

EVALUATION OF THE UAC TOOL CARRIER USED
IN MAIZE PRODUCTION SYSTEM

By

EMMANUEL MAKENZI BUNDALA KWILIGWA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF
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31 MAY 2001

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(ii)

I, EMMANUEL MAKENZI BUNDALA KWILIGWA, do hereby declare to the Senate of the University of Dar es Salaam that this is my own original work and has not been submitted for a degree at any other University.

Signature: 

EMMANUEL MAKENZI BUNDALA KWILIGWA

ACKNOWLEDGEMENT.

My sincere thanks should go to Prof. Inns, Head of the Department of Agricultural Engineering and Land Planning, University of Dar es Salaam, Morogoro, who in his capacity as my supervisor unreluctantly gave guidance and help to ensure that the project was prosperous. Thanks are also due to Mr. H. Dihenga and Dr. P. Edelsten who were co-supervisors, for their help in various ways.

I am grateful to Mr. L.O. Jonsson, former head of Agricultural Engineering Research Department at Uyole Agriculture Centre for initiating and giving suggestions on the plan of the project.

I express my gratitude to UAC and Nordic Administration for supporting the project both materially and morally. I thank the staff in various Research Departments at Uyole for giving me the technical help and data which was pertinent to my study.

I appreciate the useful knowledge gained from the Instrumentation Departments of the Agricultural Universities in Sweden and Denmark. The knowledge was valuable on the instrumentation which I used on my study.

Lastly, I thank the typist for typing the manuscript.

ABSTRACT

The Uyole Agricultural Centre (UAC) toolbar was developed to provide an effective animal drawn cultivation and planting device for use in low-rainfall farming systems and capable of manufacture by local artisans. This work describes an essential element of the development process for this toolbar viz its evaluation in practical maize production system. The evaluation was made in terms of capacity, labour requirement, draught force, costs and weed control compared with conventional methods. A split-plot design in randomized block of two replications was laid out. Main treatments included four tillage systems (hand hoe plus hand planting; mouldboard plough plus hand planting; UAC tool carrier tine plus hand planting and UAC tool carrier tine plus planter) while subtreatments included two weeding methods (hand weeding and UAC tool carrier weeder).

The UAC tool carrier tine plus hand planting, and UAC tool carrier plus planter tillage treatments gave the lowest mean grain yields of maize. There was a significant difference at 1% probability level between tillage means. There was no significant difference between weeding means. The UAC tool carrier planter gave a lower plant population than hand planting.

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The UAC tool carrier was not effective as a weed control tool on uncultivated plots. It resulted into more weed shoot counts and weed dry weights. There was a correlation between maize grain yields per hectare and weed dry weight per hectare. The variance ratio was highly significant at 1% probability level showing a sufficiently good fit of regression relationship.

The proposed UAC tool carrier system (direct drilling; 1st weeding by hand hoe on maize rows; 2nd weeding by UAC tool carrier weeder; and 3rd weeding by hand hoe) gave the lowest labour requirement (46% of the purely labour input system) and increased the area cultivable per farm family. But 1st weeding by hand hoe on maize rows which was intended to be a quick operation was limiting. The proposed system also gave not only the lowest total costs of maize production per hectare but was one of the systems that gave the highest value of a day's manpower.

The draught force of the UAC tool carrier tine was lower than that of the mouldboard and ridger even when sweeps are attached on the former. The increase in rake angle did not have a remarkable change on the draught. The sweeps

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on the UAC tool carrier tine brought about more soil disturbance than without them although they increased the draught force. The unexpectedly high force to overcome rolling resistance was probably due to the size and weight of the UAC tool carrier.

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CHAPTER I

INTRODUCTION

1.1 Background

Tanzania's economy is primarily agricultural. About 94% of the population live in the rural areas and 90% of the economically active population is engaged in agriculture. They depend upon agriculture for their employment and well being. In addition they have to produce a food surplus to feed the urban population and also food and industrial cash crops for export. In 1978, agriculture contributed roughly 36.5% of the Gross Domestic Product (GDP) and half of this was accounted for by subsistence production (NEWAFRICA, June 1980). The cash crops-mainly coffee, cotton, sisal and tea - contribute about 70% to the total foreign exchange earnings. So in a country which is critically dependent upon imports the performance of the agricultural sector is crucial.

The key to economic development, therefore, lies in raising the productivity and production of the agricultural population. For this to happen, the current limitations to total agricultural production must be given close attention with a view to their removal or alleviation.

1.2 Problems and limitations to Agricultural Production

Limitations to production and productivity are many and strongly inter-related. One important group of factors is concerned with infrastructure, climate, soils and cultivation practices.

Agricultural production may be raised by either increasing the area of land or productivity of land already under cultivation. Mechanisation is an important input in fulfilling that, but it is impracticable unless commercial outlets are available to profitably dispose of the resultant increase. Commercial outlets can be created by good infrastructure and marketing facilities in the rural areas. These factors are capable of further substantial development in Tanzania.

Rainfall and evaporation are perhaps the most important climatic elements limiting crop production. More than three-quarters of Tanzania receives less than 1000mm of rain. Whereas about 750 mm of rain is adequate for agriculture in most temperate regions, in Tanzania the same amount is probably a limit below which cultivation is marginal due to high rates of evaporation. BERRY(1971) reported that only about 20% of the country has high probability (90%) of receiving more than

750 mm. The rainfall is concentrated mainly into wet seasons which are however variable and unreliable, and it often occurs in torrential downpours typical of low rainfall areas. Taken together with high evaporation rates it can be concluded that cultivation over much of Tanzania is marginal and suitable cultivation techniques are likely to be those appropriate to arid and semi-arid areas. Research work has shown that major objectives of tillage in such areas should be to break open the soil surface to promote effective soil moisture retention by improving infiltration of rainfall and to reduce runoff. Suitable surface mulches help in retaining soil moisture, reducing soil temperature and resisting soil erosion (GIBBON et al, 1974; PHILLIPS and YOUNG, 1973; WHITEMAN, 1975; LAL, 1975).

The effectiveness of cultivation operations in Tanzania is frequently limited by availability of power. The main power source is human, using simple hand tools. BEENY (1975) shows that at least 75% of all farmed land is hoe (jembe) cultivated. Man has limited power albeit his power is versatile, directly and easily applicable. He can produce only about 0.075 kw continuously whilst 0.4 kw per hectare is considered to be

the minimum necessary, in conjunction with effective machinery and management, if yields are to reach acceptable levels (GILES, 1973; FAO, 1970). The area he can cultivate and take care of is necessarily limited. KLINE et al (1969) indicate that a Tanzanian manual farmer can till, plant and care for 1.2 ha of cash crops. SCHEFFLER (1977) reports 2 ha as an average hectarage of cereals that can be cropped by a family holding. On the other hand KLINE et al (1969) report that it is estimated in Ghana that to justify owning a pair of oxen a farmer must have 4 - 6 ha of crop land, FRIEDRICH and VAN GILST (1971) indicate that a small tractor can be economically feasible on about 20 ha. SCHEFFLER (1977) and BEENY (1975) conclude by saying that availability of power rather than land is the chief limiting factor in expanding production in many areas of Tanzania. Human power can be supplemented by animal power or engine power to increase productivity of existing farmlands or to increase the area cultivated.

Tillage implements currently used in Tanzania are ill-adapted to fulfilling tillage objectives for semi-arid areas. The disc plough is the main implement for tractor cultivations whereas ox farmers predominantly use a mould-board plough

and a ridger. The performance in terms of energy demand and ecological disturbance of these implements casts doubts upon the appropriateness of their use in drier areas. They invert the soil leading to unnecessary moisture loss and exposure of the soil to erosion. They provide no surface mulch which would help to alleviate both conditions (BEENY, 1975). The dry regions of the USA provide an example of the devastating losses of top soil due to wind and water erosion which can occur with indiscriminate use of the mouldboard plough (PHILLIPS and YOUNG, 1973). These dry regions are now being tilled by tined implements using mulch preserving techniques.

1.3 Agricultural Mechanisation policy in Tanzania

DAGG (1980) defines agricultural mechanisation policy as a course of action adopted by a government for the use of tools, implements and machines operated by human, animal or mechanical power to carry out all activities related to production, harvesting and subsequent handling, primary processing and storage of agricultural products. It should be designed to ensure that mechanisation in agriculture contributes to the economic, social and political objectives and should take into account the state of national development. The policy guides in planning programmes and projects which are to be implemented.

After independence in the early sixties Tanzania adopted the then prevalent World Bank strategy on mechanisation called the "transformation approach". Under this scheme the government resettled peasants in virgin farmland and provided them with modern farm inputs. The newly-settled farmers while growing food crops for subsistence were required to undertake cash crop production as their principal activity. The Block Mechanisation scheme was established in 1964 - 65 to use government tractors economically by amalgamating cotton fields into 121.4 hectare blocks (KLINE et al 1969). This was based on the assumption that family labour could handle a larger cotton area with mechanical assistance to cultivate additional land. The Kongwa Groundnut Scheme was established in 1947/51 with the same objectives. This was followed by the intensive Government Tractor Hire Service towards late sixties. The World Bank's transformation approach was abandoned in 1968 for various reasons the more important of which were:- enormous costs of inputs provided by the government; lack of technicians and spare parts to repair and maintain tractors; frequent tractor breakdowns because of long distance travel and rough conditions; and farmers' lack of knowledge and education.

The government retreated from this policy of actively encouraging engine - powered mechanisation of agriculture to one of more circumspect use of tractors and definite promotion of ox-power (KLINE et al 1969; DAGG 1980). Research, testing and training facilities to improve the animal-powered technology are being established. Development and local manufacture of ox-drawn implements are being encouraged. Oxen-power is considered to be more appropriate to the level of development of most areas and the level of understanding of most farmers. Reduced running costs, relatively modest levels of management skills, small repair costs for equipment, low replacement costs of draft animals, the multipurpose nature of the animal and a minimal drain on foreign exchange are all factors contributing to the appropriateness of oxen for most of Tanzanian agriculture.

1.4 Objectives of the study

In the year 1977, the Agricultural Engineering Research Department at Uyo Agriculture Centre(UAC) started developing an animal tool carrier. The specifications developed in the design philosophy of the tool carrier were to meet the objectives of:- use of local materials as necessary; local production and repair skills available and suited

to dry land farming. Tines attached to the carrier make furrows where seeds and fertilizers are dropped. Much of the trash is left on the surface as a mulch. Weeding operations can be performed by fitting the tines with sweeps. The weeding operation is done between rows and can be arranged such that some soil is pushed onto the crop rows to form small ridges. The high clearance of the tool carrier makes it possible to work on a one - metre - high maize crop. It can be converted into either a cart or wagon by fitting appropriate platforms.

Preliminary trials with the tool carrier were promising but lacked an objective assessment of its field performance prior to a study on how it can fit into existing farming systems. The present study was intended to objectively assess the tool carrier's performance in the field when used for maize production.

The major objectives were:-

1. To assess the performance of the tool carrier in terms of capacity, labour requirement and cost when used in a maize production system at Uyole and compare it with two conventional systems:-
 - a) hand labour only

b) land preparation by ox-drawn mouldboard plough followed by hand labour.

2. To measure the pull required for operations using tines with a view to:-

a) reducing the tine draught

b) matching tine draught to the pulling capacity of various animals.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical background of farming

Farming antedates civilisation. Man started farming as a hunter and fruit/seed gatherer. He lived upon the flesh of the animals he pursued and slew with his stone weapons, flint-tipped arrows, flint-headed axes, clubs etc. He was carnivorous and he must often have suffered from hunger!!! Women did not join in this difficult and dangerous work. They were left in the primitive houses and collected food from the wild vegetation, nuts, berries and edible roots. The flesh diet was supplemented by seeds from wild grasses which are the ancestors of our cereals. Wild Wheat was to be found in profusion in parts of South-West Asia while wild Emmer (Triticum dicocum) and barley possibly a variety of Hordeum hextaschium or vulgare were common in Syria, Palestine, Iran and North Africa. Flint-toothed sickles with well defined striations found in caves of mount Carmel (Palestine) are archaeological evidence of the harvesting of cereals by cutting of stalks (FUSSEL, 1966). But these tools do not show whether the grain harvested was wild or cultivated. There was a change from hunting and

gathering to sowing of seeds in order to reap the ensuing harvest. How this happened is unclear. But it is thought that some of the women may have dropped seeds on or besides the path to their homes. When they noticed that these lost grains grew and yielded a new harvest they may have started sowing by making holes with dibbling sticks. It is believed that could probably be the reason why ancient people worshipped female goddess, the giver of good bread!! Then there was a change from the dibbling stick to a hoe of some sort that could be used to break up the soil, perhaps to make a rut into which the seed could be dropped. The first hoes were probably entirely of wood with a flint-cutting-edge. This was the beginning of tillage which heralded civilisation on the basins of the Euphrates and the Tigris and the valley of the Nile.

Historical events went side by side with changes in farming techniques. First came the Graeco-Roman and Mediterranean farming (500 BC - A.D. 500) period when the iron age had already opened. Iron was used in the development of many implements e.g. mouldboard plough, reapers, sickles etc. Animals (oxen) were commonly used as sources of power on the farm. Then the Dark Age (AD 500 -

1000) period followed. It was a period of wars diseases and other catastrophes. So there was little improvement of farming. In the Middle Age (AD 1000 - 1500) period there was no complete peace. Nevertheless there were some technical advances particularly in peaceful areas. Crop and livestock husbandry improved. In the sixteenth and seventeenth centuries horses were extensively used on the farm. Although the eighteenth century was another period of wars and diseases generally farming improved. New implements were designed, and improved farming spread. Between 1815 and 1914 there was a rapid increase in population and industrial revolution. An influx of people to urban areas for better working conditions and social amenities increased. So power was increased on the farm in order to produce more food e.g. steam-power application to cultivation operations. This large scale mechanisation trend was interrupted by the First World War after which it (the trend) resumed. Tractors were intensively used and many implements were developed. There are now an array of tillage tools such as rotary tillers, ploughs, harrows, cultivators, subsoilers etc. Many of these were evolved prior to the present better knowledge of plant requirements in terms of seedling emergence.

2.2 Tillage Research

2.2.1 General

Cultivation of soil serves two main purposes: to control weeds and to provide a suitable environment for the growth of the plant roots. These needs were recognised before the dawn of the christian era and until recent decades there was little change in the basic methods used in agriculture, namely ploughing followed by secondary operations and appeared to be such an essential part of good husbandry that there was little incentive to study the functions they served. It was not until the 1920's that scientists started looking at cultivation from the scientific point of view. KEEN and RUSSELL (1937) were among the first researchers to lay out detailed experiments on the effects of cultivation on crop growth in the absence of weeds. NICHOLS (1937) studied soil shear strength and the parameters that affect it in view of making cultivation more effective. Unfortunately this pioneer work was interrupted by the second world war. But it had already gained much publicity and the work continued elsewhere after the war, and eventually led to a new subject of Soil Mechanics. Since then design of soil-engaging implements emphasized soil failure patterns.

However, many experiments to compare the effect of various tillage treatments on crop yield were conducted over the past five decades. Investigators have reported and put forward the factors influenced by soil tillage which are of paramount importance to the quality and quantity of the crops grown.

LARSON (1967) and McCALLA (1967) reported that soil tillage has a major influence on water intake, storage and evaporation, on the extraction of water from the soil by the plant roots, and on microbial activity which influences soil aeration, moisture and temperature. HOLT et al (1967) observed and reported on how tillage influences nutrient relationships and fertilizer placement through its effect on the water content in surface soil layers and the 'effective' volume of soil it presents to the root systems. BUSHAM et al (1973)

investigated the change in soil structure in the seedbed due to tillage operations. They emphasized that since the crop stand depends to a great extent on the emergence of planted seeds, it is essential to provide soil physical conditions conducive to germination and seedling emergence. This may be created by suitable soil manipulation through tillage.

