by the tractor to complete each operation on each plot was recorded using a stop watch. This time did not include the idle time and the time lost due to maintenance or refuelling. Once the time was obtained it was possible to determine the speed of operation for each plot, since the length of each plot was known. The maximum available PTO power of the tractor used was tested, on laboratory basis, using a Froment Dynamometer (plate 13). The usable drawbar horse power was found as a percentage of Maximum PTO HP by using the relationship given by Bowers, (1975) shown in table 4 and it was assumed that the tractor was at this power level for all operations.

Plate 12 Weeds left as a mulch on the surface of no-tillage with manual weed control plot after being weeded manually

Plate 13 The Froment Dynamometer used to test the tractor PTO power

Table 4 Relationship between usable draw bar HP and maximum PTO HP

SOIL CONDITION - HORSE POWER		
Condition of soil	Usable draw bar HP As a percentage of maximum PTO HP	Ratio of maximum PTO HP to usable draw bar HP
Firm	67	1.5
Tilled	56	1.8
Soft or Sandy *	48	2.1

* ratio used for determining the draw bar horse power of the tractor

To determine the draught requirement for each plot equation 1 given by Hunt, 1983 was used.

$$F = \frac{DBP \times 3.6}{S} \text{------------------------------------} (1)$$

Where

F = Draught force in kilo Newton

S = Speed in kilo-meter per hour

DBP = Draw-bar power expressed in kw

3.5.1.2 *Fuel requirement*

To determine the consumed fuel at each plot, prior to the respective operations the tractor was fuelled with a full tank and then used for the operations. Two stop watches were used. One to record the time taken for the whole operation including the idle time (the total time the engine was running), and the other was used to record the actual time. I.e., the time the tractor took to perform the operation. After the completion of each operation the tractor was driven to a fixed place where the fuel was to be refilled. To refill the fuel, the engine was shut off and using a graduated cylinder the fuel was refilled. Then the amount refuelled was recorded. This was the amount of fuel consumed while the engine is running during the entire operation. To know the net amount of fuel consumed for the operation the tractor was fuelled to full tank and driven without performing any operation for one hour, and refuelled again. This amount was the fuel consumption that was related to the consumption of fuel during turning and idle time. This amount of fuel was subtracted from the total fuel consumption and the actual fuel consumed in each plot for each operation was obtained.

3.5.1.3 *Plant emergence*

The number of plants in each row was counted frequently during the time the plants were emerging from each plot starting from the date the first seed germinated to the last day when it was assumed that the total germination was considered complete. An Emergence Rate Index (ERI) was calculated for each plot by using equation 2 given by Erbach, (1982) to compare plant emergence rates among the tillage systems.

$$ERI = \sum_{n=first}^{last} \left[\frac{\%n - \%(n-1)}{n} \right] \text{--------------------} (2)$$

Where

% n = percentage of plants emerged on day n

%(n-1) = percentage of plants emerged on day n-1

n = number of days after planting

first = number of days after planting that the first Plant emerged (first counting day)

last = number of days after planting when emergence was considered complete (last counting date)

The final plant population was estimated by counting the number of plants in each plot during harvest.

3.5.1.4 *Plant height*

Plant height was taken from each row in each plot at two locations. The locations were selected randomly and any plant that came in front was measured for height using a tape measure. The measurements for all plots were taken on the same day. Measuring started 30 days after planting and were repeated each month until harvest. The average height for each plot was recorded every time the measurement was taken.

3.5.1.5 *Available soil water*

In order to determine the ability of the different tillage systems to conserve water, soil samples were taken at a selected time interval during the cropping season (15 days after germination and during flowering stage). Samples were obtained from depth ranges of 0-15 cm, 15-30 cm and 30-45 cm. The maximum sample depth was selected to be at 45 cm, because most of the root development was expected to be within this range.

$$DB = \frac{Ms}{VB} \text{---} (3)$$

A core method was used to collect the samples. The loaded soil core sampler was driven vertically into the soil by means of a hammer. After the soil had been dug away from around the sampler, the core of soil in the soil ring was ejected by pushing the soil ring and then covered with plastic sheet air tight. Fresh weight was recorded soon after sampling. In the laboratory the plastic sheets were removed and the samples placed in an oven for 24 hours at 105^{0}c.

The oven dry weight was recorded and the water content calculated as a percentage of oven dry soil weight. Equation 3, 4, 5, 6 given by McIntyre and Loveday, (1974) were used to determine both the bulk density and water content of the soil for each plot at different depths and periods.

$$Mcg = \frac{M1 - Ms}{Ms} \text{------------------------------------} (4)$$

$$Mcv = \frac{Mcg \times DB}{DW} \text{----------------------------------} (5)$$

$$VB = \frac{\pi d^2 L}{4} \text{--} (6)$$

Where

Mcg = gravimetric moisture content g/g

Mcv = Volumetric moisture content cm^3/cm^3

VB = Bulk volume (cm^3)

M1 = wet mass of core (g)

Ms = mass of solids (g)

Dw = density of water taken as $1.00 g/cm^3$ with an error of 0.2% at 20^0c

DB = Bulk density g/cm^3

d = diameter of soil ring (internal)

L = length of the soil ring.

3.5.1.6 *Labour requirement*

The amount of labour used for each operation on each plot was determined on man-day basis, where one man-day was taken to be equal to eight hours. The labour for each plot was recorded for each operation. This did not include the common operations performed in all treatments, such as clearing; harvesting, etc.,

3.5.1.7 *Available nutrients*

Soil samples were collected from each plot within the row (between plants) as well as out side the plots, but within the experimental site, after harvest. Then, they were analyzed for available nutrients (Organic matter, Nitrogen, Potassium, Phosphorous, Sodium) in the University soil chemistry laboratory. In addition, the nutrients available in each treatment were compared with that of the sample taken from out side, to see whether there was any variation from the surrounding.

3.5.1.8 *Yield*

Harvesting was carried out between March 20 to 28. Since the long rain started earlier before harvest time, the maize was cobbed and stacked under shade until the required moisture content for shelling was reached. After shelling, the yield for each plot was recorded on a kilo-gram per hectare basis.

In-order to account for the boundary effect, two rows (one from each side) from each plot were not included in the yield data.

3.5.1.9 *Residue mass production*

The maize stover from each plot was weighed in the field by using a spring balance and weight was recorded in kg/ha for each plot. After shelling, the cobs were also weighed and recorded in kg/ha for each plot. The residue mass production was recorded as the sum of stover and cob production. The stover and cobs used for the data of residue mass production were those from which yield data were obtained (Those in the boundary rows were not included).

3.6 *ANALYSIS*

3.6.1 Statistical analysis

The experiment was carried out in a 3x2 factorial experiment on a Randomized Complete Block Design (RCBD). Since the trial was conducted under field conditions; variability increased due to environmental variation, field operations, etc.

It is also of paramount importance to note that the validity and scientific merit of a certain agricultural investigation can be ascertained only, when the initial concept or hypothesis of that particular investigation passes through the rigorous testing of agricultural statistics and experimentations as it was noted by Geremew, (1989).

Therefore, for a better evaluation of the systems, all the data collected from the experiment was analyzed statistically by using the outline in table 5 given by Gomez, (1984). Further least significant difference (LSD) tests were conducted where treatment difference was significant using the outline in table 6 given by Geremew, (1989).

Table 5 Outline of the analysis of variance for 3x2 factorial experiment on a Randomized Complete Block Design.

Source of variance	Degree of freedom	Sum of squares	mean square	Computed F	Tabular F 5%	Tabular F 1%
Replication	r-1	$\frac{\Sigma R^2}{ab}$ - C.F.	$\frac{RSS}{r-1}$	$\frac{RMS}{EMS}$		
Treatments	ab-1	$\frac{\Sigma T^2}{r}$ - C.F.	$\frac{tSS}{ab-1}$	$\frac{tMS}{EMS}$		
A	a-1	$\frac{\Sigma A^2}{rb}$ - C.F.	$\frac{ASS}{a-1}$	$\frac{AMS}{EMS}$		
B	b-1	$\frac{\Sigma B^2}{ra}$ - C.F.	$\frac{BSS}{b-1}$	$\frac{BMS}{EMS}$		
AxB	(a-1)(b-1)	TSS-ASS-BSS	$\frac{AxBSS}{(A-1)(b-1)}$	$\frac{AxBMS}{EMS}$		
Error	(r-1)(ab-1)	TSS-RSS-tSS	$\frac{ESS}{(r-1)(b-1)}$			
Total	rab-1	Σx^2 -C.F.				

$$CV = \frac{\sqrt{EMS} \times 100}{GM}$$

Table 6 Outline of difference table for LSD test

Rank	1	2	3	
Treatment				LSD
Result				P - 5% =
Difference				P - 1% =
				P -0.1% =

$$LSD_\alpha = t_\alpha\sqrt{2\frac{S^2}{r}}$$

Where:-

A = Tillage

B = method of weed control

AxB = Interaction (Tillage x weed control)

a = level of factor A (i.e., tillage)

b = level of factor B (i.e., method of weed control)

r = number of replication

T = Treatment total

R = Replication total

G = grand total

GM = grand mean

C.F = correction factor = G^2/rab

C.V = coefficient of variation

Rss = Replication sum of squares

tss = Treatment sum of squares

Ass = Factor A sum of squares

Bss = Factor B sum of squares

AxBss = Interaction sum of squares

Ess = Error sum of squares

Rms = Replication mean square

tms = Treatment mean square

Ams = Factor A mean square

Bms = Factor B mean square

AxBms = Interaction mean square

F = Fisher test

S^2= Error mean sum of square

t = Student t-distribution

LSD = Least significant difference

3.6.2 Economic analysis

The economic evaluation for the set of operations carried out for each tillage system was conducted based on the available facts, figures and certain supporting assumptions. The budgeting techniques were found, more or less, appropriate to describe costs and returns and evaluate the economic performance of the tillage systems than any other analytical method.

The economic costs, benefits, the returns above variable costs of each treatment were calculated to serve as a base of comparison and show the relative benefits obtained from each treatment.

- ***Procedures and Assumptions***

In analyzing and evaluating the results, facts and figures recorded of the tillage trials, the following procedures and assumptions were used:

- The variable inputs of each tillage system were identified to be those variable items which are affected by the choice of the system assuming that the rest of the variable items are constant or identical both in type, quantity and quality for all treatments.
- Likewise, the variable costs of those variable items which could not be affected by the choice of treatments were excluded from the economic analysis, assuming that these costs are constant for all treatments; hence will not bring any significant change or return if added.
- On the other hand, the only quantitative return of the tillage systems was identified to be the yield result.
- The variable costs of each treatment were calculated as the product of the quantity of each of the identified variable items used for each treatment and the corresponding price of each.
- The economic benefit of each treatment was the product of the quantity of yield from each times

the corresponding selling price. The economic analysis of the trial is, thus based on these economic costs and benefit streams.

- The returns, above variable costs are calculated by deducting the total variable costs of each treatment from the gross benefit.
- The tractor costs were calculated by multiplying the time used for the operations in each treatment with the corresponding charge rates.

