STUDIES ON THE EFFECTS OF DIFFERENT CULTIVATION TECHNIQUES ON CROP ESTABLISHMENT, YIELD AND SOIL WATER RELATIONSHIPS IN TANZANIA

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This Thesis is submitted by permission of the Director of Agriculture and Chief Research Officer, Dar-es-Salaam.

ORIGINALITY

Except where otherwise stated this work is original. No part of it has been submitted to any other University.

The following publications from the work presented in this thesis have been submitted or are in the course of preparation as indicated.

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1. Pasture establishment and renovation by direct seeding 1969 E.Afr. agric. for. J. 35, 185-189

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2. The effect of different amounts of cultivation on the growth of maize on some soil types in Tanzania 1970 Trop.Agric. Trin. October

3. Observations on the efficiency of some recommended methods of soil and water conservation 1970 E.Afr. agric. for. J.

IN PREPARATION

1. A comparison of the effects of different tillage systems on I Yield of wheat at West Kilimanjaro

2. II Plant/water relationship at West Kilimanjaro (with Dr Willy)

3. The agronomic advantages of chemical fallowing with wheat in Northern Tanzania.

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S U M M A R Y

Minimal tillage as understood during these studies is defined as the least amount of surface area cultivation necessary to prepare a seedbed for a good germination and plant establishment. Using this definition it is clear that no single minimal tillage practice will be satisfactory for all areas and crops.

The basic advantages of increased reliability of yields, although of the greatest economic importance, is considered against a background of cultivation techniques achieving efficient soil and water conservation.

The cultural and economic problems of improved pasture establishment by conventional methods are discussed. A brief review of the development of the direct-seeding technique is given together with its possible advantages over the conventional system. Observations on direct drilling of some improved pasture species into old pasture at Tengeru using the Howard Rotaseeder are described.

Various alternative systems of tillage under semi-arid conditions at Kongwa are compared in an attempt to improve cropping reliability and reduce land preparation expenditure. Direct drilling failed in the first season due to the inherent physical properties of the soil although significant improvements in the technique by wider and deeper seedbed preparation in the second season were achieved. The benefits of ripping together with inter-row mulching on soil and moisture conservation were demonstrated and suggestions made for 'zonal tillage' incorporating

ripping of the seedbed for improving root penetration. Differences in yield and plant vigour were related to inhibited root growth due to mechanical impedance under reduced tillage practices.

The necessity of treating each soil according to its individual structural characteristics is shown by the results of width and depth of tillage trials over widely differing soil types. The amount of cultivation necessary for good germination and establishment in these trials varies from eight inches wide by three inches deep on a compacted Kongwa soil to successful direct drilling into a one inch by two inches seedbed on a West Kilimanjaro soil.

Observations and recordings of the effects of various recommended systems of soil conservation on the control of soil and water loss from a 17 per cent slope are reported. Evidence of soil structural and chemical changes due to erosion over an eighteen year period together with a progressive reduction in yield of maize are presented. Trash mulching has been effective in maintaining fertility, structure and controlling soil and water movement.

Studies with wheat comparing the effects of conventional and minimal tillage with and without fallowing at West Kilimanjaro are described. No significant differences are evident in organic matter content or structure of the surface soil over six seasons experimentation. Infiltration rates are shown to be substantially improved under stubble mulching with chemical weed control, a factor which has contributed to yield increases. The initial benefits during germination and establishment obtained with minimal tillage indicate that moisture conservation within the seedbed zone is of paramount importance.

The practical implications of the acceptance of reduced tillage practices are discussed. This philosophy of maximum crop production per acre with minimum soil deterioration is based on the concept that minimal tillage conserves organic matter and that a mulch cover protects the soil against erosion. The data to support these ideas is in no way conclusive but the trends are tentatively established. These preliminary results are encouraging and seem to indicate that these developments are sound and that the future will support the conclusion.

I INTRODUCTION

In the drier tropics there are vast areas of potentially valuable arable land where water is the limiting factor for optimum plant growth. Rainfall may appear to be sufficient when considering annual totals but its distribution, intensity and reliability are such that it becomes a main factor of production. Many soils in such areas having been subjected to continuous cultivation and extremes of temperature are low in organic content and have a poor or unstable crumb structure. With intense short duration rainfall these soils produce an almost impervious cap which reduces infiltration and encourages run-off. Surface run-off means an equivalent loss in production potential. For many grain crops, which are very susceptible to drought at the time of fertilisation, loss of water reserves can mean the difference between an economic yield and crop failure. Controlled measurements made in East Africa of run-off rates during high intensity storms (Macartney 1968 b) have shown the extent to which a reduction in effective rainfall can effect crop yields. The aim of any farming system in marginal rainfall areas should be to utilise all precipitation for crop growth and ensure that no run-off takes place.

Conventional methods of soil and water conservation using contour banks, terraces, etc. can control water movement but must be complementary to systems of cultivation designed for water infiltration and storage within the profile. Previous studies (Macartney 1964 a) using the N.I.A.E. tropical cultivation equipment have shown that a system of ripping, ridging and tieing, together with successive ripping with each post planting cultivation provides for vastly improved water storage and crop yields.

There is a lack of suitable implements available for cultivation in the dry tropics. Machinery designed for temperate regions is generally used and is often totally unsuitable. In Europe stress is laid on the formation of a fine consolidated seed bed which under tropical conditions can be disastrous from the point of view of soil and water conservation. Manufacturers are not keen to tackle the problems of the dry tropics as the initial demand for their product is small and little basic information on optimum cultivation techniques are available.

Within recent years the setting up of settlement schemes and various forms of co-operative development on an extensive scale for arable or animal production have presented problems to the Research Divisions. With few exceptions the costs of production, particularly cultivation, have invariably been high which together with transport costs and frequent crop failure have absorbed the profit margins expected.

At present within Tanzania there is strong pressure on the agricultural services to considerably increase wheat production by improvements of yields within existing areas and by increasing the wheat acreage to fill the production deficit for self-sufficiency alone. In Kenya the present policy is to lower the costs of wheat production in an attempt to compete on the world markets. Both policies require careful consideration of current cultivation costs before any measure of success can be expected.

Surveys on cultivation expenditure in East Africa (Minto, personal communication, 1965) show the necessity for either more efficient use of available equipment or alternatively some radical change in the presently recommended systems of cultivation. Overall cultivation and seed bed preparation by ploughing and harrowings is invariably expensive especially in the drier areas where initial cultivations are carried out in the dry season. This is particularly true for improved pasture establishment. Returns per acre/year are low by temperate standards which together with frequent failures using current methods make the whole question of ley establishment very doubtful as an economic enterprise.

Reduction in the amount and intensity of cultivation has recently gained popularity in many semi arid zones of the world as a farming practice. Acceptance of this has largely been based on reduced cost of operation, improved soil/moisture relations, and an arresting of soil structural deterioration.

Progress in agricultural machinery development has been closely related to progress made in the soil and plant management fields. A growing interest and awareness on the part of agronomists, engineers and soil scientists is very evident on the question of what is the optimum in tillage and seed bed preparation.

The objectives of conventional tillage have been basically to stir and loosen the soil and to control weeds. Whilst this has been generally effective in creating a satisfactory medium for plant growth it has also in many instances resulted in a deterioration in soil structure, reduced infiltration capacity, increased susceptibility to erosion and accelerated reduction of soil organic matter.

In general, the aims of studying new concepts of tillage practices have been directed at overcoming these disadvantages and yet providing an optimum tilth for plant establishment by tending towards a reduction and often elimination of cultivation. These alternative systems are often referred to as "minimal tillage", a term which is easily misinterpreted.

With the aims of alternate tillage defined, practical cultivation procedure can vary, i.e.

a) Minimising the number of trips. The least possible being one and often referred to as the "plough – plant" system. This one operation may well be essentially maximum, i.e. overall cultivation.

b) Using the least energy input for seed bed preparation. Minimum in these terms being zero, no tillage, or direct drilling.

c) Minimal tillage as understood during these studies is defined as the least amount of surface area cultivation necessary to prepare a seed bed necessary for a good germination and plant establishment. Using this definition it is clear that no single minimal tillage practice will be satisfactory for all areas and crops.

The majority of previous studies on alternative cultivation methods have involved the use of standard ploughs, discs or field type cultivators in either a modified form or in new patterns of sequence or timing. These trials also included the effects of mulches upon soil structure, temperature, nutritional balances and moisture relationships but contributed little to the machinery development side until the acceptance of the minimal technique.

1:1 Cultivation Research in Africa

The need for rapid improvement in agricultural practices, particularly cultivation practices, has received increasing emphasis of recent years (Odelola, 1965). Concrete suggestions are invariably expected from soil management symposia and committees "which will assist Member states in their quest for a quick solution to their soil conservation and tillage problems." Yet the information available, within the African continent particularly, and the current research leading to a solution of this problem has attracted low priority.

Previous research has been directed at methods of land preparation for water conservation of which the Tied Ridge or basin listing system has stimulated the widest interest. (Farbrother 1960, Bowers 1965, Peat and Prentice 1949, Cashmore and Hawkins 1957, Ofield 1958, and Dagg and Macartney 1968.)

The first successful attempts at seed bed preparation on compacted soils using minimal tillage techniques was reported by Boshoff and Hill (1964) working in Uganda. Constructive suggestions as to the priorities of tillage research were later presented by Dagg (1968).

The Specialist Committee on Agricultural Machinery of East Africa (1967) has recommended that this avenue of research be developed and fully recognise "its vital role in advising governments on the practicability of mechanisation in East African agriculture."

The reasons for this current lack of information are concisely explained by Odelola (1965) "Africa is at present in a hurry to develop her natural resources so as to enable the present and future generations to enjoy an improved standard of living. Our political masters cannot wait indefinitely for results of delayed experiments. The challenge of our time is the demand from Governmental authorities that scientists and research workers should find quickly and immediately solutions which are applicable to the urgent problems of the moment." The symposium in its recommendations noted the limited interest by agricultural scientists on run-off, erosion and cultivation techniques. The study of alternative systems of cultivation is both complex and long term as soil management constitutes one of the more complex factors of productivity. The environment provided by the soil has strong physical, chemical and biological interactions that in Africa particularly are far from completely understood. Some valuable and relevant information is readily available from sub-tropical countries where soil management has been studied in association with atmospheric environment of the plant and the relation and effect of cultivation on water storage, evaporation and transpiration demand.

1. THE EFFECT OF TILLAGE ON SOIL STRUCTURE

The most widely used implements, the plough and the disc harrow, used for the destruction of weeds, the burying of residues and the preparation of a seed bed, owe their popularity to their long and consistent use by farmers, noted for their reluctance to discard operations which have proved successful under past concepts. Advances in the science of farming outstrip the practical acceptance because they require a change in the art of farming and often involve the substitution of capital for labour and the purchase of different equipment.

The old adage of tillage and more tillage and the necessity of clean cultivation and fine seed beds were satisfactory when applied to virgin soils high in organic matter and increased yields were normally recorded for a tillage operation. Yet it is not always possible to evaluate the success of an operation by the exactness with which it appears to meet its obvious objectives.

Among the more important and obvious harmful results developing with increased tillage, Halsted (1954) discussed the (a) rapid loss of soil organic matter and loss of tilth, (b) excessive soil erosion resulting from lack of cover under clean cultivation and (c) the increased loss of water due to excessive evaporation from the bare surface and poor penetration of rain water where the structure of the soil has been affected.

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II REVIEW OF LITERATURE

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Harvey (1944) observed the alteration in soil structure resulting from two seasons of tillage operation. The restriction of water percolation by excess tillage was reported by Parker and Jenny (1945). Siddoway (1963) also noted the effect of continuous cultivation on soil structure; also criticised by Rynasiewicz (1945) and Alderfer and Merkle (1941).

As cultivation of the soil continues there is a gradual deterioration of structural qualities which has been found to vary with the intensity of cultivation and the cropping system (Anderson and Browning 1949). Among the more comprehensive surveys Anderson and Browning (1949) identified excess tillage as being responsible for decreased porosity, aggregation and organic matter content together with an increase in bulk density.

Increase in volume weight through cultivation was also reported by Retzer and Russell (1941) and Page and Willard (1946). The changes in bulk density were observed to be not limited to the ploughed layer but were recorded well beyond it to three feet in depth.

Parker and Jenny (1945) were able to correlate the effect of heavy discing and the significant increases in volume weight and reduction in soil porosity they obtained. Elimination of cultivation reduced resistance to penetration and core weights and brought about a marked improvement in the rate and amount of water infiltration.

In a silt loam after sixty years of cultivating the decrease in porosity from sixty to fifty per cent and a drop in yield of sixty bushels per acre was related by Bradfield (1936) to be due to intensive cultivation

The temperate recommendations for the preparation of a seed bed have in general been incompatible with other aspects of good soil management in the tropics. Frequent disturbance of the soil and the pulverisation by disc implements exposes the organic fraction of the soil to rapid oxidation resulting in a structural deterioration (Siddoway 1963). High intensity storms further break down the crumbs and result in capping with associated water loss and erosion (Ellison 1947 a).

1:1 Depth of Tillage and the Relation of the Sub-Soil to Water Infiltration

The influence of deep tillage on crop yields has been a controversial subject for many years. In some few instances crop yields appear to be better but generally results are negative. Winters and Simonson (1951) suggested that discrepancies in the effects of deep tillage may be due to sub-soil differences that were not recognised or described. Early work in England by Russel and Keen (1938) indicated that depth of tillage had little influence on crop yields. Similarly, Hume (1943) found little or no benefit from deep tillage on yields of maize or wheat. Crop yields were not significantly affected by deep tillage on a soil with an underlying heavy clay pan in Illinois (Smith 1925). Winters and Simonson (1951) summarised the effectiveness of deep tillage in breaking up pans near the surface, but pointed out that in most cases deep tillage had to be repeated at frequent intervals which was both expensive and power consuming.

The early theory that deep ploughing was necessary to assure water penetration and storage was backed by little, if any, experimental data. Work by Chilcott and Cole (1918) and Volk (1947) stated that deep tillage had been of no benefit in overcoming drought, although in the Evans and Lemon (1957) review of soil moisture conservation, Daniell (1952) was quoted as having obtained better percolation with both chisel and deep ploughing in Oklahoma. This effect was nullified in the third year after treatment.

The nature of the sub-soil undoubtedly exerts an important influence on the moisture relations of the entire soil profile. The capacity for storage of moisture has been considered by Veihmeyer and Hendrikson (1938), Cole and Matthews (1939) and Browning (1946) who agreed that by restricting percolation after the surface soil has become saturated the sub-soil could influence infiltration rate which resulted in run-off and erosion together with reduction in yield (Odell, 1950).

Musgrave and Norton (1937) reported that a silt loam widely representative of North Missouri absorbed rainfall seven to ten times as rapidly as Shelby silt loam which had a more dense sub-soil.

The sub-soil often affects the growth and proliferation of roots and rooting depth of the plant although most of the roots are growing in the surface soil. This effect of the sub-soil on plant growth was discussed by Woon (1938) who pointed out that root distribution and moisture regimes depended as much on the characteristics of the sub-soil as on the surface soil.

It is often not clear from the literature whether claims for improved infiltration and yield as a result of deep tillage are due to tillage induced or to naturally occurring soil conditions.

With the increasing number of tractors and limited labour supplies, soils are often cultivated before they reach the optimum moisture content for tillage. This is particularly pertinent in areas of marginal rainfall where soil preparation must be carried out during the dry season to fully utilise the short and variable rainfall (Macartney, 1964). The resultant formation of plough soles or compact layers was studied by Huberty (1944) who found that pore space was reduced by as much as fifty per cent in the uppermost layers in California. This compaction seriously affected rainfall penetration.

Weaver (1950) showed that ploughing at optimum moisture contents in Alabama produced a compact layer at nine inches. Free, Lamb and Carlton (1947), Parker and Jenny (1945) and Kachinsky (1927) among the early workers produced evidence of compaction and loss of pore space due to excess tillage. Bradfield (1936) reported results from long term trials which correlated years of cultivation with reduction in pore space; the changes in physical structure occurred from the surface to at least three feet. Hoover (1949) compared the percolation rates in virgin soil and cultivated areas of the red-yellow Podzolic soil groups and found striking differences in percolation rate and total porosity down to twenty four inches. Laws and Evans (1949) quoted similar results working on the Houston black clay. Both authors reported decreases in yield with length of cultivation.

In general, soil types with a medium textured sub-soil of a friable nature have produced higher yields for a longer period of time under continuous cultivation. This suggests that sub-soils of a favourable nature physically are less likely to affect crop growth under intensive cultivation. The limited data available suggests that current soil management practices are resulting in the development of unfavourable sub-soil conditions.

1:2 The Mechanics of Rainfall Erosion and the Formation of Surface Crusting

The loss of organic matter by the continual growing of soil-depleting crops and excess tillage was related to decreasing percolation rates by Hendricksen (1934) and Horton (1933). Aggregate dispersion as a result of tillage proceeded more rapidly at the surface. This area under cultivation was exposed to the beating action of raindrops in addition to exposure to other forces of structural decline. Crust formation following rainstorms tended to develop as dispersion of aggregates in the surface layer continued. The silt and clay in the run-off water sealed the larger pore spaces at the surface, a surface crust formed and infiltration was retarded. Duley and Kelly (1939) found a compact layer about three millimetres thick on the surface of soil after intense rain on bare soil which affected the absorption of water. The macroscopic pore space in the soil beneath this layer was favourable for rapid moisture movement. Peele et al (1945) found that beating rains formed an impervious layer on sandy loams quicker than on clay loams. This reduced rate of water absorption through the compacted layer often resulted in excessive rates and amounts of surface run-off regardless of the structural and water holding capacities of the below surface profile.

The disintergrating effect on the soil aggregates by the beating of the raindrops was measured by Ellison (1944 a, 1947, 1948) and described by Bennett (1939) as the initial phase of the water erosion process. The dispersing action of raindrop impact on bare soil, resulting in crust formation, reduced infiltration and increased surface run-off, has also been demonstrated by Levine (1952) and McIntyre (1958).

The height and distance of splash was found by Mihara (1952) to depend upon the soil surface condition and the fall velocity of the drop. On compacted soil the splash from six mm. drops reached a height of 59 inches. Uhland (1947) compared the number of raindrops, under controlled conditions, required to disperse soil aggregates from land under different cropping sequences. Land cropped annually with corn required six raindrops falling from 30 cms., and land from one year ley required 37 drops of the same size to completely disperse.

Epstein and Grant (1967) attempted to evaluate some of the factors which affected the different erodibility characteristics of soils. A linear relationship was obtained between clay content and soil loss during the first five to ten minutes of rainfall application. The rate and extent of crusting was the prime factor in run-off measurements. The bulk density of the top 0 – 5 mm. layer increased on one soil, a silt loam, from 1.15 to 1.65 gr./c.c. Olsen and

Wischmeier (1963) indicated that the erodibility of medium textured soils generally increased as silt content increased.

The speed and severity with which crusting occurs was directly related to reduced infiltration and permeability by McIntyre (1958 a & b) and Tackett and Pearson (1965).

Structural deterioration and compaction of the soil surface is a matter of considerable importance from the standpoints of both crop production and water conservation. Compacted surface layers and crust formation may also interfere seriously with seed germination and cotyledon emergence (Macartney 1967).

The beneficial effect of shallow surface cultivation on moisture infiltration by breaking the surface cap during crop emergence and subsequent growth has been recorded by Macartney and Dagg (1968 a).

Although the effect of plant cover on reducing run-off and erosion was recognised by early workers, the mechanism of this occurence was not fully understood for many years. The evaluation of each step in this process was first started by Hendrickson (1934) and Miller (1936). Realising that run-off was caused primarily by the blocking of soil pores as a direct result of rainfall impact, they suggested plant cover as being necessary for the prevention of this condition. Laws (1940) related the concentration of soil in the run-off water to the raindrop energy, and the effect of mulch in intercepting this rainfall impact was first recorded by Borst and Woodburn (1942) as reducing erosion by 95 per cent. That it was the impact of the drops on bare soil and not the run-off velocity that detached the soil was demonstrated by raising the mulch off the ground on a wire platform with the same control. Johnston (1950) also recorded the efficiency of a surface mulch of wheat residues on a fine textured Texas soil in preventing excessive surface crusting.

The importance of mulches in crust retardation with subsequent improvement in emergence of small grain was also pointed out by Army et al (1961).

A result of studying infiltration rate with respect to rainfall energy on three soils in Saskatchewan, Bisal (1967) concluded that the surface soil must be protected to prevent run-off and potential erosion.

The effectiveness of different crops at various growth stages in intercepting rainfall has been shown by Hayes (1938).

1:3 <u>The Effect of Tillage on Infiltration and Soil and Water Loss</u>

Many comparisons of different tillage systems on water infiltration have been reported in the literature,and in general minimal tillage has given significant improvements over conventional systems in the control of soil and water loss achieved. Free (1960 a) has explained these responses as being due to the layer aggregate or layer clod size resulting from minimal tillage and also the decreased compaction.

A direct comparison of plough, plant, two discings and harrowing, on first year land by Meyer and Mannering (1961) showed 63 per cent of run-off and 52 per cent of soil loss,after a simulated rainfall test two weeks after seeding, of that of conventional tillage. After cultivation on both treatments to prevent surface crusting, reduction in run-off and erosion on the minimum tilled plot was still apparent although the magnitude of the benefits decreased significantly with successive cultivation and increased vegetative growth. Run-off and erosion were greatly increased as a result of surface crusting when no cultivation of the minimum tillage plot was carried out. A one year study designed to compare the plough plant minimum tillage technique with conventional tillage, ploughing and four disc harrowings was carried out by Swamy Rao et al (1960). Their results showed that infiltration rates, clod size distribution, weed control and root development were significantly better with minimal tillage. There was an advantage in average plant heights of 16 inches but plant population was less than conventionally tilled maize, believed to be due to variable depth of planting on an extremely rough seed bed.

Allmaras et al (1967) showed that Total Porosity increase and random roughness due to ploughing were each significantly affected by the moisture content at tillage. In the three soil types studied the porosity decrease was more pronounced by subsequent discing. Burwell et al (1966) found that random roughness and total porosity account for at least 75 per cent of the variation in infiltration due to tillage induced soil structural conditions. They noted a large difference in porosity between minimum tillage and conventional tillage which they attributed to the differing amount of surface area packed by implement traffic. Infiltration measurements made on minimal tillage treatments following conventional cultivations in previous years showed striking improvements in the first year which were not maintained with continued minimum tillage. This inference that some cultivation is required was mainly derived from their findings that initial porosity increases after the first year and random roughness declines. No comparisons of surface mulching and roughness of the bare seed bed on infiltration were reported.

Soil loss and moisture infiltration from corn, for rotations ranging in intensity from corn after three year meadow to continuous corn, were measured under simulated rainstorms by Mannering et al (1968) to determine (a) the relations of various sequences of sod crops and row crops to infiltration and erosion and (b) the effects of crop sequence on soil physical properties that influence infiltration and soil loss. The beneficial effect of ploughed grassland on structure was no longer evident after the second corn crop. Soil losses from first, second, third and fourth year corn after meadow were 53, 83, 90 and 97 per cent of that from continuous corn. Two or three years of meadow were more effective than one year in maintaining high infiltration rates on first year corn. Water stable aggregation was generally the best indicator of soil erodibility.

Meyer and Mannering (1961) compared six cultivation methods including conventional and plough plant treatments in Indiana. Artificial rain was applied at a 2.6 inches per hour intensity in three runs: dry at existing soil moisture conditions, wet on the second day and very wet immediately following the second application. Of the total 5.2 inches of water applied 2.2 inches infiltrated the conventionally tilled treatment and 3.3 inches on average for all the minimum tilled plots. This was related to the rough more open and less compact conditions produced by the plough plant type of cultivation. The second phase comparisons included conventional and minimal with and without cultivation. Corresponding figures for run-off were recorded as 2.4, 1.8 and 2.9 inches.

Schaller and Evans (1954) concluded that tillage methods had no effect on total porosity and pores occupied by air at sampling time but did influence pores drained by 50 cm. of water tension.

1:4 Soil, Organic Matter and Nitrogen Loss from Protected and Unprotected Soil

The literature contains many catalogues of soil loss amount from unprotected cultivated soil on various slopes and under different rainfall and cropping patterns and the fact that "water has its most destructive action when the soil is bare" (Stallings 1953) has been more than adequately established.

Soil erosion, due to rainfall, is potentially more serious under East African conditions (Macartney 1961) than from other areas where most data is available, particularly the U.S.A.

McKay and Moss (1944) studied wheat production and soil loss in Idaho on land subtilled with a lister bottom which left 94 per cent of the 4,500 pounds of straw per acre on the surface. Soil loss was measured at two tons per acre and 8.7 tons per acre on the ploughed treatment. A similar trial was carried out by Nutt and Peele (1947) who recorded soil losses of 17 per cent of that of ploughed land.

Hendrickson (1947) estimated a soil loss of over 28 tons per acre in South Carolina on a soil planted to continuous cotton. Browning (1948) reported a change from rotation to continuous corn where the crop residues were maintained resulted in a soil loss of 14 tons per acre. Land planted to continuous corn in Iowa lost 15.6 per cent of organic matter in nine years and averaged over 38 tons of soil lost per annum (Pierre and Browning 1945).

In a study by Mannering and Meyer (1961) simulated rain was applied at two and a half inches per hour to various quantities of straw mulch spread evenly over freshly ploughed and disced wheat stubble. Soil loss of bare soil was 12 tons per acre, but with two tons per acre of mulch no run-off or erosion occurred.

Homer (1960) analysed fifteen years soil loss measurements and found that the kind and amount of cover provided during the winter season on a silt loam at Pullman, Washington, was the dominant factor affecting run-off and erosion. Unprotected summer fallowing caused the largest erosion losses and the most rapid depletion of organic matter.

A heavy mulch of chopped maize stover provided excellent erosion control on Fayette silt loam on a 16 per cent slope (Taylor and Hays 1960). Seed bed preparation by subtillage which left shredded cornstalks on or near the surface was advocated by Whitaker et al (1961) under high rainfall intensity conditions.

Shredded cornstalks proved a more efficient erosion control cover under artificial rainfall conditions than whole cornstalks in work by Meyer and Mannering (1961 b). In Wyoming, Barnes and Bohmont (1958) reported trashy fallow to be more efficient than grass after haying in absorbing moisture. When loose straw was raked off a stubble field the water intake was reduced by some 30 per cent.

Slater and Carleton (1938) noted that organic matter was among the first constituents to be removed through erosion and was also the hardest to replace. They estimated organic matter depletion through erosion as being eighteen times faster than through normal oxidation. The amount of organic matter lost per acre per year on an unprotected soil has been recorded by Knoblauch et al (1942) 1149 lbs.; Hays et al (1948) 951 lbs.; Bedell et al (1946) 555 lbs. These workers reported good control of losses by soil mulching and stated that the loss of organic matter was a function of soil loss although the relationship was non-linear. Both Martin (1941) and Massey et al (1953) reported that the percentage of humus in eroded material decreased as the erosion losses increased, presumably because of the higher organic matter content of the top soil.

Control of erosion on a silt loam with a nine per cent slope was effected by Neal (1939) by the addition of organic matter although four annual applications of 16 tons/acre of farmyard manure did not give any significant build up in the soil organic matter content.

Cultivation of much of the land in the Great Plains area of the U.S.A. over the last sixty years has resulted in appreciable soil nitrogen losses particularly under certain management practices. Losses from surface soils of 9 - 62 per cent of that present in the virgin soils have been reported for periods of cultivation ranging from 25 - 41 years by Harper (1946), Chang (1950) and Hobbs and Brown (1957).

Tillage practices on these dryland soils had a marked influence on soil nitrogen losses (Hill, 1954; Rhoades, 1956). Excess tillage intensified the decomposition of soil organic matter with accompanying loss of nitrogen.

Of a total of 42 lbs. per acre of nitrogen lost, Hays et al (1948) recorded 90 per cent loss from two intense rains shortly after planting. Rogers (1941) found yearly losses of 32 lbs. per acre on Dunmore silt loam under wheat. Knoblauch et al (1942) measured 67 lbs. lost per acre per year which was reduced to 19 lbs. per acre under cover. A soil loss of 5195 lbs. per acre contained 99 lbs. nitrogen in early work by Duley and Miller (1923).

1:5 <u>The Control of Surface Run-off by Stubble Mulching</u>

Research workers are undivided in their opinions as to the efficiency of mulch covers in controlling run-off.

Hudson (1957) recorded run-off rates of 30 per cent of the total season's rainfall from a three per cent slope under sunhemp in Rhodesia. In Central Tanzania run-off rates of 40 per cent at moderate rainfall intensities and up to 80 per cent at intensities of 40 mm./hour were observed by Mantsur and Chambers (1965). Duley and Miller (1923) compared run-off losses from uncultivated and plots ploughed to four inches and eight inches depths in Missouri over a six year period. He recorded 49, 31 and 28 per cent loss in run-off respectively. Russell (1950) recorded the per cent run-off on a silt loam over a nine year period with an average rainfall of 38 inches. The effect of plant cover was quite marked, varying from loss under continuous maize of 40 per cent to permanent grass of four per cent of the total precipitation.

The comparison of water loss from conventionally and minimal tilled maize was recorded by Browning (1945) as being 38 and 18 per cent respectively. Duley and Russel (1943) have also demonstrated the effect of a mulch on run-off losses. Their subtilled treatment under mulch lost 1.27 inches of a 7.12 (8) inches monthly recorded rainfall compared to 2.83 inches lost when the mulch had been disced in, and 3.06 inches where discing had been carried out in the absence of a mulch cover. With controlled artificial rainfall, infiltration rates under various treatments were measured by Kidder et al (1943). After an application of 1.75 inches per hour for thirty minutes the run-off from unmulched plots was 66 per cent, while on the straw mulched plots 20 per cent loss in total rainfall after a four hour period was recorded.

Bnlow and Musgrave (1938) in Iowa showed that the addition of organic matter to the surface reduced run-off from 17½ inches to 13 inches in a fallow. A mulch cover was reported by Doren and Stauffer (1943) to increase water absorption of 1.75 inches of applied rainfall per hour to 1.67 inches, whereas bare plots absorbed only 0.47 inches.

In Australia, Black (1963) calculated run-off from a compacted bare soil, a compacted soil with a mulch cover, a cover crop and a perennial pasture. His averages from replicated plots were 1100, 730, 490 and 30 gallons per acre respectively.

The importance of a straw mulch cover in controlling intake of water and the formation of an impervious crust was demonstrated by

Duley (1939). The total water intake of his straw mulch treatment was 66 per cent and on cultivated bare soil 38 per cent of the total precipitation. Run-off losses from mulched and ploughed surfaces at three locations under differing crop sequences were recorded by Zingg and Whitfield (1957). Ploughing led to greater run-off consistancy.

Rain falling at the rate of three inches per hour caused little loss of soil on grassland, soil protected by a straw mulch or on wheat stubble where the crop had been combine harvested (Duley and Domingo, 1949).

Borst and Russell (1942) observed little effect on run-off by incorporation of the mulch. A mulch cover over an already compacted soil contributed little in the prevention of run-off, in fact run-off increased. They further stressed the necessity for sub-tillage under mulch to obtain the full benefit from this system of farming.

1:6 Burning of Crop Residue

The common practice of burning wheat stover after combining in East Africa meets with little support from results recorded in the literature.

Siddoway (1963) found that there was a greater structural stability and a higher proportion of non-erodible aggregates when straw was returned to the field, than when it was burnt or partially removed. Straw was best left on the surface rather than ploughed in.

Copley et al (1944 a) measured the rate of run-off on burnt and unburnt land on a ten per cent slope with an average rainfall of 46 inches. The average annual loss from the unburnt land was

0.02 inches and from the burnt land 5.38 inches. In Kansas (Chepil, 1955) comparisons were made between burning stubble and pre-seeding tillage operations that allowed residues to remain on the surface. The increase in rainfall acceptance during a storm was 0.71 inches on the burnt treatment and 1.16 inches where straw protection was maintained. Burning the stubble residue reduced water absorption by nearly 50 per cent in Wyoming (Barnes and Bohmont, 1958).

1:7 Organic Matter and Soil Structure

The literature on the relationship between soil tilth and levels of soil organic matter is voluminous and in most cases the close relationship between these factors and soil management factors is stressed.

It has been shown by Baver (1935) that a significant correlation exists between the size of aggregates and the carbon content of a wide variety of soils. His indications were that organic matter favours the formation of larger aggregates. The highest correlations resulted from soils containing less than 25 per cent of clay.

The theory that aggregation and structural stability in cultivated soils require regular additions of organic matter has much support. McCalla (1945) noted that structural stability is temporary, lasting only as long as the stabilising decomposition products continue to exist in the soil.

The effect of cultivated crops on soil structure has been studied by Lutz et al (1946). Although it seems reasonable to expect improvements in structure as a result of root growth, this improvement was nullified by the cultivation operations accompanying the growth of the crop.

The loss of tilth with excessive cultivation and the suggestion that reduced tillage may be an effective resterative measure is described by Klingebiel and O'Neal (1952). They recorded greatest structural change with cropping in the upper nine inches, or cultivated layer.

Several short term trials have shown that continuous corn on relatively flat land did not cause a measurable decrease in soil organic matter when adequate nitrogen had been supplied. Breland (1952) in a five year study at Illinois found slight increases in soil organic matter when continuous corn was provided with adequate nitrogen and extra residues were returned to the soil. Unpublished work from the same University also indicated that soil organic matter can be increased faster when minimum tillage techniques are imposed upon the continuous corn rotation. Adequate nitrogen alone was unable to maintain the levels of organic matter under clean-cultivation management.

A study also at Illinois by Lee and Bray (1949) showed that rotations with one legume break in four years were depleting the organic matter reserves, soil nitrogen was being used at the expense of decomposing soil humus. Their data support the concept that the average yearly losses of soil nitrogen and hence soil organic matter decreases as higher yields are obtained with increasing nitrogen use. High yields and adequate nitrogen use seem to be compatible with the maintenance of good soil physical conditions and organic matter. The work of Miller (1951) tends to support the conclusion that the beneficial action of a legume in the rotation is largely due to its nitrogen contribution.

Applied nutrients are generally less effective on an eroded soil than on a non-eroded, friable soil containing adequate organic matter (Lamb et al, 1950). Yet experiments by Smith (1952) using nitrogen fertiliser on an infertile soil with poor physical characteristics, succeeded in doubling the yield of maize but generally with this type of trial no measurement of the physical changes, if any, are reported. Nevertheless, the poor structure did not appear to be reflected in yields obtained under high fertility levels. Whether the added fertiliser promoted increased microbial activity causing improvement in the physical conditions of the soil or possibly the increased protection afforded by the greater amounts of residue left on the soil had a significant effect is open to discussion.

Martin (1942) compared various sources of organic matter and their effect on structure. He reported that corn stover was a particularly favourable type of organic material for improvement of soil structural conditions. The work of Metzger and Hide (1938) and Waksman and Martin (1939) provided data in agreement.

The general effect of stubble mulch tillage would seem to suggest an improvement in the soil organic matter content. Soil samples analysed for readily oxidisable organic matter, per cent carbon and nitrogen by Norstadt and McCalla (1960) showed that all constituents were slightly higher in the surface inch of sub-tilled plots than on the ploughed plots. The same trends were evident at lower depths but differences were less. Similar improvements in organic matter content with stubble mulching have been reported by Stevenson and Schuster (1945), Beale et al (1955) and Zingg and Whitfield (1957). Beale et al (1955) have suggested that this higher organic matter content of stubble mulch treatments may be due to a less rapid decline in organic matter rather than a build up.

Many short term experiments indicate that straws and stovers supplemented with mineral fertilisers will produce large quantities of soil organic matter. Ireland (1952) presented graphic data to show the relationship between quantities of straw and fertiliser added and the amount of organic matter formed. The work of Pinck et al (1948) also demonstrated that considerable gain in both carbon and nitrogen resulted from the addition of urea to millet residues. Miller and Turk (1951) have summarised the relation between the nitrogen content of plant residues and added nitrogen in the form of fertiliser.

1:8 <u>The Development of Modern Ideas for Wheat Cultivation</u>

It was not until the beginning of the 20th century that agricultural research had much effect on the farming systems of the more arid wheat lands. It is interesting and comparative to follow the development of wheat tillage during this period in the Great Plains and the Far West of the U.S.A., an area in which the problems of marginal rainfall and soil erosion are very much akin to those experienced under East African conditions. During the first ten to fifteen years of this period the necessity for deep ploughing and frequent harrowings was much publicised. It was considered necessary to loosen the soil to a considerable depth. Cultivation after every rain was recommended to prevent capillary movement of moisture to the soil surface where it would be lost by evaporation.

The then recently established agricultural research stations reported their preliminary results based on three to four years work showing that both roots and moisture penetrate unstirred sub-soil, (Stephens et al, 1923), that water sometimes enters unploughed land faster than it does ploughed land, (Grace,1915), that capillarity pulls water downwards with as much force as it does upwards, (Burr, 1914) and that ploughing 8 - 12 inches deep may be expected to cost four and nine times as much respectively as ploughing four inches deep, and that deep ploughing failed to produce any material increases in yield.

The tillage practices used at this time were chiefly those borrowed from the more humid regions, the mouldboard plough and the disc harrow being used almost exclusively. It was not until many years later that prominence was given to the spring time harrows, chisel ploughs and cultivators.

The danger of wind and water erosion by leaving the surface soil too fine was soon recognised (Severance, 1909). Later results from the dry land research stations were remarkably uniform in indicating no benefit from any tillage beginning the year that the crop was harvested. Both Stephens et al (1923) and Hunter (1927) emphasised the importance of cultivating only to control weed. During these early days the handling of the wheat stubble created a serious problem and most was burnt. Later, increasing recognition of the value of the stubble for erosion control and soil maintenance, coupled with fertility practices that improve yields on straw mulched land, greatly reduced stubble burning but the details of how best to handle a mulch cover within the cultivation system had yet to be worked out.

The first real contribution of practical importance was made by Campbell (1930), widely known as the originator of the dry farming system. He recommended the alternate wheat/fallow system and stressed the importance of a rough seed bed as opposed to the 'dust mulch' for moisture infiltration. There was at this time no concept of the actual quantities of water required by the wheat crop or that could be absorbed by, and held in, the soil. The practice of fallowing was slow to become established and it was not until the drought of the mid thirties that it became accepted. It was during this erosion conscious era that the efficiency of anchored crop residues in keeping the soil in place was first demonstrated. Referred to as stubble mulch farming, the system involved the managing of plant residues on a year round basis in which harvesting, cultivation and planting operations were performed in such a way as to keep protective amounts of vegetative material on the surface of the soil until the time of seeding the next crop.

The Duley and Russel team working at the Nebraska Agricultural Research Station were responsible for the initiation of the first research work on stubble mulch farming in 1937 (Duley, 1959). Their continuously subtilled plots are still in existence and the results present some of the most valuable data on the long term effects of the system on the chemical, biological and physical properties of the soil. A similar and complementary programme in Canada was carried out by Noble (1948) which resulted in the first implements designed specifically for this type of farming, the Noble Blade. It was not until 1941 however that serious investigations were commenced on the effects of stubble mulching on crop yields (Peele et al 1946, Browning et al 1943, and Englehorn 1946).

2. STUBBLE MULCHING AND WATER STORAGE

Although the results obtained by stubble mulch farming show a decided improvement in erosion control, it is surprising to find contradictory evidence regarding improved infiltration and storage of water. Comparisons between conventional tillage and stubble mulch farming showed no increases in moisture storage in work reported from Oklahoma (Daniel et al, 1956), North Dakota (Englehorn, 1946), Southern Idaho (McKay and Moss, 1944), Montana (Krall et al, 1958) or Texas (Lemon, 1956 and Wiese and Army, 1958).

The beneficial effects of mulch cover on water storage has equally numerous supporters. A survey over a twenty year period in Saskatchewan by Staple et al (1960) showed that while 37 per cent of the winter rainfall was conserved on stubble mulch plots, only nine per cent was retained by a bare fallow. The results of another similar survey by Thysell (1938) gave similar figures of 34 per cent conservation with stubble and 11 per cent with bare soil. Average moisture contents of the soil profiles under various tillage systems and at different sites presented by Zingg and Whitfield (1957) also showed increases in storage in favour of stubble mulching. The early work that was carried out in Kansas over a thirty six year period has been reviewed and summarised by Kuska and Matthews (1956). Their results, presented in table I, add further weight of evidence to the improvement in water storage possible by using undisturbed wheat stubble.

TABLE I **Water Storage Within the Profile Under Different Cultivation and Mulch Treatments.**

From Kuska and Matthews (1956)

Treatment Winter Wheat	1914-1915 Water stored from 6.65"	1915-1916 Water stored from 3.24"
Stubble undisturbed	5.52	1.44
Fall listed	4.65	-
Fall ploughed	3.06	0.76
Milo stubble	3.87	0.62
Maize stubble	3.47	0.82
Green manured land	2.08	-
Bare fallow	1.66	0.29

Brown (1956) found that stubble mulch fallow land stored considerably more water than ploughed or one-way disced fallowed land during a period when rainfall was unusually heavy (7.5 inches in September). The additional 1.1 inch of water stored within the six foot profile more than doubled the wheat yield. Research from the corn belt states and other areas of similar rainfall, generally show that stubble mulching improves moisture storage. Verma and Kohnke (1951) indicated that wheat or corn stover placed between soya bean rows after the first cultivation increased the available moisture content by an average of 30 per cent over that of the unmulched soil. Aldefer and Merkle (1943) using various mulches on uncropped plots showed that at no time during the three year period of the trial did the moisture content drop below 20 per cent. The mulched plots contained significantly more total moisture than did the plots with incorporated residues.

Duley and Russel (1939) measured the total accumulation of water on a heavy silt loam in plots to which different treatments had been applied to the surface. The presence of a surface cover had the most beneficial effect on the percentage of moisture conserved and also on the depth of penetration of water. Ploughing and discing showed little differences in their influence on storage either with or without straw. (Table 2)

TABLE 2 The Influence of Surface Cover and Tillage on Water Storage and Depth of Penetration.

From Duley and Russel (1939)

Surface Treatment	Rainfall Conserved in inches	Depth of Penetration	Conservation as % of Total Rainfall
Straw, 2 tons on surface	9.72	6 ft	54.3
Straw, 2 tons disced in	6.92	5 ft	38.7
Straw, 2 tons ploughed in	6.12	5 ft	34.2
Basin listed	4.95	5 ft	27.7
Land ploughed, no straw	3.71	4 ft	20.7
Land disced, no straw	3.49	4 ft	19.5
Decayed straw, 2 tons ploughed in	3.12	4 ft	17.4

The same workers (1939) concluded that a straw mulch prevented the formation of a soil crust and showed increases in absorption of water from 0.24 inches to 0.74 inches per hour, and in later experiments (1942 b) found that moisture storage in the soil to a depth of six feet under ploughed land was increased from 3.71 to 9.72 inches of water during a season of abundant rain where two tons of straw was placed on the surface after ploughing. During two dry seasons 1.96 inches more water was stored in soil under a straw mulch cover as compared with a ploughed unmulched area.

Musgrave (1955) obtained an infiltration rate of 2.10 inches/hour for the first hour after cultivation of the top surface inch of soil and a cover of two tons of straw per acre. Without mulch, but with surface cultivation, the infiltration rate dropped to 0.28 inches/hour.

Results of trials carried out by Larson et al (1960) in Iowa adds further evidence to the conclusion that straw on the surface acts more efficiently than when it is ploughed in. His results show that there was little difference in soil moisture in the top six inches but wide differences were apparent between treatments in the soil moistures immediately below the surface.

Borst and Woodburn (1942) covered a five per cent slope with two tons of straw per acre nine weeks before applying artificial rainfall and found that 97.5 per cent was absorbed compared with unmulched plots which absorbed 92 per cent. Although the difference in water absorption was not great the soil loss from the mulched plot was negligible whereas the bare plot lost soil at the rate of ten tons per acre. Barnes and Bohmont (1958) found that comparative water intake at the end of one hour for bare fallow, grassland and stubble mulch was 0.3, 1.20 and 2.26 inches/hour. McCalla (1943) in emphasising the importance of mulches on soil structure claimed that a surface mulch was more important than soil organic matter in increasing water infiltration and storage.

Beale et al (1955) reported a gradual improvement in the amount of water stable aggregates over 0.2 mm. with mulch tillage after the first year. This increase in water stable aggregates has also been evident in work by Stauffer (1946), Dawson (1945) and Stephenson and Schuster (1945). Decomposing mulches have also increased water stability aggregate at the surface (McCall 1959) but Chepil (1955) concluded that although mixing the decomposing vegetative material with the soil decreased erodibility,far greater protection was afforded by keeping residues on the surface. Lane (1961) reported double the amount of water infiltration under the till - plant system as compared to conventional tillage under irrigation. Plant emergence was also better, an advantage which was maintained until harvest.

From the results of their experiments Army et al (1961) concluded that the effect of surface mulches only affects the immediate two inches of underlying soil. Only if rains are frequent do the residues have any material effect in increasing the depth of penetration and storage. Early evidence to support this concept was produced by Burr (1914), again working under very marginal rainfall conditions. His treatments included ploughing, discing and undisturbed soil where the weeds had been cut by hand. He concluded that over a number of years the advantage of ploughing over discing would be small provided the weeds were thoroughly killed. Data are available on the efficiency of water storage under summer fallow from 23 dryland stations over the Great Plains, and were summarised by Mathews and Cole (1938) who found an average storage at the end of the fallow period of only 20 to 25 per cent of the precipitation that fell. An average over sixteen years fallowing in North Dakota showed that water storage in the fallow varied from 1.01 inches to 9.07 inches under rainfall varying from 16 to 32 inches. In a comprehensive study of water intake under different summer fallow treatments by Barnes et al (1955) a chemically controlled stubble mulch gave best results. The ploughed treatment absorbed water rapidly at first but on the breakdown of the cloddy structure infiltration rate slowed due to surface sealing. Thysell (1938) records the driest years as having above average storage and concluded that there was no close relationship between total precipitation and moisture storage. Low storage was due to the high proportion of the total precipitation falling as small rains with a high water loss by evaporation. A summary of rainfall intensities for Kansas in that year by Robb (1938) showed that 60 per cent of the total rain fell in amounts of 0.25 inches or less. They concluded that the solution to moisture conservation in the fallow must be found in increasing the effectiveness of precipitation that falls in amounts less than half an inch.

The curves presented by Duley and Kelly (1941) representing the rate of intake of water when the land was bare showed a rapid drop after run-off began. The second application of water coming soon after the first gave a further reduction in the rate of intake and the rate became nearly constant within a short time. The curve of intake rate when the soil was protected by a straw mulch showed a much more gradual drop and was maintained at a high level for a considerable period, and even then did not drop as low as that for the bare soil. In these studies the moisture content of the soil was of very much less importance than the condition of the surface.

The emerging fact that shallow sub-tilling, provided a mulch cover is retained, is more efficient than any form of bare cultivation was further advanced by Whitfield et al (1949). A sub-tilled fallow with cover contained consistently more moisture than a one-way ploughed (mulch partially incorporated) fallow, but with continuous wheat sub-tilling did not give any significant improvement in moisture storage. In a study of the relation of plant cover to infiltration and erosion, Dortignac and Love (1960) concluded that under mulch the large pore space of the upper two inches of soil and the quantity of dead organic materials were the two properties that accounted for most of the variation in infiltration rates.

Triplett et al (1968) have recently reported the results of work designed to assess the effects of three application rates of cornstalk mulch on yields of corn grown without tillage. With five per cent cover (stover removed), 45 per cent cover (stover left in place) and 80 per cent cover (double level of stover) yields were directly correlated with the amount of cover, the 45 per cent level being equal to conventional tillage. In an attempt to relate yield and some of the measurements made on the crop and soil, they were successful in showing correlation between plant cover, plant height and soil moisture content. These values, used in a multiple regression programme, showed that per cent cover only was significant. Its influence on soil moisture regime was probably the causative factor affecting yield. At the end of the third year water infiltration (determined with a sprinkling infiltrometer) was significantly greater with an 80 per cent stover cover than for the other treatments.

The effect of mulching coffee at Moshi, Tanzania, was large enough for the trees to be wilting on the clean weeded plots, but growing well on the mulched plots at the time the first samples were taken by Gilbert (1945).

Citing work on infiltration in a number of locations in the world, Jacks et al (1955) concluded that there seemed to be little doubt that mulching with plant residues increased water infiltration.

The bulk of the literature studied points out very clearly that a mulch cover applied to an already crusted surface will not improve infiltration rates. Responses obtained from stubble mulch tillage have invariably included sub-tillage to break up the surface crust.

2:1 Evaporation and Moisture Loss from the Soil Surface

Penman (1948) has estimated evaporation from a continuously wet soil as 0.9 times that of an open water surface, and the evaporation from turf, varying with season, from 0.6 to 0.8 times. It might be expected that mulch cover would reduce the amount of evaporation from the soil surface.

Different cultivation treatments of fallow land appeared to have little effect on loss of moisture by evaporation from work by Wiese and Army (1958). Russell (1939) observed that the major effect of a mulch on evaporation rate persists for about two days and makes an effective reduction in the evaporation rate of 0.1 inches during the first twenty four hours after wetting. If, however, the period between rains is such that evaporation proceeds until the surfaces of both mulched and bare plots are dry, then there may be a slightly higher total evaporation from the mulched surface.

Jacks et al (1955) proposed that evaporation was reduced where the soil surface was maintained at high moisture content by frequent rains. Gardner (1959) admitted a lower initial evaporation rate with a surface mulch, but thought that there may be little long term benefit unless this lower evaporation rate permitted greater downward percolation of water.

In both Australia (Holmes et al, 1960) and the U.S.S.R.(Burov,1952) recorded greater water loss with a coarse clod surface or with no tillage. A fine crumb structure was most effective in slowing down evaporation losses.

Mathews and Army (1960) attributed low moisture storage efficiency in the fallow to evaporation which was influenced by the amount of energy available to convert water to vapour, and also to the soil moisture properties. They postulated that, when the soil was wet and advective energy was insignificant, evaporation was almost proportional to nett radiation. As the soil dried out evaporation was increasingly dependent on the factors governing the upward flow of water to the surface. Tillage or chemical control methods that leave residues on the surface decrease the energy reaching the soil as was evidenced by lower and lagging soil temperatures. Residues were also effective in decreasing air movement immediately above the soil. It is logical to assume that mulch cover could be a pertiment factor in minimising moisture losses and thereby increasing moisture storage at least until soil factors limit the evaporation rate.

2:2 Soil Temperature under a Mulch Cover

During spring and summer the temperature under a mulch cover was cooler than in a ploughed soil (McCalla,1959). During the latter part of the summer a reversal in temperature became evident.

The amount and kind of mulch were found to have the main influence on soil temperature. McCalla and Duley (1946) found the temperature under an eight ton straw mulch to be as much as 17 degrees centigrade lower at the one inch depth than in ploughed soil.

With continuous temperature records from July - October comparing mulched and bare plots, Lemon (1956) showed that temperatures were lower at the three inches level and higher at the six to twelve inches level with a mulch cover. He concluded that mulched plots conserved more heat than ploughed plots. Lower temperatures in the surface layers were also reported by Borst and Mederski (1957) and Verma and Kohnke (1951). Soil temperature was inversely related to the amount of mulch present in work at North Dakota by Englehorn (1946).

Light reflection appeared to be an important factor influencing the temperature of the soil under a mulch. McCalla (1947) found that up to 80 per cent more light was reflected from a mulch cover than from a bare soil.

3. THE EFFECT OF STUBBLE MULCHING ON YIELD

3:1 Nitrogen and Yield

One of the main criticisms levelled at the mulch farming system is that incorporation of the straw into the soil will decrease the yield of the subsequent crop. Anderson and Russell (1964) and McCalla and Army (1960) both report depressions on yield and attribute this factor to the competition for available nitrogen by organisms decomposing the straw. Other short term experiments indicate little effect on yield in Manitoba (Ferguson, 1957, and Ferguson and Gorgly, 1964).

There is quite a lot of support for the theory that crop residues on the soil surface generally depress nitrate formation (Scott 1921; Gamble et al 1943; McKay and Moss 1944; McCalla and Russell 1948; Jacks et al 1955). The immediate depression of nitrate when residues were ploughed in was not evident when mulches were left on the surface. During spring and summer nitrate content was about 5 - 7 per cent less on stubble mulching than on ploughing, and in the winter months nitrate content may be higher under mulch. Soil temperature and decomposition stage of the mulch would appear to be the controlling factors.

The causes of nitrate depression under a mulch cover have been expressed as lack of aeration by Albrecht and Uhland (1925) and due to the soluble organic compounds in the mulch by Moore et al (1948 a,b).

Studies on the time of cultivation and its effect on yield has been reported by Moorhouse (1905), Call (1913) and Salmon and Throckmorton (1929), who claimed yield responses with early ploughing. Later work indicated that these increases in yield were related to precipitation falling between harvest and planting. Early cultivation encouraged the storage of rainfall after harvest and provided conditions favourable to nitrate formation. In areas where more moisture was stored by early as opposed to late tillage, this moisture was sufficient to utilise the nitrate formed. Where less rainfall and consequently less stored moisture could be expected, the excess nitrate produced by early tillage was as likely to be injurious resulting in more serious drought injury and lower yields. Hallsted and Matthews (1936) found that it required a season of fallowing to provide sufficient moisture to ensure crop prospects comparable with those under early tillage in the higher rainfall areas. Salmon et al (1953) also recognised the advisability of early tillage if rain falls after harvest to control weed growth which if left unchecked will dissipate stored moisture.

The use of nitrogen fertiliser under stubble mulching has been responsible for material improvement in wheat yields in certain areas particularly those with a relatively high rainfall. Salmon et al (1953) sum up the results obtained within the wheat belt and conclude that nitrogen is beneficial on most soils unless moisture is the limiting factor. These areas they define as having less than 12 - 14 inches of precipitation. Below this level responses are variable and usually unprofitable. Where the average rainfall is 14 - 18 inches and where fallowing is practiced the use of nitrogen permits retaining the straw on the surface for erosion control without depressing the yields. Applications of nitrogen have generally been unprofitable on fallow land with more than 18 inches of rain. With continuous wheat in the higher rainfall belt nitrogen responses have raised yields to the level which make fallowing unnecessary.

A comprehensive study of the long term effects of straw application on yield was undertaken by Ferguson (1966). Nine combinations of straw and nitrogen fertiliser were applied annually to a Manitoba sandy loam. The addition of nitrogen fertiliser was found to increase yields ($P<.05$) whereas the straw applications tended to decrease yields although not significantly. The amount of nitrogen mineralised during incubation was increased by repeated straw application, an effect which declined rapidly when the treatments were discontinued. These results confirmed his previous reports that rather than depress yields, straw application had a residual effect which resulted in increased yields of cereals.