2.2.2 Tillage Research and weed control

The losses of potential crop production due to weeds in Africa is reported to be 15.7%, the highest in the world (FAO, 1970). Weeds are one of the major problems of tropical agriculture and the inability to control weeds will be one of the greatest obstacles to continuous cultivation in the tropics. Weed growth and weeding is reported to be the major restriction limiting the cropping area that can be effectively cultivated by the small farmer, and that weeding is the most severe limitation to farmers using animal power (KLINE et al, 1969). The time spent on weeding, as derived from farm survey in Western Nigeria, accounts for more than half of the total labour input (IITA, 1974). RUTHENBERG (1971) reports that many shifting cultivation systems manage with

little weeding, as the fallow suppresses the growth of weeds and as fire clearance often leaves the soil weed-free, but that the effort spent on land preparation and weeding increases as the period of cultivation increases. The increased weed growth is often the primary reason for a patch of land being abandoned (NYE and GREENLAND, 1960).

Planting techniques can influence weed growth. Planting in rows results in less weed competitions and requires less weeding time than broadcasting (PILLAINAYAGAN, 1974; GRIST, 1965). Closer row spacing also result in a quick establishment of the canopy which suppresses weeds (MOODY, 1974). WEVER and KUIPERS (1976) showed that the mouldboard plough can effectively suppress annual weeds by burying them deep in the ground. They suggest two methods of controlling perennial weeds. The first method is by exhaustion whereby a non-dormant period in form of a fallow growing season is necessary. The second method is by desiccation which involves deep ploughing followed by several repeated operations prior to the dry season. The validity and applicability of these methods of weed control is doubtful in the tropics. Tropical soils

are known to have a weak structure. Repeated tillage operations will certainly destroy the soil aggregates and make the soil more vulnerable to erosion due to high intensity rainfall. The meagre moisture in many tropical areas ought to be deployed to the maximum advantage for the benefit of the crops. Soil inversion using the mouldboard plough causes tremendous loss of moisture by evaporation.

The success of any reduced or zero tillage technique depends mainly on the availability of suitable chemicals for weed control (BAEUMER and BAKERMANS, 1973). Chemically killed weeds in zero tillage can act as an additional mulch. LAL(1975) and IITA (1974) indicate that a good surface cover from crop residues may reduce weed growth.

Weeds cause greater yield losses in maize under low than under high soil fertility (IITA, 1974). Under dry conditions chemical weed control must be followed by interrow cultivation if there are remaining weeds because only a few weed plants per square metre can cause a considerable water stress under low rainfall conditions due to competition for moisture (MATTSON et al, 1979). Therefore the biggest increase in food production can be

obtained if the losses due to weeds can be reduced on the small farms where fertility is low and moisture meagre, and where weeds still cause most damage.

2.2.3 Tillage Research in Tanzania

The former Northern Research Centre at Tengeru and Arusha was among the first centres to show interest in tillage research. The background of cultivation studies in that area (1959 - 1962) showed that conventional cultivation (i.e. disc ploughing and harrowing) have little importance in the successful establishment of maize and beans. A considerable saving in time, power and labour due to direct drilling was reported at Tengeru by MACARTNEY and NORTHWOOD (1966).

Experience with cultivations at Uyole Agriculture Centre, Agronomy department (REPORT 1973 - 1976), which involved comparing tractor - mouldboard system on the one hand and a hoe on the other, on both maize and wheat, indicated no marked yield difference due to tillage treatments.

At the Faculty of Agriculture, Forestry and Veterinary Science, Morogoro, University of Dar es Salaam, there have been a number of projects

on tillage. Zero cultivation (HUXLEY, 1975/76) was started as a small programme. Preliminary observations showed that the non-cultivation system using mulch and fertilizers brought about a large yield increase and reduced the differential between cultivating and not cultivating. An experiment was laid out by MASHINA and JANA (1980) to investigate the effect of minimum tillage, mulches and fertilizers of intercropped cowpeas with maize. The results showed the lowest yields in zero tillage and in no mulch treatments. Nitrogen and phosphorous together gave the highest yields. HAVE and DIHENGA (1978) looked at the feasibility of reduced tillage systems in Tanzania. They observed a considerable saving in time, labour, power and cost due to minimum tillage. However there is much to investigate in the use of herbicides. Currently tillage research is going on at Morogoro, Uyole and elsewhere in the country.

2.3 Reduced tillage systems

Escalating labour, machinery and fuel costs and the continual drift of labour from the land make it increasingly important to develop cultivation equipment that is capable of achieving high work rates with lower power and labour inputs

and without adversely affecting crop production. So reduced or minimum tillage has become a common key-word among tillage researchers. The conventional way of seedbed preparation includes ploughing followed by secondary operations. This means many passes on the farm. Reduced tillage implies that the number of passes on the farm should be minimized. The extent to which this should happen will depend on, inter-alia, climate and soil type. In some areas it is possible to have no ploughing at all.

There are many adopted names for this system of no ploughing i.e. no till farming, zero-tillage, mulch farming, stubble farming, direct drilling etc (LAL, 1975). The no-tillage farming is more suited to the humid tropics than to the temperate regions because whereas slow soil warming and poor drainage with no-tillage are disadvantages of no-tillage farming in the latter, they are advantageous in the former. LAL (1976) observed that soil erosion from uncontroled watershed under no-till maize was significantly lower than that from a watershed with regular anti-erosive contours and waterways but planted to maize with conventional seed-bed preparation methods. He also

observed not only lower soil temperature and better soil moisture regime in no-till plots but also high biological activity of earth worms (Hyperiodrils africanus) under mulch which kept the soil porous and the bulk density low. The only potential problem that can confront no - till farming is weed control particularly rhizomatous weeds.

2.4 Oxen Cultivation techniques in Tanzania

Animal-powered mechanisation in Tanzania is confined to non-tsetse infested areas. The predominant ox-drawn implement is the single furrow mouldboard plough. Historically the mouldboard plough was introduced in highlands of East Africa where climatic conditions are similar to those where it was designed for (BEENY, 1975). Unfortunately its use spread even to the more arid areas.

So the most common oxen cultivation technique is the use of this plough and to some extent the ridger for primary cultivation. The subsequent operations are usually done by hand. The population of other ox-drawn equipment (planters interrow cultivators, harrows and even carts) is insignificant in most parts of the country. This unbalanced approach to ox-mechanisation is undesi-

rable and is probably the chief reason why the ox programme is making a small headway. Some of the reasons for the lack of a wider range of ox-equipment include:- farmers are not aware of the complete range of equipment; problem of distribution and availability; the feeling amongst some farmers and many government officers that use of draught animals is retrogressive.

2.5 Development of tool Carriers

When a system approach was widely accepted by many researchers as the only rational way in which research results are to be made available to farmers many versions of animal tool bars were developed. They are now available in different parts of the world commonest of which is the Ariana which is being manufactured in Senegal (MUSA, 1979). Despite their existence efforts continue to develop new ones in many countries.

GIBBON et al (1974) working in Botswana developed a minimum tillage tool (Versatool 'animal - drawn tool) which famously came to be known locally as the 'magic tool' because it could do all operations on the farm.

In Tanzania the Tanzania Machinery Testing Unit (TAMTU) based at Arusha, started developing a tool - frame in early 1960's with the assistance of the National Institute of Agricultural Engineering (NIAE), England (CONSTANTINESCO, 1963). Presently tool frames developed by TAMTU and Ubungo Farm Implement (UFI) are available. But they are rarely seen in use in the rural areas probably because either the farmers are not aware of their existence (not on the market) and/or their cost is prohibitively high. In 1977 a research project was initiated at Uyolet Agriculture Centre by the Agricultural Engineering Research Department to cover many aspects of 'oxen' mechanisation amongst which is tillage. A UAC tool Carrier which is a minimum tillage implement was designed and developed putting into consideration the social, ecological and economical factors of the country. With respective implement attachments the tool carrier can till, plant, apply fertilizer/insecticide, weed and transport.

The report follows an investigation and evaluation of the performance of the UAC tool carrier when used in a maize production system compared with other conventional techniques.

2.6 Force measurement, techniques on tillage tools

A tillage tool is subjected to three independent force systems. These are the weight acting at the center of gravity of the tool, the soil forces acting on the tool and forces acting between the tool and the prime mover. They are in equilibrium if no acceleration is involved. The soil forces are determined by the soil - tool system, tool weight being constant, so that forces acting between the tool and the prime mover adjust to maintain equilibrium. So one way of measuring the soil forces is to replace the prime mover by a dynamometer.

One of the early recording tillage tool dynamometer was developed by KEEN and HAINES (1925) at Rothamstead Experiment Station in England. These early dynamometers, of which operated with hydraulic units, were used to tow a tractor with the tillage tool. The indicator showed the reading of forces on a scale of the dynamometer. The major problem with them was that they measured forces on one axis i.e. longitudinally.

Discovery of electric resistance strain gauges has improved instrumentation in this field. The early dynamometers are now being replaced by the

strain gauges. A strain gauge is a thin wire whose resistance changes when stretched or compressed making an electric signal. This phenomenon is used to determine forces on tillage tools by amplifying and recording the signal. The strain gauge is attached directly on the beam of the tool or on the tine in any direction or axis so that horizontal, lateral or vertical forces can be measured. At the same time they are being built up in one unit called a load cell to make them more versatile. Each load cell can have two, four or more strain gauges depending on the purpose.

ROGERS (1955) reports five methods of expressing a three dimensional force system on a tillage tool:-

1. A wrench - that is, a force with a couple in a plane perpendicular to the force.
2. A force through a chosen point and a couple in a plane inclined to the force.
3. Two forces, one on a chosen line.
4. Three forces on mutually perpendicular axes and three couples in the planes of intersection of the axes.
5. Three forces in three major planes.

For a two dimensional force system on the tillage tool there are two main methods:-

1. Force (or components in defined direction) through a chosen point together with a couple.
2. Single force defined in terms of magnitude, direction and position.

Presently scientists are using computer programmes to analyse results from force measurement systems.

2.7 Theory of Soil Shear Strength.

Soil is extremely weak in tension, very strong in compression and in practice fails mainly in shear (O'CALLAGHAN and FARRELLY, 1964). When it is strained the shear stress builds up to a peak value which, depending on the soil type either remains constant or falls off before levelling out with increasing strain. The magnitude of the shear stress developed is a function of normal stresses. The stress/strain and stress/stress relationships exist either for a soil sheared in bulk i.e. bulk shear strength or for the shear of individual clods i.e. clod shear strength. Which type of shear occurs will depend on how strong the other one is. And this is a function of the soil moisture content.

Bulk shear strength depends on the particle internal friction due to interlocking, and film cohesion due to surface tension forces. Clod shear strength, on the other hand, is a function of the molecular cohesion due to bonding between the particles. Soil moisture content has an effect on both bulk and clod shear strength. At high moisture content film cohesion dominates and thus bulk shear strength exceeds clod shear strength and vice versa. Tillage operations at high moisture content (plastic range) could lead to high draught force due to adhesive forces, and can cause puddling condition because of movement of clods on infinite number of planes (clod shear strength being lower than the bulk shear strength). Tillage when the soil is dry requires also more draught because of strong bondage between the particles and soil/metal friction. Somewhere in between both bulk shear strength and clod shear strength are relatively weak (friable soil) so that tillage requires less draught.

The rake angle of a soil-engaging implement has a large effect on the shearing pattern of the soil hence the draught force. The draught force

increases slowly from rake angle of 10° to 50° , above 50° , however the rate of increase is very rapid. This is because soil movement during shearing is upward and forward (brittle failure) due to low external vertical confining stresses (PAYNE and TANNER, 1959). At rake angle above 90° the vertical confining stresses are high so that compressive failure predominates, resulting in high forces.

CHAPTER 3

MATERIALS AND METHODS

3.1 LOCATION

The research was carried out at the Uyole Agriculture Centre (UAC) which is about 9 kilometres from Mbeya town towards Dar es Salaam on the Tanzania-Zambia highway. It is located at latitude $8^{\circ} 55'S$ and longitude $33^{\circ} 32'E$. Its altitude is 1800 metres above sea level. The Centre is one of the areas in the Southern Highlands that receives high rainfall. The rainfall pattern is monomodal (table 3.1). Rains normally begin in November and end in May. The average annual rainfall is usually less than 1000 mm but the area received very heavy rains during 1978/79 season. Other parts of the country also received heavy rains which caused floods and erosion. The hot months are September, October and November. The same months have the highest wind speeds and potentially highest rates of evaporation of moisture. The cold months are June, July and August. The temperatures are at times below freezing point during these chilly months.

The soils at Uyole are young volcanic and of tertiary to recent age. The topsoils consist of

Table 3.1: Rainfall, temperature, pan evaporation rates, wind speeds for 1979/80 season and Rainfall average for 30 years (1942 - 1972) at Uyole.

MONTH	1979/80	MONTHLY	NO OF	30 YEARS	PAN EVAP.	TEMPERATURES		WIND
	TOTAL (MM)					DAYS IT	AVERAGE	
	1/		1/	2/	2/	1/	1/	1/
AUGUST	0	0	2	192	24	6	17	
SEPTEMBER	3	1	3	240	25	8	21	
OCTOBER	23	3	14	233	27	9	25	
NOVEMBER	62	16	50	180	26	12	15	
DECEMBER	243	21	143	155	25	12	14	
JANUARY	146	24	195	121	24	11	5	
FEBRUARY	81	15	165	182	24	10	8	
MARCH	140	18	161	124	24	11	5	
APRIL	157	15	118	129	24	12	4	
MAY	79	4	17	121	24	10	3	
JUNE	0	0	0	131	23	5	5	
JULY	0	0	0	159	22	7	9	
TOTAL	934	117	868	1967				

Source: 1/ Meteorological Station, Uyole Agriculture Centre.
 2/ Recorded at Mbeya Airport, about 9 km from Uyole.

Table 3.2: Analytical data of Uycle Soils

pH	Organic % Carbon	Total Available N(%)	F(ppm)	CEC (me/100gm soils)	Exchangeable bases (me/100gm soil)			%	%	%	
					Ca	Mg	K				Na
6.1	4.2	0.27	1.5	15.5	7.51	1.08	0.42	0.05	25	48	27

Source: Kamasho (1980)

dark slightly gravelly silt loam overlying pumice gravel. The drainage is generally very good. The pH is in the acidic range of about 6 (table 3.2). The predominant cations include calcium, magnesium and potassium. The soils are reported to have a deficiency in some of the micronutrients particularly Copper and Boron (KAMASHO, 1980). The bulk density of the top soil (upper 20 cms) is around 1.13gm/cc.

3.2 Experimental design

There were two groups of treatments in this experiment:-

- A. Four cultivation systems as main treatments.
 1. Hand hoe tillage plus hand planting (HH).

The soil was tilled manually using a hoe. The trash was thoroughly mixed with the soil. This is the normal way of cultivation under peasant agriculture. Planting was done by hand using ropes and a hoe.
 2. Mouldboard plough tillage plus hand planting(MH)

A pair of oxen was used to plough with the mouldboard plough. This was followed by harrowing operation using the UFI triangular spike - tooth harrow (wooden). Planting was done as in 1. above.

3. UAC Tool Carrier tillage (farrowing) plus hand planting (UH). Tines with short knives or sweeps (each about 10 cms long) were attached to the tool Carrier and furrows were made at 75 cm spacing. Planting was done on the furrows by hand.
4. UAC Tool Carrier tillage (farrowing) plus planter (UP). Tines as in 3. above and planter were attached to the tool carrier so that farrowing and planting were done simultaneously.

B. Two weeding methods as subtreatments:

1. Hand weeding (HW)

A hand hoe was used to weed between the maize rows.

2. UAC Tool Carrier Weeder (UW)

Tines with long sweeps (each about 20 cms long) were attached to the tool carrier. The approach angle of the sweeps was about 45° . This enabled the soil to be inverted and pushed on the maize rows to form small ridges, effectively covering weeds.

