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Energy Utilization Modeling of Animal Draft Power (EUMDAP) For Kenyan Small-Holder Semi-Arid Agriculture

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# ENERGY UTILIZATION MODELING OF ANIMAL DRAFT POWER (EUMDAP) FOR KENYAN SMALL-HOLDER SEMI-ARID AGRICULTURE

By

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ABSTRACT

ENERGY UTILIZATION MODELING OF
ANIMAL DRAFT POWER
(EUMDAP)
FOR KENYAN SMALL-HOLDER SEMI-ARID
AGRICULTURE

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A computer simulation model developed by this study was used for modeling of energy utilization of draft animal power by small-holder farmers in semi-arid areas of Kenya. EUMDAP simulation modeling program can be used to monitor existing DAP-SYSs or project a proposed system that is not operational yet. The user is provided with output data that enables decisions to be made about the current level of utilization of DAP-SYSs. The program can also provide data about the expectations of a proposed DAP-SYS in terms of energy utilization, the amount of feed required to perform tillage and other tasks at the farm level as well as the time required to complete tillage operations in time for planting before the onset of rains in semi-arid lands.

Simulations performed with the model showed that the current rate of DAP-SYS utilization in days per year can be increased from the existing average of about 60 days per year to over 100 days per year. The low utilization rate of current DAP-SYSs can be attributed to the scarcity of alternative implements that can be used after the tillage operations season is over.

The quality of feed available for draft oxen determines the energy that the animals can generate for work without losing weight. Since draft oxen in semi-arid areas lose about 20% of their body weight during the dry spell preceding the seed-bed preparation season, it is imperative that adequate feed (quality and quantity) is provided for tillage work periods if draft animals are to be maintained in optimum physical working condition.

***Legacy passes on…***

*Were my father, deceased at*
*my tender age of four alive,*
*he'd be delighted to know that*
*his legacy lingers on.*

*He plowed for family, relatives,*
*neighbors and friends,*
*when few were the ox-teams*
*that tilled the valleys and plains of Ndeiya.*
*His fame earned him a name in our dialect*
*that literally means:*
*father of plows;*
*for the young and old alike knew him and*
*called him so.*

*Mungai Ndethi has been gone many a decade,*
*but in me flows the same desire -*
*to ease the burden and drudgery*
*of tillage.*

*At times I've wondered why, and how come*
*I chose draft animal power to pursue*
*in studies this far?*

*Like Elisha, it's my father's mantle that fell on, and*
*the legacy was passed on!*

## *Dedication*

*Its been a long journey this far we've come;*
*We've toiled modestly and honorably;*
*In tasks great and small, to do the needful*
*For which we've traveled abroad.*

*Alone I'd have been worn, tired and discouraged;*
*But with Anne my constant companion,*
*We've covered considerable ground.*

*A mate like her its hard to find;*
*One who cares and tends for the family;*
*She's diligently met immediate needs and more,*
*While her helper was afar.*

*She's worked tirelessly in and out of academia;*
*Achieving her goals too.*

*It's to her that I dedicate this work;*
*And to our four daughters:*
*Catherine, Caroline, Lilian and Pauline*
*To whom we pass on the baton.*

*The horizon is theirs,*
*To read and to learn where we left*
*And carry on the pursuit of knowledge*
*In fields diverse to heights unparalleled.*

*Finally and most of all*
*I give glory and honor to my Lord and Savior*
*Jesus Chist who brings seemingly*
*impossible undertakings within reach.*
*For without Him I could do NOTHING!*

*For its through Him that*
***"I can do all things through***
***Christ Jesus which strengthens me."***
***Philippians 4:13.***

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# CHAPTER I

# INTRODUCTION

## 1.1 Background

Semi-arid lands of sub-Saharan Africa have been experiencing rapid population growth, both from natural growth and from in-migration from neighboring high potential areas. The majority of the farmers in these areas are subsistent small-holders with land holdings of less than 8 ha (20 acres). In Kenya, arable agricultural production in the semi-arid lands, commonly referred to as marginal lands, is hinged on the use of draft animal power (DAP) as the primary and dominant mode of mechanization. The Victory moldboard plow is used almost exclusively for tillage and weeding operations and sometimes for hurried plow-planting when rains come before the farmers have prepared the land for planting. The energy level of the predominantly Zebu draft oxen used in semi-arid areas is usually perceived by many small-holder farmers as too low for tillage work when a single pair of oxen is used. Hence most farmers who own more than one pair of oxen tend to use two or three pairs in tandem, but at low operating efficiency in hours per day per unit draft animal. However, a well managed and maintained pair of Zebu oxen is capable of carrying out tillage work in suitable soil conditions. In general, the power from the draft animals is not used to its annual potential because the utilization level of draft oxen in work days per year is very low.

The amount of food required to meet the needs of developing countries is speedily increasing, especially in Africa. According to FAO estimates cited by Mohan Raj (Ed. 1992), by the year 2000 sub-Saharan Africa will be producing only 75% of its required food supply, if present trends of declining food production continue. With this increasing food supply, if present trends of declining food production continue. With this increasing need for food security, new and veritable indigenous crop production methods (especially tillage systems in the famine prone marginal areas) are required to enhance sustainability of land and other locally available resources in the face of highly variable and erratic agro-climatic conditions. This need is made more critical by the limited and often degraded land resources, hard and poor soil conditions, poor physical condition of draft animals and the low economic level of the majority of the farming community. Many small-holder farmers devise various cultural and traditional innovations to improve the chances of obtaining a harvest particularly due to the unreliability of rainfall in both quantity and distribution. For example, some farmers in agro-ecological zones III and IV of Machakos and Mbeere (formerly Embu district) districts hurriedly plow-plant as soon as the first rain showers fall. This strategy enables them to maximize on the limited moisture available and also take advantage of the softened ground conditions as the draft animals are usually too weak to plow the hardened soils before the rains set in.

In general, over 80 percent of the rural population in most developing countries depend on agriculture for their food supply and economic sustenance. The majority of the farmers are small-holders who operate at a subsistence level. Iftikhar and Kinsey (Eds. 1984) in their recommendations to International Labor Organization (ILO) emphasized that development of agricultural production for most sub-Saharan Africa should be directed to the small-holder farmers who aggregately produce the bulk of the food and export commodities. In Kenya, the aggregate value of agricultural production by small-holder farmers outstrips that of the large-scale capital intensive farmers (Republic of Kenya, *Economic Survey* 1963, 1970). Small-holders, therefore, play a significant role in the economy of the country. Overall, the agricultural industry provides livelihood to about 90 percent of the total population of about 25 million (1990 census), employs about 85 percent of the total labor force either directly or indirectly in agro-industries or agricultural support industries, and generates over one third of the nation's gross domestic product- GDP - (Pearson et al. 1995).

There are about 1.5 million small-holder farmers (Table 1.1) in Kenya of which about 74 percent have less than 3.0 hectares of land while the vast majority (96%) have 8 ha or less (Republic of Kenya, *Statistical Abstracts* 1983). The total land area of the country is about 56.91 million hectares and only about 17 percent is climatically suitable for cropped agriculture in the high and medium potential lands (Republic of Kenya, *Statistical Abstracts* 1978). According to Muchiri and Minto (1977) and Muchiri (1981), of the 6.82 million hectares cultivated in Kenya, about 84 percent were cultivated by hand tools, 12 percent were oxen cultivated and only 3.5 percent were cultivated by tractors.

The predominant technology used by the small-holder farmers for their agricultural mechanization is either hand tools, draft animal power (DAP) or a combination of both. Attempts to alleviate the mechanization constraints of small-holder farmers should be designed to use locally available resources that are socio-economically viable, employment generating and not labor-displacing. Although rural employment is a major concern, the potential for increasing agricultural productivity through human power alone is severely limited by the inadequacy of human beings to develop and sustain ample power for extended periods of time. A human being is rated at about 0.07 kW while minimum power requirement for efficient agriculture has been estimated at about

0.35 kW per hectare (Kline et al. 1969). De Vries (1986) estimated that an average household of 5 people can cultivate 2 to 4 hectares using hand tools. However, the average size of farming communities' households in the small-holder is estimated at 4 adults and the land size needed for subsistence food crop production is about 2 hectares in the medium and high potential agricultural zones. The land size required to sustain a household in the semi-arid lands is estimated at about 4 hectares.

Table 1.1 Percentage distribution of Kenyan small-holdings by size and province (except the pastoral and large farms). 1974 - 1975.

| Acreage (ha) | Provinces (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Central | Coast | Eastern | Nyanza | Rift Valley | Western | Total |
| below 0.5 | 6.74 | 20.37 | 9.55 | 15.72 | 22.99 | 21.53 | 13.91 |
| 0.5 - 1 | 10.50 | 18.46 | 17.35 | 28.18 | 12.11 | 17.67 | 17.92 |
| 1 - 2 | 36.96 | 22.52 | 33.39 | 22.03 | 17.59 | 17.27 | 26.99 |
| 2 - 3 | 16.47 | 11.42 | 14.82 | 15.23 | 14.78 | 14.68 | 15.11 |
| 3 - 4 | 11.86 | 7.68 | 8.57 | 6.79 | 10.11 | 8.60 | 8.89 |
| 4 - 5 | 5.92 | 8.15 | 9.63 | 8.13 | 5.72 | 4.36 | 7.22 |
| 5 - 8 | 7.63 | 5.87 | 5.43 | 4.09 | 6.87 | 10.22 | 6.50 |
| 8 and more | 3.92 | 5.53 | 1.22 | 1.83 | 9.83 | 5.68 | 3.47 |
| number of holdings | 329,530 | 69,861 | 353,431 | 386,431 | 89,823 | 254,618 | 1,483,422 |

*Source: Republic of Kenya Statistical Abstracts (1978).*

The limited productivity of semi-arid lands calls for both intensive and extensive cultivation of land to offset the risk of climatic uncertainties and meet the food requirements to feed the increasing populations. The prospects of adopting engine or tractor power for small-holder agriculture has little or no potential for the majority of subsistence farmers in Kenya. A World Bank study cited by Pingali et al. (1987) concluded that most African farming systems will go through stages of gradual intensification and almost invariably DAP will become viable before *tractorization* becomes economically feasible. As in most developing countries, the use of engine power mechanization is limited to large-scale farming which is a small proportion of the total farm land. Increasing land and labor productivity for the small-holder farmers requires adoption of suitable, sustainable, appropriate and affordable technologies to augment the family labor available at the farm level. DAP is already in widespread use in the semi-arid agricultural zones of Kenya. It is, therefore, imperative and appropriate to make efforts to increase the efficiency of utilizing DAP for both intensive and extensive cultivation of land. This can be done through better nutritional management of draft animals and optimization of the use of their energy output in order to increase productivity and hence help alleviate the plight of small-holder farmers in the marginal lands.

## 1.2 Draft animal power technology

Although DAP was introduced into Kenya about eighty years ago (Mutebwa, 1979; Starkey, 1990), it has not made an impact in the overall agricultural development partly due to lack of institutional support. In the 1960's the mechanization strategy adopted by most African countries was that of leaping from hand tools into the advanced level of mechanization in an attempt to mimic the contemporary state of development in the Western world. For over twenty years since Kenya became independent, policy makers considered DAP technology a retrogressive approach to agricultural development. The government and other development agencies promoted engine or tractor use through subsidy and tariff reduction on imported machinery and facilitated institutional support structures for the same. This approach implicitly discouraged the establishment of suitable institutions for DAP promotion. This lead to the offshoot of a "bimodal" rather than a "unimodal" mechanization organization structure as described by Ruttan (1990) in his models of agricultural development. The trend is now changing. Efforts are being made to pursue DAP as a viable option for mechanizing small-holder agriculture. There is need for support of both an institutional structure and technical and technological innovations to effectively utilize the current resources and cultural endowments of the small-scale semi-arid farming community.

Treating technical development of DAP as endogenous rather than an exogenous independent factor, along with the technological innovations for crop production, will make DAP play the role of a catalyst in inducing agricultural productivity as prescribed by Ruttan and Hayami (1990). It is possible and desirable to do so, given the existing wide adoption of DAP in semi-arid lands of Kenya. Small-holder farmers are rational decision-makers who are keen in providing for their own welfare while maintaining the production capacity of their land by using sustainable production methods. Evidence of the latter is the soil and water conservation practices that are a common feature especially in the Machakos district such as bench terraces designed to improve water infiltration and retention.

There is now an increasing realization of DAP's potential as an intermediate technological innovation for the small-holder farmers. Kenya's public institutions, development agencies and non-government organizations (NGOs) are enhancing their participation and promotion of DAP usage by the small-holder farmers. The establishment of Kenya Network for Draught Animal Technology (KENDAT) in 1993 is one example of this trend (Kaumbutho et al. 1995). The main reasons for this new development approach are the failure of engine or tractor power to meet agricultural mechanization needs of small scale farmers and the need to alleviate chronic food shortages especially in the medium potential regions of the country that always require government intervention through food rations during drought years.