Two tons straw per acre applied to corn after planting in Illinois decreased corn yields over a three year period from 92.7 to 76.5 bushels. The same treatment resulted in increased yields of soya bean (Van Doren and Stauffer, 1944). Free et al (1946) obtained corn yields in New York State of 54.9 bushels on ploughed land, 40.8 bushels on sub-surface tilled plots, and 28.8 bushels on disced plots. The application of trash resulted in poorer populations and difficulty of weed control.

Duley and Russel (1941) reported no yield differences when corn residues were left on the surface or ploughed in. An increase of about three bushels per acre of wheat was obtained when wheat straw was left on the surface. In 1949 Duley and Russel summarised some averages of yields of corn, wheat and oats under Nebraska conditions but no fixed pattern of yield increases or decreases was evident. Browning and Norton (1947) accumulated evidence over 52 trials on eleven soil types in Iowa and average figures for corn production with ploughing were 70.8 bushels while sub-tilled land produced 63.6 bushels.

Unpublished data by Cox and Tucker (1958-1959) recorded comparison of yields of wheat with no nitrogen application on clean tillage as 10.3 bushels/acre higher than stubble mulching. With 40 lbs. of nitrogen application to continuous stubble mulch tillage wheat yields were improved by 15 bushels/acre compared to an increase of 6.4 bushels/acre with nitrogen on clean tillage. The same workers applied 0, 20, 40 and 80 lbs. of nitrogen to stubble mulch and clean tillage and obtained yields of 10.2, 14.9, 16.7 and 23.1 bushels/acre compared with 17.5, 21.2, 21.6 and 22.7 bushels/acre for clean tillage. These results are in agreement with those of Winterlin et al (1958) and Parker et al (1957) who both reported yield increases over unmulched plots with nitrogen application.

The reduction in nitrate content with stubble mulching, regardless of the causative factors, undoubtedly accounts for some of the adverse effects of stubble mulching on crop yields, particularly under higher rainfall conditions.

3:2 Stored Moisture and Yields

In the American dryland work, there is a good overall relationship between the amount of water stored in the soil at planting and the ultimate crop yield. This relationship is better on fallowed land than on continuously cropped land, as stored water makes up a larger proportion of the available moisture on the former.

Hallsted and Matthews (1936) related yields to moisture storage and found that when winter wheat was seeded in soil without available moisture in the profile, it yielded four bushels per acre and less, 71 per cent of the time. Soil at field capacity to three feet or more at planting yielded in excess of 20 bushels per acre, 70 per cent of the time.

A comparison of yields obtained in the Northern Plains, over 275 station/years between fallowing and continuous cropping was summarized by Cole (1938). The average yield of fallow was quoted as 18.54 bushels and from continuous cropping 11.16 bushels per acre respectively. Cole and Mathews (1923), by grouping total biological yield into 1,000 lb. increments, produced results to show that the water required to produce one pound of dry matter progressively decreased as the yield increased. With yields less than 1,000 lbs. per acre, 2,165 lbs. of water were required to provide each pound of dry matter, in comparison with 754 lbs. of water for each pound of dry matter for total crop weights within the 4,000-5,000 lbs. increment. In south Saskatchewan, Barnes (1935) found that 2,000 lbs. of water was required for each pound of grain produced under continuous cropping, but only 1,350 lbs. for wheat grown on fallowed land.

Smika and Whitfield (1966) have stressed the importance of water storage in the profile on yields of wheat and grain sorghum. Their treatments included an average of 6,000 lbs. wheat residue both on the surface and incorporated by a 24 inch one-way disc. The residue was approximately 50 per cent lying on the soil surface and the remainder standing stubble 18 inches high. Soil moistures were determined using a neutron probe at 12 inch intervals to six feet in depth and crop yield/soil moisture relationships were based on available soil moisture at seeding. The results showed an increase of two to six bushels per acre per one inch of moisture stored. This yield increase, per inch of stored water, increased rapidly with decreasing total precipitation between seeding and harvest. When available soil moisture at seeding was increased from nine to ten inches with a rainfall of 17 inches, a two bushel yield increase was to be expected. If, however, available moisture was increased from four to five inches and growing season precipitation was less than seven inches, grain yields may be expected to increase by six bushels per acre for each additional inch of stored moisture.

In Texas, Mathews and Barnes (1940) obtained a correlation coefficient of 0.75 between grain sorghum yields and available soil moisture at planting.

Further evidence on the importance of stored soil moisture and its effect on yield has been presented by Call and Hallsted (1915), Hallsted and Cole (1930) and Hallsted and Mathews (1936). However, moisture differentials compared in these studies were between continuous cropping and fallow systems.

Differences in yield of wheat on stubble mulched land versus ploughed land have been related to climate by Zingg and Whitfield (1957). They reported that the ratio of yield from stubble mulching to that from ploughing was related to the Thornthwaites' P-E index (precipitation/evaporation). This ratio exceeded one, where the P-E index was less than 32, and was less than one where the P-E index exceeded 32.

4. IMPLEMENT DESIGN FOR STUBBLE MULCH AND MINIMAL TILLAGE

Since 1950 the study of alternative tillage techniques has received much attention. The comparison of various forms of mulch tillage, trash ploughing, minimal tillage, plough - plant techniques with conventional systems of seed bed preparation have been summarised by Cook and Peikert (1950), Baugh et al (1950), Moody et al (1952), Schaller and Evans (1954), Buchele et al (1955 a,b), Jacks et al (1955), Willard et al (1956), Aldrich (1956), McCalla (1958) and many others.

It was the erosion hazard of summer fallowing that first stimulated thought on alternate systems of tillage. Intensive cultivation with disc harrow and plough for weed control pulverised the soil to an ideal texture for wind erosion. It was in these areas that equipment designed to replace conventional tillage first originated. These implements were used to replace disc harrowings and to encourage the formation of surface mulches by sub-surface tillage for weed control. The duckfoot tine was first used for cultivations after ploughing but later it was found to be successful on stubble land to replace ploughing as the first operation.

Implements such as the one-way disc and chisel plough were developments of this principle of providing a cheaper method of initial and subsequent breaking. Over the last twenty years many suggested cultivation practices and a range of implements to carry them out have been introduced on an experimental basis. The general principles of these techniques has been to reduce the amount and intensity of tillage and to encourage the build up of a protective soil cover in the form of a living or trash mulch with the objectives of erosion control, organic matter build up, weed control and optimum soil tilth. These implements have one characteristic in common, that of leaving the soil surface rough, covered,and as undisturbed as possible.

The basic engineering problem of maintaining crop residues on the surface and providing a satisfactory seed bed has been discussed in detail by Woodruff and Chepil (1956), Chepil and Woodruff (1955), Krall et al (1958), Anaheim (1949) and Ryerson (1950).

A detailed description of the implements that may be used with stubble mulching and their effectiveness under different conditions has been described by Jacks et al (1955), Ryerson (1950), Duley (1954), Duley and Russel (1941, 1942 a), Hutt and Peele (1947), Ackerman and Ebersole (1945) and Fenster (1960 b).

The problems of coping with large amounts of straw under hard

y conditions have resulted in the production of undercutting
nes operating parallel with the surface so as to provide for
nimum mixing of the soil and mulch and minimum pulverisation
the soil. It was soon evident that breaking of the straw
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The depth of working for the first operation depended on the
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Draught and horsepower requirements were recorded as being
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956) reported that the draught for a plough and a blade tiller
s 7.20 and 5.67 pounds per square inch respectively.

An extensive study on power requirements of various machines
Promersberger and Pratt (1958) indicated that a mouldboard plough
erating to five to seven inches in clay soils required 11.6 to 12.6

dry conditions have resulted in the production of undercutting tines operating parallel with the surface so as to provide for minimum mixing of the soil and mulch and minimum pulverisation of the soil. It was soon evident that breaking of the straw residue into workable lengths was necessary, and various beaters of heavy design and high clearance soon made their appearance. Sweep ploughs, rod weeders and various types of field cultivators equipped with coil shanks rapidly found adaptation. Most of the sweeps were detachable and could be replaced with units of different shapes and sizes depending on the results required. Any modification through interchange with other implements was permissible as long as it did not conflict with the general principles.

The depth of working for the first operation depended on the moisture content of the soil and the intensity of the mulch cover. Generally, the drier the soil and the heavier the mulch, the greater the depth of cultivation. A five to six inch first tillage operation was usual. If unusually heavy mulches were present the one-way disc plough was often used to cover part of the residue and hasten decomposition. Stubble pulverisers or busters were also used with heavy residues (Fenster et al, 1958).

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An extensive study on power requirements of various machines by Promersbeyer and Pratt (1958) indicated that a mouldboard plough operating to five to seven inches in clay soils required 11.6 to 12.6

horsepower hours per acre. The comparative figure for the Noble blade operating at six to ten and a half inches deep required 5.8 to 7.2 horsepower hours per acre.

4:1 Cereal Row Crops

The interpretation of minimal tillage in the early days was to limit seed bed preparation for row crops to ploughing and light harrowing. The plough plant system, (Peterson et al, 1958) was developed as a variation of this and consisted of planting directly after ploughing, using the tractor wheel to compact and smooth the immediate seed bed. Trailer type planters and planting units mounted on the plough frames were developed and described by Musgrave et al (1955) and Aldrich and Musgrave (1955). The importance of accurate planting and depth of seed cover was stressed. These studies were again based on the use of the commercially available conventional tillage equipment which often limited the application of the system under practical farming conditions. Fenster (1960 b) planted successfully with a planter equipped with furrow openers or with listers at shallow depth. The furrows were deep enough for a clean seed bed and the residue between rows was left uncovered. Poynor (1950) has described efficient weed control with rotary hoes and sweeps to keep the residue on the surface.

Early mulch tillage work with row crops reported by Nutt (1950 a) had to make do with modified conventional type implements. Most studies involved the use of standard ploughs, discs and cultivators, often in new patterns or sequence or timing. Although agronomic comparisons of the different treatments were possible, the practical application of the system on a field scale was often difficult. The general principles were later incorporated into a commercially available mulch planter described by Poynor (1950). This heavily constructed machine utilised a series of sweeps and rotary hoe sections to replace planting furrows. High power requirements and problems of maintaining adjustment were encountered.

When the preceeding crop supplying the mulch was perennial, the conventional undercutting by sweeps as used by Duley (1948,1954) on annual grain stubbles was not effective. The regrowth of the sods and weed problems caused in many cases a sharp decline in crop yield when herbicides were not used.

To overcome this regrowth problem Tillard et al (1950) used the double cut plough principle. The plough was adjusted to slice free and invert the top sod and at the same time tilling the four inches below the plough base. After drying, the inverted sod was broken up with a field cultivator without incorporation of the humic matter. This principle was further developed by Free (1953) using modified standard ploughs.

Standard implements used in a modified form prompted many important studies on the effects of mulches on soil physical relationships, but contributed little on the machinery development side.

4:2 Seeding

With the advent of stubble mulch farming the methods of planting cereal grains changed from broadcasting and harrowing into direct seed placement; surface moisture was usually lacking and the seed had to be placed at a controlled depth under the mulch. The furrow drill, and the increases in yields obtained by using this implement, have been demonstrated by Brandon and Mathews (1944). These drills which incorporate heavy disc openers effectively planted the seed in a clean furrow through a heavy trash cover.

A development of this principle resulted in the production by Plant Protection* of a triple disc planting unit with a forward single disc for opening and two following offset discs for placement and covering. Many of these planters are essentially standard drills that have been made heavier and equipped with larger disc openers and a higher clearance.

Of recent years hoe drills have become popular and as described by Robins and Blakely (1960) their wider spacings and staggering of spouts has considerably reduced the possibility of clogging.

Favourable comments on the use of rotary planters have been recorded by Cleeson (1964) and Douglas (1965) under United Kingdom conditions for direct drilling into previously uncultivated land. It was felt that litter incorporation by the rotor action acted as a moisture retaining layer. Other advantages claimed were:

(a) good seed soil contact
(b) obtaining a good tilth under difficult conditions
(c) the remaining weed growth or dead weed (after spraying) were incorporated
(d) spraying and planting in one operation was advantageous to overcome quick recovery and competition.

It should be pointed out that under temperate conditions the moisture retention and mulch coverage aspects are of less importance.

4:3 Weed Control

In summer fallowing, to obtain most favourable moisture storage, it is absolutely necessary to control weed growth efficiently.

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* Plant Protection, Fernhurst, Haslemere, Surrey, U.K.

Poyner (1950) reported shallow tillage with A blade tines as giving good control of annual weed growth during dry weather. In wet conditions the undercutting action was not successful as without inversion the soil remained in contact with the roots. The longer roots were severed but with following rain regrowth occurred. The skew treader, somewhat similar to a rotary hoe run with the tongues reversed, was used successfully for breaking stubble, spreading bunched stubble, breaking surface crusts and controlling weeds under wet conditions.

Both Aasheim (1949) and Englehorn (1946) have indicated that weed control can be more difficult with stubble mulching practices.

A possible alternative for weed control under mulch farming could be by flame control. Although some attention has been given to the use of flame cultivators in cotton (Stanton, 1954 and Stanton and Tavernetti, 1956), no information is available on weed control in cereal fallows.

4:4 Maintenance of Mulch Cover

In any management system deterioration of the mulch is inevitable. The residue reduction by using various implements has been summarised by McCalla and Army (1961) from data by Anderson (1953), Woodruff and Chepil (1958) and Fenster (1960 b), and shows that up to 70 per cent of the residue can be covered by a one-way disc working at six inches, while a blade implement will cover less than ten per cent. Running of machinery over residues causes fragmentation and hastens decomposition.

Other factors reported by Anderson (1953) to affect the conservation of a residue are stubble height and depth and speed of operation.

5. THE USE OF CHEMICALS IN MINIMAL TILLAGE PRACTICES

With the continuously accelerating agricultural technical revolution, it has now become possible to prescribe chemical treatments which can kill weeds completely without any cultivation.

The abandonment of tillage must necessarily lead to changes in the soil physical condition. An understanding of the importance of the effects of no tillage or minimal tillage is essential to a comprehensive consideration and possible adoption of crop production with the minimum of cultivation, which is considered essential for reasons of soil and water conservation combined with herbicide use.

In his review of tillage and crop environment, Hawkins (1967) concluded that the most immediate practical application of the establishment of relationships between soil physical properties and crop growth would probably be in the specification of adequate minimum tillage techniques.

5:1 The Effect of Reduced Tillage on Weed Populations

It has been claimed that by reduced or no tillage weed populations show a progressive reduction. Roberts (1963) concluded that when the soil was allowed to remain undisturbed for a period of years it would be expected that, due to exhaustion of the population of non-dormant seeds within 'striking distance' of the surface, and partly because of enforcement of dormancy following compaction of the surface soil, weed populations would decline.

The need for weed control measures, and hence the costs of crop production, was shown to progressively diminish by Day and McCarty (1957) with non-disturbance of the soil. Roberts (1963) also points out that herbicide applications in short term arable crops must lead to a cumulative decrease in the viable seed reserves of the soil, provided no seeding occurred during the inter-crop period. Harper (1957) also commented that provided only shallow tillage of the surface was carried out for seed placement, the dormancy-breaking stimuli being most effectively encountered at the surface, a rapid decrease in seed populations of the surface, disturbed, layer would be expected. With no cultivation and a soil surface compacted by rainfall Bibbey (1935) also recorded reduced germination of weed seeds. In the Wellesbourne vegetable experiments described by Roberts (1963) a four fold increase in weed seed numbers occurred during one wet season when cleaning cultivations were rendered ineffective. A frequent occurrence, particularly under East African conditions, is for an early break in the rains after which the land lies so wet that seed bed preparations and planting have to be delayed with associated serious weed problems (Macartney 1964). The study of dormant weed seed populations in the soil has been somewhat neglected aspect of ecology, possibly because the methods of assessment are laborious and time consuming (Brenchley and Warington 1930, Hyde and Suckling 1953); estimates are however available from some countries to show the appreciable quantities which are present within the plough layer. Weed populations have been found to vary from 138 million/acre under continuous wheat, 116 million under wheat and 121 million/acre under barley (Brenchley and Warington 1933). Other figures given show populations varying from 17 - 229 million (Roberts 1958) under different crops.

The balance of weed seeds in the soil, their survival or decay, depended on their viability (Darlington and Steinbauer, 1961) which was shown to vary between species of 5 - 80 years. The variation between dormancy of the seed and in their germination requirements defined the differences with which viable seeds will decline under clean cultivation. Under fallowing at Wellesbourne, Brenchley and Warington (1933) found considerable differences between species.

An 8 to 85 per cent survival in viable seed numbers dependent on species was recorded by Roberts (1958) during the first year of a vegetable rotation. It also seems reasonable to suppose that because of frequent cultivation this estimate is a fair reflection on the maximum expected rate of reduction in a weed population.

5:2 The Bipyridyl Herbicides

The development of the bipyridyl herbicides (Brain et al 1958 and Fielden et al 1955) has made possible a challenging new approach to the general principles on which weed control have been founded. The chemistry and mode of action of paraquat (1,1'-dimethyl-4,4'-bipyridylium-2A) and diquat (9,10-dihydro-8a,10a-diazoniaphenanthrene-2A), the commercially available preparations, has been described by Boon (1956). It has been shown by Mees (1960) that light is essential for a rapid kill of vegetation and that they suffer virtually immediate inactivation in contact with most soils. These characteristics have made possible a substitution of herbicide weed control for tillage, and where crops can be established immediately into a previously sprayed weed growth with no residual effect. The herbicides dessicate the aerial growth of plants, leaving the root systems intact thereby helping to stabilise the soil against rainfall and wind erosion. Rain falling shortly after the application of paraquat was reported by Brian et al (1958) to have had no effect on herbicidal activity whereas Robinson (1963) claimed better results with rain falling 20 minutes after application.

5:3 Chemical Fallowing

It is often recorded that a residual herbicide, which is non-toxic to the following crops, giving weed control throughout the fallow period deserves consideration within the stubble mulch system.

The beneficial effect of summer fallowing on conservation of moisture, accumulation of nitrates, reduced weed population and easier preparation of a good seed bed, was realised in Western Canada at the end of the last century; at present approximately 27,000,000 acres (34.6 per cent of improved land) are summer fallowed. The main aim of chemical fallowing in the Canadian and American work is to reduce tillage for the purpose of mulch maintenance.

The Canadian Government recommendation for complete protection of moderately erodible soils is from 500 - 1,000 lbs. straw/acre. The Soil Conservation Service, U.S.D.A., technical standards and specification states that 750 lbs of wheat straw per acre is the minimum amount required to prevent soil erosion.

In the semi-arid parts of the prairies four cultivations are usually necessary to control weeds during a summer fallow. Hay (1968) has described the preferred implements which undercut the weeds 3 - 4 ins. below the surface but estimates that some 20 per cent of the trash is turned over by the heavy duty cultivator and ten per cent with a rod-weeder. He also claims a 20 - 50 per cent degradation of straw during the summer fallow period by the natural breaking down processes.

Studies to determine methods of utilising herbicides for weed control during fallow periods have been underway since 1948. In 1956 Baker et al concluded that where chemicals controlled weeds in fallows, grain yields were the same as those obtained from conventional tillage. Yields were usually reduced when weeds were not effectively controlled. Since this work, chemical fallow research has been expanded to investigate the effects of chemical fallowing on moisture storage, production costs and soil structure.

Alley and Bohmont (1957) and Barnes et al (1955) working in Montana showed that chemical fallow with or without chisel ploughing increased infiltration rates over conventional tillage. Further work carried out using herbicides as a partial or complete substitute for tillage during the fallow period gave inconclusive results (Alley et al 1962, Army et al 1961, Baker et al 1956, Phillips 1954 a and b, and Weise and Army 1958). The herbicide used was invariably 2.4,D (the ester of 2,4-dichlorophenoxyacetic acid) which gave good control of most broadleaved weeds but failed to control grasses. Army et al (1961) did however report chemical fallowing and stubble mulch tillage i.e. sub-tilling, to be equally effective in moisture conservation. Black and Power (1965) later compared complete chemical fallow and combinations of chemical and mechanical tillage and reported little difference in moisture conservation. With chemical fallowing they reported a ten per cent increase in the surface residue cover. This was also in agreement with results obtained by Wiese and Army (1958) and McCalla et al (1957).

Further evidence that method of tillage or chemical fallow did not affect moisture storage was produced by Wiese and Army (1960) and Wiese et al (1960) again working under low intensity rainfall conditions.

In recent work on the value of chemical fallows carried out by Ford et al (1968) in Saskatchewan no attempt was made to limit the number of herbicide applications, their objective being to compare a non-cultivation regime with the farmers' cultivation in order to determine the response in soil moisture conservation, erosion control and crop yield. They reported a reduction in the number of operations for fallow control from four to five mechanical weedings to three to four chemical applications. Although trash maintenance was much better with chemical fallowing no significant differences in soil moisture to four feet were recorded.

Molberg et al (1967) described a co-operative project at seven Canadian stations to determine the minimum number of tillage operations required to give adequate weed control in the fallow. They concluded that complete elimination of tillage was not possible with the herbicides tested, 2,4-D, TCA (trichloroacetic acid), dalapon (2,2-dichloropropionic acid) and amitrole (3-amino-1,2,4-triazole). They later included soil acting herbicides which with one application it was hoped would control weeds during the summer fallow year, and have no phytotoxic effect on the following crop. A 90 per cent weed control was obtained but difficulty was experienced over the surviving weeds which required spot treatment with paraquat.

The case for cocktail mixtures of paraquat plus a residual herbicide for weed control in the fallow has been stated by Darter (1962).

Black and Power (1965) achieved good weed control in the fallow by using an initial spray of 2,3,6-TBA (2,3,6-trichlorobenzoic acid) and dalapon and by subsequent applications of 2,4-D when required. However, further applications of TCA or dalapon failed to provide season long control of grass type weeds in years of above average precipitation. Wiese et al (1967) successfully eliminated one tillage operation by use of propazine (4,6-bisisopropylamino-2-chloro-1,3,5-triazine) in the fallowing period.

Triplett (1966) in an investigation of numerous herbicidal mixtures concluded that the most effective application must depend on the composition of the weed flora or sward. None of the individual herbicides used controlled all the vegetation and his recommednations showed an atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)/paraquat combination as being most effective against grasses, and a paraquat/2,4-D or amitrole mixture for broad leaved weeds.

A clean fallow was maintained by Blackmore (1961) using a dalapon/amitrole mixture followed by a cross spraying with paraquat. After the first spraying there was considerable weed recovery. The need for residual herbicidal control in sisal bulbil nurseries has been pointed out (Anon. 1961) and preliminary testing has shown some measure of success using low dosage rates of dalapon, aminotriazole or simazine (4,6-bisethylamino-2-chloro-1,3,5-triazine) in mixture with paraquat.

The relative efficiency of chemicals and cultivations for weed control was discussed by Molberg (1967) who recorded 47 weeds/m^2 on the chemically controlled plots and 196 weeds/m^2 in the cultivated plots 37 days after treatment.

In work at Swift Current by Anderson (1968) no difficulty was encountered by seeding into trash remaining at the end of the chemical summer fallow. He reported improved establishment due to the firmer seed bed resulting from chemical as compared to cultivated fallow and also to the insulating effect of the standing stubble on the germinating wheat.

In their review of chemical fallowing research, Ford et al (1966) considered that reliable benefits from the system have not been consistently demonstrated. In some cases soil acting materials have remained inactive under semi-arid conditions or large doses have been necessary to give adequate weed control; evidence of the carry-over of phytotoxic residual herbicides was presented. Non-residual as well as some residual herbicides lacked the wide spectrum of weed control necessary for maintaining a weed free environment.

The adoption of chemical fallow to replace all or some cultivation in the fallow will be eventually determined by cost, an aspect which has received scant attention. Phillips (1964), however, has produced figures to show a marked increase in sorghum crop nett return by using atrazine for weed control at the expense of tillage. In Regina (Anon. 1951) annual weed susceptible to 2,4-D were successfully controlled in a test on summer fallow. Comparative costs using 2,4-D and tillage made by the Manitoba Department of Agriculture (Beamish, personal communication, 1967) showed that the cost of the chemical treatment made it a very acceptable substitute for tillage. In addition to better conservation of trash, the herbicide was more effective on susceptible weeds than cultivation in wet weather.

6. THE PRODUCTION OF CROPS WITHOUT TILLAGE

There is little doubt that a large proportion of both hand and mechanical cultivation carried out in crops is for the main purpose of eliminating weeds. The possibility of obtaining a 'weed free' environment with the use of chemicals has been discussed and this situation opens up avenues of research for careful investigation of integrated systems of no tillage and crop production.

In the literature covering the use of herbicides, in land preparation systems the minimal cultivation techniques described can be divided into three groups:

(1) Where chemicals are used in place of cultivation in keeping down weeds in perennial crops,

(2) Where chemicals are used in place of cultivation to control weeds in growing arable crops,

(3) Where chemicals are used as a substitute for cultivations after harvest and in preparing the ground for cropping.

We are particularly concerned with the third where paraquat can be applied regardless of what crop has to be planted, and this research considers two aspects i.e. using the chemical as a substitute for ploughing in the renovation of grassland, and secondly using the chemical in the arable rotation for the establishment of row crops (maize) and broadcast cereals (wheat).

6.1 Pasture Establishment and Renovation by Direct Seeding

The improvement of pastures by re-seeding is an expensive and time-consuming operation using conventional cultivation methods involving several operations with disc or mouldboard ploughs, harrows and roller for seed bed preparation. Large areas of natural grassland in Tanzania and other parts of East Africa have remained unimproved because the generally low returns per acre for many animal products will not cover the high cost of cultivations and seed (Owen, 1962). In addition, the terrain and soil type may mitigate against the use of conventional overall cultivation. Attempts to re-seed by traditional methods have often failed due to such factors as insufficient moisture at establishment, particularly in the drier areas, or excessive weed growth which smothered the emerging pasture plants. Loss of moisture from the seed bed by cultivation for weed control immediately before sowing may considerably reduce the chances of successful establishment. Naveh and Anderson (1966, 1967) and Naveh (1966) noted the generally slow development of many improved pasture grasses and legumes in their work at Tengeru and experienced considerable trouble and cost in controlling weeds. Poor germination and establishment in seasons of low rainfall resulted in the necessity for re-sowing, often with irrigation. Higher seed rates (30 lbs. per acre or more) were recommended by Anderson (1968) for the drier areas to overcome establishment problems, but the cost of the seed of approximately two hundred (E.A.) shillings per acre would not be economically acceptable under these conditions (Mukurasi, 1967). Using conventional cultivation methods, the cost of establishing 46 acres of cenchrus ciliaris pasture at Kongwa was estimated at E.A.sh 84/70 per acre. This was almost certainly on the low side as it included a subsidised seed price (Wigg, personal communication, 1966). The nett return from the neighbouring ranch was 5/10 per acre and the conclusion being that even with the above costings the economics of sown pastures was doubtful in that area. The production of a fine tilth and shallow planting recommended by Anderson (1968) could be disastrous where, under intense rainfall conditions, the potential danger from soil erosion may seriously affect establishment, particularly on sloping land which is unsuitable or of limited use for arable cultivation, but is often classified under permanent pasture. The small scale, hand-managed experiments of Anderson and Naveh (1966-68) have at best demonstrated some of the potential of many introduced pasture species, but the problem of a cheap and reliable large-scale method of establishment for the very variable environments remains. Most leys which have been planted in Tanzania have been of the pure Rhodes grass (chloris gayana) type as the local selections are vigorous in establishment and the seed cost is not prohibitive. They have usually been left down for long periods and there has been little attempt at alternate ley/arable rotations as this involves additional capital for fencing and water supplies.

The advent of the non-residual bipyridylium herbicide paraquat has provided a substitute for those cultivations which are mainly necessary to kill and/or bury inferior grassland prior to re-seeding. The opportunity for eradication of the old sward and direct re-seeding of new species in a single operation has therefore been realised. From the literature it would appear that:

(a) Capital expenditure on machinery may be reduced and also working costs since only one operation is required.

(b) It is easier to achieve the optimum planting date. Where rainfall is erratic this is particularly advantageous and considerably reduces the chance of failure due to drought.

(c) Chemical weed control and direct seeding involving the minimum of soil disturbance means that relatively weed-free conditions are maintained during establishment.

(d) The old sward provides a mulch which will minimise soil erosion and also improve rainfall infiltration.

Initial research on grassland 'renewal' in Britain was commenced on Welsh upland pastures in 1960-61 by Douglas et al (1965) who demonstrated that grass swards could be suppressed by paraquat and new grass/legume mixtures established by minimal cultivation. The scope of the programme was further extended by Douglas (1965) to include lowland permanent pastures using an overall spray regime followed by rotary cultivation. These experiments demonstrated the possibilities of a technique which in the early stages was not invariably successful. Difficulties were encountered with getting the seed into contact with sufficiently consolidated soil and with regeneration of undesirable species. Nevertheless, this work was invaluable in defining the type and extent of seed bed preparation required for successful pasture establishment.

The value of paraquat and rotary cultivation compared with rotary cultivation alone was challenged by Evans (1965) while Douglas (1965) showed a more favourable sward composition by using the former.

It might be said that a satisfactory pasture renewal technique had been established by the end of 1963. A tillage operation following paraquat application was required but the machine necessary to do the job was not available. In consequence the 'sod seeding' technique practiced successfully in New Zealand by Bramley (1961) and Blackmore (1964) was investigated. The procedure consisted of drilling directly into the sprayed vegetation by cutting a slot and placing the seed. Machinery used was progressively developed from the conventional corn disc drills to the Fernhurst Triple Disc Drill (Allen, 1967) and achieved most success by the eventual production of the Howard Rota Seeder in 1964. The advantages of the latter were that the trash or mat problem was avoided, soil disturbance was minimum and adequate soil/seed contact was achieved.

In New Zealand, Australia and the U.S.A. complementary experimentation by Ross (1962 and 1963), Robinson and Cross (1963), Blackmore (1962), Twentyman (1962), and Kay (1966) added further fundamental information on the viability of the system and particularly in the development of machinery capable of carrying it out. Kay (1966) described a disc-seeder with mounted spray equipment specially designed for weed control, fertilising and seeding in one operation on rough, steep or stony terrain.

In Tanzania, sod-seeding of Louisiana White Clover into natural pasture at Kitulo using a chisel-seeder has been successful (Williams, 1968) and proved cheaper than conventional methods. In contrast, attempts to establish Cenchrus ciliaris using minimum cultivation at Kongwa have usually failed (Brzostowski, 1962; Owen,1965) and this may be due to the extreme cohesiveness of the soil preventing root development (Macartney and Northwood, 1969). Some success has been achieved by broadcasting Glycine javanica onto a previously burnt natural sward at West Kilimanjaro (Owen, 1967). Trampling of the seed by sheep either before or after seeding did not appear to improve establishment.

6:2 Direct Drilling of Cereals

The technique of direct drilling, into either killed pasture land without ploughing or into sprayed stubbles has been successfully carried out in many parts of the world. Crops have been drilled into undisturbed seed beds under conditions that would not allow the preparation of conventional seed beds. Many claims for a more widespread acceptance of this principle have been made and are reviewed.

In 1961 trials were commenced at Jealotts' Hill in an attempt to drill a number of crops into permanent grassland without cultivation. Hood et al (1963) have described the difficulty of drilling into untilled ground and the regeneration of the previously sprayed grass. Initially a standard wheat drill, heavily weighted, was used but penetration of the heavier soils was reported by Hood et al (1964) to be a limiting factor.

The Howard Rotaseeder was developed, followed by the Plant Protection triple disc drill in an attempt to overcome the seed placement difficulties encountered with compacted soils and heavy trash covers.

Jeater and McIlvenny (1965) reported on the continuation of this work by successfully drilling cereals into weed sprayed pastures and stubble and compared direct drilling with normal cultivation at various levels of nitrogen application. Individual trials showed significant yield differences but there was no consistent advantage in favour of either techniques. Generally the advantages of ploughing and drilling over direct drilling declined with increasing nitrogen applications (Hood et al, 1963). They concluded however that although satisfactory crops could be grown by direct drilling there was no suitable machinery available for a practical application of the technique. The lack of a satisfactory drill for establishing cereal crops on heavy clays was also reported from the Boxworth Experimental Farm (Anon. 1964). Standard drills did not achieve satisfactory penetration or seed coverage and it was stated that entirely new designs would be necessary.

Arnott and Clement (1963) denied any evidence that yields on unploughed land were limited by reduced mineralisation of nitrogen or by soil compaction.

6:3 Minimal Tillage and Row Crops

The effect of non cultivation on erosion control has been reviewed by Steele (1966). He speculates that under tropical conditions herbicides could be of great assistance in solving erosion problems by maintaining a surface cover to break the force of the rain. He has compared minimal tillage to strip cropping in its effect on controlling erosion.

There is much information in favour of minimal tillage as an erosion control measure. Lane (1961) reports control of wind, water and weeds in Nebraska; Meyer and Mannering (1961) have described the beneficial effects of this method of tillage on infiltration and erosion. Witmuss and Swanson (1964) have also shown how minimum tillage can reduce soil loss. The general opinion, however, amongst these workers is that some degree of cultivation assisted conservation by increasing infiltration.

Many detailed investigations have been made on the soil properties under minimal and conventional tillage (Shelby and Andrews 1962, Arnott and Clement 1962, Treaner and Andrews 1965, and Arnott and Clement 1963) but the objects were nearly always to try and relate yield with cultivation, a procedure strongly criticised by Hawkins (1967).

Meanwhile the system of no-tillage, till plant, zero tillage and chemical tillage was being investigated for row crops, particularly corn, establishment in the United States. As early as 1954 Davidson and Barrons reported satisfactory corn production using herbicides rather than tillage. Barrons and Fitzgerald (1952) reported success with growing soya beans and flax in a sod killed seed bed, and during the same period Porter (1955) grew strawberries in a sod killed with dalapon. Interest in no tillage corn production developed rapidly and further valuable contributions were made by Free et al (1963), Moody et al (1961 and 1964) and Triplett et al (1964). Most of these evaluations involved some tillage and many useful advances were made in the development of tillage implements specifically designed for minimal cultivation techniques.

Jones (1961) working in Ontario discarded the system of plough-plant and supported the trend towards tillage practices such as:

(1) Once over primary tillage with a heavy duty offset disc harrow or heavy cultivator.

(2) Once over rotary cultivation.

(3) Zero tillage planting from sod.

The benefit of zero planting from sod with built in desirable tilth conditions was also stressed by Shear and Moschler (1968). He compared sod planting with conventional tillage on many different soils varying from clay loam and silt loam to sandy loam,and commented on the flexibility of the system. Covers other than sod were investigated and it was determined that provided they produced an adequately persistent mulch and could be readily killed by herbicide the origin was unimportant.

Martin et al (1966) defined the most favourable soils for sod planting as uneroded with at least six to nine ins. of soft friable top soil and a permeable subsoil to a depth of at least 18 ins. He recommended a 14 - 20 ins. band of completely killed sod. Maximum yields were not to be expected on soils which had been severely compacted. Jones (1966) also stressed the importance of a well drained fertile 'good structure' soil if the equivalent production to conventional tillage was to be obtained. He recognised the need for studies on root distribution and development as there were indications that root restriction was limiting yields.

7. SOIL COMPACTION AND PLANT GROWTH

Reliable estimates of mechanical impedance are of great importance when attempting to assess the role of minimal or reduced cultivations under conditions where one or more of the soil structural indices are limiting.

Excessive compaction due to genetically derived soil conditions (Winters and Simonson, 1951) or to loss of water stability due to cultivation of virgin soils is believed to cause decreases in productivity. The increased soil density and reduced pore space resulting has been shown by Fontaine (1958) to severely affect root growth. Mechanical impedance, reduced aeration, altered soil moisture availability are all factors that may become critical for plant growth.

It is generally accepted that soil compaction can have adverse effects by (a) increasing the mechanical impedance to the growth of roots, and (b) by altering the extent and configuration of the pore space.

Fontaine (1959) stated that measurements of properties such as porosity or aggregate stability were valueless unless calibrated against plant growth.

The three physical properties, per cent oxygen, soil temperature taken at the four inch layer, and soil moisture, were not statistically different due to various compaction treatments and did not affect yield in work by Phillips and Kirkham (1962). Mechanical impedance, measured by needle penetration, and bulk density, were however strongly correlated with yield. Soil compaction also reduced the stands of corn.

A copious literature describing the adverse effect of excessive soil compaction has been reviewed recently by Rosenberg (1964). Many of the experiments described demonstrate empirical relations between bulk density and growth, but do not explain why growth is affected. The growth of roots and underground shoots at a given temperature was influenced strongly by the physical factors: mechanical resistance, soil moisture and aeration. These factors were themselves interdependent and also the response of the plant to a change in one factor may modify its response to another.

Although the simple correlation of mechanical properties and plant growth as described by Culpin (1936) was useful in diagnosing physically adverse soil conditions, correlation did not identify the particular factors controlling growth. It was often possible however to detect mechanical effects by visual observation, examples of which have been given by Taylor and Burnett (1964).

Circumstantial evidence that mechanical impedance may be limiting is often presented (Phillips and Kirkham, 1962) by showing that other physical factors are unlikely to be limiting. Having found a simple correlation between probe resistance and corn yield, they proceeded to show that soil temperature and oxygen content of bulk samples of the soil air were similar at the various levels of compaction.

7:1 Mechanical Impedance and Root Growth

The very high pressures which can be exerted by the root tip were first described by Pfeffer (1893, 1904) and translated and summarised by Gill and Bolt (1955), but it was not until quite recently that Gill and Miller (1956) extended these early investigations by measuring the mechanical resistance that could be overcome by young roots. Their data clearly demonstrated that roots were only able to penetrate a pore which had a diameter exceeding that of the young root. The rigidity of the pore structure was shown to be important by these workers who were the first to demonstrate the ability of roots to force their way through pores smaller than the roots by pushing aside the obstructing particles.

The nature of substrate use in the investigation of the forces exerted by roots has been shown to be critically important by Veihmeyer and Hendrickson (1946). They described field observations in which further penetration by roots was prevented by a soil density of 1.8 g/cc or more. In their second publication Veihmeyer and Hendrickson (1948)however, showed that the limit for sand may be 1.75 and for clay 1.46 - 1.63 g/cc. Similar observations have been made by Bertrand and Kohnke (1955) who showed that maize roots did not penetrate a silty clay loam subsoil compacted to 1.5, but grew profusely in a subsoil of 1.2 g/cc.

Although under favourable conditions a plant may develop a more or less characteristic root system, unfavourable conditions in the soil can bring about marked alteration in the form of the root system. Shallow rooting can be the consequence of a number of different factors of which Wiersum (1957) claims mechanical resistance of the soil to be not infrequently responsible for restriction of root penetration. He pointed out the difficulty in evaluating this factor due to the close similarity of the effects of soil density, excess moisture and poor aeration.

The early work on the effects of mechanical impedance, root penetration and plant growth, is the subject of a review by Lutz (1952).

The response of plants to a wide range of soil densities was discussed and 'threshold densities' for root penetration of different crops were given.

Trouse and Humbert (1961) surrounded compacted cores with loose soil and measured sugar cane root penetration into a compacted soil within the range of bulk density from 0.50 - 1.92 g/cc. They established critical densities where no root penetration took place. A core of 1.52 g/cc did not allow penetration and incorporated trash was undecomposed after a two year period, indicating that biological activity was depressed in the compacted cores. Thus on a low humus latosol, bulk densities of 1.02 or below did not restrict root development, at 1.12 root distribution in the compacted cores was slightly reduced, but at 1.25 was still reasonably satisfactory although branching of rootlets revealed a tendency to angular turning and a slight flattening. At a bulk density of 1.36 g/cc root distribution in the cores was reduced and rootlet distortion became evident. Root penetration was seriously reduced at 1.46 and penetration ceased at 1.52 g/cc. At a bulk density of 1.05 the mean growth rate was 1.75 cm/day and this was reduced to 1.25 cm/day and 0.25 cm/day by increasing bulk density to 1.20 and 1.45 respectively. There were no significant variations in root penetration when soil cores compressed to a high bulk density were kept at different moisture content. Similar experiments on other soils demonstrated that root growth in hydrol humic latosols was reduced with bulk densities of 0.56 and above, root penetration ceasing at a bulk density of 1.05 g/cc. On grey hydromorphic clays root penetration was severely restricted at 1.75, while root growth in alluvial soils was similar to that in low humic latosols.

Zimmerman and Kardos (1961) reported a highly significant negative correlation between bulk density and penetrating root weight for soya beans and Sudan grass on four soil types. On a clayey silty loam and on a silty clay, root penetration was completely arrested at 1.8 and on a sandy clay loam no roots penetrated at 1.9 g/cc.

Bunt (1961) found that any degree of compaction of a substrate of poor structure (for example, fine sand series) decreased fresh weight and internode lengths of tomato, while moderate compaction of a substrate of good structure significantly increased growth. Flocker and Menary (1960) also noted root branching by tomatoes to have been restricted to the top inch in pots of soil compacted to bulk density 1.79 and to the four to six inch layer at bulk density 1.49 g/cc. Borden (1961) found that a bulk density of 1.4 to 1.5 limited tomato root growth in one soil while in another a bulk density of 1.6 g/cc was needed to restrict growth. Flocker and Nielson (1960) demonstrated how, in two soils at various levels of bulk density and soil moisture tension or a combination of both, growth of tomatoes was affected whereas air space had little effect at the levels explored. Phillips and Kirkham (1962) working with maize seedlings and a clay soil at bulk densities of 0.94, 1.10 and 1.30 g/cc found that a regression of growth rate on bulk density was closely linear. Rosenberg and Willits (1962) described experiments in which various levels of compaction were obtained by means of a vibrating probe. The response to compaction varied according to the crop and soil type and correlations were not consistent from one soil to another and from one crop to another.

Pendleton (1950) found that sugar beet roots failed to penetrate either a sandy loam or a silt loam compacted to 1.95 but at 1.8 g/cc the main root alone usually penetrated. At 1.5 g/cc root penetration and distribution was unrestricted and he related these responses to capillary and non-capillary porosity measurements.

Meredith and Patrick (1961) noted a fairly close linear relationship between bulk density and penetrating root weight but the slopes of the curves were steeper for two silt loams than for a clay.

For a clay loam compacted to bulk densities from 1.10 to 1.60 g/cc the slope was -0.54 and for a silt loam over the range 1.50 to 1.75 g/cc the slope was -1.64.

Phillips and Kirkham (1962) measured physical properties associated with soil compaction and reported bulk density and needle penetration as being the physical properties most highly correlated with the reduction in growth and yields of corn.

7:2 The Effect of Soil Moisture, Compaction and Porosity on Germination and Establishment

Kuleta and Williams (1967) recorded lower germination on their more compacted treatments and obtained a close correlation between establishment and degree of compaction.

The need for moisture during germination and emergence has long been recognised and the specific requirements of many species have been determined. Hunter and Eriksen (1952) have recorded the minimum seed moisture content for germination of corn, soya and sugar beet in terms of soil moisture tension. Hanks and Thorp (1956, 1957) reported that the ultimate seedling emergence of wheat, sorghum and soya was the same when the soil moisture content was maintained between field capacity and permanent wilting percentage provided the other factors were optimum. The rate of emergence, however, was related directly to the soil moisture content. Stout (1959) in designing precision planting equipment stressed the point that seed bed preparation and planting should promote maximum capillary flow of water to the seed. He also pointed out (Stout et al, 1956) that rapid emergence was desirable in that it reduced the possibility of erratic stands resulting from surface crusting following rains. He concluded that retention and conservation of soil moisture during seed bed preparation was of paramount importance and suggested minimal tillage as the most effective means of achieving optimum conditions.

The importance of mechanical impedance, aeration and soil moisture in soils with different levels of moisture and compaction on the growth of seedling roots has been closely studied by Eavis (1965) who noted that the growth of the radical in length, fresh weight and volume was inversely proportional to the level of mechanical impedance when the other growth controlling factors were kept optimal and constant.

Phillips and Kirkham (1962,b) showed that the growth of primary and secondary corn seedling roots decreased as bulk density increased. The low growth rate at the high bulk densities was due to mechanical impedance and not aeration. This conclusion did not imply that aeration would not limit the corn growth during the later stages of its physiological development.

7:3 Soil Compaction and Yield

The behaviour of crop species grown in compacted soil cannot be characterised simply. This brief review of some major economic species illustrates the uncertainty that exists in this area of soil research.

Cereals

In a field compaction experiment by Phillips and Kirkham (1962) corn yields decreased with increasing bulk density. Plant height and quantity of roots were also reduced and tasselling and silking dates delayed. Grain yields were directly proportional to the weight of roots in the top two foot layer of soil in both compacted and uncompacted plots.

Adams et al (1960) recorded a 7.5 per cent reduction in corn yield on a silty clay loam with surface compaction and 14.5 per cent when both subsoil and surface were compacted by vehicular traffic. Surface soil density rose from 1.07 to 1.19 g/cc and permeability and penetrability were also reduced. Corn germination and population were decreased and maturity was slower. Swanson and Jacobson (1956) found that corn yields over a three year period were correlated with surface hardness of the soil. De Boodt et al (1953) studied the effects of cultivation within a crop rotation and recorded yield decreases in all cases with increasing bulk densities. Oat yields were significantly higher on uncompacted treatments in work carried out by Bourget et al (1961).

In a study of the factors affecting the use of minimal tillage for corn, Van Doren and Ryder (1962) recorded a 66 bushel yield of corn on their high compaction treatment compared to 112 bushels per acre with no artificial compaction.

The relation between yield of wheat, soil factors and rainfall was studied by Millington (1961). He found marked seasonal changes in bulk density measurements associated with rainfall amount after sowing. High bulk densities were accompanied by a reduction in seedling establishment and yields.

Root Crops

Baver and Farnsworth (1940) noted a fifty per cent decrease in yield on a heavy clay where the non-capillary porosity was reduced to two per cent of the soil volume. The deleterious effect of compaction on sugar beet yields was also demonstrated by Smith and Cook (1946). Excess moisture also reduced yields but not to the same extent as compaction. Cook (1950) also recorded a reduction in sugar beet yields of approximately eighty per cent by comparing the soil from a volume weight of 1.0 to 1.43. Trouse and Humbert (1961) noted how yields of sugar declined from 88.4 tons per acre to 60 tons per acre after two years of mechanical harvesting. The yields of sugar were directly related to the depth of the plough pan by Scarsbrook (1952).

The reduction in yield of potatoes with soil compaction was thought by Bushnell (1935) to be due to reduced soil porosity. Soil compaction also depressed yield and quality of potatoes in work by Flocker et al (1960). Dunn and Tyford (1946) reported that their most dense treatment produced the lowest yields of potatoes whereas the next most dense treatment (with an air space of 12.8 per cent) gave higher yields than any of the other less dense treatments. Potatoes grown in traffic induced compaction plots by Adams et al (1961) showed yield decreases of up to 54 per cent when bulk density was increased from 1.07 to 1.19 g/cc.

Cotton

Reduction in cotton yield as a result of growing under controlled oxygen restriction and compaction was attributed largely to the former by Jameson and Domby (1956). The authors considered that although root extension was affected by compaction, except at very high densities the influence of the pan arose more from air/water relationships than from physical resistance to root penetration. Hubbell and Staten (1951) reported yield increases with compacted treatments while Randolph et al (1940) found that an increase in bulk density was highly correlated with reduction in cotton yields. Where specific soil densities are not recorded it is often difficult to interpret the results presented as being due to soil compaction or to seed bed consolidation.

7:4 Soil Compaction and Organic Matter

The effect of soil compaction upon plant growth has more often than not been demonstrated and studied under laboratory or artificially compacted field treatments. The natural occurrence of compacted soils influencing root growth has been recorded from the southern plains of the United States of America by Besson and Murphy (1922), Randolph et al (1940) and Tayler et al (1964). This problem recognised for some forty years has become more relevant and serious with the increasing use of inorganic fertilisers, pesticides and new crop varieties.

Although soil compaction has been recognised as a plant growth limitation, no general theory has been advanced that adequately explains its origin or intensity. Taylor et al (1964) in a detailed study of the chemical and physical properties of seventeen Southern Plains soils, were unable to define the origin of both the genetic and tillage induced condition.

Davidson et al (1967) studied the development of this condition under normal cultivation practices and showed that maximum compaction was extremely sensitive to small changes in organic matter content caused by different cropping practices. The work of Locke et al (1960) shows a similar relationship existing between cultivation, organic matter and compaction. They effectively demonstrated the deleterious effect of deep ploughing on organic matter content and its relation to increasing bulk densities through a rotation. Curtis and Post (1946) found a similar relation between bulk density and organic matter. Similarly Klute and Jacobs (1949) and Free et al (1947) recorded reductions in bulk density with field applications of organic matter.

The relation of organic matter to compaction at the time of cultivation has been described by Davidson et al (1967). A decrease in organic matter content due to excess tillage made it necessary for soils to be worked at lower soil water contents than when the soil was first cultivated if soil compaction was to be prevented. They conclude that their studies 'may show additional benefits to the present minimal tillage practices which involve the incorporation of crop residues'.

The use of sweeps and subsurface tillage in stubble mulch farming raises the question of whether the physical condition of the surface soil is improved or otherwise. Page et al (1946) in Ohio reported that sweep cultivation resulted in seed beds with lower non-capillary porosity and a higher soil density as indicated by 26 strokes of a penetrometer required to penetrate three inches of soil compared with 14 strokes for ploughed soil. At Lincoln, Nebraska, McCalla (1959) recorded no difference between stubble mulching and ploughing with respect to bulk density, specific gravity, total porosity or compaction. Plots subtilled for twenty years had in fact a more open structure at the immediate surface than ploughed plots (Turelle and McCalla, 1961). Borst and Mederski (1957) and Johnston (1950) found very little differences in bulk density while comparing the two tillage systems.

8. THE ROOTS OF CEREALS

The roots of cereals are not in themselves economically important; they are of value only in that they are necessary for the plant to produce grain and for their residual value as organic matter in the soil after harvest.

The information and knowledge of root development and function is fragmentary. The only facets of their existence that have been studied at all intensively are certain of their physiological processes and their microbial associations. The root systems of some of the common field crops are described by Weaver (1926) and a comprehensive review of the roots of the temperate cereals has been made by Troughton (1962).

8:1 Penetration and Distribution

The roots of cereals have been reported to penetrate to considerable depths. In the deep and light soils of Nebraska Kmoch et al (1957) recorded root penetration of wheat to 13 ft (400 cm) and Weaver (1926), also in Nebraska soils, to 7 ft (210 cm).

The maximum depths reported from Europe seem to be generally less than those from America but the sparsity of data make comparisons unreliable. Rooting depth of wheat to nine feet (290 cm) was reported by West (1934) working in Australia.

Hurd (1964) in a study of the rooting habits of three varieties of wheat observed that in all treatments roots ceased to penetrate the soil at heading time, and that the depth of penetration was reduced by initial soil dryness. Balass (1954) was of the opinion that cereal root growth continued right up to harvest and this was supported by the results of Knoch (1960).

In the evaluation of individual root systems, Boatwright and Ferguson (1967) devised a technique whereby plants could be grown with complete root systems, with primary only and with adventitious roots only. Grain yields were significantly greater when plants developed both root systems but adventitious roots were found to be physiologically more active than primary roots. In general, incomplete root systems decreased grain yields more than straw yields. Translocation of total nitrogen was greater with both root systems well developed.

The root behaviour of seven varieties of spring wheat grown at two moisture levels was observed by Hurd (1968) and the total weight of roots at each depth recorded. Considerable varietal differences in rooting proliferation and depth were related to drought resistance and yield of the varieties. He pointed out that correlation between yields and total root length or total dry weight was invalid as water could be wastefully passed through the plants so that dry matter production would not be directly related to water use nor to the extent of the root system. The advantages of having a larger proportion of the roots at depth during periods of moisture stress was noted.

8:2 Root Growth and Available Water

In a series of early experiments with wheat, oats and barley, Seelhorst (1902) showed that within certain limits the greater the supply of moisture in the soil the greater the root growth. More recent workers have contributed little to this general conclusion.

The depth of penetration was influenced by a number of environment factors of which the most important appeared to be soil moisture (Kmoch et al,1957 and Goedewaagen and Schuurman,1956). Russell (1957) and Weaver (1926) have both related the uptake of water by wheat to the extent and depth of root growth. The growth of oat roots was found by Leishout (1957) to be greater when the soil contained 40 per cent of its moisture holding capacity than when the soil contained 20 per cent or more than 40 per cent. Harris (1914) concluded that the application of large quantities of water to wheat from sowing to the five leaf stage had more effect in reducing the percentage of the plant weight in the roots than applying water after this stage.

Bengmann (1954) observed that root length and Polle (1910) that root development varied inversely with available moisture.

The relationship between root length and depth of moisture penetration has been studied by Miège (1938), Singh (1922) and Goedewaagen (1955). In general, root length increased with water availability at depth. Surface application of irrigation water or heavy continuous rainfall increased the proportion of roots in the surface soil and decreased depth of penetration. In the prairies Weaver (1926) reported the depth of rooting and the length of straw varied directly with the amount of rainfall. When the subsoil was dry, root depth of wheat was reduced and lateral spread, degree of branching and absorption from the surface soil were greatly increased.

The extent of root growth was correlated with soil moisture content by Salim et al (1965) who, together with Robertson et al (1934) showed that wheat roots could not penetrate into soil which had been depleted of its moisture reserves to wilting point or below.

The need for adequate available water to enable the nodal roots to become established was stressed by Kravtson (1928). The wheat plant was particularly susceptible to drought injury before nodal root production and the advisability of early planting under marginal rainfall conditions was mentioned.

8:3 Root Growth and Nitrogen

Within certain limits root growth of cereals has been increased by the addition of nitrogen fertilisers (Brenchley and Jackson 1921, Rippel and Meyer 1933, and Kmoch et al 1957).

In herbage grasses it was found that each succeeding increment in the level of nitrogen supply produced smaller increases in root growth until a point was reached where further increase resulted in a retardation of growth (Troughton 1957). Similarly, high levels of nitrogen have effectively reduced root weight of cereals under a variety of conditions (Mulder 1954). This reduction was more noticeable in the lower (20 - 100 cm) soil layers (Goedewaagen 1955). Kohne and Greiffenberg (1954) were unable to distinguish any effect of nitrogen application on root growth although the aerial parts of the plants showed striking responses.

A number of workers have reported increased root weight with the addition of organic matter (Livingstone 1906, Gericke 1946, and Spahr 1960). Fehrenbacher and Snider (1954) studying the effect of plant nutrient level on root penetration, found that in a well fertilised rotation the roots of corn penetrated considerably deeper than without fertiliser. With fertiliser application there was one inch of avialble water in the top 42 ins. of soil, and with no fertiliser there was 4.5 ins. of available water. However, on the well fertilised plot the amount of water needed per bushel of corn was 5,600 galls., while on the low fertility area the requirement was 21,000 galls.

8:4 The Effect of Surface Mulch on Rooting Behaviour

A comprehensive review, Jacks et al (1955), concluded that with heavy mulches roots tended to accumulate at the surface of the soil and beneath the mulch. This was attributed to more favourable moisture conditions at this level.