The experimental design was a split-plot with two replicates. Both the main plots and subplots

were randomized (Figure 3.1)

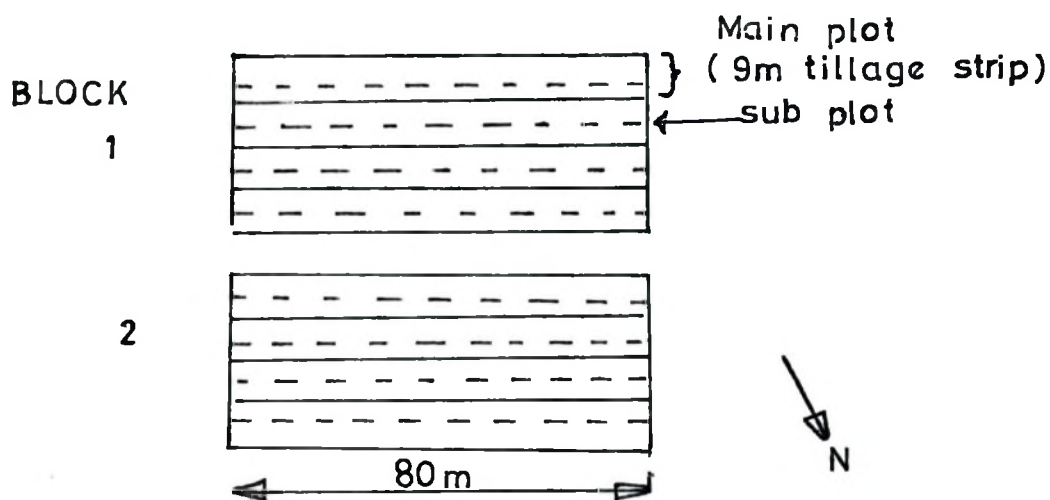


Figure 3.1: Field plan and lay out.

To achieve the required depth, speed and field efficiency, long plots of 80 metres were chosen. The width of a main plot was 9 metres from which two subplots each with six 75cm - apart-rows were obtained as weeding treatments.

Hybrid maize (H 6302) bought from a Tanzania Seed Company (TANSEED) branch at Mbeya was used. The recommended plant population at Uyole and most of the Southern Highlands is 44,444 plants per hectare (LYIMO, 1980; KILIMO, 1977). This can be achieved by having two row spacings i.e. 75 cms and 90cms. When the former is chosen the spacings between the plants within a row must be 30cm while with the latter it must be 25cms. The UAC tool carrier was designed for the 75cms row spacing and

30 cms between plants. So the spacing used in the experiment was 75 cms x 30 cms. Experience with fertilizer trials at Uyole has shown that maize is a crop which demands a great deal of fertilizers and it shows a very good response to nitrogen fertilizers (LYIMO, 1980). Under high rainfall conditions like Uyole a nearly linear response to nitrogen is obtained up to 100 kg/ha N and above. In drier areas like Iringa the good response is limited to rates up to 50 or 60 kg/ha N. As for phosphatic fertilizers it was found out that higher rates than 20 kg/ha P are not advisable, on the economic point of view. In this experiment 100 kg/ha N and 20 kg/ha P were used. Nitrogen was applied in two forms. The first one was Diammonium Phosphate (DAP) 15-50-0 fertilizer which contains 15% N. It was applied as a pre-emergence fertilizer. It supplied all of the phosphorous required (20 kg/ha) and some of the nitrogen to boost up the young maize seedlings. The main nitrogen came from Calcium Ammonium Nitrate (CAN) with 26% N which was applied as post-emergence/germination fertilizer. It was applied in two equal parts once after first weeding and again after second weeding. Furadan 5% (granulated) was also applied at the rate of 15 kg/ha to control cutworms (Agrotis Spp) and stalkborer

(Busciola fusca). The plant population for each main treatment was determined by counting the number of plants when germination was complete (3 leaves stage).

For each operation the work rate was measured using a stop watch to record the time taken and a tape measure for measuring the area covered. The method of measuring work rate suggested by INNS (1980) was used in hand hoeing operations where a 'spot check' was done i.e. the amount of work done in an interval of 30 minutes was recorded. The operators were not notified in each case of the work rate measurements although they might have been aware of them. Results from the 'Spot check' are discussed later on in the text.

3.3 Weed regeneration study

Weeds compete with maize, or any crop for that matter, for light, water and soil nutrients leading to low yields. Young maize plants do not grow as fast as most tropical weeds. If they are not given an advantage over weeds they will not be able to compete and a crop failure will result.

One method of studying weeds in the field is to observe the effect on crop yields. This is the

most common way used by agronomists. The reductions in yields with no weeding, one weeding, two weedings etc. are compared so that the optimum number of weedings for good yields are obtained. This method does not consider the nature and type of the weeds within the field. Another method is to collect, dry and weigh the aerial parts of the weeds after a pre-determined period of time following the operation. A square frame is usually used. It is thrown randomly in the field and the enclosed weeds are taken to be dried and weighed. The method is normally used to study the effect of various implements on weed control (CURF, 1976; WEAVER and KUIPER, 1976). The regeneration of weeds a few days after the operation is ignored. The need to know how effectively the weeds were cut by the implements, which species are more resistant and which species germinate more quickly, is important. Of course effectiveness of the implements on cutting the weeds will also be reflected on the weed weights. The weed study method described below was chosen in view of these points.

The weed study was done to assess the effectiveness of the UAC tool Carrier weeder in comparison

with hand weeding. About three weeks after germination on 7th January 1980 a first weeding was done on maize rows only for all treatments. This was intended to be a very quick operation whereby some soil was pushed on the maize rows by a hand hoe to form small ridges, thus covering the weeds (figure 3.2). But for reasons explained later on in the text the operation turned out to be a difficult one. This operation of weeding the maize rows was introduced to suit the proposed UAC tool Carrier system.

The second weeding which was done about two weeks after the first weeding on 23rd January 1980 consisted of two subtreatments (hand weeding and UAC tool Carrier weeder). After this weeding three localities (0.5m x 0.5m square) were chosen at random on each subplot where regeneration and establishment of weeds were studied by counting the weed shoots at intervals of seven days. The counting was done four times on 30/1, 6/2, 13/2 and 20/2. The most common species of weeds were noted during counting. Just before the third weeding which was done one day after the last count on 22nd January 1980, and by hand because the maize was too tall for the implement

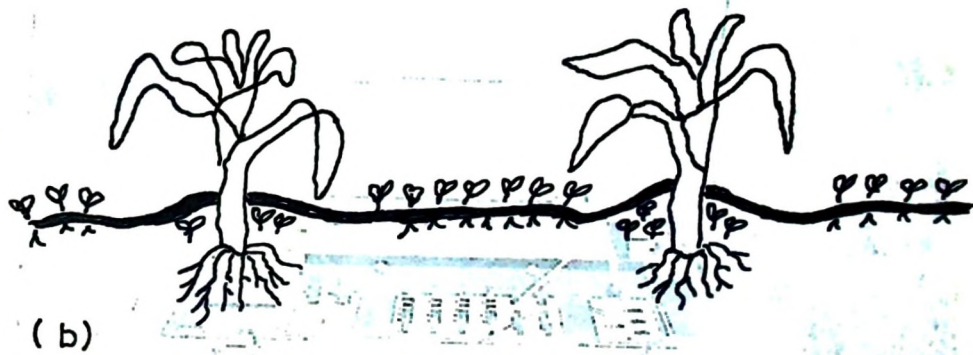
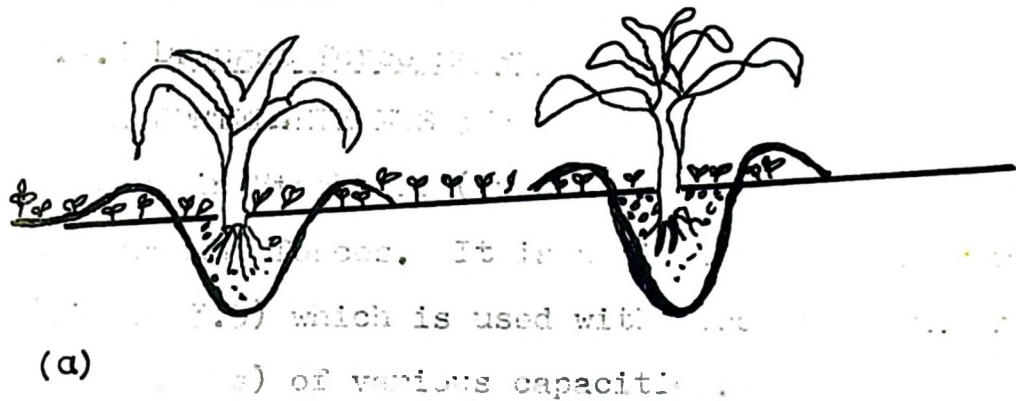


Figure 3-2 (a) Maize growing on furrows
before first weeding.

(b) Small ridge on maize rows
after first weeding.

The transducer (Figure 3.4) is essentially a closure of four strain gauges which when connected to the Recorder form a full bridge. The mirror galvanometers within the recorder reflect light from a halogen lamp onto a sensitive

to move through, the weeds from the demarcated areas were removed, dried and the dry weights were used for comparisons.

3.4 Engineering measurements

3.4.1 Draught force measurements

A PORTELLETE MTS 337 Recorder from ABEM factory in Stockholm (Sweden) was used to record the draught forces. It is a six channel recorder (figure 3.3) which is used with force transducers (load cells) of various capacities.

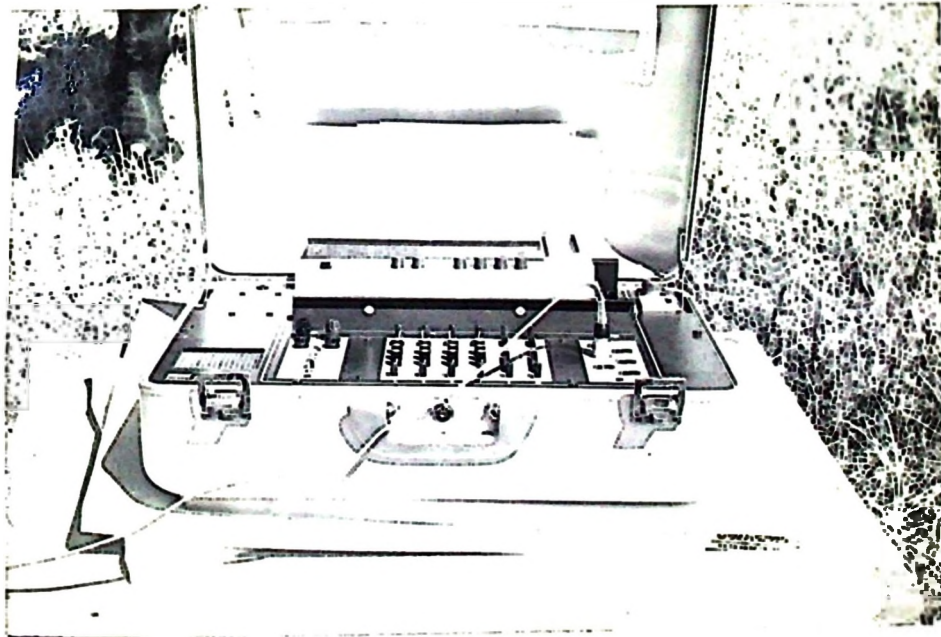


Figure 3.3: A PORTELLETE MTS 337 RECORDER

The force transducer (figure 3.4) is essentially an enclosure of four strain gauges which when connected to the Recorder form a full bridge. The mirror galvanometers within the recorder reflect light from a halogen lamp onto a sensitive

moving paper and hence making traces in accordance with the draught force.



Figure 3.4. Force transducer (load cell)

After calibration of the recorder the force per unit deflection of the galvanometer can be known. A planimeter was used to find the average height of traces on sensitive papers. The average force was obtained by multiplying the force per unit deflection by the average height:-

$$\text{Force per unit deflection} \times \text{Average height} = \text{Average Force}.$$

WILKINSON (1969) observed that to measure a complete force in three dimensions on a vertical rigid tine, a minimum of five force transducers are required, but six are required for inclined and flexible tines. This will make it possible

to measure the horizontal force L , the vertical force V and the side thrust S . The horizontal force L is of more interest in cultivations because it gives rise to the draught force. So for simplicity, in this experiment only the horizontal force was measured to obtain the draught. The force transducer was connected such that it was more sensitive to this horizontal force (figure 3.5 and diagram at annex 1a).

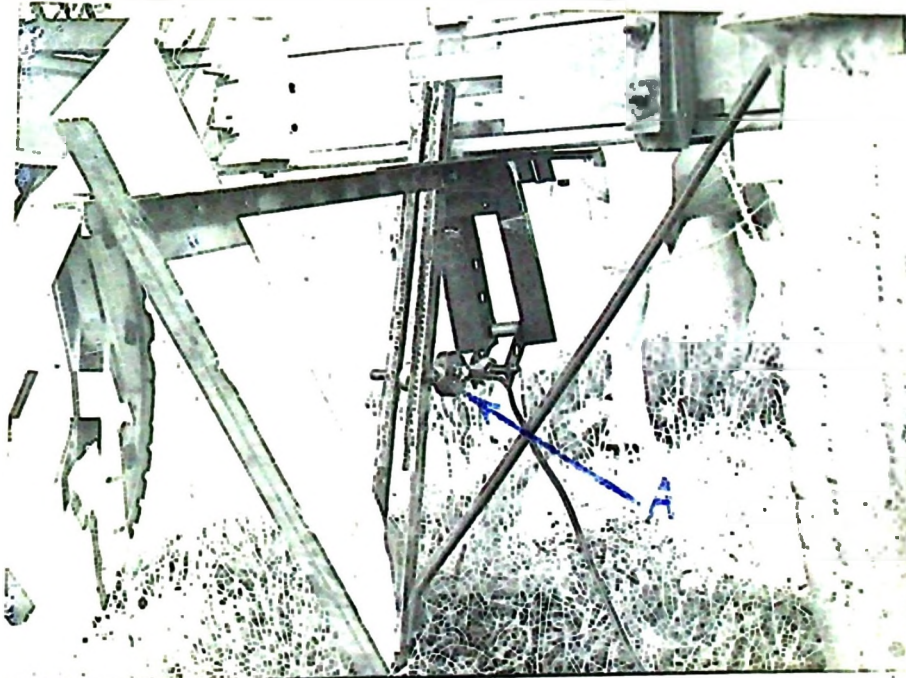


Figure 3.5: Force transducer attachment on the UAC tool carrier tine.

A test run of 15 metres length was chosen to give an adequate length of record and to limit the size of the test area to one in which the soil conditions were reasonably uniform. The soil surface was flat and even but rhizomatous weeds

were in profusion. The force obtained from each test was an average of two 15 metre runs. The width of the UAC tool Carrier tine used was about 5 cms. To examine the effect of rake angle on the draught force on the tine three positive rake angles were used (45° , 57° and 68°).

It was assumed that the soil force acts at half the working depth. The tine geometry was such that the pivot point was perpendicularly above the point of action of the soil force on the tine. By resolving the soil force into vertical and horizontal components and using the theory of moments it was possible to calculate the horizontal component force (draught force). The vertical component force cancelled because its line of action passed through the pivot point (see Annex 1a for details). The lateral force had minimum effect because of the flexible joint on the force transducer.

A sliding mechanism was also constructed on the beam of the tool carrier (figure 3.6). A force transducer was attached so that the rolling resistance of the wheels of the tool carrier could be measured. The horizontal force which gives rise to the rolling resistance was obtained

by using the knowledge of trigonometry (see Annex 1b for details).