The soil and climatic conditions of the medium potential lands inhibit land preparation with draft animals before the onset of rains due to the hard soil conditions and the poor physical state of the draft animals. The rainfall pattern of the semi-arid areas is bi-modal and ranges between 612 and 857 mm annually, split almost equally between the long rains falling in March-April and the short rains falling in October-November. Evapotranspiration levels are high and in much of the area potential evapotranspiration is exceeded by rainfall only in the months of April and November *(Republic of Kenya, Statistical Abstracts* 1987). During both rainy seasons, the distribution of rainfall is subject to considerable fluctuation that is unpredictable. The highly variable long rains fail 30% of the time as compared to 10 to 20% rate of failure of the short rains (Siberfein and Marilyn, 1989).

Although DAP technology is culturally integrated by the small-holder semi-arid farming sector, it is not utilized to its optimum potential as observed from the low acreage plowed by farmers and the existence of few off-farm activities employing draft animals. Considering DAP as an enabling capital input, it can be used to maximize its enabling potential productivity capacity in order to optimize the productivity of land and labor. While labor at the household level is considered an inelastic economic resource, land has the potential of both expansion and intensive utilization in the semi-arid agricultural zones.

Lack of technical guidelines in DAP has led to inefficient utilization of animal power from both the energy-use standpoint and equipment design and development aspect. This contention is evident from the fact that farmers design and adopt their own tillage practices such as plow-planting to meet their mechanization needs. Over the years government mechanization extension services have placed greater emphasis on large-scale (capital intensive) mechanization at the expense of DAP mechanization. In order for farmers and researchers to realize the maximum potential of DAP, there is need for increased concerted efforts in research at both basic and applied levels. DAP has the potential of enhancing agricultural productivity, as well as improving the welfare of the rural communities, if adequately managed and utilized during both the "working" season and off season periods. It has distinct benefits over the use of hand tools and engine power for the small-holder farmers, which include:

- reduction of human and animal fatigue (drudgery)
- increasing agricultural productivity
- expansion of area cultivated
- reduction or elimination of labor bottlenecks
- minimal use of imported inputs (foreign exchange conservation)
- renewable energy source at low running cost
- improvement of timeliness or increase of the intensity of operations
- multi-purpose use of animals
- manure for garden fertilization

DAP use in Kenya for over eight decades has remained relatively static. Farmers have tended to use the same tools, basically a Victory moldboard plow for both primary tillage (often plow-planting especially when late in land preparation) and inter-row weeding as observed by the researcher during his tenure in mechanization extension services. There is little evidence of the use of other DAP farm tools, except ox carts for transportation. Lack of technological innovations has kept the farming community in the predominantly DAP farming zones in a "static" economic equilibrium limiting them from making upward advancement of their welfare. Utilization of this power source has also remained quite low, as farmers do not use their animals in-between the cropping seasons. One way of getting the most out of DAP in small-holder agricultural production is to increase its utilization in terms of productive work-days per year, acreage plowed, and diversification of its application at the farm and regional level.

Personal contact with researchers and agricultural extension workers revealed that there is a perception that if modest technical changes that would not demand high extra investment, but instead improve the utilization and management practices of DAP are introduced, farmers would be willing to make changes that have the potential of high returns. In order to make the best use of DAP, the potential power output from animals and the draft force demand by the implements must be known or be estimated accurately. Matching implements to the available animal power would enhance the efficiency of energy use and create less fatigue to the prime mover (animals) and operator. However, unlike engine power which can be easily estimated from the specific calorific value of petroleum fuels and the predetermined power output of the engines, DAP energy source does not render itself to convenient methods of prediction. However, the physiological demands of an animal at work and the mechanical draft requirements of the implements are two primary variables that can be used for the determination of the level and rate of energy utilization in DAP systems.

The data base on DAP utilization is scant because research in this area has been limited. Availability of a DAP data base would benefit researchers on DAP farming systems, rural development project implementers and agricultural mechanization extension workers who would use the data on DAP for prediction of energy utilization, power requirement or modeling purposes.

Tillage is considered the most energy demanding cultivation exercise at the farm level. Almost one-third of the energy needed in the total farm operations is taken up by tillage (Kitani, 1987). Draft animals derive their work energy from the feed they eat. Regrettably, they have to be fed throughout the year, despite their being used for only a fraction of the time. It is therefore important to make the best use of the animals during the working season in order to efficiently use their energy output. Understanding the animal-implement interaction and the effect of the variables that influence the performance of the DAP system as a whole would enhance the utilization of this energy source through computer simulation modeling.

A computer simulation model, Energy Utilization Model for Draft Animal Power (EUMDAP), was developed by this research exercise to be used for the improvement of DAP utilization. The program is capable of simulating various scenarios given varying field conditions, size of animals, implement size and the feed quality and quantity for the draft animals. Development of computer simulation models requires the use of historical data or acquisition of primary field data for parameter estimation. Limited research has been conducted in the area of animal-implement systems due to the difficulty of simultaneously monitoring both the mechanical output from animals and the physiological parameters that affect the DAP system performance. In this study, therefore, field data collection was performed to obtain authentic parameter estimators in Machakos and Mbeere districts in Eastern province of Kenya where DAP is widely adopted. Simultaneous collection of mechanical and physiological data of the DAP systems was done using a sophisticated electronic data acquisition system (DAS). A total of seven physiological and physical parameters were monitored. The physiological data of the oxen and the equipment performance data were collected for varying soil types and conditions, varying operational speeds and various teams of animals, as well as varying depths and widths of tillage. Historical and operational data at the household level were also gathered through a questionnaire administered by the researcher with a random sample of small-holder farmers in the two districts.

## 1.3 Objectives of the study

The primary objective of this research exercise was to develop a computer simulation model for energy utilization of DAP systems that can be used by researchers and extension workers in the promotion and improvement of DAP technology in order to enhance utilization of DAP systems. The main focus of the research project was in the semi-arid areas of Machakos and Mbeere districts where DAP is predominantly used. Specific objectives of the study included the following:

1 Develop and build an electronic data acquisition system for monitoring physiological and mechanical parameters of an animal-implement system simultaneously.

2 Perform DAP-SYS data collection in the farmers' fields with electronic DAS to be used for validation of the computer simulation model.

3 Obtain socio-economic field data from a random sample of farmers in semi-arid lands for estimating DAP-SYS operational parameters for the computer simulation model.

4 Develop a computer simulation model that would provide estimates of various output variables for optimum utilization of DAP systems in varying field conditions.

5 Perform simulations for various DAP system scenarios for different levels of applications to include:

- sole use of DAP-SYS by owner-operator
- DAP-SYS owner-operator/hiring out

In order to achieve the above objectives, a DAS for collecting and monitoring energy input and output of a DAP system was designed and built (see description in chapter III). It was capable of collecting physiological and physical data of the animal-implement system at work. The data collected with the DAS from the DAP system at work were monitored, logged and saved with a commercially available data logger (RAMLOG EI9000[1]) and a portable personal computer.

The physiological variables monitored for the animal were: heart rate, respiration rate, stepping rate and body temperature. Four mechanical variables: depth of tillage, ground speed and horizontal and vertical draft force were monitored simultaneously with the physiological data. The results of the field tests are discussed in chapter V.

[1] Trade names are used in this dissertation solely to provide specific information. Mention of a product name does not constitute an endorsement of the product by the author to the exclusion of other products not mentioned.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Draft animal power in agriculture

The use of animals to augment human beings' limited power supply dates back to about 3200 B.C. when the Summerians first used animals for plowing, threshing and transport (Zeuner, 1963). Though animal power preceded tractor power in the historical development of agricultural mechanization, literature is scarce on the prediction and evaluation of this age-old power source. DAP technology has been considered as an intermediate technology that would phase out for improved, efficient and more complex technologies. Though this has been the case for the Western civilizations where constraints imposed by inelastic supply of labor have been offset by technical and technological advances in agricultural production, DAP still plays a significant role in the agricultural production and transportation sectors of most developing countries.

Draft animals commonly used for tillage, processing, transportation and water pumping are horses, mules, oxen, buffaloes, camels and donkeys. Oxen, and donkeys are the most popular work animals in sub-Saharan Africa. Donkeys are used mainly as pack animals and occasionally to pull carts while oxen are used primarily for tillage purposes. Sims and Ramirez (1989) postulate that the use of animals as a power source is extremely important. They quote Smith (1981) and Lawrence and Pearson (1985), who estimated that there are about 200 million draft oxen and buffaloes in the world that produce 85% of the power used in developing countries' agriculture. Kemp (1987) documents that global animal power represents about 35 GW of power source in the countries where DAP is used.

An estimated 15 million draft animals are in regular use in sub-Saharan Africa, cultivating between 5 and 10% of the land area planted with annual crops (FAO, 1983). The trend to use DAP in Sub-Saharan Africa is increasing. Starkey (1986) emphasizes that since there is currently a significant interest in animal traction, it is important that the resources being allocated to DAP systems are effectively utilized. Singh et al. (1989) concurs with other proponents of DAP by stating that this vast power resource should be utilized more efficiently. An increase in the number of hours DAP systems are used per year through hiring out and off season usage would be a way of increasing the systems' utilization level.

Attempts to promote the use of engine power through government tractor hire services for small-holder agriculture in sub-Saharan Africa have been a technical and economic disaster (Pingali, et al. 1987). The failure and subsequent disbanding of the government of Kenya's National Tractor Hire Service that was started in the early 1960s bears testimony to this contention. The use of DAP in most developing countries will continue to play a significant role in the foreseeable future for the food production and transportation in developing countries. Research findings and development efforts on DAP technology will contribute in a great measure towards improving the utilization and effectiveness of this mode of mechanization.

## 2.2 Draft animal power in Kenya

The role of DAP in agricultural mechanization has a varied history in Africa and other developing countries. In Kenya animal power was introduced over 80 years ago by white settlers (Mutebwa, 1979; Starkey, 1990). The ox plow was first used in Machakos district by settlers in 1903 and adopted by local farmers in 1910 (Downing et al. 1988).

This innovation was not widely accepted primarily because there was little institutional support. For over twenty years since Kenya became independent in 1963, policy makers did not consider DAP as being important in agricultural development. This meant that the advancement of DAP as a mechanization option was relegated to the enterprising small-holder farmers and non-government development agencies. Despite this apparent indifference by the public institutions on DAP promotion, Starkey (1988) has documented that about 700,000 working cattle are employed in agricultural production in Kenya predominantly in Eastern, Nyanza and Western provinces.

In the recent past, there has been a change in the right direction for DAP proponents. Kenya's development plan of 1974-78 enunciated a policy of giving priority to increasing the productivity of Kenya's small-scale farmers which included emphasis on animal powered equipment and other 'appropriate technologies'. A workshop on "Farm Equipment Innovations for Agricultural Development and Rural Industrialization" held at Kabete, Kenya in 1975 (Westley and Johnson, Eds. 1975) accelerated this positive change of attitude on DAP. Policy makers have realized the critical role that DAP plays in tillage and transportation for small-holder agricultural producers. The National Food Policy Paper of 1981 (Republic of Kenya, 1981) specifically cited promotion of animal power by stating that:

> ...the main aim of the policy will be the development and wider usage of more appropriate technology to increase labor productivity and to reduce the present emphasis on imported capital-intensive equipment. The availability of agricultural machinery, particularly that required for land preparation and seeding, will be increased through programs to supply mechanized ox-drawn and hand equipment.

The majority of draft oxen used in Kenya are Zebu (*Bos indicus*) whose weight seldom exceeds 350 kg and often drops to 250 kg in the dry season when natural pasture is deficient of forage. It is believed that the Zebu cattle were introduced into Africa from India in about 1500 B. C. They are also found in East Asia, Gulf Coast states of the USA, and Latin America where they are called Brahman cattle. Zebus are better adapted to the tropics because they have been selected under these conditions for hundreds of years by both artificial and natural means. They have adaptive traits like resistance to, or tolerance of pests and diseases; tolerance of intense sunshine, heat and humidity; and ability to utilize high-fiber content forages (Lasley, 1981; Mukasa-Mugerwa, 1989). They also mature late but produce little milk.

The Zebu cattle are characterized by a pronounced hump over the shoulder and neck, horns which usually curve up, and drooping ears. In Kenya, as in most sub-Saharan African countries, oxen (mature castrated bulls) and steers (young castrated males) are used for draft work. Female cattle are primarily used as breeding stock and for domestic milk production and not for draft purposes. Draft cattle are usually trained from the age of two to four years and work for a period of between five and ten years before they are replaced.

Although in some developing countries single animals are used either with head yokes or breast harnesses, this research project concentrated on a pair of oxen harnessed together with a neck yoke. The harnessing system most commonly used in Kenya as a force transmission system linking the animals to their working implements consists of a yoke and a chain. The chain's length is used to regulate the vertical position of the line of pull, increasing or reducing the angle of pull. The ideal line of pull being collinear with the animals' center of mass, the implement's center of gravity and the soil's force (Inns, 1990). Two major types of yokes are used in Africa, those that are tied to the horns of the animal and those that take power from the withers (Starkey, 1989). The latter version of yokes are often referred to as neck or shoulder yokes. The withers refers to the part of the back that is over the shoulders, directly above the thoracic vertebra. In Zebu cattle the withers are immediately in front of the hump. The hump, therefore, helps to support the yoke which is placed right ahead of it. Kenyan small-holder farmers use neck yokes exclusively.