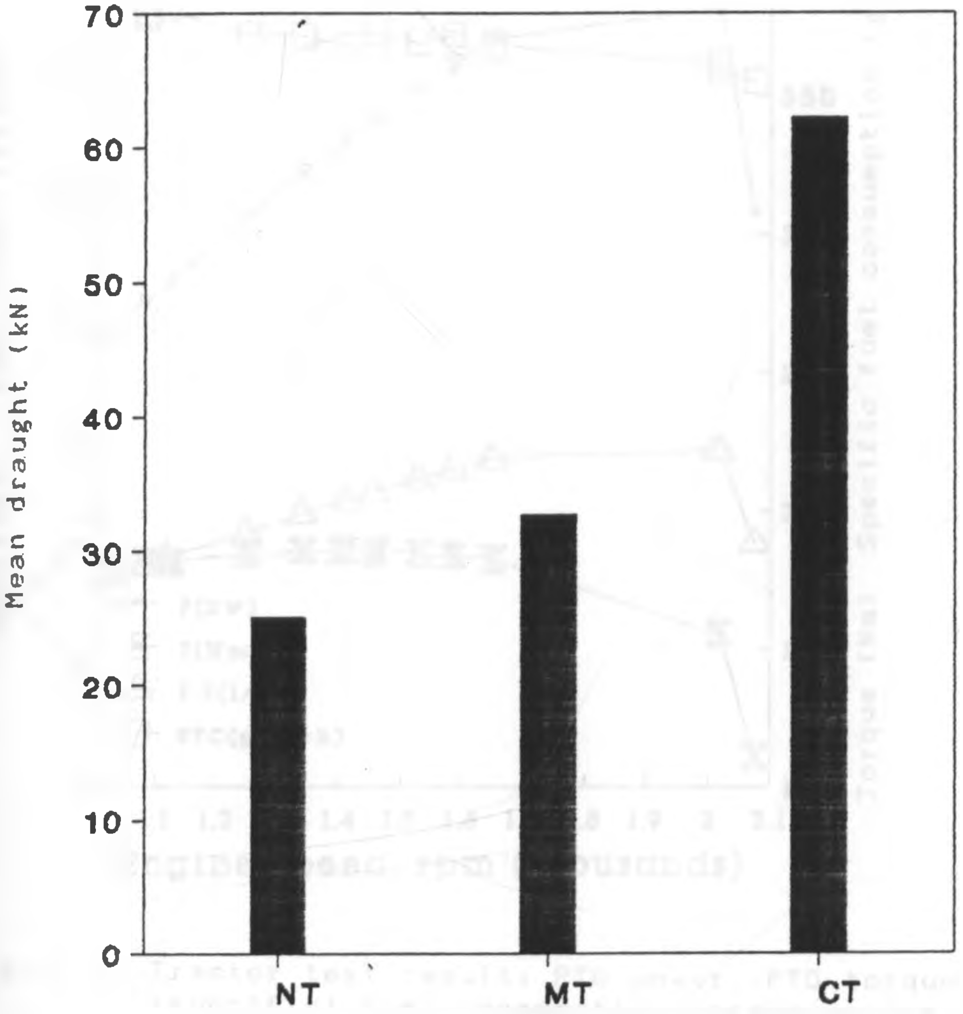
With these assumptions and procedures in mind, the results of the trial were analyzed.

4.0 RESULTS

4.1 *DRAUGHT REQUIREMENT*

Reducing tillage reduced the estimated draught requirements for the systems tested (Table 7, Fig. 1). A reduction of 47.4% and 59.6% per hectare of draught requirement was obtained by using minimum tillage and no tillage, respectively, as compared to the conventional tillage system.

Statistical analysis showed that the treatment difference was significant at 1% level (Appendix 1). To determine where the differences lie, least significant difference test (LSD) was computed as shown in Appendix 2. The results showed that the conventional tillage system had very high significant difference from the other treatments, i.e., high draught requirement as compared to the other two tillage systems. Moreover, minimum tillage required significantly more draught than no tillage at the 5% level.



NT = no-tillage
MT = minimum tillage
CT = conventional tillage

Figure 1 Mean draught requirement for each tillage system

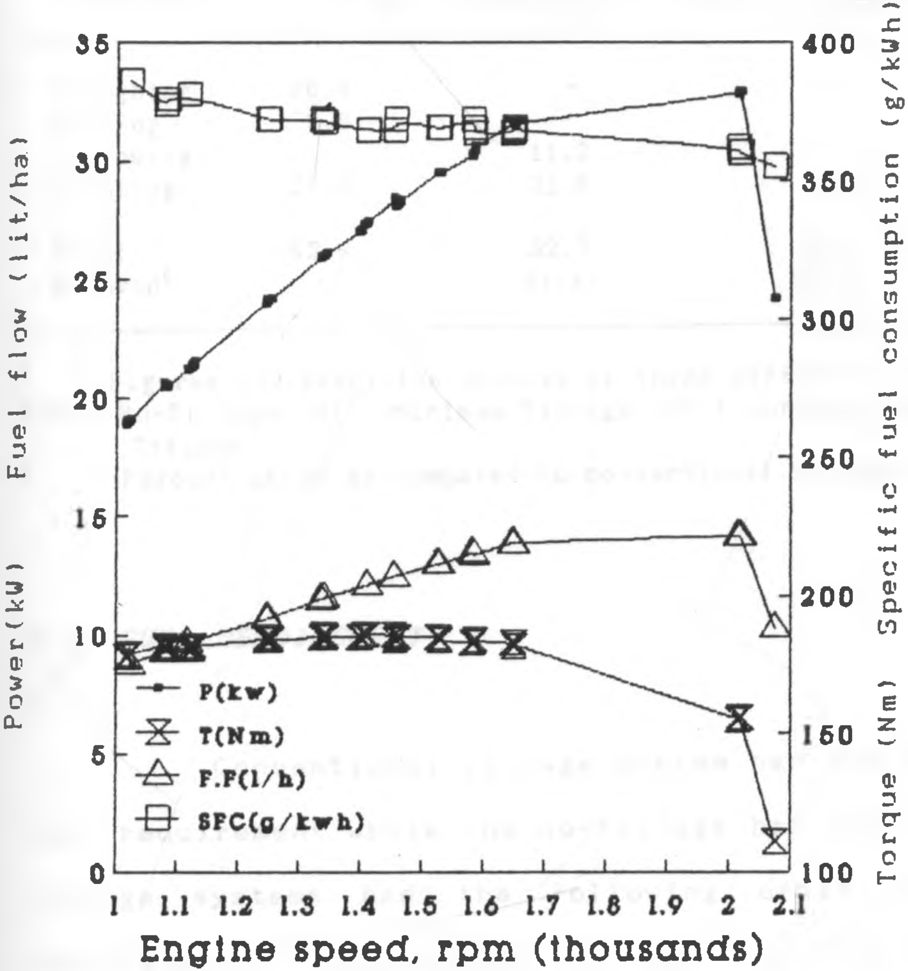


Figure 2 Tractor test result; PTO power, PTO torque, and (specific) fuel consumption versus engine speed

Table 7 Summary of draught requirement (kN)[a]

Operations	Systems[b]		
	CT	MT	NT
Ploughing	26.4	-	-
Discing	9.8	-	-
Harrowing	-	11.2	-
Planting	26.0	21.5	25.1
Total	62.2	32.7	25.1
% saved[c]	-	47.4	59.6

[a] = Figures represent the average of three different plots

[b] NT = No-Tillage, MT = Minimum Tillage, CT = Conventional Tillage

[c] = Percent saved as compared to conventional tillage

4.2 *FUEL REQUIREMENT*

Conventional tillage system had the highest fuel requirement while the no-tillage had the lowest. Tillage systems had the following order of fuel requirements : Conventional Tillage > Minimum Tillage > No-Tillage. Compared to conventional tillage, minimum tillage system saved 50.3% and No-tillage saved 78.2% per hectare (Table 8 and Fig.3).

Analysis of variance (Appendix 3) indicated that there was a highly significant difference among treatment means (significant at the 1% level). Further, LSD tests (Appendix 4) showed that both conventional and minimum tillage treatments required highly significant more fuel usage over no-tillage.

Table 8 Diesel fuel requirement (lit/ha) for the three tillage systems[a]

Operations	Systems[b]		
	CT	MT	NT
Ploughing	29.7	—	—
Cultivation	11.5	—	—
Harrowing	—	15.8	—
Planting	8.4	8.8	10.8
Total	49.6	24.6	10.8
% saved[c]	--	50.3	78.2

[a] = Figures represent the average of three different plots

[b] CT = Conventional tillage, MT = Minimum tillage, NT = No-tillage

[c] = Percent saved as compared to conventional tillage.

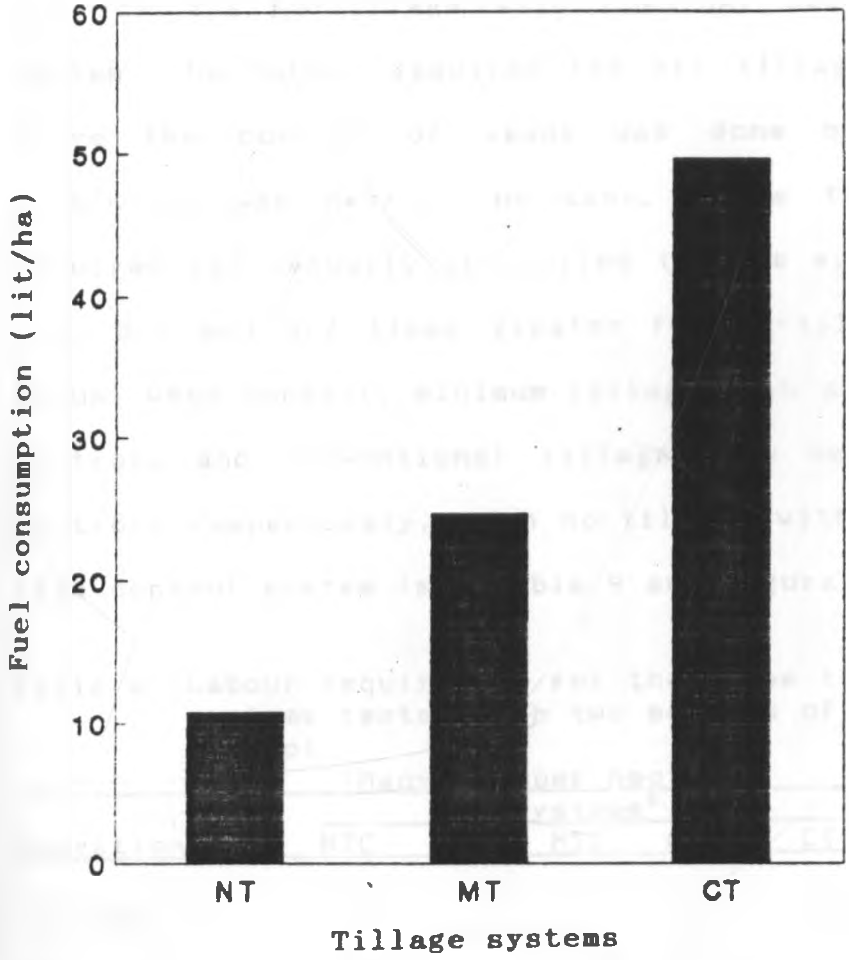


Figure 3. Mean diesel fuel requirement for each tillage system

4.3 *LABOUR REQUIREMENT*

The highest labour was required for the no-tillage with manual weed control system and the lowest was for the no-tillage with chemical weed control system. The labour required for all tillage systems where the control of weeds was done by use of herbicides was nearly the same, while the labour required for manually controlled tillage systems was 4.8, 3.1 and 3.7 times greater for no-tillage with manual weed control, minimum tillage with manual weed control, and conventional tillage with manual weed control, respectively, than no-tillage with chemical weed control system (see table 9 and figure 4).