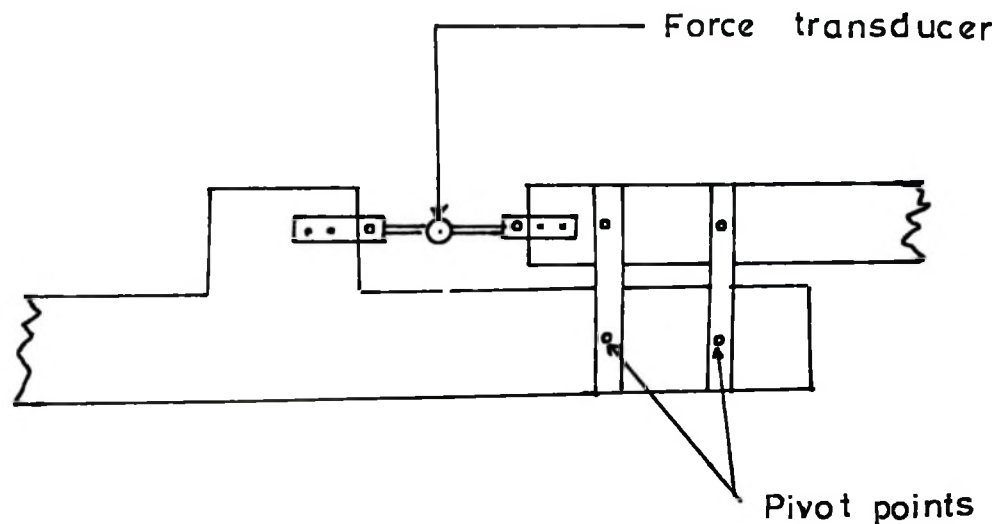


Figure 3.6: Drawing of sliding mechanism on the U/C tool carrier beam

For comparison purposes, the draught force on a mouldboard plough and a ridger were also measured. The force transducer was attached on the chain that connects the plough on the hake and the yoke. The horizontal force was obtained in exactly the same way as in rolling resistance measurement above by using the knowledge of trigonometry. In order to determine the power required to pull the implements, the speed of the oxen was measured. There are two possible methods of measuring the speed. The first is to use one of the wheels of the tool carrier as an

odometer. The time for a pre-determined number of revolutions e.g. 10 of the wheel is taken or recorded using a stop watch. The distance covered is calculated by multiplying the circumference of the wheel by the number of revolutions:-

$$\pi D \times N = \text{distance}$$

$$(\text{m/rev}) (\text{revs}) (\text{m})$$

Where D is the diameter of the wheel in meters
N is the number of revolutions.

The speed of the oxen can then be obtained by dividing the distance over the time taken. This method is commonly used in tractors when measuring slip on the driven wheel. The second method is to time a run over a measured length using a stop watch. The speed is again calculated by dividing distance over time taken. The latter method was used. The experimental tillage strips (80 metres) were used as measured length.

3.4.2 Soil disturbance study

The method of measuring soil disturbance used by SPOOR and GODWIN (1978) was adopted. A simple profile meter was constructed in the workshop (figure 3.7).

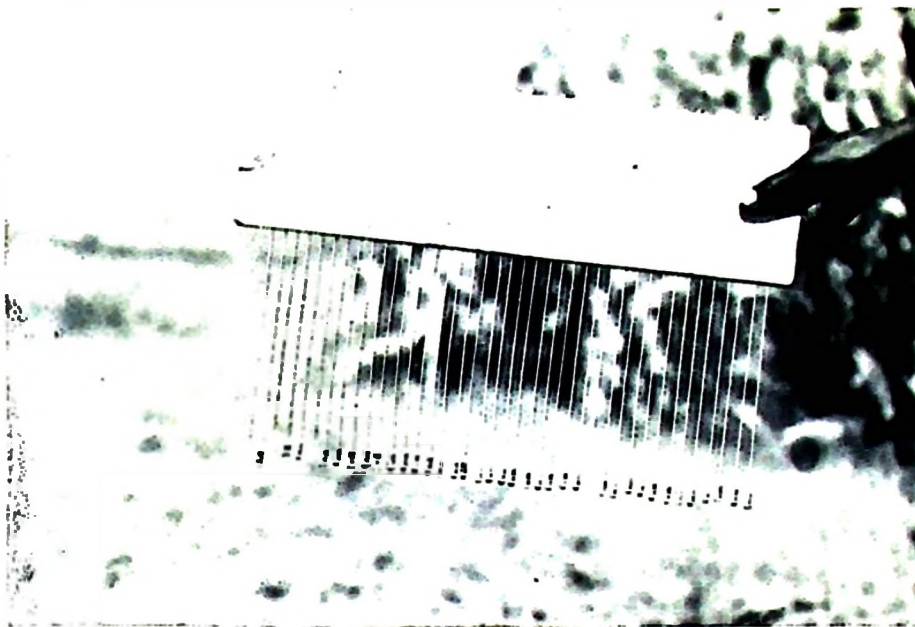


Figure 3.7: A profile meter.

In the field the disturbed soil was removed by hand after a run so that the undisturbed soil profile was exposed. The undisturbed soil profile was measured by the profile meter. The soil disturbance study was done on the UAC tool carrier tine with and without the sweeps at rake angle of 45° .

3.5 The economic analysis used

The days available for farm operations per week was deliberately taken as six (only Sundays excluded). This is practicable especially during peak times albeit surveys on labour use on peasant agriculture have indicated that adult members of farm families work in the fields for

47.

only 120 - 160 days in a year (CLEAVE, 1974). In the same surveys the length of a working day was reported to vary considerably over the year. It varies with the age and sex of the farm worker, crops grown and type of farm operation. It was found out that on average the length of a working day tended to be between 4 hours and 6 hours. In the calculations here 6 hours is taken as the length of a working day except when costing labour where 8 hours was used because labour has been costed at the industrial minimum wage whose length of working day is 8 hours was used because labour has been costed at the industrial minimum wage whose length of working day is 8. The average length of a working day of 5 hours, which is usual at Uyole, has been used in oxen operations.

A household here is defined as a group of persons living together and sharing the costs of living. Surveys being carried out in the Southern Highlands of Tanzania by Agro-Economics Research Department at Uyole have so far shown that on average the household consists of a husband, wife, three children and one relative (woman over 50 years old). Only one of the children can work on the farm (TEMU and MUGARULA, 1980).

To standardise measures of the rates of work of family members while at work on the farm the man-equivalent concept has been used. Table 3.3 shows Collinson's key to man-equivalents which were used for the analysis and calculations. These values should be interpreted with caution and should only be taken as guidelines which assist planners. As some researchers (CLEAVE, 1974) have pointed out that the relative values of different sex/age groups will change with the operation. Men may cultivate faster but harvest or weed more slowly than women. So when a woman works half the speed of a man on one operation and twice as fast on another, fixing her equivalent value at 0.5 on the basis of the first will grossly underestimate family labour capacity on the second.

Table 3.3: Collinson's key to man-equivalents

S E X	A G E (years)	ADOPTED MAN-EQUIVALENT
Male	10 - 14	0.25
	15 - 19	0.67
	20 - 50	1.00
	over 50	0.67
Female	10 - 14	0.25
	15 - 19	0.50
	20 - 50	0.67
	over 50	0.50

Source: Ruthenberg (1968) page 15

Using Collinson's key to man-equivalents the total man-equivalents for the household was obtained:-

Husband	(20 - 50 years)	1.00	man-equivalent
Wife	(20 - 50 years)	0.67	"
Child	(10 - 14 years)	0.25	"
Relative	(woman over 50 years)	0.50	"
		Total	2.42 "

Available manhrs per day = Man-equivs x length
of a working day (6 hrs)

During work rate measurements a geng of a known number of men worked from 9.00 a.m. to 1.00 p.m. The amount of work done was measured using a tape measure. Then the time to finish one hectare was calculated. This was multiplied by the number of men to obtain manhrs per hectare i.e. labour requirement. One oxen-team consisted of a pair of oxen and two operators working 5 hrs per day. The time taken for an oxen-team to finish a known amount of work was recorded using a stop watch. The oxen-team hrs per hectare were calculated.

From the above information the number of days for a household to finish one hectare was calculated:-

$$\frac{\text{Required manhrs per hectare}}{\text{Available manhrs per day}} = \frac{\text{Days per hectare}}{\text{per household}}$$

Knowing the number of days per hectare per household the area in hectares that can be taken care of by the household for each operation was calculated using the calendar of work in figure 3.8:-

$$\frac{\text{Days Available}}{\text{Days per hectare per household}} = \text{Hectares per household}$$

For oxen operations the days per hectare per household were calculated as follows:-

$$\frac{\text{Required oxen-team-hours per hectare}}{\text{Available oxen-team-hrs per day}} = \frac{\text{Days per hectare}}{\text{per household}}$$

The available oxen-team-hours per day are 5 in this case. It is assumed that 2 adult oxen operators are used so that 2 man-equivalents are involved. This means that labour is set free as redundant or free labour during oxen operations. The hectares that can be taken care of by the household was calculated as above. However, with well trained draught animals it is possible to have only one adult operator per pair or one adult operator and a lad, in which case the man-equivalents would

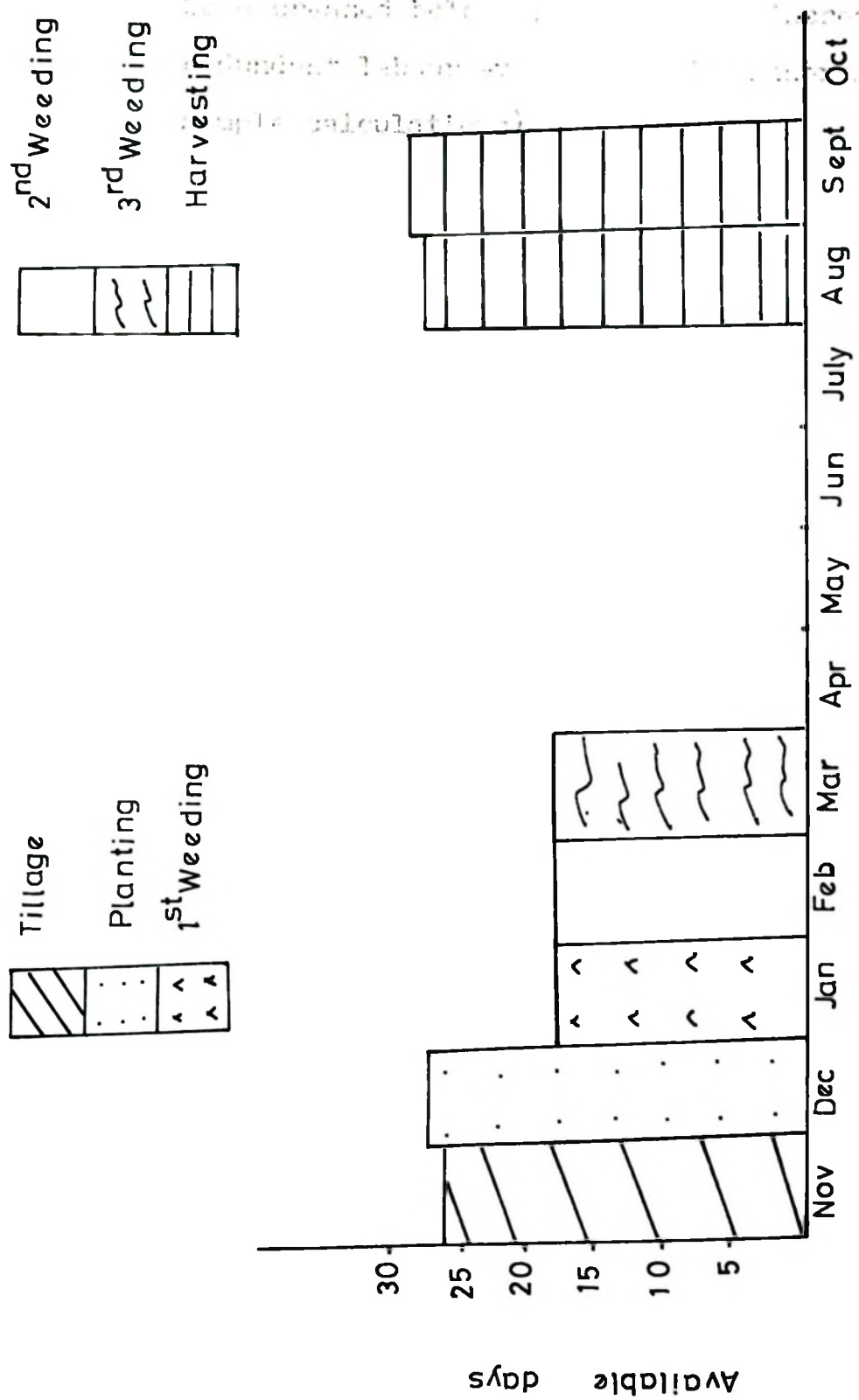


Figure 3-8 Monthly available days for different operations for maize production at Uyole.

be decreased below 2. This would increase the redundant labour even more. (See Annex 2 for sample calculations)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Plant population and yields.

Plant population in crop yields is a crucial parameter. If the plant population is lower than the recommended one for a particular farming situation, the yields will be lowered. The profit or loss will be decreased or increased respectively because the costs of operations will remain the same or increase. Weed problem will be serious because of the reduction in closed crop canopy to suppress them. Soils will be vulnerable to erosion due to inadequate vegetative cover. On the other hand, if plant population is too high there will be high competition for light, nutrients, moisture etc. leading to etiolation or chlorosis and other physiological defects of the crop with a consequence of crop failure or low yields. So an optimum plant population is required for high yields. The optimum plant population in an area is dictated by climate and fertility of the soil.

KILIMO (1977) gives the optimum plant population for various parts or areas of Tanzania. In high elevations where growing seasons are longer and

the rainfall is plentiful it is possible to have as many as 55,000 plants per hectare. However, this will mean more fertilizer and lodging might be severe, For these reasons the recommended optimum plant population is 44,444 plants per hectare. In low elevations where rainfall is in short supply or late planting is necessary, only about 35,000 plants per hectare should be planted. Most farmers in Tanzania do not plant maize thickly enough. They either plant in rows too far apart or in widely spaced hills with two, three or four plants. The plant population per hectare hardly exceeds 20,000.

The plant populations, obtained from the experiment, for the tillage treatments are shown in table 4.1.

Table 4.1: Plant population following four tillage techniques

TREATMENT	PLANT POPULATION (plants/ha)
HH	42312
MH	40512
UH	41511
UU	35111

Level of significance between means:- 5%

L.S.D. (0.05) :- 2598 plants/ha.

It is evident from the results that the UAC tool carrier planter gave a significantly lower plant population than hand planting. Thus means of treatments HH, MH and UH are significantly greater than the mean of treatment UU. Treatments HH, MH and UH are not significantly different. This is expected because the planting methods were the same for the three treatments (hand planting). It also means that tillage technique did not have a significant effect on germination. There is however a need to examine technically the metering mechanism of the UAC tool carrier planter.

Table 4.2 gives the dry grain yields of maize as influenced by cultivation and weeding treatments.

Table 4.2: Yields of dry grain maize(kg/ha) following four tillage systems and two weeding methods.

TILLAGE SYSTEM	WEEDING METHODS		TILLAGE MEAN YIELD (kg/ha)
	HW	UW	
HH	7491	7778	7635
MH	6767	8321	7544
UH	7000	6221	6611
UU	6741	5444	6093
WEEDING MEAN YIELD(kg/ha)	7000	6941	6971

Level of significance: (a) between tillage means:-0.1%
LSD (0.05):- 279kg/ha
(b) between weeding means:- N.S.
LSD (0.05):- 197kg/ha.

The variety of maize used (H 6302) in the experiment has a very high potential yields. It can yield as high as 11,000kg/ha under intensive management e.g. nurtured experimental plots (LYIMO, 1980). Such varieties, however, require a high level of crop management. So introduction of these high yielding varieties to the farmers should go hand in hand with improved crop managements. The crop managements which have to be improved include use of fertilizers or manure, optimum plant population, early planting, use of chemicals to control insects and diseases, weed control etc coupled with use of suitable implements.