Neck yokes are wooden poles used to hitch two animals together side-by-side. In their simplest form, they are made of a wooden pole with pegs inserted in holes on either side of the animal's neck that help to restrain lateral movement. Improvement of neck yokes has been concerned with increasing the contact area of the yoke on the animal and also padding the yoke to minimize bodily abrasion and subsequent sores (Oudman, 1994).

## 2.3 DAP utilization

The overall utilization of draft animals can be measured in terms of the number of hours the animals work per year. Small-holder farmers in Kenya tend to use their animals mainly for tillage and to some limited extent for transportation. Land preparation is carried our during a three-week period in each of the two cropping seasons. Depending on the acreage under cultivation, draft animals can be used for a maximum of about 180 hours per year when working for 6 hours per day for 6 five-day weeks on tillage work for the two cropping seasons. Srivastava (1987) and Thakur (1989) both document that annual utilization of oxen in India ranges from 300 to 1500 hours when used for multi-task purposes. The economics of using DAP in Kenya are currently limited to the immediate needs of land preparation in order to plant in time.

The draft oxen are rarely used beyond the land preparation period when they are in their prime physical condition. After the tillage season is over and forage supply is plentiful the oxen regain their physical condition. Although most farmers have only one type of ox implement (Victory plow), there are scope and potential for increasing the utilization of DAP for small-holder farmers by engaging the animals in other on and off-farm tasks. Muchiri (1984) cited Heyer et al. (1976) who noted that:

> As long as the ox equipment in use consists of the mouldboard plough, ox carts and little else, as at present, the usefulness of oxen is very limited. Only in a few areas are oxen used at all extensively and while the scope for using oxen is obviously restricted to areas where the topography is suitable and the availability of land sufficient, there is certainly scope for more intensive use of oxen in some areas and there are additional areas that could benefit from the use of oxen at present.

There are a number of other DAP implements that have been tried and utilized in other sub-Saharan African countries that could be useful in Kenya's semi-arid lands. An assortment of weeding implements, ridgers and mutli-purpose tool-bars have been developed and used in Tanzania, Zambia and Zimbabwe (Stevens, 1994; Kwiligwa et al. (1994); Kayumbo, 1994; and Hagmann 1994). The main drawback in the acquisition of single purpose implements is the high relative price of an implement that is used for a specific task only.

## 2.4 DAP energy output

Physical work by humans and animals is a complex interactive process involving both the active and passive elements in a power transmission system. The normal regime for energy supply to the animal's muscles is up to the sub-maximal level of metabolism (aerobic). In draft cattle the likelihood of reaching anaerobic threshold is only when activities involving sudden intense efforts are done, say pulling a cart out of a ditch (Pearson and Archibald, 1989) or when the animals are constrained to work beyond their aerobic limits. Continued work in anaerobic range results in the accumulation of lactic acid in the muscles and body fluids leading to fatigue which inhibits further glycogen breakdown (Wilmore et al. 1994).

A draft animal can be considered a 'machine' that converts chemical energy to mechanical energy in the muscle tissue which does the work. An analogous comparison of draft animals with mechanical chemical energy converters (engines), shows that the basal energy supply of an animal are utilized for maintenance and growth when not doing any work. A fossil fuel engine on the other hand needs "basal" energy (idling) for basic functions such as cooling, battery charging, and overcoming friction.

The energy derived from feed by animals is referred to as metabolizable energy (ME). ME is obtained from the digestible energy (DE) of the feed that the animals eat. Gross energy (GE) of the feed minus the energy lost in the feces constitutes DE. ME and DE are strongly correlated. DE as a proportion of GE may vary from 0.3 for very mature, weathered forage to nearly 0.9 for processed, high quality cereal grains. For most forages and cereal grains, the ratio of ME to DE is about 0.8 but can vary considerably depending on intake and feed resource (ARC, 1980; NRC 1996). The priority in the energy utilization by an animal is to meet the net maintenance energy ($NE_m$) needs first. The remaining energy is then available as production or growth energy ($NE_p$), for storage of body mass or for work as in the case of working animals. Under-fed draft animals utilize their storage energy for work leading to loss of weight.

Theoretically it is possible to calculate the amount of feed necessary for an animal in order to get a certain level of energy output (Crossley and Kilgour, 1983). The gross energy (GE) value of typical feed stuffs can either be measured in the laboratory using bomb calorimeter or it can be determined from animal nutrition literature such as National Agricultural Research (NRC) or Agricultural Research Council (ARC). Mature animals require energy for bodily maintenance and production (milk, meat) or work whereas growing animals require extra energy for growth as well.

Growing cattle require about 1.3 to 1.7 kg of total digestible nutrients (TDN)[2] above maintenance in order to gain 0.45 kg per day (cited by Sen, 1966). According to FAO (1972), the maintenance requirement of working oxen in West Africa was estimated at 2.6 TDN. Lawrence (1985) and Singh (1985) in separate experiments concluded that the energy used by oxen during a normal working day is equivalent to between 1.67 and 2.5 times the energy they require for the maintenance need when working 5.5 hours per day. The major constraint to providing this energy where only poor quality feed (containing about 9MJ of ME/kg of dry matter [D.M]) is available, is the voluntary dry matter intake (VDMI-or appetite limit) of the animal.

In determining the performance of draft animals, the question arises as to which measurable parameters should be used and varied in such a manner as to optimize performance of the DAP system. The energy available from the animals is a direct output from the feed the animals consume. The duration of working for the draft animals depends on the quality and quantity of the feed they eat and also on the amount of energy they expend per unit time (power developed). The work that the animals are able to perform is

[2] 1 kg TDN = 4.4 Mcal DE (NRC, 1966); 1 Mcal = 4.184 MJ

based on the physiological processes associated with movement and muscular activity (Pearson, 1985; Macmillan, 1985). While prediction of the energy requirements for DAP is not directly deterministic, the rate at which animals use oxygen in sub-maximal (aerobic) metabolism has a linear relationship with the power which animals can develop.

Mueller et al. (1994) working with donkeys showed that oxygen consumption varies linearly with mass-specific work rate ($W_t$/kg). Gottlieb-Vedi et al. (1991) demonstrated that the volumetric rate of oxygen consumption ($VO_2$ ) and draft of standard bred trotters had a direct relationship. Kuhlmann et al. (1985) also arrived at similar conclusions when working with Hereford calves on a treadmill. Although oxygen uptake is the most direct measurement of energy expenditure in animals (Brody, 1964), it is difficult to monitor oxygen utilization in field conditions. The constraints inherent in the determination of animal performance are the finite energy reserves that decline with time and the limitation of the amount of oxygen intake for oxidation of the energy source (Macmillan, 1985).

Various researchers have shown that the heart rate (HR) can be used to predict the energy expenditure of animals since $VO_2$ is directly related to cardiovascular response of animals. The aim of any physiological study of draft animals should be to knit together the observations made in the laboratory with field experiences, so that a complete picture can be constructed (Pearson, 1985). Pearson (1985) further emphasizes that measurements such as heart rate, respiration rate and body temperature are relatively easily monitored in animals in the field and can be useful in comparative studies of animals at work.

### 2.5 DAP energy utilization models

Experiments conducted by the Center for Tropical Veterinary Medicine (CTVM) in Costa Rica showed that there is very little need for extra protein during work for draft animals. However, there was need of more energy feed to avoid loss of weight (Lawrence, 1985). If the net energy required for work is known and the heat increment associated with work is also known, combining the two would enable computation of the extra metabolizable energy required for work and hence the feed requirements. Lawrence (1985) used the following factorial model to compute the extra energy used for work including energy for walking, carrying loads, pulling loads and walking uphill:

$$E = AFM + BFL + \frac{W}{C} + \frac{9.81HM}{D} \qquad (1)$$

where:

E = extra energy used for work, kJ
A = energy used to move 1 kg of body weight 1 m horizontally, J
F = horizontal distance traveled, km
M = live-weight, kg
B = energy used to move 1 kg of applied load 1 m horizontally, J
L = load carried, kg
W = work done whilst pulling loads, kJ
C = efficiency of doing mechanical work (work done/energy used)
D = efficiency of raising body weight (work done raising body)
H = vertical distance traveled, m

Empirical and experimental data are available for the parameters used in the above model for various sizes and types of draft animals (Appendix A). The model developed by Lawrence is useful for estimating energy requirements for performing various field tasks. It is especially useful when the energy demand from draft equipment and the maintenance energy of draft animals can be accurately estimated. Simulation of the energy needs to perform farm and off-farm tasks with animal-implement systems without subjecting the draft animals to body weight loss can be done with this model.

Crossley and Kilgour (1983) developed energy-feed relationships that can be used to compute the quantity and quality of feed required for a pair of animals to perform a particular task. The relationships used for the calculations are:

| | | |
|---|---|---|
| DE | = | 0.45 to 0.85 * GE |
| ME | = | 0.8 * DE |
| MR | = | 8.3 + (0.091 $W_t$) MJ/day |
| AL | = | 0.025 * $W_t$ kg/day |
| 1 kWh | = | 3.6 MJ |

where:

| | | |
|---|---|---|
| DE | = | digestible energy, MJ |
| GE | = | gross energy, MJ |
| ME | = | metabolizable energy, MJ |
| $W_t$ | = | live body weight of oxen, kg |
| MR | = | maintenance ratio |
| AL | = | appetite limit |
| kWh | = | kilowatt-hour |

These relationships can be used to estimate the amount of feed required per season and hence the area of land required to maintain the animal per year, provided the yield per unit area is known. This model together with Lawrence's model are complementary in the estimation of draft energy requirements and the amount of feed required to provide this energy to the animals.

Models based on physiological parameters have been developed and used by various researchers. Estimates of energy use derived from the heart rates of working animals and their body weight have been accurately predicted for draft oxen. Richards and Lawrence (1984) derived a predictive equation for Brahman oxen (*Bos indicus)* that uses the relative heart rate (RHR) and the metabolic weight[3] $(W_t)^{0.75}$ of the animal to determine energy requirements of working draft cattle under field conditions. The RHR was defined as:

$$RHR = \frac{WorkingHeartRate}{RestingHeartRate} \tag{2}$$

The weight of the animals used in their experiments ranged between 510 and 630 kg. Other researchers have developed similar models that confirm the validity of Richards and Lawrence's model in varying ambient conditions and size of cattle. Even though the animals which they used are larger than those found in Kenya; Sneddon (1986), Mathers et al. (1985), and Sneddon et al. (1984) have all documented that the model works well and is independent of ambient temperature and animal size. The regression coefficient of the model developed by Sneddon et al. (1984), equation (5), compared well with that of Richards and Lawrence (1984), equation (3) as shown below:

$$EE_w = 24.94RHR - 16.25 \qquad (r = 0.91;\ n = 49;\ P=0.001) \tag{3}$$

$$HR = 0.0318EE + 46.2 \qquad (r = 0.94;\ n = 56) \tag{4}$$

$$EE_w = 25.4RHR - 17.7 \qquad (r = 0.95;\ n = 54) \tag{5}$$

where:

$EE_w$ = actual energy expenditure per unit metabolic weight, $W/(W_t)^{0.75}$
HR = heart rate

Extrapolation of the value of $EE_w$ when RHR = 1.0 (the energy demand of the oxen at resting heart rate) in the first model was found to be 6.94 $W/(W_t)^{0.75}$. This figure derived

---

[3] *Metabolic weight ($W^{0.75}$) or Empty Body Weight ($EBW^{0.75}$) is the body weight of an animal in kilograms raised to the three-fourths power (NRC, 1981; NRC, 1996).*

experimentally by Richards and Lawrence (1984) compares well with 6.62 $W/(W_t)^{0.75}$ obtained for Japanese cows by Yamamoto et al. (1979).

O'Neill and Kemp (1989) working at the Central Institute of Agricultural Engineering (CIAE), in Bhopal, India showed that the HR and work rate of Brahman cattle and buffaloes have a direct relationship. Their model shown below predicts the heart rate for Brahman cattle from the work rate:

$$HR = 0.06P + 72 \qquad (r = 0.95) \qquad (6)$$

where:

P = power developed by animals, W.
HR = heart rate

Since these models have been tested under both laboratory and field conditions, they can be used with confidence to model the energy requirements of Zebu cattle (*Bos indicus*). Subsequently the amount of feed required to provide the net energy ($NE_p$) that will give the power needed from the animals can be estimated from the ME of the feed. This would require that the maintenance energy ($NE_m$) or the basal metabolism rate (BMR), voluntary activity and heat increment due to feeding and digestion, be accurately estimated too. The various energy utilization models developed can be used to predict the energy use of Zebu oxen depending on the field conditions and the allometric parameters of the draft animals.