Table 9 Labour requirement for the three tillage systems tested with two methods of weed control

(Man-days per hectare)

	Systems[a]					
Operations	NTC	NTM	MTC	MTM	CTC	CTM
Ploughing	-	-	-	-	0.81	0.81
Discing	-	-	-	-	0.16	0.16
Harrowing	-	-	0.32	0.32	-	-
Planting	0.38	0.38	0.38	0.38	0.38	0.38
Weeding	8.00	40.0	8.00	25.0	8.00	30.00
Total	8.38	40.38	8.70	25.7	9.35	31.35
%[b]	79.2	-	78.4	36.3	76.8	22.4

[a] NTC = no-tillage with chemical weed control
NTM = no-tillage with manual weed control
MTC = minimum tillage with chemical weed control
MTM = minimum tillage with manual weed control
CTC = conventional tillage with chemical weed control
CTM = conventional tillage with manual weed control

[b] % = percent saved as compared to NTM system

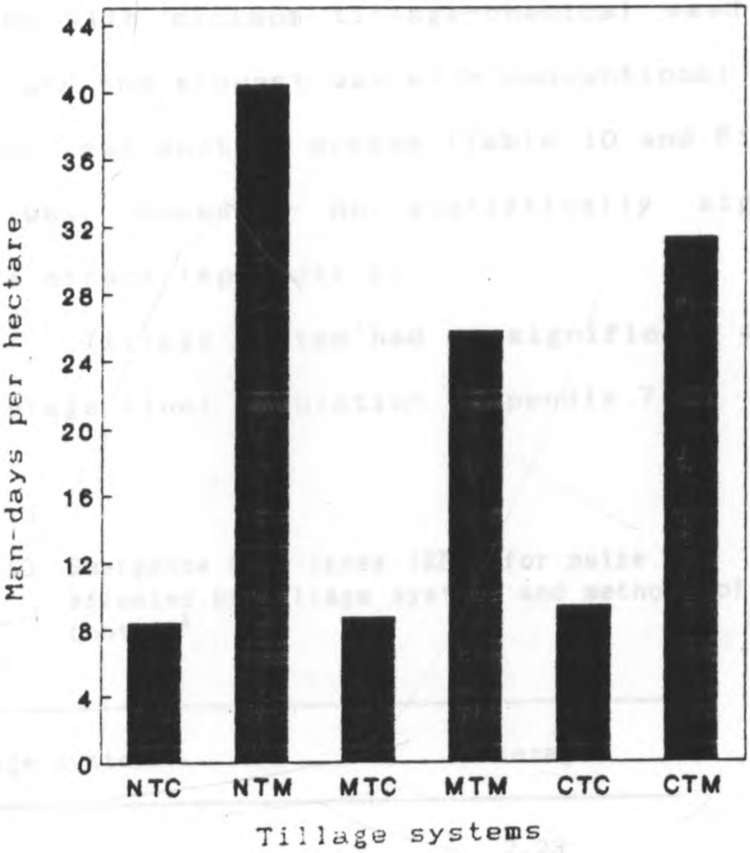


Figure 4. Labour requirement for each tillage system

4.4 *PLANT EMERGENCE*

The most rapid emergence, as indicated by emergence Rate Index, for maize tested under different tillage system, and methods of weed control, was obtained with minimum tillage-chemical weed control system and the slowest was with conventional tillage-chemical weed control system (Table 10 and Figure 5). There was, however, no statistically significant tillage effect (Appendix 5).

Tillage system had no significant effect on the average final population (Appendix 7).

Table 10 Emergence Rate Index (ERI) for maize as affected by tillage systems and methods of weed control[a]

Tillage systems[b]	Average
NTC	7.23
NTM	6.83
MTC	7.37
MTM	7.09
CTC	6.75
CTM	7.15
Average	7.07

[a] = Figures represent averages of three different plots

[b] NTC = No-tillage chemical weed control, NTM = No-tillage manual weed control, MTC = Minimum tillage chemical weed control, CTC = Conventional tillage chemical weed control, CTM = Conventional tillage manual weed control

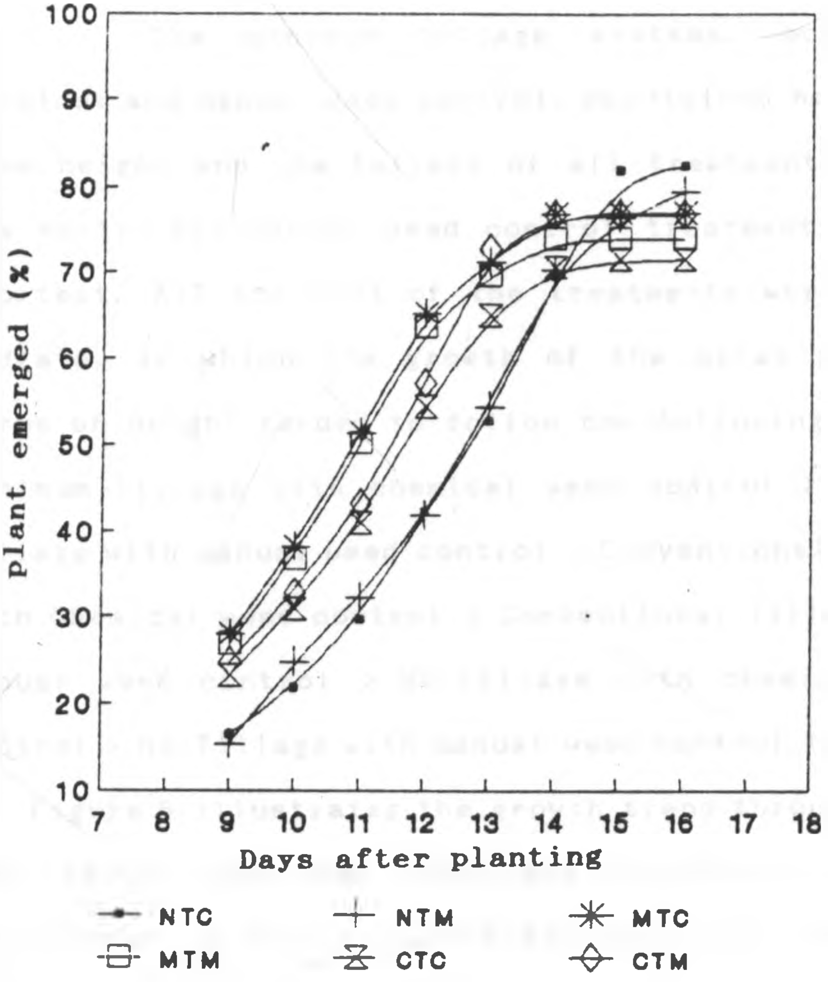


Figure 5. Maize plant emergence with time for each tillage system

4.5 *PLANT HEIGHT*

The minimum tillage systems, both with chemical and manual weed control, maintained nearly the same height and the tallest of all treatments. While the no-tillage-manual weed control treatment had the shortest. All the rest of the treatments were intermediate, in which the growth of the maize plant in terms of height tended to follow the following order:- Minimum Tillage with chemical weed control > Minimum Tillage with manual weed control > Conventional Tillage with Chemical weed control > Conventional Tillage with Manual weed control > No-Tillage with chemical weed control > No-Tillage with manual weed control (Appendix 8). Figure 6 illustrates the growth trend through time. The figures show that there was a uniform trend of plant height growth for all treatments until one month after planting, but changed then until harvest.

Measurements taken three times during the growing period at 30 days interval were combined and the average of the three measurements was taken for the analysis of variance. The result indicated that there was a significant difference at 5% level among the tillage systems (Appendix 9). However, the LSD test showed no-significant difference in all cases (Appendix 10 - 14).

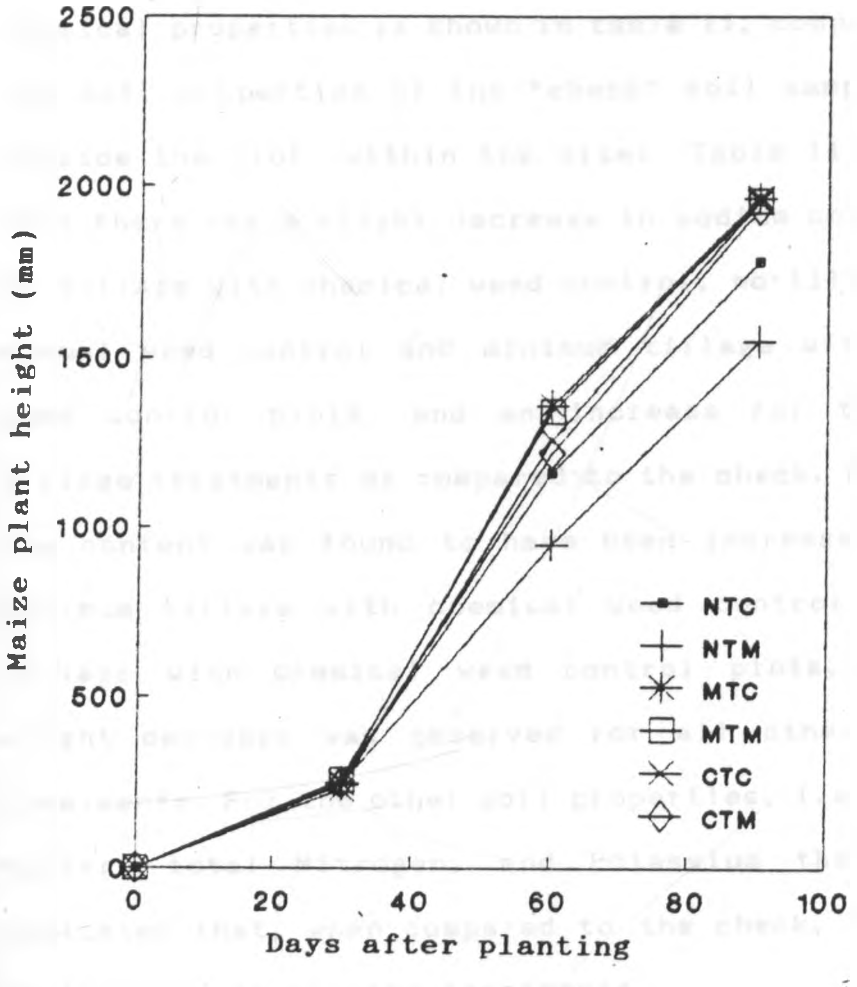


Figure 6. Average maize plant height as affected by days after planting

4.6 *AVAILABLE NUTRIENTS*

The effect of tillage systems, tested with two methods of, weed control, on a number of soil chemical properties is shown in table 11, compared with the soil properties of the "check" soil sample taken outside the plot (within the site). Table 11 displays that there was a slight decrease in sodium content for no-tillage with chemical weed control, no-tillage with manual weed control and minimum tillage with manual weed control plots, and an increase for the other tillage treatments as compared to the check. Phosphorous content was found to have been increased in the minimum tillage with chemical weed control and no-tillage with chemical weed control plots, while a slight decrease was observed for all other tillage treatments. For the other soil properties, i.e. organic matter, total Nitrogen, and Potassium the results indicated that, when compared to the check, there was an increase in all the treatments.

In general, according to this experiment, soil chemical properties under the different treatments tended to follow the following sequence :

Organic matter : MTC > CTC > NTC > NTM > CTM > MTM
Total Nitrogen : MTC > CTC > NTC > MTM & CTM > NTM
Phosphorous : MTC > NTC > MTM > CTC > CTM > NTM

Potassium : NTM > CTM > CTC > NTC > MTC > MTM
Sodium : MTC > CTC > CTM > NTM > NTC & MTM

Statistical analysis showed no-significant difference among treatment means for Total Nitrogen, Potassium and Sodium content (Appendix 18, 22 & 23). However, the effect of the weed control methods showed a significant difference at 5% level for organic matter and Phosphorous content (Appendix 15 and 19). Nevertheless, the LSD test indicated that there was no-significant difference (Appendix 16, 17, 20 and 21). Therefore, if there were any differences due to the six treatments it was masked by spatial variability.