Unpublished data from Montana (Beamish, personal communication, 1968) indicated that surface residues delayed the initiation of adventitious roots in winter wheat and with some varieties encouraged the development of the crown near the soil surface. Adventitious roots often did not develop normally during dry periods, particularly early in growth. It was suggested that this influence of surface mulch on root development and distribution may be a factor in the reduced grain yields sometimes experienced with stubble mulch farming.

III DISCUSSION

From the review of literature it is apparent that reduced tillage practices have certain agronomic advantages over the traditional systems of ploughing and harrowing for seed bed preparations. These advantages quoted from parts of the world other than East Africa often claim control of erosion, improved penetration of rainfall, negative yield responses from deep tillage, beneficial effects of surface cultivation, good correlations between water stored at planting and yield and improved root growth. All these factors are of very real relevance to East African arable farming.

The climatic factor of greatest economic significance in East Africa is rainfall. With altitudes within the farming areas from sea level to over 10,000 feet rainfall probabilities vary from below ten inches to over 100 in. Further there is a wide variation in the time of year when the rain falls. Nearly two-thirds of the area suffers a drought of six months or more while only two per cent of the country has reasonable rainfall (over two inches) in every month. The original work (Manning 1956) shows that the percentage of the land area receiving less than 20 in. annual rainfall in four years out of five is 35 per cent; only four per cent receives an expected 50 in. annually. The effectiveness of this rainfall is closely related to its distribution, which is strongly seasonal. In a really wet season the whole countryside is overloaded with water whilst during the dry season many of the lower areas are subjected to very severe droughts. In East Africa many stations have recorded maximum annual rainfall of more than four times the minimum. Due to the wide variety in climate and the drought hazard, study of the water economy of a region is fundamental to the formulation of any good land use policies.

It is also unfortunate from an agricultural viewpoint that over much of East Africa, as the annual rainfall decreases so an increasing proportion tends to fall in erratic and often violent convectional storms and at the same time evaporation rates from an open water surface tend to rise. Intensity of rainfall generally varies with altitude, the lower altitudes having a higher intensity. This is particularly true of the low drier areas where the vegetative cover tends to be poor and although rainfall is low, intensity is high resulting in soil erosion. Man has also had a profound influence by the indiscriminate removal of the vegetative cover, poor land management and over grazing and cultivation. The processes of erosion have been accelerated leading to truncated soils.

The soil types selected for these experiments are widely different yet representative of a large proportion of East Africa. They are described under the separate sections but do have certain features in common being relics of the Pluvial Era during which the gneisses and schists of the Basement Complex and the Massive Tertiary and Quarternary lava flows have been converted in situ to give soil depths from ten feet to over 60 feet. They are all highly erodible.

In practice it has not yet been possible to devise a system of cultivation that will preserve the soil structure and allow all the rain to percolate through the soil. Results reported in the review of literature, should they be of relevance to East African conditions, would enable policies for intensifying agricultural production to be formulated which would allow the optimum use of the strictly limited amounts of rain that most of the region receives.

IV OBJECTIVES

(a) To critically examine the relative efficiency of the accepted methods of soil conservation in Tanzania. Measurements of soil and water loss and yield of maize from controlled plots will be taken and changes in soil chemical constituents and physical structure noted under different erosion control methods. The effect of stubble mulching on soil and water movement will be investigated to provide an indication of any benefits which could result from accepting the mulching principle for wheat growing at West Kilimanjaro.

(b) To attempt the renovation of unproductive pastures by direct drilling of recommended legumes using a strip rotary cultivator (Howard Rotaseeder). If successful, overall spraying and drilling of pasture/legume mixtures will be investigated.

(c) To observe the effectiveness of the triple disc, designed to facilitate trash planting, in the establishment of maize and sorghum.

(d) To investigate the effects of different cultivation techniques ranging from conventional tillage, based on disc ploughing as traditionally practiced in East Africa, to direct drilling into undisturbed soil at Kongwa, Central Tanzania. Recordings will be made on the physical characteristics of the soil, plant populations and yields achieved. Moisture status of the soil profile will be plotted using electrical resistance units together with gravimetric soil moisture samplings at planting, flowering and harvest. The overall aim being to ascertain what intensity of cultivation is practical on this soil noted for its difficult structure. The rooting depth and plant vigour under each cultivation treatment will be recorded.

(e) To investigate the optimum width and depth of cultivation under the zonal tillage pattern using four very different but widely representative soil types of Tanzania. Plant vigour will be recorded in terms of population achieved, plant heights, and grain yields. An attempt will be made to classify these soil types by a structural index relating to their suitability for reduced forms of tillage.

(f) To compare the effects of a range of tillage intensities from conventional to minimum with and without fallowing on soil moisture penetration and availability, soil structure, and the growth and yield of wheat at West Kilimanjaro, Tanzania. Other factors to be investigated will include the effects of tillage on organic matter status. Plant population, tillering, plant height and root growth. Direct drilling will be by Howard Rotaseeder; the testing and observational trials on its effectiveness for wheat establishment will be described.

The results will be critically examined in an attempt at determining the optimum technique for wheat farming at West Kilimanjaro with reference to agronomy and economic cost. A comparison of the expenditure between conventional and minimal tillage will be made over an extensive acreage.

V. OBSERVATIONS ON THE EFFICIENCY OF SOME RECOMMENDED METHODS OF SOIL AND WATER CONSERVATION

1. Introduction

A programme of research on soil and water conservation was commenced in 1950 at the Northern Research Centre, Tengeru, to investigate the effects of various recommended systems for erosion control on sloping land.

The early work showed that mulching with maize stover controlled water and soil loss although the results of this practice on yields were inconclusive (Anon 1959). In the first year the mulch was incorporated and yield was depressed by 27 per cent. No soil was lost compared to 15 tons washed from the control, clean, weeded plot. In the following year the addition of 1½ cwt. of sulphate of ammonia (35 lb. N) per acre arrested the depression in maize yield. In 1955 an application of 3 cwt. per acre of the same fertilizer together with a surface unincorporated mulch was recorded as giving significantly higher yields. The conclusion reached was that 'the short term effect of the application of a mulch, surface or buried, tends to depress the yield of maize. While a response to Nitrogen is generally achieved, the increased yield of maize would not appear to be economic.' Further experimentation comparing the yields of maize when stover was buried, burnt or removed suggested that after the third year there was a beneficial cumulative effect when maize trash was left on the surface or incorporated by shallow cultivation.

2. Experimental Layout and Methods

The run-off plots were recorded from 1950 until the closing down of the Research Centre in 1968 during which period the changes in the soils' physical and chemical properties under various soil conservation measures were investigated.

The trial consisted of eight plots each 30 x 145 ft. (0.1 acre) in size laid out across a 17-19 per cent slope. Each was surrounded by a nine inch high wall to prevent lateral soil and water movement. Calibrated soil and water traps were constructed at the bottom of each plot.

The conservation treatments comprised:

(1) No soil conservation.
(2) Elephant grass (Pennisetum purpureum) contours at nine foot Vertical Interval.
(3) Elephant grass contours at seven foot V.I.
(4) Maize trash bunds at nine foot V.I.
(5) Maize trash bunds at seven foot V.I.
(6) An established ley of Rhodes grass (Chloris gayana)
(7) Clean weeded coffee at nine foot by six foot spacing.
(8) Bananas at nine by nine foot spacing.

In the 1968-9 rains Treatments Nos. 1 and 7 were replaced with one and two tons per acre of wheat straw mulch respectively, the coffee having been removed in Treatment 7.

The volume of run-off was determined by measuring the depth of water in the tanks regularly during the rainy seasons and by removing, drying and weighing the soil in each tank at the end of each month. Rainfall records were recorded daily on the site using a standard five inch Meteorological pattern raingauge. Maize was planted each year in both the long and short rains on the arable plots using the variety H6 at a three foot by one foot spacing across the slope. From 1960 onwards the maize trash from Treatments Nos. 4 and 5 was spread as a surface mulch and no longer added to the already

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By the 1961 season, marked differences in the growth of maize between and within treatments were evident. Terrace effects on the bunded plots resulted in poor, medium and good plant vigour from the back to the front of the terrace. Soil samples within the 0-15 cm. range were therefore taken from representative areas between the bunds and analysed with a view to ascertaining the effect of differential soil wash between the physical barriers and from the plots as a whole. Soil cores were sampled in 1965 by the method described by Hosegood (1958) to compare the physical structure of the soil between treatments.

3. Results

The average rainfall at Tengeru is 42 in. falling in two distinct periods between March and May, and November and January. The mean rainfall intensity over the period of the trial was recorded as 1.2 in./hr. (29mm./hr.) Daily records and other relevant climatological data have been reported elsewhere (Macartney 1963, 1964b, 1965 and 1966a and b).

a) Soil and Water loss

The results are presented for three years from 1958-60 inclusive, and for the final year which included the stubble mulch treatments (Table 3). By 1958 the various treatments had fully established, i.e. grass ley, bananas and the elephant grass bunds, and were considered to have reached their optimum potential for controlling run-off.

TABLE 3 SOIL AND WATER LOSS FROM 1958-1960 AND 1968 TENGERU RUN-OFF PLOTS

	Water loss in 1,000 gal/acre				Soil loss in tons/acre			
Year & Total Rainfall / Treatment	1958 (42.7")	1959 (35.0")	1960 (43.2")	1968	1958	1959	1960	1968
1	38.0	48.5	32.5	-	16.4	15.9	19.5	-
2	31.0	27.0	10.0	12.4	6.0	0.4	6.6	5.2
3	30.5	26.5	8.7	8.2	4.7	0.5	3.9	2.8
4	29.0	28.5	7.4	3.0	5.4	0.5	1.2	1.1
5	29.5	25.0	6.8	1.6	1.2	0.2	0.4	0.3
6	28.0	10.0	2.2	1.5	0.01	0.05	0.002	NIL
7	59.5	72.5	72.2	-	29.1	22.6	29.0	-
8	36.5	17.5	2.2	1.5	0.7	0.2	0.004	0.04
1. with 1 ton wheat straw mulch per acre	-	-	-	1.8	-	-	-	0.03
7. with 2 ton wheat straw mulch per acre	-	-	-	0.4	-	-	-	NIL

b) Yields

The yields of the long rains crops of maize recorded from 1958 to 1965 are given in Table 4. No account has been taken of the area of land physically occupied by the elephant grass and trash bunds in calculating yields. Sample areas were harvested during 1960-1962 from the back, mid and front of terrace on Treatments Nos. 2 to 5 and yields of grain are presented in Table 5.

TABLE 4 YIELDS OF MAIZE IN lb./acre FROM RUN-OFF PLOTS 1958-65
LONG RAINS CROPS ONLY

Treatment Year	No soil Conservation	Elephant grass 9ft.V.I.	Elephant grass 7ft.V.I.	Trash Bund 9ft.V.I.	Trash Bund 7ft.V.I.	Total rain during growing season
1958	2395	1560	1985	2215	2000	30.5"
1959	2260	1830	1600	2100	2280	24.5"
1960	1400	1312	1205	1420	1340	34.0"
1961	970	1570	1680	1750	1500	23.2"
1962	943	940	902	1245	980	20.8"
1963	170	163	175	350	410	30.3"
1964	555	540	503	745	710	33.0"
1965	630	575	540	980	824	15.5"
MEAN	1165	1061	1074	1351	1256	

L.S.D. (Treatment means) at 5% = 208

TABLE 5 YIELD OF MAIZE IN lb./acre FROM BUNDED PLOTS
TENGERU 1960-62

Year	Conservation Treatment	Back Terrace	Mid Terrace	Front Terrace	Mean	Control with No Conservation
1960	Grass at 9ft V.I.	1080	1296	1487	1288	
	Grass at 7ft V.I.	1014	1285	1490	1263	
	Trash at 9ft V.I.	1173	1299	1631	1368	
	Trash at 7ft V.I.	1156	1320	1541	1339	1400
1961	Grass at 9ft V.I.	480	1323	2025	1276	
	Grass at 7ft V.I.	494	1317	2012	1274	
	Trash at 9ft V.I.	520	1672	2394	1529	
	Trash at 7ft V.I.	518	1686	2140	1448	970
1962	Grass at 9ft V.I.	580	1468	1879	1309	
	Grass at 7ft V.I.	543	1329	1902	1258	
	Trash at 9ft V.I.	695	1450	1883	1343	
	Trash at 7ft V.I.	690	1448	1921	1353	943

Note: No corrections were made for the area occupied by the barriers in the calculation of yield.

c) Soil Chemical Analysis

The analysis carried out in 1961 on Plots Nos. 2 to 5 from the top, middle and bottom of each terrace and on Plots Nos. 6,7 and 8 with no soil conservation measures are given in Table 6.

TABLE 6 SOIL ANALYSIS DATA FROM RUN-OFF PLOTS (0-15cm. Composite Samples TENGERU 1961

Plot No. Treatment	Position	pH ($CaCl_2$)	Organic Carbon %	Avail. P (PPM) Extractable in 0.3N HCl	Total P (PPM)	Organic P (PPM)	% Organic P in Total P
1. Control Maize (No Conservation Measures)	Top	5.82	3.24	377	4188	845	20.2
	Middle	5.76	3.47	560	4813	1000	20.8
	Bottom	5.96	3.60	605	5063	501	9.9
	Mean	5.85	3.44	514	4688	782	17.0
2. Maize with Elephant Grass Bunds at 9' V.I.	Top	5.96	2.90	362	4563	885	19.4
	Middle	5.87	3.38	388	4563	188	4.1
	Bottom	6.07	3.31	395	4625	500	10.8
	Mean	5.97	3.20	382	4584	524	11.4
3. Maize with Elephant Grass Bunds at 7' V.I.	Top	5.89	3.29	427	3750	375	10.0
	Middle	6.00	3.08	489	3063	375	12.2
	Bottom	5.96	3.30	438	5750	437	7.6
	Mean	5.95	3.22	451	4188	396	9.9
4. Maize with Trash Bunds at 9' V.I.	Top	5.76	3.44	376	4563	813	17.8
	Middle	5.99	2.84	345	3813	1038	27.2
	Bottom	6.22	2.73	376	3875	925	23.9
	Mean	5.99	3.00	366	4084	925	23.0
5. Maize with Trash Bunds at 7' V.I.	Top	5.94	3.26	387	4250	1300	30.5
	Middle	6.06	3.31	430	3875	312	8.1
	Bottom	6.21	3.08	419	4063	1125	27.7
	Mean	6.07	3.22	412	4063	912	22.1
6. Rhodes Grass (Chloris gayana)	Top	6.05	3.60	352	4873	1900	39.0
	Middle	6.14	3.65	464	5063	2363	46.7
	Bottom	5.79	3.44	545	5750	3100	53.9
	Mean	5.99	3.54	454	5229	2454	46.5
7. Coffee (Clean weeded)	Top	6.03	3.20	463	2750	300	10.9
	Middle	5.80	2.59	395	3625	775	21.4
	Bottom	5.74	2.50	425	3250	275	8.5
	Mean	5.86	2.76	428	3208	450	13.6
8. Bananas	Top	6.04	2.85	387	7375	3975	53.9
	Middle	6.02	2.78	405	6250	1950	31.2
	Bottom	5.94	3.08	415	3813	407	10.7
	Mean	6.00	2.90	402	5813	2111	31.9

4. d) Soil Physical Analyses

Three soil cores per treatment were sampled in July 1965 after the trial had been down for ten years. The results for the three main physical determinations that describe the soil structural state, together with the least significant differences, are given in Table 7.

TABLE 7 PHYSICAL CHARACTERISTICS OF SOILS SAMPLED FROM RUN-OFF PLOTS TANGERU 1965

MEAN OF 3 SAMPLES	TREATMENTS								L.S.D. at	
	1	2	3	4	5	6	7	8	P=0.05	P=0.01
Total Pore Space as % of Total Volume	61.1	63.2	64.0	66.6	65.3	65.8	63.2	65.6	3.6	N.S.
Free Draining pore space at 20 cm. water tension as % total Volume	17.0	18.2	22.2	24.5	22.2	23.6	15.4	25.0	4.4	6.1
Rainfall accept-ance from a 1 in. application in 10 minutes	0.62	0.50	0.57	0.80	0.97	0.61	0.50	0.66	0.09	0.12
Bulk Density	0.98	0.83	0.91	0.87	0.89	0.89	0.95	0.89		

4. Discussion

The greatest soil and water loss was recorded from both the clean weeded treatments although the total amounts lost are much below that recorded for similar slopes by Van Rensburg (1954) working at Mpwapwa. This is due to both the length of the plots,which partially controls the sheet erosion potential, and also to the relatively non-erodible nature of the Tengeru soil. The reduced losses from the maize plot with no soil conservation compared to the clean weeded coffee is probably due to the partial protection afforded by the developing maize crop in intercepting rainfall impact. A similar reduction in both soil and water loss was recorded by Van Rensburg (1954) between his clean weeded fallow plots and from bullrush millet (Pennisetum typhoideum) grown on similar slopes. Damage was observed to be more intense if heavy storms were experienced at the onset of the rains when the vegetation cover was poor or non-existent. Under bananas the canopy together with the trash from leaves and prunings again exercised some measure of protection.

With physical barriers the water loss during 1958-59 was considerable but showed significant reduction in 1960 with the spreading of the previous season's crop residue as a surface mulch. Both elephant grass and trash bunding effectively controlled soil movement but by virtue of their definition as a soil conservation measure are designed for the controlled disposal of 'excess' water. Both elephant grass and trash bunding at seven foot vertical interval have given better control of soil and water movement which is in agreement with that interval recommended for an 18 per cent slope on the basis of a formular adopted empirically by the Soil Conservation Service and quoted by Pereira et al (1966). Elephant grass bunds have long been recommended by the advisory service based on information and design of terraces from the U.S.A. in complete absence of any critical data for local conditions. The deleterious effects on soil fertility by terrace formation under these conditions demonstrates the importance of a surface mulching system to complement physical barriers and thus prevent this soil movement.

The striking results obtained in the final year of the trial by superimposing a wheat straw mulch formed the basis of a comprehensive programme on the effect of stubble mulch farming reported later. With two tons of wheat straw per acre the erosion control was comparable with that achieved by the Rhodes grass ley. Both soil and water loss was recorded on four occasions during the year under a one ton per acre cover when rainfall intensity recorded 1.7 in./hour or over.

The highest mean yields over an eight year period were given by the trash bunding treatments which at nine foot V.I. was significantly better ($P>0.05$) than any other treatment with the exception of trash bunding at 7 foot V.I. This is a general reduction in yield with duration of cropping although with surface mulching biannually the decrease is less pronounced. No correction was made for the area of land occupied by the barriers which with the seven foot V.I. barriers was estimated as some 30 per cent. On all bunded plots a bench terrace had developed by 1961 with plant growth more vigerous on the soil accumulation immediately above each bund. Yield differences were quite markedly affected by this loss of nutrient by soil creep or by decline in structure.

Chemical analysis data provided further information on the effect of continuous cropping with no soil protection on soil fertility. Whilst there was no guarantee that the soil under each treatment was uniform from the start the differences were so marked that they could only be explained in terms of soil and water losses and the return of crop residues to the trash bunded plots. Both maize with no soil conservation and clean weeded coffee have the lowest mean pH which is in accord with their higher soil and water losses. The coffee soil is the lowest in organic matter showing that continuous clean weeding (organic carbon 2.76%) can bring about a marked loss of organic matter in a few years (c.f. organic carbon 3.54%) under Rhodes grass). Total Phosphorus is highest under the bananas and grass with over one third of the total lost from the coffee plot in ten years. The much greater content of organic phosphorus and the higher percentage of organic P to Total P under the former treatments indicate their efficiency in preventing soil and nutrient loss. Assuming the grass and banana soils as a rough standard of the original soil status, about three quarters of the organic phosphorus has been lost from the coffee and elephant grass bund treatments. This illustrates how erosion markedly depletes soil humus as it is always the rich top soil which is lost first.

The Total Pore Space measurements which record the degree of aeration and conversely give an indication of compaction, show that neither of these factors are limiting for growth and results are typical of those obtained on the volcanic soil series (Hosegood 1961). The main treatment with no conservation measure has a significantly lower Total Pore Space value with the clean weeded coffee also showing signs of deterioration in structure.

Free draining pore space or the proportion of the large pores which drain rapidly demonstrates the soil's ability to retain and transmit rainfall. The results obtained are all above the critical level but again the clean weeded treatments are showing significant reductions.

The fact that continuous cropping with no soil conservation measure and no return of crop residue has caused a steady deterioration in soil structure is shown by the rainfall acceptance results. The rates of acceptance are generally poor with the exception of the trash mulched treatments, plots 4 and 5, which give a significantly higher rate at a level where run-off would not be expected to occur.

5. Conclusion

These studies show that grass ley, bananas and trash mulching have a distinctive effect in maintaining fertility, structure and controlling soil and water loss. Unconserved soil under maize and coffee has become noticeably more acid and as much as one third of the total phosphorus and three quarters of the organic phosphorus has been lost as a result of erosion. Continuous arable cropping has reduced the rate of rainfall acceptance although major erosion has been successfully controlled by the elephant grass and trash bunding. The amount of run-off has been markedly affected by the conditions of the surface layer. Trash mulching has been most effective in preventing soil and water movement with complementary physical barriers. The efficiency of both types of bunds for erosion control is undeniable but the resulting bench terrace formation has a deleterious effect on yield and still some soil is always lost which in the long term is an amount which is unacceptable.

With no surface mulching there is a definite limit to the arable break and it is open to conjecture that by leaving crop residues as an added protection the vertical interval between barriers could be increased without detracting from the efficiency of conservation achieved. Stubble mulching is an integral part of land management under slopes of this nature to obtain maximum infiltration consistent with arable cropping requirements.

VI PASTURE ESTABLISHMENT AND RENOVATION BY DIRECT SEEDING

1. Methods and Equipment

Observation plots of approximately 1/3 acre each were used for trial establishment of different tropical legumes in an unproductive sward by direct reseeding. Complete replacement of the old sward with a grass/legume mixture was attempted on a ½ acre plot. The work was carried out on the farm of the Northern Research Centre, Tengeru, during the 1967 Long Rains. The soil type chosen was an 'Mbuga' (Vertisol) of good fertility, subject to seasonal water-logging and difficult to cultivate by conventional methods. The natural sward consisted mostly of *Sporobolus* sp. and *Bothriochloa* sp. and was of low nutrient value.

Following a dry season lasting four months, the indigenous sward was burnt at the end of February 1967. Regeneration of the grass started and was enhanced with the onset of the Long Rains on 9 March. Band-spraying of the grass on four of the observation sites with 'Gramoxone'* using a modified tractor-mounted Massey-Ferguson boom sprayer was carried out on 11 March. Three nozzles at twenty inch centres were used, which at ten inches above the ground gave a spray band approximately seven ins. wide, leaving a between-row unsprayed area of 13 ins. (Plate 1). The sprayer was calibrated to apply 50 galls. of solution/acre at two pounds/square inch pressure. Gramoxone was applied at three pints/acre sprayed or just over one pint/acre overall as little more than one third of the pasture was sprayed. By using a low spray pressure a large droplet size was achieved and drift minimised.

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* Active ingredient Paraquat, marketed by Plant Protection Ltd. (Imperial Chemical Industries, Ltd.)

An excellent kill was obtained and on 14 March drilling of the legumes took place using the Howard Rotaseeder with three sets of blades spaced at 20 ins. intervals following the sprayed strips (Plate 2). Four plots (A1-4) were established using a seed rate of six pounds/acre.

A1. Glycine javanica

A2. Desmodium intortum

A3. Desmodium sandwicense

A4. Medicago sativa (Hairy Peruvian)

The Desmodium species and Medicago sativa were treated with a standard Rhizobium inoculum prior to planting. It was considered unnecessary to treat the Glycine javanica as it is indigenous to the area.

On 16 March another plot (B1) of Glycine javanica was established by spraying and planting on the same day.

On 27 April a further observation plot (C1) of half an acre was established in an attempt to completely replace the natural sward with an improved grass/legume mixture. By this time the existing herbage was nine to ten inches high. It was therefore mowed to a height of three to four inches and then sprayed overall with four pints of Gramoxone in 50 galls. water/acre. A total kill was obtained and on 3 May drilling took place with the Howard Rotaseeder using the following mixture planted in five inch rows:

Panicum coloratum	1½ lb per acre
Setaria sphacelata	½ lb per acre
Glycine javanica	5 lb per acre
Stylosanthes humilis	1 lb per acre

The seed bed prepared by the Rotaseeder for all treatments was a slit ½ in. wide and ½ - 1 in. deep depending on the undulation of the ground. This gave good soil/seed contact but at the same time the seed was covered by only a very small amount of soil which was considered ideal for good germination.

The seed rates used are fairly generous for some species in terms of cost but the main object of the work at this stage was to become familiar with the technique and critically examine its potential under local conditions.

2. Results

Fairly dry conditions followed the sowing of plots A1-4 and B1 and the few light showers that fell were insufficient to germinate the seed. It was not until 12 April after four days effective rainfall that germination commenced.

The legumes in plots A1-3 and B1 germinated and established well, except in localised depressions where waterlogging occurred (Plate 3). The seedling population was if anything too high in some places. The lucerne in plot A4 germinated poorly, only a few plants being counted.

Ten days after germination had started the Glycine javanica in plot A1 was severely attacked by the leaf-eating beetle Ootheca mutabilis, and by the time control measures (two pints/acre of 25 per cent D.D.T. in six gallons of water) could be applied on the following day only about 20 per cent of the plants survived, the Desmodium species were not attacked.

Growth of the legumes was steady (Plate 4) but a little slow. The Glycine javanica and Desmodium intortum were three to four inches high after seven weeks but the Desmodium sandwicense was slightly shorter (Plate 5). Hardly any of the lucerne plants had survived. At this stage the indigenous grass between the rows of legumes on plot B1 had grown to eight - nine inches tall and was starting to shade the legumes. The grass on half the plot was topped to the same height as the Glycine which was observed to help the subsequent development of the legume. Most of the competition was from the grass between the rows as the sprayed bands remained surprisingly free from regenerating grass. The sprayed strips were still visible one year later, probably due to the fact that the indigenous grasses were mostly tufted and lateral spread was slow.

No further management of the plots was possible due to the closure of the Research Station towards the end of the year. However, many of the legumes were still present 15 months later (Plate 6) despite the intense grass competition.

On the completely reseeded plot C1, initial germination was poor owing to heavy rains following planting through to the end of May. At times the plot was almost completely submerged, but as conditions became drier during June further plants established and after six months the improved species covered some 50 - 55 per cent of the ground (Plate 7), but the legumes were rather sparse. Very little of the natural grass had regenerated but annual weeds occupied about 20 per cent of the ground cover.

3. Discussion

These observations show that improved pasture species will establish with direct drilling, and considering the difficult soil type chosen and problems of waterlogging these initial efforts can be counted as quite successful. The rather slow development of the legumes although characteristic of the species has been aggravated to a considerable extent by the wet conditions and cohesiveness of the soil. An additional retarding factor may have been nitrogen shortage up to the time of effective nodulation. Slower development of Louisiana White Clover established by direct drilling compared with conventional cultivation and planting methods was noted at Kitulo (Williams, personal communication, 1964) and with direct-drilled cereals (Jones, 1968), but has not been recorded with direct-drilled wheat at West Kilimanjaro (Macartney and Northwood, 1969). The rate of development of direct-drilled pasture plants and other crops will depend mostly on soil type. With soils of favourable structure and fertility which allow free root growth, it is probable that no retardation at establishment would occur. On the other hand with soils of extreme cohesiveness as at Kongwa, little success may be expected and in such cases consideration should be given to wider and deeper cultivation.

Germination of the Glycine and Desmodium species was excellent and is probably due to the firm seed bed and thin soil covering provided by the Rotaseeder. Also the dead grass mulch and the slot made for the seed has probably provided a favourable micro-environment for establishment. There does therefore seem some prospect of being able to establish adequate plant populations with reasonably low seed rates which is so important from the economic point of view.

The failure of the lucerne to establish was expected as conditions were entirely unsuited for this species. However it was thought worthwhile to include it as an observation at this initial stage.

There is a need now for this work to be expanded to include establishment of different pasture species on a range of soil types and under varying rainfall conditions. Attention should be given to determination of optimum seed rates and post-establishment management. The effect of paraquat in controlling regeneration of the natural pasture species was encouraging but the cost is considerable, particularly for complete renovation of swards. The cost of the chemical for the complete renewal treatment was E.A. Shs. 80.00 per acre and for the band spraying E.A. Shs. 20.00 per acre. Despite the high cost of the overall renovation treatment it is probably less than that of conventional establishment methods but has additional agronomic advantages. The cost of conventional cultivation methods is continually rising but the chemical may well become cheaper.

There are large areas of natural grassland in Northern Tanzania and other parts of the country which have soils of excellent structure and fertility but are producing considerably less than their potential. They are capable of improvement by direct-reseeding and with suitable refinements of the technique it could well become economic to do so. It is in the direction of elimination of unnecessary operations and cost cutting with the establishment of different crops that farmers must look for maintenance of profits and full development of land potential.

VII OBSERVATIONS ON SORGHUM AND MAIZE ESTABLISHMENT BY DIRECT DRILLING

The Fernhurst triple disc coulter (Plate 8) was designed and developed by Plant Protection for the placement of cereal grains through a protective trash mulch. The coulters were produced to replace the planting units on a standard wheat drill. Later it was found necessary in their initial development work to rebuild the drill itself on a heavier frame to achieve adequate penetration. It was planned to obtain a complete prototype drill but when this proved impracticable a series of observations were carried out using the coulters alone mounted on a 'Tropiculteur' ox drawn toolbar at 24 in. centres and pulled by tractor. A 'Tropicana' seeder was modified to fit the triple disc. The seeder was driven by a connecting rod from the crank on the toolbar wheel. Two seed tubes were attached to convey seed by gravity to the disc units.

Initial attempts to plant sorghum into a light friable volcanic loam at Tengeru (Plate 9) were successful. There was a very light trash cover and weed growth which had been sprayed with Gramoxone the previous day. Germination and establishment were excellent. A further spraying was carried out three weeks later. Hand weeding was necessary after five weeks (Plate 10) when the crop had covered in the rows.

A later attempt to establish maize on the 14 June using the same technique was unsuccessful. The ground was covered with a heavy maize trash from a previous crop and the units failed to penetrate. An uneven stand was obtained due to the coulters riding over the trash cover. It was evident that the triple disc technique had practical possibilities for seed placement on these soils but a frame or toolbar of considerable weight would be necessary to ensure adequate penetration through a mulch cover. The results of later work at Kongwa showed that successful direct drilling would be limited to the volcanic soil types of Northern Tanzania and would have little or no application on the compacted granitic soils of the Central maize and sorghum growing areas. These observational trials were therefore suspended.

VIII EXPERIMENTS

A. THE EFFECT OF DIFFERENT CULTIVATION TECHNIQUES ON SOIL MOISTURE CONSERVATION AND THE ESTABLISHMENT AND YIELD OF MAIZE AT KONGWA, CENTRAL TANZANIA

1. Description of the Area and Experimental Site

The Kongwa Plain lies in the Central Region of Tanzania at approximately 6°S., 37° E. It is at the southern end of the Masai Steppe and to the north of the Kiboriani Mountains and consists of gently undulating country between 3000 - 4000 feet altitude with occasional steep-sided inselbergs.

The climate is classed as semi-arid, there being a single rainy season from November to April; most of the rain falling between mid-December and mid-April. The long-term average rainfall is approximately 22 ins., with a mean of 53 rain days as recorded at the Pasture Research Station, Kongwa. The lowest rainfall recorded in a season was eight inches. Most of the rain comes in the form of intense, localised, short-duration storms. Simple probabilities of rainfall reliability (Table 8) showed that less than 16 ins. would be expected one year in five and this would be insufficient to support most arable crops. Glover et al (1954) have shown the expectation of 20 ins. or more rainfall to be less than seven years out of ten.

TABLE 8 RAINFALL PROBABILITIES KONGWA (Owen, 1965)

Total Rainfall (Inches per annum)	Probability (Per cent)
Less than 20	40.9
19	35.2
18	29.8
17	25.2
16	20.6
15	16.6
14	13.2
13	10.4
12	8.0

Mean monthly maximum and minimum temperatures are approximately 90.5°F (November) and 50.5°F (July). The average open-water evaporation from a four feet diameter sunken insulated pan was 80 ins. per annum and reached a monthly total of 11 ins. in November.

The natural vegetation of the upland soils is mostly deciduous Commiphora thicket with an admixture of species of Acacia, Cassia, Albizzia and Euphorbia. Baobabs (Adansonia digitata L.) are common on soils with a high Calcium status. The low-lying 'Mbuga' soils carry mostly short grass with scattered shrubs and trees.

The soils have been formed from rocks of the Lower Basement Complex. At Kongwa successive strata of quartz-granulite, acid gneiss and plagioclase-amphibolite outcrop as bands running roughly east - west. The soils do not show signs of this banding, probably because the weathering products of the strata have been mixed into a fairly uniform 'mantle' as a result of hillside 'creep'. (Anderson, 1957). A soil 'chemical catena' has been formed owing to the different intensities of the soil forming processes at different positions on the hillsides. Leaching of bases has been severe in the upper part of the catena, whilst at the foot of the slope deposition of Calcium and Magnesium carbonates occur as concretions in the profile. The lower soils are usually richer in nutrients than the upper soils due to this movement of bases and their formation from colluvium consisting of ungraded deposits washed from the upper slopes.

Anderson (1957) has classified the soils of Kongwa under four main headings:

1. Red Earths
2. Pallid Soils (Degraded Upland Soils)
3. Calcareous Valley Soils
4. Soils derived, at least in part, from lake-bed limestone (Travertine)

These groups were further divided into soil series and in some cases sub-series. The Chamaye soils of the experimental site are red earths and are probably the most useful arable soils of the uplands. The topsoil is normally slightly acid at the surface decreasing to a minimum pH of about 5.0 at 50 cm. depth. The topsoil of 10 - 12 cm. contains one to two per cent organic matter and about 20 per cent clay content increasing to as much as 40 per cent at depth. Soil depths checked by digging pits round the experimental area showed uniform profiles with no visible horizons other than a stone line at six feet. Good crops of maize, sorghum, sunflower, soya beans and groundnuts have been obtained in seasons of adequate rainfall. Fertilizer trials have indicated only small responses to nitrogen and phosphorus (Le Mare, 1953).

These soils are fairly easy to work when moist but on drying out cultivation is extremely difficult and the wear on machinery due to abrasion is severe. The low and erratic rainfall combined with the difficult soil type presents a particularly harsh agricultural environment. In addition the short rainy season produces conditions where there is, at the most, three weeks in which seed bed preparation and planting may be carried out if some chance of reasonable yields are to be obtained.

In 1947 the Overseas Food Corporation groundnut scheme commenced clearing of the Kongwa area and by 1951 had partly cleared some 100,000 acres of land for cultivation. Crop failures due to drought and the difficulty and expenditure involved in cultivation led to the abandonment of the original production programme in favour of ranching. The scientific team built up by the O.F.C. at Kongwa during this era contributed much information on crop research but little if any attempt was made to investigate water relations of crops or alternative cultivation techniques. Work by Pereira et al (1958) demonstrated the value of fallowing in alternate years for water conservation in improving the reliability of cropping, but the system proved impractical both from the soil conservation and economic points of view. The deterioration in soil structure with both conventional systems of cultivation and bare fallowing was also demonstrated.

Tillage research has top priority in this area, so widely representative of much of the Central Region of Tanzania which, although marginal for rainfall, has vast potential for the production of the staple food crops maize and sorghum. Characterised by frequent crop failures under the present peasant shifting agriculture, the development of the area is dependent on the recommendation of a viable tillage technique which takes cognisance of soil and water conservation and which provides for satisfactory germination and establishment at a greatly reduced cost compared to the conventional tillage practices.

2. Experimental Design and Equipment

The trial was laid out as a randomised block with five treatments and two replications on an approximate three per cent slope. The plot size was 150 ft x 120 ft ($\frac{1}{2.42}$ acre).

The cultivation treatments were as follows:

A. Conventional tillage using the disc plough to a depth of four to five inches followed by disc harrowing and planting on the flat.

B. Ripping from eight to ten inches at three foot centres prior to the onset of the rains followed by disc harrowing after effective rain and planting on the flat.

C. Ripping as in B. followed by ridging using No 1 lister bottoms mounted on the N.I.A.E. toolbar and planting on the ridge.

D. Ripping as in B. followed by planting into a half inch wide by two inch deep microseedbed prepared using the Howard Rotaseeder. In the second season the seedbed was increased to eight inches wide by four inches deep. Weed control within the inter-row uncultivated area was effected by the use of Gramoxone spray with the object of maintaining a dead weed mulch cover to assist water infiltration and prevent soil erosion (Plate 11)

E. Ripping followed by tie ridging using the N.I.A.E. tie ridging equipment and planting on the ridge

The N.I.A.E. Tie Ridging Equipment

This cultivation system has been described by Cashmore and Hawkins (1957). The subsequent modifications to the equipment (Macartney 1968) were used in this work. The ridging treatment C. was set up with the same equipment except that the ridges were not tied and no ripping of the furrow bottoms was carried out (Plate 12).

In the first season the N.I.A.E. ripping tines were used for primary cultivations on treatments B.- E. Although a good shattering action was achieved it was considered beneficial to leave the surface of the rip mark more open and in 1967-68 a blade was attached to the ripper shank for this purpose (Plate 13). The results obtained are shown in Plate 14.

3. Experimental Methods

a) Soil Moisture Sampling

The total available moisture within the root range was measured by gravimetric soil moisture samplings at flowering and harvest. Samples were taken at one foot intervals using the four inch

Australian Jarrett auger and collected in two ounce airtight tobacco tins, fresh weights being recorded as soon as possible after sampling. In the laboratory the tin lids were removed and the samples placed in a drying oven for 48 hours at 100°C. The oven dry weight was recorded after cooling and the moisture content calculated as a per cent oven dry soil. The gravimetric results of moisture were converted into volumetric measurements and expressed as inches of water by the use of a conversion factor derived from volume weight. The soil moisture expressed on a volume basis gave a measure of the actual quantity of water in the known depth of soil. Water at wilting point was subtracted to give the available water within the profile.

Two profiles were taken at each sampling from one replicate of each treatment. These determinations were combined with frequent records from electrical resistance units to give continuous information on tension and fluctuations in the soil moisture content.

b) Electrical Resistance Units

Cylindrical gypsum blocks supplied by E.A.A.F.R.O. and based on the Bouyoucos (1940) design modified by Pereira (1951) were used to provide continuous information on the soil moisture tension, depth of moisture penetration and the availability of soil moisture to the growing plant. A 'Sciex' ohm-meter with a log-ohm scale was used for reading the resistance. When the blocks were considered to have come into equilibrium with the surrounding soil they were read twice weekly. All readings were plotted on a working graph which included daily rainfall.

c) Placement of Units

A hole was drilled by auger to the required depth and 500 ml. of water poured in and allowed to soak away. Each unit was slowly saturated by lowering into a bucket of water an inch at a time and eventually left submerged for five minutes. A saturated reading was taken with the ohm-meter to check that the unit was working satisfactorily. The block was then lowered into position and another reading taken. The lead was held taut while the hole was refilled; the soil being returned in the same order as it was excavated. The soil was tamped back into the hole and about one inch above the unit it was rammed hard to form a plug and prevent free drainage down the profile. A final reading was taken to check that the leads had not been damaged during refilling. The connecting wires were channelled at a depth of 18 ins. to avoid damage during cultivation.

d) Field and Laboratory Techniques Used in Soil Core Analyses

For determination of infiltration rate, total pore space and pore space drained at successive tensions, undisturbed samples of soil were required. Three six foot pits were core sampled in the range 0-6 ins.,1,2,3,4,5 and 6 feet on the 15 May 1968.

For the collection of this type of core, specially adapted samplers have been designed by the Soil Physics Division, E.A.A.F.R.O. and are described by Dagg and Hosegood (1962). Tins of standard size with slip-on lids at both ends were used for storage. The size of core taken was four inches in diameter, three inches deep and had a volume of 597 cc.

e) Collection of Undisturbed Cores of Topsoil

Before the collection of a sample the cutting ring was removed from the sampler and the numbered tin or sleeve fitted in and the cutting ring replaced. The loaded sampler was driven vertically into the soil by means of the sliding hammer. After the soil had been dug away from around the sampler the core of soil in the sleeve was ejected by pushing the piston, the soil cut off level with the sleeve and lids placed on both ends. If the tin was not completely full a volume correction was made in the laboratory.

f) Laboratory Preparation of Soil Cores

The bottom lid of the core was removed and replaced by a coarse cloth membrane. Those cores requiring a correction for volume were re-measured and, after all determinations had been completed, re-checked by rapidly flooding the core while still wet. The amount of water required to fill the space unoccupied by soil was recorded.

g) Initial Wetting of Soil Cores

The cores were placed cloth down on the stage of a large dessicator and the pressure reduced by means of a filter pump. When the pressure had dropped to about ½ atmosphere the water level in the dessicator was slowly raised to within one cm. of the top rim of the core. The cores were thus gently wetted by water percolating up through the cloth membrane. When the soil on the top of the core was thoroughly saturated re-entry of air was slowly permitted after five minutes. The water was then siphoned out of the dessicator.

h) Pore Space Determination, Field Capacity and Wilting Point

Water was allowed to drain under gravity from the layer pores until the system had reached the pre-set tension of 20 cm. of water. This proportion of pore space drained is a useful measure of structure for surface soils and of the drainage properties of sub-soils.

Field capacity and moisture content at wilting point were determined in the laboratory by the use of 'pressure plates'. A tension of 330 cm. of water has been shown to correspond to field capacity for some East African soils. (Pereira 1955). At this tension drainage under gravity had become slow enough to regard the remaining soil water as 'stored'. The 'Ceramic tile' type field capacity tension tables (Hosegood 1961) were used for the determination.

The cores having been placed on the low tension tables were left for 24 hours to drain before weighing. After the first weighing the cores were replaced on the partially reflooded tension table. The cores were re-weighed every 24 hours until equilibrium was reached and were then transferred to the tension tables set at ½ atmosphere and the procedure repeated until equilibrium was reached at this tension. The moisture content was then calculated for the equilibrium weight of the core at each tension as a percentage of the oven dry weight of soil and also as a proportion of total pore space.

Wilting point was determined by use of pressure plates using compressed nitrogen at 15 atmospheres. An assessment of wilting point was also made in the field by soil moisture sampling in conjunction with the gypsum units which record a tension of 4.8 log-ohms or over at 15 atmospheres.

i) Determination of Percolation Rate

After thorough slaking during the course of tension place determinations, the cores were transferred to a Buchner funnel for percolation under a static hydraulic head. A wide rubber ring fixed to a spare tin was fitted to the sleeve of the core to form a watertight upward extension. A No.1 grade filter paper was placed on the soil surface of the core and flooded to a depth of one cm.

The depth was maintained by a constant level siphon and when the flow of water through the core became steady four consecutive two minute readings were taken. The water percolated through the core was measured as ml. of water/2 min. and for final presentation as inches/hour.

j) Rainfall Acceptance

The rainfall acceptance test developed by Pereira (1956) was carried out by applying the equivalent of one inch of rain at a standardised drop-size in ten minutes, with a suction of 20 cm. applied at the base of the core. After this period the core was allowed to drain under suction for five minutes when percolation and run-off was measured.

k) Determination of Real Volume

The specific volume (reciprocal of the specific gravity) is usually fairly constant and it was only necessary for a limited number of samples to be taken for this measurement.

A 100 gm. sample from the pulverised soil of the core was placed in a 500 ml. graduated flask quarter filled with water. The flask was shaken and more water added to cover the soil. A suction of $\frac{1}{4}$ atmosphere was then applied by filter pump for five minutes. Water was then added to fill the flask.

W_1 = weight of flask in gm.

W_2 = weight of flask + soil (100 gm. sample + water)

Vol. of flask (in ml.) $- W_2 - (W_1 + 100)$ = R.V. for 100 gm. of soil.

l) Bulk Density Measurements

Bulk density measurements were made on each replicate of each treatment after the first year's harvest at the 0 - 1½ in. and 1½ - 3 in. depth and from uncultivated soil around the experimental area. The details of the sampler used are shown in Fig.1.

m) Root Washings

The roots of plants representative of each treatment were exposed by washing with a small hand sprayer and photographed.

n) Rainfall

In view of the extreme variability in the rainfall pattern over the area rainfall records were averaged from three permanent sites equidistant from the trial from which records were available from 1953.

4. Field Operations 1966 - 67

The five acre experimental site was cleared and stumped during early November. The indigenous regenerating Acacia/Comiphera fifteen foot high thicket was raked off and piled on the perimeter of the trial as a partial protection against game animals. There was little perennial grass cover with the exception of isolated patches of star grass (Cynodon dactylon).

Fertilizer Application. An overall dressing of two cwts/acre of single Super Phosphate (21% P_2O_5) and one cwt/acre of Ammonium Sulphate Nitrate (26% N) was broadcast by hand before cultivation.

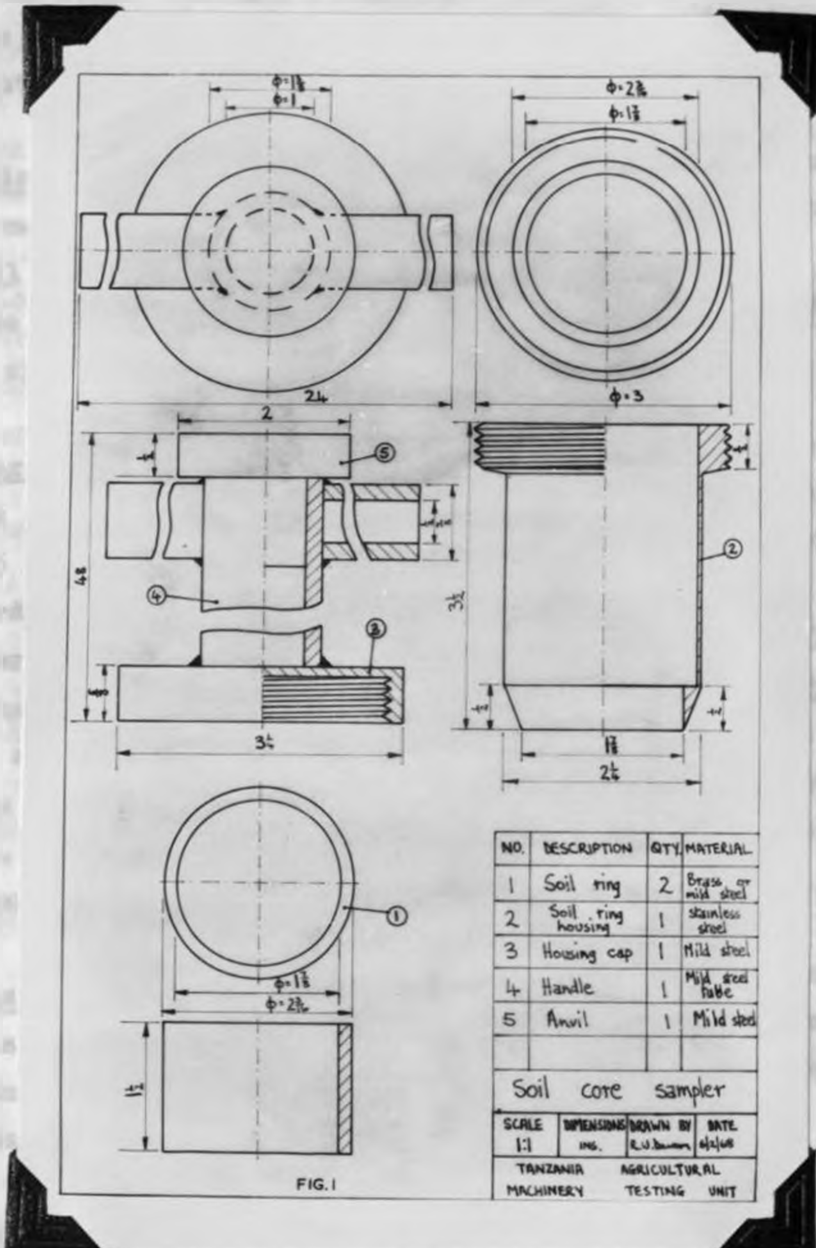


FIGURE 1.

Hand sampling tool for taking undisturbed soil cores

Ripping. Ripping of treatments B,C,D and E was first attempted using two rippers at six foot centres on the 3 December. The bodies failed to penetrate. Using one ripping body with an offset marker a reasonable standard of work was obtained with a penetration of between eight and ten inches.

Ploughing. Treatment A was ploughed on the 3 December using a single furrow disc plough pulled by a MF 35 tractor. With no rain since the 23 November conditions were dry and difficult. It was necessary to heavily weight the plough beam to achieve a penetration of four to six inches.

Ridging. Initial ridge building on treatments C and E was carried out on the 6 December using three No.1 lister bottoms on the N.I.A.E. 15 ft. toolbar pulled by a Fordson Super Major tractor. The standard of work was only moderate as the ridging bodies tended to jump over the hard patches of soil. A certain amount of lateral swing on the toolbar made accuracy of building difficult. Tying of the ridges on treatment E was omitted at this stage as large clods left in the furrow bottom would have made the operation virtually impossible. It was also considered that the clods would act as a physical barrier to water movement down the ridge.

Placement of Gypsum Blocks. The two profiles of blocks at one foot intervals on each plot were installed on the 17 December. Soil moisture tensions were read twice weekly throughout the growing season.

Final Seedbed Preparations and Planting, 21 December.

i. The ploughed plots were disc-harrowed twice and planted.

ii. The ripping and harrowing treatment plots were disc harrowed three times and planted.

iii. The ridges in the tie-ridge and ridge treatments were split back, 'rubbed up' and planted.

iv. The direct drilled plots were sprayed with 'Gramoxone W' at a rate of 1½ pints per acre in 20 galls. of water and the seedbed prepared with the Howard Rotaseeder.

The variety M6 maize, a short term drought resistant selection, was used at a three by one foot spacing throughout. On all treatments the planting operation was satisfactory with the seed well covered and accurately placed.

Post Planting Operations. Aldrin was applied on 27 December at one pound active ingredient/acre on the surface for the control of termites and millipedes. Hand weeding and thinning were carried out on 30 January and population counts recorded on 15 February.

Gravimetric soil moisture samplings were taken on the 9 February (flowering) and on the 12 May (harvest).

5. Results

a) Rainfall

The precipitation recorded in inches during the 1966-67 season was:

Pre-planting	November 1966	1.55	(3)
	December	1.50	(5)
		3.05	(8)
Planting to harvest	December 1966	1.94	(5)
	January 1967	3.14	(10)
	February	3.29	(11)
	March	2.35	(8)
	April	6.94	(22)
	May	0.86	(6)
		18.52	(62)

The season could be described as 'average' with a total of 18.52 in. compared to the 14 year average of 22 in. Effective rain fell immediately after planting and continued to give favourable moisture conditions during the establishment period, while the above average April rainfall helped to boost the final yields obtained.

b) Plant Populations and Yields

Population count of total number of plants per 25 rows and plant population per acre calculated after thinning to one plant on the 15 February are given together with yields in Table 9. Rainfall (0.49 in.) immediately after planting on the 22 December was followed by 1.32 in. in four days by the end of the month. The large differences in plant counts can therefore be attributed to the different treatments used in seedbed preparation.

The best establishment was obtained on the ploughed and harrowed plot, followed closely by the ripped and ridged and ripped tie ridged treatments. A sharp decrease in population was recorded with decreasing depth of cultivation i.e. ripping and disc harrowing with a virtual failure on the ripped and direct drilled treatment.

Harvesting was carried out between 2 - 19 June. Because of late season rainfall plants were cut and stooked and later cobbed.

Yields were generally good for this area which was largely due to well distributed rainfall throughout the growing season. Results of cob and grain weights are closely comparable with population establishment. The ripped and tie ridged treatment gave the best yield although the plant population on this treatment was slightly below that of ploughing and discing.

TABLE 9 MEAN PLANT POPULATIONS AND GRAIN YIELDS (lb) PER ACRE KONGWA 1966-67

Treatments	Plant Populations		Grain Yields	
	per acre	% of total population	per acre	shelling %
A. Disc plough and harrow	8,887	61.2	1,053	83.5
B. Rip and disc harrow	6,111	42.1	905	84.0
C. Rip and ridge	8,401	57.9	1,067	82.5
D. Rip and direct drill	671	4.6	28	-
E. Rip and tie ridge	8,517	58.7	1,147	83.4

c) Bulk Density of Soil

The bulk density of the top soil was recorded at 1½ in. and 3 in. on each cultivation treatment after harvest and also from four sites on a non cultivated area adjacent to the trial (Table 10). The high bulk densities recorded on uncultivated soils would appear to be limiting for maize root penetration as recorded by Veihmeyer and Hendrickson (1948), Kohnke (1957) and Trouse and Humbert (1961).

TABLE 10 MEANS OF BULK DENSITY (g.cc) MEASUREMENTS TAKEN AT HARVEST FROM THE EXPERIMENTAL TREATMENTS AND FROM UNCULTIVATED SOIL

Depth (inches) Treatments	0 - 1½	1½ - 3	Depth (inches) Site	0 - 1½	1½ - 3
A. Disc plough and harrow	1.19	1.22	Site 1	1.37	1.28
B. Rip and disc harrow	1.39	1.47	Site 2	1.52	1.53
C. Rip and ridge	1.25	0.98	Site 3	1.52	1.50
D. Rip and direct drill	1.38	1.11	Site 4	1.55	1.47
E. Rip and tie ridge	1.23	1.03			

Volume of sampling cylinder 69.48 cm^3

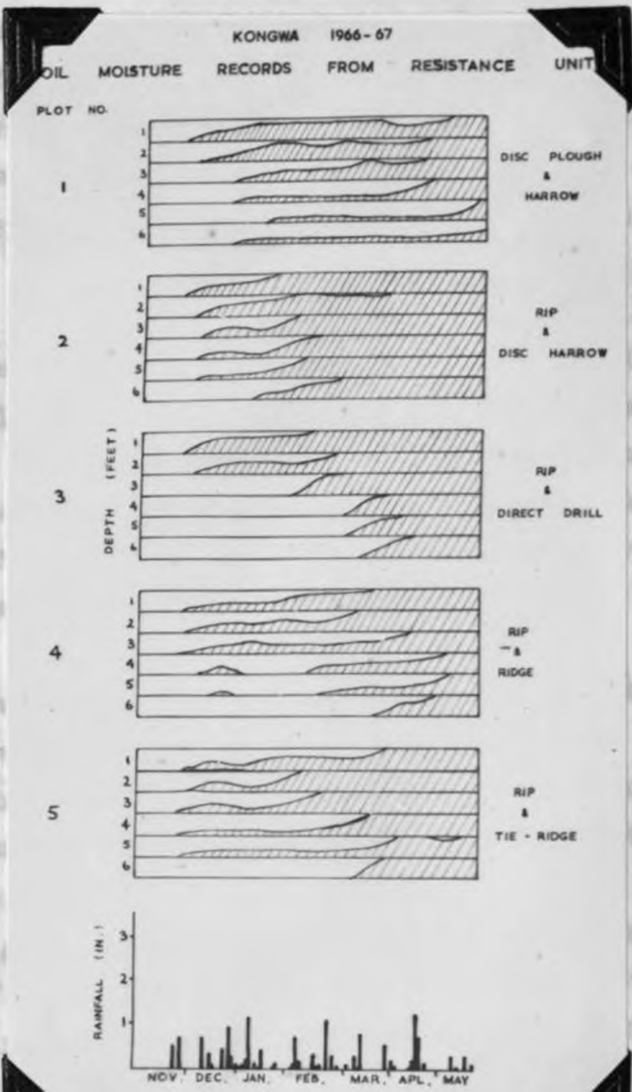
The bulk density is lowered with increasing 'intensity' and depth of cultivation. Yield of grain also appears to be related to the final bulk density readings. On the rip and direct drilled plots the bulk density recorded is within the range where maize seedling root penetration would be inhibited (Kulota and Williams, 1967).