## 2.6 Data acquisition systems

Electronic data acquisition systems have been developed and used to collect data, or monitor variables of biological and physical systems in production and research environments. One of the major advantages in this advent of technological data acquisition methodology is the speed, accuracy and data storage capacity of the systems.

Rugged and miniaturized computer packages are now available for field data collection and storage. Several research institutions have developed tailor-made packages for DAP-SYS data acquisition primarily to collect physical and physiological data independently. CEEMAT in France, Silsoe Research Institute (UK) and the Swedish University of Agricultural Sciences, Uppsala, have developed instrumentation for monitoring DAP energy utilization. O'Neill (1989) documented the development of a computerized instrumentation package that has been used for a comprehensive assessment of draft animal performance. This package has been used in India and Ethiopia as reported by O'Neill and Kemp (1989). The data collected using the instrumentation package included mechanical variables to monitor the energy expenditure by the animals and the physiological responses of the animals at work. The instrumentation was made to work in such a way that the "animal-implement" system was considered as a single entity composed of various components in order to observe the interactions that occur between animals and implements and which may influence the system's performance. The conclusions drawn from the experiments conducted by O'Neill and Kemp (1989) indicated that the instrumentation was reliable.

The ideal method for the determination of energy use is by the collection and analysis of data on oxygen consumption rates ($VO_2$ – ml/kg/hr) and the corresponding rates of carbon dioxide emission ($VCO_2$ - ml/kg/hr). The respiratory exchange ratio - $VCO_2/VO_2$ - (RER) obtained from the ratio of oxygen used versus carbon dioxide produced can be used to compute the heat increment and hence the energy used as well as the mix of substrates (types and mixtures of fuel) burned in the process (Wilmore and Costill, 1994). The RER value varies with the type of fuels being used for energy production (Appendix B). The amount of oxygen needed to completely oxidize a molecule of carbohydrate or fat is proportional to the amount of carbon in that fuel. For example, glucose has six carbon atoms. During combustion six molecules of oxygen are used to produce $6CO_2$ molecules, $6H_2O$ molecules and 38 ATP molecules[4]. For example, RER for carbohydrates is 1.0, fats have an RER of 0.71 and proteins 0.69. Oxidation of these fuels yields 5.05, 4.69 and 4.46 kcal per liter of oxygen consumed respectively (Wilmore and Costill, 1994). Instruments like the Oxymax System by Columbus Instruments, Ohio, USA, are perfected for measurements of gaseous exchanges in animals but are restricted to laboratory applications where work situations are simulated with small animals such as rats and rabbits.

According to Pearson (1985) and Rautaray (1987) the most important physiological responses to work that can be measured on working animals without causing them too much discomfort are changes in heart rate, breathing rate and temperature. The greatest stress to the animals as observed by Rautaray (1987) was due to erratic draft force which elicited a higher heart rate response than a smooth draft force at the same mean power output.

### 2.7 Computer simulation models

Simulation modeling in agriculture has grown in parallel with the popularity of systems analysis. The demand for a better understanding of the real agricultural systems makes simulation modeling a valuable tool for analyzing existing systems and designing new ones. Like other farming systems, DAP systems are dynamic in nature and are based on biological, physical and economic principles. A systems approach to DAP simulation enables the various components involved in the production of and utilization

[4] $6CO_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + 38ATP$. $\therefore$ the $RER = 6VCO_2/6VO_2 = 1.0$

of energy by animals to be monitored and predictions made for varying endogenous and exogenous factors.

The concept of modeling, as defined by Manetsch and Park (1993), is the construction of an abstract model as a representation of "the real thing" where the latter is the real situation or problem that is being studied, and the model is a useful representation of that situation that can be dealt with intellectually and reasonably in terms of mathematics or computer programming. Computer simulation models have become useful tools in modeling agricultural production systems. This research technique is considered cost effective because *near-real* systems that mimic real world physical systems can be designed and constructed on computers. There is no limit of the level, number and configurations of manipulations that a computer model can be subjected to, hence providing large possibilities of scenarios. Naylor et al. (1968) describes the purpose of a simulation model as being to enable the analyst to determine how one or more changes in aspects of a modeled system may affect other aspects of the system as a whole. System modeling on computers has been applied in machinery systems management. Various researchers have used computer simulation for machinery management systems. Tokida (1992) developed a Tillage Machinery Management Model for Rice Farming Projects in Kenya. Pingali et al. (1987) noted that appropriate agricultural mechanization should be developed based on a farming system model. Ismail (1991) also developed a Simulation Model for Field Crop Production Machinery System. Little work, though, has been done on computer simulation of DAP systems. Phillip et al. (1986) applied principles of linear programming in their research on economic implications of animal power in Nigeria.

Although much work has been done on DAP in various developing countries, centralized and comprehensive documentation is scarce. Renewed interest in DAP has changed the *status quo*. In the recent past, research agencies and individuals have made efforts to document DAP literature and other related materials. Notable publications include a selected animal traction bibliography by Goe and Hailu (1983) and a comprehensive one by Starkey (1991). Several researchers have collected data that can be used to estimate coefficients of variables for DAP parameters. Data collection for a computer simulation program requires that parameters be estimated accurately. Similarly, the range of variables used should be realistic in order to reflect real world scenarios. The data collection procedures used in this research included a soio-economic data survey administered through a questionnaire by the researcher and an electronic DAS for the physiological and mechanical data of draft oxen at work in two districts in Eastern Province of Kenya.

# CHAPTER III

# DATA COLLECTION INSTRUMENTS

## 3.1 Introduction

The data required for the development of the DAP computer simulation model were obtained through two methods using two types of instruments. Socio-economic baseline data covering historical aspects, operational factors and resource endowments for a cross-section of small-holder farmers in two administrative districts of Eastern Province of Kenya were obtained through a survey questionnaire. The procedure of the baseline data collection is described in chapter IV. Secondly, a custom-made DAS was used to collect empirical data of energy utilization of draft animals while performing tillage operations. This chapter will describe the DAS equipment. Both the empirical and socio-economic data collected were used to design and implement an energy utilization model code named Energy Utilization Model for Draft Animal Power (EUMDAP) for DAP systems in semi-arid lands of Kenya.

## 3.2 Data acquisition system hardware

Various researchers have used data acquisition systems similar to the one described in this chapter for collecting physiological and mechanical data that can be used in the estimation and prediction of energy expenditure of draft animals at work. Draft animal energy data monitors have recently gained importance as researchers investigate the nature and manner of energy delivery from draft animals to tillage and other farm implements. The motivation driving this renewed interest is the need to enhance the utilization of DAP energy source for improved land and labor productivity especially for small-holder agriculture in semi-arid lands of developing countries where the risk of inadequate feed supply is a chronic issue. The DAS for this research was designed and made by the researcher in collaboration with the Swedish University of Agricultural Sciences, Uppsala, Sweden, specifically to meet the animal draft energy data acquisition needs for DAP systems of working draft oxen.

Animal power sources derive their energy for work from metabolic fuels stored in the animals' muscle and liver (glycogen peripheral pools) as well as in their fat (adipose tissue). The process of energy conversion from the stored chemical energy to mechanical energy at the cellular level (catabolism) is a complex one involving the breakdown of the compound adenosine triphosphate (ATP), the immediate energy source for muscle contraction, which contains a high energy phosphate bond (Bursztein et al. 1989). Animals utilize oxidative metabolism (aerobic) for continuous energy supply when working (Wilmore and Costill, 1994). The process of breaking down finite ATP and replenishing it is a continuous one for any muscular activity to take place in an animal.

Energy expenditure is the key factor for quantifying animal work load physiologically. The most direct method of determining the energy expenditure of animals is to measure the gaseous exchange ($O_2$ and $CO_2$) by direct calorimetry (heat increment) or indirect calorimetry because the level of energy expenditure and the type of fuel oxidized are directly proportional and related to the volume of oxygen consumed by the animal and the volume of carbon dioxide released during the combustion of energy fuels.

The purpose of the DAS developed for this project was to monitor the mechanical energy produced by oxen at work and the effect that the rate and intensity of work has on the physiological response of animals at work. Traditionally the force exerted by draft animals whilst pulling loads has been measured using a dynamometer such as a mechanical spring, a hydraulic cylinder or strain gauge on a mechanical linkage. The measuring transducer connects the power source (animal) and the load it pulls in such a way that the reading obtained is proportional to the force exerted by the animals (Lawrence and Pearson, 1985). Due to limitations of making direct accurate measurement of energy expenditure by animals in field conditions, new methods of estimating it have been devised. Some physiological changes such as cardiovascular responses to work can be used to provide information on the rate of energy expenditure of animals in work load situations. Estimation of energy use through relative heart rate (RHR) and the metabolic weight, $(W_t)^{0.75}$, of oxen have been used by various researchers successfully (Richards and Lawrence 1984; Sneddon 1986; Mathers and Sneddon 1984 and O'Neill 1989). This research exercise used similar DAS equipment tailor-made for the project and utilizing a commercial data logger to obtain both physiological and mechanical data from DAP systems of oxen at work.

The DAS equipment consisted of four physiological sensors, three mechanical sensors, a data logger, a portable computer, and a battery power source. The electronic circuitry of the mechanical sensors was housed in a box together with a 7.0 V battery that provided power for the whole DAS (Figure 3.1). A separate box contained the four physiological sensors. The layout of the system enabled the data transmission cables from each box to be fed into the data logger for temporary storage of the data before dumping it into the portable computer or floppy diskettes. The system was designed to operate as an integral part of the animal-implement DAP system with all the data from the transducers being monitored and recorded simultaneously. Figure 3.2 shows the complete layout of the instrumentation as it was mounted on both the draft oxen and the tillage implement. When the DAS was collecting data, it was operated as one integral DAS-DAP system operating as a unit with all the data collected being channeled to the RAMLOG EI9000 data logger. Three electronic circuit cards for the physiological and

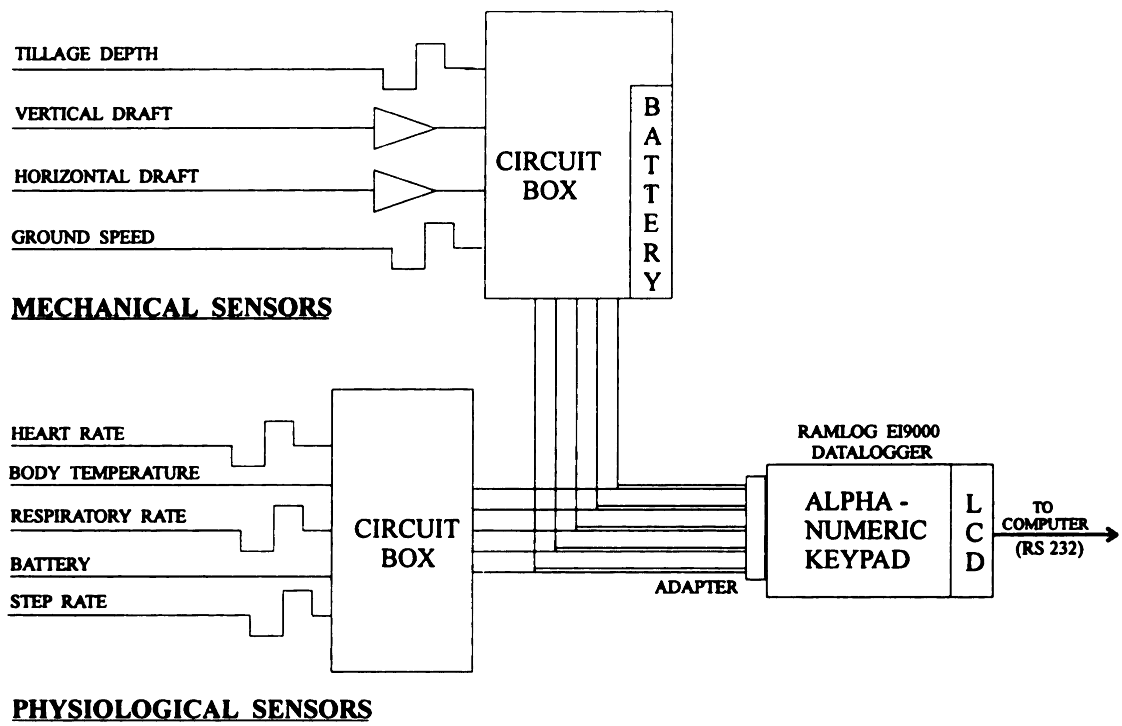


Figure 3.1: Block diagram of Data Acquisition System (DAS).

mechanical transducers were built and housed in three separate boxes. The circuits for the four physiological variables, heart rate, breathing rate, body temperature and stepping rate, were housed in a plastic box that was secured on the side of the animal's body with a leather belt strap during the data collection exercise. This box was mounted in such a way that the researcher could monitor the analog needle display which monitored the operation of the heart rate sensor during the data collection process. The box containing the tillage depth and ground speed electronic circuitry and the battery power pack were contained in a separate box which was mounted on the plow beam together with the load cell circuit box (junction box). The load cell sensor output