Table 11 The effect of tillage systems, tested with two methods of weed control, on the soil properties at harvest[a]

	Tillage treatments						
Soil property	NTC	NTM	MTC	MTM	CTC	CTM	Check
Organic matter (%)	4.94	4.78	5.68	4.27	5.24	4.74	4.02
Total Nitrogen (%)	0.28	0.26	0.31	0.27	0.29	0.27	0.24
Phosphorous (ppm)	0.103	0.06	0.13	0.083	0.08	0.07	0.10
Potassium (ml/100ml)	0.338	0.384	0.314	0.305	0.347	0.352	0.285
Sodium (ml/100ml)	0.092	0.105	0.129	0.092	0.120	0.117	0.112

[a] Figures represent average from three different plots

4.7 *YIELD*

Table 12 shows the effects of tillage system and methods of weed control on yields of maize. It can be observed that the minimum tillage-manual weed control system had the greatest average yield. Conversely, the no-tillage manual had the lowest. The average yield from the other systems was intermediate between the minimum tillage with manual weed control system and no-tillage with manual weed control systems ; whereby, the yield tended to decrease in the following order: MTM, CTC, CTM, MTC, NTC, NTM . Showing 9.1%, 12.9%, 21.9%, 36% and 50.6% reduction in yield for CTC, CTM, MTC, NTC, NTC and NTM respectively as compared to the observed maximum yield from the minimum tillage with manual weed control system.

Statistical analysis indicated that there was a significant difference among the tillage treatments at the 5% level, while the effect of weed control did not show any difference from one another, and it was evidenced that no interaction existed between the tillage systems and weed control methods (Appendix 25).

In order to ascertain the performance of tillage systems and to find out the effectiveness of the weed control methods, LSD tests were conducted and the result showed that there is no significant difference in all cases (Appendix 26, 27 and 28).

Table 12 Mean Maize grain yield (kg/h) arranged according to treatments[a]

Treatment	Yield	% Reduction[b]
NTC	2412	36
NTM	1862	50.6
MTC	2945	21.9
MTM	3730	--
CTC	3427	9.1
CTM	3282	12.9

[a] = for treatment description see table 9

[b] = percent reduction of yield as compared to the average maximum yield

4.8 *RESIDUE MASS PRODUCTION*

The residue mass production was estimated from air-dried material collected after harvest and the weight of cob obtained after shelling. The highest residue mass production was obtained from conventional tillage with manual weed control treatment, while the lowest was from the no-tillage with manual weed control treatment. The residue mass production from each treatment tended to decrease in the following order: CTM > CTC > MTM > MTC > NTC > NTM (Table 13).

Analysis of variance was carried out and the result indicated that there was a significant difference at 5% level among the tillage treatments while there existed no significant difference between the weed control methods. Moreover, it was found that there was no interaction between tillage system and weed control method (Appendix 28). Furthermore, the performed LSD test indicated that no significant difference existed in all cases (Appendix 29 and 30).

Table 13 Mean residue mass production (stover + cob) arranged according to treatments (kg/ha)[a]

Treatment	Production	% Reduction[b]
NTC	5482	25.1
NTM	3983	45.6
MTC	6978	4.7
MTM	7023	4.1
CTC	7218	1.4
CTM	7319	--

[a] = for treatment description see table 9

[b] = percent reduction of residue mass production as compared to the average residue mass production

4.9 *BULK DENSITY AND MOISTURE CONTENT*

The bulk density profiles for the two sampling dates are shown in Figure 7 and 8 . The conventional tillage with chemical weed control system had the highest bulk density in the top 150 mm during the first sampling date and on the second sampling date conventional tillage with manual weed control system had the highest. No-tillage with chemical weed control and no-tillage with manual weed control systems had the lowest bulk density for the first and second sampling dates respectively. At the depth between 150 mm and 300 mm, the minimum tillage with manual wed control system was found to have greater density on the first sampling date and conventional tillage with manual weed control system had the highest for the second sampling date. Below 300 mm depth, it was found that minimum tillage with manual weed control system and conventional tillage with manual weed control system had the highest bulk density for the first and second sampling dates respectively. An increase in the bulk density from the first to the second sampling dates was observed for the conventional tillage with manual weed control system, while the other systems had shown a decrease (Table 14).

Gravimetric water content for the surface 0-150 mm (first sampling depth), was greater for minimum tillage with chemical weed control than for the other systems, on both sampling dates. On the first sampling date, it was observed that no-tillage with chemical weed control, minimum tillage with manual weed control and conventional tillage with manual weed control systems showed an increase in soil water with increasing depth. On the other hand, the no-tillage with manual weed control and conventional tillage with manual weed control systems had an increase in water for the second sampling depth (150-300 mm) which decreased at the third sampling depth (300-450 mm). Soil water for the minimum tillage with chemical weed control system was found to decrease with depth (Figure 9 & 10).

Table 14 The effect of the three tillage systems, tested with two methods of weed control, on moisture content and bulk density

Depth (mm)	Treatments					
	NTC	NTM	MTC	MTM	CTC	CTM
			Bulk density (g/cm^3)			
			First sampling date			
0-150	1.04	1.14	1.11	1.12	1.21	1.16
150-300	1.11	1.2	1.17	1.24	1.2	1.21
300-450	1.16	1.18	1.15	1.24	1.23	1.23
			Second sampling date			
0-150	1.04	0.91	0.95	0.93	1.07	1.21
150-300	1.1	1.24	1.06	1.08	1.05	1.25
300-450	1.09	1.05	1.02	0.96	0.93	1.25
			Gravimetric water content (%)			
			First sampling date			
0-150	39.68	39.68	40.51	37.45	38.06	38.89
150-300	40.16	40.42	40.01	37.92	40.01	39.7
300-450	40.66	38.54	38.34	38.58	39.58	41.27
			Second sampling date			
0-150	50.25	53.52	55.16	51.49	45.76	46.92
150-300	49.35	46.91	48.47	46.24	45.37	46.95
300-450	48.71	48.34	51.22	49.44	47.25	49.13