Bulk density is on the average higher in the surface 1½ in., presumably due to raindrop compaction. The rip and disc harrow treatment shows a slightly higher density in the 1½ - 3 in. layer which may be due to the consolidating effect of the discs working at that level.

d) Distribution of Soil Moisture

The distribution of available moisture with depth and time by plotting the log resistance of the gypsum blocks is summarised in Figs. 2 and 3. The shaded areas show with useful accuracy the time and depth at which the soil moisture tension reached the approximate limits of one and fifteen atmosphere. The curves joining these points outline the conditions of water availability between these limits, the relation of log-resistance to p.f. being linear (Pereira and Jones, 1954).

The 1966-67 season was not particularly suitable for demonstrating moisture difference within the profile due to the various tillage treatments which could be expected to be reflected in the final yields. Good establishment rains were followed by sufficient rain pre-flowering to maintain crop growth and were followed by heavy end of season precipitation which recharged the profiles to six ft. by harvest. Differences were evident however in the initial and subsequent infiltration and percolation rates between treatments, although the effect of this on yield was masked by good rainfall distribution.



KONGWA 1966-67
OIL MOISTURE RECORDS FROM RESISTANCE UNIT
PLOT NO.
DISC PLOUGH & HARROW
RIP & DISC HARROW
RIP & DIRECT DRILL
RIP & RIDGE
RIP & TIE - RIDGE
DEPTH (FEET)
RAINFALL (IN.)
NOV. DEC. JAN. FEB. MAR. APL. MAY

FIGS. 2 & 3

The ploughing and discing treatments showed good initial infiltration to the two ft. level with the early rain but rapid capping of the surface soil affected the rate of water penetration thereafter. It was not until the March - April rain that the four to six ft. levels showed field capacity. The available moisture at two and three ft. was utilised during drought periods in mid-January and mid-February showing good root growth to four ft. by the latter period. The rapid recharging to the three ft. level on the 21 February may well be due to the breaking of the surface cap by hand weeding.

There were no apparent differences between initial infiltration rates on the ploughing and ripping and ridging treatments but there is evidence of better moisture regimes existing at depth with the ridging treatments as the season progressed. This was backed up by observations of run-off on the ploughed plots while rainfall was readily absorbed on the ridged plots.

Both the ripped and disced and 'ripped and direct' drilled treatments showed excellent initial infiltration and percolation. However, poor root development with the former and crop failure with the latter has rather distorted the moisture withdrawal pattern.

There is good agreement in the benefit of ripping in the improvement of water infiltration in all the ripped treatments when compared with ploughing. Full profiles by the end of March were recorded but it was only on the tied ridge treatment that roots were beginning to withdraw water from the five ft. level.

e) Gravimetric Soil Moisture Samplings

The mean total available soil moisture to six ft. for both seasons given in Table 11. The individual sampling data are too numerous to set out in full and are included under Appendices 1 - 4. These figures afford useful confirmation of the soil moisture availability described by Figs. 2 and 3 and in particular the beneficial effects of ripping on percolation of water to depth. The apparent high water availability on the ripped and disced plots is due to stored water at depth below the rooting zone.

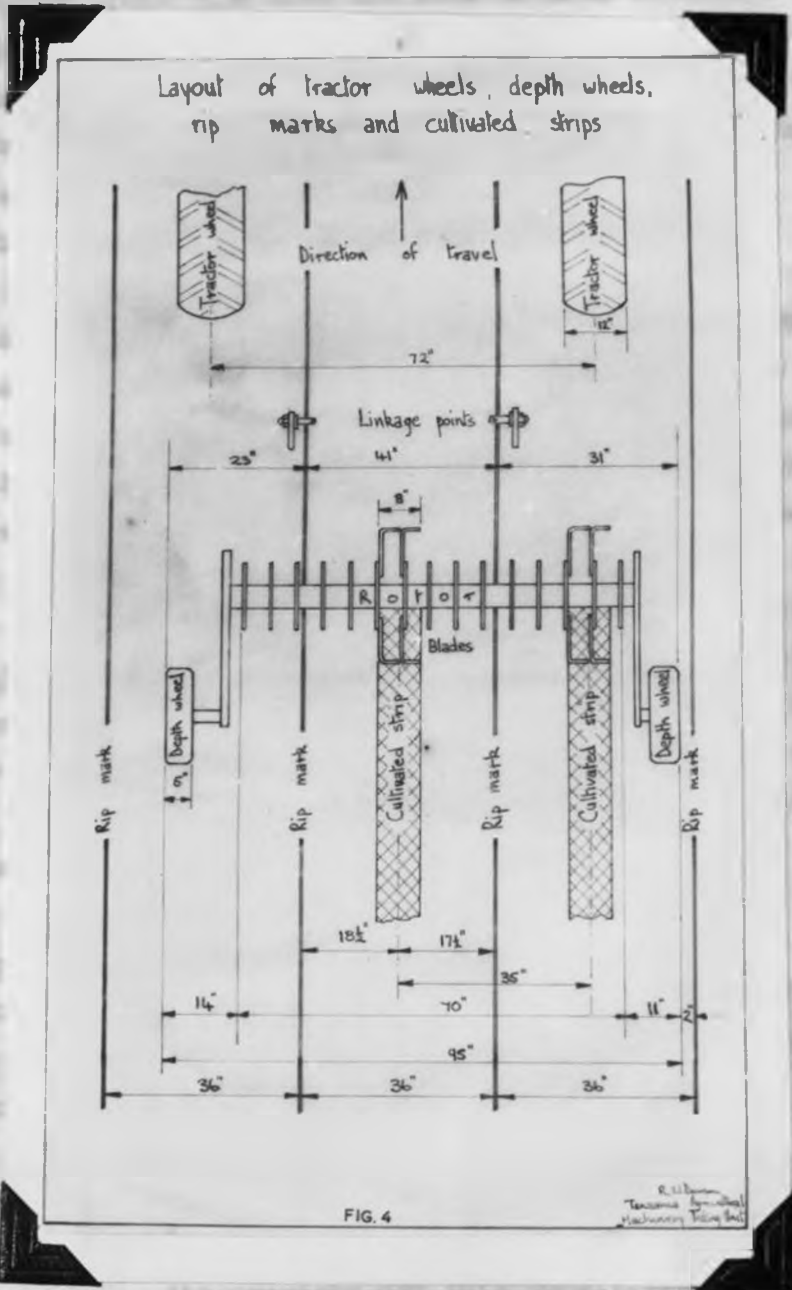
TABLE 11 MEAN TOTAL AVAILABLE MOISTURE IN INCHES WITHIN THE POTENTIAL ROOT RANGE (SIX FEET)

Treatment Means	1966-67 season		1967-68 season	
	Flowering 9 February	Harvest 12 May	Flowering 6 March	Harvest 19 May
Disc plough and harrow	1.16	2.42	5.17	4.66
Rip and disc harrow	1.54	3.23	6.54	5.07
Rip and direct drilling	*	*	5.99	5.12
Rip and ridge	1.38	4.34	6.13	4.83
Rip and tie ridge	1.64	3.84	7.62	6.19

* Crop failure, plots were not sampled.

As a result of the complete failure of the direct drilling treatment during the 1966-67 season, a complementary programme of research was commenced to investigate the reasons for this occurrence. The results of this work are reported in Section D. The width and depth of cultivation used in the minimal tillage treatment during the 1967-68 Kongwa season was increased to eight by four inches in accordance with the findings of this interim work.

The Howard Rotaseeder was modified (Fig.4) during the dry season to work the increased width and depth of cultivation.



Layout of tractor wheels, depth wheels, rip marks and cultivated strips
Direction of travel
Tractor wheel
Tractor wheel
12"
72"
Linkage points
23"
41"
31"
8"
Rotor
Blades
Depth wheel
Depth wheel
Cultivated strip
Cultivated strip
Rip mark
Rip mark
Rip mark
Rip mark
18½"
17½"
35"
14"
70"
11"
2"
95"
36"
36"
36"

FIG. 4

6. Field Operations 1967 - 68

Land Preparation. The site was hand cleared of small regenerating bush and ploughing of plots 1 and 6 carried out on 8 November using a single disc mounted on a MF 35 tractor. The depth of ploughing varied from three to six inches, averaging about 4½ in. The soil was dry and working conditions were difficult with the plough set for maximum penetration.

All ridged plots were ripped along the furrow bottoms of the previous season's cultivation using two ripper tines set at six feet centres. During the dry season the insulation from the wiring of the gypsum blocks was removed by termites. The block profiles were replaced and Aldrin applied to the trenches carrying the wires.

Fertiliser Application. One cwt. single super Phosphate and one cwt. Ammonium Sulphate Nitrate per acre was applied by hand on 12 December. One pound active per acre 40 per cent Aldrin was also given as a top dressing and later incorporated by cultivation for termite control.

Herbicide Application. The direct drilled plots were sprayed with Gramoxone at two pints/acre on 12 December. These plots were carrying a heavy weed cover and results of spraying were generally satisfactory.

Pre-Planting Cultivations. The ridged and tie-ridged plots were 'rubbed up' using three No.1 lister bottoms. Light but penetrating rain on the previous day left conditions ideal and excellent results were obtained with this cultivation.

On the ripped and disced plots three separate discings were necessary to control a heavy weed cover. The previously ploughed plots required only one harrowing for seedbed preparation.

The direct drilled treatment was cultivated using the Rotaseeder carrying eight inch blade combinations at 35 in. centres. Strips were cultivated to four inches depth and a further hand spraying of Gramoxone at one pint per sprayed acre was applied to the inter-row growth after cultivation.

Planting. The trial was planted with the variety M6 on the 16 December using MF planters on the N.I.A.E. toolbar. Between final cultivation and planting 1.58 in. of continuous rain falling in 14 hours was recorded. Conditions at planting were ideal and excellent germination and establishment was achieved.

Thinning and Population Counts. All plots were hand weeded and thinned to one plant per hill on the 27 - 29 December. Further weedings were necessary on the 8 January, 19 January and 10 February. Plant population counts were recorded on the 20 February.

Soil Moisture Recordings. Block recordings commenced on the 1 December and continued to harvest. Gravimetric soil moisture determinations were made on the 6 March (mid-flowering) and the 19 May (harvest).

Harvest. The maize was cut and stooked on 10 - 12 April and after drying the cobs were removed to store for threshing and weighing.

Plant Heights and Root Washings. Representative plants from each treatment were photographed at harvest (Plates 16 - 19) and root washings carried out after harvest (Plates 20 - 23).

7. Results

a) Rainfall

Pre-planting rains	November	1967	2.42	(4)
	December		8.84	(8)
			11.26	(12)
Planting to harvest	December	1967	4.35	(9)
	January	1968	7.67	(14)
	February		6.13	(7)
	March		10.29	(19)
	April		3.17	(6)
			31.61	(55)

This season was the highest rainfall on record at Kongwa. Early November rain helped to give a good standard of initial tillage preparation and continuous effective daily rain after planting resulted in good germination and establishment.

b) Plant Populations and Yields

Population counts per acre and the percentage of the total optimum population together with yields are presented in Table 12. Little differences were evident in these counts taken nine weeks after planting, with the exception of the ridged treatments which were slightly lower. This was due to plants being washed out of the ridge during heavy intense January storms. Leaching of nitrogen through the profile resulted in visual nitrogen deficiency in all treatments.

TABLE 12. MEAN PLANT POPULATIONS AND GRAIN YIELDS (lb) PER ACRE

KONGWA 1967-68

Treatments	Plant Populations		Grain Yields	
	per acre	% of total population	per acre	shelling %
A. Disc plough and harrow	11,129	76.6	740	80.7
B. Rip and disc harrow	11,054	76.1	623	82.9
C. Rip and ridge	10,379	71.5	646	81.5
D. Rip and direct drill	11,227	77.3	590	83.6
E. Rip and tie ridge	10,579	72.9	745	79.6

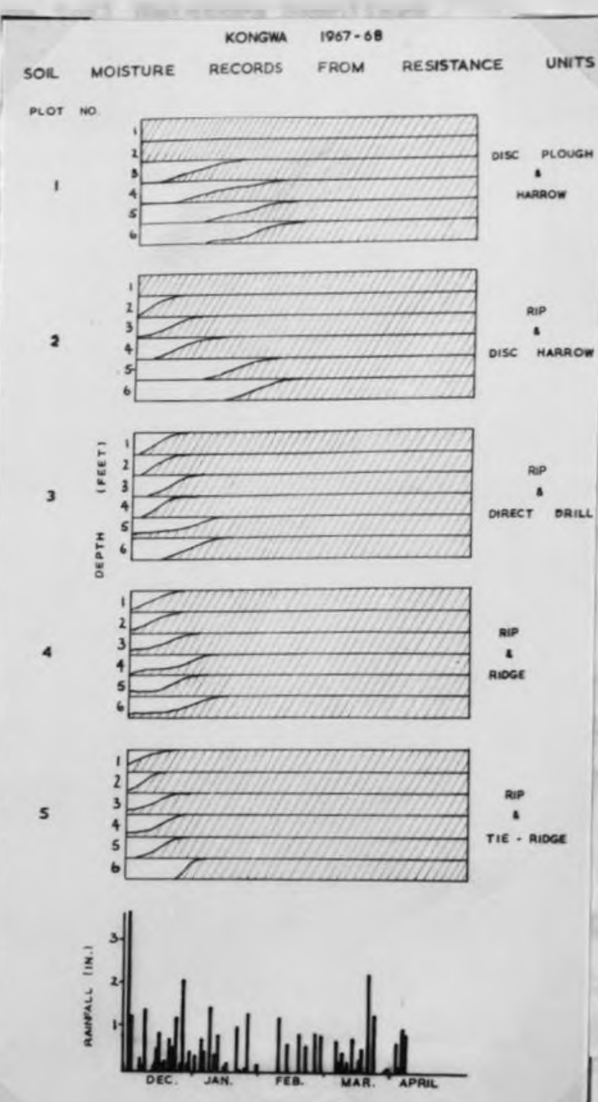
Average grain yields were less than the 1957-58 season which was primarily due to the excess rainfall throughout the growing season. The maize variety used, M6, selected for its dwarf, drought resistant characteristics, was quite out of environment during this season. The ploughing and tied ridge treatments gave the best yield with minimal tillage producing over 100 lb. less grain per acre although with a higher grain/cob ratio.

c) <u>Distribution of Soil Moisture</u>

The water distribution within the profile is presented in Figs. 5 and 6. The well above average rainfall recorded resulted in all profiles remaining at field capacity from the end of December until the end of April. There were however differences between the various treatments in the recharging period during December. Effective rainfall was recorded on 18 and 24 November and when the readings were commenced on 1 December the one and two foot levels were showing available moisture. This was particularly true of the ploughed plots where the top two feet were saturated by 1 December. The delayed infiltration beyond this level was again evident which together with observations of severe run-off on this treatment bears out the previous criticism of poor subsequent rainfall acceptability once random roughness has been lost and surface sealing occurs.

All the ripped treatments showed rapid recharge to the five foot level with the ridged treatments slightly more favourable in this respect. Tie ridging was, as would be expected under this rainfall condition, the most efficient treatment for water absorption and it was on these plots and those of the rip and direct drilled treatment only that surface run-off was well controlled.

The ripped and disced plots again showed reduced infiltration rates after good initial absorption while the effect of surface cultivation remained. Sealing of the rip marks was observed at an


KONGWA 1967-68
SOIL MOISTURE RECORDS FROM RESISTANCE UNITS
PLOT NO.
1
2
3
4
5
DEPTH (FEET)
1
2
3
4
5
6
DISC PLOUGH & HARROW
RIP & DISC HARROW
RIP & DIRECT DRILL
RIP & RIDGE
RIP & TIE - RIDGE
RAINFALL (IN.)
3
2
1
DEC.
JAN.
FEB.
MAR.
APRIL

FIGS. 5 & 6

early stage with resultant loss of permeability down the profile.

Insufficient data was available to plot the log-ohm records of Replicate II of the tie ridged treatment.

d) Quantitive Soil Moisture Samplings

The mean total available water within the profiles recorded at one foot intervals at flowering and harvest (Table 11) again confirm the general picture given by the resistance units. In addition they support the observations made on rooting depth with evidence of water withdrawal at differing depths for the various treatments. Although roots were observed at 80 cm. in the tied ridge plot, the available water in this treatment as a mean of the replicates was 1½ in. more than ridging, the second best treatment for water storage. This increase in available moisture was not only a reflection of better storage at depth but also within the two to three feet level where the roots were withdrawing water.

The comparatively poor availability of moisture under the ploughed treatment at depth is shown. This affected the total availability, within the profile, averaging five inches as compared to 7.6 in. under tie ridging.

e) Observations on Root Growth and Plant Vigour

In a year of well above average rainfall where the plants were never under moisture stress, it was expected that rooting depth would be limited compared to that reported by Pereira (1958) under a 22 in. rainfall.

The root systems of the maize on the ploughed plots showed good development to the depth of ploughing only (Plate 20). Similarly on the disced plots main roots were concentrated in the top ten cm., the depth of disc cultivation (Plate 21). The same was true under minimal tillage where roots were concentrated in the top 13 cm. (Plate 22). The root systems under the tied ridge cultivation showed the beneficial effects of ripping together with deeper cultivation (Plate 23).

The plant growth at harvest (Plates 16 - 19) further demonstrates the differential effect of cultivation treatment.

f) Water Storage Capacity of the Soil Profile

The physical characteristics of the Kongwa soils are presented in Table 13. The results obtained for each foot in depth were used to convert the moisture sampling data into equivalent inches of rain.

The cores showed very little variation in the real and apparent soil densities of successive horizons. The soil is relatively free draining which is shown by the volume/weight ratio. The bulk densities are high and decrease slightly with depth which is also reflected in the total pore space distribution.

The tension determinations on the soil cores wetted under reduced pressure showed that 6½ ft. of soil could hold a maximum of 27½ in. of water at a tension of 20 cm. This would drain very rapidly to about 23 in. at field capacity.

The water holding capacity calculated from field capacity and wilting point showed that the profile could hold 12½ in.or 1.9in.per foot. These are limiting maximum values which the soil moisture samplings subsequently showed to be substantially beyond those reached in the field when the profile was saturated during harvest 1968. This may be partly due to entrapped air preventing the soil from reaching full saturation and also to the fact that the soil profile does not reach equilibrium

TABLE 13 PHYSICAL CHARACTERISTICS OF KONGWA SOILS
(Means of 3 pits and 2 cores per site)

	Surface 0-3 in.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	TOTAL
Moisture, in. of water at 20 cm.	1.64	4.12	4.30	4.29	4.26	4.53	4.44	27.58
Moisture, in. of water at 330 cm.	1.23	3.12	3.48	3.61	3.54	3.90	3.95	22.83
Moisture, in. of water at wilting point (15 atmospheres)	0.92	1.46	1.48	1.56	1.55	1.63	1.82	10.42
Apparent volume of 100 grm. dry soil	73.1	75.1	74.4	74.5	74.5	76.0	78.4	
Bulk density in g./cc.	1.37	1.33	1.34	1.34	1.34	1.32	1.28	
Percolation rate in in./hr.	25.6	19.8	12.8	17.3	7.4	13.2	10.9	
Pore space drained at 20 cm. as % T.V.	18.2	13.4	10.8	11.3	11.6	10.3	12.7	
Pore space drained at 330 cm. as % T.V.	24.9	21.8	17.3	17.1	17.6	15.5	16.9	
Rainfall acceptance of 1½ in. of rain in 10 minutes	0.38"							

at field capacity at all depths simultaneously.

The surface stability of the soil under simulated rainfall conditions is shown to be poor, and despite the good percolation rates run-off is to be expected due to surface capping.

The pore space drained at 20 cm. as a percentage of total volume is well above the nine per cent level where aeration can become limiting to plant growth.

8. Discussion

At the outset the aim of reducing cultivation expenditure under Kongwa conditions using direct drilling techniques was based on local observation of peasant agriculture procedures for maize growing. The land is cleared and at the onset of the rains the maize is planted in shallow holes prepared with a hand hoe. The mechanisation of this system using the Howard Rotaseeder and opening a micro seedbed resulted in complete failure of the crop to germinate. The primary root was unable to penetrate the bottom of the slit and with rapid drying and wetting, the seed rotted. The physical analysis of the soil shows that the reason for this failure is undoubtedly due to the highly compacted soil. Increasing the width and depth of the seedbed in the second season overcame this compaction problem sufficiently to enable good establishment. Grain yields were however less than those obtained with the overall cultivation treatments and it would appear from the root growth that the amount of cultivation was still insufficient for this soil with such an adverse physical nature.

Too much emphasis was placed in providing for optimum infiltration in the overall system in this study and there is little doubt that had the ripping operation been carried out under the immediate seedbed instead of between rows this compaction problem could at least have been partially overcome, as shown by Stout (1959) in his work on sugar beet emergence. Maintenance of a dead weed and crop residue mulch between the rows has been shown to improve moisture infiltration. Burwell et al (1968) refer to this system as 'zone tillage' and define it as providing satisfactory seedbed requirements while allowing a proportion of the field surface area to be managed to satisfy infiltration needs by mulching with crop residues.

The fact that cultivation at Kongwa has a deleterious effect on soil structure (Pereira et al 1958) suggests that the zone tillage system would have an advantage over the tie ridging system as soil disturbance is less. Theoretical power requirements and therefore cost of cultivation shoudl also be reduced. It should be noted that maintenance of mulch at Kongwa is dependent on termite (Microtermes sp)control which can be effected by applying Aldrin to the seedbed (Bigger 1965).

The beneficial effect of ripping on moisture infiltration is shown by the amount of water available at planting and harvest during the dry season of 1966-7 (Table 11). All the ripped treatments had more water available at flowering than the disc ploughed plot . Better infiltration to depth by ripping is well demonstrated by the gypsum blocks (Figs. 2-4). The desirability of ripping was realised during the final stages of the O.F.C. scheme (Minto, personal communication, 1968). Compacted regions at ploughing and discing depth seriously restricted water movement down the profile. This reduction in infiltration not only increased the opportunity for surface water run-off and soil erosion but could become a further limiting factor to crop growth in a year of average or below average rainfall where water storage is of prime importance. The difference in run-off observed between treatments indicated that an operation which promotes water entry must be an integral part of the system.

The heavy rainy season in 1967-8 provided conditions where moisture was at no time limiting for growth yet the mechanical impedance to root development with reduced tillage was equally evident as compared to the previous season. The ploughing and discing treatments exhibited lower infiltration rates as a result of surface sealing and although germination and establishment was good, later root development was retarded, a factor which would result in crop failures in a dry year when moisture would be withdrawn from the five to six foot range (Pereira 1958). The root washings taken at harvest showed the reduction in adventitious roots at depth under ploughing and disc harrowing. The physiological importance of these roots in relation to final yield was stressed by Boatwright and Ferguson (1967). Ploughing at Kongwa, during wet or dry conditions, leaves a surface with a low level of random roughness, the importance of which for moisture infiltration is stressed by Burwell (1968). Initial infiltration is good but transitory as demonstrated by both the resistance units and soil samplings.

This present work has attempted to minimise cultivation expenditure and as a result has more closely defined the inherent difficulties of crop production on this soil under a particular environment where tillage research hopefully could ameliorate a serious physical problem. The evidence presented suggests that mechanical impedance should be regarded as having a widespread influence on the growth of roots rather than a factor that operates only in unusually strong soils.

The physical properties of the soil which influence the behaviour of plants are relatively few but their interactions are so complex as to make it almost impossible to reach quantitive conclusions with respect to the significance of individual factors. Some, though certainly not all, of the confusion and non reproducibility of the results abstracted from the literature is due to the lack of uniformity in the methods whereby soil physical conditions are altered for experimental purposes. The interpretations of results of these many and varied experiments in terms of one variable alone is only valid if 'sub-optimal' levels of other factors are shown to be absent in all treatments. These conditions can be said to be, for all practical purposes, fulfilled under field conditions at Kongwa. The status of our understanding of this problem does permit the research worker with access to information on soil texture, pore size distribution, available water etc. to anticipate intelligently where compaction problems are likely to arise and to diagnose the existence of soil conditions unfavourable to plant growth because of compaction.

The application of this work and its minor contribution to plant-soil-climate relations of the Kongwa area should help to define the job that a tillage tool must do. The fact that soil mechanics has been the domain of the engineer has been a handicap in attempting to apply the subject to agronomic problems, the solving of which must precede the development of agricultural machinery capable of overcoming such factors as mechanical impedance in the growth of crops.

9. Conclusions

The results indicate the importance of the soil physical properties in determining the growth of maize and the necessity for cultivation at some level of intensity to alleviate the compaction problem. Disc ploughing and harrowing combined with planting on the flat has been shown to be inefficient in terms of soil and water conservation. The operation is expensive and inevitably involves a delay in planting while the land is being prepared.

Ripping prior to the commencement of the rains has been shown to be efficient in conserving early rainfall. One subsequent operation whereby all necessary seedbed preparation and planting is done as a combined operation would make optimum use of rainfall and improve the reliability of cropping together with a reduction in cultivation costs.

The development of a zonal tillage system holds potential advantages over the tied ridge system in terms of reduced cost and soil structural deterioration.

B. THE EFFECT OF DIFFERENT WIDTHS AND DEPTHS OF CULTIVATION ON THE GROWTH AND YIELD OF MAIZE UNDER THE ZONAL TILLAGE SYSTEM

1. Background

The failure of direct drilling at Kongwa and the outstanding success of the same technique with wheat establishment, described later, at West Kilimanjaro presented an interesting problem on the amount of tillage necessary on different soils to achieve yields comparable with those from overall tillage in the first season.

From a critical appraisal of the Kongwa data including plant population, root growth and soil/moisture relationships, it was apparent that mechanical impedance to root growth was mainly responsible for initial crop failure and reduced yields in the second season. There appeared to be two separate considerations, firstly the preparation of a seedbed sufficient for germination and establishment, and secondly to overcome the soil compaction existing to depth which inhibited subsequent development and influenced yield.

Soil temperature, moisture and aeration are related in varying degrees within a compacted soil and have some bearing on the resistance met by roots in the soil and on their ability to overcome it. Any departures from the range of optimum values for these properties will reduce the ability of roots to penetrate (Hawkins and Brown, 1967). The current thought that lack of yield responses using minimal tillage practices elsewhere (Austin, personal communication, 1969) may be due to mechanical impedance as a result of too little tillage is becoming more prevalent.

New agricultural techniques often result in the need for a reappraisal of traditional practices. With reduced tillage the capacity of the soil to conduct and retain air and water and the requirements of the roots to be free to explore the whole soil zone need careful examination. With changing tillage procedures there is a growing appreciation of the significance of the influence of the physical condition of the soil on plant growth. For such a broadly defined property as soil structure,however, many evaluating procedures have been developed which differ not only in procedural details but in the identity of the particular characteristics that are measured. A complete physical description of the structural condition of the soil is essentially impossible although measurable factors that serve as indicators of soil structure have been described in the review.

In much of the literature indirect measures of soil physical characteristics have been employed as independent variables in regression equations. These are based on penetrometer readings, hammer blows etc. and can be used (Vomocial 1957) to predict the effects to be expected with the soil tested, for a particular crop and under identical weather conditions as obtained during the experimental period.

These empirical measures of mechanical resistance have in the past contributed little towards a real understanding of the reason for inhibited growth and provide little scope for generalisation; nevertheless their value in diagnosis of a compaction condition is undisputed.

The literature reviewed has described the maximum forces which can be exerted by roots, and critical values of bulk density have been established for various crops. It is certain that under conditions which inhibit root growth there can be no doubt about the need for increased soil disturbance. What is much less clear is the effect on root growth function and yield of soil resistances below the limiting value and hence the level at which tillage becomes essential (Hawkins and Brown, 1967). There also exists a certain confusion as to the difference between soil compaction and seedbed consolidation. The results reported show a general increase in yield with increasing bulk density or artificial compaction (Heath 1937, Stranak 1968) to an optimal value followed by a marked decrease in yield.

Many field experiments reviewed have demonstrated significant reduction in yield with increases in bulk density. The level of bulk density which caused reduced yields on one soil might not be critical on a different soil as there are other contributory factors.

The plant in compacted soil may respond to alterations in mechanical impedance, aeration and moisture availability within a critical density range for a given set of climatic conditions. Rosenburg (1964) has stated that the relationship of plant response to compaction, if expressed over a wide enough range, is parabolic.

In this work the objective was to be able to give some guidance on the amount of tillage necessary on four widely representative soil types of Tanzania through observations on plant growth.

2. Experimental Procedure

The first two trials carried out at Tengeru and Kongwa during the dry season were purely observational in an attempt to ascertain whether reduction in tillage was in fact a practical possibility on these two high bulk density soils which both showed symptoms of compaction. The Howard Rotaseeder was modified to give 1 in., 4 in., 8 in., 12 in. and 18 in. widths of cultivation (Fig. 7) with variable depths of cultivation possible by adjustment of the working depth control. As a result of the differences in plant population and plant height observed between the different treatments, further trials were laid down at Kongwa during the following rainy season and also at Sambwa and West Kilimanjaro. These experiments with the same treatments were fully replicated and more comprehensive plant vigour recordings were made.

3. <u>Experimental Soil Types</u>

The Kongwa soil has been described in the previous section. The West Kilimanjaro soil is described later in the text. Sambwa, a sub-station of the Ministry of Agriculture, lies on the western fringe of Masailand at the foot of the Kondoa Highlands escarpment. The soils are typical of most of Dodoma and Singida regions, being reddish-brown sandy loams, light textured, and containing about 80 per cent sand in the surface horizon. They are derived from gneisses, quartzites and schists of the Basement Complex and would fall into the Ferrallitic Groups as described by D'Hoore (1964). The area is extremely erodible with sandy material brought down off the highlands by rivers and surface wash. Rainfall, (Macartney 1966, 1967) has averaged 26.9 in. (683 mm.) over five growing seasons where records were available.

The Tengeru soil is described as a Tropical Vertisol or 'Mbuga' containing about 60 per cent clay and 20 per cent silt in the surface horizons. This compact cloddy clay exhibits typical vertical cracking during the dry season and although of high fertility

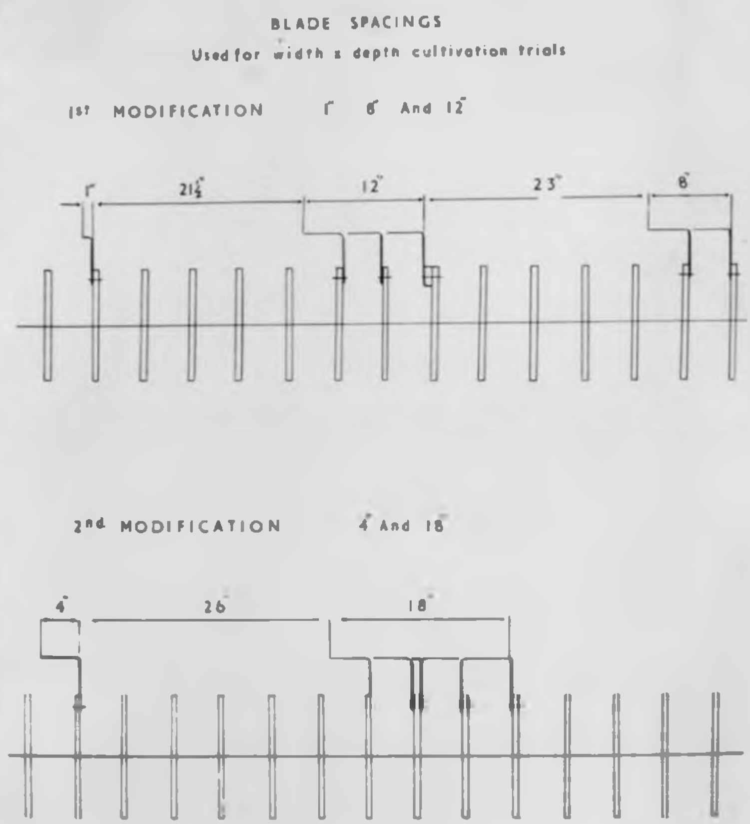

BLADE SPACINGS
Used for width x depth cultivation trials
1st MODIFICATION 1" 6" And 12"
1"
21½"
12"
23"
6"
2nd MODIFICATION 4" And 18"
4"
26"
18"

FIG. 7

is notoriously difficult to work when wet.

Circumstantial evidence of soil compaction exists for the Kongwa, Sambwa and Tengeru sites.

4. Field Operations

Tengeru. The observational trial was laid out on a Black Mbuga soil which had been under Rhodes grass (*Chloris gayana*) ley for three years. Prior to cultivation a hay cut had been taken. Band spraying with Gramoxone W at three pints/sprayed acre was carried out on the 27 June 1967 followed by cultivations two days later. Five runs each of 40 yd. using different depth settings gave 13 different treatments comprising the five widths at depths of $1\frac{1}{4}$ and $2\frac{3}{4}$ in. together with an additional three widths at $3\frac{3}{4}$ in. The $3\frac{3}{4}$ in. deep cultivation, at the 4 in. and 18 in. widths was not attempted due to the strain which would result to the Rotaseeder bearings.

Maize variety M6 was planted by hand on the 29 June and populations were recorded on the 25 July, four weeks after planting.

Kongwa dry season. The experimental area was sprayed overall with Gramoxone W at three pints/acre and cultivations carried out on the 11 July 1967 using the Howard Rotaseeder with the same width settings. Depth of cultivation achieved was two and four inches, giving ten non-replicated treatments. Maize was planted at a one foot spacing on the following day and irrigated from a water bowser carrying a two foot wide spray reservoir. At a predetermined tractor speed the spray delivered was 178 gal./plot equivalent to one acre/inch. Further irrigation was carried out as and when it was considered necessary to maintain optimum growing condition. Thinning was carried out on the 18 July. For recording purposes three sub-plots each 38 yd. long were pegged out and plant population counts taken on 20, 24, and 27 July together with plant height measurements on the 25 July and 3 August.

Kongwa wet season. This trial was repeated during the rainy season of 1967-68 using the same treatments but with three replicates and treatments randomised. Maize was planted on the 16 December and thinned to one plant at emergence. Population counts were recorded on the 23 and 27 December and 2 January. Plant heights were measured on the 3 and 11 January. The trial was harvested on the 25 April, both cob and grain weights being recorded. No supplementary irrigation was necessary during a heavy and well distributed rainfall season.

West Kilimanjaro. The same width treatments each at 2 in. and 3½ in. depth of cultivation were included in a replicated trial and planted with M6 maize (Plate 24) after spraying with Gramoxone on the 23 January 1969. Due to the early arrival of the long rains it was not necessary to irrigate. Plant heights and populations were recorded on the 19 February, 4 March and 20 March.

Sambwa. An exact replicate of the West Kilimanjaro trial was established at Sambwa on the 28 January 1969. Population after thinning at one, two and three weeks together with plant height measurements at two, three and four weeks were recorded.

5. Results

The plant population recorded at four weeks after planting for different widths and depths at Tengeru is presented in Figure 8.

Although this trial was not designed to give an indication of optimum width and depth of cultivation for seedbed preparation for this soil, certain definite trends are evident on the relative importance of the amount of cultivation. The 1 in. x 1½ in. treatment which failed completely at Kongwa during 1966-67 gave only 50 per cent of the optimum population under the less rigorous climate of Tengeru. Seed germination and establishment appeared to

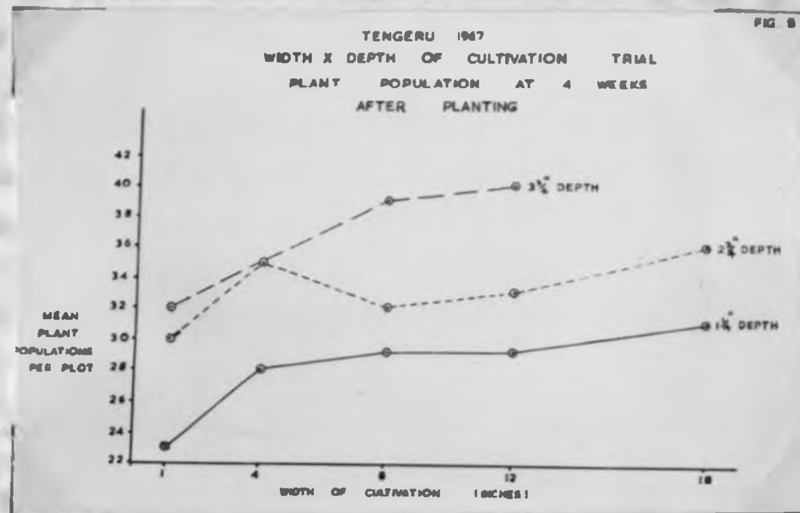


FIGURE 8.

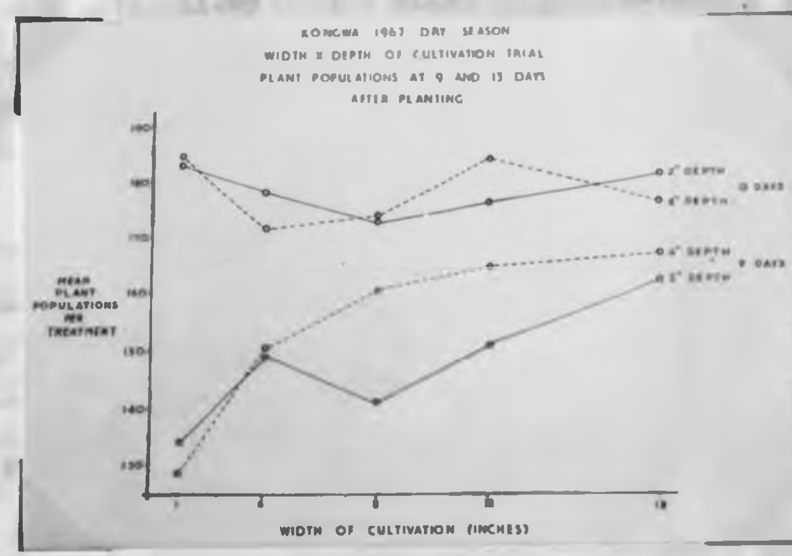


FIGURE 9.

be closely related to depth of cultivation with a steady improvement from $1\frac{3}{4}$ in. to $3\frac{1}{2}$ in. at all cultivation widths. It was unfortunate that the 4 in. and 18 in. width using deep cultivation was not included but nevertheless it appears that 8 in. by $3\frac{1}{2}$ in. is necessary to give an acceptable population.

At Kongwa during the dry season trial plant populations and heights were recorded during the first three weeks of the establishment period and are presented in Figure 9 and Table 14.

TABLE 14 AVERAGE HEIGHT MEASUREMENTS (cm.) OF MAIZE AT KONGWA 1967

Depth of cultivation	2"		4"	
Width/ /Date	25/7/67	3/8/67	25/7/67	3/8/67
1"	11.69	21.93	8.78*	19.69
4"	11.11	16.41*	9.73*	20.90
8"	12.89	23.83	11.01	22.65
12"	9.72*	19.67*	14.80	25.20
18"	13.35	23.60	14.61	24.20
Mean	11.75	21.09	11.79	22.53

* Plots affected by tractor wheel compaction during watering

At the first stand count nine days after planting there was a rapid improvement in population recorded at the four inch depth of cultivation with rapid increases in width up to eight inches. Wider cultivation gave only a marginal beneficial effect. The increase in population at the four inch width of cultivation compared with the one inch was marked at both depths. At the 18 in. width the establishment was good at both depths but better with deeper tillage. Increasing the width of cultivation would appear to compensate somewhat for the lack of depth.

A later recording at thirteen days after planting showed little differences between treatments. The delay in germination at the one inch and four inch width of cultivation is quite striking. This has a practical significance, as under marginal rainfall conditions early, even germination is essential to reduce the possibility of erratic stands resulting from surface crusting following rain. The results are very variable in some cases due to wheel compaction over the rows during watering.

Plant height measurements three weeks after planting show a gradual and consistant improvement up to the 12 in. width of cultivation at the four inch depth. Statistical analysis was not possible due to five plots being affected by tractor wheel compaction during watering.

Plant heights and yield for the Kongwa 1967-8 rainy season are given in Figures 10 and 11 together with plant populations Table 15.

During the 1967-8 season rainfall was well above average with a good distribution and the soil profiles remained at or near field capacity throughout the season. The delay in germination is again marked for widths less than eight inches at the two inch depth of cultivation. This effect is not so pronounced with the deeper cultivation. At both depths of cultivation there is a rise in the number of plants established up to the eight inch width treatments. The effect of width of cultivation on population count after 17 days is highly significant ($P > .001$) and of depth ($P > 0.05$)

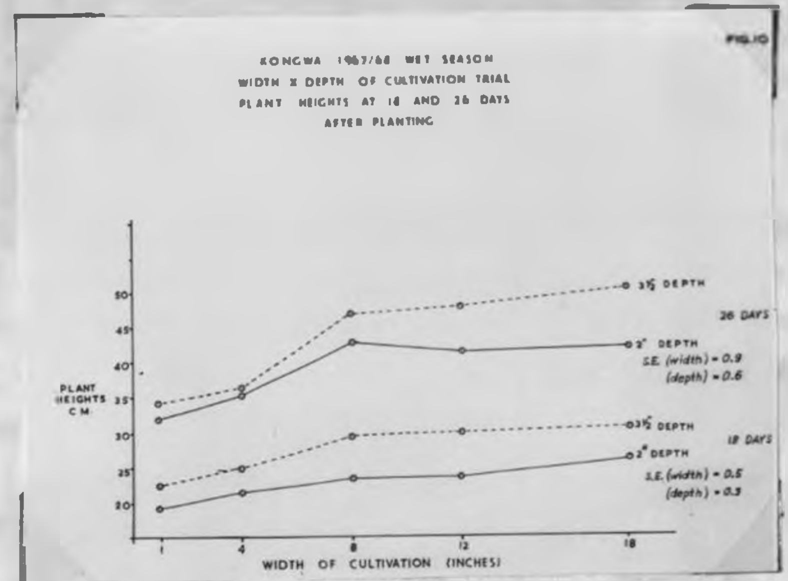


FIGURE 10.

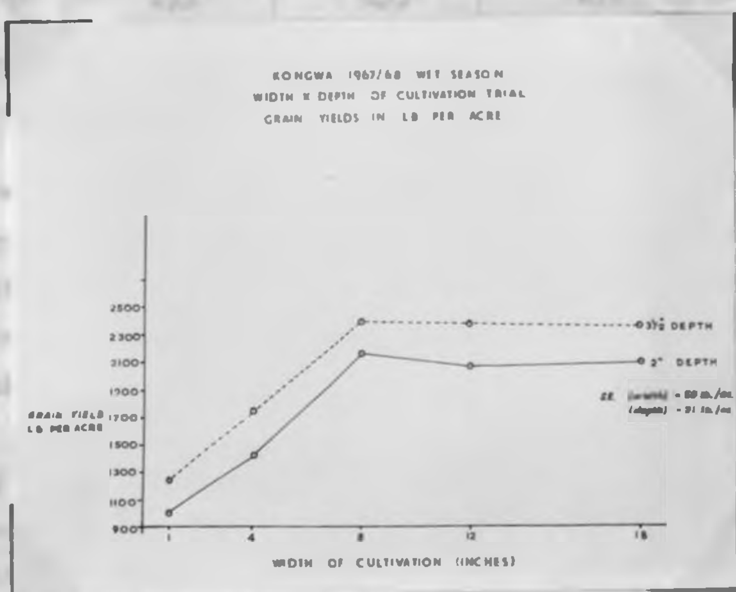


FIGURE 11.

TABLE 16 POPULATION COUNTS, KONGWA 1967-68

Depth	Width	Total Population of Three Replicates		
		7 days	11 days	17 days
2"	1"	174	209	217
	4"	169	183	194
	8"	238	251	257
	12"	231	239	260
	18"	230	243	254
3½"	1"	218	226	229
	4"	213	218	223
	8"	240	253	256
	12"	251	257	263
	18"	253	255	257

S.E.(Width)=0.4

S.E.(Depth)=0.6 at 17 days

C.V. = 9%

Figure 10 shows clearly the importance of increasing depth of cultivation on plant vigour during the establishment phase. Width of cultivation appears less critical at this stage although the effect is still highly significant statistically (P>0.001). There is no significant interaction between width and depth.

Plant heights recorded after 26 days show that growth is checked at the one and four inch widths of cultivation even at the 3½ in. depth. With the two inch depth the graph levels out at the eight inch width level but continues to rise with the deeper cultivation. The main effects of width and depth are highly significant (P>0.001). The interaction between width and depth is also significant (P>0.05).

The main effects of both width and depth of cultivation on yield are highly significant (P>0.001). Width of cultivation is most important over the range of widths and depths included. The significant interaction (P>0.01) indicates that for a given depth there is an optimum width of cultivation.

Figure 11 shows the rapid rise in yield which resulted from increased width of cultivation up to eight inches. As no increase in yield occurred beyond the eight inch width at either depth, increasing the depth of cultivation by ripping may well give improved yield responses at 12 in. or possibly 18 in. width.

TABLE 16 MEAN PLANT HEIGHTS (cm.) RECORDED AT 4 WEEKS, 5½ WEEKS AND 8 WEEKS. WEST KILIMANJARO 1969

	Width / Depth	1"	4"	8"	12"	18"	MEAN	
4 Weeks	2"	22.0	21.2	22.1	20.3	22.7	21.7	N.S.
	3½"	22.0	20.8	22.3	21.7	21.3	21.6	C.V. = 5.1%
	Mean	22.0	21.0	22.2	21.0	22.0		
5½ Weeks	2"	35.8	36.2	37.7	37.5	37.4	36.9	N.S.
	3½"	36.4	35.9	37.7	38.1	35.8	36.8	C.V. = 4.8%
	Mean	36.1	36.1	37.7	37.8	36.6		
8 Weeks	2"	79.8	79.0	85.4	83.4	85.7	82.7	N.S.
	3½"	82.4	80.5	84.0	86.1	80.3	82.7	C.V. = 1.1%
	Mean	81.1	79.8	84.7	84.8	83.0		

The mean plant heights for the width and depth treatments at West Kilimanjaro are given in Table 16. Rainfall recorded during the growing season was more than adequate to maintain a satisfactory moisture status. There were no significant differences between width or depth of cultivation and plant vigour. There is a suggestion that increasing the width to eight inches has assisted growth at the two inch depth. Populations remained constant and optimum from the first recording.

The mean plant heights from the Sambwa trial during the first four weeks of growth are presented in Table 17.

TABLE 17 MEAN PLANT HEIGHTS (cm.) RECORDED AT 2 WEEKS, 3 WEEKS AND 4 WEEKS. SAMBWA 1969

	Width / Depth	1"	4"	8"	12"	18"	MEAN
2 Weeks	2"	9.6	9.6	9.4	10.5	10.4	9.9
	3½"	9.6	10.4	9.0	9.9	10.0	9.8
	Mean	9.6	10.0	9.2	10.2	10.2	
3 Weeks	2"	12.4	12.7	12.2	13.8	14.3	13.1
	3½"	13.0	14.3	12.9	13.8	14.4	13.7
	Mean	12.7	13.5	12.6	13.8	14.4	
4 Weeks	2"	18.2	19.1	18.1	19.8	21.4	19.3
	3½"	20.7	20.4	18.9	22.0	23.7	21.1
	Mean	19.5	19.8	18.5	20.9	22.6	

2 Weeks: N.S.
C.V. = 3.8%
S.E.(Width)
(Depth)

3 Weeks: C.V. = 6.5%
S.E.(Width)=0.4
(Depth)=0.3

4 Weeks: C.V. = 10.6%
S.E.(Width)=0.5
(Depth)=0.

There are no significant differences in plant heights at two weeks. After three weeks the effects of both width and depth of cultivation are significant (P>0.05). There is a suggestion that increasing the depth has had more effect at the narrow widths of cultivation but the overall interaction is not significant. At four weeks the depth of cultivation only has a significant effect (P>0.01).

Bulk density measurements were taken from all sites. Eight cores were sampled at random over the experimental area at 0-5 and 5-10 cm. in depth. The means are presented in Table 18.

TABLE 18 MEAN BULK DENSITIES IN Grm./cc. TAKEN FROM EIGHT SITES OVER THE EXPERIMENTAL AREA

SITE	BULK DENSITY (grm./cc.)	
	0 - 5 cm.	5 - 10 cm.
TENGERU	1.49	1.33
KONGWA	1.37	1.33
WEST KILIMANJARO	0.85	0.87
SAMBWA	1.48	1.45

6. Discussion

At three sites Tengeru, Kongwa and Sambwa, both the width and depth of cultivation have at some period had a significant effect on plant population and growth. These soils are very different in texture and fertility but all have a high bulk density. The interpretation of results in terms of mechanical impedance alone is only valid if sub-optimal levels of other factors are shown to be absent. During these trials the plant moisture relationships were not limiting and results of soil structural analysis showed that on all soils the pore space drained at 20 cm. was more than nine per cent of the total volume. This is the critical value below which aeration may become limiting (Hosegood 1958, Gill and Miller 1956, Phillips and Kirkham 1962). The general overall reductions in plant vigour with reduced tillage do therefore suggest mechanical impedance as being the causal agent. There is strong support in the literature for the use of bulk density measurements as criteria for the evaluation of physical resistance to rooting. In these trials circumstantial evidence is consistent with this assumption. The soil density above which roots do not penetrate is not necessarily the same for all soils (Veihmeyer and Hendrickson, 1948) but for a particular soil, above a certain bulk density level, the growth of seedling roots have been shown to decrease with increasing bulk density (Phillips and Kirkham 1962, Rosenburg and Willits 1962), a relationship which held independently of free pore space. In soils with a high bulk density root growth was restricted to the topmost layers (Flocker and Menary 1960).

The populations obtained at Tengeru and in both Kongwa trials show that the depth of cultivation is more important than width provided a certain minimum width is cultivated. Responses to increases in width greater than eight inches were small. Depth of cultivation was also more important than width at Sambwa although overall responses to cultivation intensity were lower than those obtained at Kongwa. Both Sambwa and Kongwa exhibit high bulk densities but the pore space drained at 20 cm. on the Sambwa soil is approximately twice that of the Kongwa soil.

With seedbed preparation limited to the one inch by two inch deep level on the compacted soils, it was observed that the developing root system was unable to penetrate easily the walls and bottom of the cultivation 'slit'. Reduced germination in compacted soils has also been noted by Phillips and Kirkham (1962) and Kulota and Williams (1967). The latter also showed a close correlation between establishment and compaction using bulk densities. The delayed emergence factor with minimal seedbed preparation was also noted by Flocker and Menary (1960) and Morton and Buchele (1960) who stated that the energy required for seedling emergence increased with increasing bulk density. Compacted soils low in organic matter are generally more widely representative of marginal rainfall areas (Russel 1964) where early and rapid establishment are of prime importance (Macartney 1964). With satisfactory moisture regimes during these trials the plants were able to establish but the delay observed could cause eventual crop failure.

When the maize plants have become established it would appear width of cultivation assumes more significance than depth; a stage which corresponds with the development of the lateral roots. At Kongwa plant height at 26 days after germination showed a definite reduction below the four inch width of cultivation even at the 3½ in. depth. The interaction between width and depth was also significant.

Although only one trial was continued for yield estimations, the bulk of the literature records yield reductions caused by compaction. Yield decreases with increasing bulk density above certain levels have been reported by Adams et al (1960), Flocker et al (1959), Baver and Farnsworth (1940) and Blake et al (1960) working with maize. At Kongwa width and depth of cultivation and their interaction have had a significant effect on yield. The optimum width of cultivation appears to be the eight inch level and there seems little to be gained by increasing this except possibly with deeper cultivation.

The compacted soils of Kongwa, Sambwa and Tengeru are difficult and expensive to cultivate. When dry, the power requirement is uneconomically high for the ploughing operation. Overall tillage has been shown at Kongwa to cause further serious structural deterioration, a rapid oxidation of the organic faction and reduced aggregate stability. It is on soils of this type that the minimal cultivation principles have the greatest practical application. Direct drilling using the absolute minimum of tillage for seed placement has been shown to be unsuccessful. At the other extreme, it is of no benefit to consider a cultivation width greater than 18 in. which, with a three foot row crop such as maize, gives 50 per cent of the surface cultivated, bearing in mind the advantages of maintaining an inter-row surface mulch for erosion control and water infiltration.

The seedbed environment required for plant emergence has not yet been described in precise terms for factors such as soil moisture content, seedbed tillage, depth of planting, amount and position of compacting pressure, aeration and mechanical impedance to rooting.

There is clearly a limit to the resistance that plant roots can overcome. When soil conditions which prevent root growth occur there can be no doubt about the need for tillage. Below these critical densities for root penetration however, it is not always clear when increased tillage becomes advisable. Any tillage operation which brings about a reduction in resistance would almost certainly ensure that the other important soil properties were within the desirable range as far as external factors permitted. The effect of tillage in loosening soil is generally considered desirable in that physical conditions necessary for germination, emergence and early growth are produced.

On the three compacted soils described it is evident that for good germination and optimum plant populations it is necessary to till to at least three inches during seedbed preparation. For subsequent plant growth the possibility of ripping or chisel ploughing at three foot centres should be considered. Significant increases in yield have been reported from chiselling compact soils during the dry season by Doneen and Henderson (1953), Savenson et al (1958) and Raney et al (1954). A response to rooting depth by ripping was also recorded by Carter et al (1965).

7. Conclusions

(a) The results of this work show that direct drilling of maize can be unsuitable on soils which show mechanical impedance to root growth. This factor has been shown to be overcome by using both wider and deeper cultivation.

(b) On the 'compacted soils', Tengeru, Sambwa and Kongwa a seedbed of eight inches in width by four inches in depth was necessary to give optimum population and vigour. West Kilimanjaro soil with its lower bulk density was ideally suited to the direct drilling techniques.

(c) Depth of cultivation assumes greater importance during germination. With direct drilling on compacted soils reduction in population together with delayed emergence can have a serious effect on plant vigour. Width of cultivation becomes important during the establishment phase with lateral root development.