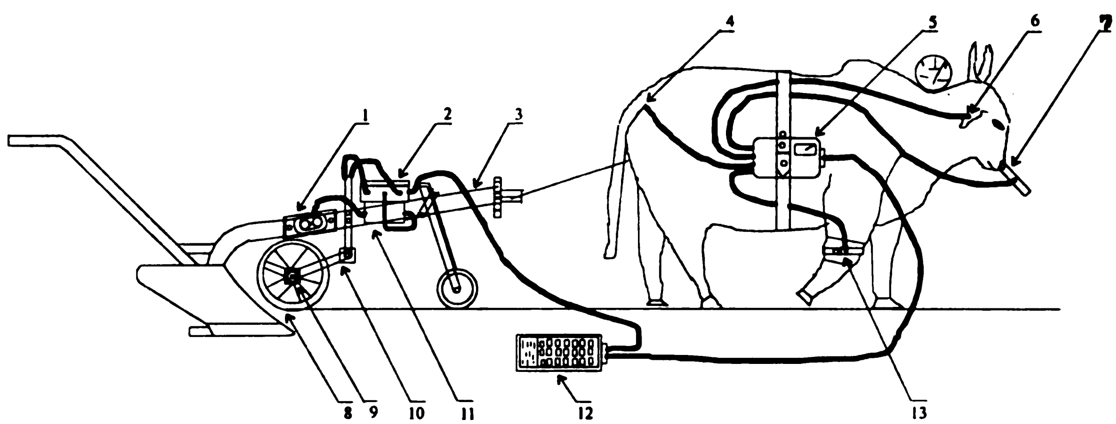


Figure 3.2: Schematic view of the animal-implement Data Acquisition System instrumentation.. 1: Load cell; 2: Depth-ground speed sensor junction box; 3: Plow beam; 4: Body temperature sensor; 5: Physiological electronic-junction box; 6: Heart rate sensor; 7: Respiration rate sensor; 8: Depth-ground speed measuring wheel; 9: Ground speed sensor; 10: Depth sensor: 11: Mechanical electronic-junction box; 12: Ramlog EI9000 data logger; 13: Step rate sensor.

cables transmitted data to the logger via the depth-speed wheel circuit box. Two shielded cables, one for each respective set of sensors, transmitted the data from the respective junction boxes to the data logger through a 37-pin female-male adapter connector. The transmission cables were long enough to allow the researcher to walk along-side the DAS-DAP system some distance away from the plow operator and the animals as he operated the data logger.

One 25.4 cm (10") single-bottom Victory moldboard plow was modified and used for all of the experiments including those at the farmers' fields. Using the same plow for all experiments eliminated equipment variability as a factor. One plow share was used for all experiments. It did not show obvious signs of wear that would have necessitated its replacement.

The central feature of the DAS was a 20 channel hand held data logger (RAMLOG EI9000) weighing about 500 gm including batteries. The logger is an interactive commercial microcomputer developed by A.B.I. Data of Belgium. It operates on a real time clock with a programmable system software for monitoring, sampling, recording, and saving data in a 128 KB RAM. It operates on a power supply range of 4.2 to 7 V provided by either four AA alkaline batteries or a commercially available rechargeable power pack (PU-1) that has a life span of 30 hours when fully charged. The logger's memory capacity is $1.5 \times 10^6$ data points when in continuous use with multiple channels (RAMLOG EI9000 User Manual). The micro-computer-user interface is through a full alphanumeric keyboard that is menu driven.

The signal sensors were connected to the RAMLOG data logger through four types of interface modules (signal conditioners): voltage/current inputs; counter inputs/digital event inputs; thermocouple inputs; and temperature/humidity/pressure inputs. The differential and single ended analog data acquisition sensors had a programmable range from $\pm$ 100mV to $\pm$ 10V. The analog-to-digital converter (ADC) had a capability of 11 bits plus sign, a programmable gain amplifier and software calibration. Technical details of the logger are provided in Appendix C.

When the logger RAM filled up, the data were transferred to a portable computer via an RS232 cable using the built-in data transfer software (FIRMWARE). The portable computer used for downloading the data was an IBM compatible CityNote with a

486DX hard disk of 4 MB working memory (RAM) and 170 MB storage ROM with aa operating speed of 25 MHz.

Seven data sensors were used for the physical and physiological variables of the animal-implement system. Three mechanical sensors monitored the tillage depth, ground speed and the draft force (vertical and horizontal components) generated by the implement. The plow beam of the Victory plow used for the experiments was cut into two pieces to accommodate the draft force transducers (load cell) which were bolted as an integral part of the two section-plow beam. A 50.8 cm (20") bicycle wheel (depth-speed wheel) was instrumented to measure tillage depth and ground speed. The axle of the depth-speed wheel was connected to a hinged frame whose vertical section was bolted to the plow beam in such a way that the wheel rolled freely on the unplowed land and also the wheel's axis of rotation moved vertically in response to the changing depth of tillage because of its hinged joint (Fig. 3.2).

The speed sensor (pulse generator) was incorporated with the axle of the depth-speed wheel thereby rotating with the wheel to measure the ground speed. It generated pulses per unit time interval at the rate of 500 pulses per wheel revolution. The pulse generator was mounted as an integral part of the axle of the wheel. A linear potentiometer was used for the tillage depth measurement. It was mounted at the hinge joint of the depth-speed wheel frame to register the vertical displacements of the wheel. The range of depth wheel's vertical measurement was from 0 to 29 cm.

### 3.3 Data acquisition system software

The RAMLOG EI9000 data logger can be programmed to work on all 20 channels or only a few of them, depending on the number of transducers in use. Each of the channels can also be programmed to receive data in accordance with the individual needs of the sensors and also to meet the needs of the user. The logger has sixteen analog channels (channels 1 to 16), two 8-bit counters (channels 17 and 18) one 16-bit counter (channel 19) and one 8-bit digital input channel (channel 20). The program used for monitoring, recording and saving of the data as well as programming of the channels, was a built-in system software (FIRMWARE) that was stored in the logger's non-volatile memory. The data acquisition rate ranges from 10 msec interval (100 data points/sec) for one channel to 100 msec interval (10 data point/sec/channel) for 16 channels. On-site monitoring of the data is done through 2 lines of a 16 character liquid crystal display (LCD). User communication is done through a 20-key keypad with triple functions, full alphanumeric with punctuation, arithmetic operators and function keys. Initialization of data collection is triggered by the "F1' key and data collection is terminated by "F2" key. This enables the user to vary the time and or distance covered by a particular "run". Data sampling and recording automatically stops when the logger power supply falls below 4.4 V reserving the remnant power for memory content reading and peripheral transfer or dumping of the data. The data holding capacity is 77,500 data points, (analog - 12 bits) for the 128 Kbytes version. The capacity of the logger when using 16 channels at a sampling rate of 10 data points per second per channel was about 8 minutes.

A complementary menu-driven data processing software (PROLEC-TRA EI9000) that is stored in the portable computer handles the data transfer to a PC (via RS 232 cable) as well as subsequent initial data analysis and data saving in various formats. Processed data can be saved in ASCII (Text, Lotus 123 or Dbase), or graphic versions. For each sensor, the PROLEC-TRA software calculates the average, maximum and minimum values. These statistics are stored in the volatile memory of the logger together with the individual data points. During each data collection exercise, before a new "run" is started the user is prompted to create a new record name to be used for subsequent data saving in the same file.

A maximum of 8 digital and or analog channels can be displayed on the computer screen at any one time in graphic format. Print-outs of the results are available in graphic, tabular or mathematical formats for 8 channels at a time.

### 3.4 Calibration of data sensors

The ground speed and the depth sensors were calibrated by using the data logger to read the voltage generated by the potentiometer and also the pulses recorded over a predetermined distance on the ground. The ground speed was later computed on the basis of the rate at which the pulses were generated. Calibration of each of the mechanical sensors was done and a calibration response equation computed. Calibrating the potentiometer involved clamping the wheel assembly on a bench vice, varying the height of the wheel and taking data logger voltage readings corresponding to the depth. The $R^2$ value for the calibration curve was 0.999 (Figure 3.3).

Calibration of the speed sensor was done to establish the number of pulses per revolution and the respective ground displacement. Data logger readings of the cumulative pulses generated over a fixed distance, time taken and the number of revolutions over the distance were used for the computation of ground speed.

The energy that the animals develop is translated into a pull force when they are used for work. The draft force generated and put to useful work constitutes a fraction of the total effort that the animals produce. Measuring the pull force and comparing it with the actual net energy expenditure would provide an estimate of the energy utilization of the

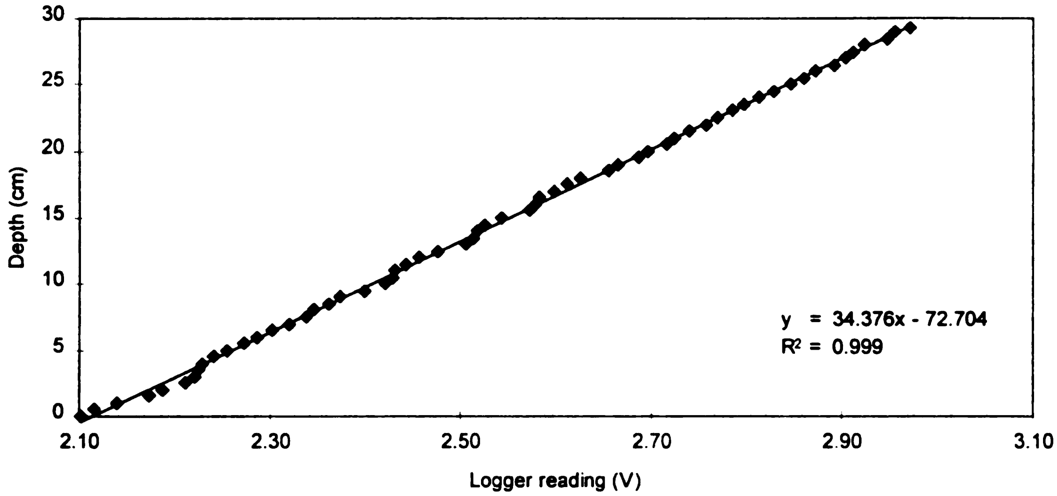


Figure 3.3: Depth sensor calibration curve

animals at work and also the gross and net energetic efficiency. The draft force was the most rapidly changing variable. It was measured through vertical and horizontal draft force components of the pull force using an extended octagonal ring type transducer (dynamometer). The force transducer was integrated into the plow beam (Figure 3.2) in such a way that the horizontal and vertical components of the forces acting on the soil engaging part of the plow were measured independent of each other. The analog signal (voltage) from the load cell was digitized and logged at 0.06 sec intervals (approximately 17 Hz). The transducer was calibrated by loading it in both "X" and "Y" axes when the unit was clamped in a rig specifically made for the calibration process. Analog voltage readings of each load were recorded and regression analysis done. Calibration of the transducer showed that the interaction between the vertical and horizontal forces was less than 1.5% and the observed hysteresis was insignificant. The $R^2$ value of the calibration curve for the horizontal and the vertical draft were 1.0 and 0.9998 respectively (Figures 3.4 and 3.5). The calibration response equations and the $R^2$ values for the mechanical sensors are shown in Table 3.1.

The regulation of the amount of nutrients oxidized, blood flow rate and the oxygen demand for the generation of energy from food substrates is done by the cardiovascular system. Gottlieb-Vedi et al. (1991) established that there is a linear relationship between the heart rate of draft horses and the rate of oxygen uptake. The pumping rate of the heart of a working animal can, therefore, be used as an indicator of the energy demand and expenditure of a working animal. Whereas most animals work at sub-maximal levels of heart rate, the maximum heart rate indicates the physiological endurance limit. Measurement of heart rate in a laboratory environment can be done with instruments that have been perfected for that purpose. Richards and Lawrence (1984) used electrocardiograph (ECG) to record the heart rate of oxen. The instrument measures the potential difference associated with ventricular depolarization (QRS complex) phase of the heart beat. In their experiments they found that the heart rate correlation with the energy expenditure of oxen indicated that heart rate can be used for the prediction of energy expenditure.