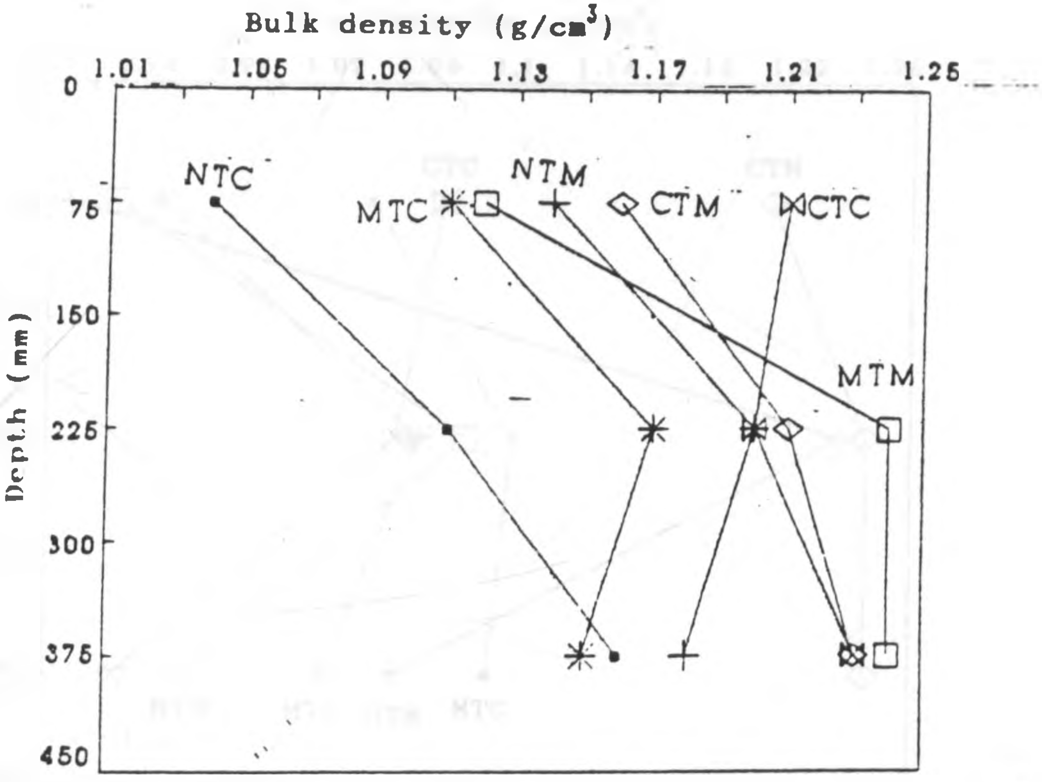


Figure 7. Bulk density profile for the first sampling date

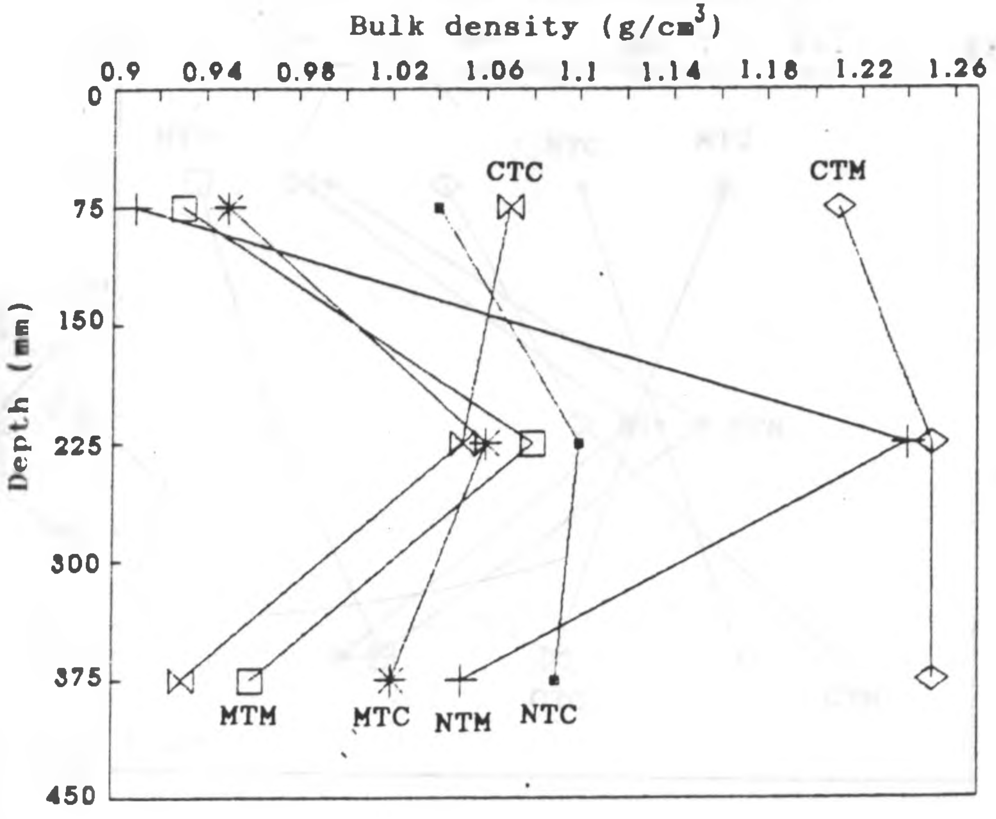


Figure 8. Bulk density profile for the second sampling date

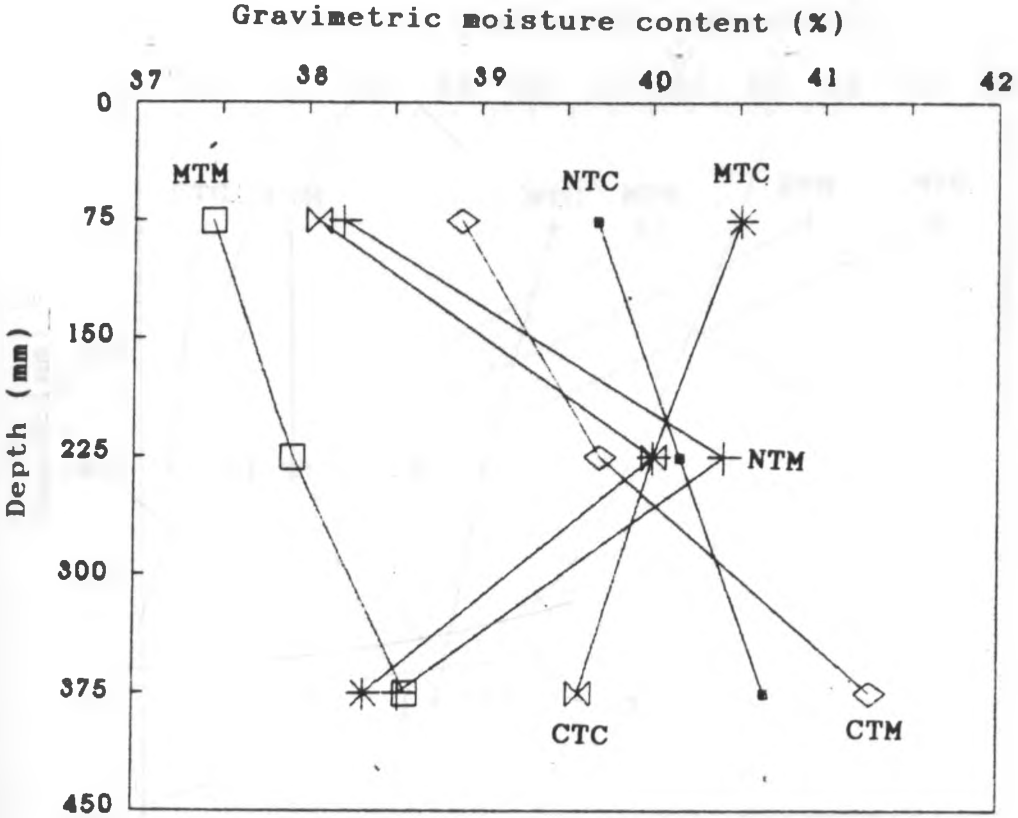


Figure 9. Gravimetric soil water content profile for the first sampling date

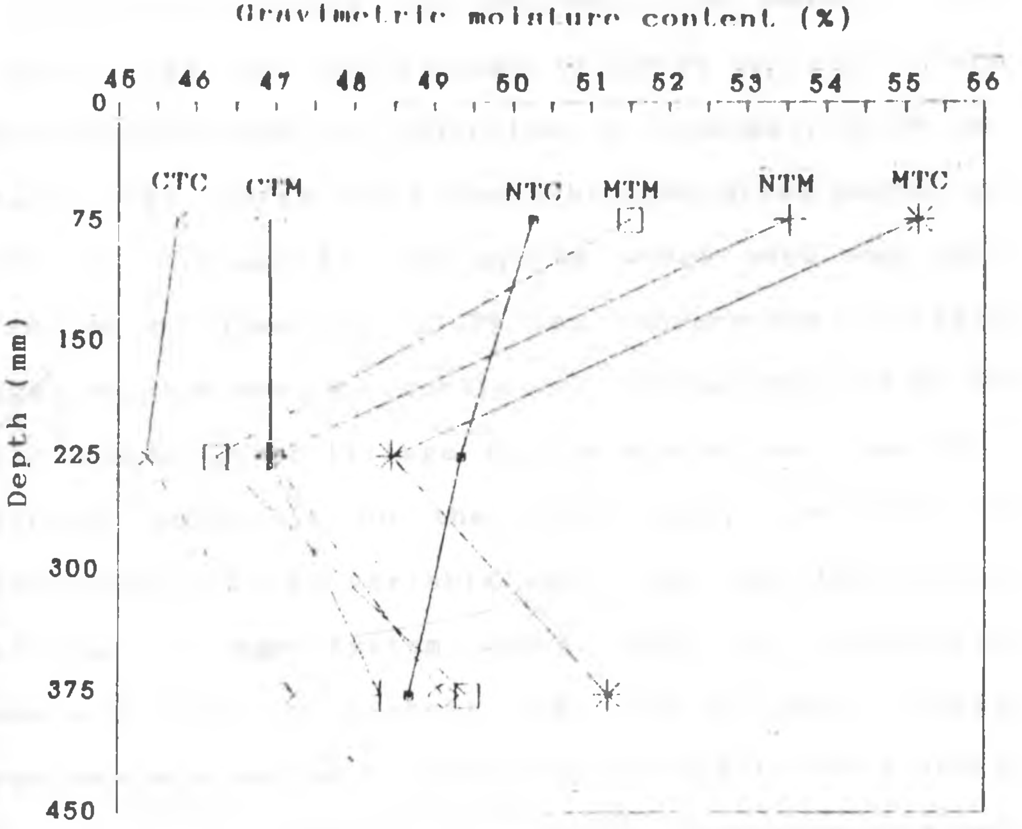


Figure 10. Gravimetric soil water content profile for the second sampling date

4.10 *ECONOMIC ANALYSIS*

In table 15, it is demonstrated that the minimum tillage, with manual weed control production method was more profitable for the area as compared to the other production methods. As compared to minimum tillage system where weed was controlled manually, the return from the land reduced by 53.2% for no-tillage system where weed was controlled by chemical, 65.6% for no-tillage system where weed was controlled manually, 39% for minimum tillage system where weed was controlled by chemical, 16.3% for conventional tillage system where weed was controlled by chemical and 25.5% for conventional tillage system where weed was controlled manually. On the other hand, the cost of production (Total variable cost) was the lowest for minimum tillage system where weed was controlled manually and the highest was from minimum tillage system where weed was controlled chemically. This shows that the system with the lowest total variable cost had the highest return from the land. However, this cost comparison does not include those un-affected costs that are common to all systems, such as seed, fertilizer, harvesting, etc.

Table 15 Comparison of maize tillage system costs[a]

Description	systems					
	NTC	NTM	MTC	MTM	CTC	CTM
Field benefits						
Yield (kg/ha)	2412	1862	2945	3730	3427	3282
Gross income[b]	6030	4655	7362.5	9325	8567.5	8205
Variable costs						
Tractor cost[c]						
Ploughing	-	-	-	-	715	715
Discing	-	-	-	-	144.1	144.1
Harrowing	-	-	278.3	278.3	-	-
Planting	330	330	286	286	341	341
Labour cost[d]						
Spraying	333.6	-	333.6	-	333.6	-
Weeding	-	1668	-	1042.5	-	1251
Chemical cost						
Roundup @ Ksh 500/lit	1500	-	1500	-	-	-
Atrazine @ Ksh 128/lit	256	-	256	-	576	-
TVC	2419.6	1998	2653.9	1606.8	2109.7	2451.1
RAVC[e]	3610.4	2657	4708.6	7718.2	6457.8	5753.9
Rank	5	6	4	1	2	3
% reduction	53.2	65.6	39	---	16.3	25.5

[a] = unaffected costs such as seed, fertilizer, harvesting, etc., not included

[b] = Harvest at a selling price of Ksh 2.5 per kilogram

[c] = tractor cost at Ksh 110 per hour use

[d] = labour cost at Ksh 41.7 per man-day

[e] = gross income minus total variable cost

5. DISCUSSION

- *Draught and fuel requirements*

Since the exact procedure for determining available drawbar horse power for a specific tractor and a set of conditions is very complicated, an attempt was made to relate maximum PTO power of the tractor used to a usable drawbar horse power based on the relation discussed in section 3.5.1.1. As a result, the maximum draught was required for conventional tillage system and the minimum was for no-tillage system. This was mainly due to the number of operations required in each system. I.e., as the number of operations increased the need for draught was also increased and the fact that the no-tillage system required only one operation (planting) resulted in the draught requirement for this system to be the lowest.

On one other hand, due to the inherent character of the conventional tillage system having more than one operation (ploughing, discing and planting), the draught requirement was observed to be the highest. The same result was also observed by Mathew, (1975); Happer and Henderson, (1985).

Diesel fuel required for actual operation, excluding the time lost for turning & repair, was 49.5, 24.6 and 10.7 litre per hectare for CT, MT and NT respectively. Although fuel use depends on the specific field operations as well as the soil draught, this result appeared to be higher than those reported by Young, 1982 and Stobbe, 1989. This was due to the high fuel consumption of the tractor (attributed to its poor maintenance) as was observed in the dynamometer test carried out at the department (Appendix 33 and Fig. 2). But, when comparing the tillage systems for their fuel requirement it followed the same pattern as draught requirement. That is, the fuel requirement was directly proportional to draught requirement.

Furthermore, when no-tillage system was used there was a high reduction in energy requirement for maize cropping. This means that the greatest reduction in energy consumption was realized by eliminating a number of operations and combining them into one operation. Which in turn, reduce the cost of production (since the maximum cost for production was the cost for energy) and increases profit.

Therefore, for farmers to take full advantage of every opportunity to reduce costs and conserve energy, the no-tillage system appeared to be the best as compared to minimum tillage and conventional tillage systems, when considered with respect to energy consumption. But since energy consumption was not the only determining factor for evaluating the system and yield is our major concern, it will be discussed later with further consideration.

- Plant emergence:

It was mentioned in section 4.4 that the most rapid emergence was found from minimum tillage with chemical weed control system, while the slowest was from no-tillage with manual weed control system and conventional tillage with chemical weed control system. As cited by Hayes, 1982 and reported by Michigan State University, seed germination and seedling emergence are most rapid when: (a) Soil is packed firmly below the seed level (b) seeds are pressed into compacted soil, and (c) seeds are covered with loose soil. Moreover they also noted that application of soil more than one-half pound per square inch pressure on top of the seed will delay plant emergence. Therefore, the reasons for the NTM system to have slow emergence was assumed to be the following:

The tine used to open the furrow formed clods of soil and these clods covered some of the seeds along the furrow. It was observed that, during the time of germination, some of the seeds faced a problem of over coming the comprehensive force exerted by the clod on the seed, until the rain that followed planting consolidated the clods into loose, which delayed the germination. In line with this Willcocks, (1979) described that seedling emergence was better from a small convex ridge (<30 mm high) as the soil surface was then submitted to tensile forces by the plant during emergence and these soils, although strong in compression, are weak in tension.

The other reason could be the effect of the residue during planting. That is, the interference of the residue preventing some of the seeds from having good seed-soil contact. Also, residue close to the seed will contribute to drying out the area around the seed and give out toxic substances that affect germination and seedling growth.

The exact reason for the conventional tillage with chemical weed control system to have slowest emergence was not clear, however, it can be assumed due to the fact that:-

1. This system had the highest bulk density ($1.21 g/cm^{3)}$ for the depth 0 to 15 cm as compared to the other systems, and may have hindered the seedling emergence. That is, compaction at seed level was shown to improve emergence of crops, while compaction from

the surface downwards may instead have opposite effects (Stout et al, 1961. Cited by Tessier, 1989).

2. The break-down of the less stable surface soil aggregate, in this treatment, by the rain following planting, that may have resulted in the formation of a surface crust, which may have reduced seedling emergence either through reduced gaseous exchange between the soil and the atmosphere or through the increase in the surface soil strength as it is also reported by Francis et al, (1987) and Hayes, (1982).

3. The last but not least possible reason, observed during planting, could be due to the smooth seed-bed prepared for this treatment in which some of the seeds were placed deeper than the required. This might have resulted in the delay of emergence. On the other hand some of the seeds might have been placed too shallow, to the surface and may have been attacked by pests. As a result, the number of emerged seedlings was reduced.

- ***Final plant population:***

Although there was no significant tillage system effect on the average final population, a difference was observed between treatments. This was attributed mainly to the damage caused by the wild animals which came during the night at one time and the week stand of some of the plants. Moreover, it was probably due to the interactions between Planter performance, weather and tillage as it had been indicated by Erbach, (1982).

- ***Plant height:***

The growth of the maize plant within the no-tillage treatment where weeds were controlled manually was observed to be of smaller height, spindly stalks and with a pale-yellowish-green colour.

As has been shown in Figure 5 of the previous chapter, the growth of the plant in the no-tillage treatment where weeds were controlled manually showed similar growth as in all other treatments for the first 30 days. However, as the days went by, the trend was found to have changed in that it showed a decline as compared to the rest of the treatments. This was mainly attributed to the low Nitrogen and Phosphorous contents of the soil caused by the competition between the maize plant and weed for the available nutrients.