(d) Soil compaction problems are very relevant in Tanzania where a large proportion of the soils are formed from aged, intensely weathered rock under low rainfall conditions. With the limited application of the direct drilling technique and the expense and inefficiency of overall cultivation, there is a need for the acceptance of a mechanised zonal system with its economic and agronomic advantages.

(e) The minimum amount of cultivation necessary will vary with the soil type and probably also with the crop planted. It will be necessary to investigate the effect of tillage on a wide range of soil types and crops by observations on plant growth.

C. STUDIES ON COMPARISONS OF DIFFERENT CULTIVATION TREATMENTS ON YIELD, POPULATION, DISTRIBUTION OF SOIL MOISTURE, ROOT GROWTH ETC. WITH WHEAT AT WEST KILIMANJARO

1. Agriculture and Soils

The western slope of Mt. Kilimanjaro which lies between 4,500 - 7,000 ft. altitude is a major wheat producing area in Tanzania.

Most of the present arable area of about 25,000 acres was opened up in 1951 since when wheat has been the principal crop. During the 1950's stem (*Puccinia graminis* var. *triticae*) and leaf rust (*Puccinia recondita*) became so serious on the susceptible wheat varieties available at that time that many farmers were forced out of wheat into mixed arable/ livestock farming. The advent of wheat breeding and the availability of more rust resistant material resulted in a swing back to continuous wheat, two crops per year, by 1957/58. In recent years there has been a tendency to alternate fallowing and at present about 80 per cent of the wheat land is farmed in this manner.

In this zone the soils are derived from volcanic lavas with some ash addition; the majority would fit into the group of Entrophic Brown Soils (D'Hoore 1965) and the remainder into the Ferruginous Tropical group. Phosphorus and potassium are normally adequate for wheat, and responses to application of these nutrients have not so far been obtained. The soils are loams or clay loams containing about 30 per cent silt and 40 per cent fine sand, usually with little coarse sand. In consequence, they are subject to rapid surface sealing and are very susceptible to erosion.

The inherent levels of carbon and nitrogen in these Montane Forest Soils are much higher than those under Tropical Rain Forest (Cunningham 1963). These high levels are due not only to the considerable elevation but also to the base richness of the parent material.

The physical and chemical properties of these soils have been markedly influenced by climate and cultivation. Within similar climatic and soil zones Anderson (1964) has recorded considerable variations in nutrient status largely as a result of differences in cropping history. Anderson's (1965) later examination of the West Kilimanjaro soils in the light of their cultivation history showed the deleterious effect on yield of continuous cropping using conventional ploughing and disc harrowing techniques. He recognised the rapid decline in structure and rainfall acceptance rates, the latter causing reduced moisture availability. The number of years under cultivation was closely related to the decline in organic carbon, total nitrogen and exchange capacity. From his study of the soil samples taken each cropping season following a six year ley there was a reduction of about 0.5 per cent organic carbon and 0.05 per cent nitrogen per annum. Between the penultimate and final samplings this decline increased and it was suggested that this was due to low moisture and higher soil temperatures promoting greater oxidation. The rise in base saturation to 100 per cent was favoured by the reduced exchange capacity resulting from organic matter decomposition. Scott (1962) has also shown that within the 30 - 45 in. rainfall areas of East Africa organic matter is closely related to base saturation.

From Anderson's analytical data it is evident that extractable phosphorus, organic carbon and total nitrogen are much lower in soils cultivated for over eight years. The differences are too striking to be due to the slight variation in climate and slopes.

Anderson, Houston, Northwood and Patel (1965) working in the same area found that fallowing increased both the nitrogen and moisture available to the following crop. This system was criticised as 'it is probably worse than a wheat crop in accelerating decomposition of organic matter and release of bases. This is because of the higher soil temperatures on bare soil.' The results of their long-term fertility trials suggested that the physical deterioration which occurred in these erosion-prone soils as a result of cultivation was probably more serious than nutrient losses. The progressive reduction in yield due to continuous cultivation for eight years was recorded as 284 lb./acre.

Anderson (1964) recommended the establishment of productive leys for the maintenance and improvement of soil structure, a conclusion which is at variance with the findings of Pereira, Chenery and Mills (1954) who stated that the effect of grass leys on soil structure lasted little more than one year; neither does the work of Clement and Williams (1964) lend much hope of a rapid build up of organic matter with ley farming under similar conditions.

2. Description of the Experimental Area

The location of the experimental site at 3° 00' S, 37° 05' E, and an altitude of 6,000 ft. could be described as representative of the 'average' conditions of West Kilimanjaro in relation to soil type and climate.

The site was cleared from forest in 1951 and cropped with cereals until 1956 when it was planted with Rhodes grass (*Chloris gayana*). The 1966 Long Rains crop (the first of the experiment) was the seventh continuous wheat crop after ploughing out the ley. Composite soil samples were taken in April 1966 from the trial area and an analysis is given in Table 19. The results illustrate the fertile nature of the soil; of the major plant nutrients responses to applied nitrogen only would be expected.

TABLE 19 ANALYSIS OF COMPOSITE SURFACE SOIL SAMPLES - WEST KILIMANJARO, EXPERIMENTAL SITE, APRIL 1966

Depth of Sample	pH Water	pH $CaCl_2$	Conductivity	Avail P	Total P	Total Organic P
0-15 cm.	7.11	6.18	61.8	96.9	3140	1000

Ca	Mg	Na	K	Mn	% Organic Carbon	% Total Nitrogen
25.64	6.12	0.03	2.56	0.013	3.55	0.27

METHOD OF ANALYSIS

1. Exchangeable bases - ammonium acetate leaching at pH = 7.0.
2. Calcium - by the oxalate method.
3. Magnesium - by precipitation with 8-hydroxy-quinoline.
4. Manganese - colorimetrically after oxidation with potassium periodate.
5. Potassium, Sodium - by Eel flame photometer.
6. 'Available' phosphate - by extracting with 0.3N Hcl for 3 minutes.
7. Organic Carbon - Walkley and Black method (1934) assuming 80% recovery of C.
8. pH - 1:2.5 soil: $\frac{M}{100}$ $CaCl_2$ suspension using a glass electrode.
9. Exchange Capacity - by removal of absorbed ammonia using normal potassium sulphate and distillation of the displaced ammonia.
10. Total Nitrogen - by Bremner (1960).

TABLE 20 RAINFALL CONFIDENCE LIMITS, EXPERIMENTAL SITE, WEST KILIMANJARO

2 x 10 day Moving Totals in millimetres. 75% Level (P=0.5)

Standard Period	Lower Limit	Upper Limit
01	9.4	54.9
02	6.5	43.8
03	6.4	53.1
04	7.8	56.5
05	6.1	52.5
06	2.5	38.0
07	1.0	17.6
08	6.4	44.0
09	22.6	92.1
10	44.7	103.2
11	37.3	118.3
12	50.4	140.5
13	57.9	141.7
14	26.9	106.8
15	12.2	57.4
16	10.3	30.0
17	0.4	16.5
18	Nil	6.5
19	Nil	6.2
20	Nil	4.9
21	Nil	4.9
22	Nil	3.7
23	Nil	4.5
24	Nil	6.6
25	Nil	4.9
26	0.1	6.5
27	Nil	11.9
28	1.3	16.8
29	5.8	26.8
30	18.3	68.9
31	15.5	87.0
32	29.7	116.1
33	54.5	174.6
34	41.3	138.3
35	17.6	73.5
36	11.7	52.8

The rainfall has a bimodal distribution with peaks in November - December (Short Rains) and March - April (Long Rains). The annual average precipitation on the site over 18 years was 29 in. with approximately equal amounts falling in both seasons. An analysis of the daily records using the Kamulonge Rainfall Confidence Limits programme (Manning 1956) was carried out on a basis of 20 day totals moving at ten day intervals on an I.C.T. 1500 computer (Table 20).

The analysis indicates the rainfall which can be expected to fall between the upper and lower limits twice in every four years and shows the extreme variability in the rainfall pattern.

3. Experimental Layout and Design

The experimental design included five main treatments randomised with two replications. Plot size was 92ft. x 120ft. (Approx. ¼ acre) giving a total trial area of 2½ acres.

The treatments were as follows:

1. Conventional tillage as practiced in the area using the disc plough and disc harrow for land preparation and weed control. Two crops were taken annually (double cropping) in the Long and Short Rains.

2. Tie-ridging (double cropped).

3. Conventional tillage as in Treatment 1. but cropping in the Short Rains only. The Long Rains fallow was kept clean by disc harrowing or ploughing as necessary.

4. Minimal tillage using the Howard Rotaseeder for planting. Weed control was by the use of Paraquat (Gramoxone W). Two crops were taken annually.

5. Minimal tillage as in Treatment 4 but cropping in the Short Rains only. The Long Rains fallow was kept clean by the application of Paraquat.

The tie-ridge treatment was included because of the proven efficiency of this method of cultivation for water infiltration and therefore in this respect it acted as an excellent control treatment against which the effectiveness of the other treatments could be compared.

Each of the five main plot treatments was split for nitrogen fertiliser application. A top-dressing of 43 lb/acre of nitrogen as Ammonium Sulphate Nitrate was given at the four to five leaf stage to one of the sub-plots, whilst the other sub-plots acted as a control and did not receive any fertiliser.

The experiment ran for six seasons from the 1966 Long Rains until the 1968/69 Short Rains.

4. Experimental Methods

Laboratory procedures and sampling techniques followed in this work have been described under Section C (Kongwa).

Soil Moisture Samplings. One profile from each treatment replicate was sampled at planting, flowering and harvest within the 0-6in., 6-12in., 12-18in., 18-24in. ranges and at the 3, 4 and 5ft. levels. Results are presented in total inches of available water within the 5½ft. profile.

Electrical Resistance Units. A profile of these units at one foot intervals down to five feet depth was installed in all sub-plots on 24 February 1966. Moisture tension readings commenced on the 14 March 1966 and were read three times weekly. The single control hand generator ohm-meter constructed by Ripley and Hosegood (1965) was used throughout the three year experimental period.

<u>Soil Physical Analysis</u>. Soil cores were sampled on the 6 July 1966 from two six foot deep pits adjacent to the site. A later sampling of surface cores was carried out on the 29 February 1969 from each sub-plot and from surrounding area.

<u>Organic Matter Sampling</u>. Two pint composite samples were taken from the top 2½cm., 2½-10cm., 10-20cm. and 20-30cm. of each sub-plot on the 31 January 1969 during the final season of the trial. Samples were analysed for pH, organic carbon and nitrogen index as described by Robinson (1968).

<u>Plant Populations, Tiller Counts and Plant Heights</u>. Plant populations and number of viable tillers were recorded each season from 100 quadrats of one square foot taken at random within each sub-plot. Average plant heights per sub-treatment were recorded by measuring the main tiller of 100 random plants at heading.

<u>Root Washings</u>. The depth and rooting behaviour of the crop between the different cultivation and fertilizer treatments was observed by digging pits 6ft by 4ft within one replicate and washing the roots free from the pit face using a hand operated sprayer. Roots were photographed at harvest of the Long Rains crop in 1968 and at the ear emergence and harvest stage of the 1968/69 Short Rains crop.

<u>Water Table Measurements</u>. Four two inch galvanised pipe lengths were sunk, one at each corner of the trial, to a depth of six feet to measure the water table should it rise to within the rooting zone.

<u>Rainfall</u>. Daily rainfall was recorded on the site using a standard five inch rain-gauge.

5. <u>Observation Trials Using the Howard Rotaseeder.</u>

The 'Rotaseeder' has been developed for direct seeding into previously uncultivated soil. The implement is based on the E Series III, Mounted Rotavator with a modified rotor fitted with 15 flanges at five inch centres. The blades, six per flange, are of the reduced 'L' type having a hooked cutting edge ½in. wide and are mounted on alternate sides of the flanges. Rotor speed has been increased to 290 r.p.m. at a standard P.T.O. speed of 540 r.p.m.

The mounted seed box with a capacity of 4½ bushels has an external force-feed type mechanism driven from a spoked land wheel. The seed coulters are lightly sprung to ensure that they run in the slot opened by the blades. Depth control wheels are fitted on each side of the machine in line with the rotor giving adjustable depth control between ½ and 4in.

The total surface area cultivated is about 15 per cent of the width of the machine when sowing in five inch rows. The working rate is approximately two acres per hour. The seed is covered by soil thrown back by the action of the rotors. Blanking off plates can be fitted to give row widths of 10, 15 or 20 in.

The implement weighs about 17 cwt. (with seed) and requires a tractor with Category 2 linkage and at least 40 P.T.O. horsepower.

A Howard Rotaseeder was loaned to the Northern Research Centre in November 1966 by Plant Protection. Observational trials on wheat establishment were carried out at West Kilimanjaro prior to the equipment being used in the formal replicated trial.

a) <u>Mdzimet Farm</u>

(i) An area which had been cropped during the previous season and was carrying a heavy straw cover was selected. It was immediately obvious that the equipment could not cope with a concentrated undecayed stover residue. The unchopped straw was thrown back from the blades completely clogging the planting attachment. The problem was partially overcome by removing the tension springs on the individual planting brackets thus allowing the shoes to ride over the stover. Subsequent germination was patchy due to uneven covering of the seed.

(ii) An area which had been fallowed during the previous season and was carrying a semi-decayed matt of wheat straw was successfully planted. The blades were capable of cutting through the mulch leaving an undisturbed cover between planting rows.

b) <u>Hugo's Farm</u>

(i) The selected area with a six per cent slope at 7,000ft. was planted as a demonstration of the machine for wheat farmers in the Northern Region. The first planting was carried out on a plot that had been cropped with wheat in the previous season. About half the crop residue had been removed by raking. Gramoxone W at ½ pint/acre had been applied with a tractor mounted sprayer on the previous day. During planting the tension springs were again removed and an efficient plant was obtained. The surface after planting (Plate 25) was considered ideal from the point of view of subsequent soil conservation and water infiltration.

(ii) An adjoining plot where the total previous crop residue was spread over the surface was also successfully planted. However, the stover from the previous crop was much less than at Ndaimet.

e) Simba Farm

A further observation area was selected representative of the lower altitude wheat areas. At planting there was a heavy growth of nutgrass (*Cyperus rotundus*), which had been sprayed with Gramoxone W on the previous day, together with a thick matt of semi-decomposed straw lying in windrows. Complete blockage of the Rotaseeder during planting occurred and the operation was abandoned (Plate 26).

From these general observations it appeared that

(a) With a heavy straw cover the tension springs on the coulters should be removed.

(b) The machine will not cope with an undecomposed straw cover in windrows, i.e. as left by a combine under continuous cropping.

(c) When the straw is spread over the surface planting difficulties and blockages are not so serious. Further improvements in planting efficiency would result from a straw chopping attachment on the combine.

(d) The machine itself was much too heavy and more robust than is necessary. A powerful tractor was required for working on slopes at this altitude.

6. Field Operations

Land Preparation. The wheat crop previous to the commencement of the trial was combine harvested on the 5 February 1966 and the straw burnt. After each subsequent harvest the straw was left on the minimal tillage plots but on the conventionally tilled and tied-ridged plots was burnt to conform with local practice. The conventionally tilled double crop treatments were cultivated by ploughing and disc harrowing twice a year at the same time as the surrounding field. The number of operations required to produce a conventional type seedbed varied from season to season. The conventional tillage fallowed plots were disc harrowed when weeds became established and again the number of operations required varied with the season. Both minimal tillage with fallow and double cropped plots were kept clean by the use of Paraquat (Gramoxone W) at dosage rates varying from one to three pints per acre depending on the intensity of the weed growth at the time of spraying.

Planting. The Howard Rotaseeder was used for each planting operation with the exception of the tie-ridged plots which were planted by hand. The seed coulters were removed and the seed broadcast and covered by the soil thrown back from rotors. The variety W 1915 was used in the first season and thereafter Romany (W 3455). Seed was dressed with an organo-mercurial and planted at 90 lb./acre on all treatments. Depth of planting due to the broadcasting technique followed was an even one inch throughout.

Fertiliser Application. Ammonium Sulphate Nitrate was applied at the rate of 1½ cwt (43 lb. nitrogen) per acre to the appropriate sub-plots at the 4 - 5 leaf stage each cropping season.

Aerial Spraying. The whole trial was aerial sprayed each season with 2,4-D according to normal farm practice.

Harvesting. Sample areas of 40 sq.yd. from each sub-plot were hand cut and threshed separately to obtain total crop weights. The remainder of the trial was combine-harvested and grain weights recorded. Samples of grain were retained for baking quality tests. In the final season the weight of grain from a 500 head sample and from the combine were weighed to give a biological and commercial yield estimate respectively.

7. Results

A. 1966 LONG RAINS

During the course of this trial the single crop per year treatments were fallowed during each long rains.

The conventional tillage double cropped treatment was ploughed on the 14 March followed by two disc harrowings. The cultivated fallow was similarly treated on the 24 June. The minimal plots cropped this season were sprayed with three pints/acre of Gramoxone W on the 4 April, and the chemical fallow received two similar treatments on the 4 May and 7 July. Planting was carried out on the 5 - 6 April with the variety W 1915; the nitrogen top-dressing was given on the 3 May and the crop aerial sprayed on the 9 May. Harvesting was completed by 8 September.

Rainfall

The early start to the Long Rains on the 1 February resulted in well above average rainfall before planting. A fall of 0.88 in. immediately after planting together with 0.57 in. one week later resulted in good even germination. No rainfall was recorded after 1 June.

Pre-planting	February 1966	6.67 (12)
	March	9.18 (16)
	Total	15.85 (28)
Planting - Harvest	April	6.01 (10)
	May	4.42 (10)
	June	0.26 (1)
	Total	10.69 (21)

Yields, Populations and Quality

Results are presented in Tables 21 and 22. Conventional tillage has given slightly better grain and total crop yields than tie-ridging or minimal tillage. The application of nitrogen has increased total crop weights, plants and tillering, but decreased grain weights. More plants/acre were recorded with minimal tillage but less tillers by comparison with the other treatments.

TABLE 21 YIELDS AND POPULATIONS, WEST KILIMANJARO - LONG RAINS 1966

		Conventional Tillage double crop	Tie Ridge double crop	Minimal Tillage double crop	Means
Without N.	Plant Population	752	684	778	738
	Tiller Counts	1,364	1,435	1,327	1,375
	Total Crop	10,806	9,701	8,456	9,654
	Grain Yield	2,730	2,589	2,514	2,611
With N.	Plant Population	859	762	907	843
	Tiller Counts	1,752	1,999	1,590	1,780
	Total Crop	12,087	10,627	9,098	10,604
	Grain Yield	2,552	2,453	2,472	2,492
Means	Plant Population	806	723	842	
	Tiller Counts	1,558	1,717	1,458	
	Total Crop	11,447	10,164	8,777	
	Grain Yield	2,641	2,521	2,493	

Plant populations and tiller counts per sample area.
Grain and total crop weights in lb./acre.

Baking quality test results, carried out on grain samples from each main treatment, showed little differences in the first season. There is, however, a positive effect on protein with the application of nitrogen.

TABLE 22 BAKING QUALITY TEST RESULTS (VARIETY W 1915)
WEST KILIMANJARO - LONG RAINS 1966

Treatment	Nitrogen	Bushel Weight	Strength	L/P	Protein
Conventional Tillage -double crop	-	65	42	0.63	13.0
" "	+	64	36	0.73	13.7
Tie Ridge -double crop	-	65	36	0.69	13.3
" "	+	65½	47	1.01	13.4
Minimal Tillage -double crop	-	65	40	0.44	11.8
" "	+	65	33	0.76	13.0

Gravimetric Soil Moisture Sampling

The comprehensive results of the soil moisture samplings at planting (21 April 1966), flowering (11 July) and harvest (13 September) are given in Appendices 5 - 7 and summarised in Table 23.

TABLE 23 SUMMARY OF TOTAL AVAILABLE WATER (in.) WITHIN THE 5½ ft. PROFILE
WEST KILIMANJARO - LONG RAINS 1966

Treatment	Mean of Replicates Planting	Flowering	Harvest
Conventional Tillage -double crop	1.63	1.60	0.49
Tie Ridge -double crop	2.60	3.52	1.57
Cultivated Fallow	2.89	3.91	2.56
Chemical Fallow	3.39	5.32	3.55
Minimal Tillage -double crop	2.21	2.99	1.00

The minimal tillage double crop treatment showed more favourable soil moisture conditions existing throughout the season than the conventional tillage double crop. The difference between the fallow treatments were very much in favour of chemical fallowing. The effect of the different cultivation methods on infiltration of the pre-planting rains is well demonstrated. Available moisture recorded at the five foot depth on plots 1 and 10 (both conventional tillage) was well above that expected and later shown to be a water table effect at the lower end of the trial.

Distribution of Soil Moisture

The seasonal availability of water to the crop throughout the soil profile is presented in Figs. 12 and 13.

On the six plots which were cropped this season, all had reached field capacity by the end of March. This status was maintained until the end of the rains when the crop began to utilise the stored moisture within the profile. There is a consistent picture showing that water was used earlier and to a greater depth where nitrogen had been applied. The water withdrawal pattern for all cultivation treatments is similar although it does appear that rooting depth on the tied ridge plots was limited to three feet. This was probably due to the proportion of the crop carried on the ridge crest which is an extra foot above the level of the other treatments.

There is a suggestion of more rapid water use at a greater depth with the minimal tillage treatment. This was also reflected in crop vigour observed in the field and yields should have followed this pattern.

Both the cultivated and chemical fallows rapidly reached field capacity which was maintained until the end of the recording period.

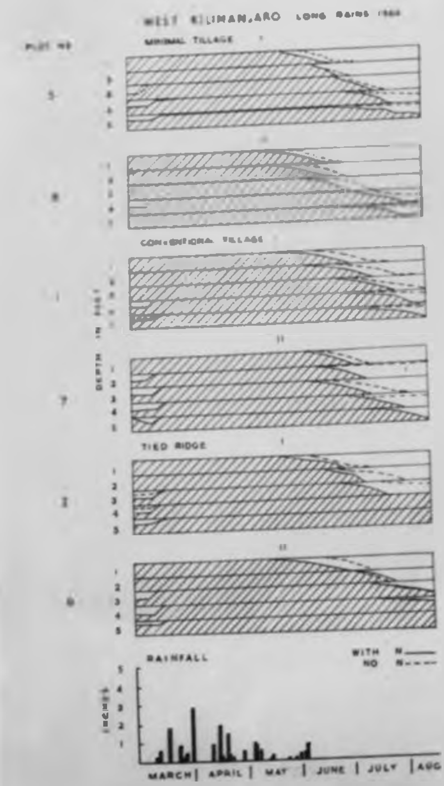


Figure 12: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1966 Long Rains season.

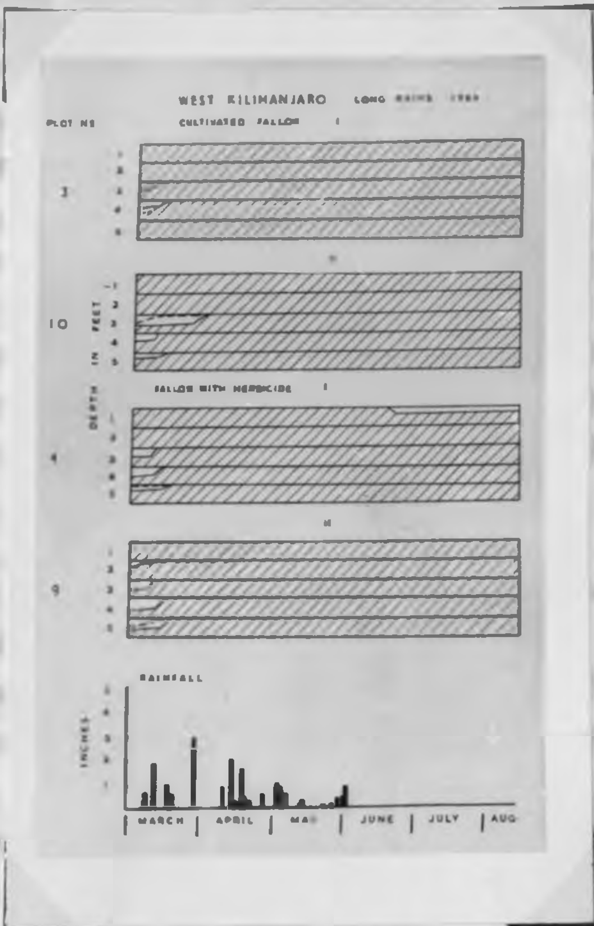


Figure 13: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1966 Long Rains season.

In replicate 1. of the herbicide fallow, late spraying of weed growth has resulted in water withdrawal from the one foot level.

Discussion

Yield responses to tillage treatments were not expected in the first season particularly with rainfall above average and well distributed. Moisture was not limiting to plant growth up to flowering on the 10 June. The variety W 1915, selected for its rust tolerance, was considered to have reached its optimum yield potential during this season.

On both minimal tillage plots slightly more moisture was utilized by the onset of flowering than with the other treatments. At full flowering the minimal treatments were under greater moisture stress which could account for the slightly lower yield due to a reduced grain set per ear, assuming similar populations and bushel weights.

A grain yield response to applied nitrogen was expected on all treatments which had been double cropped. There was an increase in total crop weight but grain yields were lower. The reasons for this are not clear but there are several possibilities:

(a) A later application of fertiliser at the five or six leaf stage may have had less effect on the straw and more on the grain.

(b) Nitrogen has increased both plant and tiller number which may be above the optimum level.

(c) The greater water use with nitrogen appliation would result in a greater comparative water stress during the grain setting phase, although with similar bushel weights throughout this is unlikely.

(d) With good distribution of wetting and drying periods during the season conditions were ideal for nitrogen

The improved moisture retention on the chemical fallows compared to the cultivated fallows is shown by the gravimetric soil samplings. These differences can only be due to the cultivation necessary for weed control dissipating stored moisture within the top layers. The loss of moisture from the chemical fallow shown by the gypsum blocks demonstrates the importance of timely spraying to control weed growth if the full benefits of fallowing are to be achieved.

B. 1966-67 SHORT RAINS

The double-cropped treatments were ploughed on the 5 October and disc harrowed three times before planting. Two sprayings of the minimal double-cropped treatment at 2 pints/acre Gramoxone W were necessary on the 25 October and 5 November while the minimal fallow plots required one spraying on the 18 October at 1½ pints/acre to maintain adequate weed control. The variety Romany was planted on the 5 November and the nitrogen top dressing applied on 16 December. The crop was aerial sprayed for weed control on the 5 December and harvested between the 25 - 28 February.

Rainfall

The 1966-67 Short Rains were a virtual failure with slightly over two inches falling during the growing season. A fall of 0.25 in. immediately after planting was sufficient to give reasonable germination by the 11 November.

Pre-planting	October	1966	1.12	(3)
	November		0.65	(1)
		Total	1.77	(4)
Planting - Harvest	November		0.42	(5)
	December		1.46	(5)
	January	1967	NIL	
	February		0.37	(2)
		Total	2.25	(12)

<u>Yields, Populations and Plant Heights</u>

The populations and yields recorded are presented in Table 24 together with plant heights near maturity (Table 25).

TABLE 24 YIELDS AND POPULATIONS, WEST KILIMANJARO - SHORT RAINS 1966-67

		Convent-ional Tillage double crop	Convent-ional Tillage with culti-vated fallow	Tie Ridge double crop	Minimal Tillage double crop	Minimal Tillage with chemical fallow	Means
Without N.	Plant Population	672	853	618	748	764	731
	Tiller Counts	1,191	2,039	1,191	1,924	2,066	1,682
	Total Crop	475	2,486	312	332	2,249	1,171
	Grain Yield	132	802	73	78	1,232	463
With N.	Plant Population	663	746	557	762	721	689
	Tiller Counts	1,142	1,787	989	1,929	2,123	1,594
	Total Crop	528	2,326	491	343	1,940	1,126
	Grain Yield	136	779	150	97	1,121	457
Means	Plant Population	668	799	588	755	743	
	Tiller Counts	1,167	1,913	1,090	1,927	2,095	
	Total Crop	502	2,406	402	338	2,095	
	Grain Yield	134	791	112	88	1,177	

Plant populations and tiller counts per sample area. Grain and total crop weights in lb./acre.

The application of nitrogen has resulted in a slight reduction in plant population. Both minimal treatments and the conventional fallow gave higher plant populations. Tiller counts followed the same trend.

The best yield was given by the minimal tillage treatment after chemical fallowing with a 50 per cent increase over the corresponding conventionally cultivated treatment (Plates 27, 28). In this drought year the application of nitrogen has had a depressing effect on yield.

The total crop weights from both conventional treatments was again substantially greater compared with the minimal treatments.

Mean plant heights also showed a reduction with fertiliser application. The conventionally tilled crop after fallow was more vigorous up to flowering.

TABLE 25 PLANT HEIGHTS (feet) AT HEADING, WEST KILIMANJARO - SHORT RAINS 1966-67

		Conventional Tillage Double Crop	Conventional Tillage with Cultivated Fallow	Minimal Tillage Double Crop	Minimal Tillage with Chemical Fallow	Tie Ridge Double Crop	Means
Without N.	Rep. I	1.39	1.63	1.03	1.59	1.33	
	Rep.II	1.11	1.80	1.15	1.64	1.30	
	Mean	1.25	1.72	1.09	1.62	1.32	1.40
With N.	Rep. I	1.26	1.79	1.10	1.60	1.25	
	Rep.II	1.04	1.83	1.08	1.25	1.16	
	Mean	1.15	1.81	1.09	1.43	1.21	1.34
MEANS		1.20	1.77	1.09	1.53	1.27	

Distribution of Soil Moisture

Moisture tensions for the different treatments throughout the season are presented in Figs. 14 and 15.

The gypsum blocks recorded full profiles at planting on both fallow treatments. With little contribution from precipitation it is shown that a satisfactory crop of wheat can be grown on about 10 in. of available stored moisture.

With the double-cropped treatments moisture infiltration to one foot was recorded on the minimal tillage treatment but not on the conventionally tilled plots. In all double-cropped treatments the two and three foot levels remained at or below wilting point throughout the season. Roots were unable to penetrate through this layer of dry soil resulting in a virtual crop failure due to moisture stress.

Discussion

The differences in the yields of grain harvested from the previously fallowed and the double-cropped treatments is a direct result of moisture stored within the profile from the previous rainy season. Double cropping failed but the fallowed treatments gave an economic return on a rainfall sufficient only for germination. The large increase in yield resulting from chemical fallowing is probably due to the avoidance of moisture loss through cultivation of the seedbed.

C. 1967 LONG RAINS

The conventional double-cropped plots were ploughed on 31 March and disc harrowed twice before planting. Chemically fallowed plots were sprayed with Gramoxone W at 1½ pints/acre on the 10 April,

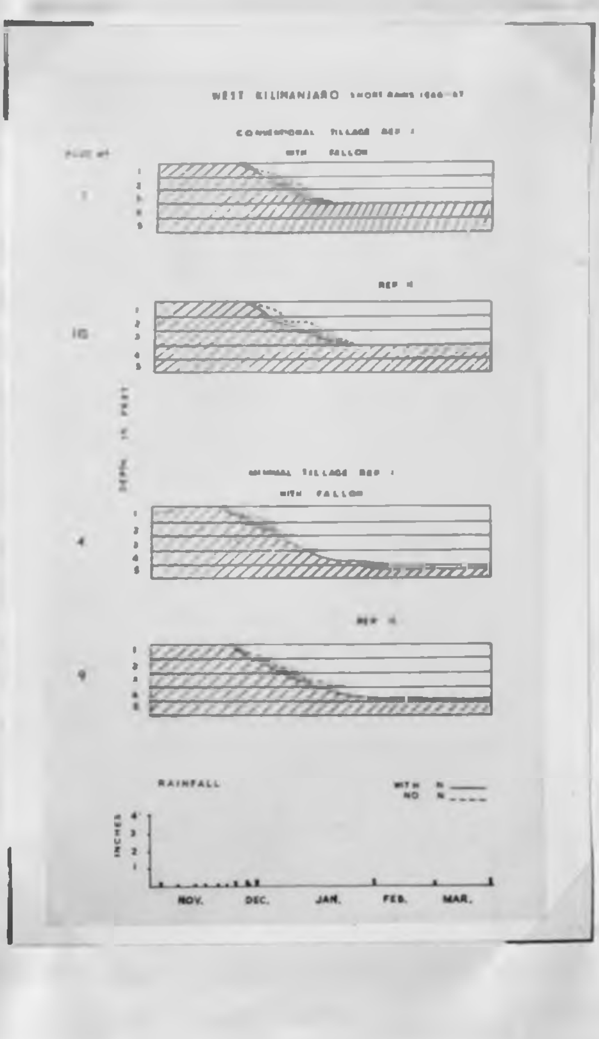


Figure 14: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1966-67 Short Rains season.

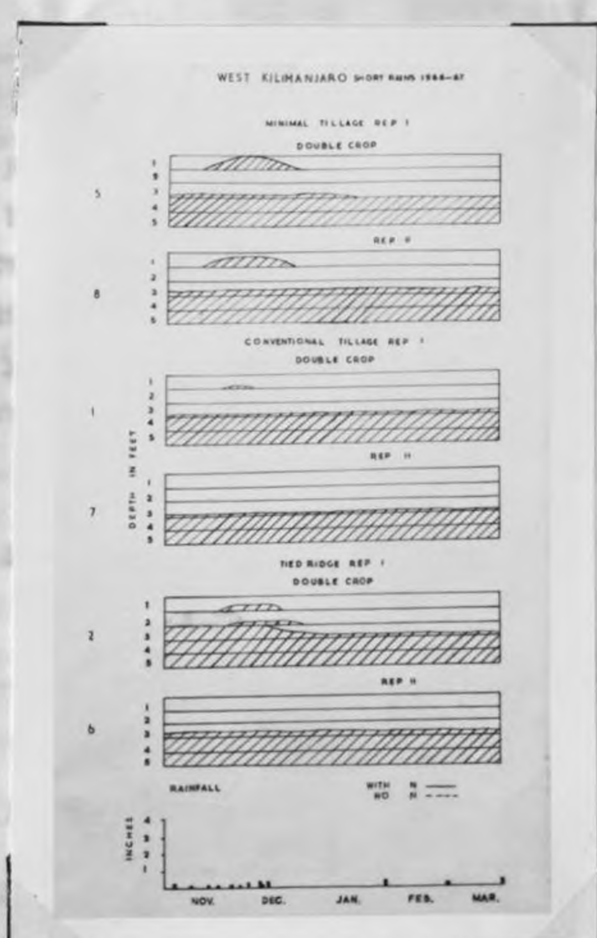


Figure 15: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1966-67 Short Rains season.

18 May, 12 June and 1 August. The double-cropped minimal treatment was treated once at the same rate on the 10 April immediately before planting. Conventionally cultivated fallows were ploughed on the 13 July after two disc harrowings had failed to keep the weeds in check. The trial was planted on the 10 April and top-dressed with nitrogen on the 5 May after aerial spraying on the 26 April. Harvesting was carried out on the 3 October.

Rainfall

The Long Rains commenced on the 31 March and five inches were recorded before planting. Over one inch of rain fell immediately after planting followed by well distributed April - May precipitation. Late season rainfall in May contributed to the excellent yields obtained. Difficulty was experienced with the cultivated fallow weed control due to the continuous early rain.

Pre-planting	March	1967	0.53 (1)
	April		5.19 (9)
		Total	5.72 (10)
Planting - Harvest	April		4.98 (12)
	May		7.47 (15)
	June		0.12 (3)
	July		0.44 (3)
	August		0.73 (4)
	September		1.72 (4)
		Total	15.46 (41)

Yields, Populations and Plant Heights

Yields, populations and plant heights are presented in Tables 26 and 27

TABLE 26 YIELDS AND POPULATIONS, WEST KILIMANJARO - LONG RAINS 1967

		Conventional Tillage double crop	Tie Ridge double crop	Minimal Tillage double crop	Means
Without N.	Plant Population	865	788	907	853
	Tiller Counts	2,393	1,901	2,794	2,363
	Total Crop	9,169	6,904	9,354	8,476
	Grain Yield	2,843	2,166	2,727	2,578
With N.	Plant Population	919	640	680	806
	Tiller Counts	2,378	1,649	2,261	2,096
	Total Crop	10,575	8,034	9,810	9,473
	Grain Yield	2,716	2,091	2,636	2,481
Means	Plant Population	892	714	884	
	Tiller Counts	2,386	1,775	2,528	
	Total Crop	9,872	7,469	9,582	
	Grain Yield	2,779	2,129	2,682	

Plant populations and tiller counts per sample area.
Grain and total crop weights in lb./acre.

The overall yields obtained this season were at a high level. Grain weights were not affected by nitrogen application but total crop weights have shown a positive response. Conventional cultivation has given only slightly better mean yields of grain and total crop.

The tie ridging treatment has given lower plant populations, tiller counts and reduced grain and total crop yield which is largely due to the practical difficulty in establishing wheat on ridges.

Nitrogen has again depressed population and tillering. There were no differences in population between the conventional and minimal tilled plots but tillering was slightly better under minimal tillage. It is surprising to note the lower tiller number per plant with tie ridging considering the lower plant populations. Fertiliser application has had no effect on plant height measurements but there is a noticeable effect between cultivation treatments.

TABLE 27 PLANT HEIGHTS (feet) AT HEADING, WEST KILIMANJARO - LONG RAINS 1967

		Conventional Tillage double crop	Tie Ridge Double crop	Minimal Tillage double crop	Means
Without N.	Rep. I	3.86	4.18	4.07	
	Rep.II	3.85	3.84	4.11	
	Means	3.86	4.01	4.09	3.95
With N.	Rep. I	3.63	4.29	4.18	
	Rep.II	3.92	3.75	3.92	
	Means	3.78	4.02	4.05	3.95
MEANS		3.82	4.02	4.07	

<u>Gravimetric Soil Moisture Samplings</u>

The comprehensive results of the soil moisture samplings before planting (1 April) and at harvest (28 September) are given in Appendices 8 and 9 and summarised in Table 28.

TABLE 28 SUMMARY OF TOTAL AVAILABLE WATER (in.) WITHIN THE 5½ ft. PROFILE, WEST KILIMANJARO - LONG RAINS 1967

Treatment	Mean of Replicates Planting	Harvest
Conventional Tillage - double crop	3.68	2.81
Tie Ridge - double crop	2.50	3.85
Cultivated Fallow	1.82	3.47
Chemical Fallow	1.71	6.15
Minimal Tillage - double crop	3.20	4.13

The double-cropped treatments show a more favourable moisture status at planting than the fallowed plots. This is due to the moisture remaining at depth which was not utilised during the previous season owing to crop failure. The fallowed plots were at wilting point from the two foot level and moisture recorded at planting was a result of water infiltration to this level from the pre-planting rains.

By harvest both the minimal tillage treatments were showing considerably more available moisture stored at the four and five foot levels.

<u>Distribution of Soil Moisture</u>

Readings from the gypsum resistance units (Figs. 16 and 17) show the advantages of chemical fallowing over cultivation for weed control in a season of good rainfall. Recharging of the profile during heavy April rainfall was much more rapid on the stubble mulched plots which remained at field capacity throughout the season.

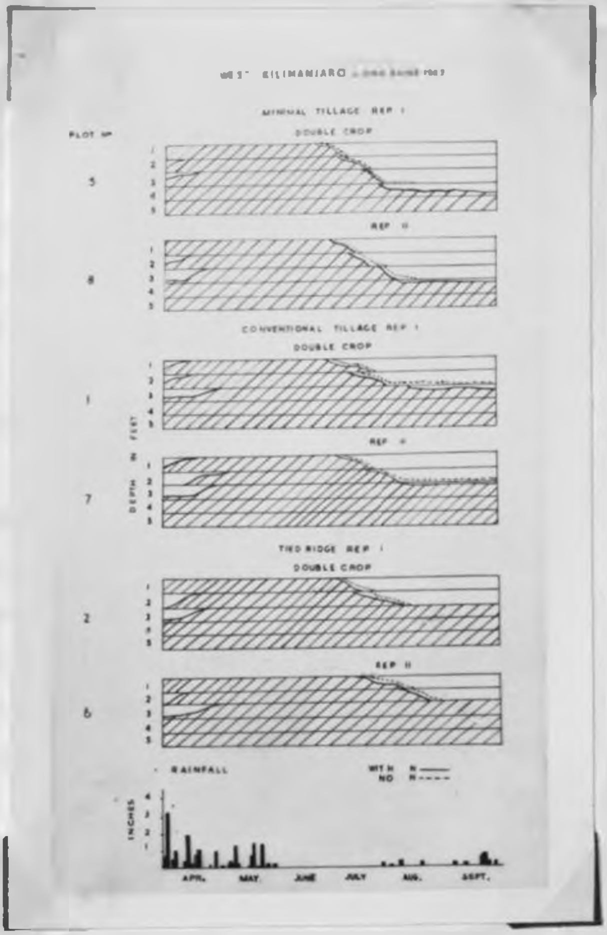


Figure 16: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1967 Long Rains season.

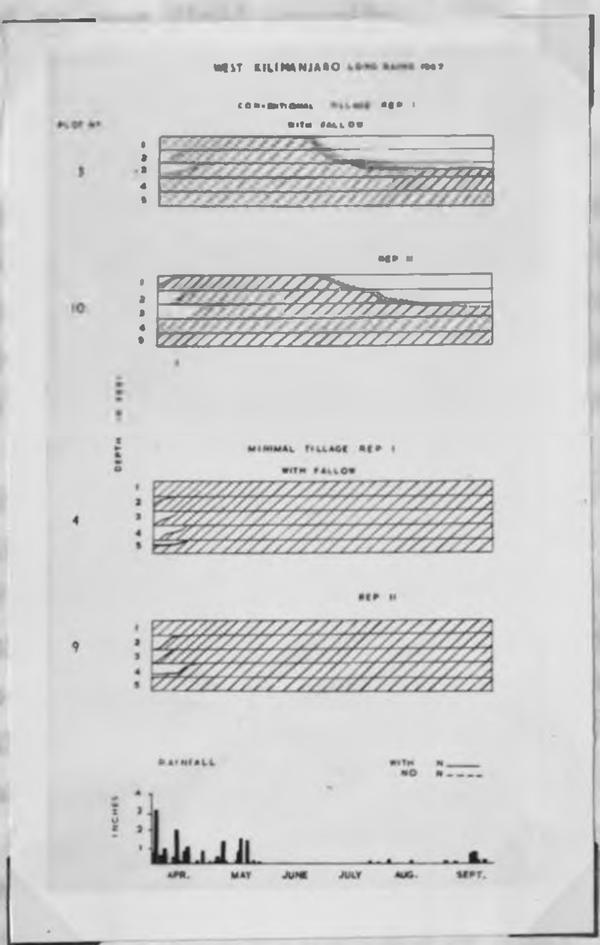


Figure 17: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1967 Long Rains season.

Uncontrolled weed growth on the cultivated fallows withdrew water in one replicate to three feet where nitrogen had been applied in the previous season and not utilized.

The minimal tillage double-cropped plots also showed a more favourable recharging of the profile compared with the conventionally tilled double-cropped plots. The withdrawal pattern was similar for all cropped treatments, more moisture being used under nitrogen application as would be expected. At flowering on the 24 June all profiles were at or near field capacity.

Discussion

In this third season the effect of stubble mulching on water infiltration is becoming evident. Observations in the field during the heavy and often intense April - May rainfall substantiated these recordings. Run-off and erosion were recorded on the conventionally tilled plots as a result of surface capping early in the rains.

The conventionally tilled fallow plots lay wet until the end of May when the first cultivation for weed control was possible. The result of water withdrawal by the weed growth and volunteer wheat, together with the moisture lost by this ploughing operation, is recorded by the gypsum blocks. In seasons having this sort of rainfall distribution planting is often delayed due to the early onset of the rain and waterlogging of the overcultivated and 'fluffy' seedbed. With a difficult planting season fallow cultivations are also delayed and the value of the system as a water storage reserve is open to doubt.

D. 1967-68 SHORT RAINS

The conventionally tilled plots were ploughed and disc harrowed and the minimal treatments sprayed with 1½ pints/acre Gramoxone W on the 26 October. All plots were planted on the 28 October and nitrogen applied four weeks later. The crop was aerial sprayed on the 30 November and harvested on the 15 February.

Rainfall

The Short Rains commenced on the 8 October and over three inches of well-distributed rainfall were recorded before planting. A fall of 0.3 in. the day after planting was sufficient for a good, even, germination on all treatments. Rain recorded during November and December was well below average and marginal for crop growth. After flowering on the 16 December only 0.65 in. of effective rainfall was recorded up to harvest.

Pre-planting	October	1967	3.38	(6)
Planting - Harvest	October		0.30	(1)
	November		3.71	(9)
	December		1.60	(4)
	January	1968	NIL	
	February		0.44	(2)
		Total	6.05	(16)

Yields, Populations, Plant Heights and Quality

The crop yields and plant populations are given in Table 29 and plant height measurements in Table 30. The results of baking quality tests carried out on the harvested grain are given in Table 31.

TABLE 29 YIELDS AND POPULATIONS, WEST KILIMANJARO - SHORT RAINS 1967-68

		Conventional Tillage double crop	Tie Ridge double crop	Minimal Tillage double crop	Minimal Tillage with chemical fallow	Conventional Tillage with cultivated fallow	Means
Without N.	Plant Population	1,068	989	733	492	711	799
	Tiller Counts	2,489	2,116	1,422	1,388	1,501	1,783
	Total Crop	4,871	5,339	6,413	7,291	6,081	5,999
	Grain Yield	1,786	1,582	2,125	2,076	1,898	1,893
With N.	Plant Population	1,033	1,031	718	483	1,009	855
	Tiller Counts	2,417	2,069	1,572	1,537	1,279	1,775
	Total Crop	5,929	5,415	6,322	6,988	6,609	6,253
	Grain Yield	1,849	1,562	2,004	2,295	1,745	1,891
Means	Plant Population	1,050	1,010	726	488	860	
	Tiller Counts	2,453	2,093	1,497	1,463	1,390	
	Total Crop	5,400	5,377	6,368	7,139	6,345	
	Grain Yield	1,818	1,572	2,065	2,186	1,822	

Plant populations and tiller counts per sample area.
Grain and total crop weights in lb./acre.

Minimal tillage with previous chemical fallow has outyielded all other treatments in the fourth season. The double-cropped minimal treatment produced slightly less grain than the chemical fallow cultivation but has given over a bag*/acre of grain more than both the conventionally tilled treatments.

NB * 1 bag of 200 lb. grain

A grain yield response to nitrogen was evident with the minimal tillage after fallow treatment only. Both fallow treatments recorded considerably higher total crop weights at harvest.

Application of nitrogen has increased plant populations slightly but not tiller numbers. The effect of cultivation has been striking on both plant population and tillering. Both minimal treatments showed a marked reduction in plant numbers which has been compensated for by tillering. There is little doubt that the plant populations on both double-cropped treatments were affected by volunteer wheat from the previous season.

Plant heights recorded at heading have shown a noticeable response to applied nitrogen. The minimal tillage after fallow treatment has given the most vigorous growth.

TABLE 30 PLANT HEIGHTS (feet) AT HEADING, WEST KILIMANJARO - SHORT RAINS 1967-68

		Conventional Tillage Double Crop	Tie Ridge Double Crop	Minimal Tillage Double Crop	Minimal Tillage with Chemical Fallow	Conventional Tillage with Cultivated Fallow	MEANS
Without N.	Rep. I	2.85	2.73	2.91	2.71	2.68	
	Rep.II	2.21	2.70	2.51	2.79	2.80	
	MEAN	2.53	2.72	2.71	2.75	2.74	2.69
With N.	Rep. I	2.83	2.96	2.97	[illegible]	2.81	[illegible]
	Rep.II	2.21	2.68	2.63	[illegible]	[illegible]	[illegible]
	MEAN	2.52	2.82	2.80	[illegible]	[illegible]	[illegible]
MEANS		2.53	2.77	2.76	[illegible]	[illegible]	[illegible]

TABLE 31 BAKING QUALITY TEST RESULTS (VARIETY ROMANY)
WEST KILIMANJARO - SHORT RAINS 1967-68

Treatment	Nitrogen	Bushel Weight	Strength	L/P	Protein
Conventional Tillage -double crop	-	63	33	3.12	12.2
" "	+	64	38	4.70	12.6
Tie Ridge -double crop	-	64	39	3.56	13.4
" "	+	63	35	3.70	15.0
Minimal Tillage -double crop	-	64	39	3.78	11.9
" "	+	63.5	39	3.46	13.5
Minimal Tillage with chemical fallow	-	63.5	39	4.15	14.4
	+	63.5	49	5.38	15.3
Conventional Tillage with cultivated fallow	-	64	36	3.58	13.0
	+	64	43	5.03	13.2

Nitrogen has in all cases given an increase in grain protein content. The increase is larger in the minimal than the conventional treatments. The highest strength and protein values were recorded from the minimal after fallow with applied nitrogen treatment.

Gravimetric Soil Moisture Samplings

Results of samplings taken at planting (31 October), flowering (24 January) and harvest (20 February) are given in Appendices 10 - 12 and summarised in Table 32.

At planting the cultivated fallow was still showing the effect of the uncontrolled weed growth during the previous rains. The double-cropped minimal treatment in particular has a more favourable moisture status at flowering due to control of run-off by the surface mulch. At flowering time the minimal treatments are showing three and two inches of available water at the four and five foot levels respectively which is virtually exhausted by harvest.

Available water at harvest in the lower profile levels of the conventionally tilled double-cropped treatment indicates that the roots have not penetrated below the three to four foot levels.

TABLE 32 SUMMARY OF TOTAL AVAILABLE WATER (in.) WITHIN THE 5½ ft. PROFILE, WEST KILIMANJARO - SHORT RAINS 1967-68

Treatment	Mean of Replicates		
	Planting	Flowering	Harvest
Conventional Tillage double crop	5.69	1.31	1.20
Tie Ridge double crop	4.76	1.65	1.36
Conventional Tillage with cultivated fallow	3.85	1.52	0.34
Minimal Tillage with chemical fallow	7.34	1.94	0.41
Minimal Tillage double crop	6.27	3.12	0.44

Distribution of Soil Moisture

The gypsum blocks records (Figs. 18 and 19) verify the gravimetric moisture sampling results in demonstrating the better storage of the chemical fallow at planting. Recharge of the minimal double-cropped plots was more rapid compared to the conventional tillage and tied ridge plots. At flowering the moisture at depth on the minimal tillage double-cropped plot is recorded together with its utilization by harvest. The water withdrawal picture supports the theory of a difference in rooting depth between conventional and minimal tillage.

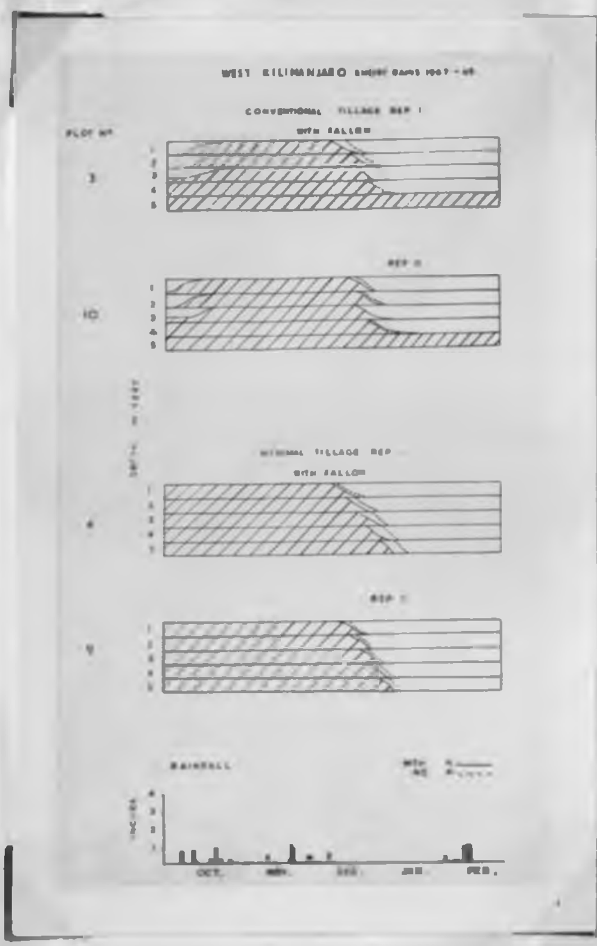


Figure 18: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1967-68 Short Rains season.

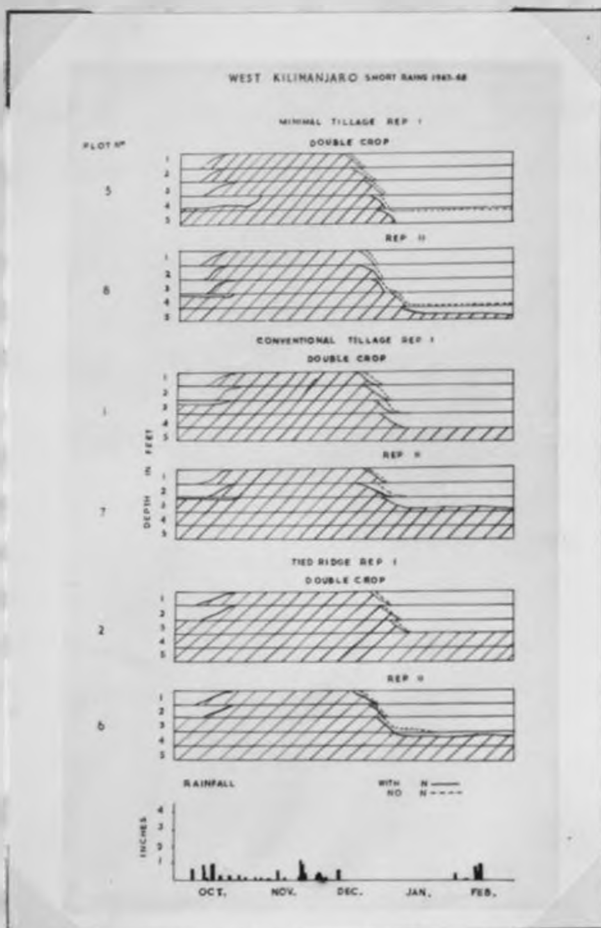


Figure 19: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1967-68 Short Rains season.

Discussion

The difficulties experienced in achieving a satisfactory seedbed using conventional cultivation in a year of early and heavy rainfall under the fallow farming system have been evident in this season. Weed growth was excessive and resulted in water loss from the fallow. It is also likely to be responsible for reduced plant populations on the minimal treatments due to planting through an excessively heavy mulch of killed weed. The nitrogen response on the minimal fallow plots may also be a result of early utilisation of available nitrogen by weed growth.

Improved and more rapid infiltration rates recorded on the minimal double-cropped treatment has certainly been a contributory factor to the high yields obtained from these plots.