Measurement of heart rate in field situations requires a method that would be accurate and un-intrusive to the animals. A method of detecting the changes in infra-red absorptance of the ear as blood pulses through it was used successfully by O'Neill (1989)

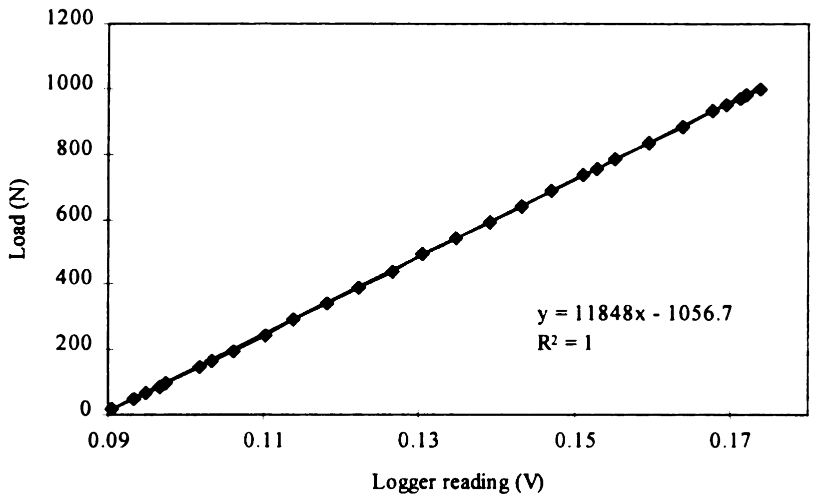


Figure 3.4: Horizontal draft calibration curve

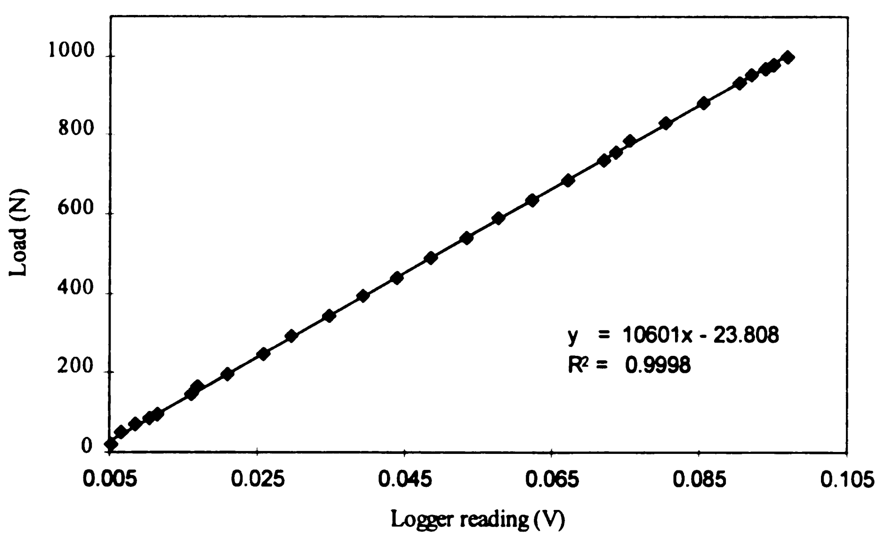


Figure 3.5: Vertical draft calibration curve

and Zerbini et al. (1992). An ear-clip sensor comprising of two arrays of three diodes was used to sense the QRS complex or peak surge of blood flow. One array emits near infra-red radiation and the other, on the other side of the ear, is sensitive to it. A signal conditioning circuit was made to give an electronic square wave coincident with the maximum absorptance of the blood flow. A similar sensor was fabricated for this research. Several prototypes of the heart rate sensor were made and tried in the field for sensitivity and accuracy. The final version was clamped on the ear of the animal and secured with medical tape to minimize interference from sunlight. The signal from the heart rate sensor was channeled through both analog (voltage) and digital circuits. Obtaining a suitable position for the heart rate sensor to provide transmittal of the signal to the logger was a considerable challenge. Analysis of the heart rate was done using the digital signal.

Table 3.1: Calibration response equations

| Channel | Variable | Calibration Response Equation | $R^2$ | n |
|---|---|---|---|---|
| 1 | Horizontal Draft | Draft (N) =11848.1279 * V - 1056.663 | 0.9999 | 27 |
| 2 | Vertical Draft | Draft (N) = 10600.575 * V - 23.808 | 0.9998 | 27 |
| 5 | Depth (cm) | Depth (cm) = 34.3756 * V - 72.7044 | 0.999 | 27 |
| 19 | Distance (m) | Distance (m) = 0.004347 * P - 3.6447 | 0.9443 | 13 |

The rate of breathing, although by itself is not an indicator of the energy demand from working animals, can be used to indicate the physiological response of the intensity of work. The breathing or respiration rate was determined by sensing the air movement through a tube in one of the animal's nostrils. Inside the tube was a miniature heater element. The heater yields differential temperature signals depending on the moisture content of the air flowing during inhalation and exhalation. The differential temperature signals are counted in real time and are used for computing the breathing rate.

The body temperature was measured with a standard bead thermistor model made by Fenwal Electronics USA. This is a small NTC Type 112 K fast response thermistor measuring 1.09 mm (0.043") in diameter and is hermetically sealed in glass. It is highly reliable and has long term stability and had a 20% tolerance at 25°C. It was mounted in a plastic probe that gave it protection for handling. Its resistance at 25°C is 100,000 Ω and requires a minimum power supply of 0.4 mW/°C.

The step rate sensor used was a commercial accelerometer type 8308A model K-Beam made by Kistler of Switzerland. It consists of a miniature sensor with built-in electronics to measure the lowest acceleration down to 0 Hz. The sensor generates an electronic pulse during peak acceleration which is logged in real time. It is suitable for a wide range of applications which include measurements in low speed machines and in bio-mechanics. It has a high sensitivity and high temperature stability. The zero reading of the signal is set at +2.5 V so that the output voltage is always positive and has a full scale output of ±1 V. It was connected to an A/D converter with 0 - 5 V input. A leather pouch was made for the sensor which was strapped on the front foreleg of the animal. The sensitive axis of the accelerometer was mounted parallel to the direction of the movement. Technical details of the accelerometer are provided in Appendix D.

# CHAPTER IV

# FIELD EXPERIMENTAL METHODOLOGY

## 4.1 Data collection sites

The locations for the field experiments were chosen in two districts in Eastern Province. Although DAP is widely used in three Provinces of Kenya (Eastern, Western and Nyanza), Western and Nyanza Provinces are in the high potential agro-climatic zone (Table 4.1). The agro-climatic zones of most areas of Eastern Province where DAP is the dominant mechanization system is zone III, an area with medium to low crop production potential that is generally referred to as semi-arid. The climatic conditions of agro-climatic zone III describe the medium and low potential area from the standpoint of agricultural output. On the other hand zone II is considered as high potential area which does not have similar agroclimatic constraints that limit agricultural production present in zone III.

Eastern Province is divided into four administrative Districts (Machakos, Embu, Meru, and Kitui). Machakos and Embu were in the process of being subdivided into Machakos and Makueni districts and Embu and Mbeere districts, respectively, during the time the research was being conducted. The research sites chosen for the field work were in the new Machakos and Mbeere districts. The choice of the two districts was based on logistical considerations, and also on the fact that they represented the semi-arid agro-climatic zones. Parts of lower Meru district that borders with Mbeere district have similar climatic conditions as Mbeere. Most of Kitui district which borders with Machakos district has the same climatic regime as Machakos district.

Table 4.1 Kenya's agro-climatic zones and rainfall regimes

| Agro-ecological Zone | Description | Area ($km^2$) | % of Total | Annual Rainfall (mm) |
|---|---|---|---|---|
| I | Humid and Semi-humid | minor % in Kenya[5] | | |
| II | High Potential | 67,850 | 11.89 | 857.5 or more |
| III | Medium Potential (Semi-Arid) | 31,570 | 5.54 | 612.5 to 857.5 |
| IV | Low Potential | 422,370 | 74.07 | 612.5 or less |
| V and VI | All Other Land | 48,430 | 8.49 | |
| | Total Land Area | 570,220 | 100.00 | |

Each district is divided into four or five administrative divisions. Research sites selected for the Machakos district were in three of the four divisions - Mwala, Central and Kalama. Mbeere District is divided into two divisions - Mbeere and Gachoka - which were covered in the research. In each of the five divisions, farmer surveys were performed to obtain socio-economic data of the small-holder peasant farmers which represented the historical and operational data base for the computer simulation program.

## 4.2 Socio-economic data collection

The socio-economic data were collected through the administration of a questionnaire (Appendix I) with 80 randomly selected farmers in Machakos and Mbeere districts. Sixteen farmers were randomly sampled from each of the five administrative divisions of the two districts and interviewed to obtain the required data base. In selecting the farmers, the only criteria that had to be met was that the land size of the farmers was not to exceed 8 ha (20 acres). As noted earlier, the vast majority (96%) of small-holder

[5] climate governed by altitude, not moisture.

farmers in semi-arid areas have 8 or less hectares of land on which they grow their food crops and also keep livestock.

The data collected included the following general areas of DAP utilization:

- farm size and acreage tilled
- mechanization resources available
- oxen utilization
  - hours and number of days oxen were used
  - number of days farmer hired or rented oxen
  - rates of renting and hiring (cost)
- tillage practices
  - timing of tillage operations
  - post plowing operations
- labor availability
  - family size
  - hired labor
- crop yields and sales
- current energy constraints and future plans

All interviews were conducted by the researcher personally after the working season of the 1995 short rains (September through November) and after the working season of the 1996 long rains (March through May). All of the interviews were conducted by the researcher in order to minimize personal errors or enumerator error, reduce the data collection costs and maintain consistency of eliciting information from the farmers. The researcher translated the English questionnaire to the respondents' local dialects with which he was familiar in both districts. The researcher understood the two languages spoken in Mbeere district (Kiembu) and in Machakos district (Kikamba). Likewise the farmers in the two districts can understand Kikuyu, the mother tongue of the researcher. There was, therefore, no need to translate the questionnaire into either the national language (Kiswahili) or the native languages spoken in the two districts.

A cross-section of the farmers interviewed were followed up for the DAP energy data collection with the DAS during the long rain tillage period when they were preparing the land for planting. Three farmers were selected out of the sixteen in each division. The DAS energy data collection was performed on a randomized block design pattern. Collection of the energy data was preferably done during the actual tillage period in order to obtain data that were pertinent to the farmer's calendar of cropping events and at the time that farmers usually prepare their land for planting. Small-holder farmers in the two districts do not leave any of their open land fallow. It was therefore not possible to get free parcels of land for carrying out the energy experiments when the tillage season was over.

### 4.3 Energy expenditure data collection

The energy expenditure data collection was done at the University of Nairobi farm (Field Station) and in farmers' fields. The procedure for collecting energy data was the same for both the Nairobi experiments and the experiments in farmers' fields. The DAS equipment and the farmers' animals were used with the same modified moldboard plow to obtain data on physiological response of animals at work and the mechanical energy requirement of the DAP implement. In each case soil moisture data was obtained as well as the data on the soil shear strength. Tests of each kind were taken at four sites in the field at random. For each test site three moisture content samples were obtained at three locations at three depths (5cm, 10cm and 15 cm) in each location for a total of nine samples. Soil moisture content was obtained with Time Domain Reflectometry (TDR) that measured instantaneous volumetric soil water content *in situ* (Appendix E). Soil shear strength readings were also obtained with a hand penetrometer at three places in the field. In each location readings were obtained at three depths (5cm, 10cm and 15 cm). The shear strength values were used to estimate the specific resistance of the soil for simulation.

The weights of the animals used for the field tests were estimated using body physical measurements. The two measurements needed to compute the weight of the oxen were the body length, from the point of the shoulder to the point of the rump-pinbone (length) and the circumference (heart girth), from a point slightly behind the shoulder blade, down over the fore-ribs and under the body behind the elbow. The conversion of the measurements to the weight was done with the following formula adapted from Ensiminger (1990) and the measurements taken in cm:

$$Bodyweight(kg) = \frac{(heartgirth)^2 * length}{660} \tag{7}$$

The above weight conversion formula or variations of it have been used for weight estimation of cattle by various researchers in East Africa (Young, 1972; and Semenye, 1979).

Estimating the oxen weights using the physical measurements method is considered accurate enough for the purpose for which the estimated weights are used. The oxen used at the University of Nairobi experiments were measured both by a weigh bridge and with the physical measurements in order to find out how closely the physical measurements estimated oxen weights. The data obtained showed that the estimate was within ±10% which for the purpose of the experiments performed was acceptable. The University of

Nairobi oxen like most of the draft oxen used in Kenya were locally bred Zebu type. However, the University of Nairobi oxen were well fed and maintained and hence the estimation of the weight by physical measurement method gave a higher value than the actual weight. Although estimating the weight of the farmers' draft oxen with equation (7) was expected to be within ±10%, this method was likely to overestimate the oxen weights due to the poorer maintenance standards of the farmers' oxen.

The purpose of the tests at the University farm was to perform a pretest with the DAS in controlled experiments. From these tests relationships between the oxen's physiological parameters and the mechanical energy used to pull implements when varying the draft force were obtained. Changing the depth and width of tillage varied draft force. The pretests were necessary to ensure that all the instrumentation was working well and that the data being collected were reliable. Data obtained from the field tests were analyzed and the results are presented in Chapter V.

The mechanical sensors were relatively easy to work with because they were already connected to the source of the signal. The physiological transducers were, however, difficult to handle because they had to be connected to the animals at various positions. The draft oxen at the University farm were well trained and so working with them was not difficult. Positioning of the sensors on the animal required patience and practice to do it well.