This was due to the fact that, in this treatment weeds were merely controlled by cutting and no weed uprooting was done. This gave chance for the roots of the weeds to compete with the maize plant for the necessary nutrients for their growth and made the availability of nutrients to the crop to be reduced and as a consequence the crop resulted in having a poor growth.

Samuel, Scott and Leng (1978) stated that nutrient shortages are not critical in the first days, but as the roots begin to take over the job of nourishing the young plant, shortages of the major elements, especially Phosphorous, can seriously slow growth and development. Moreover, Berger (1962) said that nitrogen is essential to the growth and reproduction of a plant. Based on these statements it can be suggested that the observed slow plant growth in the no-tillage treatment where weeds were controlled manually was mainly due to the low nitrogen and phosphorous availability to the maize plants as a result of weed competition. This is to say, that had the weeds been controlled by uprooting or been killed by herbicide, the nitrogen and phosphorous content of the soil would have been sufficient to maintain a proper growth of the maize plant. Hence, the competitive weeds were the culprit for the plant growth reduction owing to their contribution in depleting soil nutrients.

The other cause that could have possibly contributed to the low growth was perhaps due to the soil temperature in this treatment. Even though the temperature of the soil was not investigated during the trial, many researchers have indicated that from the moment when the seed is sown, the growth of a crop can be influenced by the temperature of the soil provided the soil is moist (Monteith, 1979; Janick et al., 1981; Hayes, 1982; Aston and Fisher, 1986). That means the amount of solar radiation striking the surface is a primary consideration because it determines the maximum potential input of heat. Therefore, in this treatment (NTM) since the solar radiation first strikes the soil residue on the surface, soil beneath the surface may not be warmed immediately by the radiation incident on the surface and a temperature lag occurs because heat must be conducted through the trash which in turn may have caused low temperatures of the soil as compared to other treatments and as a result affected the growth. In section 2.3 it has been described by many researchers that conventional tillage system had the highest soil temperature as compared to no-tillage system. Similarly, as cited by Stobbe (1989), Griffith et al, (1986) found that the shortest plant height occurred in the zero-tillage system having the lower temperature than the spring plough system.

The pale-yellowish green colour and spindly stalks of the maize plant in this treatment (No-tillage treatment where weeds were controlled manually) were also attributed to Nitrogen deficiency as described by Samuel et al, 1978.

- ***Yield and residue mass production:***

The different tillage systems were also tested with respect to yield. The results obtained, hence, showed that the highest yield was achieved from the minimum tillage where weed was controlled manually. Tillage affects several factors like soil compaction, soil temperatures, nutrient distribution, weed control, insects, etc., which intern influence crop production. Weather (rainfall in particular) is also a factor, in addition to the above mentioned, greatly affecting yield. Therefore, having this in mind, the reasons that were assumed to have contributed to the observed yield differences can be explained as follows.

The main cause for the low yield from no-tillage system were weeds were controlled manually was attributed to the poor stand of the maize in these plots due to the high competition of weed and maize plants as explained earlier in this section. Since a higher percentage of the ground in this treatment was covered by the maize plant, weeds and residue, it may have contributed to a lower soil temperature which may have caused slow growth of the plant and low yield.

Hayes, (1982) also explained that crop residues conserve moisture and contribute to lower soil temperature, and when soils are cold, soils are more likely to lose Nitrogen through denitrification. Moreover, lower soil temperatures slow down all processes in the soil including organic matter breakdown, which results in the release of organic Nitrogen to plants so that the growth and yields of the crop will be affected. It can also be seen from Figure 6, Table 11 and 14 that this treatment had the shortest plant height, lowest available Nitrogen and higher bulk density (higher compaction) which all leads to low yield. Moreover, this treatment had also the lowest residue mass production due to spindly stalks and short height of the stalks. This low yield result corresponds to other reported data that show a yield advantage for conventional tillage (Erbach, 1982 and Siemens, 1986).

On the other hand, yield from the minimum tillage system, where weeds were controlled manually, was found to be the highest because the above mentioned problems were minimal compared to the others. Since the weeds from this plot were uprooted, the problem of competition was minimum. Hence, the available nutrients were used by the maize plant which may have led to high growth and yield. Moreover, the furrow made by the tined harrow might have resulted in the more efficient infiltration of available rainfall as evidenced by higher soil water content, and better root development than the others. This might have also contributed to the observed highest yield. Shumba, (1988) also got similar result in which tine tillage produced more yield than mouldboard ploughing. Moreover, Ngugi and Michieka, (1984) got higher yield from minimum tillage systems than conventional tillage during the short rains.

The treatment having the highest yield does not have the highest residue mass production. In the contrary, the treatments having the next higher yield (Conventional tillage systems where weeds were controlled manually and by chemical) had the highest residue mass production which was perhaps due to the vegetative growth of the plant in this treatment so that its contribution towards the development of maize kernels was slowed, which resulted in lower yield but higher residue mass production.

Plate 14 The weed infestation between the NTM and NTC plots, one month after planting

6.0 CONCLUSION AND RECOMMENDATION

In order to fulfil the objectives described in section 1.1 all the necessary data were collected and the results were presented in section 4 and consequently discussed in section 5. This section summarizes the investigation based on the previous chapters and finally ends with recommendation.

6.1 *CONCLUSION*

- *Energy Requirement*

The energy requirement, in terms of draught and fuel requirement, was found to be the lowest for no-tillage system while highest for the conventional tillage system. Minimum tillage system was intermediate. When compared to conventional tillage system, having the highest energy requirement, 59.6% and 47.4% draught requirement was saved by no-tillage and minimum tillage respectively. Moreover, no-tillage saved 78.2% fuel while minimum tillage saved 50.3 % as compared to conventional system. This saving in energy was attributed to the nature of operations involved in each tillage system. That is, the more operations were involved the more energy was required and vice versa.

Despite its benefit of low energy requirement, no-tillage systems failed to out yield both minimum and conventional tillage systems.

- *Labour Requirement*

The need for labour increased were weeds were controlled manually. As compared to the no-tillage system with chemical weed control (where 8.38 man-day was required) the other systems (No-tillage manual weed control, Minimum tillage chemical weed control, Minimum tillage manual weed control, Conventional tillage chemical weed control and Conventional tillage manual weed control) needed 4.08, 1.04, 3.07, 1.12 and 3.74 times more labour respectively.

- *Available Nutrients*

All soil properties investigated, except the available potassium, improved under minimum tillage with chemical weed control system while the other systems showed varied results. However, this result can not be called conclusive since these changes are only likely to become appreciable and conclusive if they are observed over a longer time period.

- *Crop Performance*

The crop under minimum tillage treatment where weeds were controlled manually gave the highest yield while no-tillage with manual weed control had the lowest. Even though, the performance of the crop in terms of rapid emergence and plant height was found to be best for the minimum tillage treatment where weed was controlled by the use of chemical, the yield from this treatment was the fourth in rank. On the other hand, the conventional tillage system with manual weed control had the highest residue mass production and the third highest yield. In general, the performance of the crop under no-tillage treatment where weeds were controlled manually was poor in all aspects as compared to the other treatments.

- *Economic Benefit*

Since yield was taken as the only quantifiable return, the maximum return was obtained from the minimum tillage with manual weed control system as it was found to give the highest yield. Moreover, this system had also the lowest total variable cost.

- *Overall Evaluation*

Several advantages were mentioned by different researchers for conservation tillage systems that are not quantified in terms of money. Among them are: Moisture conservation, reduction in erosion, reduction in soil compaction, improvement of soil structure and soil properties etc.

In order to evaluate different tillage systems for their overall benefit, these advantages should also be included as a return to the farm in the course of evaluating the different tillage systems. But, it will be very difficult to quantify them in terms of money and add to the gross return of a farm. Moreover, it is also difficult to convince farmers about the advantages of conservation tillage since there basic interest is to get the maximum yield from their land in order to get the highest profits on their inputs.

However, for the purpose of this investigation, attempt was made to rank all the investigated parameters according to the performance of each tillage system and the ranks were given according to their percent advantage. That is, the best performing having the first rank (table 16 and 17), in order to find out the tillage system that has performed best for the area of investigation. Accordingly, the minimum tillage with chemical weed control treatment had performed the best, having 696.7% over all advantage. The minimum tillage with manual weed control system was the next best, having 660.7% over all advantage, while no-tillage with manual weed control had the lowest (265.3%).

However, as mentioned earlier, the basic idea of this investigation was to help farmers in finding out the tillage system that can provide them with the maximum output by incurring the minimum input. The minimum tillage system where weed was controlled manually was found to meet the objectives for the area during the short rainy season of 1989/90. But, this should not be taken as guarantee since the trial was only conducted for one season. Nevertheless, the preliminary results obtained and the analysis made were deemed to serve as a stepping-stone towards the achievement of the trial objectives so that further investigation should also be conducted for the long rains in order to support this trial.

Table 16 Summary of the result for all investigated parameters and showing the respective rank

Item no.	Description	NTC	R	NTM	R	MTC	R	MTM	R	CTC	R	CTM	R
1.	Draft requirement (kN)	25.1	1	25.1	1	32.7	2	32.7	2	62.2	3	62.2	3
2.	Fuel requirement (lt/ha)	10.8	1	10.8	1	24.6	2	24.6	2	49.6	3	49.6	3
3.	Labour requirement (MD/ha)	8.4	1	40.4	6	8.7	2	25.7	4	9.3	3	31.3	5
4.	Plant emergence (ERI)	7.2	2	6.8	5	7.4	1	7.1	4	6.7	6	7.1	3
5.	Plant height (cm)	106.7	5	91.5	6	119.2	1	118.7	2	115.0	3	113.6	4
6.	Yield (kg/ha)	2412.0	5	1862.0	6	2945.0	4	3730.0	1	3427.0	2	3282.0	3
7.	Residue Mass Production (kg/ha)	5482.7	5	3983.3	6	6978.0	4	7023.0	3	7218.3	2	7319.0	1
8.	Available organic matter (%)	4.94	3	4.78	4	5.68	1	4.27	6	5.24	2	4.7	5
9.	Available total Nitrogen (%)	0.28	3	0.26	5	0.31	1	0.27	4	0.29	2	0.3	4
10.	Available Phosphorous (ppm)	0.103	2	0.06	6	0.13	1	0.083	3	0.08	4	0.07	5
11.	Available Potassium (ml/100ml)	0.338	4	0.384	1	0.314	5	0.305	6	0.347	3	0.352	2
12.	Available Sodium (ml/100ml)	0.092	5	0.105	4	0.129	1	0.092	5	0.120	2	0.117	3
13.	Gravimetric water content (%)[a]	39.7	2	38.2	4	40.5	1	37.4	6	38.1	5	38.9	3
14.	Gravimetric water content (%)[b]	50.2	4	53.5	2	55.2	1	51.5	3	45.8	6	46.9	5
15.	Bulk density (g/cm^3)[a]	1.04	1	1.14	4	1.11	2	1.12	3	1.21	6	1.16	5
16.	Bulk density (g/cm^3)[b]	1.04	4	0.91	1	0.95	3	0.93	2	1.07	5	1.21	6
17.	Total variable cost (Ksh/ha)	2419.6	4	1998.0	2	2653.9	6	1606.8	1	2109.7	3	2451.1	5
18.	Return above variable cost (Ksh/ha)	3610.4	5	2657.0	6	4708.6	4	7718.2	1	6457.8	2	5753.9	3

a first sampling date

b second sampling date

R=rank

Table 17 Percent advantages of all investigated parameters

Item no.[a]	Treatments					
	NTC	NTM	MTC	MTM	CTC	CTM
1.	59.6	59.6	47.4	47.4	0	0
2.	78.2	78.2	50.3	50.3	0	0
3.	79.2	0	78.4	36.3	76.8	22.3
4.	7.1	1.2	9.2	5	0	5.9
5.	16.6	0	30.2	29.7	25.7	24.1
6.	29.5	0	58.2	100.3	84.1	76.3
7.	37.6	0	75.2	76.3	81.2	83.8
8.	15.7	11.9	33	0	22.7	11
9.	7.7	0	19.2	3.9	11.5	3.9
10	71.7	0	116.7	38.3	33.3	16.7
11.	10.8	25.9	3	0	13.8	15.4
12.	0	14.1	40.2	0	30.4	27.2
13.	6	2	8.2	0	1.6	3.9
14.	9.8	17	20.5	12.5	0	2.5
15.	14.1	5.8	8.5	7.4	0	4.1
16.	14.1	24.8	21.5	23.1	11.6	0
17.	8.8	24.7	0	39.5	20.5	7.6
18	35.9	0	77.2	190.5	143.1	116.6
Total	502.4	265.3	696.7	660.7	556.3	421.3
OR	4	6	1	2	3	5

[a] = see Table 16 for item description

OR = overall rank

6.2 *RECOMMENDATION*

1. Experimental results favoured the combination of minimum tillage and manual weed control over any other tillage treatment tested in the study

2. Effective measures to obtain adequate plant stands, control weeds, and provide good management must be adopted if favourable results are to be obtained from the no-tillage method. The field preparation and planting methods used in this experiment makes it unacceptable for farmer use. Similarly Michieka (1982) recommended that this system will be more applicable in semi-arid areas where moisture has to be conserved.