This is the first indication of better rooting at depth by the use of minimal tillage. It is probably due in part to the rather inferior seedbeds produced by the conventional cultivation system which have resulted in poorer root growth and consequent inability to tap the deeper moisture reserves later in the season. It would appear that a good start is essential for deep rooting.

E. 1968 LONG RAINS

Straw from the previous harvest was burnt on the conventional and tie ridge plots (Plate 29) but was left on both minimal treatments (Plate 30).

The conventional tillage plots were ploughed and disc harrowed on the 29 February. Reploughing and harrowing was necessary on the 30 March before planting. As a result of heavy continuous rain it was not possible to re-cultivate the fallows before 14 June.

Another disc harrowing followed on the 12 August. Both the minimal treatments were sprayed with Gramoxone W at 2 pints/acre on the 30 March and spot sprayed at the same dosage on the 2 April at 1 pint/acre. The minimal fallow was again treated with 1 pint/acre on the 30 April, 16 May and 15 August. The trial was planted on the 6 April, topdressed with nitrogen on the 11 May and aerial sprayed on the 29 April. Harvesting was completed by the 16 September.

Rainfall

The well above average and out of season preplanting rains caused great difficulty in land preparation of the conventionally tilled treatments. Conditions were ideal at planting and with 0.9 in. of rain falling on the day after, excellent germination and establishment was achieved. Striking visual responses to nitrogen were recorded on all treatments. Flowering was completed by the 26 June after which only 0.5 in. effective rainfall was recorded until harvest.

Pre-planting	February	1968	3.35 (4)
	March		12.39 (18)
	April		3.15 (4)
		Total	26.89 (26)
Planting - Harvest	April		6.26 (7)
	May		7.46 (21)
	June		3.12 (12)
	July		0.09 (2)
	August		0.22 (1)
	September		NIL
		Total	17.15 (43)

Weed Control

After two seasons of heavy rainfall where weed control by cultivation had been both difficult and largely ineffective due to the land lying wet, a heavy infestation of cleavers (Gallium spurium) had established in the conventionally tilled plots. Successive sprayings with Gramoxone W on the minimal tilled, chemically treated plots had kept the weed under control (Plates 31 and 32).

Yields, Populations and Quality

The populations and yields recorded are presented in Table 33 together with plant heights at heading (Table 34) and the results of baking quality tests on harvested grain (Table 35).

TABLE 33 YIELDS AND POPULATIONS, WEST KILIMANJARO - LONG RAINS 1968

		Conventional Tillage double crop	Tie Ridge double crop	Minimal Tillage double crop	Means
Without N.	Plant Population	1,269	1,388	2,232	1,630
	Tiller Counts	2,676	2,326	3,514	2,839
	Total Crop	4,568	3,994	5,855	4,806
	Grain Yield	755	628	1,093	825
With N.	Plant Population	1,817	1,622	2,012	1,817
	Tiller Counts	3,171	3,299	3,444	3,305
	Total Crop	6,566	5,219	5,733	5,839
	Grain Yield	855	646	1,312	938
Means	Plant Population	1,543	1,505	2,122	
	Tiller Counts	2,924	2,813	3,479	
	Total Crop	5,567	4,607	5,794	
	Grain Yield	805	637	1,203	

Plant populations and tiller counts per sample area.
Grain and total crop weights in lb./acre.

In this wet year the response to nitrogen application is shown by the increase in both plant populations and tillering, both recordings show a large increase over previous seasons.

The highest populations and most vigorous tillering has been produced on the minimal tillage treatments.

The overall yields were quite severely affected by an outbreak of stem rust. The best yield was given by the minimal tillage treatment which outyielded the conventional tilled plots by over 30 per cent. Grain yield has shown a positive response to nitrogen particularly on the minimal plots. The mean effect of nitrogen may have been greater but for stem rust which was more severe on the nitrogen applied plots. The application of nitrogen has increased the mean total crop weight by some twenty per cent.

TABLE 34 PLANT HEIGHTS (Feet) AT HEADING, WEST KILIMANJARO - LONG RAINS 1968

		Conventional Tillage Double crop	Tie Ridge Double crop	Minimal Tillage Double crop	Means
Without N.	Rep. I	3.38	3.45	3.08	
	Rep. II	3.47	3.53	3.09	
	Means	3.43	3.49	3.09	3.34
With N.	Rep. I	4.01	3.58	3.90	
	Rep. II	3.77	3.93	3.89	
	Means	3.89	3.76	3.90	3.85
MEANS		3.66	3.63	3.50	

Nitrogen application has increased the mean plant heights, the most noticeable effect being on the minimal tillage treatment.

TABLE 35 BAKING QUALITY TEST RESULTS (VARIETY ROMANY)
WEST KILIMANJARO - LONG RAINS 1968

Treatment	Nitrogen	Bushel Weight	Strength	L/P	Protein
Conventional Tillage -double crop	-	60	25	1.04	10.0
" "	+	59½	25	1.48	10.4
Tie Ridge -double crop	-	60	23	1.68	10.2
" "	+	60	22	1.37	10.4
Minimal Tillage -double crop	-	62	25	0.94	10.1
" "	+	61	25	1.12	10.3

Baking quality tests carried out on the harvested grain show the positive response of protein content to nitrogen application. Strength and bushel weight were not affected by either cultivation treatment or applied fertiliser.

Gravimetric Soil Moisture Samplings

The comprehensive results of the soil moisture samplings at planting (24 April), flowering (8 July) and harvest (12 September) are given in Appendices 13 - 15 and summarised in Table 36.

TABLE 36 SUMMARY OF TOTAL AVAILABLE WATER (in.) WITHIN THE 5½ ft. PROFILE, WEST KILIMANJARO - LONG RAINS 1968

Treatment	Mean of Replicates		
	Planting	Flowering	Harvest
Conventional Tillage -double crop	8.08	6.17	5.09
Tie Ridge -double crop	9.91	5.07	4.78
Cultivated Fallow	6.86	5.73	4.25
Chemical Fallow	8.55	6.42	5.42
Minimal Tillage -double crop	8.72	5.83	3.45

The tie ridged treatment has stored approximately ten inches of available water at planting compared to the 6.8 in. of the cultivated fallow where moisture was observed to be lost by run-off. The profile on this fallow showed poor infiltration to depth and loss from the top foot due to excessive weed growth. The fact that the water table had risen to five feet in plot number 10 (conventional tillage with fallow) during March - April, has substantially affected the true water availability picture on this treatment.

At flowering there are little differences in moisture availability between the cropped treatments, but the chemical fallows show better retention which is maintained until harvest. The differential rooting depth between minimal and conventional tillage is again reflected in the harvest recordings.

Distribution of Soil Moisture

The availability of water throughout the season as recorded by the gypsum blocks is presented in Figs. 20 and 21.

In this year with continuous rainfall the efficiency of tie ridging for water storage is evident from the rapid recharge recorded by the gypsum blocks. Rooting on this treatment was limited to one foot where no nitrogen had been applied; the three to five foot profile remained at field capacity or above during the growing season.

The minimal tillage profile showed complete recharge by mid-March and the conventionally tilled treatments by the end of March. The initial withdrawal pattern between these treatments was similar but later utilization on the minimal plots was much more rapid and to a greater depth than on the conventional tilled.

The extraction of moisture by weeds is recorded by the blocks

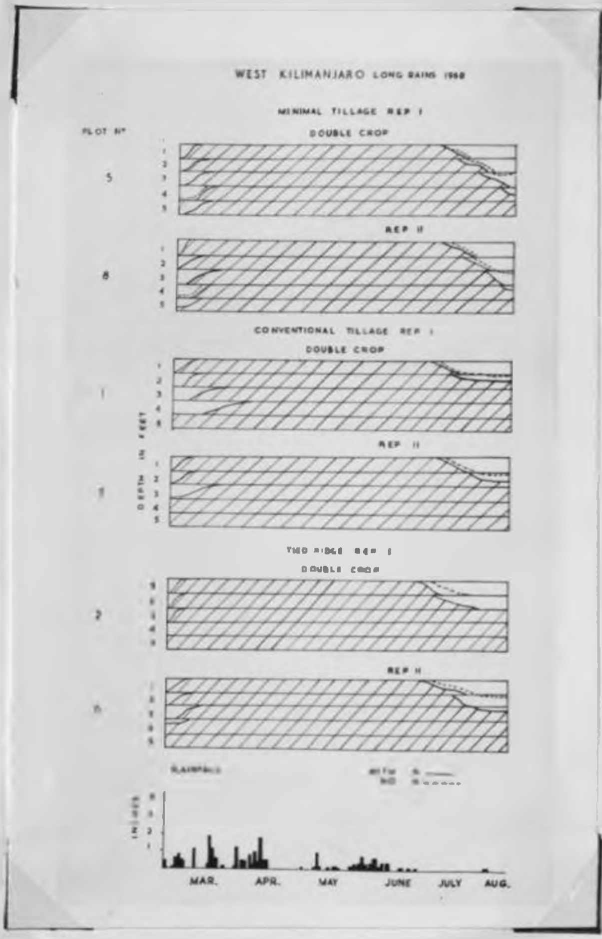


Figure 20: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1968 Long Rains season.

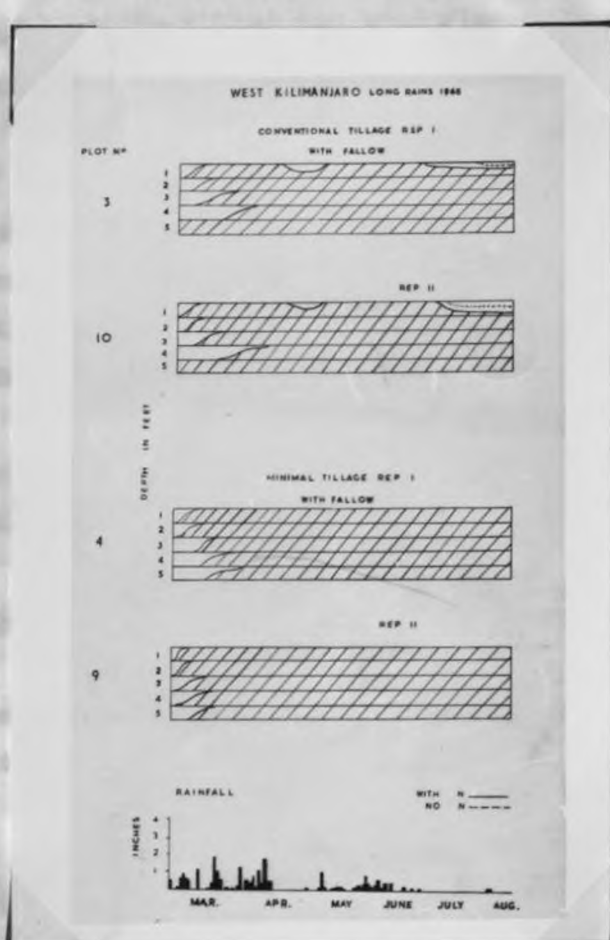


Figure 21: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1968 Long Rains season.

on the conventionally cultivated fallow twice during the season. Rainfall was more than adequate to produce saturated profiles on both fallow treatments by harvest. There is however a difference in the rate of recharge at the five foot level in favour of the chemical fallow.

Root Growth

Root washings of one replicate of the minimal and conventional tillage treatments, with and without nitrogen, were photographed at harvest (Plates 33 - 36).

The rooting behaviour in the conventional tillage plot showed little improvement with nitrogen application. Both treatments had poor root distribution to 10 in. depth with the concentration of roots in the top two inches.

The roots of the minimum tillage treatment with nitrogen were profuse and concentrated to 24 in.

Discussion

The populations and tillering recorded this season on the minimal treatment were substantially better than on the conventional treatment. The former had a heavy semi-decomposed straw and dead weed cover which controlled water movement off the plot during the establishment phase. The germinating seed had no difficulty in emerging through the trash cover (Plate 37).

The large grain yield increase with minimal tillage plus nitrogen could be due to the increased rooting depth compensating for the more rapid leaching of nitrogen under well above average rainfall conditions.

Better soil/water relationships were recorded with stubble mulching both in the control of run-off and in the profile recharge recorded by the gypsum blocks.

F. 1968-69 SHORT RAINS

The wheat straw after combining the previous crop was burnt on the conventionally tilled and tied ridge plots. Couch grass (*Digitaria scalarum*) which had been spreading on these plots was dug out by hand and afterwards they were chisel ploughed, following normal farm practice, to a depth of seven inches on the 4 October leaving an exceptionally rough surface.

Both the minimal tilled after fallow and double-cropped plots were scarified to a depth of two inches. Conventional tilled and tied ridge plots were disc harrowed on the 9 October and the latter remade by hand. Only one spraying was necessary on the minimal plots at 1½ pints/acre Gramoxone W before planting with variety Romany on the 5 November. Fertilizer was applied to the sub-plots on the 12 December and aerial spraying carried out with a mixture of 2,4-D and Cambilene* to control cleavers on the 19 December. Harvesting was completed by the 19 March.

Rainfall

This Short Rains produced more than adequate total precipitation for a good crop but the distribution was very unfavourable. After

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*Cambilene a mixture of: dicamba (3,6-dichloro-2-methoxy benzoic acid)
MCPA (4-chloro-2-methylphenoxy acetic acid)
2,3,6-TBA (2,3,6-trichlorobenzoic acid)
mecoprop (dl2-(4-chloro-2-methylphenoxy) propionic acid (2-(MCPP)))

marketed by Fisons Ltd.

planting a fall of 0.23 in. on the 7 November was sufficient to germinate both minimal tilled treatments. The seed on the conventional and tied ridge plots lay dry until the 21 November when germination took place after 0.71 in. A total of 5.5 in. during the latter part of November gave good establishment growth. No rain fell from the 19 December until the 23 January by which time both the conventional treatments were severely droughted and were considered to be a virtual crop failure. Late January and early February rainfall of some six inches altered the overall picture considerably to the benefit of the conventional tillage treatments.

Throughout the season the minimal tillage plots maintained the advantage of early germination. Population, tiller counts, plant heights and harvest were all recorded two weeks earlier on these treatments compared to the conventional and tied ridge plots.

Pre-planting	October	1968	1.11 (3)
	November		0.53 (3)
		Total	1.64 (6)
Planting - Harvest	November		10.01 (17)
	December		10.47 (14)
	January	1969	2.96 (6)
	February		4.48 (9)
	March		0.05 (2)
		Total	27.97 (48)

<u>Yields, Populations and Plant Heights</u>

Yields and populations are presented in Table 37 together with plant height measurements (Table 38).

TABLE 37 YIELDS AND POPULATIONS, WEST KILIMANJARO - SHORT RAINS 1968-69

		Conventional Tillage double crop	Conventional Tillage with cultivated fallow	Tie Ridge double crop	Minimal Tillage double crop	Minimal Tillage with chemical fallow	Means
Without N.	Plant Population	1,461	1,594	1,327	1,415	1,256	1,411
	Tiller Counts	2,251	2,269	1,983	1,839	2,149	2,098
	Grain Yield *	1,547	1,529	1,263	1,378	2,321	1,608
	Straw Weight	3,473	3,594	2,493	2,499	4,992	3,410
With N.	Plant Population	1,587	1,481	1,491	1,448	1,194	1,440
	Tiller Counts	3,066	2,653	2,587	2,325	2,592	2,645
	Grain Yield *	1,949	1,727	1,601	1,766	2,707	1,950
	Straw Weight	4,544	3,355	3,068	3,240	4,901	3,822
Means	Plant Population	1,524	1,538	1,409	1,432	1,225	
	Tiller Counts	2,659	2,461	2,235	2,082	2,371	
	Grain Yield *	1,748	1,628	1,432	1,572	2,514	
	Straw Weight	4,009	3,475	2,781	2,869	4,947	

* Grain Yields corrected to 15 per cent moisture.
Plant populations and tiller counts per sample area.
Grain and straw weights in lb./acre.

Nitrogen has had no overall effect on mean populations but has increased tillering on all treatments. Plant survival was higher on the fertilized double-cropped plots with mean plant counts lower for the minimal treatments.

In this the final season, the minimal tillage after chemical fallow treatment has given a large increase in grain yield over the other treatments, having outyielded the conventional fallow by 880 lb/acre (54 per cent). With the double-cropped treatments the conventional has given an increase of 176 lb/acre over the minimal.

The minimal after fallow without nitrogen treatment has given an increase of 792 lb/acre (52 per cent) over the conventional equivalent whilst with application of nitrogen an increase of 980 lb/acre (57 per cent) was achieved. There is a suggestion of a slightly better response to nitrogen with minimal tillage.

Comparing the conventional tillage double-cropped with the minimal tillage double-cropped, there is an increase of 169 lb/acre (12 per cent) in the absence of fertiliser and an increase of 183 lb/acre (10 per cent) with nitrogen applied, a further indication of a better nitrogen response with minimal tillage.

There are increases in straw weight on the double-cropped plots with applied fertiliser but no responses were obtained with the fallow treatments.

TABLE 38 PLANT HEIGHTS (feet) AT HEADING, WEST KILIMANJARO - SHORT RAINS 1968-69

		Conventional Tillage Double Crop	Conventional Tillage with Cultivated Fallow	Minimal Tillage Double Crop	Minimal Tillage with Chemical Fallow	Tie Ridge Double Crop	Means
Without N.	Rep. I	2.47	2.31	2.02	2.44	2.09	
	Rep.II	2.32	2.30	2.05	2.73	2.13	
	Mean	2.40	2.31	2.04	2.59	2.11	2.29
With N.	Rep. I	2.63	2.27	2.20	2.48	2.31	
	Rep.II	2.58	2.45	2.18	2.80	2.27	
	Mean	2.61	2.36	2.19	2.64	2.29	2.42
MEANS		2.51	2.34	2.12	2.62	2.20	

Nitrogen has increased plant height in all main treatments but the differences are larger with the double-cropped treatments. The minimal tillage after fallow has produced the most vigorous growth in both the presence and absence of fertiliser.

Gravimetric Soil Moisture Samplings

The comprehensive results of the soil moisture samplings at planting (12 November,1968), flowering (25 January,1969) and harvest (14 March,1969) are presented in Appendices 16 - 18 and summarised in Table 39.

TABLE 39 SUMMARY OF TOTAL AVAILABLE WATER (in.) WITHIN THE 5½ ft. PROFILE, WEST KILIMANJARO - SHORT RAINS 1968-69

Treatment	Mean of Replicates		
	Planting	Flowering	Harvest
Conventional Tillage -double crop	1.98	5.50	4.87
Tie Ridge -double crop	4.24	5.78	4.47
Conventional Tillage with cultivated fallow	2.21*	5.35	4.54
Minimal Tillage with chemical fallow	4.09	3.87	2.34
Minimal Tillage -double crop	3.00	5.88	3.90

* 1.72 in. of available water was recorded at 5 ft. on plot 10 affected by water table.

The moisture samplings again indicate the more efficient utilisation of stored soil moisture to depth by the minimal fallow treatment. At planting both minimal treatments and the tie ridged had substantially more moisture stored at depth from the late rainfall during the previous season. The particular advantage of mulching and reduced soil disturbance is shown by the moisture stored at the 6 - 12 in. zone on both minimal treatments. Seedbed preparation by ploughing and disc harrowing resulted in the top 18 in. being at or near wilting point at planting - hence the overall two weeks delay in growth commencing.

At flowering the minimal fallow contained two inches less available water due to water withdrawal in the two to three foot zone.

Distribution of soil moisture

The water availability picture as recorded by the gypsum blocks is presented in Figs. 22 and 23.

The poor root development on both cultivated treatments is shown by the moisture withdrawal pattern and the importance of the late rainfall in saving these crops is evident.

During later growth the minimal fallow treatment was withdrawing moisture from four feet.

Root Growth

Root washings were made and photographed during this final season. The root growth of both conventional and minimal after fallow and double-crop at flowering are presented in Plates 38 - 41 showing the top one foot profile only.

Grain yield components from harvest samples

The results of head and grain weights from 500 random head samples and 1,000 grain weights from each treatment are presented in Table 40. With the exception of the ridged treatment, minimal tillage with fallowing has produced the highest number of grains per head. This treatment also shows the harvest mean grain weight. The minimal tillage double crop has given a reduced grain set in the absence of nitrogen. Harvested sample weight and graded commercial sample agree fairly closely, indicating good grain filling conditions due to the late rain.

TABLE 40 GRAIN YIELD COMPONENTS FROM HARVEST SAMPLES, WEST KILIMANJARO SHORT RAINS 1968-9

		YIELD FROM 500 HEAD RANDOM SAMPLE			1,000 GRAIN WEIGHTS (gms)		BUSHEL
TREATMENT	NITROGEN	Mean Grains/ Head	Mean Weight Grain/ Head (gms)	Mean Grain Weight	Harvested Sample	Graded Commercial Sample	WEIGHT
Conventional Tillage double crop	-	27.5	1.05	.038	38.2	38.3	62.1
	+	27.4	0.99	.036	36.1	38.5	61.4
Tie Ridging double crop	-	30.8	1.23	.040	39.9	39.3	61.1
	+	29.9	1.14	.038	38.2	40.0	62.8
Conventional Tillage with cultivated fallow	-	24.9	1.01	.040	40.5	40.3	64.6
	+	25.7	1.03	.040	40.3	41.0	64.3
Minimal Tillage with Chemical fallow	-	28.8	1.23	.043	42.9	43.0	64.2
	+	29.0	1.19	.041	40.9	41.5	64.3
Minimal Tillage double crop	-	19.4	0.72	.037	37.2	37.3	62.8
	+	25.4	1.01	.040	39.9	36.5	62.1

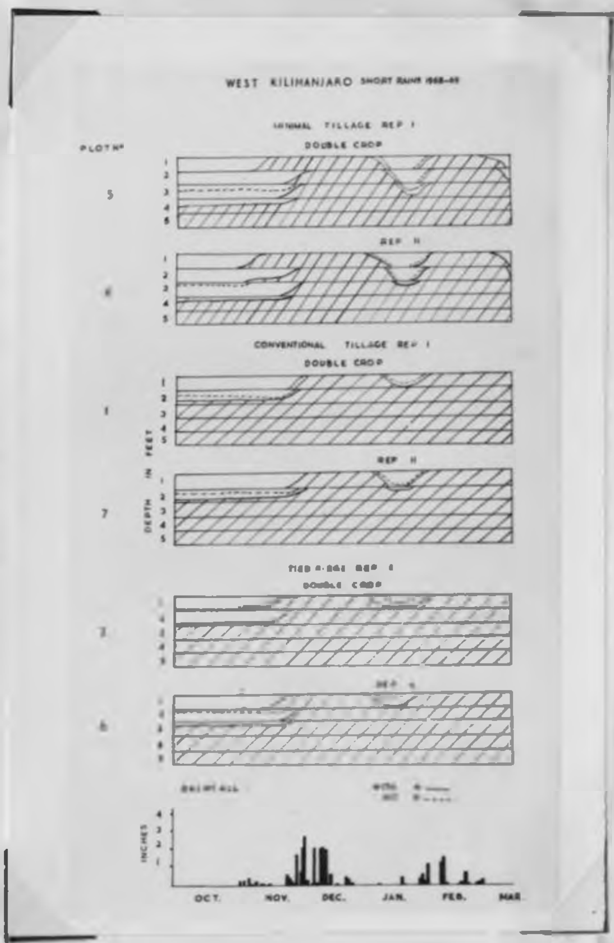

Figure 22: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1968-69 Short Rains season.

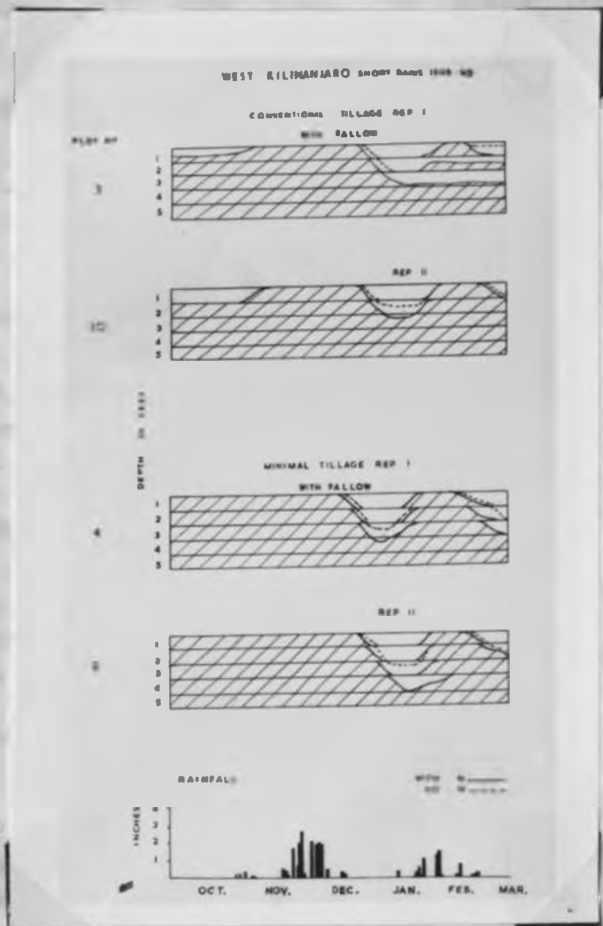

Figure 23: Resistance unit records showing penetration of rainfall in the top 5 ft. for the 1968-69 Short Rains season.

TABLE 41 SUMMARY OF YIELD DATA FROM WEST KILIMANJARO OVER SIX SEASONS

Year and Season	Treatment	- N					+ N				
		1	2	3	4	5	1	2	3	4	5
1966 L.R.	P.P.	752	-	684	778	-	859	-	762	907	-
	Tillers	1364	-	1435	1324	-	1752	-	1999	1590	-
	Total C	10806	-	9701	8456	-	12087	-	10627	9089	-
	G.Y.	2730	-	2589	2514	-	2552	-	2453	2472	-
	C.Index %	25.2	-	26.7	29.7	-	21.1	-	23.1	27.2	-
1966-67 S.R.	P.P.	672	853	618	748	764	663	746	557	762	721
	Tillers	1191	2039	1191	1924	2066	1142	1787	989	1929	2123
	Total C	475	2486	312	332	2249	528	2326	491	343	1940
	G.Y.	132	802	73	78	1232	136	779	150	97	1121
	C.Index %	27.8	32.2	23.4	23.5	54.8	25.8	33.5	30.5	28.3	57.8
1967 L.R.	P.P.	865	-	788	907	-	919	-	640	680	-
	Tillers	2393	-	1901	2794	-	2378	-	1649	2261	-
	Total C	9169	-	6904	9354	-	10575	-	8034	9810	-
	G.Y.	2843	-	2166	2727	-	2716	-	2091	2636	-
	C.Index %	31.0	-	31.4	29.2	-	25.7	-	26.0	26.9	-
1967-68 S.R.	P.P.	1068	989	733	492	711	1033	1031	718	483	1009
	Tillers	2489	2116	1422	1388	1501	2417	2069	1572	1573	1279
	Total C	4871	5339	6413	7291	6081	5929	5415	6322	6988	6609
	G.Y.	1786	1582	2125	2076	1898	1849	1562	2004	2295	1745
	C.Index %	36.7	29.6	33.1	28.5	31.2	31.2	28.8	31.7	32.8	26.4
1968 L.R.	P.P.	1269	-	1388	2232	-	1817	-	1622	2012	-
	Tillers	2676	-	2326	3514	-	3171	-	3299	3444	-
	Total C	4568	-	3994	5855	-	6566	-	5219	5733	-
	G.Y.	755	-	628	1093	-	855	-	646	1312	-
	C.Index %	16.5	-	15.7	18.7	-	13.0	-	12.4	22.9	-
1968-69 S.R.	P.P.	1461	1594	1327	1415	1256	1587	1481	1491	1448	1194
	Tillers	2251	2269	1983	1839	2149	3065	2653	2587	2325	2592
	Total C	5020	5123	3756	3877	7313	6493	5082	4669	5006	7608
	G.Y.	1547	1529	1263	1378	2321	1949	1727	1601	1766	2707
	C.Index %	30.8	29.8	33.6	35.5	31.7	30.0	34.0	34.3	35.3	35.6

G. YIELD DATA

All relevant yield data for six seasons is summarised in Table 41.

1. Conventional tillage double crop
2. Conventional tillage with cultivated fallow
3. Tie ridge couble crop
4. Minimal tillage double crop
5. Minimal tillage with chemical fallow.

The minimal double cropped treatment has given the highest crop index per cent in 1966 particularly in the presence of nitrogen. In the dry season of the 1966-7 short rains the minimal fallow treatment show crop index per cents of nearly double that of the other treatments.

Low crop index per cents resulted in the 1968 long rains with heavy preplanting rains stimulating heavy vegetative growth, although again, the minimal double cropped treatments have given more favourable percentages.

The comparison of grain yield from the five cultivation treatments over three short rains seasons is summarised in Table 42.

TABLE 42 MEAN YIELDS (lb/acre) OVER THREE SEASONS WITH ALL TREATMENTS CROPPED. WEST KILIMANJARO.

Nitrogen	Conventional Tillage Double Crop	Tie Ridge Double	Minimal Tillage Double Crop	Conventional Tillage with Cultivated Fallow	Minimal Tillage with Chemical Fallow	Means
-	1,155	972	1,193	1,410	1,876	1,321
+	1,311	1,104	1,289	1,417	2,041	1,423
Means	1,233	1,038	1,241	1,414	1,958	
	S.E. of difference between means (nitrogen) = 36 lb/acre (cultivations) - 57 lb/acre					

The analysis of variance shows both seasonal and cultivation differences to be significant at the P = 0.001 level and the effect of nitrogen application at the P = 0.01 level. The interaction between season and cultivation and season and nitrogen are also significant (P > 0.01).

Over these three seasons the minimal after fallow treatment has given a 540 lb/acre mean increase over the comparative conventional fallow. No differences are evident in the mean yields of both double cropped treatments.

Nitrogen has given a significant difference for the main effect but there has been no cultivation/nitrogen interaction. The season/nitrogen interaction shows that nitrogen response is very dependent on rainfall distribution during the growing season. There has been a suggestion of a nitrogen response on the minimum after fallow treatment but not with conventional tillage after fallow. The reason for this is possibly due to the return of straw to the plots. As the yields of the conventional fallow without nitrogen are similar to the yields with nitrogen it would appear more likely that the structural/aeration/moisture aspect is more limiting with this treatment. If, as is postulated, the surface environment is improved by minimal tillage then nitrogen may become limiting at the higher yield levels achieved.

The comparison between grain yields per annum for the five cultivation treatments over the entire experimental period are summarised in Table 43.

The conventional tillage double cropped has given an annual mean increase of 6½ bags per acre over minimal tillage after fallow. The implications of this result are discussed later.

It is interesting to analyse the effects of straw disposal of the previous crop on the responses of grain yields to nitrogen in the following season. Nitrogen gave no response in the first season after all straw on the trial had been removed. In the Short Rains 1966-7 the amount of straw produced due to the drought was low and again no nitrogen response was recorded in the following crop. A gradually increasing response however was observed on the minimal plots from the 1967-8 Short Rains season until the final season with three good crops grown under a heavy mulch cover.

TABLE 43 GRAIN YIELDS (lb/acre) per annum FOR FIVE CULTIVATION TREATMENTS OVER SIX SEASONS. WEST KILIMANJARO

Year	Nitrogen	Conventional Tillage Double Crop	Minimal Tillage Double Crop	Tie Ridge Double Crop	Conventional Tillage with Cultivated Fallow	Minimal Tillage with Chemical Fallow
1966	-	2,862	2,592	2,662	802	1,232
	+	2,688	2,569	2,603	779	1,121
	Means	2,775	2,581	2,633	791	1,171
1967	-	4,629	4,852	3,748	1,898	2,076
	+	4,565	4,640	3,653	1,745	2,295
	Means	4,597	4,746	3,701	1,822	2,186
1968	-	2,302	2,471	1,891	1,529	2,321
	+	2,804	3,078	2,247	1,727	2,707
	Means	2,553	2,775	2,069	1,628	2,514
Totals	-	9,793	9,915	8,301	4,229	5,629
	+	10,057	10,287	8,503	4,251	6,123
Means/Year	-	3,264	3,305	2,767	1,410	1,876
	+	3,352	3,429	2,834	1,417	2,041
Difference from Minimal Fallow	-	+1,388	+1,429	+ 891	- 466	
	+	+1,311	+1,388	+ 793	- 624	

H. PHYSICAL PROPERTIES OF THE EXPERIMENTAL SOIL

The results of the physical determinations recorded in the first year of the trial are summarised in Table 44.

TABLE 44 PORE-SPACE RELATIONSHIPS OF SOIL (WEST KILIMANJARO) 6 JULY 1966. (Mean of two pits)

Depth	Bulk Density in gm/cc.	Vol. of 100 gm. of O.D. Soil (cc.)	Total Pore Space as % Total Volume
0-3"	0.92	108.4	62.9
at 1 ft	0.98	102.7	62.0
2	1.00	100.2	61.6
3	1.02	97.5	60.5
4	1.05	95.6	60.1
5	1.03	97.1	61.9
6	1.14	87.7	55.3

The bulk density is remarkably constant throughout the profile with no sign of compacted layers due to previous cultivation. The free draining nature of the soil is shown by volume/weight figures. Total pore space expressed as a percentage of the total volume also gave no fluctuations with depth.

The broad uniformity and low variability of this initial physical description should make the detection of any changes due to cultivation procedure relatively easy.

TABLE 45 STORAGE CAPACITY FOR WATER AVAILABLE TO CROP
WEST KILIMANJARO - 6 JULY 1966. (Mean of two pits)

Depth	Range in inches	Field Capacity in inches (⅓ atmosphere)	Wilting Point in inches (15 atmospheres)	Capacity for available water (inches)
SURFACE	0-6	2.27	1.33	0.94
at 1 ft	6-18	4.45	2.69	1.76
2	18-30	4.60	3.36	1.24
3	30-42	4.90	3.53	1.37
4	42.54	5.04	3.78	1.26
5	54-66	5.01	3.52	1.49
6	66-78	5.23	3,58	1.65
Total 6½ ft	-	31.50	21.79	9.71

The available water stored in the 6½ ft. at Field Capacity averaged 9.71 in. which agrees closely with the field samplings taken at Field Capacity, i.e. Long Rains planting 1968. The distribution of this storage in the profile is summarised in Table 45.

An attempt was made to estimate the crop water use over the five seasons where data was available. The summary is presented in Table 46. These calculations take no account of drainage through the profile or of loss of water by run-off. It was thought that regression analyses between water available to the crop at various stages of growth and yields obtained would provide further proof of the more favourable conditions existing under the minimal tillage treatment.

The following analyses were made.

1. Yield and moisture within the 5½ ft. profile at planting
2. " " " " " " " at flowering
3. " " " " " " " at harvest
4. " " " in the top six inches at planting
5. Yield and precipitation between planting and harvest plus water use from the profile as indicated by the gravimetric soil moisture samplings.
6. Mean total crop and mean of the water use over five seasons.

The results obtained provided little of value to add to the comments made on moisture/yield relationships described previously within the results of each season. From the data available it was not therefore possible to derive an equation defining any of these relationships due to the complexity of many variables particularly climate.

The situation has arisen where the minimal tillage double crop treatments fall outside the relationship mainly due to what appears to be higher water use (1967, 1968 and 1968-9) during crop growth without the expected yield response. This feature is more likely to be a result of improved drainage through the profile due to the more vigorous and deeper rooting in previous seasons. This conclusion is borne out by the gypsum block diagrams particularly in the wet season of 1968 and 1968-9.

The first season as expected showed little treatment response on

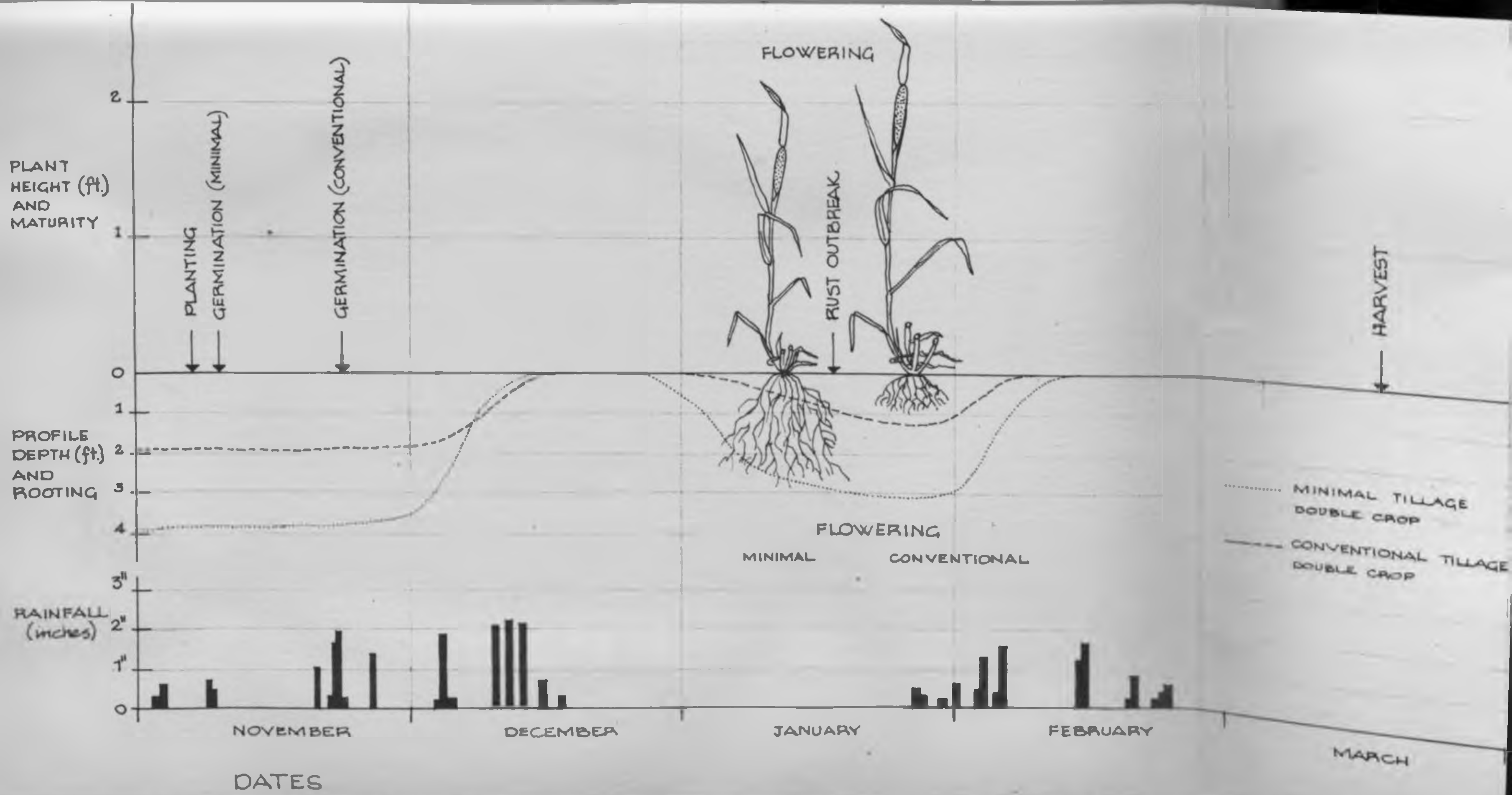

Figure 24: Growth of wheat in relation to soil water availability, rooting depth and rainfall short rains 1968–9 comparing minimal and conventional double cropping.

TABLE 46 ESTIMATE OF CROP WATER USAGE OVER FIVE SEASONS WEST KILIMANJARO

Year and Season	Period	Rainfall & Water in Profile (in.)					Estimate of water usage (in.)					
		1	2	3	4	5		1	2	3	4	5
1966 L.R.	Pre P	15.85										
	P-H	10.69										
	At P	1.63	2.89	2.60	2.12	3.39	P-H	10.69		10.69	10.69	
	At F	1.60	3.91	3.52	2.99	5.32	water used	1.14		1.03	1.21	
	At H	0.49	2.56	1.57	1.00	3.55	Total	11.83		11.72	11.90	
1967 L.R.	Pre P	5.72										
	P-H	15.46										
	at P	3.68	1.82	2.50	3.20	1.71	P-H	15.46		15.46	15.46	
	at F	-	-	-	-	-	water used	0.87		-1.35	-0.93	
	at H	2.81	3.47	3.85	4.13	6.15	Total	16.33		14.11	14.53	
1967-68 S.R.	Pre P	3.38										
	P-H	6.05										
	at P	5.62	3.85	4.76	6.27	7.34	P-H	6.05	6.05	6.05	6.05	6.05
	at F	1.31	1.52	1.65	3.12	1.94	Water used	4.42	3.51	3.40	5.83	6.93
	at H	1.20	0.34	1.36	0.44	0.41	Total	10.47	9.56	9.45	11.88	12.98
1968 L.R.	Pre P	28.89										
	P-H	17.15										
	at P	8.08	6.86	9.91	8.72	8.55	P-H	17.15		17.15	17.15	
	at F	6.17	5.73	5.07	5.83	6.42	Water used	2.99		5.66	5.27	
	at H	5.09	4.25	4.25	3.45	5.42	Total	20.14		22.81	22.42	
1968-69 S.R.	Pre P	1.64										
	P-H	27.97										
	at P	1.98	2.21	4.24	3.00	4.09	P-H	27.97	27.97	27.97	27.97	27.9
	at F	5.50	5.35	5.78	5.88	3.87	Water used	-2.89	-2.33	-0.23	-0.90	1.7
	at H	4.87	4.54	4.47	3.90	2.34	Total	25.08	25.64	27.74	27.07	29.7

P - Planting, H - Harvest, F - Flowering

TABLE 47 PHYSICAL PROPERTIES OF SOIL (WEST KILIMANJARO) FROM SURFACE CORES. 28 FEBRUARY 1968

Treatment Mean of 8 Samples	Bulk Density in gm/cc.	Free Draining Pore Space at 20 cm. tension as % T.V.	Percolation rate in in. per hour	Rainfall Acceptance of 1 in. rain in 10 min.
Conventional Tillage Double Crop	0.89	26.5	107.3	0.74
Tie Ridge Double Crop	0.80	29.0	96.6	0.87
Conventional Tillage with Cultivated Fallow	0.86	23.9	90.0	0.81
Minimal Tillage with Chemical Fallow	0.82	27.0	104.7	0.80
Minimal Tillage Double Crop	0.84	26.5	106.3	0.80
Surrounding area	0.86	26.8	-	0.70

After six seasons of cultivations the physical condition of the surface soils for all treatments is summarised in Table 47. Studies were also undertaken to provide supplementary evidence of the ability of the soil to accept rainfall. No significant differences were recorded and the results show the excellent surface structure for all tillage treatments despite the well defined differences visually in their surface appearance.

I. SOIL CHEMICAL ANALYSIS

The analyses for pH,organic carbon and nitrogen index from samples taken at the end of the experimental period are given in Table 48.

TABLE 48 CHEMICAL ANALYSES AT END OF EXPERIMENTAL PERIOD
WEST KILIMANJARO

Main Treatment Effects	pH*	Organic C.**	N. Index***
Straw burnt (1 & 3)	6.00	2.77	64.1
Straw not burnt (4 & 5)	6.10	2.77	69.0
Conventional Tillage Double Crop	6.05	2.93	66.1
Conventional Tillage with Cultivated Fallow	6.01	2.62	62.1
Minimal Tillage with Chemical Fallow	6.24	2.83	75.6
Minimal Tillage double Crop	5.99	2.72	62.4
Nitrogen	6.06	2.72	72.0
No Nitrogen	6.08	2.83	61.1
Depth 0 - 2.5 cm.	6.06	3.65	81.1
2.5 - 10 cm.	6.14	3.42	74.6
10 - 20 cm.	6.16	2.33	62.3
20 - 30 cm.	5.93	1.69	48.2
5% L.S.D.	0.12	0.23	6.7

* pH in $\frac{M}{100}$ $CaCl_2$, 1 : 2.5 soil to $CaCl_2$ ratio.

** Organi C. by Walkley - Black method, uncorrected for recovery (% over dry soil).

*** N. Index by hot water hydrolysis, ppm NH_4^+ - N over dry soil.

(Cont'd ....)

These results are all non-significant and it would seem that the trial period was too short to detect significant differences of a chemical nature.

The interaction between soil depth and nitrogen fertilizer for nitrogen index only was significant.

Depth	+ N	- N	Mean
0 - 2.5cm.	90.8	71.5	81.1
2.5 - 10 cm.	81.1	68.0	74.6
10 - 20 cm.	68.6	56.0	62.3
20 - 30 cm.	47.5	48.9	48.2
Mean	72.0	61.1	

5% L.S.D. within N treatments at different depths = 9.5

between N treatments at the same depths = 18.7

J. WEED CONTROL

An assessment of weed cover and weed species present was made at the end of the Long Rains 1969, one season after the conclusion of the trial. The results are given in Table 47.

The following weeds were found to be present on some or all of the treatments:

Amaranthus sp.

Galinsoga parviflora

Galium spurium

(Cont. ....)

Malva verticillata
Commelina benghalensis
Chenopodium sp.
Polygonum convolvulus
Setaria verticillata
Cyperus bulbosus

With the exception of Cyperus (a perennial Sedge) and Setaria (an annual grass) all the weeds present were annual broad-leaved species.

TABLE 49 PERCENTAGE WEED COVER AS A MEAN OF EIGHT SAMPLE ASSESSMENTS PER TREATMENT, WEST KILIMANJARO - 12 MAY 1969

TREATMENT / WEED	Conventional Tillage Double Crop	Conventional Tillage with Cultivated Fallow	Minimal Tillage Double Crop	Minimal Tillage with Chemical Fallow
Amaranthus sp.	8.25	7.75	0.50	+
Galinsoga sp.	10.75	21.25	3.25	3.13
Galium sp.	3.0	4.0	+	+
Malva sp.	+	+	+	+
Commelina sp.	+	+	+	0
Chenopodium sp.	+	+	0	0
Polygonum sp.	0	+	0	0
Cyperus sp.	0	0.50	0	0
Setaria sp.	+	+	+	0.50
T O T A L	22.0	33.0	3.75	3.63

0 = not present

+ = < 0.25% cover

Over the six seasons there has been considerable reduction in the general weed flora with successive applications of Paraquat. No build up or introduction of perennial grass species was recorded in the absence of cultivation. During this work no serious attempt was made to limit the number or concentration of Paraquat sprays. The prime object was to maintain as near as possible weed-free conditions.

It is not valid to compare the number of chemical and cultivation operations required for fallow weed control. Frequently during heavy rains it was impossible to get the implements on the ground with the result that weed growth remained uncontrolled on these occasions. On the double cropped plots the ratio of mechanical cultivations to chemical sprayings averaged about 2:1 before planting.

In an attempt to reduce the number of herbicide applications necessary during the fallow period, consideration was given to the use of cocktail mixtures of Paraquat plus residual soil acting herbicides. Concern has been shown over the increasing incidence of annual grasses particularly Setaria sp. in the West Kilimanjaro area. This increase is thought to be due in some measure to the widespread use of 2,4-D for control of broad-leaved weeds with consequent reduction in competition to the annual grasses. To be effective a cocktail mixture should therefore be capable of controlling these grasses.

The initial screening of promising herbicides was carried out and reported by Foster and Terry (1968). Recordings were made on the various parameters of the early growth of the weeds, of the total weed flora and of the specific types. As a result five herbicides which showed a good spectrum of weed control and selectivity to wheat under West Kilimanjaro conditions were incorporated in two further replicated trials, the object being to observe the period of weed control exercised under fallow conditions.

The results (Macartney 1968, unpubl. data) showed that all the chemicals in combination with Paraquat, namely Fluometuron (N-(3-trifluormethyl-phenyl)-N^1,N^1 -methylurea), Linuron (N^1-(2,4-dichlorophenyl) -N^1methoxy-N^1-methylurea), Diuron (N^1-(3,4-dichlorophenyl)-N^1-dimethylurea), C 6989 and GS 14260 were successful in fallow weed control, the period of control being dependent on the season. All herbicides were considered to have some relevance to the control of annual grasses in wheat and none had any effect on the yield of the following crop. Nevertheless, the period of activity of up to three months was considered insufficient. The fallow period extends from May - November for the Long Rains and from September - March for the Short Rains fallow. To achieve complete weed control with a single dosage of herbicide mixture over a rainy season is not feasible at present with the materials available. For optimum water storage the fallows must be kept virtually weed free, moisture withdrawal being particularly disadvantageous after the rains have ceased. It is at this time that an early herbicide application would no longer be active. Therefore it is also at this stage when either cultivation at the expense of mulch maintenance or further application of Paraquat would have to be decided.

8. Discussion

Seed Emergence

The fundamental reason given for cultivation is that it provides the proper soil physical conditions for seed germination, emergence and root development, although the ideal seedbed environment has not yet been defined in precise terms.

Moisture stress within the immediate top layers is believed to cause or, at least, to be related to differential seedling emergence. It is however very evident from the literature that growth results from intricate combinations of many physiological processes, probably not all equally affected by changes in the internal water balance of cells and tissues when moisture stress is increased.

It is generally agreed (Stout et al, 1960) that a good seed-soil contact is needed to obtain rapid flow of moisture to the seed from the soil immediately surrounding it. Under marginal rainfall conditions the rapid emergence of seedlings is desirable to reduce the possibility of erratic stands resulting from surface crusting following rains. Stout et al (1960) also observed that in soils with a moisture content less than the critical level required for emergence, many seeds germinated but failed to emerge. Small quantities of added water produced marked increases in the emergence percentage.

The emergence of wheat ultimately showed no differences when the soil moisture content was maintained between field capacity and wilting point, provided other factors were optimum, in work by Hanks and Thorpe (1956). They did however emphasise that the rate of emergence was more rapid with a higher surface soil moisture content.

In this work differences in plant populations achieved varied considerably between treatments and seasons. Better establishment was recorded using minimal tillage in seasons with poor rainfall distribution at planting (1966-67 Short Rains) and also during seasons with above average pre-planting rains (Long Rains 1966 and 1968) when concentrated cultivations were necessary for weed control and seedbed preparation.

It is not difficult to find supporting evidence of the beneficial effects of surface mulching in producing more favourable conditions during germination and which could account for better establishment achieved with minimal tillage in poor rainy seasons. Weise and Army (1958) noted the delayed drying under a mulch compared to disced plots after rain, and Army et al (1961) also reported that surface residues significantly improved moisture conditions in the seedbed zone. Their field and laboratory studies showed that the drying rate of the first ½ in. of soil was greatly reduced under mulch but below two inches the available soil moisture was not affected. There is good reason to believe that evaporation is reduced from the protected soil surface (Mathews and Army, 1960) by both lower soil temperatures and a reduction in air movement above the soil. Surface moisture availability also appears to be comparatively better under frequent rainfall conditions by using stubble mulching (Jacks et al, 1955).

There is no doubt that excess cultivation prior to planting both dissipates surface moisture and encourages rapid surface capping due to soil pulverisation, as was demonstrated during the final season at West Kilimanjaro. The early and rapid germination with minimal tillage compared to the conventional could well have made the difference between an economic yield and crop failure but for the unusually late rains.

Smika and Whitfield (1966) maintain that surface soil moisture availability at seeding time was the basis for predicting the success or failure of the wheat crop. The correlations between yields and seedbed moisture content have also been reported by Thomas et al (1958), Cole and Mathews (1940) and Army and Hanson (1960)

Time of Planting

There is a substantial body of evidence in East African agriculture which shows reduced yields as a result of late planting. Pereira (1958) has described the two main contributory factors to crop failure as

(a) an early gap in the rains soon after planting
and
(b) the premature cessation of the rainy season.

It is natural for the farmer to hesitate to commit his planting material until enough rain has fallen to minimise hazard (a), but this delay increases directly hazard (b). Of these two the greater danger is from an early end to the rains. Pereira's calculations on moisture requirements throughout the season have presented a convincing pattern in favour of early planting under unreliable rainfall conditions.

Akehurst and Sreedharan (1965) investigated the problem of reduced yield with late planting in Tanzania and reported it to be dependent on factors other than water stress or the leaching of nutrients by the early rains. Yields were found to decline rapidly due to late planting even in seasons of good total rainfall. That the moisture stress during certain periods of growth may be responsible for this phenomenon was briefly noted.

It is at planting that minimal tillage and herbicidal weed control has shown to greatest advantage. Frequently when the rains break they do so with effective daily precipitation for up to three weeks which leaves the land unsuitable for ploughing or disc harrowing. Weed growth builds up rapidly thus reducing the storage effectiveness of this early rain by transpiration and increasing further the mechanical problems of preparing a seedbed.

The design and objects of the West Kilimanjaro trial assumed similar planting dates between treatments. In the wetter seasons the direct drilled treatment was delayed while waiting for land preparation of the conventionally tilled plots, thereby partially nullifying the advantages to be gained from early planting by direct drilling.

The results shown by gypsum blocks and gravimetric soil samplings demonstrate the more favourable moisture regimes which exist in the profile in the absence of excess seedbed cultivation. Minimal tillage with weed controlled by chemicals presents the possibility of optimum timeliness of planting virtually irrespective of weather conditions owing to the better working conditions.

Organic Matter

That the organic matter content of the soil varies with cultivation treatment and that this fraction is important in stabilising and aggregating soil, has much support in the literature (Stallings 1953, Slater and Carlton 1938). The decline in organic carbon with continuous cropping has been stressed by Norstadt and McCalla (1960) and Klingebiel and O'Neal (1952), although Slater and Carlton (1938) pointed out that losses resulted largely from erosion of topsoil rather than from oxidation of the organic fraction. The rate of decline appears to be influenced by the crop grown (Hobbs and Brown, 1957), crop rotation (van Bavel and Schaller, 1951), disposal of crop residues (Oveson 1966), climate (Carney et al, 1929), soil characteristics (Anderson and Browning, 1950), fertilizer application (Dodge and Jones, 1948) and tillage practices (Johnson 1950).

Many workers have given evidence of an improvement in organic matter content with stubble mulching. This improvement would seem to be in the immediate surface zone, the amount depending on the quantities of residues returned and the period under experimentation.

After six seasons of cropping at West Kilimanjaro the soil analysis shows no significant differences between treatments in organic carbon or nitrogen index. There is however a definite trend indicating a relative improvement under minimal tillage practices. The nitrogen index was higher in the top 2.5cm. on treatments where straw was not burnt, particularly on the minimal fallow plots.

Very rapid breakdown of the mulch was observed, particularly in seasons with heavy pre-planting rains. Under these conditions the straw had mostly disappeared by five weeks after planting. The transitory value of the stubble may have made small contribution to the chemical status but indirectly contributed to the maintenance of organic matter in the surface soil by control of run-off. McCalla (1945) also noted the temporary nature of 'structural stability' which lasted only as long as the stabilising decomposition products continued to exist on the soil.