The step rate on the animal's foreleg sensor was the easiest one to attach. There were practical problems of connecting the breathing rate sensor, the body temperature sensor and the heart rate sensor. Several attempts were made before placing the temperature probe into the rectum of the oxen. Medical tape had to be used to maintain the temperature probe in position. The heart rate sensor comprised of two arrays of three diodes in an ear clip that was clamped into place over the animal's ear. It was difficult to find a suitable position from where the heart rate reading could be obtained. The analog heart rate needle indicator on the physiological sensors junction box was used to identify a suitable position because it indicated the pulses when the signal was received by the electronic circuit. When a suitable position was found, medical tape was used to secure it in place as well as to help keep sun light out of the sensors. The heart rate sensor worked on the principle of absorptance of near infra-red radiation (0.7 to 102 μm wavelength) which is emitted and sent through the ear by three diodes while another set of diodes on the other side of the ear is sensitive to it. When blood surges through the blood veins of the ear, the infra-red radiation is absorbed by the blood. The degree of absorption depends on the volume of blood flowing. The signal conditioning circuit was made to give a binary pulse read-out (from 0 to 1) when the peak surge of blood was sensed. The peak surge corresponds to the systolic phase (QRS complex) of the cardiac cycle when the heart is in the ventricular contraction. The interval between each QRS complex represented the period of each heart beat.

The breathing rate sensor was housed in a plastic tube that was attached to a muzzle and then placed into the nostril of the animal with a muzzle holding it in place especially because the animal tried to remove it with its tongue. It was ensured that the tube was fitted into the nostril so that the animal breathed through it. The sensor received the breathing rate signal through the differential temperature of the inhaled and exhaled air.

Moist air coming from the animal's body cooled the miniature heater on the sensor. Inhaled air being drier caused the temperature of the miniature heater to rise. The differential temperature was conditioned and read as pulses by the data logger.

Trials at the farmers' fields were conducted to obtain the variability of the energy expenditure in various farming situations and with different sets of oxen. The same equipment (plow) was used for both the University of Nairobi experiments and the trials on farmers' fields. The reason for this approach was to eliminate the equipment factor as a variable. The integration of the draft measurement transducer into the plow beam also precluded the use of different plows. The Victory plow used for the experiments is almost exclusively used by DAP farmers in Kenya. The plow's widespread use is primarily due to lack of other suitable implements in the market. The Victory plow is a single bottom moldboard plow ranging in size from 30 to 38 cm (12" to 15") wide. A ground wheel that rides ahead of the plow bottom is used for depth adjustment. The width of plowing is regulated with a U-bolt that is positioned laterally across the front end of the beam.

#### 4.3.1 Data logger programming

Before the RAMLOG EI9000 data logger could be used to collect, record and store data, it had to be programmed or configured for the desired mode of operation. A two-line 16-character alphanumeric liquid crystal display (LCD) provides a display for the key pad entries as the user programs the logger. Nine of the 20 channels available in the data logger were used for these experiments. Table 4.1 shows the logger channels and the transducers that each of them processed. Further information on the logger parameter settings are available in Appendix C. Three of the four mechanical sensors (horizontal and vertical draft, tillage depth), the battery power, and the body temperature of the animal were monitored by the analog channels of the data logger with the output of the reading in volts (V). The ground speed sensor was monitored in pulses (P) by channel 19 which is a 16-bit counter. The heart rate was monitored in both analog (channel 6) and digital (channel 20) formats. The same process was used for the respiration rate sensor in channels 7 and 20 while the digital channel measured the step rate only. The digital channel (20) has eight digital (binary) inputs. The heart rate was required for the estimation of the energy expenditure of working oxen. Other physiological parameters, including respiration rate were obtained mainly to monitor the animals' response to work.

Table 4.2 Parameter settings for RAMLOG EI9000 logger DAS

| Channel Number | Function | Scale | Range |
|---|---|---|---|
| Mechanical Sensors: | | | |
| 1 | Horizontal Draft | 0.5 V | 0 - 4kN |
| 2 | Vertical Draft | 0.5 V | 0 - 2kN |
| 5 | Tillage Depth | 5.0 V | 0 - 29 cm |
| 19 | Ground Speed | Pulse | 0 - 2 m/sec |
| 9 | Battery | 10 V | |
| Physiological Sensors: | | | |
| 6, 20 | Heart Rate | 10 V | 40-160 beats/min |
| 7, 20 | Respiration Rate | 10 V | 14 -140 breaths/min |
| 8 | Body Temperature | 0.5 V | 25 - 45° C |
| 20 | Stepping Rate | Pulse | 0 - 100 steps/min |

The heart rate and respiration rate were monitored in both analog and digital forms in order to identify the peaks of the traces of the pulse rate and also correlate the trace with the binary (0, 1) or "low" and "high" positions of the pulse rate. The peaks of the trace and the digital output were clearly identifiable in the graphical outputs of the PROLEC-

TRA over the time interval of the experiments. The data analysis results covered in chapter V show graphical outputs in both analog and digital format. A standard mode (or point-to-point mode) of configuration for the logger was preferred for the energy data collection. In this mode the data logger sampled each sensor's signal for a short duration of time which was determined by the length of the run or the time span in which the data was to be collected. The number of points visited by the logger for each sensor was contingent on the rate or frequency of sampling. For instance at a sampling rate of 10 Hz, 1200 data points per channel (sensor) would be visited and recorded in two minutes. For each channel, the logger calculated and recorded the average, maximum and minimum values as well as the individual values. In this mode, the measured values were also displayed cyclically on the LCD for on-site monitoring of the logger readings as the sampling proceeded. The cumulative data points were saved in the read only memory (ROM) of the logger at the end of each experiment in a specific file name for subsequent down loading to a computer.

Recording configuration also included setting the date and time, defining the recording name for each of the field trials, the name of each run, the recording interval in centi-seconds and the record begin option. The appropriate record begin option for the field experiments was through the data logger keypad. Pressing the FI key when the operator was ready to collect data started the data collection process. This was done after the animals and the implements were in a steady state mode. Pressing the F2 key stopped the data collection. The ability to stop and start data collection any time using the "F1" and "F2" keys was convenient especially when the animals stopped or encountered an obstruction (stone or stump) in the ground. At the end of each run the logger prompted for a new record name to be used for the subsequent saving of the data.

In the standard mode, each channel was configured individually to meet the respective sensor's parameter settings as well as the sampling and recording frequency needs. The parameter settings for the channels included:

- the channel number
- function of the sensor
- scale or measuring range
- units of measurement
- scaling factor
- record type and
- recording interval

The recording interval is a multiple of the sampling frequency, which allows the recording interval to be varied to suit each signal's rate of change and the memory capacity of the logger. Channels that had fast changing sensors should be sampled at a higher frequency to capture the short interval of change. For these research experiments the sampling frequency for all the sensors was set at 16.7 Hz (0.06 sec interval) based on the rate of change of the draft force signal which was the most rapidly changing one. For all of the sensors, all of the sampled data points were recorded so that 16 records were obtained per second for each parameter as shown in the printout in Appendix F.

After the initial programming, only a new record name was needed for the subsequent runs until the logger's memory was exhausted and the data transferred to the portable computer or into floppy diskettes. After the data were transferred, it was necessary to reprogram the logger for all the channels except the date and time before proceeding with further data collection.

### 4.3.2 Experiments at University of Nairobi farm

The field site for the controlled experiment performed at the University of Nairobi was the Field Station farm. The field was fairly flat and had been under a maize crop during the preceding short rains season. The design of the experiments was randomized block design (RBD) consisting of six treatments replicated three times. The six treatments comprised of three depths (5cm, 10cm and 15cm) and two widths of tillage. Although attempts were made to maintain the required depth and width of tillage, the moldboard plow used was not designed for precise settings for depth and width. The actual depth and width of tillage was roughly estimated by the operator and was later measured at the end of each "run". Each replication was treated as a block and all the experiments for each block were performed and completed in one day. The variables of the treatments were:

| *Treatment (replication 1)* | *Definition* |
|---|---|
| 5NRR1 | 5 cm depth, narrow width |
| 5WR1 | 5 cm depth, medium width |
| 10NRR1 | 10 cm depth, narrow width |
| 10WR1 | 10 cm depth, medium width |
| 15NRR1 | 15 cm depth, narrow width |
| 15WR1 | 15 cm depth, medium width |

At the start of each experiment the following data and information were obtained for each field.

- soil shear strength
- soil moisture content
- weather conditions

At the start of each set of tests, a data recording configuration was programmed for each field. This included such parameters as the date and time, file name to be used for down loading data, and the name of the "run". Configuration for each of the channels used was done by setting the following parameters:

- channel number
- function
- unit of measurement
- scaling factor
- sampling and recording interval

The test "runs" ranged in length from about 20 m to about 37 m and the completion time for the test runs ranged from 14.5 to 120.0 seconds. The length of the "runs" was subject to the speed of operation and the time that the data collection was started relative to the end of the field (see Table 5.10 in chapter V). Data collection was not started until the DAP-SYS was considered to be in a stable operating condition. This caused a wide variability of the length of the test "runs". Data collection was also stopped before the end of the field if the oxen stopped due to obstruction in the ground. However the sampling and recording rate was fixed at 16.67 Hz. for all the channels.

### 4.3.3 Experiments in farmers' fields

The energy data collection at the farmers' fields was performed for 15 of the total farmers sampled with the survey questionnaire. For each of the farmers' oxen teams tested, physical dimensions of the animals were taken for estimating their weights. The same instrumented Victory moldboard plow was used for all the experiments both at the University of Nairobi and all off-campus energy data collection.

Experiments were performed in five administrative divisions. Mbeere district has only two divisions while Machakos district has four divisions of which three were used for the experiments. Each of the divisions was considered an experimental block consisting of three draft animal teams (one from each farmer) to be tested. Therefore, the data analysis for each block (or division) was done separately before it was pooled for the whole district. Since the same tillage equipment was used for all experiments, the three draft oxen teams were used as factors for the trials. In each site (farm), the tillage trials were replicated three times within the same day for each of the three farmers per division. The experimental plan was randomized block design (RBD) for the divisions with the experiments done at three different sites. The same operator was used with the tillage system throughout all the trials. He controlled the implement depth and speed while the researcher did the data logging. The farmer's help was, however, required to hitch the animals and help control the animals while at work with voice commands.

The length of the test "runs" in the farmers' fields varied from one farmer to another depending on the configuration of the fields, the level of control of the animals and the starting of the data collection. The shortest field "run" was about 14 m while the longest was about 58 m.

CHAPTER V

# FIELD EXPERIMENTAL RESULTS

The field experimental energy data collected with the DAS and the socio-economic survey data obtained from the farmers' surveys were analyzed using different statistical packages. Eighty farmers were surveyed for the socio-economic data in five administrative divisions of Machakos and Mbeere districts, Eastern Province of Kenya. Of the 80 farmers surveyed, 48 were from Machakos district and 32 were from Mbeere district. The socio-economic data were analyzed with the SPSS data analysis package while the electronic instrumentation data were analyzed with the complementary PROLEC-TRA software of the RAMLOG-EI9000 data logger and the EXCEL spreadsheet program. The data obtained from the two sources were used for computation of the energy utilization of DAP in small-holder tillage operations, and the results were used for the EUMDAP computer simulation model design and implementation. The SPSS data analysis procedures used were mainly the descriptive statistics which were used for determining the mean, maximum and the expected variability of the energy input variables and the resources used for the EUMDAP computer simulation model.

## 5.1 Socio-economic data analysis

### 5.1.1 *Land holdings*

The small-holder farmers surveyed were limited to those farmers that had a total farm land area of 8 ha (20 acres) or less. As indicated earlier in Table 1.1, only about 4% of small-holder farmers in Kenya have more than 8 ha of land. In Eastern Province where the research was conducted only 1.22% of the farmers have farm sizes in excess of 8 ha.

The results of the pooled data showed that ninety-eight per cent of the farmers surveyed own their land, and less than 2% lease the land that they cultivate. This is an important factor because most of the farmers can use their land as collateral for obtaining agricultural development loans for future investments.

The average land size of the pooled data was 4.69 ha (11.6 acres). When the data were analyzed by t-tests with the independent samples routine of SPSS for the two districts, the results showed that the null hypothesis that the mean difference of the land size of the two samples (0.33 ha, $P = 0.05$) was the same could not be rejected because the observed significance level was more than 5% (34.8%).

The results also showed that the mean difference of zero for the two districts was included in the 95% confidence interval meaning that the mean land size value obtained in the two districts (Table 5.1) was the same. This statistic confirms that the average size of the small-holder farms in the two districts surveyed may be considered the same. Similarly the land currently used for tillage or land generally referred to as cropped land for the two districts had a mean difference of 0.046 ha with a significance level of 87.2% ($P>5\%$) and the value zero of the difference was within the 95% confidence interval showing that for the two population samples used, the size of land currently used for tillage by farmers had the same mean size in the two districts. The size of the grazing land was also found to have a significant level above 5% (5.8%) with a mean difference of 0.538 ha. Hence from the data obtained for the two districts, farmers' land size, the land under tillage and the land allocated to grazing had the same mean size in the two districts surveyed.