3. The conventional maize planter used performed well for minimum tillage with a little modification on the tines. Therefore, for farmers owning this planter and in need to change their practice into conservation tillage they can easily modify and use it as a no-tillage planter. However, the machine proved to be functionally inadequate because it covered some of the seeds with bigger clods that created problems in germination.

4. In order to adopt the minimum tillage system, incentive must be provided to small 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 benefits. Therefore, until they realize the benefit of this system they should be subsidized.

5. Further research should be carried out for a longer period, for a better and conclusive result. In order to eliminate the bias an expert may have towards his own research and help to identify where new research efforts should be directed. techniques for integrating knowledge from multiple experts should be practised as suggested by Clarke et al, 1989.

6. Recommend for farmers to make the transition from conventional tillage to minimum tillage at this time, but to await research development before going to no-tillage

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8.0 APPENDICES

Appendix 1 Analysis of Variance of Draft Requirement for the Tillage systems[a]

Source of Variation	Degree of freedom	Sum of square	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Rep.	2	18.2	9.1	0.8^{ns}	6.9	18
Treatment	2	2304.2	1152.1	104.9^{**}	6.9	18
Error	4	43.9	11			
Total	8	2366.3				

[a] cv = 8.3

[b] ns = not significant, ** = significant at the 1% level

Appendix 2 Comparison of Mean Draft Requirement between the tillage systems using LSD Test

Rank	3	2	1	
T.systems[a]	NT	MT	CT	LSD
F(KN)	25.1	32.7	62.2	P-5% = 7.5
Difference	–	7.6^{*}	37.1^{***}	P-1% = 12.5
		–	62.2^{***}	P-0.1% = 23.4

[a] NT=no-tillage, MT=minimum tillage, CT=conventional tillage

* significant at 5% level, *** significant at 0.1% level

Appendix 3 Analysis of variance of fuel requirement for the tillage systems[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	21.88	10.94	1.39^{ns}	6.94	18
Treatment	2	2317.79	1158.89	147.4**	6.94	18
Error	4	31.45	7.86			
Total	8					

[a] cv = 9.89%

[b] ns = Not significant, ** = Significant at the 1% level

Appendix 4 Comparison of Mean Fuel Requirement between the three tillage systems using LSD test

Rank	1	2	3	
Tillage systems[a]	NT	MT	CT	LSD
Fuel required (l/ha)	10.79	24.64	49.58	P-5% = 6.35
Difference	__	13.85**	38.79***	P-1% = 10.54
		__	24.79***	P-0.1% = 19.71

a For description see Appendix 2

=Significant at 1% level, *=Significant at 0.1% level

<u>Appendix 5</u> Analysis of variance of emergence rate index for maize as affected by tillage systems, tested with two methods of weed control, from a 3 x 2 factorial experiment in the RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	4.696	2.348	5.39*	4.10	7.56
Treatment[c]						
A	2	0.254	0.127	0.29^{ns}	4.10	7.56
B	1	0.037	0.037	0.05^{ns}	4.96	10
AB	2	0.562	0.281	0.65^{ns}	4.10	7.56
Error	10	4.353	0.4353			
Total	17	9.902				

[a] cv = 9.33%

[b] * = Significant at 5% level, ns = Not significant

[c] A = tillage, B = weed control, AB = interaction

<u>Appendix 6</u> Final maize plant population as affected by tillage systems tested with two levels of weed control in the RCB Design.

Treatment[a]	Thousand plants / ha Rep. I	Rep. II	Rep. III	Treat. Total	Treat. Mean
NTC	33.88	24.80	20.44	79.12	26.37
NTM	19.84	24.72	27.68	72.24	24.08
MTC	24.52	23.60	25.46	73.58	24.53
MTM	17.32	24.00	28.29	69.61	23.20
CTC	29.00	24.20	24.24	77.44	25.81
CTM	29.92	29.60	23.80	83.32	27.77
R	154.48	150.92	149.91		
G				455.31	
GM					25.295

[a] for description of treatments, see Table 9.

Appendix 7 Analysis of Variance of Data in Appendix 6 from a 3 x 2 Factorial Experiment in the RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	1.92	0.96	0.043[ns]	4.10	7.56
Treatment[c]						
A	2	25.77	12.89	0.572[ns]	4.10	7.56
B	1	1.37	1.37	0.061[ns]	4.96	10
AB	2	14.91	7.46	0.331[ns]	4.10	7.56
Error	10	225.27	22.53			
Total	17	269.24				

[a] cv = 18.76%
[b] ns = Not significant
[c] A = tillage, B = weed control, AB = interaction

Appendix 8 Maize plant height (cm) of manually weeded and chemically controlled plots under three tillage systems[a]

Treatment	Plant height (cm) Rep. I	Rep. II	Rep. III	Treat. Total	Treat. Mean
NTC	105.64	99.45	115.00	320.09	106.70
NTM	79.74	82.34	112.42	274.50	91.50
MTC	115.78	107.75	134.01	357.54	119.18
MTM	104.66	110.96	140.47	356.09	118.70
CTC	115.83	115.00	114.11	344.94	114.98
CTM	112.57	120.75	107.44	340.76	113.59
R	634.22	636.25	723.45		
G				1993.92	
GM					110.77

[a] Figures represent an average of three measurements taken at one month interval after planting

Appendix 9 Analysis of variance of data in appendix 8 for 3 x 2 factorial experiment in the RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	864.99743	432.49872	3.92^{ns}	4.10	7.56
Treatment[c]						
A	2	1291.7577	645.87885	5.86*	4.10	7.56
B	1	145.74935	145.74935	1.32^{ns}	4.96	10.00
AB	2	203.92115	101.96058	0.93^{ns}	4.10	7.56
Error	10	1102.1324	110.21324			
Total	17	3608.558				

[a] cv = 9.48%

[b] * = Significant at 5% level, ^{ns} = Not significant

[c] A = tillage, B = weed control, AB = interaction

Appendix 10 Combination table showing the mean height (cm) of the two factors (Data in Appendix 8)

Tillage systems (A)	Weed control methods (B) Chemical (C)	Weed control methods (B) Manual (M)	$\bar{X}_A$
NT	106.70	91.50	99.10
MT	119.18	118.70	118.94
CT	114.98	113.59	114.29
$\bar{X}_B$	113.62	107.93	

Appendix 11 Comparison of the performance of tillage systems for maize plant height by using LSD test (Data in Appendix 10)

Rank	3	2	1	
Tillage systems	NT	CT	MT	LSD
Maize plant height	99.1	114.29	118.94	P-5% = 26.06
Difference	—	15.19^{ns}	19.84^{ns}	P-1% = 60.18
		—	4.65^{ns}	P-0.1% =191.50

Appendix 12 Comparison of the effects of weed control method on maize plant height by using LSD test (Data in Appendix 10)

Rank	2	1	
Method of control	Manual	Chemical	LSD
Maize plant height (cm)	107.93	113.62	P-5% = 62.90
Difference	—	5.69^{ns}	P-1% =315.05
			P-0.1% =3150.63

Appendix 13a Interaction between the two factors, Tillage systems x weed control methods, (Data in Appendix 10)

(Manual weed control)

Rank	3	2	1	
Tillage system	NTM	CTM	MTM	LSD
Maize plant height	91.5	113.59	118.7	P-5% = 36.86
Difference	—	22.09^{ns}	27.2^{ns}	P-1% = 85.12
			5.11^{ns}	P-0.1% =270.88

^{ns}=not significant

Appendix 13b Interaction between the two factors, Tillage systems x Weed control methods, (Data in appendix 10)

(Chemical weed control)

Rank	3	2	1	
Tillage system	NTC	CTC	MTC	LSD
Maize plant height	106.70	114.98	119.18	P-5% = 36.86
Difference	—	8.28^{ns}	12.48^{ns}	P-1% = 85.12
			4.2^{ns}	P- 0.1% =270.88

Appendix 14 Influence of weed control methods on maize plant height for no-tillage system (Data in Appendix 10)

Rank	2	1	
Weed control method	Manual	Chemical	LSD
Maize height	91.5	106.7	P-5% = 36.86
Difference	—	15.2^{ns}	P-1% = 85.12
			P-0.1% =270.88

^{ns} = not significant

Appendix 15 Analysis of variance for Organic matter content from a 3 x 2 factorial experiment in the RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	0.1707444	0.0853722	0.22^{ns}	4.10	7.56
Treatment[c]						
A	2	0.0597444	0.0298722	0.08^{*}	4.10	7.56
B	1	2.1286722	2.1286722	5.59^{ns}	4.96	10.00
AB	2	1.2444784	0.6222392	1.63^{ns}	4.10	7.56
Error	10	3.805761	0.380576			
Total	17	7.4094				

[a] cv = 12.49%

[b] * = Significant at 5% level, ^{ns} = Not significant

[c] A = tillage, B = weed control, AB = interaction

Appendix 16 Effect of weed control level on Organic matter content as tested by LSD

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Available organic matter (%)	4.60	5.29	P-5% = 3.7
Difference	—	0.69^{ns}	P-1% =18.5
			P-0.1%=185.1

Appendix 17 Influence of weed control method on the available Organic matter for minimum tillage system as tested by LSD

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Available organic matter (%)	4.27	5.68	P-5% = 2.17
Difference	—	1.41^{ns}	P-1% = 5.00
			P-0.1%=15.9

Appendix 18 Analysis of variance for available total Nitrogen from a 3 x 2 factorial experiment in a RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	0.00188	0.00094	0.84^{ns}	4.10	7.56
Treatment						
A	2	0.001411	0.00071	0.63^{ns}	4.10	7.56
B	1	0.0032	0.0032	2.86^{ns}	4.96	10.00
AB	2	0.00043	0.00022	0.19^{ns}	4.10	7.56
Error	10	0.0111911	0.001119			
Total	17	0.00188				

[a] cv = 11.86%

[b] ns = Not significant

Appendix 19 ANOVA for available Phosphorous from a 3 x 2 factorial experiment in a RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	0.00152	0.000751	1.19^{ns}	4.10	7.56
Treatment						
A	2	0.00409	0.00204	3.23^{ns}	4.10	7.56
B	1	0.00605	0.00605	9.58*	4.96	10.00
Interaction	2	0.00109	0.000545	0.86^{ns}	4.10	7.56
Error	10	0.006315	0.0006315			
Total	17	0.0190651				

[a] cv = 28.9%

[b] * = Significant at 5% level, ^{ns} = Not significant

Appendix 20 Effect of weed control level as tested by LSD for available Phosphorous

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Available Phosphorous (ppm)	0.068	0.105	P-5%= 0.151
Difference	—	0.037^{ns}	P-1%= 0.754
			P-0.1%= 7.542