Examination of the results on table 4.2 reveals that direct drilling or planting on uncultivated plots gave the lowest yields. The UAC tool carrier weeder treatment recorded the highest yields on cultivated plots although on average hand weeding gave higher yields. The lowest grain yield obtained from the uncultivated plots was probably due to the compactness of the undisturbed soil which reduced the rate of root growth and ramification (ERIKSSON et al, 1974). The rhizomatous weed (couch grass) which was common on the site could have aggravated the situation by binding the soil together making it

even more hard and compact. Weed growth differences could be another possible reason for the yield differences (see results on weed regeneration study). Cultivation loosens the soil and hence increases water infiltration and makes it easy for the roots to establish and ramify deep into the soil profile searching for the nutrients and moisture. Air exchange between the soil and the atmosphere is also made easy. This could have been the case in the cultivated plots.

Statistical analysis for grain yield of maize between tillage means showed a significant difference at 0.1% probability level. There was no significant difference between weeding means. There was also a significant interaction (at 0.1% level) between tillage and weeding treatments (see ANOVA in ANNEX 2a).

4.2 Results from weed study

Table 4.3 and 4.4 respectively give shoot counts and dry weights of weed as influenced by cultivation and weeding treatments. The most common species of weeds were the rhizomatous couch grass (Digitaria scalarum) and the gallant soldier (Gallinsoga paviflora).

Examination of table 4.3 reveals that in all plots there was an increase in weed growth within a short time. This is because of a quick emergence of gallant soldier weeds. The uncultivated plots however showed, ab initio, high weed shoot count. There was no significant difference between tillage means for all counting times. Weeding means differed statistically significantly at 5% level only during the first count (7 days after weeding). It was observed that the UAC tool carrier weeder was not very effective on uncultivated plots. Penetration of the tine was inadequate due to soil compaction and large densely populated weeds. As a result many weeds were not properly cut giving rise to the higher weed shoot counts.

Table 4.3: Weed shoot count per m² following 4 tillage systems and 2 weeding methods

	Weeding Method	Tillage Method					Mean	LSD (0.05) Weeding method	between:- tillage systems
		HH	NH	UH	UU	Mean			
7 DAYS AFTER WEEDING	HW	26	30	28	24	27			
	UW	30	30	38	56	39	*8	12	
	Mean	28	30	33	40	33			
14 DAYS AFTER WEEDING	HW	402	224	234	276	284			
	UW	224	264	368	314	293	98	139	
	Mean	313	244	301	295	288			
21 DAYS AFTER WEEDING	HW	437	336	334	376	371			
	UW	374	334	438	395	385	116	164	
	Mean	406	335	386	386	378			
28 DAYS AFTER WEEDING	HW	447	436	437	418	435			
	UW	414	394	450	420	420	44	62	
	Mean	431	415	444	419	427			

* Only significant difference (at 5% level) was between weeding methods after 7 days.

Table 4.4: Weed growth in kg/ha following 4 tillage systems and 2 weeding methods.

TILLAGE SYSTEM	WEEDING METHOD		TILLAGE MEAN (WEED WEIGHT(Kg/ha))
	HW	UW	
H H	213	221	217
M H	290	209	250
U H	213	413	313
U U	237	444	341
WEEDING MEAN WEED WEIGHT (Kg/ha)	238	322	280

Level of significance:-

- (a) between tillage means:- 1%
LSD (0.05):- 55 kg/ha
- (b) between weeding means:- 1%
LSD (0.05):- 39 Kg/ha

It is evident from table 4.4 that the uncultivated and weeded by the UAC tool carrier weeder plots gave the highest dry weights of weeds per hectare. There was significant differences both between tillage means (at 1% probability level) and weeding means (1% level) -- see ANOVA in Annex 2b. Mean of tillage treatment UU was significantly greater than of HH. The mean of hand hoe treatment was significantly lower than that of the UAC tool carrier weeder. It seems for the weeder to be more efficient and effective

the soil must be loose i.e. cultivation is essential. Hand hoe weeding controlled weeds better than the UAC weeder on the uncultivated plots. The problem with hand hoe weeding was the high population of weeds within the maize rows. The UAC tool carrier weeder controlled weeds better on cultivated plots.

There was a highly significant interaction (0.1% probability level) between tillage and weeding treatments. Cultivation and weeding by either hand hoe or UAC weeder gave a negative interaction i.e. reduced the dry weed weight. On the other hand no cultivation and weeding by the UAC weeder gave a positive interaction i.e. increased the dry weed weight. These interactions can be related to the yields on table 4.2. The former combination increased yields whereas the latter decreased them. There was a correlation between dry weed weights (kg/ha) and yields of maize (kg/ha). The linear regression equation obtained was as follows:

$$Y = 9251 - 8 X$$

Where Y is the yield of maize (kg/ha)

X is the dry weed weight (kg/ha).

system probably could be more applicable if selective herbicides could be used to kill weeds between the maize rows prior to interrow cultivation using the UAC weeder.

4.3 Labour Requirements

The results from the 'spot check' method of measuring work rate is presented on figure 4.1. It shows the variation during the day of manhours required to hoe one hectare. It is evident that before 10:00 a.m. manhours required to hoe one hectare of land was less, and increased between 10:00 a.m. and 11:00 a.m. to the peak. Then decreased again between 11:30 a.m. and 1:00 p.m. This implies that labour was more efficient before 10:00 a.m. in the morning probably because of less heat stress. The high manhours between 10:00 a.m. and 11:00 a.m. perhaps suggest a rest period which could be associated with light meal or drink! This kind of study could help to plan for high labour use efficiency on the farm. However much more and intensive study is required to make plausible conclusions on labour utilisation during the day.

Labour required per hectare to produce maize for eight mechanisation systems is indicated on

Figure 4-1 Manhours required per hectare of land hoed during the day

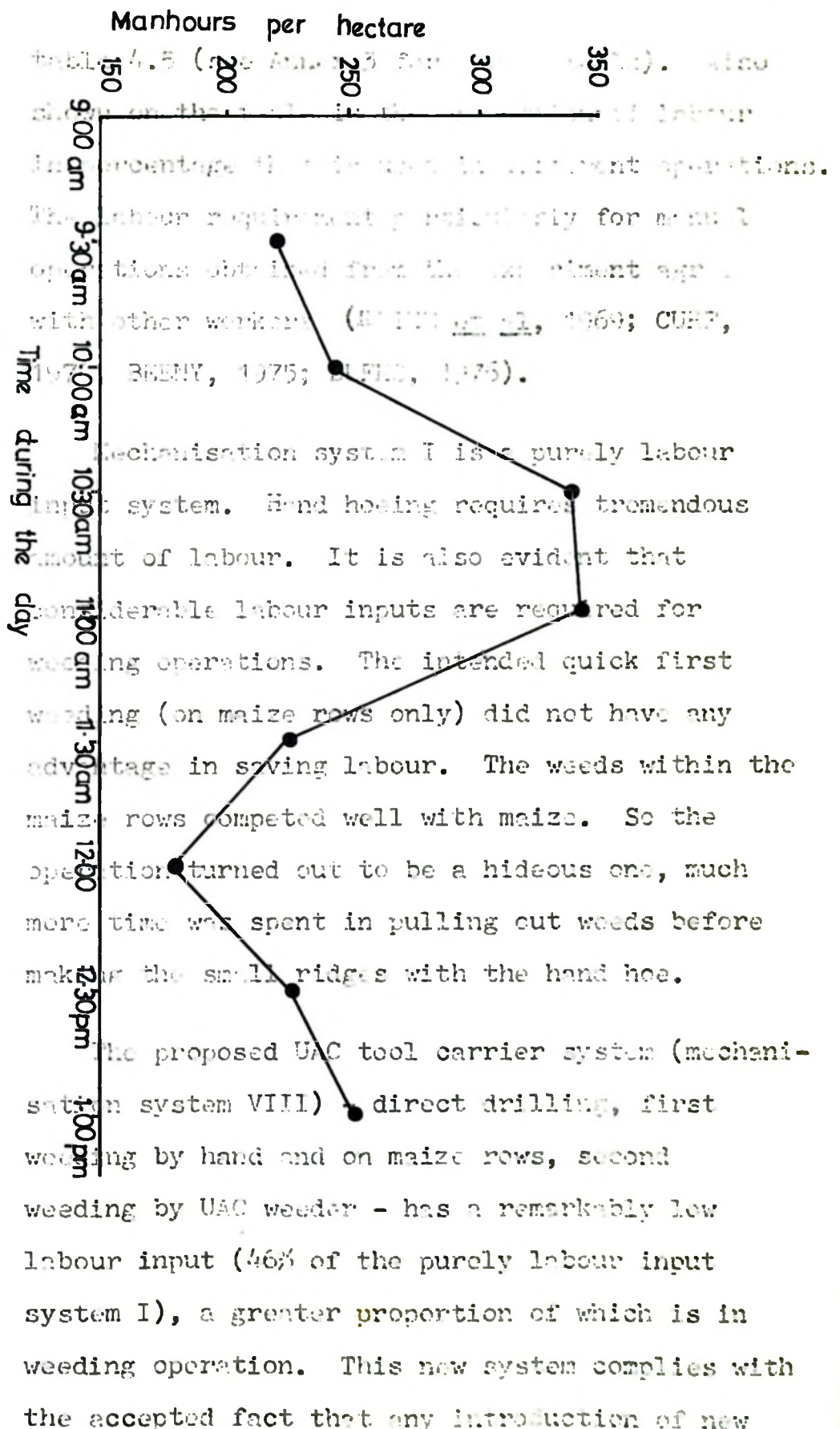


table 4.5 (see Annex 3 for more details). Also shown on the table is the proportion of labour in percentage that is used in different operations. The labour requirement particularly for manual operations obtained from the experiment agree with other workers (KLINE et al, 1969; CURF, 1976; BEENY, 1975; DLFES, 1975).

Mechanisation system I is a purely labour input system. Hand hoeing requires tremendous amount of labour. It is also evident that considerable labour inputs are required for weeding operations. The intended quick first weeding (on maize rows only) did not have any advantage in saving labour. The weeds within the maize rows competed well with maize. So the operation turned out to be a hideous one, much more time was spent in pulling out weeds before making the small ridges with the hand hoe.

The proposed UAC tool carrier system (mechanisation system VIII) - direct drilling, first weeding by hand and on maize rows, second weeding by UAC weeder - has a remarkably low labour input (46% of the purely labour input system I), a greater proportion of which is in weeding operation. This new system complies with the accepted fact that any introduction of new

Table 4.5: Labour requirements (manhrs per ha) of the various operation in maize production for eight mechanisation levels.

OPERATION	I	II	III	IV	V	VI	VII	VIII
Tillage	Hoe	Hoe	Plough (oxen)	Plough (oxen)	Tine (oxen)	Tine (oxen)	Tine plus Planter	Tine plus Planter
	236	236	36	36	11	11	21	21
Planting	Man	Man	Man	Man	Man	Man		
	118	118	134	134	82	82		
Weeding (e times)	Man	Man+ oxen	Man	Man+ oxen	Man	Man+ oxen	Man	Man+ oxen
	300	217	308	221	316	205	325	215
Harvesting	Man	Man	Man	Man	Man	Man	Man	Man
	139	139	140	140	138	138	130	130
Total	793	710	618	531	546	436	476	366
% Tillage	30	33	6	7	2	3		
% Planting	15	17	22	25	15	19	4	6
% Weeding	38	31	50	42	58	47	68	59
% Harvesting	18	20	23	26	25	32	27	36

Source: Compiled by the author.

equipment on a farm must be accompanied either by an increase in area cultivated or by a reduction in manpower or by increased yields; if not there will inevitably be increased under employment of the available manpower (FAO, 1972).

4.4 Draught force measurements

Figure 4.2 shows a photograph of a typical recording paper from the recorder. The dark traces indicate the variation of the tine draught force. The traces fade when exposed to direct light that is reason why photographs of recorded paper were taken. The area under the trace was measured using a planimeter. To obtain the average height the area was divided by the horizontal distance.

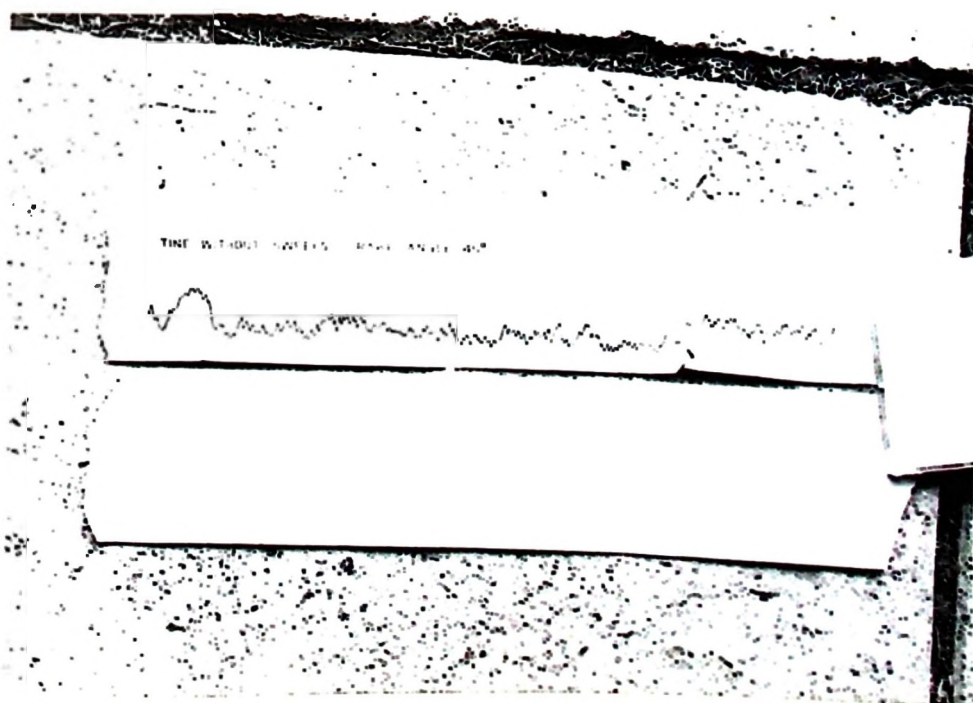
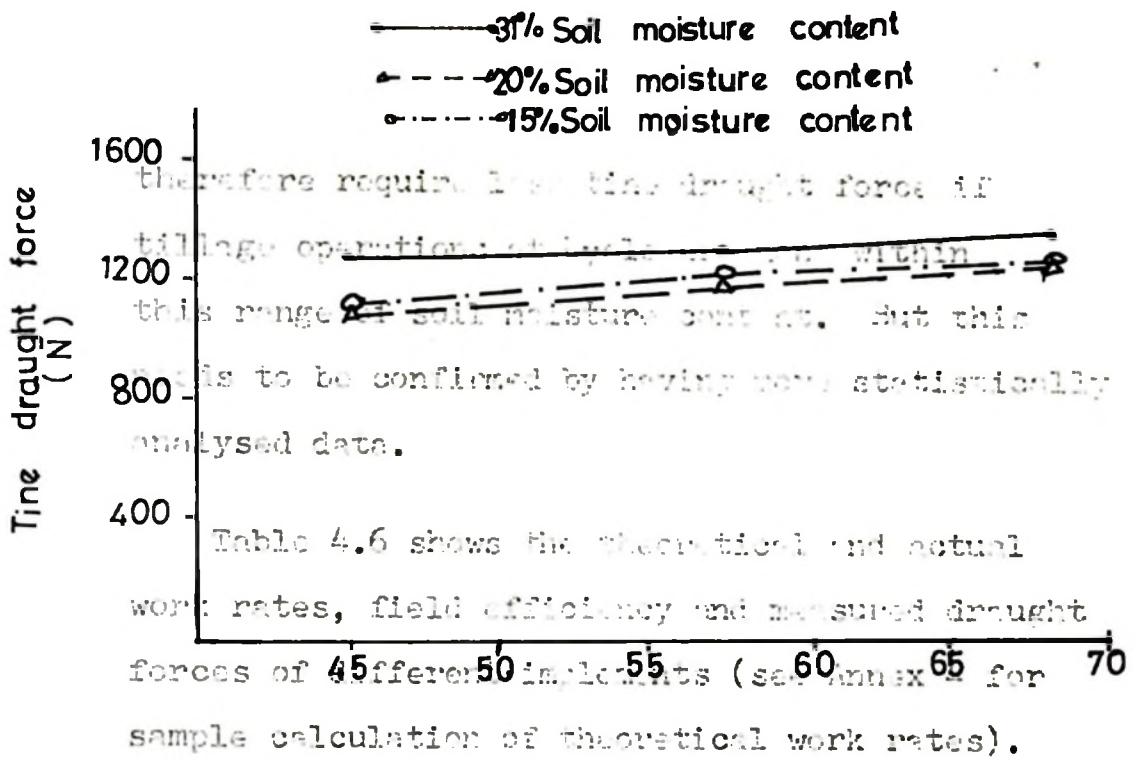


Figure 4.2: Typical recording paper from the recorder.