There is some indication that a higher equilibrium level of organic matter and nitrogen could be established in the soil as a result of minimal tillage practice. The possibility of maintaining organic matter and nitrogen in the soil at a level consistent with high crop yields by using minimal tillage must be investigated further. To achieve an improved structural status in the surface soil will undoubtedly depend on the amount of residue returned and for what period. The data obtained under a limited period of experimentation are not adequate to predict when or at what level soil organic matter would become stabilized.

Infiltration and Stubble Mulch

The entry of water into the soil and its retention in the rooting zone has been shown to be of paramount agricultural importance in the hydrological cycle. The amount of water that actually enters the soil depends on its porosity (Mannering et al, 1968), previous moisture content (Meyer and Mannering, 1961) and intensity and duration of precipitation (Duley and Kelly, 1939). Numerous workers have recorded the value of stubble mulching in increasing the infiltration and storage of high intensity rainfall by controlling run-off and reducing surface sealing. If the rains are infrequent the cumulative moisture loss on a mulched soil may lag behind a bare soil but eventually will reach approximately the same moisture content in the total profile.

Run-off was observed from the conventionally tilled plots during intense rainfall. The protection afforded by the mulch cover on the minimal plots was sufficient to show improved rates of infiltration presumably due mainly to delayed surface sealing.

The efficiency of chemical fallowing compared to bare fallowing for moisture storage is supported by the recordings of Staple et al (1960), Thysell (1938) and Zingg and Whitfield (1957). Their climatic characteristics were similar in terms of rainfall amount and intensity to those recorded at West Kilimanjaro. The percentage of available water conserved at depth bears a close similarity to the results obtained in study.

The conclusion reached by Army et al (1961) and Burr (1914) that, with stubble mulching, infrequent and light rain produces a transitory advantage in the soil surface and that frequent and intense rain has a significant effect in increasing the depth and penetration of storage, was corroborated by the results presented for the extreme seasons of 1966-67 and 1968-69 Short Rains.

Soil Structure

Despite the well defined visual differences in the appearance of the surface soil between the various treatments, the physical analyses did not wholly substantiate these observations. Although there is a slight lowering of the bulk density and a small increase in the rainfall acceptance rate with minimal cultivation, these improvements would not account for the very much better infiltration rate observed in the field. The core sampling results show that the soil has an excellent structure and is highly porous. The free draining pore space at 20 cm. tension averages at over 26 per cent of the total volume. At this level there could be no aeration problem.

The evidence presented by Weaver (1950), Parker and Jenny (1945) and Bradfield (1936) of structural deterioration due to tillage with associated reduction in percolation rate and total porosity, were the result of work on less stable soils than those represented at West Kilimanjaro. Laws and Evans (1949) concluded that medium textured soils of a friable nature were able to withstand the effects of continuous cultivation for a longer period of time.

Yields, Populations, Heights etc.

During the last decade a marked change has taken place in the study of yield determinations in the cereals. Previously research work was aimed at identifying the components of yield and on the basis of a very thorough study of the crop in the field it was hoped to interpret the mechanisms controlling yield Engledow and Wadham, 1923). Detailed comparisons of varieties led to the resolution of yield into its four major compments : the number of plants per unit area, the number of ears per plant, the number of grains per ear and the weight per grain. Useful and necessary as this body of work has been it has become increasingly obvious that these components are not only highly interdependent but also of doubtful physiological significance. Langer (1967) has reviewed recent major achievements in the field of wheat physiology in an attempt to isolate factors determining yield and has supported the dominant role of moisture availability at all stages of growth in its effect on final yield.

In studies where better moisture status has been reported through stubble mulch farming, the records of plant growth invariably show improved vigour in terms of tillering, plant heights, rooting depth and biological yields (Swamy Rao 1960, Phillips 1968, Aspinall et al 1964, Jonker 1959 and Triplett et al 1968). It is not within the confines of this research to become involved with the body of information which exists as to reaction of the plant to moisture stresses at various periods of growth; suffice to say that any system which attempts to provide optimum availability of moisture as far as possible during the entire life of the crop must also provide for improved yields.

During these trials the seed rate has been constant throughout yet the populations and tiller counts have shown wide variation from season to season and between cultivation treatments within a season. Plant density under these conditions is primarily a result of seedbed moisture at time of planting and following rainfall. Before optimum population densities can be considered it is necessary to first establish a seedbed preparation technique giving optimum plant survival and also to provide for available moisture within the profile particularly during flower initiation.

Root Growth

The root washings made during the final seasons have shown considerable differences both in extent and depth in favour of minimal tillage. From the literature it is difficult to establish an exact role that root growth could play in the determination of growth. The great number of factors which can influence root development at any stage make the interpretation of results difficult. The nature and extent of root development are however major factors governing plant response to moisture conditions and are highly responsive to the physical property of the soil.

It is generally accepted (Salim et al 1965) that there is little root penetration by the wheat plant into soil at or below permanent wilting point as was evidenced during the 1966-67 Short Rains. The extent and proliferation of roots is also encouraged by the amount of moisture within the profile and the tension at which it is available to the plants. Root growth is encouraged between 20 and 40 per cent moisture content of the soil (Leishout 1957), a status which occurred more frequently and for longer periods under chemical fallowing than in any other treatment. Deeper rooting with an increase in available water at depth was also recorded by Kmoch et al (1957).

It is also generally accepted that the uptake of water by wheat depends considerably on the extent and depth of root growth (Weaver 1926). This factor could explain the heavier water utilisation recorded by minimal tillage and the advantage gained by this treatment with its more extensive root system when moisture became limiting.

One cannot expect yield to be directly correlated with total root length nor with total dry weight, nevertheless an inhibited rooting system together with limited moisture within the profile will adversely affect photosynthesis thereby lowering yields (Russell 1957).

The more efficent root system developed by the chemical fallow at flowering during the final season was undoubtedly a prime factor in determining the final yield increase. An extensive root system at flower initiation was quoted by Hurd (1967) as producing conditions for optimum carbohydrate movement towards grain filling.

Pre-planting cultivation, resulting in less favourable moisture conditions in the top soil could be a reason for the inhibited root growth on the conventionally tilled treatment. Hurd (1964) recorded reduction in root penetration with initial soil dryness.

The better root growth and increased height measurements recorded with minimal tillage and nitrogen application are substantiated by the work of Troughton (1957) and Kmoch et al (1957) who reported that both root and shoot growth increased with the addition of nitrogen. Conversely depth of rooting and height of straw varied directly with the depth of infiltration (Weaver 1926).

Quality

Concern has been expressed in the past over the progressive deterioration of the baking quality of Tanzania wheat (Northwood 1966). The work of Zingg and Whitfield (1957) showed a deterioration in the protein content of the grain harvested from stubble mulch treatments as compared to that from ploughing; the relationship between cultivation and baking quality being indirectly due to the effect on moisture availability and nitrogen. Grain protein has also been found to be highest under conditions of periodic wilting (Sosulski et al 1963, Hutcheson and Paul 1966). Protein contents higher than 16 per cent were found only where moisture was below optimum for maximum yields.

A vast body of information is available on the interaction between nitrogen and protein content which suggests that late application of nitrogen only is effective in raising protein content (Aleximsky and Coic 1955).

The results of this current study have shown more favourable moisture conditions during crop growth with minimal tillage. This improvement in moisture availability could be expected to have a deleterious effect on grain quality according to previous work.

The test results in fact show very little difference in quality between cultivation treatments. In the below average rainfall season of 1967-68 Short Rains there was an increase in grain protein from the minimal after fallow treatments. The better infiltration rates recorded with minimal fallowing have probably also been effective in leaching nitrogen to the lower root zone where later utilization has been possible. This would be expected to have a beneficial effect on grain protein percentage.

Weed Control

Both chemical fallowing and fallowing by cultivation have much support in the literature.

The advantages claimed for the use of herbicides are mainly the maintenance of mulch cover (Hay 1968), the reduction in weed populations through minimal soil disturbance (Roberts 1963), an increase in infiltration rates (Alley and Bohmont 1957) and better plant establishment with a firmer seedbed (Blackmore 1961). These claims have been substantiated in the present study together with advantages of yield increases and more favourable soil/moisture relationships.

A straight comparative costing of the Paraquat application against cultivation for weed control does not encourage widespread use of the herbicide. The improvements gained from chemical fallowing are progressive which makes the inclusion of the increased crop return difficult as a factor in offsetting the increased expenditure. How far yields are likely to increase with continued use of chemical fallowing has not been established. It would however appear from the comparative densities of the weed flora after six seasons with the two fallow control methods that progressively lower dosage rates and reduced number of applications would be necessary for chemical control as also shown by McCarty (1957).

The advantages resulting from the use of chemical fallowing in terms of timeliness of weed control and planting under wet conditions, have proved to be of great importance in achieving the yields obtained. The rapid build-up of weed under conditions when cultivation has to be delayed has also been recorded by Roberts and Black (1963) and Power (1965). During wet weather, chemical control has been observed to be much more effective with susceptible weeds than cultivation.

In support of cultivation during the fallow several workers have advocated at least one shallow cultivation for the control of resistant weeds and to break the surface crust. Although crust formation under mulch is delayed it has been recorded to effectively reduce infiltration rates (Alley and Bohmont 1957, Barnes et al 1955). Ford et al (1968) also supports the theory that consistent benefits from chemical fallowing with complete elimination of cultivation have not generally been achieved.

From a general analysis of all contributory factors it appears that the theory of a combined chemical/cultivated fallow (Army et al 1961) should be supported. Shallow cultivation can be carried out at the end of the previous rainy season with little loss of moisture from the profile. Final weed control before planting should be with herbicide to ensure conservation of the early rain in the seeding zone.

Stubble Mulching and Disease

There is still a considerable lack of information on the influence of stubble mulching on fungal disease carry-over. Brooks and Dawson (1968) working in the United Kingdom reported a reduction in the incidence of take-all (<u>Ophiobolus graminis</u>) and eyespot (<u>Cercosporella herpotrichoides</u>) when wheat was direct drilled compared to establishment by ploughing and harrowing. There was a progressive improvement in the plant vigour and health over their five year experimental period. The significantly higher level of fungal disease from the ploughed plots is surprising since the long-established recommedation for the control of these diseases is early ploughing to encourage decomposition of infected plant residues. Further investigations showed that this reduction in plant disease was associated with factors resulting from the direct drilling technique which limited the spread of the fungi in undisturbed soil.

Shipton and Tweedie (1967), on the other hand, found stubble mulching had a marked deleterious effect on seedling emergence in West Australia. The products of plant decomposition were reported to be responsible for the stunted and distorted seedling growth.

No visual differences were observed in the incidence of other diseases between cultivation treatments. The most common diseases are the Rusts and Blotches (<u>Septoria</u> sp. and <u>Helminthosporium</u> sp.) of which the blotches only are carried over on plant debris. With continuous wheat cropping the inoculum potential is high whatever methods of cultivation and straw disposal are used. <u>Helminthosporium</u> sp. can also exist independently in the soil for long periods.

<u>Continuous cropping and fallowing - Yields</u>

The comparisons recorded between grain yields <u>per annum</u> from the different treatments appear at first sight to weigh strongly in favour of double cropping. The mean yields achieved from the two double-cropped treatments were 6½ bags per year better than from minimal tillage after chemical fallow and 9 bags more than from conventional tillage after fallow. However this advantage is not so great as it would appear.

The double crop system requires extra machinery due to difficulty in the timing of operations, as harvesting, seedbed preparation and indeed planting will be going on simultaneously. Unseasonal weather at harvest may cause delays resulting in late planting. The schedule of operations therefore invariably becomes progressively later each season. Weed growth due to inefficient and hurried land preparation, and which is costly to eradicate subsequently, has also been shown to become a major problem.

The acceptance of the possibility of chemical weed control would further encourage a consideration for reverting to double cropping on a percentage of the acreage. However, the threat of complete crop failure in years of poor rainfall would still be a deterrent and some land will probably always be fallowed to ensure cash return in such years.

9. Conclusions

Minimal tillage with surface mulching has been shown to control surface run-off and to achieve a considerable improvement in the penetration of rainfall into the soil.

Progressive yield increases were recorded over six seasons by the use of chemical fallowing. The introduction of effective herbicide for weed control presented extensive advantages in soil management practices.

The improved root growth and more vigorous establishment are reported to be due to more favourable seedbed conditions under reduced tillage practices.

There exists a possibility of decreasing weed populations by minimum soil disturbance and substitution of chemicals for cultivation during the fallow period.

No differences in grain quality or disease incidence were evident by using stubble mulching.

IX PRACTICAL CONSIDERATIONS AND ECONOMICS OF THE ACCEPTANCE OF AN ALTERNATE TILLAGE SYSTEM AT WEST KILIMANJARO

Any new or modified cultivation techniques will be accepted by the farmer only if it can be proven to be economically sound. It must be shown that there is a reduction in either or both fixed and variable costs together with equal or improved agronomic advantage. Accepted farming principles are steeped in tradition so that any changes from conventional practice must be gradual ones indeed. To discard the basic farm implement, the plough, and expect a substitution of chemical weed control may have convincing arguments to the research workers but is unlikely to be enthusiastically received by the farmer.

The case put forward for minimal tillage is based on a sound theoretical background of soil/plant/water relationships but the improvements achieved have been gradual and progressive, a factor which encourages scepticism among farmers. In addition recommendations resulting from replicated cultivation experiments are as often as not classified as 'theoretical'. Attempts were therefore made to stimulate the results of this work in the field using more modern widely adaptable machinery which, although available, is usually without the budget of the researcher. During this programme excellent co-operation was received from a machinery company in the provision of capital equipment designed for minimal tillage techniques. Observational trials were carried out to determine the efficiency of this equipment in achieving the effects desirable, as shown by the results obtained from year to year in the main programme.

To present a comprehensive picture of the advantages of minimum tillage it was necessary to attempt an analysis of cultivation expenditure in the West Kilimanjaro area and to compare the modified system in its most practically acceptable form.

From the survey of machinery utilization in terms of work rate, capital input and cultivation operations, the ultimate cost for the production of one bag of wheat (Macartney 1969 Unpubl. data) showed such variation that the figures were eventually ignored. As a comparative guide the costings for the most efficiently managed farm were accepted.

On this unit some 5,000 acres of wheat are grown using the alternate crop/fallow system and yields are above average for the area. The plough, disc harrow and conventional planter were replaced by implements designed for shallow sub-surface tillage and capable of working through a heavy mulch cover.

a. Connor-Shea Scarifier

A Connor-Shea Spring Release Scarifier (Plate 44) was lent by the Connor-Shea Company of Australia for trial at West Kilimanjaro. The working width of the implement was 14' 7", carrying 25 spring loaded tines bolted between high tensile forged pivot plates and held in place with one inch steel pins pressed into the bracket side member. The heavy duty release springs were adjustable to varying ground conditions. Both manual screw lift and hydraulic lift were assembled. The alternative eight inch 'A' blade scarifying points were used for test as it was agreed that they would have the wider application for modified minimal tillage practice at West Kilimanjaro. Later in the season the chisel ploughs were also modified for scarifying by the fitting of 'A' blades (Plate 43).

Field 1. This area had carried a light volunteer crop of wheat in the previous Long Rains. Harvesting had been carried out about two months previously. The soil was baked hard with a relatively heavy weed and light undecomposed straw cover. The

International 806 tractor (110 H.P.) was hard pushed to carry out an effective cultivation under undulating conditions. At the working altitude of 6,000 ft. the loss in power was estimated at some 23 per cent. Six tines were removed to compensate for this and provided a speed of at least 4 - 5 m.p.h. was maintained, the results were excellent. A depth of 3½ in. gave best results for complete weed control. It was obvious that the working depth and speed were of prime importance. These conditions were the most difficult it was envisaged would be coped with in this area.

Field 2. This field was in fallow and carried a heavy cover of evenly spread straw with light weed growth. The implement was worked at a three inch depth and at a speed of 4 - 5 m.p.h. the trash mulch was cleared efficiently (Plate 45). At lower speeds a build-up occurred which was sufficient to lift the scarifier from its working depth; an increase in speed resulted in rapid clearing of the tines. The results of this observation were most encouraging in that previously it had been accepted that straw chopping would be necessary for efficient tine cultivation. Weed control was complete and the surface mulch was left as an ideal cover for rainfall infiltration. The International 806 had little or no difficulty in pulling the complete complement of tines with this slightly shallower working depth and easier soil conditions.

Field 3. These conditions were typical of most fallows at this time of year. Harvesting of the previous Short Rains crop had been completed in February and two disc harrowings had been carried out for weed control leaving the straw partially chopped and incorporated, The fallow had extensive outcrops of couch grass (*Digitaria* sp.) which would have necessitated ploughing and cultivating for grass control alone.

The scarifier, set to work at four inches, gave excellent control of this perennial grass; two runs in opposite directions brought all the stolons to the surface where they subsequently dried out.

The overall efficiency of this implement in dealing with and maintaining a trash cover was most impressive. This was due mainly to the large clearance between tines (28 in.) and the high vertical clearance (22 in.).

Field 4. This site had been disc harrowed twice and was ready for planting. The area was badly fouled with nut-grass (*Cyperus rotundus*). The present method of control is further disc harrowing after rain and before planting when the nutlets have germinated. The scarifier brought the sprouting nutlets to the surface unbroken. After germination of the wheat it was estimated that a 70 per cent control had been achieved. Working conditions after rain were decidedly easier and the value of this tool in final seedbed preparation and weed control was evident.

b. Connor-Shea One-Way Plough

Observations were carried out using the twenty two disc one-way plough giving a cut of from 12 to 15½ ft. depending on the angle of set. The independently mounted discs (22 in. x 88 gauge) were connected by 2½ in. solid jump arms. Fitted with stationary disc axles the total weight was slightly over 2½ tons.

The plough was used on undulating land carrying a heavy annual weed cover and the previous crop's undecomposed straw lying in windrows. The undulations resulted in an uneven depth of work and the discs also tended to ride over the straw lines. The power required was less than the scarifier and the International 806 tractor had little trouble in pulling the completely offset complement of discs. Weed control was excellent but where a thin covering of straw was present, this also was chopped and incorporated. Difficulty was experienced in turning at the headlands which could be impractical with narrow strips.

The incorporation of the stubble mulch was an undesirable feature of the implement. It was considered that its use would be limited to the initial cultivation in the first year of a change over to stubble mulch farming, or conversely where heavy weed growth was present in the fallow after a particularly wet season. Weed control could be achieved at the expense of losing much of the mulch cover.

c. Connor-Shea Super Harrow (Straw Jump)

This implement was designed and recommended for the breaking down of fallows after ploughing or chisel ploughing. In the system of stubble mulch farming it was considered ideal to keep the surface rough and maintain the straw cover. This posed certain difficulties at planting due to lack of suitable machinery. The Super Harrow (three sections of four feet each) was therefore attached behind a 13 ft. Connor-Shea seed drill (Plate 46) with all coulters and spouts removed. The tines were in gangs of four, with a lateral clearance of one foot, and were staggered to work in three inch rows.

The 13 in. long tines gave good clearance and tripped easily with a build-up of straw. The combination was worked up to 12 m.p.h. and altogether 1,580 acres were planted at an average of eight acres per hour. A good even placement of the seed and excellent germination establishment was achieved.

For the three seasons, 1967-68 Short Rains, 1968 Long Rains and 1968-69 Short Rains, a costing was attempted on the comparative cultivation expenditure of minimal and conventional cultivation on a 2,500 acres per season basis.

Conventional cultivation included ploughing, four disc harrowings and seed placement by drill. The minimal system omitted the ploughing operation and substituted tine tillage for disc harrowing.

Operational costs are low compared to generally accepted standards throughout East Africa. The efficiency of utilization is due to both management backed with sound technical ability and to the large acreage farmed.

Tractor Costs

(a) International Harvester Co. 806 Type

Fuel per hour 3½ gallons diesel

Purchase price shs EA 85,000

Worked for 10,000 hours

Resale value shs EA 25,000

Interest at 9½% shs EA 8,000

Replacements shs EA 18,300

Oil, 4 gals./100 hours shs EA 4,800

Licence and Insurance shs EA 500 per annum

Major engine overhaul shs EA 12,000

Driver's wage shs EA 200 per month

Operating cost per hour shs EA 35

(b) Massey-Ferguson 175

Fuel per hour 1½ gallons diesel

Purchase price Shs EA 32,000

Worked for 10,000 hours

Resale value Shs EA 8,000

Interest at 9½% Shs EA 3,000

Replacements Shs EA 14,500

Oil, 2 gals./100 hours Shs EA 2,400

Licence and Insurance Shs EA 300 per annum

Driver's wage Shs EA 200 per month

Operating cost per hour Shs EA 17/50

Note: Total operating costs/hour include maintenance, repair and workshop charges together with Field Management and supervision.

Operations

(a) Ploughing

With I.H.C. 806 and I.H.C. 195 plough at 2 acres/hour Shs EA 18 per acre

(b) Disc Harrowing

With I.H.C. 806 and I.H.C. A1, 12 ft. harrow at 6 acres/hour Shs EA 7 per acre

(c) Seeding by Drill

With M.F. 175 and Connor-Shea Super Seeder 13 ft. at 2½ acres/hour Shs EA 8 per acre

(d) Broadcast Planting

With M.F. 175 and Connor-Shea Super Seeder with no coulters and followed by Connor-Shea Super Stump-Jump harrow at 8 acres/hour Shs EA 2/70 per acre

(e) Scarifying

With I.H.C. 806 and Connor-Shea mounted scarifier at 4 acres/ hour Shs EA 9 per acre

Fixed costs common to both systems:

Aerial spraying	Shs EA 10/50
Combine harvesting	18/-
Seed at 100 lb/acre	25/-
Insect and bird control	1/-
Total	Shs EA 54/50

The comparative costs of production are presented in Table 50

TABLE 50 COST OF PRODUCTION PER ACRE AND PER BAG OF WHEAT COMPARING MINIMAL AND CONVENTIONAL CULTIVATION SYSTEM, WEST KILIMANJARO

	COSTS PER ACRE IN SHS. E.A.	
	Minimal Cultivation	Conventional Cultivation
Ploughing	-	18/-
Disc Harrowing x 4	-	28/-
Drilling	-	8/-
Scarifying x 4	36/-	-
Broadcast seeding	2/70	-
Fixed costs	54/50	54/50
Total	93/20	108/50
Average Yield over 3 seasons, bags/acre	9.3	7.1
Production Cost of 1 bag	10/-	15/20

Note: Excludes charges for management, water supply, buildings and haulage.

X DISCUSSION

The results of the observations on the efficiency of some currently recommended methods of soil and water conservation presented a background of information to suggest that the stubble mulch system may well have direct application for wheat growing in Tanzania.

It is also interesting to note the agreement with Anderson and Russell (1964) that incorporation of the mulch depresses yield. This factor was also recorded from work at Oljoro in Tanzania (Macartney 1964a) where the competition for available nitrogen by organisims decomposing the straw resulted in severe nitrogen deficiencies during the early growth of the crop.

Results of soil and water loss from bare soil at Tengeru agree with the overall picture presented by the review. Physical barriers control the movement of water off the area but produce a terrace effect with resultant depression in yield due to soil movement. Run off from bare soil on slopes of this nature is inevitable regardless of the initial structure and water holding capacity of the soil. Run off and soil loss over this ten year period has also given reductions in yield, total pore space, rainfall acceptance rate and organic matter as previously recorded by Anderson and Browning (1949), together with an increase in bulk density. The control afford by a surface mulch in buffering the force of rainfall impact and controlling run-off velocity is considered to be an integral part of minimal tillage proposals for cereal row crops and wheat growing in Tanzania.

The need for improved, more productive pastures is becoming a subject of increasing priority in East Africa. This has been stimulated by the opening of export markets for beef and the emerging peasant dairy industries in all three territories. The introduction of exotic type cattle with their higher nutritional requirements has also stimulated interest in the improvement of the natural pastures. There seems little doubt that the high costs of establishment using conventional tillage techniques will continue to inhibit any development. The success of the legume and pasture establishment trials at Tengeru suggests that improvement of pasture composition is possible by direct drilling even on this difficult to cultivate adhesive black cotton soil.

The Kongwa area was selected for the first of the tillage trials as it was considered to have the most problem soil type in Tanzania due primarily to its compacted and abrasive characteristics. The principle factor governing the physical properties would appear to be the amount of quartz present in the parent material giving a sandy soil. Structure and downward movement of water through the soil is largely controlled by its texture. From field observations it appeared that the presence of sand gives greater compaction. This soil at low altitude characterised by heavy intense unreliable rainfall is highly erodible.

It is in areas such as this that reduction in cultivation expenditure and control of soil and water movement is of prime importance. The current practice of deep ploughing after rain results in a delay in planting and evaporation of moisture from an already wetted land surface by cultivation. The alternative suggested, of ripping instead of ploughing has given very encouraging results. Whilst ploughing has given good initial penetration of rain, random roughness is rapidly lost and capping occurs leading to greater run-off consistancy also noted by Zingg and Whitfield (1957) and Barnes et al (1955). Later percolation rates are severely restricted. With disc harrowing the porosity decrease is even more pronounced due presumably to a finer surface which seals more readily. Water moving down the profile carries with it the fine particles from the tillage layer and deposits them when slowed up further reducing permeability.

Both seasons at Kongwa were very atypical of expected rainfall distribution and amount. In 1966-7 total rainfall and distribution was ideal for maize thus nullifying the expected responses from earlier stored moisture in the profile with ripping. Also 1967-8 produced the highest rainfall on record under which at no time was water limiting for crop growth. This factor does not however detract from the improved penetration of rainfall on all the ripped treatments particularly the ripped and direct drilled plots with an inter-row mulch. The effectiveness of this mulch has been noted by many workers (Kohnke 1951) and has been described by Steele (1966) as being comparative to strip cropping in its effect in controlling erosion.

A most interesting feature of these experiments was the failure of the direct drilled treatment in the first season. The general consensus of opinion of other workers is that, whilst all are agreed on the desirability of an inter-row mulch, most evaluations with cereal row crops showed that some intensity of tillage was necessary for optimum establishment (Free et al 1963, Moody et al 1961 and 1964). They recognised the need for studies on root distribution after indications that maximum yields were not obtained on compacted soils where root growth was inhibited. Without ripping at Kongwa the roots of the ploughed and the direct drilled (ripping inter-row) treatments were limited to 10 and 13 cm. respectively. In a dry season this would have represented crop failure due to the very limited area from which the plant would be extracting moisture.

Many field experiments have demonstrated significant reductions in yield with increases in bulk densities (Phillips and Kirkham 1962, Adams et al 1960). Such results have a very limited application as the bulk density which caused reduced yield on one soil might not do so on others of a different structural constitution. What is much less clear from the literature is the effect on root growth function and crop yield of soil resistances below the limiting values. (Rosenburg 1964) and hence the level of soil resistances at which increasad tillage becomes essential. This is particularly pertinent to an interpretation of results from temperate direct drilling trials where cereals will often give lower yields than ploughed treatments, but, with extra nitrogen application yields can be comparative. The obvious conclusion that tillage in some way augments the supply of nitrogen to the roots is not necessarily true. It is just as likely that the absence of tillage resulted in physical conditions which either restricted root growth so that the crop could not explore as much soil in search of nitrates, or reduced root efficiency in some way caused a reduced uptake of nitrates.

At Kongwa there is no doubt that with bulk densities of up to 1.55 gm/cc. in the surface layer excessive compaction due to genetically derived soil conditions does exist. Even with intensity of tillage increased to eight in. by four in. in the second season, the impedance to root growth at depth has had an effect on yield. Best establishment and yield were achieved with ploughing and ripping and ridging. The former treatment was inferior in terms of water storage and control of run off.

A recommended system of tillage must therefore include ripping as a primary cultivation. To overcome the deleterious effects of soil compaction at depth this operation should be carried out under the immediate seed-bed thus giving a combination of all the advantages associated with an inter-row mulch, and reduction in cultivation expenditure. The plough plant system (ploughing only to an 8 in. width) with this previous ripping would, it is suggested, provide the ideal combination. It is interesting to note that, since these trials, a set of adjustable tines which cultivate between five and nine in. have been incorporated into the rotaseeder by the Howard Rotavator Company for use on compacted soils.

The four sites selected for the width and depth of cultivation studies were considered to represented a large proportion of the arable farming soil types in Tanzania. On three of the four soils the direct drilling technique was not acceptable in providing optimum conditions for germination and establishment of maize,yet it is on these soils that minimal tillage presents the best possibilities for more efficient and reliable cropping. These trials aimed at creating an environment suitable for germination and for root growth and function. The various widths and depths of cultivation used give some guidance as to the amount of tillage necessary on these soils.

The Tengeru, Sambwa and Kongwa soils have structural properties which make conventional tillage impracticable in terms of costs and erosion. The other extreme represented by direct drilling has resulted in 50% populations at Tengeru and seriously delayed establishment at Kongwa. It was shown, however, that by tilling an eight by four in. seedbed these difficulties could be overcome, at least during early plant growth.

At Kongwa the relationship between width of cultivation and population achieved is highly significant. Plant height during establishment and depth of cultivation is also significant and finally yield and both width and depth of seed bed preparation has a highly significant relationship. The results from Sambwa show more favourable soil structural conditions existing as indicated by no significance of varying widths and depths of cultivation on establishment after two weeks. Later in growth both variables become significant whilst at four weeks only depth of cultivation is having an effect. At Tengeru plant populations respond more actively to depth of cultivation provided a minimum width of eight in. is cultivated.

The low bulk density soil of West Kilimanjaro appears to be ideally suited to the direct drilling or minimum tillage technique.

Minimal tillage practice is increasingly accepted in many parts of the world and not least in tropical East Africa, due mainly to certain shortcomings in the traditional systems and also because scientific advancements have allowed a better understanding of the requirements of different crops in relation to soil conditions. There is no doubt that the conventional system of cultivation involving soil inversion with a disc or mould-board plough (and developed largely under temperate world conditions) is not only unnecessary in terms of crop growth and yield but is also basically unsuited to large areas of the tropics having intense rainfall and therefore high erosion potential. Soil inversion and trash burial followed by disc harrowing results in a fine textured or completely pulverised, bare seed-bed which 'caps' readily and provides optimum conditions for rainfall or wind erosion. It was this system which resulted in the North American 'dustbowls' of the 1930's and its destructive effect is to be seen in Tanzania today even in areas where mechanised agriculture has only very recently been introduced. With further development of large potential wheat areas planned, it is essential that these dangers be avoided and they may be by using a minimal tillage system, which, in this discussion is interpreted as the least amount of cultivation (least soil disturbance) necessary for good crop establishment and yield with a particular soil. This implies reducing to a minimum the depth of cultivation, number of operations, power requirement, time and expense needed. On most soil types a surprisingly small amount of cultivation is needed, certainly less than is commonly believed. The ultimate possibility is just the one operation of 'direct drilling' into the undisturbed stubble of the previous crop and use of herbicides for weed control (chemical ploughing).

The use of direct drilling at West Kilimanjaro has resulted in significant and progressive increases in yield over conventional tillage. Whilst it is often dangerous to evaluate tillage treatments solely in terms of crop yield (Hawkins and Brown, 1967) it is safe to say that in these trials minimal tillage has modified the soil properties to give improvements in the most important variables affecting plant growth in Tanzania i.e. water infiltration, root growth and plant emergence. Over the three double cropped seasons seasonal and cultivation differences are highly significant. It is reasonable to expect that these improvements would have been even greater but for the above average rainfall recorded in 1966 (26.54 in.) 1967 (21.18 in.) and 1968 (46.04 in.).

Improved infiltration of rainfall with resultant moisture available at lower tensions and to a greater depth is claimed to be the main reason for these yield increases. Many workers have shown a strong relation between water stored and yield (Brown, 1956, Hallsted and Matthews 1936, Simika and Whitfield 1966). In this work regression analyses were attempted between the water available to the crop at different stages of growth and crop yield. Other variables in all cases masked the relationship an example of which is presented in Figure 24. In this short rain season 1968-9 all the advantages of minimal tillage are represented, more rapid rechange of profile, greater utilization with deeper rooting, better initial start, earlier flowering under better moisture availability etc. Although yield improvements with minimal tillage were achieved, both rust infection, more serious on the earlier minimal double cropped plots, and late season rain, which benefited only the later maturing conventionally tilled plots, severely affected the overall picture. From the same data it is obvious that major yield differences are being brought about as a result of reduced number of grains per ear head which would indicate that treatment effects occur early in the crops life, probably between flower initiation and flowering. However there is also evidence from the tiller counts (Table 37) that some treatment effect has occured even earlier than this i.e. between establishment and initiation.

Sufficient data has been presented to postulate that soil conditions during planting, germination and emergence are more favourable with minimal tillage and straw mulching there is no doubt that soil inversion for weed control prior to planting considerably dissipates the available moisture. There is also a considerable body of evidence to show that rates of emergence are related directly to soil moisture content (Hanks and Thorp 1956, 1957). Seed-bed preparation should promote maximum capillary flow to the seed (Stout 1959) lack of which has been shown to have a deleterious effect on yield Hallsted and Matthews (1936). In the dry seasons of 1966-7 and 1967-8 disc harrowing for weed control has resulted in surface moisture loss as shown by both the blocks and moisture samplings. Decreased yields are a feature of this pre planting cultivation. Also with heavy rain before planting 1966 and 1968 heavy weed growth and wet soil have delayed primary cultivations resulting in delayed planting, and has in 1967-8 effectively delayed germination by two weeks due to dry surface soil (Figure 24). During this latter season the cultivated fallow was still showing the effects of previous uncontrolled weed growth on moisture storage during the pre planting period. All through this trial better water storage has resulted from chemical fallowing and minimal soil disturbance which certainly in part explains the yield increases obtained.

The effects of stubble mulch on water storage within the profile would seem to depend on rainfall intensity. Results quoted in the review would suggest that only if rains are frequent (Army et al 1961) will responses be obtained. In much of the previous work a high proportion of the rainfall has fallen in small amounts (Thysell 1938), and stubble mulching has not given significant improvement in water infiltration. It is interesting to compare the West Kilimanjaro rainfall amounts and rain days with those quoted by Robb (1938) in Kansas where 60 per cent of the total rain fell in amounts of less than 0.25 in. giving little if any advantages with stubble mulch on moisture availability but vital for control of wind erosion. There is also a body of evidence to show that stubble retained on a crusted seed-bed has no effect on improving moisture status. At West Kilimanjaro the crust formed was effectively broken by the action of the Rotaseeder during planting. In the final year the stubble mulched plots required scarifying to overcome the crusting problem, and maintain the high infiltration rates recorded during previous seasons. The necessity for sub-tilling under surface mulch has been noted by many workers (Jacks et al 1955 and Borst and Russell 1942).

The application of nitrogen has given significant yield responses. There is a suggestion that better responses have been obtained with minimal fallow treatments which may be due to some incorporation of the mulch. The season, nitrogen interaction is significant which is undoubtedly due to rainfall falling during crop growth. Generally it has been agreed that nitrogen application is of value only in years of heavy rainfall. Salmon et al 1953 quotes figures of total rainfall between 12 and 14 in. as giving unprofitable responses whilst 14 to 18 in. permits straw retention with nitrogen application. These parameters would also seem to apply at West Kilimanjaro where yield increases resulted with nitrogen application in 1967 (15 in.) 1968 (17 in.) and 1968-9 (27 in.). No yield effects from nitrogen were obtained in 1966 (10 in.), 1966-7 (2 in.) and 1967-8 (6 in.).

The greater rooting depth and vigour of the minimal cultivation treatments was one outstanding feature and undoubtedly contributed to the increased yields obtained from this treatment. Better rooting is claimed to be due to more favourable moisture conditions during the early stages of plant growth. Hurd (1964) has claimed that depth of root penetration is reduced by initial soil dryness. It is also generally accepted from the results quoted in the review that the greater the supply of moisture in the soil the greater the root growth. Swarmy Rao (1960) also records improved root growth under minimal tillage.

Stubble mulching is claimed by many workers to improve the organic matter status of the soil which did not occur at West Kilimanjaro from comparisions made in the first and final seasons. McCalla (1945) however explained that structural stability is temporary, lasting only as long as the stabilising decomposition products continue to exist in the soil. At West Kilimanjaro the breakdown of the mulch was extremely rapid and was scarcely visible six weeks after planting. It was nevertheless invaluable to contain rainfall of which the bulk falls during early plant development.

During the twenty years continuous wheat cultivation at West Kilimanjaro yields have progressively fallen from the 3,000 lb per acre level to current averages of 1,400 lb per acre. Whilst this in part may be due to the use of rust resistant varieties with a lower yield potential there is little doubt that over-cultivation is one of the main reasons for this decline. The practical implications of these studies suggests that significant improvements can be made by an acceptance of the reduced tillage principles.

Whilst direct drilling is still in the development stage and may not in any case by applicable to all soil types and conditions, it is suggested that a less extreme form of a minimal cultivation has wide adaptability and is well suited to Tanzanian wheat growing conditions. The system differs from the traditional being the substitution of tined implements such as the chisel plough or scarifier for the disc plough. Instead of inverting the soil, a straightforward stirring or undercutting effect is achieved and a protective mulch of trash and dead weeds is maintained on the surface. The depth of cultivation is normally restricted to 2-4 inches except for deeper working in occasional seasons if shown to be necessary. With some cohesive soils there may be a need to assist root development by deeper working to 5-6 inches before each planting.

Secondary cultivations are as few as possible and are related more to achieving weed control than tilth formation. The fitting of a chopper/spreader to the combine harvester would help to achieve an even straw cover and facilitates the passage of tined implements. Where trash cover is very heavy such that germination of the crop might be impaired then an extra cultivation might be required to achieve more incorporation. Normally however there is difficulty in maintaining a complete protective cover, particularly in the wetter areas where several weed control operations may be required, consideration could be given to the use of a herbicide to assist weed control particularly for final weed control operation before planting.

XI CONCLUSIONS

1. Over a ten year experimental period bare soil on a 17 per cent slope under continuous maize has become more acid and has lost approximately one third of the total phosphate and three quarters of the organic P as a direct result of erosion.

2. Rate of rainfall acceptance, total pore space and free draining pore shape has been reduced in the absence of soil surface protection.

3. Trash mulching has given excellent control of soil and water movement when compared with grass leys. This system is an integral part of land management on slopes of this nature to maintain optimum infiltration and protection from erosion.

4. Direct drilling of legumes into unproductive pastures and pasture renovation by overall seeding on a black cotton soil has interesting possibilities in East Africa. The technique is considerably less expensive in terms of cultivation and seed expenditure and the added advantages of erosion control and moisture retention.

5. Soil properties which are most important in their effects on plant growth at Kongwa are moisture availability and resistance to penetration by roots.

6. Tillage has a large influence on the proportion of rainfall which becomes available to crops due to its effect on rates of infiltration.
   (a) Ploughing has given good initial penetration but rapid surface sealing has resulted in run-off and poor percolation to depth.
   (b) Moisture availability throughout the season and to deeper levels of penetration has resulted from ripping as the primary cultivation operation.

(c) Disc harrowing has produced the most rapid and serious surface sealing.

7. Maintenance of an inter-row mulch together with ripping, under the immediate seedbed, is recommended as the optimum system for water conservation and overcoming the restriction to root penetration in this high bulk density soil.

8. Soil resistance to penetration by roots can bring about marked responses in germination, establishment plant vigour and yield. Resistance to penetration is controlled in the main by tillage.

9. On the compacted soils of Tengeru, Sambwa and Kongwa conventional tillage has the disadvantage of high cost together with the accelerated loss of soil and water through the processes of erosion. It is on these soils that reduced tillage would have the greatest advantages.

10. Wider and deeper cultivation to the 8 in. by 4 in. level has shown that the compactive effect of the soil on germination establishment and yield can be satisfactorily overcome.

11. Over a twenty year period of continuous wheat cultivation at West Kilimanjaro yields have progressively fallen due to over cultivation. Excessive cultivation has led to decreased percolation rates and rapid surface sealing after rain.

12. The low bulk density soil lends itself to the direct drilling technique which has given significant increases in yield over conventional tillage.

13. Yield differences have been brought about by modification of the soil properties to give improvements in water infiltration, root growth and

emergence. Results show this tillage treatment to have a beneficial effect early in the crops life.

14. Conditions at planting, with no soil inversion, by chemical weed control are more favourable for rapid establishment.

15. Responses to nitrogen application with stubble mulching were evident only with rainfall of above 14 in. during the growing season.

16. Stubble mulching gave no improvement in the organic matter status of the soil. Under West Kilimanjaro conditions the break down of the mulch is very rapid.

17. Considerable reduction in the weed flora were achieved by chemical fallowing.

18. A system is described by which chisel ploughing, scarifying and seed broadcasting has the agronomic advantages shown by direct drilling and is considerably more economic compared to conventional tillage.

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APPENDIX [illegible]

[illegible] 1966-67

[illegible]

A P P E N D I C E S

No.	TREATMENT	R E P. I					R E P. I I			
		[illegible]	[illegible]	[illegible]	[illegible]	AVAIL-ABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL-ABLE WATER
[illegible]	Plough Disc Harrow and Plant on Flat	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.84	2.11	1.46	0.65
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.59	1.85	1.48	0.37
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.65	1.56	0.09
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.64	1.55	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.81	1.63	0.18
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.82	1.82	NIL
			Tot. Water	[illegible]		[illegible]	Tot. Water	10.88		1.38
[illegible]	Rip, Disc Harrow and Plant on Flat	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.35	[illegible]	0.89
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.03	1.48	0.55
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.86	1.56	0.30
		3'-4'	[illegible]	[illegible]	[illegible]	[illegible]	11.16	1.80	1.55	[illegible]
		4'-5'	[illegible]	[illegible]	[illegible]	[illegible]	11.04	1.78	1.63	0.15
		5'-6'	[illegible]	[illegible]	[illegible]	[illegible]	11.70	1.83	1.82	[illegible]
			Tot. Water	[illegible]		[illegible]	Tot. Water	[illegible]		[illegible]

APPENDIX 1:

GRAVIMETRIC SOIL MOISTURE SAMPLING KONGWA 1966-67

FLOWERING

No.	TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS.AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS.AT W.P.	REP. II AVAILABLE WATER
6	Plough Disc Harrow and Plant on Flat	0'-1'	10.96	1.80	1.46	0.34	12.84	2.11	1.46	0.65
		1'-2'	10.62	1.70	1.48	0.22	11.59	1.85	1.48	0.37
		2'-3'	10.90	1.75	1.56	0.19	10.23	1.65	1.56	0.09
		3'-4'	10.49	1.69	1.55	0.14	10.19	1.64	1.55	0.09
		4'-5'	10.43	1.68	1.63	0.05	11.27	1.81	1.63	0.18
		5'-6'	10.21	1.59	1.82	0.00	11.67	1.82	1.82	NIL
			Tot.Water	10.21		0.94	Tot.Water	10.88		1.38
7	Rip, Disc Harrow and Plant on Flat	0'-1'	12.33	2.02	1.46	0.56	14.31	2.35	1.46	0.89
		1'-2'	10.80	1.73	1.48	0.25	12.66	2.03	1.48	0.55
		2'-3'	10.36	1.67	1.56	0.11	11.56	1.86	1.56	0.30
		3'-4'	9.31	1.50	1.55	NIL	11.16	1.80	1.55	0.25
		4'-5'	9.54	1.54	1.63	NIL	11.04	1.78	1.63	0.15
		5'-6'	11.33	1.77	1.82	NIL	11.76	1.83	1.82	0.01
			Tot.Water	10.23		0.92	Tot.Water	11.65		2.15

APPENDIX 1: (Contd.)

T No.	TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
9	Rip & Ridge	0'-1'	10.33	1.69	1.46	0.23	12.04	1.97	1.46	0.51
		1'-2'	10.84	1.73	1.48	0.25	12.97	2.08	1.48	0.60
		2'-3'	11.11	1.79	1.56	0.23	11.79	1.90	1.56	0.34
		3'-4'	10.02	1.61	1.55	0.06	11.88	1.91	1.55	0.36
		4'-5'	10.06	1.62	1.63	NIL	11.08	1.78	1.63	0.15
		5'-6'	11.23	1.75	1.82	NIL	11.82	1.84	1.82	0.02
		Tot.Water		10.19		0.77	Tot.Water	11.48		1.98
8	Rip and Tie-Ridge	0'-1'	12.59	2.06	1.46	0.60	13.86	2.27	1.46	0.81
		1'-2'	11.58	1.85	1.48	0.37	13.22	2.12	1.48	0.64
		2'-3'	10.70	1.72	1.56	0.16	11.15	1.80	1.56	0.24
		3'-4'	10.38	1.67	1.55	0.12	9.92	1.60	1.55	0.05
		4'-5'	11.28	1.82	1.63	0.19	10.04	1.62	1.63	NIL
		5'-6'	12.27	1.91	1.82	0.09	10.94	1.71	1.82	NIL
		Tot.Water		11.03		1.53	Tot.Water	11.12		1.74

GRAVIMETRIC SOIL MOISTURE SAMPLING KONGWA 1967-68

MID FLOWERING

No.	TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
6	Plough Disc Harrow and Plant on Flat	0'-1'	12.52	2.04	1.46	0.58	11.88	1.95	1.46	0.49
		1'-2'	12.92	2.07	1.48	0.59	13.56	2.17	1.48	0.69
		2'-3'	14.23	2.29	1.56	0.73	15.26	2.46	1.56	0.90
		3'-4'	14.37	2.31	1.55	0.76	16.95	2.73	1.55	1.18
		4'-5'	16.58	2.67	1.63	1.04	17.80	2.86	1.63	1.23
		5'-6'	17.12	2.67	1.82	0.85	19.92	3.11	1.82	1.29
			Tot.Water	14.05		4.55	Tot.Water	15.28		5 .78
7	Rip, Disc Harrow and Plant on Flat	0'-1'	12.97	2.13	1.46	0.67	14.40	2.36	1.46	0.90
		1'-2'	15.11	2.42	1.48	0.94	15.26	2.44	1.48	0.96
		2'-3'	15.10	2.43	1.56	0.87	16.21	2.61	1.56	1.05
		3'-4'	18.02	2.90	1.55	1.35	17.54	2.82	1.55	1.27
		4'-5'	17.50	2.82	1.63	1.19	19.18	3.09	1.63	1.46
		5'-6'	19.30	3.01	1.82	1.19	19.52	3.05	1.82	1.23
			Tot.Water	15.71		6.21	Tot.Water	16.37		6.87

APPENDIX 3:

GRAVIMETRIC SOIL MOISTURE SAMPLING KONGWA 1967-68

HARVEST

No.	TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
6	Plough Disc Harrow and Plant on Flat	0'-1'	9.79	1.61	1.46	0.15	11.45	1.88	1.46	0.42
		1'-2'	11.68	1.87	1.48	0.39	13.97	2.24	1.48	0.76
		2'-3'	13.10	2.11	1.56	0.55	15.15	2.44	1.56	0.88
		3'-4'	14.25	2.29	1.55	0.74	16.43	2.65	1.55	1.10
		4'-5'	15.86	2.55	1.63	0.92	17.39	2.80	1.63	1.27
		5'-6'	17.44	2.72	1.82	0.90	19.57	3.05	1.82	1.23
			Tot. Water	13.15		3.65	Tot. Water	15.06		5.66
7	Rip, Disc Harrow and Plant on Flat	0'-1'	11.56	1.89	1.46	0.43	11.19	1.84	1.46	0.38
		1'-2'	12.55	2.01	1.48	0.53	11.84	1.89	1.48	0.41
		2'-3'	14.33	2.31	1.56	0.75	13.16	2.12	1.56	0.56
		3'-4'	16.29	2.62	1.55	1.07	15.78	2.54	1.55	0.99
		4'-5'	18.77	3.02	1.63	1.39	16.86	2.71	1.63	1.08
		5'-6'	21.17	3.30	1.82	1.48	18.54	2.89	1.82	1.07
			Tot. Water	15.15		5.65	Tot. Water	13.99		4.49

APPENDIX 3: (contd.)

No.	TREATMENT	DEPTH	R E P. I				R E P. I I			
			% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
10	Rip and Minimal Tillage by Direct Drilling	0'-1'	9.86	1.62	1.46	0.16	11.56	1.89	1.46	0.43
		1'-2'	12.07	1.93	1.48	0.45	11.55	1.85	1.48	0.37
		2'-3'	15.08	2.43	1.56	0.87	12.72	2.05	1.56	0.49
		3'-4'	17.30	2.79	1.55	1.24	14.07	2.27	1.55	0.72
		4'-5'	19.10	3.08	1.63	1.45	19.10	3.08	1.63	1.45
		5'-6'	20.84	3.25	1.82	1.43	19.23	3.00	1.82	1.18
			Tot. Water	15.10		5.60	Tot. Water	13.37		4.64
9	Rip and Ridge	0'-1'	12.01	1.97	1.46	0.51	11.72	1.92	1.46	0.46
		1'-2'	12.08	1.93	1.48	0.45	12.10	1.94	1.48	0.46
		2'-3'	13.53	2.18	1.56	0.62	13.47	2.17	1.56	0.61
		3'-4'	16.71	2.69	1.55	1.14	15.76	2.54	1.55	0.99
		4'-5'	16.56	2.66	1.63	1.03	17.63	2.84	1.63	1.21
		5'-6'	18.24	2.84	1.82	1.02	19.10	2.98	1.82	1.16
			Tot. Water	14.27		4.77	Tot. Water	14.39		4.89
8	Rip and Tie-Ridge	0'-1'	12.07	1.98	1.46	0.52	12.25	2.01	1.46	0.55
		1'-2'	18.98	3.04	1.48	0.56	18.70	3.00	1.48	0.52
		2'-3'	16.15	2.60	1.56	1.04	16.78	2.70	1.56	1.14
		3'-4'	18.68	3.01	1.55	1.46	18.13	2.89	1.55	1.34
		4'-5'	19.38	3.12	1.63	1.49	19.86	3.19	1.63	1.56
		5'-6'	19.01	2.97	1.82	1.15	18.35	2.86	1.82	1.04
			Tot. Water	16.72		6.22	Tot. Water	16.65		6.15

APPENDIX 4:

GRAVIMETRIC SOIL MOISTURE SAMPLING KONGWA 1966-67

HARVEST

			R E P. I				R E P. II			
No.	TREATMENT	DEPTH	% M.C.	INCHES OF WATER	INS.AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS.AT W.P.	AVAILABLE WATER
6	Plough Disc Harrow and Plant on Flat	0'-1'	11.30	1.85	1.46	0.39	10.27	1.68	1.46	0.22
		1'-2'	11.98	1.92	1.48	0.44	12.67	2.03	1.48	0.55
		2'-3'	12.51	2.01	1.56	0.45	13.01	2.09	1.56	0.43
		3'-4'	13.29	2.14	1.55	0.59	13.69	2.20	1.55	0.65
		4'-5'	13.01	2.09	1.63	0.46	12.03	1.94	1.63	0.31
		5'-6'	13.93	2.17	1.82	0.35	10.87	1.69	1.82	NIL
			Tot.Water	12.18		2.68	Tot.Water	11.63		2.16
7	Rip, Disc Harrow and Plant on Flat	0'-1'	10.01	1.64	1.46	0.18	12.08	1.98	1.46	0.53
		1'-2'	13.21	2.11	1.48	0.63	15.42	2.47	1.48	0.99
		2'-3'	14.40	2.32	1.56	0.76	13.00	2.09	1.56	0.43
		3'-4'	12.59	2.03	1.55	0.48	16.32	2.63	1.55	1.08
		4'-5'	11.69	1.88	1.63	0.25	15.16	2.44	1.63	0.81
		5'-6'	11.31	1.76	1.82	NIL	13.63	2.13	1.82	0.31
			Tot.Water	11.74		2.30	Tot.Water	13.74		4.15

APPENDIX 5.

GRAVIMETRIC SOIL MOISTURE SAMPLING 1966 LONG RAINS PLANTING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	28.6	1.57	1.33	0.24	27.7	1.52	1.33	0.19
	6"-12"	29.1	1.72	1.45	0.27	32.3	1.91	1.45	0.46
	12"-18"	26.2	1.52	1.56	NIL	25.8	1.52	1.56	NIL
	18"-2ft	26.5	3.18	3.29	NIL	28.8	3.46	3.29	0.17
	3ft	30.8	3.79	3.53	0.26	28.8	3.54	3.53	0.01
	4ft	33.3	4.20	3.78	0.42	32.7	4.12	3.78	0.34
	5ft	35.3	4.38	3.52	0.86	28.6	3.55	3.52	0.03
	Total Water (5½ft)		20.36		2.05	(5½ft)	19.62		1.20
Tie Ridging Double Crop	R	29.6	1.63			37.7	2.07		
	U1	30.3	1.79			28.3	1.67		
	U2	35.5	2.06			29.1	1.69		
	0"-6"	31.6	1.74	1.33	0.36	27.0	1.49	1.33	0.45
	6"-12"	30.0	1.71	1.45	0.30	30.1	1.78	1.45	0.28
	12"-18"	28.6	1.66	1.56	0.30	28.8	1.67	1.56	0.12
	18"-2ft	26.2	3.14	3.29	NIL	33.6	4.03	3.29	0.74
	3ft	32.1	3.95	3.53	0.42	30.9	3.80	3.53	0.27
	4ft	31.7	4.00	3.78	0.22	35.3	4.45	3.78	0.67
	5ft	32.1	3.98	3.52	0.46	33.3	4.13	3.52	0.61
	Total Water (5½ft)		20.37		2.06	(5½ft)	21.60		3.14

APPENDIX 5 (Contd.)