Appendix 21 Influence of weed control methods as tested by LSD on Available Phosphorous

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Available Phosphorous (ppm)	0.057	0.103	P-5% = 0.088
Difference	—	0.046^{ns}	P-1% = 0.204
			P-0.1%= 0.648

Appendix 22 ANOVA for available Potassium from a 3 x 2 factorial experiment in a RCB design

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F	
					5%	1%
Replication	2	0.00421	0.00211	0.71[ns]	4.10	7.56
Treatment						
A	2	0.00873	0.00437	1.47[ns]	4.10	7.56
B	1	0.00091	0.00091	0.31[ns]	4.96	10.00
Interaction	2	0.00252	0.00126	0.42[ns]	4.10	7.56
Error	10	0.02973	0.002973			
Total	17	0.0461				

[a] cv = 16.04%

[b] ns = Not significant

Appendix 23 ANOVA for available Sodium from a 3 x 2 factorial experiment in a RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F	
					5%	1%
Replication	2	0.000806	0.000403	1.07[ns]	4.10	7.56
Treatment						
A	2	0.00121	0.000607	1.61[ns]	4.10	7.56
B	1	0.000374	0.000374	0.99[ns]	4.96	10.00
Interaction	2	0.00202	0.00101	2.67[ns]	4.10	7.56
Error	10	0.00378	0.000378			
Total	17	0.008182				

[a] cv = 17.84%

[b] ns = Not significant

Appendix 24 Analysis of variance for maize grain yield from a 3 x 2 factorial experiment in the RCB design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	2594937.5	1297468.8	2.08^{ns}	4.10	7.56
Treatment[c]						
A	2	5943061.5	2971530.8	4.75*	4.10	7.56
B	1	8277.6	8277.6	0.01^{ns}	4.96	10.00
Interaction	2	1497963.4	748981.7	1.20^{ns}	4.10	7.56
Error	10	6252179	625217.9			
Total	17	16296419				

[a] cv = 26.81%

[b] * = Significant at 5% level, ^{ns} = Not significant

[c] A = Tillage system, B = Method of weed control

Appendix 25 Combination table showing the mean yields (kg/ha) of the two factors (Data in Table 12)

Tillage System[a] (A)	Weed control method (B) chemical (C)	Weed control method (B) manual (M)	$\bar{X}_A$
NT	2412	1862	2137
MT	2945	3770	3357.5
CT	3427	3282	3354.5
$\bar{X}_B$	2928	2971.33	2949.67

[a] NT = no-tillage, MT = minimum tillage, CT = conventional tillage

Appendix 26 Comparison of performance of tillage systems for maize grain yield using LSD test

Rank	3	2	1	
Tillage system	NT	CT	MT	LSD
Yield	2137	3354.5	3357.5	P-5% = 1963.04
Difference	—	1217.5^{ns}	1220.5^{ns}	P-1% = 4533.24
			3.0^{ns}	P-0.1% =14426.03

^{ns} = Not significant

Appendix 27 Comparison for the effectiveness of weed control method on yield using LSD test (Data in appendix 26)

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Yield (kg/ha)	2928	2971.33	P-5% = 4737.53
Difference	—	43.33^{ns}	P-1% = 23728.63
			P-0.1% = 237293.74

^{ns} = Not significant

Appendix 28 Analysis of variance for maize residue mass production (Stover + Cob) from a 3 x 2 factorial experiment in a RCB Design[a]

Source of Variation	Degree of freedom	Sum of Squares	Mean Square	Computed F[b]	Tabular F 5%	Tabular F 1%
Replication	2	8467992.5	4233996.2	1.73[ns]	4.10	7.56
Treatment[c]						
A	2	23292555	1646277	4.75[*]	4.10	7.56
B	1	916206.7	916206.7	0.37[ns]	4.96	10.00
Interaction	2	2474144.3	1237072.1	0.50[ns]	4.10	7.56
Error	10	24542996	2454299.6			
Total	17					

[a] cv = 24.7%

[b] ns = Not significant, * = Significant at the 5% level

[c] For description, see Appendix 24

Appendix 29 Comparison of performance of tillage systems for residue mass production using LSD test

Rank	3	2	1	
Tillage treatments	NT	MT	CT	LSD
Residue mass prod.	4733	7000.84	7269	P-5% = 3889.31
Difference	—	2267.84[ns]	2536[ns]	P-1% = 8981.59
		—	268.16[ns]	P-0.1% =28581.89

Appendix 30 Comparison for the effectiveness of weed control methods on maize residue mass production using LSD test

Rank	2	1	
Method of weed control	Manual	Chemical	LSD
Residue mass production	6108.67	6559.89	P5%=9386.46
Difference	--	451.22[ns]	

ns = not significant

Appendix 31 Sample calculation of Draught Requirement per hectare

One of the replication for the conventional tillage treatment was used to show the sample calculation.

Step 1 Determination of speed of operation

a) For ploughing

Length = 50 meters (The length of the plot)
No. of passes = 12
Time = 1125 seconds (Actual time required for the operation; excluding turning time)
Total length covered during ploughing = 12x50 = 600m

$$Speed = \frac{Distance\ covered}{Time\ required}$$

$$= \frac{600m}{1125s}$$
$$= 0.533\ m/s$$
$$= 1.92\ km/h$$

b) For cultivation

No. of passes = 7
Total distance covered = 7x50 = 350m
Time required = 251 seconds

$$Speed = \frac{350m}{251s}$$
$$= 1.394\ m/s$$
$$= 5.02\ km/h$$

c) For planting

No. of passes = 6
Total distance covered = 6x50 = 300m
Time required = 575 seconds

$$Speed = \frac{300m}{575s}$$
$$= 0.522\ m/s$$
$$= 1.88\ km/h$$

Step 2 Available draw bar HP determination

The maximum PTO HP of the tractor used at 1500 rpm of the engine = 29 kw (obtained from tractor test Appendix 33). The available draw bar power was calculated by using the relationship given in Table 4 for soft soil condition which is 48% of the maximum PTO HP.

Therefor usable draw bar HP = 0.48 x 29kw
= 13.92 kw

Using equation 1 the draught requirement for each operation was obtained as follows

$$F(kN) = \frac{DBP(kw) \times 3.6}{S(km/h)}$$

$$= \frac{13.92kw \times 3.6}{S(km/h)}$$

a) ploughing

$$F(kN) = \frac{13.92kw \times 3.6}{1.92\ km/h}$$
$$= 26.1\ kN$$

b) Cultivation

$$F(kN) = \frac{13.92kw \times 3.6}{5.02\ km/h}$$
$$= 9.98\ kN$$

c) Planting

$$F(kN) = \frac{13.92kw \times 3.6}{1.88\ km/h}$$
$$= 26.66\ kN$$

Total draught force = Draught force required for ploughing +
Draught force required for cultivation +
Draught force required for planting

Therefore,

Total draught force = 26.1kN + 9.98kN + 26.66kN
= 62.74 kN

Note :- The figures shown in Table 7 were the average of three different plots of the same treatment.

Appendix 32 Sample calculation to determine Emergence Rate Index (ERI)

Example:- Data for No-Tillage treatment where weed was controlled by using chemical, Replication 1.

Days after planting	9	10	11	12	13	14	15	16
Population count(%)	22.26	27.64	34.25	42.48	52.64	80.59	94.4	94.4

Using equation 2,

$$ERI = \sum_{n=first}^{last} \frac{n\% - (n-1)}{n}$$

$$\begin{aligned}
ERI &= \frac{[22.26-(9-1)]}{9} + \frac{[27.64-(10-1)]}{10} + \frac{34.25-(11-1)]}{11} + \\
&\quad \frac{[42.48-(12-1)]}{12} + \frac{[52.64-(13-1)]}{13} + \frac{[80.59-(14-1)]}{14} + \\
&\quad \frac{[94.9-(15-1)]}{15} + \frac{[94.4-(16-1)]}{16} \\
&= \frac{(22.26-0)}{9} + \frac{(27.64-22.26)}{10} + \frac{(34.25-27.64)}{11} + \\
&\quad \frac{(42.48-34.25)}{12} + \frac{(52.64-42.48)}{13} + \frac{(80.59-52.64)}{14} + \\
&\quad \frac{(94.4-80.59)}{15} + \frac{(94.4-94.4)}{16} \\
&= 2.47 + 0.54 + 0.60 + 0.69 + 0.78 + 2.00 + 0.92 + 0 \\
&= 8.00
\end{aligned}$$

Note:- Each plot was treated the same way and the average of the three different plots were taken to determine the emergence rate index of the tillage systems.

Appendix 33 Tractor test result performed by the Froment Dynamometer available in the University

DYNAMOMETER TEST REPORT

using

FROMENT

Tractor Test Centre

Report of test on:-

FORD 5000

Serial No B214988 Reg No KRY720
Year of manufacture - 1973
Recorded hours - 00 40 00
Owner - UNIV.OF NAIROBI(Agr.Eng.Dept.)
P.O.BOX 30197
TEL.592211 EXT.288
KENYA
Test by GERA-WORK ZELEKE
of AGRI.ENG.DEPT.
P.O.BOX 30197
NAIROBI
KENYA

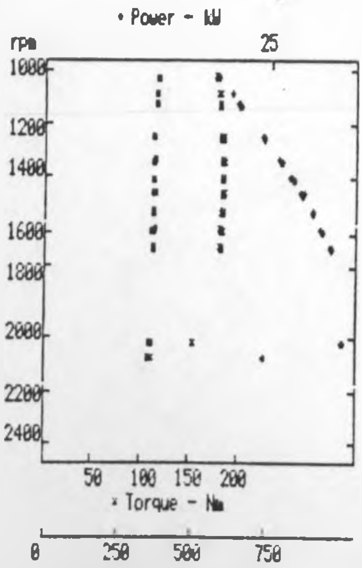
Time - 12:21 Date - 07/05/90

Test conducted with 540 rpm PTO. All speed figures are Engine rpm based on Engine:PTO ratio of 1900:540

Specific fuel consumption figures are based on fuel density of:- 0.8350 kg/l

Summary of test

Maximum power - 32.9 kW
Speed @ max. power - 2016 rpm
Maximum torque - 186 Nm
Speed @ max. torque - 1454 rpm
Torque back-up ratio - 19.7 %



Test results

Engine Speed rpm	Power kW	Torque Nm	Fuel flow l/h	Specific fuel con g/kWh
1016	18.9	178		
1018	19.0	178		
1020	19.0	178		
1022	19.1	179	8.8	386
1079	20.6	182	9.3	377
1081	20.5	181	9.3	379
1083	20.5	181	9.3	379
1084	20.5	181		
1117	21.2	181	9.7	381
1123	21.3	181		
1124	21.4	182		
1126	21.4	181		
1128	21.5	182		
1245	24.0	184		
1246	24.1	185	10.7	372
1248	24.1	184	10.7	372
1250	24.1	184		
1252	24.2	185		
1254	24.2	184		
1334	25.9	185	11.5	372
1338	26.0	186		
1340	26.0	185	11.6	371
1342	26.1	186		
1344	26.1	185		
1397	27.0	185		
1399	27.1	185		
1401	27.1	185		
1405	27.3	186		
1410	27.4	186	12.1	368
1454	28.4	186	12.5	368
1456	28.1	184	12.5	372
1458	28.2	185		
1460	28.3	185		
1462	28.3	185		
1525	29.5	185	13.0	369
1527	29.5	185	13.0	369
1529	29.5	184	13.0	369
1530	29.5	184		
1580	30.2	183		
1582	30.3	183	13.5	372
1584	30.4	183	13.4	369
1586	30.6	184	13.4	367
1647	31.6	183	13.9	367
1649	31.5	182	13.9	369
1650	31.6	183	13.9	368
2014	32.8	155	14.2	362
2016	32.9	156	14.2	360
2018	32.9	156	14.2	360
2074	24.2	111	10.3	355