Annex 6 shows the measured rolling resistance and implement draught forces at different rake angles and soil moisture content. Figure 4.3 shows graphical presentation of the effect of rake angle and soil moisture content. There was little change in tine draught force as the rake angle increased. The reason is probably that the increase in rake angles was too small to have any significant effect. Moreover the presence of rhizomatous (couch grass) weeds on the experimental plots could have not only affected the soil failure pattern, due to soil binding, but also increased tine draught force because of ripping and bulldozing the rhizomes. However, the results show that there is an increase in tine draught force as the rake angle is increased from 45° .

The moisture content of the soil affected the tine draught as indicated in figure 4.3. The draught decreased with decrease in moisture content to 20% soil moisture content, but appears to stabilise or increase at lower moisture content (15% soil moisture content). This implies that between 20% and 15% moisture content soils are friable and both bulk and clod shear strengths, particularly the former, are weak. It would

(a) Tine without sweeps



therefore require less tine draught force if tillage operations are to be carried out within this range of soil moisture content. But this needs to be confirmed by having more statistically analysed data.

Table 4.6 shows the theoretical and actual work rates, field efficiency and measured draught forces of different implements (see Annex 5 for sample calculation of theoretical work rates).

The UAC tool with sweeps has higher theoretical and measured field capacities than the mouldboard plough. This is because the latter involves completely ploughing the land whereas the former is planting furrows at a spacing of 75cm and the rest of the land is unploughed. However, the mouldboard plough had higher field efficiency than the UAC tool carrier. Time was spent to check the metering mechanism and refill the hoppers of the UAC tool carrier planter with seeds and fertilizers. Moreover turning with mouldboard plough was faster than the UAC tool carrier planter. But such more field trials are required before making any plausible conclusions on the capacity of the UAC tool carrier planter.

Figure 4.3 The effect of rake angle on tine draught force at 10cm depth of work

therefore require less tine draught force if tillage operations at Uyole are done within this range of soil moisture content. But this needs to be confirmed by having more statistically analysed data.

Table 4.6 shows the theoretical and actual work rates, field efficiency and measured draught forces of different implements (see Annex 4 for sample calculation of theoretical work rates). The UAC tool Carrier had higher theoretical and measured field capacities than the mouldboard plough. This is because the latter involves completely ploughing the land whereas the former makes planting furrows at a spacing of 750m and the rest of the land is unploughed. However, the mouldboard plough had higher field efficiency than the UAC tool carrier. Time was spent to check the metering mechanism and refill the hoppers of the UAC tool carrier planter with seeds and fertilizers. Moreover turning with mouldboard plough was easier and faster than the UAC tool carrier planter. But much more field trials are required before making any plausible conclusions on the capacity of the UAC tool carrier planter.

Table 4.6: Work rates and total draught forces of implements at 20% soil moisture content and 10cm working depth.

Implement	Rake angle	Width of Cut(m)	Spacing (m)	Forward Speed (km/hr)	Theoretical rate (ha/hr)	Measured work rate (ha/hr)	Field Efficiency (%)	Time ¹ draught (N)	Rolling Resist- ance	Time ² / Total Draught (N)
UAC tool	45°	0.12	0.75	3.2	0.24	0.1	41.7	1080	307.5	1390
Carrier tine	57°	0.12	0.75	3.2	0.24	0.1	41.7	1190	308.0	1500
Without sweeps	68°	0.12	0.75	3.2	0.24	0.1	41.7	1230	307.8	1540
UAC tool Carrier tine with sweeps	45°	0.26	0.75	3.2	0.24	0.1	41.7	1410	306.0	1720
	57°	0.26	0.75	3.2	0.24	0.1	41.7	1470	306.8	1780
	68°	0.26	0.75	3.2	0.24	0.1	41.7	1510	309.0	1820
Mouldboard plough		0.20	0.20	3.0	0.06	0.055	91.7	2300	-	2300
Ridger		0.43	0.43	3.0	0.129	-	-	2340	-	2340

1/ Obtained from Annex 6a at 20% soil moisture content.

2/ Obtained from Annex 6b at 20% soil moisture content.

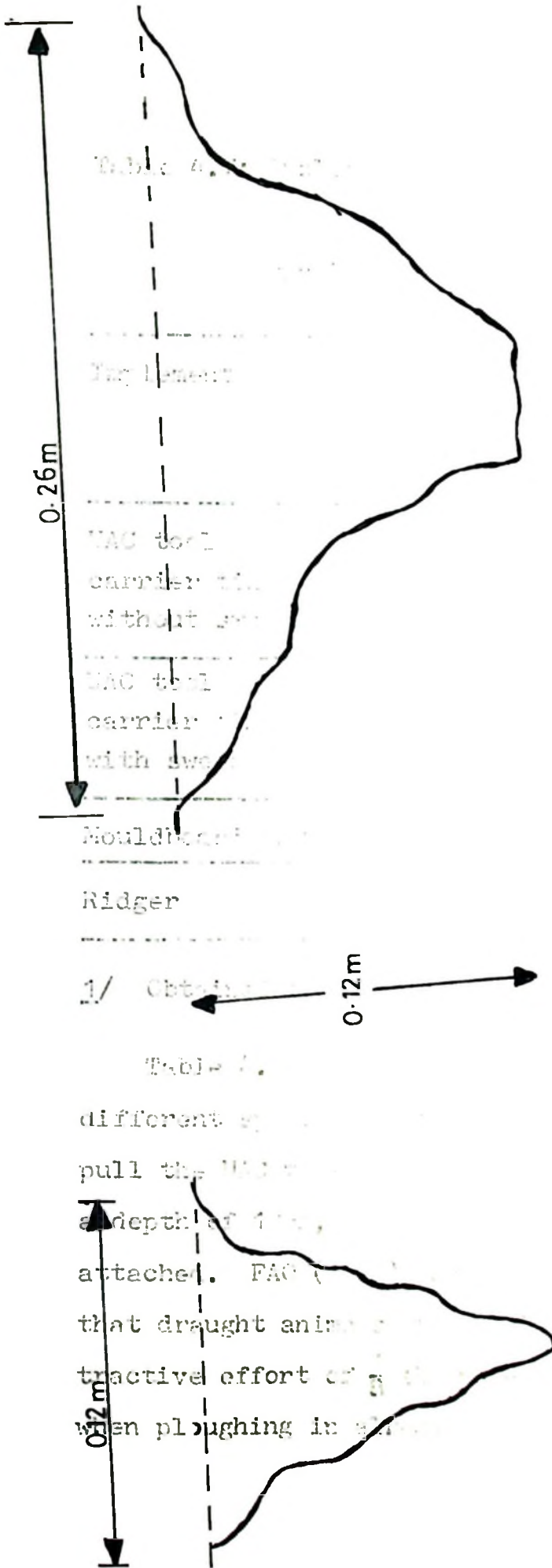
It is also evident from table 4.6 that the mouldboard plough requires much more draught force than the UAC tool carrier tine even when the rake angle of the latter is increased to 68° and sweeps attached. Other workers have also observed that tined implements tend to have low draught force and energy input (PATTERSON et al. 1973; PATTERSON, 1975, DOWDING et al, 1967; DLFRS, 1976). The higher draught forces on the mouldboard plough and ridger can perhaps be attributed to the soil/metal parameters i.e. adhesion and soil/metal friction. The interface area of these implements is considerably larger than that of tines. This means that adhesion is higher especially at high soil moisture content and, frictional force is higher during soil scouring. Moreover the weight of the soil slice on the mouldboard increases the surcharge thus adding more to the draught force.

Another important observation from table 4.6 is the force to overcome rolling resistance. This appears to be larger than expected. The larger proportion of force to overcome rolling resistance might be due to weight of the tool carrier because the size of the wheels (one metre diameter) is

perhaps large enough to have any significant effect on it. Therefore the only way to reduce this is to decrease the weight of the tool carrier.

Table 4.7 gives the implement power and energy requirements (see Annex 4 for sample calculations of power and energy requirements). The mouldboard plough and ridger requires more power and energy per hectare than the UAC tool carrier tine. The energy applied to soil is the highest for the UAC tool carrier tine without sweeps. Generally implements that disturbed more soil have low energy applied per cubic metre of soil.

Attachment of sweeps on the UAC tool carrier tine increased the power and energy requirement per hectare. However, much more soil was disturbed as a result. Fig. 4.4 shows results, obtained from the experiment, of soil disturbance pattern when the tine is used without and with the sweeps. It is evident that the tine with sweeps had more disturbance and loosening effect on the soil. This means a better soil environment. Specific resistance is the draught force per unit area of soil disturbed (SPOOR and GODWIN, 1978). The lower the specific resistance the more the soil disturbance relative to the draught force.



Tines with knives
(Rake angle = 45°)

Tines without knives
(Rake angle = 45°)

Figure 4.4 Soil disturbance patterns
Source: From experimental results

... sweeps
... indicate
... ting a
... weight
... cultural

Table 4.7: Implement power and energy requirement at 20% Soil moisture content and 10cm working depth.

Implement	Rake angle	Total draught ^{1/} (N)	Power (W)	Implement Energy requirement (MJ/ha)	Energy Applied to Soil (kJ/m ²)
UAC tool	45°	1390	1240	18.5	115.8
carrier tine	57°	1500	1330	20.0	125.0
without sweeps	68°	1820	1620	24.3	70.0
UAC tool	45°	1720	1530	22.9	66.2
carrier tine	57°	1780	1580	23.7	68.5
with sweeps	68°	1820	1620	24.3	70.0
Mouldboard plough	-	2300	1920	115.0	115.0
Ridger	-	2340	1950	54.4	54.4

^{1/} Obtained from table 4.6

Table 4.8 gives the calculated number of different species of draught animals needed to pull the UAC tool carrier tine when working at a depth of 10cm, rake angle of 45° and with sweeps attached. FAO (1972) and HOPFEN (1969) indicate that draught animals are capable of exacting a tractive effort of $\frac{1}{8}$ th and $\frac{1}{10}$ th of the weight when ploughing in already well-worked agricultural

land and ground containing obstacles respectively. The latter was used in the calculations to obtain table 4.8. It is evident that donkeys and mules are not desirable for use on the UAC tool carrier. More than two pairs of the indigenous Zebu animals are required. The mouldboard plough requires in most cases more than two pairs of the small Zebu animals. It is common for example in Mwanza and Shinyanga Regions to site four pairs of oxen ploughing or pulling a sledge. This demands more land for grazing.

Use of more than one pair of oxen on the UAC tool carrier will probably make it difficult to plant and weed as it might not be easy to control the animals. Moreover use of two or more animals harnessed together results in a relative loss of efficiency of each of them. According to a special study of the relationship between the number of animals used together and the resulting loss of efficiency, this amounts, with relation to the tractive effort of a single animal, to 7.5% for two animals, 15% for three, 22% for four, 30% for five and 37% for six (FAO, 1972). Calculations on the table 4.8 did not consider these losses. So the number of animals required

Table 4.8: Draught animals required for the UAC tool Carrier tine with sweeps at rake angle of 45° and 20% soil moisture content.

Animal Species	Adult Weight (kg)	Tractive effort 1/10 th of wgt (N)	Draught ^{1/} force requirement (N)	Number ^{2/} of animals required
Zebu bullock	350	343.4	1720	5
Donkey	200	196.2	1720	9
Mule	300	294.3	1720	6
Horse	450	441.5	1720	4
Dromedary	500	490.5	1720	4
Friesian ox	850	833.9	1720	2
Buffalo	650	637.7	1720	3

Source: Compiled by the author with aid of data from FAO (1972).

1/ Draught force of UAC Tool Carrier tine taken from table 4.6 at the lowest rake angle (45°) and tine with sweeps. Normal working depth is 10 cm.

2/ Rounded up figures.

could have been underestimated. If the proportion of draught force to overcome rolling resistance of the wheels is reduced by reducing the size of the tool carrier, the number of animals required will probably decrease. As for the exotic friesian

oxen one pair is quite sufficient to pull the tool carrier. The practice of using one pair of Friesian oxen at Uyole concurs with the theoretical calculations on table 4.8.

4.5 Economic Analyses

Table 4.9 shows the area that can be handled by one household for each operation. The limiting operations are those with low hectares per household. For the purely labour input system the limiting operations are soil tillage and weeding, and account for the labour peak. Employment of draught animals to some of the farm operations increases the capacity of them but causes bottlenecks in others. The most common tillage system in Tanzania as far as oxen mechanisation is concerned is the use of a mouldboard plough for tillage while all other subsequent operations are done by manual labour. As shown on Table 4.9 the household can till up to 7.2 ha with the plough but can manually plant and weed no more than 3 hectares. So weeding and planting are the limiting factors in intensified expanded animal-powered production when all operations subsequent to tillage must be done by hand-harvesting is not as limiting.

Table 4.9: Cultivable area per household for each operation in four tillage treatments.

Treatment	Operation	Days available	Man-hrs/ha. required	Man-hrs per family available	Cultivable area (ha).
HH	a) Hoeling	26	235	376	1.6
	b) Planting	27	119	393	3.3
	c) 1st weeding	18	95	266	2.8
	d) 2nd weeding	18	102	265	2.6
	(1) hand hoe	18	19	181	9.5
	(11) UAC Weeder	18	103	258	2.5
MH	e) 3rd Weeding	18	139	765	5.5
	f) Harvesting	53	36	259	7.2
	a) Ploughing	26	134	389	2.9
	b) Planting	27	100	260	2.6
	c) 1st Weeding	18	106	265	2.5
	d) 2nd Weeding	18	19	181	9.5
UH	(1) hand hoe	18	102	265	2.6
	(11) UAC Weeder	18	140	770	5.5
	e) 3rd Weeding	53	11	264	2.2
	f) Harvesting	26	83	390	4.7
	a) Ploughing	27	95	266	2.8
	b) Planting	18	132	264	2.0
UU	c) 1st Weeding	18	22	180	8.2
	d) 2nd Weeding	18	88	264	3.0
	e) 3rd Weeding	18	21	271	5.6
	f) Harvesting	53	94	263	12.9
	a) Planting	27	134	268	2.8
	b) 1st Weeding	18	24	180	2.0
UU	c) 2nd Weeding	18	97	262	7.5
	d) 3rd Weeding	18	130	767	2.7
	e) Harvesting	53			5.9

The proposed UAC tool carrier consists of the operations:- direct drilling (oxen), first weeding done by hand hoe on maize row only, second weeding done by UAC weeder (oxen), third weeding done by hand hoe. If the first two weedings are done properly and in time the third one is not necessary. The results indicate that between 60% and 90% more land can be planted using the UAC tool carrier planter than by hand. The first weeding which was hoped to be a quick operation was still a limiting factor. The problem was that the weeds within the maize rows competed and in some cases tended to suppress the maize. Weed seeds, being small in size, germinated first and could have made use of the nitrogen in the Diammonium phosphate (15 - 50 - 0) fertilizer which was applied as a pre-emergence fertilizer. So weeding was rather laborious and much time was spent on pulling large weed shoots within the maize rows prior to ridging with a hand hoe. This system could perhaps be more applicable in more semi-arid areas like Iringa where weeds are not a serious menace.