TREATMENT	DEPTH	R E P. I				R E P. I I			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL-ABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL ABLE WATER
	0"-6"	36.0	1.98	1.33	0.65	34.5	1.90	1.33	0.57
	6"-12"	30.2	1.78	1.45	0.33	30.8	1.82	1.45	0.37
	12"-18"	30.1	1.75	1.56	0.19	30.0	1.74	1.56	0.18
Conventional Tillage With Fallow	18"-2ft	23.8	2.86	3.29	NIL	33.3	4.00	3.29	0.71
	3ft	29.2	3.59	3.53	0.06	36.1	4.44	3.53	0.91
	4ft	25.0	3.15	3.78	NIL	33.9	4.27	3.78	0.49
	5ft	22.0	2.73	3.52	0.21	37.3	4.63	3.52	1.11
	Total Water (5½ft)		17.84		1.44	(5½ft)	22.80		4.34
	0"-6"	30.4	1.67	1.33	0.34	35.5	1.95	1.33	0.62
	6"-12"	32.4	1.91	1.45	0.46	28.8	1.70	1.45	0.25
	12"-18"	28.4	1.65	1.56	0.09	27.8	1.61	1.56	0.05
Minimal Tillage with Fallow	18"-2ft	28.4	3.41	3.29	0.12	26.7	3.20	3.29	NIL
	3ft	32.1	3.95	3.53	0.42	30.4	3.74	3.53	0.21
	4ft	38.5	4.85	3.78	1.07	40.0	4.98	3.78	1.20
	5ft	35.2	4.36	3.52	0.84	37.3	4.63	3.52	1.11
	Total Water (5½ft)		21.80		3.34	(5½ft)	21.81		3.44
	0"-6"	36.2	1.99	1.33	0.66	34.6	1.90	1.33	0.57
	6"-12"	31.4	1.85	1.45	0.40	33.3	1.96	1.45	0.51
	12"-18"	30.1	1.75	1.56	0.19	30.5	1.77	1.56	0.21
Minimal Tillage Double Crop	18"-2ft	22.7	2.72	3.29	NIL	28.3	3.40	3.29	0.11
	3ft	29.0	3.57	3.53	0.04	29.8	3.67	3.53	0.14
	4ft	31.6	3.98	3.78	0.20	33.3	4.20	3.78	0.42
	5ft	34.3	4.25	3.52	0.73	28.8	3.57	3.52	0.05
	Total Water (5½ ft)		20.11		2.22	(5½ft)	20.47		2.01

APPENDIX 6

GRAVIMETRIC SOIL MOISTURE SAMPLING 1966 LONG RAINS

FLOWERING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAIL-ABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAIL-ABLE WATER
Conventional Tillage Double Crop	0"-6"	23.4	1.29	1.33	NIL	24.5	1.35	1.33	0.02
	6"-12"	23.9	1.41	1.45	NIL	27.8	1.64	1.45	0.19
	12"-18"	25.2	1.46	1.56	NIL	28.7	1.66	1.56	0.10
	18"-2ft	27.8	3.34	3.29	0.05	30.6	3.67	3.29	0.38
	3ft	33.8	4.16	3.53	0.63	35.2	4.33	3.53	0.80
	4ft	25.1	3.16	3.78	NIL	36.1	4.55	3.78	0.77
	5ft	21.8	2.70	3.52	NIL	37.8	3.78	3.52	0.20
	Total Water	(5½ft)	17.52		0.68	(5½ft)	20.98		2.52
	R	24.6	1.35			22.5	1.24		
	U1	23.6	1.39			27.7	1.63		
	U2	25.4	1.47			26.9	1.56		
	0"-6"	25.9	1.42	1.33	0.06	26.5	1.46	1.33	0.02
Tie Ridging Double Crop	6"-12"	29.8	1.76	1.45	0.13	30.2	1.78	1.45	0.26
	12"-18"	30.7	1.78	1.56	0.07	30.9	1.79	1.56	0.12
	18"-2ft	31.7	3.80	3.29	0.51	31.4	3.77	3.29	0.48
	3ft	36.1	4.44	3.53	0.91	34.7	4.27	3.53	0.74
	4ft	35.7	4.49	3.78	0.71	37.5	4.73	3.78	0.95
	5ft	36.4	4.51	3.52	0.99	37.2	4.61	3.52	1.09
	Total Water	(5½ft)	21.84		3.38	(5½ft)	22.12		3.66

TREATMENT	DEPTH	REP. I				REP. II			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
	0"–6"	31.0	1.71	1.33	0.38	32.7	1.80	1.33	0.47
	6"–12"	30.4	1.79	1.45	0.34	32.9	1.94	1.45	0.49
	12"–18"	32.1	1.86	1.56	0.30	32.0	1.86	1.56	0.30
Conventional Tillage With Fallow	18"–2ft	30.7	3.68	3.29	0.39	34.8	4.18	3.29	0.89
	3ft	33.0	4.06	3.53	0.53	37.9	4.66	3.53	1.13
	4ft	38.7	4.88	3.78	1.10	38.9	4.90	3.78	1.12
	5ft	29.0	3.60	3.52	0.08	38.8	4.81	3.52	1.29
Total Water	(5½ft)		21.58		2.12	(5½ft)	24.15		5.69
	0"–6"	25.1	1.38	1.33	0.05	26.2	1.44	1.33	0.11
	6"–12"	33.7	1.99	1.45	0.54	30.2	1.78	1.45	0.33
	12"–18"	33.5	1.94	1.56	0.38	32.1	1.86	1.56	0.30
Minimal Tillage With Fallow	18"–2ft	36.3	4.36	3.29	1.07	32.7	3.92	3.29	0.63
	3ft	36.3	4.46	3.53	0.93	37.5	4.61	3.53	1.08
	4ft	39.4	4.96	3.78	1.18	38.8	4.89	3.78	1.11
	5ft	40.2	4.98	3.52	1.46	40.2	4.98	3.52	1.46
Total Water	(5½ft)		24.07		5.61	(5½ft)	23.48		5.02
	0"–6"	25.9	1.42	1.33	0.09	22.6	1.24	1.33	NIL
	6"–12"	26.7	1.56	1.45	0.11	25.0	1.47	1.45	0.02
	12"–18"	28.9	1.68	1.56	0.12	25.5	1.48	1.56	NIL
Minimal Tillage Double Crop	18"–2ft	31.6	3.79	3.29	0.50	29.8	3.58	3.29	0.29
	3ft	34.0	4.18	3.53	0.65	30.6	3.76	3.53	0.23
	4ft	40.2	5.07	3.78	1.29	34.9	4.40	3.78	0.62
	5ft	38.2	4.74	3.52	1.22	35.2	4.36	3.52	0.84
Total Water	(5½ft)		22.42		3.98	(5½ft)	20.29		2.00

APPENDIX 7:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1966 LONG RAINS HARVEST

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
	0"–6"	16.5	0.91	1.33	NIL	18.0	0.99	1.33	NIL
	6"–12"	22.7	1.34	1.45	NIL	22.9	1.35	1.45	NIL
	12"–18"	24.6	1.43	1.56	NIL	25.2	1.46	1.56	NIL
Conventional Tillage Double Crop	18"–2ft	24.8	2.98	3.29	NIL	24.2	2.90	3.29	NIL
	3ft	24.7	3.04	3.53	NIL	26.5	3.26	3.53	NIL
	4ft	30.3	3.82	3.78	0.04	28.3	3.56	3.78	NIL
	5ft	32.6	4.04	3.52	0.52	31.8	3.94	3.52	0.42
	Total Water (5½ft)		17.56		0.56	(5½ft)	17.46		0.42
	[illegible]	14.0	0.77			14.3	0.79		
	U1	17.6	1.04			22.5	1.33		
	U2	23.8	1.38			25.0	1.45		
	0"–6"	18.8	1.03	1.33	NIL	16.2	0.89	1.33	NIL
	6"–12"	22.0	1.30	1.45	NIL	22.7	1.34	1.45	NIL
	12"–18"	24.4	1.41	1.56	NIL	27.3	1.58	1.56	NIL
Tie Ridging Double Crop	18"–2ft	24.7	2.96	3.29	NIL	28.8	3.46	3.29	0.17
	3ft	26.6	3.29	3.53	NIL	32.9	4.05	3.53	0.52
	4ft	30.8	3.88	3.78	0.10	36.7	4.62	3.78	0.84
	5ft	32.4	4.02	3.52	0.50	36.5	4.53	3.52	1.01
	Total Water (5½ ft)		17.61		0.60	(5½ft)	20.16		2.54

APPENDIX 7: (Contd.)

TREATMENT	DEPTH	REP. I				REP. II			
		% M.C.	INCHES OF WATER	INS.AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS.AT W.P.	AVAIL ABLE WATER
	0"–6"	13.9	0.76	1.33	NIL	27.7	1.25	1.33	NIL
	6"–12"	25.5	1.62	1.45	0.17	27.4	1.62	1.45	0.17
	12"–18"	29.0	1.68	1.56	0.12	33.2	1.93	1.56	0.37
Conventional Tillage With Fallow	18"–2ft	32.8	3.94	3.29	0.65	31.1	3.73	3.29	0.44
	3ft	31.1	3.82	3.53	0.29	32.7	4.02	3.53	0.49
	4ft	32.1	4.04	3.78	0.26	35.5	4.47	3.78	0.69
	5ft	33.8	4.19	3.52	0.67	34.7	4.32	3.52	0.80
	Total Water	(5½ft)	20.05		2.16	(5½ft)	21.34		2.96
	0"–6"	23.7	1.30	1.33	NIL	22.7	1.25	1.33	NIL
	6"–12"	30.5	1.80	1.45	0.35	28.0	1.65	1.45	0.02
	12"–18"	29.7	1.72	1.56	0.16	32.2	1.87	1.56	0.31
Minimal Tillage with Fallow	18"–2ft	30.5	3.66	3.29	0.37	35.0	4.20	3.29	0.91
	3ft	33.9	4.17	3.53	0.64	34.3	4.22	3.53	0.69
	4ft	34.2	4.31	3.78	0.53	38.9	4.90	3.78	1.12
	5ft	34.4	4.26	3.52	0.74	38.5	4.77	3.52	1.25
	Total Water	(5½ft)	21.22		2.79	(5½ft)	22.86		4.30
	0"–6"	16.4	0.90	1.33	NIL	13.9	0.76	1.33	NIL
	6"–12"	23.1	1.36	1.45	NIL	20.9	1.23	1.45	NIL
	12"–18"	23.6	1.37	1.56	NIL	23.5	1.36	1.56	NIL
Minimal Tillage Double Crop	18"–2ft	26.3	3.16	3.29	NIL	25.9	3.11	3.29	NIL
	3ft	28.5	3.51	3.53	NIL	27.1	3.33	3.53	NIL
	4ft	31.4	3.96	3.78	0.18	32.4	4.08	3.78	0.30
	5ft	35.3	4.38	3.52	0.86	33.8	4.19	3.52	0.67
	Total Water	(5½ft)	18.64		1.04	(5½ft)	18.06		0.97

APPENDIX 6:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1967 LONG RAINS

PLANTING

TREATMENT	DEPTH	REP. I				REP. II			
		% W.C.	INCHES OF WATER	INS.AT W.P.	AVAILABLE WATER	% W.C.	INCHES OF WATER	INS.AT W.P.	AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	34.3	1.89	1.33	0.56	33.2	1.83	1.33	0.50
	6"-12"	33.6	1.99	1.45	0.54	33.9	2.01	1.45	0.56
	12"-18"	35.4	2.06	1.56	0.50	34.2	1.99	1.56	0.43
	18"-2ft	34.0	4.08	3.29	0.79	33.7	4.05	3.29	0.76
	3ft	34.1	4.19	3.53	0.66	34.2	4.21	3.53	0.68
	4ft	30.9	3.92	3.78	0.14	32.0	4.04	3.78	0.26
	5ft	32.5	4.03	3.52	0.51	32.2	3.99	3.52	0.47
	Total Water	(5½ft)	22.16		3.70	(5½ft)	22.12		3.66
Tie Ridging Double Crop	R	34.3	1.96			37.3	2.13		
	U1	35.2	2.01			31.1	1.78		
	U2	31.1	1.77			29.4	1.68		
	0"-6"	34.4	1.90	1.33	0.60	33.5	1.84	1.33	0.6
	6"-12"	34.3	2.03	1.45	0.57	33.9	2.00	1.45	0.4
	12"-18"	34.6	2.01	1.56	0.33	32.5	1.89	1.56	0.2
	18"-2ft	27.5	3.31	3.29	0.02	34.0	4.08	3.29	0.7
	3ft	28.2	3.47	3.53	NIL	29.5	3.63	3.53	0.1
	4ft	29.6	3.74	3.78	NIL	28.3	3.57	3.78	NI
	5ft	33.5	4.15	3.52	0.63	33.5	4.16	3.52	0.6
	Total Water	(5½ft)	20.51		2.15		21.11		2.8

APPENDIX 8: (Contd.)

TREATMENT	DEPTH	R E P. V % M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	R E P. VI % M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL ABLE WATER
Conventional Tillage with Fallow	0–6"	31,2	1,72	1,33	0,39	40,1	2,21	1,33	0,[illegible]
	6–12"	33,6	1,98	1,45	0,53	36,1	2,02	1,45	0,5
	12–18"	27,9	1,62	1,56	0,06	33,2	1,93	1,56	0.3
	18"–2ft	31,6	3,79	3,29	0.50	23,3	2,80	3,29	NI
	3ft	18,3	2,26	3,53	NIL	22,5	2,77	3,53	NI
	4ft	19,0	2,40	3,78	NIL	25,8	3,26	3,78	N
	5ft	15.1	1,88	3.53	NIL	31.1	3,86	3.53	0,3
	Total Water	(5½ft)	15.65		1.48	(5½ft)	18.85		2.1
Minimal Tillage with Fallow	0–6"	36,6	2,02	1,33	0,69	36,5	2,01	1,33	0,6
	6–12"	32,4	1,91	1,45	0,46	32,4	1,91	1,45	0.4
	12–18"	32,0	1,86	1,56	0.30	30,4	1,76	1,56	0.2
	18"–2ft	23,9	2,88	3,29	NIL	25,0	3,00	3,29	NIL
	3ft	24,6	3,03	3,53	NIL	25,2	3,10	3,53	NIL
	4ft	27,5	3,47	3,78	NIL	28,1	3,54	3,78	NIL
	5ft	28.9	3.59	3.53	0,06	33.0	4,10	3.53	0,5
	Total Water	(5½ft)	18.76		1.51		19.42		1.91
Minimal Tillage Double Crop	0–6"	37,5	2,06	1,33	0,73	34,6	1,90	1,33	0.57
	6–12"	33,8	2,00	1,45	0,55	31,1	1,84	1,45	0,3
	12–18"	35,7	2,08	1,56	0,52	33,6	1,95	1,56	0,3
	18"–2ft	33,9	4,07	3,29	0.78	34,5	4,14	3,29	0,8
	3ft	27,0	3,33	3,53	NIL	34,2	4,22	3,53	0.6
	4ft	31,6	3,98	3,78	0,20	23,8	3,01	3,78	NIL
	5ft	32.8	4,07	3.53	0,54	30.0	3,72	3.53	0,19
	Total Water	(5½ft)	21.59		3.32	(5½ft)	20.78		3.06

APPENDIX 9.

GRAVIMETRIC SOIL MOISTURE SAMPLING 1967 LONG RAINS

HARVEST

TREATMENT	DEPTH	R E P. I				R E P. I I			
		% W.C.	INCHES OF WATER	INS. AT W.P.	AVAIL-ABLE WATER	% W.C.	INCHES OF WATER	INS. AT W.P.	AVAIL ABLE WATER
	0"–6"	28.1	1.55	1.33	0.22	34.4	1.89	1.33	0.5
	6"–12"	30.2	1.79	1.45	0.34	27.8	1.70	1.45	0.2
	12"–18"	25.5	1.48	1.56	NIL	24.4	1.42	1.56	NI
...ventional ...llage ...uble Crop	18"–2ft	25.9	3.12	3.29	NIL	24.0	2.89	3.29	NI
	3ft	29.3	3.61	3.53	0.08	38.3	4.71	3.53	1.1
	4ft	35.3	4.45	3.78	0.67	37.2	4.58	3.78	0.6
	5ft	34.4	4.27	3.52	0.75	34.4	4.28	3.52	0.7
	Total Water	(5½ft)	20.27		2.06	(5½ft)	21.47		3.5
	U1	30.9	1.76			25.3	1.45		
	U2	34.2	1.95			27.4	1.56		
	0"–6"	32.8	1.81	1.33	0.48	29.4	1.62	1.33	0.29
	6"–12"	30.3	1.79	1.45	0.33	30.3	1.79	1.45	0.17
...le Ridging ...ouble Crop	12"–18"	27.3	1.58	1.56	0.21	26.5	1.54	1.56	NIL
	18"–2ft	28.2	3.39	3.29	0.10	27.3	3.28	3.29	NIL
	3ft	35.2	4.34	3.53	0.81	37.7	4.64	3.53	1.11
	4ft	38.6	4.87	3.78	1.09	37.6	4.74	3.78	0.96
	5ft	36.0	4.47	3.52	0.95	38.1	4.72	3.52	1.20
	Total Water	(5½ft)	22.43		3.97	(5½ft)	22.17		3.73

APPENDIX 9(Contd.)

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS.AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS.AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage With Fallow	0"-6"	29.8	1.64	1.33	0.31	31.1	1.71	1.33	0.38
	6"-12"	33.9	2.00	1.45	0.55	29.7	1.76	1.45	0.31
	12"-18"	29.8	1.73	1.56	0.17	28.0	1.63	1.56	0.07
	18"-2ft	32.0	3.85	3.29	0.56	32.2	3.87	3.29	0.58
	3ft	37.1	4.57	3.53	1.04	36.2	4.45	3.53	0.92
	4ft	33.7	4.25	3.78	0.47	37.1	4.69	3.78	0.91
	5ft	31.3	3.88	3.52	0.36	30.8	3.83	3.52	0.31
	Total Water	(5½ft)	21.92		3.46	(5½ft)	21.94		3.48
Minimal Tillage With Fallow	0"-6"	35.3	1.94	1.33	0.61	32.6	1.80	1.33	0.47
	6"-12"	34.0	2.01	1.45	0.56	32.2	1.90	1.45	0.45
	12"-18"	35.7	2.07	1.56	0.51	27.6	1.60	1.56	0.04
	18"-2ft	37.4	4.49	3.29	1.20	34.7	4.17	3.29	0.88
	3ft	37.4	4.61	3.53	1.08	38.4	4.73	3.53	1.20
	4ft	40.6	5.12	3.78	1.34	40.1	5.06	3.78	1.28
	5ft	42.8	5.26	3.52	1.74	35.8	4.45	3.52	0.93
	Total Water	(5½ ft)	25.50		7.04	(5½ft)	23.71		5.25
Minimal Tillage Double Crop	0"-6"	37.3	2.06	1.33	0.73	32.8	1.81	1.33	0.48
	6"-12"	33.4	1.97	1.45	0.52	27.6	1.63	1.45	0.18
	12"-18"	33.7	1.95	1.56	0.39	26.1	1.52	1.56	NIL
	18"-2ft	31.0	3.72	3.29	0.43	27.6	3.31	3.29	0.02
	3ft	34.8	4.28	3.53	0.75	38.7	4.90	3.53	1.37
	4ft	36.6	4.62	3.78	0.84	37.1	4.68	3.78	0.90
	5ft	37.9	4.71	3.52	1.19	33.2	3.98	3.52	0.46
	Total Water	(5½ft)	23.31		4.85	(5½ft)	21.83		3.41

APPENDIX 1C:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1967-68 SHORT RAINS

PLANTING

TREATMENT	DEPTH	H.B.P. I: % M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	H.B.P. II: % M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	49.0	2.70	1.33	1.37	45.4	2.58	1.33	1.25
	6"-12"	46.5	2.75	1.45	1.30	48.4	2.86	1.45	1.41
	12"-18"	39.8	2.31	1.56	0.75	39.2	2.28	1.56	0.72
	18"-2ft	32.9	3.96	3.29	0.67	32.7	3.93	3.29	0.64
	3ft	34.6	4.26	3.53	0.73	29.8	3.67	3.53	0.14
	4ft	36.7	4.63	3.78	0.85	35.4	4.47	3.78	0.69
	5ft	31.9	3.96	3.52	0.44	31.8	3.94	3.52	0.42
	Total Water	(5½ft)	24.57		6.11	(5½ft)	23.73		5.27
Tie Ridging Double Crop	U1	40.5	2.31			45.3	2.58		
	U2	46.8	2.67			33.2	1.90		
	0"-6"	44.9	2.47	1.33	1.14	45.4	2.58	1.33	1.25
	6"-12"	38.3	2.26	1.45	0.84	25.7	1.52	1.45	0.60
	12"-18"	39.8	2.31	1.56	0.93	35.4	2.05	1.56	0.42
	18"-2ft	30.5	3.67	3.29	0.38	28.1	3.37	3.29	0.08
	3ft	30.6	3.77	3.53	0.24	32.5	4.00	3.53	0.47
	4ft	35.5	4.48	3.78	0.70	35.4	4.47	3.78	0.69
	5ft	31.8	3.94	3.52	0.42	39.2	4.37	3.52	1.35
	Total Water	(5½ft)	23.11		4.65	(5ft)	23.32		4.86

APPENDIX 10: (Contd.)

TREATMENT	DEPTH	R E P. I % M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	R E P. I I % M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL- ABLE WATER
	0"-6"	38.5	2.12	1.33	0.79	40.7	2.24	1.33	0.9
	6"-12"	38.3	2.26	1.45	0.81	38.4	2.26	1.45	0.8
	12"-18"	34.1	1.98	1.56	0.42	36.9	2.14	1.56	0.5
Conventional Tillage With Fallow	18"-2ft	32.4	3.00	3.29	NIL	32.5	3.01	3.29	NI
	3ft	36.4	4.48	3.53	0.95	31.2	3.84	3.53	0.3
	4ft	31.0	3.91	3.78	0.13	37.6	4.74	3.78	0.9
	5ft	26.9	3.34	3.52	NIL	36.7	4.55	3.52	1.0
	Total Water	(5½ft)	21.09		3.10	(5½ft)	22.78		4.6
	0"-6"	42.6	2.35	1.33	1.02	40.7	2.24	1.33	0.9
	6"-12"	38.3	2.26	1.45	0.81	39.6	2.34	1.45	0.8
	12"-18"	37.0	2.14	1.56	0.58	36.9	2.14	1.56	0.5
Minimal Tillage With Fallow	18"-2ft	34.9	4.20	3.29	0.91	35.3	4.24	3.29	0.9
	3ft	36.5	4.50	3.53	0.97	43.1	5.31	3.53	1.7
	4ft	36.8	4.64	3.78	0.86	41.0	5.17	3.78	1.3
	5ft	41.4	5.14	3.52	1.62	39.7	4.92	3.52	1.4
	Total Water	(5½ft)	25.23		6.77	(5½ft)	26.36		7.9
	0"-6"	47.0	2.59	1.33	1.26	40.7	2.24	1.33	0.9
	6"-12"	44.7	2.64	1.45	1.19	38.3	2.26	1.45	0.8
	12"-18"	34.9	2.03	1.56	0.47	33.9	1.97	1.56	0.4
Minimal Tillage Double Crop	18"-2ft	33.1	3.97	3.29	0.68	34.3	4.12	3.29	0.8
	3ft	40.7	5.01	3.53	1.48	40.8	5.00	3.53	1.4
	4ft	37.6	4.74	3.78	0.96	31.0	3.91	3.78	0.1
	5ft	38.4	4.77	3.52	1.25	33.8	4.20	3.52	0.6
	Total Water	(5½ft)	25.75		7.29	(5½ft)	23.70		5.2

APPENDIX 11:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1967-68 SHORT RAINS
FLOWERING

TREATMENT	DEPTH	R E P. I				R E P. II			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	16.0	0.88	1.33	NIL	11.5	0.60	1.33	NIL
	6"-12"	24.6	1.46	1.45	0.01	26.1	1.55	1.45	0.10
	12"-18"	24.0	1.39	1.56	NIL	24.9	1.45	1.56	NIL
	18"-2ft	26.3	3.16	3.29	NIL	24.7	2.97	3.29	NIL
	3ft	27.1	3.34	3.53	NIL	24.0	2.96	3.53	NIL
	4ft	32.62	4.11	3.78	0.33	34.0	4.29	3.78	0.51
	5ft	33.5	4.16	3.52	0.64	36.7	4.55	3.52	1.03
	Total Water	(5½ft)	18.50		0.98	(5½ft)	18.37		1.64
Tie Ridging Double Crop	U1	18.8	1.07			14.7	0.84		
	U2	22.8	1.30			20.0	1.14		
	0"-6"	22.2	1.22	1.33	NIL	23.7	1.31	1.33	NIL
	6"-12"	26.5	1.57	1.45	NIL	47.8	2.82	1.45	0.98
	12"-18"	24.1	1.40	1.56	NIL	25.8	1.50	1.56	NIL
	18-2ft	28.1	3.38	3.29	0.09	26.6	3.20	3.29	NIL
	3ft	31.0	3.82	3.53	0.29	25.8	3.17	3.53	NIL
	4ft	33.6	4.23	3.78	0.45	31.7	4.00	3.78	0.22
	5ft	35.4	4.39	3.52	0.87	36.3	4.51	3.52	0.99
	Total Water	(5½ft)	19.71		1.70	(5½ft)	19.34		1.59

APPENDIX 11: (Contd.)

TREATMENT	DEPTH	REP. I				REP. II			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
Conventional Tillage With Fallow	0"-6"	11.7	0.64	1.33	NIL	21.6	1.19	1.33	NIL
	6"-12"	25.5	1.51	1.45	0.06	25.9	1.53	1.45	0.08
	12"-18"	24.6	1.43	1.56	NIL	26.2	1.52	1.56	NIL
	18"-2ft	24.7	2.97	3.29	NIL	24.0	2.89	3.29	NIL
	3ft	28.5	3.51	3.53	NIL	25.0	3.08	3.53	NIL
	4ft	35.6	4.49	3.78	0.71	34.7	4.38	3.78	0.60
	5ft	34.1	4.23	3.52	0.71	35.4	4.40	3.52	0.88
	Total Water	(5½ft)	18.78		1.48	(5½ft)	18.99		1.56
Minimal Tillage With Fallow	0"-6"	23.8	1.31	1.33	NIL	22.6	1.25	1.33	NIL
	6"-12"	24.9	1.47	1.45	0.02	21.0	1.24	1.45	NIL
	12"-18"	27.6	1.60	1.56	0.04	27.6	1.60	1.56	0.04
	18"-2ft	30.3	3.63	3.29	0.34	26.6	3.20	3.29	NIL
	3ft	31.5	3.88	3.53	0.35	26.2	3.22	3.53	NIL
	4ft	36.0	4.54	3.78	0.76	31.1	3.92	3.78	0.14
	5ft	37.2	4.61	3.52	1.09	37.2	4.61	3.52	1.09
	Total Water	(5½ft)	21.04		2.60	(5½ft)	19.04		1.27
Minimal Tillage Double Crop	0"-6"	23.7	1.31	1.33	NIL	15.3	0.84	1.33	NIL
	6"-12"	26.4	1.56	1.45	0.11	26.6	1.57	1.45	0.12
	12"-18"	29.2	1.70	1.56	0.14	24.3	1.41	1.56	NIL
	18"-2ft	30.1	3.61	3.29	0.32	29.0	3.48	3.29	0.19
	3ft	31.5	3.88	3.53	0.35	31.4	3.86	3.53	0.33
	4ft	39.6	4.99	3.78	1.21	37.1	4.67	3.78	0.89
	5ft	39.5	4.90	3.52	1.38	38.1	4.73	3.52	1.21
	Total Water	(5½ft)	21.95		3.51	(5½ft)	20.56		2.74

APPENDIX 12:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1967-68 SHORT RAINS

HARVEST

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	21.5	1.25	1.33	NIL	16.2	0.89	1.33	NIL
	6"-12"	22.7	1.34	1.45	NIL	20.9	1.23	1.45	NIL
	12"-18"	23.6	1.37	1.56	NIL	23.8	1.38	1.56	NIL
	18"-2ft	27.8	3.35	3.29	0.06	25.2	3.03	3.29	NIL
	3ft	26.1	3.21	3.53	NIL	28.8	3.54	3.53	0.01
	4ft	36.4	4.34	3.78	0.56	32.7	4.13	3.78	0.35
	5ft	31.5	3.91	3.52	0.39	36.7	4.56	3.52	1.04
	Total Water	(5½ft)	18.77		1.01	(5½ft)	18.76		1.40
Tie Ridging Double Crop	U1	14.3	0.82			18.6	1.06		
	U2	22.4	1.28			21.1	1.20		
	0"-6"	14.6	0.80	1.33	NIL	18.1	1.00	1.33	NIL
	6"-12"	22.3	1.32	1.45	NIL	22.8	1.35	1.45	NIL
	12"-18"	25.0	1.45	1.56	NIL	24.2	1.41	1.56	NIL
	18"-2ft	24.7	2.97	3.29	NIL	24.5	2.95	3.29	NIL
	3ft	27.4	3.37	3.53	NIL	30.9	3.81	3.53	0.28
	4ft	33.2	4.19	3.78	0.41	33.3	4.21	3.78	0.43
	5ft	34.4	4.27	3.52	0.75	35.1	4.36	3.52	0.84
	Total Water	(5½ft)	18.04		1.16	(5½ft)	18.85		1.55

APPENDIX 12: (Contd.)

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
	0"–6"	17.4	0.96	1.33	NIL	20.0	1.10	1.33	NIL
	6"–12"	22.2	1.31	1.45	NIL	20.1	1.19	1.45	NIL
	12"–18"	21.2	1.23	1.56	NIL	23.6	1.37	1.56	NIL
...ventional	18"–2ft	20.5	2.47	3.29	NIL	24.3	2.93	3.29	NIL
...llage With	3ft	20.3	2.50	3.53	NIL	26.4	3.25	3.53	NIL
...llow	4ft	22.3	2.81	3.78	NIL	30.0	3.79	3.78	0.01
	5ft	21.9	2.72	3.52	NIL	33.6	4.18	3.52	0.66
	Total Water	(5½ft)	14.00		NIL	(5½ft)	17.81		0.67
	0"–6"	17.3	0.95	1.33	NIL	18.7	1.03	1.33	NIL
	6"–12"	20.6	1.22	1.45	NIL	20.8	1.23	1.45	NIL
	12"–18"	21.8	1.26	1.56	NIL	21.4	1.25	1.56	NIL
...inimal	18"–2ft	22.8	2.81	3.29	NIL	23.2	2.79	3.29	NIL
...llage with	3ft	25.6	3.07	3.53	NIL	25.5	3.14	3.53	NIL
...llow	4ft	29.5	3.73	3.78	NIL	28.6	3.60	3.78	NIL
	5ft	32.8	4.08	3.52	0.56	30.5	3.78	3.52	0.26
	Total Water	(5½ft)	17.12		0.56	(5½ft)	16.82		0.26
	0"–6"	19.6	1.08	1.33	NIL	19.7	1.09	1.33	NIL
	6"–12"	22.1	1.31	1.45	NIL	19.8	1.17	1.45	NIL
	12"–18"	21.5	1.25	1.56	NIL	23.1	1.34	1.56	NIL
...inimal	18"–2ft	24.5	2.94	3.29	NIL	24.8	2.98	3.29	NIL
...llage	3ft	25.2	3.10	3.53	NIL	29.8	3.67	3.53	0.14
...able Crop	4ft	27.5	3.48	3.78	NIL	28.1	3.55	3.78	NIL
	5ft	33.2	4.12	3.52	0.60	29.5	3.66	3.52	0.14
	Total Water	(5½ft)	17.28		0.60	(5½ft)	17.46		0.28

APPENDIX 13:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1968 LONG RAINS

PLANTING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	43.7	2.41	1.33	1.08	44.1	2.43	1.33	1.10
	6"-12"	40.1	2.37	1.45	0.92	40.0	2.36	1.45	0.91
	12"-18"	39.4	2.29	1.56	0.73	38.5	2.23	1.56	0.67
	18"-2ft	36.6	4.40	3.29	1.11	40.1	4.81	3.29	1.52
	3ft	39.7	4.88	3.53	1.35	39.9	4.91	3.53	1.38
	4ft	41.2	5.19	3.78	1.41	40.3	5.09	3.78	1.31
	5ft	38.1	4.73	3.52	1.21	40.1	4.98	3.52	1.46
	Total Water	(5½ft)	26.27		7.81	(5½ft)	26.71		8.35
Tie Ridging Double Crop	U1	44.0	2.51			39.9	2.27		
	U2	42.1	2.40			44.3	2.53		
	0"-6"	42.0	2.31	1.33	0.98	44.3	2.44	1.33	1.11
	6"-12"	38.3	2.25	1.45	0.93	36.7	2.17	1.45	0.77
	12"-18"	38.6	2.24	1.56	0.76	44.5	2.56	1.56	1.00
	18"-2ft	38.5	4.63	3.29	1.34	40.4	4.86	3.29	1.57
	3ft	39.7	4.89	3.53	1.36	44.2	5.46	3.53	1.93
	4ft	45.3	5.71	3.78	1.93	47.1	5.94	3.78	2.16
	5ft	46.9	5.82	3.52	2.30	41.9	5.20	3.52	1.44
	Total Water	(5½ft)	28.06		9.60	(5½ft)	28.68		10.22

APPENDIX 13: (Contd.)

TREATMENT	DEPTH	REP. I				REP. II			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER
	0"-6"	38.4	2.12	1.33	0.79	45.0	2.48	1.33	1.15
	6"-12"	34.5	2.04	1.45	0.59	40.0	2.36	1.45	0.91
	12"-18"	40.8	2.37	1.56	0.81	40.8	2.37	1.56	0.81
Conventional Tillage With Fallow	18"-2ft	39.5	4.74	3.29	1.45	39.6	4.07	3.29	0.78
	3ft	40.5	4.98	3.53	1.45	39.7	4.89	3.53	1.36
	4ft	30.3	3.83	3.78	0.05	42.3	5.33	3.78	1.55
	5ft	30.1	3.74	3.52	0.22	42.8	5.31	3.52	1.79
	Total Water	(5½ft)	23.82		5.36	(5½ft)	26.81		6.35
	0"-6"	45.1	2.48	1.33	1.15	37.1	2.05	1.33	0.72
	6"-12"	40.4	2.38	1.45	0.93	39.0	2.31	1.45	0.86
	12"-18"	36.7	2.13	1.56	0.57	40.6	2.36	1.56	0.80
Minimal Tillage With Fallow	18"-2ft	39.8	4.78	3.29	1.49	39.5	4.74	3.29	1.45
	3ft	[illegible]	5.02	3.53	1.49	39.8	4.90	3.53	1.37
	4ft	43.6	5.50	3.78	1.72	41.2	5.20	3.78	1.42
	5ft	41.3	5.12	3.52	1.60	40.7	5.05	3.52	1.53
	Total Water	(5½ft)	27.41		8.95	(5½ft)	26.61		8.45
	0"-6"	42.3	2.33	1.33	1.00	41.5	2.28	1.33	0.95
	6"-12"	37.8	2.23	1.45	0.78	38.8	2.29	1.45	0.84
	12"-18"	39.1	2.27	1.56	[illegible]	38.9	2.26	1.56	0.70
Minimal Tillage Double Crop	18"-2ft	41.1	4.94	3.29	1.65	42.5	5.11	3.29	1.82
	3ft	41.7	5.13	3.53	1.60	[illegible]	4.89	3.53	1.36
	4ft	44.8	5.65	3.78	1.87	37.9	4.77	3.78	0.99
	5ft	45.3	5.62	3.52	2.10	37.0	4.58	3.52	1.0
	Total Water	(5½ft)	[illegible]		9.71	(5½ft)	26.18		7.7

APPENDIX 14:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1968 LONG RAINS

FLOWERING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	28.6	1.57	1.33	0.24	36.7	2.02	1.33	0.69
	6"-12"	30.6	1.81	1.45	0.36	36.2	2.14	1.45	0.69
	12"-18"	35.2	2.04	1.56	0.48	33.8	1.96	1.56	0.40
	18"-2ft	36.3	4.36	3.29	1.07	34.4	4.14	3.29	0.85
	3ft	36.9	4.54	3.53	1.01	37.6	4.62	3.53	1.09
	4ft	40.6	5.13	3.78	1.35	40.1	5.06	3.78	1.28
	5ft	41.3	5.13	3.52	1.61	30.1	3.74	3.52	1.22
	Total Water	(5½ft)	24.58		6.12	(5½ft)	23.68		6.22
Tie Ridging Double Crop	U1	24.0	1.37			28.4	1.62		
	U2	29.9	1.71			29.2	1.67		
	0"-6"	29.0	1.60	1.33	0.27	28.1	1.55	1.33	0.22
	6"-12"	33.5	1.98	1.45	0.23	30.3	1.79	1.45	0.26
	12"-18"	34.6	2.01	1.56	0.30	32.1	1.87	1.56	0.21
	18"-2ft	36.1	4.32	3.29	1.03	33.9	4.07	3.29	0.78
	3ft	37.6	4.63	3.53	1.10	36.9	4.54	3.53	1.01
	4ft	39.8	5.02	3.78	1.24	37.4	4.72	3.78	0.94
	5ft	39.3	4.88	3.52	1.36	37.9	4.70	3.52	1.18
	Total Water	(5½ft)	23.72		5.53	(5½ft)	23.06		4.60

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage With Fallow	0"-6"	35.9	1.98	1.33	0.65	34.2	1.88	1.33	0.55
	6"-12"	33.4	1.97	1.45	0.52	36.3	2.14	1.45	0.69
	12"-18"	36.1	2.09	1.56	0.53	36.0	2.09	1.56	0.53
	18"-2ft	34.3	4.13	3.29	0.84	37.9	4.56	3.29	1.27
	3ft	35.8	4.41	3.53	0.88	38.0	4.68	3.53	1.15
	4ft	36.6	4.62	3.78	0.84	39.5	4.99	3.78	1.21
	5ft	33.8	4.20	3.52	0.68	37.4	4.64	3.52	1.12
	Total Water	(5½ft)	23.40		4.94	(5½ft)	24.98		6.52
Minimal Tillage With Fallow	0"-6"	36.9	2.03	1.33	0.70	30.7	1.69	1.33	0.36
	6"-12"	33.3	1.97	1.45	0.52	35.8	2.12	1.45	0.67
	12"-18"	33.7	1.96	1.56	0.40	35.1	2.04	1.56	0.48
	18"-2ft	36.3	4.37	3.29	1.08	34.9	4.19	3.29	0.90
	3ft	35.9	4.43	3.53	0.90	38.5	4.74	3.53	1.21
	4ft	39.1	4.93	3.78	1.15	41.9	5.28	3.78	1.50
	5ft	40.3	5.01	3.52	1.49	40.3	5.00	3.52	1.48
	Total Water	(5½ft)	24.70		6.24	(5½ft)	25.06		6.60
Minimal Tillage Double Crop	0"-6"	30.5	1.68	1.33	0.35	29.0	1.60	1.33	0.27
	6"-12"	32.4	1.92	1.45	0.47	31.9	1.88	1.45	0.43
	12"-18"	33.7	1.96	1.56	0.40	34.9	2.03	1.56	0.47
	18"-2ft	35.8	4.30	3.29	1.01	35.9	4.30	3.29	1.01
	3ft	37.6	4.63	3.53	1.10	37.8	4.66	3.53	1.13
	4ft	39.3	4.96	3.78	1.18	37.2	4.69	3.78	0.91
	5ft	41.1	5.10	3.52	1.58	39.3	4.87	3.52	1.35
	Total Water	(5½ft)	24.55		6.09	(5½ft)	24.03		5.57

APPENDIX 15s

GRAVIMETRIC SOIL MOISTURE SAMPLING 1968 LONG RAINS

HARVEST

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage Double Crop	0"-6"	25.8	1.41	1.33	0.08	28.0	1.54	1.33	0.21
	6"-12"	29.0	1.71	1.45	0.26	33.2	1.96	1.45	0.51
	12"-18"	30.6	1.77	1.56	0.21	33.1	1.92	1.56	0.36
	18"-2ft	33.9	4.07	3.29	0.78	35.3	4.24	3.29	0.95
	3ft	38.5	4.74	3.53	1.21	36.8	4.54	3.53	1.01
	4ft	39.1	4.93	3.78	1.15	37.7	4.76	3.78	0.98
	5ft	37.7	4.68	3.52	1.16	38.8	4.82	3.52	1.30
	Total Water	(5½ft)	23.31		4.85	(5½ft)	23.78		5.32
Tie Ridged Double Crop	U1	32.1	1.83			18.6	1.06		
	U2	22.9	1.31			27.3	1.56		
	0"-6"	25.5	1.40	1.33	0.07	23.8	1.31	1.33	NIL
	6"-12"	31.7	1.87	1.45	0.40	28.6	1.69	1.45	NIL
	12"-18"	31.7	1.83	1.56	0.01	18.5	1.08	1.56	NIL
	18"-2ft	34.7	4.16	3.29	0.87	35.1	4.21	3.29	0.92
	3ft	36.0	4.69	3.53	1.16	40.3	4.96	3.53	1.43
	4ft	39.4	4.97	3.78	1.19	38.2	4.81	3.78	1.03
	5ft	36.9	4.58	3.52	1.06	39.7	4.93	3.52	1.41
	Total Water	(5½ft)	23.22		4.76	(5½ft)	22.92		4.79

APPENDIX 15: (Contd.)

TREATMENT	DEPTH	R E P. I				R E P. II			
		% M.C.	INCHES OF WATER	INS. AT W.P.	AVAILABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAI ABL WATE
Conventional Tillage With Fallow	0-6"	25.7	1.41	1.33	0.08	30.6	1.68	1.33	0.3
	6-12"	32.3	1.91	1.45	0.46	34.1	2.02	1.45	0.5
	12-18"	35.2	2.04	1.56	0.48	35.6	2.07	1.56	0.5
	18"-2ft	35.1	4.22	3.29	0.93	34.3	4.13	3.29	0.8
	3ft	31.7	3.91	3.53	0.38	38.1	4.69	3.53	1.1
	4ft	32.5	4.09	3.78	0.31	36.2	4.56	3.78	0.7
	5ft	31.9	3.97	3.52	0.45	38.0	4.72	3.52	1.2
	Total Water	(5½ft)	21.55		3.09	(5½ft)	23.87		5.4
Minimal Tillage With Fallow	0-6"	30.9	1.70	1.33	0.37	31.5	1.73	1.33	0.4
	6-12"	33.2	1.96	1.45	0.51	32.9	1.94	1.45	0.4
	12-18"	34.0	1.98	1.56	0.42	35.1	2.04	1.56	0.4
	18"-2ft	34.6	4.16	3.29	0.87	34.2	4.11	3.29	0.8
	3ft	39.5	4.86	3.53	1.33	37.4	4.61	3.53	1.0
	4ft	39.5	4.98	3.78	1.20	35.9	4.52	3.78	0.7
	5ft	38.2	4.74	3.52	1.22	35.7	4.43	3.52	0.9
	Total Water	(5½ft)	24.38		5.92	(5½ft)	23.38		4.9
Minimal Tillage Double Crop	0-6"	21.5	1.18	1.33	NIL	22.9	1.26	1.33	NIL
	6-12"	28.6	1.69	1.45	0.24	25.2	1.49	1.45	0.04
	12-18"	29.9	1.73	1.56	0.17	28.7	1.66	1.56	0.10
	18"-2ft	32.5	3.90	3.29	0.61	30.2	3.63	3.29	0.34
	3ft	29.3	3.61	3.53	0.08	33.5	4.13	3.53	0.60
	4ft	36.6	4.99	3.78	1.21	38.5	4.86	3.78	1.08
	5ft	39.3	4.88	3.52	1.36	36.9	4.58	3.52	1.06
	Total Water	(5½ft)	21.98		3.67	(5½ft)	21.61		3.22

APPENDIX 16:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1968-69 SHORT RAINS PLANTING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
	0"-6"	19.7	1.08	1.33	NIL	24.4	1.35	1.33	0.02
	6"-12"	17.4	1.03	1.45	NIL	25.9	1.53	1.45	0.08
	12"-18"	18.2	1.05	1.56	NIL	27.9	1.62	1.56	0.06
Conventional Tillage Double Crop	18"-2ft	29.8	3.58	3.29	0.29	34.5	4.14	3.29	0.85
	3ft	29.5	3.64	3.53	0.11	30.1	3.71	3.53	0.18
	4ft	35.7	4.50	3.78	0.72	32.5	4.10	3.78	0.32
	5ft	34.3	4.26	3.52	0.74	33.1	4.11	3.52	0.59
	Total Water	(5½ft)	19.14		1.86	(5½ft)	20.56		2.10
	U1	14.1	0.81			22.6	1.29		
	U2	18.2	1.04			18.4	1.05		
	0"-6"	22.9	1.26	1.33	NIL	33.4	1.84	1.33	0.51
	6"-12"	29.3	1.73	1.45	NIL	24.6	1.45	1.45	NIL
	12"-18"	26.5	1.54	1.56	NIL	25.3	1.47	1.56	NIL
Tie Ridging Double Crop	18"-2ft	30.2	3.63	3.29	0.34	30.1	3.62	3.29	0.33
	3ft	32.1	3.95	3.53	0.42	37.5	4.62	3.53	1.09
	4ft	40.3	5.09	3.78	1.31	43.9	5.53	3.78	1.75
	5ft	37.6	4.67	3.52	1.15	41.1	5.10	3.52	1.58
	Total Water	(5½ft)	21.14		3.22	(5½ft)	23.34		5.26

APPENDIX 16: (CONTD.)

TREATMENT	DEPTH	REP. I				REP. II			
		% M.C.	INCHES OF WATER	INS. AT W.P. WATER	AVAIL-ABLE WATER	% M.C.	INCHES OF WATER	INS. AT W.P.	AVAIL-ABLE WATER
Conventional Tillage With Fallow	0"-6"	27.4	1.51	1.33	0.18	23.4	1.29	1.33	NIL
	6"-12"	30.4	1.79	1.45	0.34	26.4	1.56	1.45	0.11
	12"-18"	29.2	1.69	1.56	0.13	30.7	1.78	1.56	0.22
	18"-2ft	29.8	3.58	3.29	0.29	29.9	3.60	3.29	0.31
	3ft	27.5	3.39	3.53	NIL	33.1	4.07	3.53	0.54
	4ft	23.5	2.96	3.78	NIL	34.5	4.35	3.78	0.57
	5ft	25.6	3.17	3.52	NIL	42.2	5.24	3.52	1.72
	Total Water	(5½ft)	18.09		0.94	(5½ft)	21.89		3.47
Minimal Tillage With Fallow	0"-6"	27.0	1.49	1.33	0.16	27.5	1.58	1.33	0.25
	6"-12"	34.7	2.04	1.45	0.59	34.8	2.06	1.45	0.61
	12"-18"	31.3	1.82	1.56	0.26	32.2	1.87	1.56	0.31
	18"-2ft	30.3	3.65	3.29	0.36	29.9	3.60	3.29	0.31
	3ft	33.6	4.13	3.53	0.60	36.8	4.53	3.53	1.00
	4 ft	31.1	3.92	3.78	0.14	38.6	4.87	3.78	1.09
	5 ft	39.1	4.86	3.52	1.34	37.7	4.68	3.52	1.16
	Total Water	(5½ft)	21.91		3.45	(5½ft)	23.19		4.73
Minimal Tillage Double Crop	0"-6"	26.8	1.47	1.33	0.14	26.7	1.47	1.33	0.14
	6"-12"	27.6	1.63	1.45	0.18	30.9	1.83	1.45	0.38
	12"-18"	29.2	1.69	1.56	0.13	31.1	1.81	1.56	0.25
	18"-2ft	29.5	3.54	3.29	0.25	28.6	3.34	3.29	0.05
	3ft	36.3	4.47	3.53	0.94	31.1	3.83	3.53	0.30
	4ft	39.5	4.98	3.78	1.20	35.4	4.46	3.78	0.68
	5ft	34.8	4.32	3.52	0.80	32.8	4.07	3.52	0.55
	Total Water	(5½ft)	22.10		3.64	(5½ft)	20.81		2.35

APPENDIX 18:

GRAVIMETRIC SOIL MOISTURE SAMPLING 1968-69 SHORT RAINS.

FLOWERING

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
	0"-6"	22.7%	1.25	1.33	NIL	28.5	1.57	1.33	0.24
	6"-12"	29.6	1.75	1.45	0.30	28.7	1.69	1.45	0.24
	12"-18"	31.4	1.82	1.56	0.26	29.7	1.72	1.56	0.16
Conventional Tillage Double Crop	18"-2ft	33.1	3.97	3.29	0.68	36.6	4.39	3.29	1.10
	3ft	34.8	4.29	3.53	0.76	39.3	4.84	3.53	1.31
	4ft	40.9	5.16	3.78	1.38	43.0	5.42	3.78	1.64
	5ft	42.1	5.23	3.52	1.71	38.1	4.73	3.52	1.21
Total Water		(5½ft)	23.47		5.09	(5½ft)	24.36		5.90
	U1	29.9	1.71			28.5	1.62		
	U2	32.8	1.87			25.5	1.45		
	0"-6"	30.1	1.66	1.33	0.33	29.5	1.62	1.33	0.29
	6"-12"	29.0	1.71	1.45	0.26	24.4	1.35	1.45	0.04
	12"-18"	33.3	1.93	1.56	0.31	26.1	1.54	1.56	NIL
Tie Ridging Double Crop	18"-2ft	34.1	4.10	3.29	0.81	33.2	3.99	3.29	0.70
	3ft	42.8	5.27	3.53	1.74	37.0	4.56	3.53	1.03
	4ft	40.6	5.12	3.78	1.34	40.7	5.14	3.78	1.36
	5ft	41.1	5.10	3.52	1.58	42.7	5.29	3.52	1.77
Total Water		(5½ft	24.83		6.37	(5½ft)	23.59		5.19

APPENDIX [illegible]: (Contd.)

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage With	0"-6"	30.0	1.65	1.33	0.32	29.0	1.66	1.33	0.33
	6"-12"	31.7	1.87	1.45	0.42	31.8	1.88	1.45	0.43
	12"-18"	30.5	1.77	1.56	0.21	29.4	1.71	1.56	0.15
	18"-2ft	34.1	4.10	3.29	0.81	34.0	4.09	3.29	0.80
	3ft	37.2	4.57	3.53	1.04	36.4	4.48	3.53	0.95
	4ft	37.3	4.69	3.78	0.91	38.9	4.90	3.78	1.12
	5ft	41.7	5.17	3.52	1.65	40.9	5.07	3.52	1.55
	Total Water	(5½ft)	23.82		5.36	(5½ft)	23.79		5.33
Minimal Tillage With Fallow	0"-6"	31.0	1.71	1.33	0.38	26.2	1.45	1.33	0.12
	6"-12"	27.4	1.62	1.45	0.17	25.5	1.51	1.45	0.06
	12"-18"	30.6	1.78	1.56	0.22	30.9	1.79	1.56	0.23
	18"-2ft	30.4	3.65	3.29	0.36	30.0	3.60	3.29	0.31
	3ft	35.0	4.31	3.53	0.78	35.0	4.31	3.53	0.78
	4ft	40.4	5.01	3.78	1.23	39.9	5.03	3.78	1.25
	5ft	36.1	4.48	3.52	0.96	35.4	4.40	3.52	0.88
	Total Water	(5½ft)	22.56		4.10	(5½ft)	22.09		3.63
Minimal Tillage Double Crop	0"-6"	30.7	1.69	1.33	0.36	32.9	1.81	1.33	0.48
	6"-12"	30.3	1.79	1.45	0.34	28.1	1.66	1.45	0.21
	12"-18"	31.1	1.80	1.56	0.24	30.5	1.77	1.56	0.21
	18"-2ft	34.5	4.14	3.29	0.85	35.5	4.27	3.29	0.98
	3ft	42.8	5.27	3.53	0.74	36.5	4.50	3.53	0.97
	4ft	45.5	5.74	3.78	1.96	40.5	5.11	3.78	1.33
	5ft	42.7	5.30	3.52	1.78	38.8	4.82	3.52	1.30
	Total Water	(5½ft)	25.73		6.27	(5½ft)	23.94		5.48

APPENDIX 18:

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAIL-ABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAIL-ABLE WATER
Conventional Tillage Double Crop	0"-6"	18.2	1.00	1.33	NIL	10.9	0.60	1.33	NIL
	6"-12"	27.8	1.64	1.45	0.19	28.8	1.70	1.45	0.25
	12"-18"	31.1	1.80	1.56	0.24	36.1	2.09	1.56	0.53
	18"-2ft	33.8	4.06	3.29	0.77	35.9	4.30	3.29	1.01
	3ft	35.6	4.38	3.53	0.85	3[illegible].9	4.78	3.53	1.25
	4ft	40.4	5.09	3.78	1.31	37.1	4.76	3.78	0.98
	5ft	40.7	5.05	3.52	1.53	35.1	4.35	3.52	0.83
	Total Water	(5½ft)	23.02		4.89	(5½ft)	22.58		4.85
Tie Ridging Double Crop	1ft	18.1				15.5			
	2ft	24.9				21.5			
	0"-6"	24.4	1.17	1.33	NIL	23.9	1.08	1.33	NIL
	6"-12"	31.2	1.66	1.45	0.21	26.6	1.51	1.45	0.06
	12"-18"	28.1	1.63	1.56	0.07	33.5	1.94	1.56	0.38
	18"-2ft	32.9	3.95	3.29	0.66	34.6	4.15	3.29	0.86
	3ft	36.2	4.46	3.53	0.93	37.1	4.56	3.53	1.03
	4ft	37.2	4.69	3.78	0.91	39.5	4.98	3.78	1.20
	5ft	37.1	4.60	3.52	1.08	40.8	5.06	3.52	1.54
	Total Water	(5½ft)	22.16		3.86	(5½ft)	23.28		5.07

APPENDIX 18: (Contd.)

TREATMENT	DEPTH	REP. I % M.C.	REP. I INCHES OF WATER	REP. I INS. AT W.P.	REP. I AVAILABLE WATER	REP. II % M.C.	REP. II INCHES OF WATER	REP. II INS. AT W.P.	REP. II AVAILABLE WATER
Conventional Tillage With Cultivated Fallow	0"-6"	23.3	1.28	1.33	NIL	16.1	0.88	1.33	NIL
	6"-12"	27.0	1.59	1.45	0.14	34.3	2.02	1.45	0.5
	12"-18"	33.6	1.95	1.56	0.39	33.6	1.95	1.56	0.3
	18"-2ft	29.4	3.53	3.29	0.24	35.6	4.27	3.29	0.9
	3ft	31.6	3.89	3.53	0.36	38.0	4.68	3.53	1.1
	4ft	39.8	5.00	3.78	1.22	39.8	5.01	3.78	1.2
	5ft	40.7	5.04	3.52	1.52	35.6	4.41	3.52	0.8
	Total Water	(5½ft)	22.29		3.87	(5½ft)	23.22		5.21
Minimal Tillage With Chemical Fallow	0"-6"	20.1	1.11	1.33	NIL	23.1	1.27	1.33	NIL
	6"-12"	22.1	1.31	1.45	NIL	27.3	1.61	1.45	0.16
	12"-18"	26.9	1.56	1.56	NIL	28.0	1.62	1.56	0.06
	18"-2ft	27.6	3.32	3.29	0.03	24.6	2.95	3.29	NIL
	3ft	28.8	3.54	3.53	0.01	30.7	3.78	3.53	0.25
	4ft	37.7	4.76	3.78	0.98	37.3	4.69	3.78	0.91
	5ft	39.8	5.01	3.52	1.49	34.8	4.32	3.52	0.80
	Total Water	(5½ft)	20.61		2.51	(5½ft)	20.24		2.18
Minimal Tillage Double Crop	0"-6"	24.7	1.36	1.33	0.03	19.3	1.06	1.33	NIL
	6"-12"	30.0	1.77	1.45	0.32	25.3	1.49	1.45	0.04
	12"-18"	33.5	1.94	1.56	0.38	30.6	1.77	1.56	0.21
	18"-2ft	33.5	4.02	3.29	0.73	34.3	4.12	3.29	0.83
	3ft	33.9	4.17	3.53	0.64	31.1	3.82	3.53	0.29
	4ft	38.7	4.88	3.78	1.10	37.3	4.69	3.78	0.91
	5ft	39.0	4.84	3.52	1.32	36.5	4.52	3.52	1.00
	Total Water	(5½ft)	22.98		4.52	(5½ft)	21.47		3.28