Table 4.10 shows a summary of the costs of maize production for the eight mechanisation systems (see Annex 7 for detailed calculations of

fixed and variable costs). When discussing the cost of maize production it is important to note two scales of production in Tanzania. First and most common is the small scale at the peasant level where maize is grown for home consumption, only surplus is sold. Family labour is employed. Hired labour is seldomly used and payment is not in monetary terms but, in most cases, in kind. It is not easy to allocate labour cost in these typical smallholdings because only unpaid labour is used.

Then there is large scale maize production state farms and public organisations e.g. National Farm Company (NAFCO), Uyolet Agriculture Centre (UAC) etc are involved. Maize is produced on a commercial basis. The whole maize harvest is sold normally to the National Milling Corporation (NMC). It is easy to allocate labour costs and to calculate profits or losses in this case.

It is evident from table 4.10 that for the purely labour input system the costs are due to labour (about 57% of the total costs). Cost of labour decreases as draught animals are employed in the systems. The proposed UAC tool carrier system has not only the lowest labour cost (about

Table 4.10: Costs (T.shs/ha) and values of a day's manpower (VDMP) in maize production for eight mechanisation systems (see table 4.5).

MECHANISATION SYSTEM	Fixed Cost (T.shs/ha)	Variable Costs (T.shs/ha)	Labour Cost ^{1/} (T.shs/ha)	Total Cost (Tshs/ha)	Gross Revenue (Tshs/ha) ^{2/}	V.D.M.F. (T.shs) ^{3/}
I	3	1068	1447	2518	6367	53
II	252	1068	1296	2616	6611	60
III	321	1068	1128	2517	5751	57
IV	153	1068	969	2191	7072	88
V	112	1068	996	2176	5959	70
VI	100	1068	796	1964	5287	76
VII	190	1068	869	2127	5729	75
VIII	140	1068	668	1876	4627	75

Source: Compiled by the author

1/ Labour cost is 14.60 T.shs per day (1979 basic industrial minimum wage). The length of a working day is taken as 8 hours.

2/ Yield (kg/ha) x price of maize. Yields are taken from table 4.2 1979 maize price was 0.85 T.shs/kg.

3/ VDMP = $\frac{\text{Gross Revenue} - \text{direct production costs (excluding labour)}}{\text{Number of man-days spent on the crop.}}$

35% of the total cost) but also the lowest total cost (26% lower than the purely labour input system). One may be tempted to conclude that it is cheaper to use the UAC tool Carrier system than any of the other systems. Fixed costs do not change with the use of the implement or draught animals. A large proportion of the fixed costs are due to the use of draught animals (2242 Tshs per year, see Annex 7). If they are used over a small area the fixed costs will be spread over that small area leading to a high fixed cost per unit area and vice versa. Systems which have a higher capacity have low fixed costs per unit area (systems V, VI and VIII on Table 4.10).

Also shown on table 4.10 are the values of a day's manpower for the different mechanisation systems. Systems with low labour input and/or high gross revenue will have high values of a day's manpower. System IV has the highest value of a day's manpower because of the highest gross revenue brought about by the high yields per hectare. The proposed UAC tool carrier system, despite having the lowest gross revenue, is one of the system which have the highest value of a day's manpower. This is because it has the lowest labour input. It is profitable to produce

maize using systems with higher values of a day's manpower. Values of a day's manpower are also important guideline to labour employment on the farm. It would be irrational to pay an agricultural labourer on the farm more than the value of a day's manpower. On the other hand, it is preferable to be self-employed on the farm than being an agricultural labourer if the standard daily wage is less than the value of a day's manpower. So with the standard daily wage in Tanzania of 14.60 Tshs it is profitable to employ labour on the farm when using any of the eight systems, but more profitable with systems IV, VI and VIII, because of the higher values of a day's manpower.

CHAPTER 5

CONCLUSIONS

There were two major concepts behind developing the UAC tool Carrier. First and foremost was to expand the area cultivable by a farm family with reasonably low increase in cost so that more family income could be achieved. Second was to try and solve the weed problem. The preliminary study was intended to verify the concepts.

The results from the study have shown that the UAC tool carrier system has failed to solve the weeding problem. The intended quick first weeding (by hand) turned out to be a labour intensive operation. The UAC tool Carrier weeder on uncultivated plots did not perform well as anticipated. Penetration of the tine in the soil was inadequate because of soil compaction and densely populated weeds. However, it was very effective in controlling weeds on cultivated plots.

The tool Carrier expanded the area cultivable (direct drilling) from 2 ha by hand hoe to 12 ha. First weeding operation, however, was limiting because the farm family could not handle more than 3 ha. If this problem could be solved by for

example either using the tool carrier in more arid regions or use of herbicide so that the weeding. capacity could also be increased to more or less 12 ha then the UAC tool carrier system could be more feasible. This would increase the income of a farm family from 7,698 Tshs with purely labour input system to 33,102 Tshs, assuming the maize yields on table 4.2 could be achieved and costs on table 4.10 remain the same.

It is clear also from the results that an appreciable energy or power is required just to pull the tool carrier (rolling resistance). This is probably due to its size and weight. The design could be changed to reduce the size.

The introduction of the UAC tool carrier in rural areas is likely to affect the sociological system there. It has been reported that women tend to work longer on the farm and specialize on food crops (FORTMANN, 1977). Men are responsible for cash crops and control funds for purchase of capital goods. Because of its high capacity, the UAC tool carrier will turn maize into a cash crop thus making it a men's crop.

The UAC tool Carrier is likely to be suitable and acceptable on large scale farming e.g. Ujamaa Villages where communal farms exist. It could be organized such that some oxen and the tool carrier could be owned by the village government. These, then, could be used on cooperative maize farms for specified number of days in a week. Hiring to individual farmers could be made possible. Of course this will need cooperation not only among farmers but also at District, Regional and National levels. Viable oxen training Centres (OTCs), veterinary facilities, communication, marketing facilities should be made available to farmers. Otherwise the tool Carrier would be confined to favoured producers like the Uyole Agriculture Centre without benefiting the majority in the rural areas.

Lastly, there are a number of animal toolbars available now in different parts of the world. It is recommended that they be tested and evaluated under Tanzania's local conditions of soils and climate. Then, they, together with the UAC tool Carrier, should undergo pilot study in villages. The suitable ones should be selected for local manufacture.

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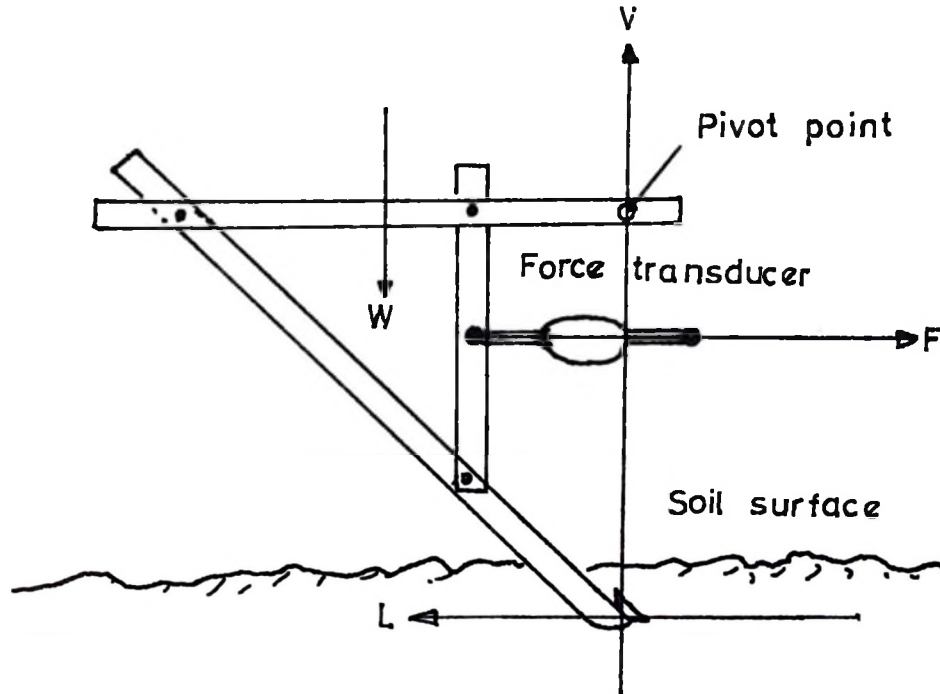
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ANNEX I: DETERMINATION OF HORIZONTAL FORCE(L).

- a) Calculation of horizontal force on the U_hC tool Carrier tine geometry.



L is the soil horizontal component force (N)

V is the soil vertical component force (N)

F is the average force from the recorder (N)

W is the weight of the tine geometry (N)

Let the perpendicular distance from pivot point to W be X metres, that to F be y metres and that to L be Z metres. Distances are obtained by drawing the tine geometry to scale.

Taking moments about the pivot point

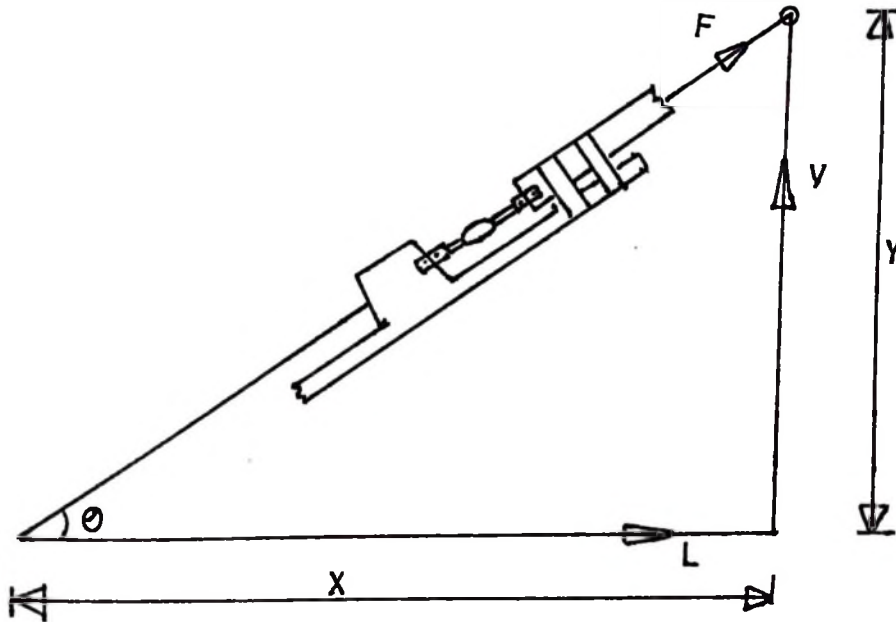
$$OV - xW - yF + zL = 0 \text{ (clockwise moments positive)}$$

Note that the distance to the vertical component force V is 0

Hence $zL = xW + yF$

$$L = \frac{xW + yF}{z} \quad (N)$$

b) Calculation of rolling resistance



F is the average force from the recorder and can be resolved into horizontal force L and vertical force V.

By taking measurements on the UAC tool Carrier and drawing to scale, angle θ will be obtained and measured. Using trigonometrical laws the horizontal force L can be calculated:-

$$\frac{L}{F} = \text{Cosine } \theta$$

$$L = F \text{ cosine } \theta \quad (N)$$

ANNEX 2 CALCULATION SAMPLE FOR HECTARAGE TO BE
HANDLED BY A HOUSE HOLD - SECOND WEEDING
OPERATION

1. Manual Labour

Required manhrs for 2nd Weeding = 102 manhrs/ha

(See Annex 3)

Available manhrs per day = manequivs x length of
working day

= 2.42 x 6 hrs

= 14.52 manhrs/day

Days/ha/household = $\frac{\text{Required manhrs per hectare}}{\text{Available manhrs per day}}$

= $\frac{102}{14.52} = 7$ days/ha/household

From figure 3.8 the available days for 2nd weeding

= 18 days

Area per household = $\frac{\text{days available}}{\text{days/ha/household}}$

= $\frac{18}{7} = 2.6$ ha/household

2. Oxen operation

Required oxen - team - hrs per hectare

= 10 (See Annex 3)

Available oxen-team-hrs per day

= 5 (length of a working
day for one oxen-team)

∴ Days/ha/household = $\frac{\text{Required oxen-team-hrs}}{\text{per ha}}$

Available oxen-team-hrs
per day

= $\frac{10}{5} = 2$ days/ha/household

From figure 3.8 days available for weeding = 18 days.

$$\begin{aligned} \text{Area per household} &= \frac{\text{Days available}}{\text{days/ha/household}} \\ &= \frac{18}{2} = 9 \text{ ha/household} \end{aligned}$$

Since only two man equivalents (2 adults per pair of oxen) are used during oxen operation for 5 hrs a day there is free labour.

$$\begin{aligned} \text{Free labour} &= 0.42 \text{ man equivs} \times 5 \text{ hrs/day} \times 18 \text{ days} \\ &\quad + 2.42 \text{ man equivs} \times 1 \text{ hr/day} \times 18 \text{ days} \\ &= 37.8 + 43.56 \\ &= 81.36 \text{ manhrs} \end{aligned}$$

$$\text{Free labour} = \underline{81.36 \text{ manhrs.}}$$

ANNEX 3: ANALYSIS OF VARIANCES (ANOVA)

a) ANOVA for dry grain maize yields (kg/ha)

Source of Error	Degrees of Freedom	Sums of Squares	Variance	Variance Ratio
Tillage	3	6,681,000	2,227,000	80***
Weeding	1	13,000	13,000	0.47
Interaction	3	4,773,000	1,591,000	57***
Replicates	1	69,000		
Error	7	195,000	27,857	
Total	15	11,732,000		

b) ANOVA for weed weights (kg/ha)

Source of Error	Degrees of freedom	Sums of Squares	Variance	Variance Ratio
Tillage	3	38,847	12,949	11,98**
Weeding	1	27,496	27,496	25.44**
Interaction	3	61,412	20,471	18.93***
Replicates	1	310		
Error	7	7,593	1,081	
Total	15	135,658		

c) ANOVA for goodness of fit of the regression equation

Source of Error	Degrees of freedom	Sums of squares	Variance	Variance Ratio
Total	7	5,733,000		
Regression	1	4,264,665	4,264,665	17.43**
Residual	6	1,468,335	244,723	

ANNEX 4: SAMPLES CALCULATIONS OF WORK RATES, POWER AND ENERGY REQUIREMENTS

1. Theoretical Work rates

a) The UAC tool Carrier

Work rate = Area in hectares worked per hour.

The tine spacing was .75m and the speed of oxen was 3.2 km/hr.

$$\begin{aligned} \therefore \text{Work rate} &= \frac{3.2\text{km}}{\text{hr}} \times 0.75\text{m} \\ &= \frac{3200\text{m}}{\text{hr}} \times 0.75\text{m} \\ &= 3200 \times \frac{.75\text{m}^2}{\text{hr}} \times \left\{ \frac{\text{ha}}{10,000\text{m}^2} \right\} \\ &= \underline{0.24\text{ha/hr}} \end{aligned}$$

b) Mouldboard plough

The land was completely ploughed so that each run cultivated a 0.2m strip of land. The speed of oxen was 3.0km/hr

$$\begin{aligned} \therefore \text{Work rate} &= 3.0\text{km/hr} \times 0.2\text{m} \\ &= 3000 \times \frac{0.2\text{m}^2}{\text{hr}} \times \left\{ \frac{\text{ha}}{10,000\text{m}^2} \right\} \\ &= \underline{0.06 \text{ ha/hr.}} \end{aligned}$$

c) Ridger

All land covered i.e. ridger operating at spacing of .43m between runs. Oxen speed was 3.0km/hr

$$\begin{aligned} \therefore \text{Work rate} &= 3.0\text{km/hr} \times 0.43\text{m} \\ &= 3000 \times \frac{0.43\text{m}^2}{\text{hr}} \times \left\{ \frac{\text{ha}}{10,000\text{m}^2} \right\} \\ &= \underline{\underline{0.129 \text{ ha/hr}}} \end{aligned}$$

2. Powera) The UAC tool Carrier

Power is the rate of doing work.

The speed of oxen was 3.2 km/hr and the total draught force was 1390 N (at 45° rake angle, tine without sweeps).

$$\begin{aligned}
 \therefore \text{Power} &= 1390\text{N} \times 3.2 \text{ km/hr} \\
 &= 1390\text{N} \times 3200 \frac{\text{M}}{\text{hr}} \\
 &= \frac{1390 \times 3200}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{1390 \times 3200}{3600} \text{ J/s} \\
 &= \underline{\underline{1240 \text{ W}}}
 \end{aligned}$$

b) Mouldboard plough

The speed of oxen was 3.0 km/hr and the total draught force was 2300N.

$$\begin{aligned}
 \therefore \text{Power} &= 2300\text{N} \times 3.0 \text{ km/hr} \\
 &= \frac{2300 \times 3000}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{2300 \times 3000}{3600} \text{ W} \\
 &= \underline{\underline{1920 \text{ W}}}
 \end{aligned}$$

c) Ridger

The speed of oxen was 3.0km/hr and total draught force was 2340N

$$\begin{aligned}
 \therefore \text{Power} &= 2340\text{N} \times 3.0\text{km/hr} \\
 &= \frac{2340 \times 3000}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{2340 \times 3000}{3600} \text{ W} \\
 &= \underline{\underline{1950 \text{ W}}}
 \end{aligned}$$

2. Powera) The UAC tool Carrier

Power is the rate of doing work.

The speed of oxen was 3.2 km/hr and the total draught force was 1390 N (at 45° rake angle, tine without sweeps).

$$\begin{aligned}
 \therefore \text{Power} &= 1390\text{N} \times 3.2 \text{ km/hr} \\
 &= 1390\text{N} \times 3200 \frac{\text{M}}{\text{hr}} \\
 &= \frac{1390 \times 3200}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{1390 \times 3200}{3600} \text{ J/s} \\
 &= \underline{\underline{1240 \text{ W}}}
 \end{aligned}$$

b) Mouldboard plough

The speed of oxen was 3.0 km/hr and the total draught force was 2300N.

$$\begin{aligned}
 \therefore \text{Power} &= 2300\text{N} \times 3.0 \text{ km/hr} \\
 &= \frac{2300 \times 3000}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{2300 \times 3000}{3600} \text{ W} \\
 &= \underline{\underline{1920 \text{ W}}}
 \end{aligned}$$

c) Ridger

The speed of oxen was 3.0km/hr and total draught force was 2340N

$$\begin{aligned}
 \therefore \text{Power} &= 2340\text{N} \times 3.0\text{km/hr} \\
 &= \frac{2340 \times 3000}{3600} \frac{\text{NM}}{\text{s}} \\
 &= \frac{2340 \times 3000}{3600} \text{ W} \\
 &= \underline{\underline{1950 \text{ W}}}
 \end{aligned}$$

3. Implement energy requirements

a) UAC tool carrier

Consider 1 metre forward movement of the oxen.

Work done = draught force x distance
 Total draught = 1390N (at 45° rake angle,
 tine without sweeps)

$$\therefore \text{Energy (work done)} = 1390\text{N} \times 1\text{m}$$

$$\text{Area covered} = \text{spacing (m)} \times \text{distance (m)}$$

$$= 0.75 \text{ m} \times 1\text{m}$$

$$\text{Implement energy} = \frac{1390\text{N} \times 1\text{m}}{0.75\text{m} \times 1\text{m}}$$

$$= \frac{1390 \times 1 \text{ Nm}}{0.75 \times 1\text{m}^2} \times \frac{(10,000\text{m}^2)}{\text{ha.}}$$

$$= \underline{\underline{18.5 \text{ MJ/ha.}}}$$

b) Mouldboard plough

Also consider 1 metre forward movement
 total draught force = 2300N

$$\text{Spacing} = 0.2\text{m}$$

$$\therefore \text{Energy} = \frac{2300\text{N} \times 1\text{m}}{0.2\text{m} \times 1\text{m}}$$

$$= \frac{2300 \times 1 \text{ Nm}}{0.2 \text{ m}^2} \times \frac{(10,000\text{m}^2)}{\text{ha.}}$$

$$= \underline{\underline{115 \text{ MJ/ha}}}$$

c) Ridger

Also consider 1 metre forward movement.

Total draught = 2340N and spacing = 4.3m

$$\therefore \text{Energy} = \frac{2340 \text{ N} \times 1\text{m}}{0.43\text{m} \times 1\text{m}}$$

$$= \frac{2340 \times 1 \text{ Nm}}{0.43 \times 1\text{m}^2} \times \frac{10,000\text{m}^2}{\text{ha.}}$$

$$= \underline{\underline{54.4 \text{ KJ/ha}}}$$

4. Energy Applied to the Soila) The UAC tool Carrier

Consider again 1 metre forward movement of the oxen.

$$\text{Work done} = \frac{\text{total draught}}{(\text{N})} \times \frac{\text{distance}}{(\text{m})}$$

$$\text{Total draught} = 1390\text{N (at } 45^\circ \text{ rake angle, tine without sweeps).}$$

$$\therefore \text{Energy} = 1390\text{N} \times 1\text{m}$$

$$\begin{aligned} \text{Volume of Soil worked} &= \text{area covered} \times \text{depth} \\ \text{of work} &= (0.12\text{m} \times 1\text{m} \times 0.1\text{m}) \\ &= (0) \end{aligned}$$

$$\begin{aligned} \therefore \text{Energy} &= \frac{1390\text{N} \times 1\text{m}}{\text{applied to soil } 0.12\text{m} \times 1\text{m} \times 0.1\text{m}} \\ &= \frac{1390 \times 1 \text{ Nm}}{0.12 \times 1 \times 0.1\text{m}^2} \\ &= \underline{\underline{115.8 \text{ kJ/m}^2}} \end{aligned}$$

b) Mouldboard plough

Consider 1 metre forward movement

$$\begin{aligned} \text{Total draught} &= 2300\text{N and volume of soil worked} \\ &= 0.2\text{m} \times 1\text{m} \times 0.1\text{m} \end{aligned}$$

$$\begin{aligned} \therefore \text{Energy applied} &= \frac{2300\text{N} \times 1\text{m}}{\text{to soil } 0.2\text{m} \times 1\text{m} \times 0.1\text{m}} \\ &= \frac{2300 \times 1 \text{ Nm}}{0.2 \times 1 \times 0.1\text{m}^3} \\ &= \underline{\underline{115 \text{ kJ/m}^3}} \end{aligned}$$

c) Ridger

Consider 1 metre forward movement

$$\begin{aligned} \text{Total draught} &= 2340\text{N and volume of soil} \\ \text{worked} &= 0.43\text{m} \times 1\text{m} \times 0.1\text{m} \end{aligned}$$

$$\begin{aligned} \therefore \text{Energy applied to soil} &= \frac{2340\text{N} \times 1\text{m}}{0.43\text{m} \times 1\text{m} \times 0.1\text{m}} \\ &= \frac{2340 \times 1 \text{ Nm}}{0.43 \times 1 \times 0.1\text{m}^3} \\ &= \underline{\underline{54.4 \text{ kJ/m}^3}} \end{aligned}$$

ANNEX 5: TIME AND LABOUR REQUIREMENTS FOR MAIZE PRODUCTION

A51 Hand hoeing and hand planting

OPERATION	Time (hrs/ha)	Oxen (No)	Labour (men)	Oxhrs (per ha)	Manhrs (per ha)	Oxen- team hrs (ha)	Days Availa- ble	Manhrs/ house- hold Availa- ble	Ha/house- hold cu- ltivable	Free Labour (man hrs)
Hoeing	47	-	5	-	236	-	26	376	1.6	-
Planting(Fert- and Inct.appli- cation)	20	-	6	-	119	-	27	393	3.3	-
1st Weeding (in maize rows)	19	-	5	-	95	-	18	266	2.8	-
2nd Weeding										
a) Hand hoe	20	-	5	-	102	-	18	265	2.6	-
b) UAC Weeder	10	2	2	20	20	10	18	181	9.0	81
3rd Weeding	52	-	2	-	103	-	18	258	2.5	-
Harvesting	14	-	10	-	140	-	53	765	5.5	-

A52 Mouldboard ploughing and hand planting

OPERATION	Time (hrs/ha)	Oxen (No)	Labour (men)	Oxhrs (per ha)	Manhrs (per ha)	Oxen- team hrs (perha)	Days Avai- lable	Manhrs/ house hold Available	Ha/ house hold culti- vatable	Free labour (manhrs)
Ploughing and Harrowing	18	2	2	36	36	18	26	259	7.2	118
Planting (Fert./ Inct. appli- cation)	22	-	6	-	134	-	27	389	2.9	-
1st Weeding (on maize rows)	20	-	5	-	100	-	18	260	2.6	-
2nd Weeding										
a) Hand hoe	21	-	5	-	105	-	18	265	2.5	-
b) UAC Weeder	9	2	2	18	18	9	18	181	9.5	81
3rd Weeding	51	-	2	-	102	-	18	265	2.6	-
Harvesting	14	-	10	-	140	-	53	770	5.5	-

A5.3 UAC Tool Carrier time and hand planting

8

OPERATION	Time (hrs/ha)	Oxen (No)	Labour (men)	Oxhrs (per ha)	Manhrs (per ha)	Oxen- team hrs (per ha)	Days available	Manhrs house hold available	Ha/house hold available	Free labour (man hrs)
Furrowing	5	2	2	10	10	5	26	264	23.6	118
Planting (Fert./Insect. application)	14	-	6	-	84	-	27	390	4.7	-
1st Weeding (on maize rows)	19	-	5	-	95	-	18	266	2.8	-
2nd Weeding										
a) Hand hoe	26	-	5	-	130	-	18	264	2.0	-
b) UAC weeder	11	2	2	22	22	11	18	180	8.2	81
3rd Weeding	44	-	2	-	88	-	18	264	3.0	-
Harvesting	14	-	10	-	140	-	53	773	5.6	-

A54 UAC Tool Carrier plus Planter

OPERATION	Time (hrs/ha)	Oxen (No)	Labour (men)	Oxhrs (per ha)	Manhrs (per/ha)	Oxen- team hrs (per/ha)	Days Availa- ble	Manhrs/ hold Available	Ha/house hold cultiva ble	Free labour (man hrs)
Planting (UAC Planter)	10	2	2	20	20	10	27	271	12.9	122
1st Weeding (on maize rows)	19	-	5	-	95	-	18	263	2.8	-
2nd Weeding										
a) Hand hoe	27	-	5	-	135	-	18	268	2.9	-
b) UAC Weeder	12	2	2	24	24	12	18	180	7.5	81
3rd Weeding	49	-	2	-	98	-	18	262	2.7	-
Harvesting	13	-	10	-	130	-	53	767	2.9	-

ANNEX 6: MEASURED IMPLEMENT DRAUGHT FORCES AND
ROLLING RESISTANCE

a) Measured implement draught forces

IMPLEMENT	RAKE ANGLE	IMPLEMENT DRAUGHT FORCE (N)		
		31% SMC	20% SMC	15% SMC
UAC tool Carrier	45°	1260	1080	1100
tine without	57°	1290	1190	1210
sweeps	68°	1340	1230	1220
UAC tool Carrier	45°	1540	1410	1420
tine with sweeps	57°	1620	1470	1490
	68°	1610	1510	1530
Mouldboard Plough		2330	2300	2320
Ridger		2350	2340	2400

b) Measured Rolling Resistance

IMPLEMENT	RATE ANGLE	ROLLING RESISTANCE (N)		
		31% SMC	20% SMC	15% SMC
UAC tool Carrier	45°	309.5	307.5	306.0
tine without	57°	308.5	308.0	307.0
sweeps	68°	308.0	307.8	305.8
UAC tool carrier	45°	308.0	306.0	306.0
tine with sweeps	57°	308.9	306.8	306.1
	68°	310.0	309.0	306.2

ANNEX 7: DETERMINATION OF COST OF MAIZE PRODUCTION

A7.1 Implement Costs (September 1979)

IMPLEMENT	Cost Price (T.sh)	Estimated life (hrs)	Depn. (Tsh/ hr)	Repairs as % of Cost price	Repairs & spares (Tsh/hr)	Total Rate of Fixed cost (Tsh/ hr)	Rate of Work (hrs/ha)	Fixed Cost (Tsh/ha)
UAC Tool Carrier	1142	2000	0.57	130	0.74	1.31	10.4	13.65
Planter	968	2000	0.48	130	0.63	1.11	12.0	13.40
Weeder	403	3000	0.13	120	0.17	0.30	13.6	4.05
Plough (1 furrow)	700	2500	0.28	120	0.34	0.62	4.3	2.70
Harrow (UFI wooden frame)	26	1000	0.03	120	0.03	0.06	47.1	2.85

Source: Compiled by the author

1/ Estimated by the author

2/ Adopted from Beeny (1975)

3/ Obtained from experiment (See Annex 5)

A 7.2 CALCULATIONS OF COSTS OF USING DRAUGHT
ANIMALS (OXEN)

a) Itemized details of Costs:

- Purchase price of a pair of oxen	Tshs 3600	<u>1/</u>
- Estimated economic life: 6 years		
- Resale value (for Slaughter).....	" 3000	<u>1/</u>
- Maintenance feed 3.2 feed units/ day/ox at 0.20 T.Shs/Unit	" 1.38/day	<u>2/</u>
- Veterinary Care per pair of oxen	" 180	
- Cost of high quality feed per year per pair of oxen	" 1200	<u>1/</u>
- Housing per pair of oxen per year...	" 160	<u>2/</u>
- Insurance..... 3% of 75% value/year		<u>3/</u>
- Cost of yoke	" 50	<u>1/</u>
- Estimated life of yoke: 3 years		

1/ Based on costs at Uyole

2/ Adopted from Have and Dihenga (1978)

3/ Adopted from FAO (1972)

b) Cost of utilization

FIXED COST	Depreci- ation (Tsh/yr)	Maintena- nce feed (Tsh/yr)	Vet.Care (Tsh/yr)	Conc- entra te (Tsh/ yr)	Hous- ing (Tsh/ yr)	Insu- rance (Tsh/ yr)
1 pair of oxen	100.00	503.70	180.00	1200	160.00	81.00
2 double yoke.	17.70	-	-	-	-	-

Total Fixed cost of using a pair of oxen = Tshs 2242.40/yr.

A. 7.3: CALCULATION OF VARIABLE COSTS PER HECTARE

The prices of items are based on Tanganyika Farmers Association (TFA) prices in Mbeya (November 1979).

- Fertilizers

a) DAP (15-50-0) 100kg (2bags à 50kg) 117.70 T.shs
per bag 235.40 Tshs

b) CAN (26%) 327.5kg ($6\frac{1}{2}$ bags à 50kg) 73.50 T.shs
per bag 477.75 "

- Maize seed (H 6302) 20 kg (195/=per 25kg) 156.00 "

- Chemicals a) Furadan 5% 15kg 10.00 Tshs
per 1 kg 150.00 "

b) DDT 1% 10kg 24.50 Tshs.
per 5 kg 49.00 "

Total 1068.15Tsh/ha.

ANNEX 8: FIELD OPERATIONS USING THE UAC TOOL CARRIER



A.8.1: The UAC tool Carrier planting - direct drilling.



A.8.2: A close view at the UAC tool Carrier weeding.



A.8.3: The UAC tool Carrier used for weeding.

A.8.4: Hand hoe weeding.





A.8.5: The UAC tool carrier used as wagon to transport agricultural produce during harvesting.