Descriptive statistics obtained from further analysis of the pooled data showed that about 56.3% of the farmers had between 4 and 6 ha (10 to 15 acres) and only 10% had more than 6 ha (15 acres). About half of the land-holdings were cultivated for crop production while the rest was reserved for grazing purposes (Table 5.2). The range of the individual farm size holdings was from 1.21 ha (3 acres) to 8.00 ha (20 acres).

Table 5.1: The t-test results for independent samples (equality of means) of land size for Machakos and Mbeere districts.

| Variable | Mean Difference | d.f. | 95% CI for Difference | Standard Error | 2-Tail Sig. |
|---|---|---|---|---|---|
| Land size | 0.3324 | 78 | -0.369, 1.034 | 0.352 | 0.348 |
| Cropped land | 0.046 | 78 | -0.522, 0.614 | 0.285 | 0.872 |
| Grazing land | 0.5383 | 74 | -0.019, 1.095 | 0.280 | 0.058 |

Table 5.2: Descriptive statistics of the small-holder farms in Machakos and Mbeere districts

| | Descriptive Statistics (ha); n = 80 | | | |
|---|---|---|---|---|
| **Variable** | **Minimum** | **Mean** | **Maximum** | **Std. Dev.** |
| Land size | 1.21 | 4.69 | 8.00 | 1.54 |
| Cropped land | 0.60 | 2.83 | 6.07 | 1.24 |
| Grazing land | 0.00 | 1.79 | 6.48 | 1.21 |

The distribution of the land holdings in the two districts shows that the most frequently occurring land size is between 4.0 to 4.8 ha. (9.9 to 11.9 acres). The mean land size is included in this range of most frequently occurring land size. The "stem and leaf" plots of SPSS, which provides frequency distribution, shows that the land size has a normal distribution with land size between 4.0 and 4.8 ha being the most frequent size of small-holding with a count of 24 out of 80 farms. A modified print-out of the SPSS output is shown in Table 5.3 showing the distribution of the land size and the range in each cluster of cases. The stem column represents the integer value of land size while the leaf digits represent the decimal (*tenth*) value of land size within the cluster. For instance, the most frequently occurring land size has 24 cases which consist of eight 4.0 ha, two of 4.6 ha and fourteen of 4.8 ha cases. The tail ends of the histogram has two cases of 1.2 ha. and 1.6 ha. on the lower end and one case of 8.1 ha on the upper end. The stem width is a multiplier factor of the stem before adding on the leaf for each of the cases[1].

The cropped land had a similar distribution pattern showing also that the most frequent size of cropped land is between 2.0 to 2.8 ha. which is about half the size of the land holdings (Table 5.4).

### 5.1.2 *Farm implements and hand tools*

Small-holder farmers in semi-arid areas use hand tools or DAP or a combination of both for their agricultural mechanization needs. The results of the survey show that the variety of DAP implements available at the farm level was limited to plows, ox-carts and cultivators. Although there were about 54% of the farmers that had both a plow and an ox-cart, the low utilization of DAP after the tillage season is over indicates that ox-carts are not widely used for transportation purposes. Multipurpose use of DAP is also limited

[1] *In general to compute the value of the cases in a stem and leaf histogram, the stem is multiplied by the stem width and the values added to each leaf one at a time. For a stem width of 1, the leaf is a decimal value ($10^{th}$) while a stem width of 10 has a leaf of unit values.*

Table 5.3: Stem-and-leaf plot of the farm size in hectares (pooled for Machakos and Mbeere districts)..

| Frequency | Stem (ha) | Leaf (decimal, 10th ha) |
|---|---|---|
| | Farm size, ha | |
| 2.00 | 1 . | 26 |
| 10.00 | 2 . | 0044444888 |
| 12.00 | 3 . | 022222226666 |
| 24.00 | 4 . | 000000006688888888888888 |
| 14.00 | 5 . | 02244666666666 |
| 10.00 | 6 . | 0000000000 |
| 7.00 | 7 . | 2222226 |
| 1.00 | 8 . | 1 |

Stem width: 1.00
Each leaf: 1 case(s)
*Source: Modified SPSS print-out*

Table 5.4: Stem-and-leaf plot of the cropped land size in hectares (pooled for Machakos and Mbeere districts).

| Frequency | Stem (ha) | Leaf (decimal, 10th ha) |
|---|---|---|
| | Cropped land, ha | |
| 6.00 | 0 . | 678888 |
| 13.00 | 1 . | 0222226666666 |
| 24.00 | 2 . | 000000444444444468888888 |
| 20.00 | 3 . | 22222222222222566666 |
| 14.00 | 4 . | 00000000044888 |
| 2.00 | 5 . | 66 |

Stem width: 1.00
Each leaf: 1 case(s)
*Source: Modified SPSS print-out.*

because only 10% of the farmers owned a plow, an ox-cart and a cultivator while 33% had a single plow only and about 3% had no ox-implement at all (Table 5.5). The scarcity of cultivators among the farmers explains why more than 50% of the farmers use a moldboard plow for inter-row weeding of pure stand (single crop) maize plantations. The few farmers that had a cultivator either bought them second hand from outside the district or arranged to import them directly from outside the country. The local DAP market does not cater for the distribution of cultivation or weeding implements. This is primarily because there are no local manufacturers of weeding implements and no formal importation from outside either. Although farmers indicate that weeding is a major concern, weeding implements are not in demand especially because they are single purpose tools whose cost may not be justified for non-commercial crop production. However, farmers owned a wide variety of hand tools including machetes, digging forks, hoes, spades, manure forks, wheel barrows, and axes. The number and type of hand tools available at the farm level depend on the family size and the number of adult-equivalent labor in the household. The average farm labor force available at the farm on a regular basis was three adults.

### 5.1.3 *Draft oxen*

The majority of the farmers (68.8%) had only one pair of trained oxen and 27.5% had two pairs. Some of the farmers with two pairs of trained oxen did not use the two pairs simultaneously for tillage, especially when the land was plowed either soon after harvest or when the rains set in. The main reason for using only one pair of oxen while owning two pairs of trained ones was because the soils were soft enough for a single pair to manage at the time the tillage was done. The two pairs of oxen were used alternately to keep them in condition, otherwise, the second pair was on stand-by in case it was needed to work in 'fours' when the ground conditions demanded higher draft force than one pair could provide. The expected productive working life span of the working oxen was reported by about 53% of the farmers to range between 7 and 10 years. Table 5.6

summarizes the data on the ownership and usage of draft oxen.

Table 5.5: Pooled distribution of ox implements in Machakos and Mbeere districts.

| Ox Implement | Frequency | Percent |
|---|---|---|
| None | 3 | 3.8 |
| Plow only | 26 | 32.4 |
| Plow and ox-cart | 43 | 53.8 |
| Plow, Ox-cart and cultivator | 8 | 10.0 |

Table 5.6: Ownership and usage of draft oxen in Machakos and Mbeere districts.

| | Response | | Number of oxen used for tillage | |
|---|---|---|---|---|
| Ownership of Oxen | Frequency | % | Frequency | % |
| No oxen owned | 3 | 3.7 | 3 | 3.7 |
| One pair | 55 | 68.8 | 58 | 72.5 |
| Two pairs | 22 | 27.5 | 19 | 23.8 |

### *5.1.4 Animal feed supply*

The primary feed source for the draft oxen is natural grazing and natural hay (harvested natural grass) either from the farmer's own land or that of friends (or relatives) which can be made available free of charge or from rented grazing land. Table 5.7 shows that 85% of the respondents indicated that they depend on grazing land as the main source of feed. However, about 43% of the respondents indicated that they had sufficient feed supply for their livestock from their own grazing land. Renting grazing land from neighbors that either have no livestock or have more grazing land than they need is a common practice in the two districts surveyed. About 31% of the respondents depend on renting grazing land for supplementary livestock feed whereas only 6% indicated that renting was their main source of animal feed. Commercial feeds are not commonly used due to lack of availability and their high cost when brought in from the high potential districts. Less than 4% of the farmers use commercial feeds for their draft oxen.

Table 5.7: Livestock feed supply and sufficiency

| Main Food | Frequency | % | Feed Sufficiency | Frequency | % |
|---|---|---|---|---|---|
| No Livestock | 3 | 3.75 | No Livestock | 3 | 3.75 |
| Grazing Fields | 68 | 85.00 | Sufficient | 43 | 53.75 |
| Renting | 6 | 7.50 | Rented | 31 | 38.75 |
| Commercial feed | 3 | 3.75 | Commercial feed | 3 | 3.75 |

### *5.1.5 Farm labor and energy supply*

Seventy-five percent of the farmers indicated that they did not have sufficient energy for all their farming needs. When asked what area they would need extra energy for, 38.8% indicated that weeding required more energy than was available at their disposal. They also indicated that labor was most scarce during the hand weeding and harvesting periods of the crop production season. Twenty-five percent indicated that plowing required more labor than they had available at the farm. Plowing was also considered by about 95% of the respondents as the most difficult, crucial and most labor demanding activity at the farm. While labor bottlenecks during the peak weeding and harvesting period represented the highest energy deficiency, food requirements for the draft oxen was cited as the next most energy deficient area. Weeding by hand was also considered to be the most time demanding activity on the farm followed by harvesting when the crop is good.

### *5.1.6 Using two pairs of oxen*

There is a tendency of farmers to use more than one pair of oxen for plowing. Respondents were asked the reason for using two or more pairs of oxen in tandem. Their response indicated that in most cases the second pair was used just because it was available and also that using it kept all the draft animals in good working condition. While 73.8% of the respondents said that they used only one pair of oxen, 18.8% indicated that they used the second pair because it was already trained and available. Interestingly, only 2.5% used the second pair of oxen because a single pair of oxen was inadequate. This implies that the use of a second pair of oxen in tandem is not necessitated by draft requirements. Most of the farmers that used one pair of oxen prepared their land after the rains came or soon after harvest when the ground was friable.

### *5.1.7 Start of plowing*

The timing of plowing for the next cropping season is always critical if the season is to succeed. Table 5.8 shows that about 55% of the farmers plow soon after harvest, mainly because they want to bury stubble. The other reasons for plowing soon after harvest are that the soil conditions after the crop is harvested are friable (low draft requirements), the animals are still in good physical condition, and there is sufficient feed for them. This practice was observed mainly with the farmers that receive organic farming extension services from a non-government organization (NGO) in the two districts.

The next most important time of starting tillage work was reported to be at the onset of the rains. The main reason why many farmers start plowing at the onset of the rains was because the animals were not strong enough to work before the rains due to the prevailing hard soil conditions at the land preparation time caused by feed shortage. Justification for this timing was the softened ground conditions because the ground conditions would be too hard for the weakened oxen prior to the falling of the initial rain showers.

Table 5.8: Timing of plowing

| Plowing time | Frequency | Percent | Reasons |
|---|---|---|---|
| Soon after harvest | 44 | 55 | Bury Stubble |
| At first rain showers | 20 | 20 | Soil softened |
| Just before the rains | 16 | 25 | Soils heavy when wet |

### *5.1.8 DAP utilization*

The amount of time that draft oxen are utilized per year and the number of hours that they work per day are measures of the level of utilization of the DAP. Over 70% of the farmers reported that they used their draft oxen between 5 and 6 hours per day during the peak plowing season. These results were consistent in both districts. The t-test results showed that the null hypothesis that the mean difference of hours worked by oxen per day is zero could not be rejected. The mean daily work hours in Machakos was 5.96 whereas that of Mbeere was 6.03. The mean difference of -0.07 hour was included in the 95% confidence interval for difference and therefore the mean of the daily work hours in the two sample sites can be considered to be the same.

The analysis of the annual utilization of draft oxen showed that the mean annual utilization of DAP in Machakos was 45.67 days as compared to 40.65 days in Mbeere. However, the mean difference value of 5.02 days was found to be not significant at P = 0.05. This difference was expected to occur about 23.4% of the time if the mean annual working days of the two sampled populations were equal (Table 5.9). The pooled stem and leaf procedure (Table 5.10) shows that most of the farmers (about 70%) use their oxen for 50 days or less per year with a few on either of the tail ends of the distribution (3 farmers more than 80 days and 5 farmers less than 20 days per year).

The utilization of oxen drops off after the planting period is over and only picks up again at the beginning of the next tillage season. Generally draft oxen are utilized for less than 50 days per agricultural year (October - September). It is notable that this rate of

Table 5.9: The t-tests for independent samples of daily work days, ox-life span and annual work days (equality of means) for Machakos and Mbeere districts.

| Variable | Mean Diff | d.f. | 95% CI for Diff | Standard Error | 2-Tail Sig. |
|---|---|---|---|---|---|
| Daily Work Hours | -0.0739 | 77 | -0.440, 0.292 | 0.184 | 0.688 |
| Ox Life Span | 0.3000 | 76 | -0.956, 1.556 | 0.630 | 0.636 |
| Annual Work Days | 5.0215 | 77 | -3.318, 13.361 | 4.188 | 0.234 |

DAP utilization is far short of the potential rate of utilization, especially if DAP can be used in-between the tillage seasons. The range of the days animals work per year was wide meaning that there are farmers that use their animals marginally while others attempt to make the best use of the draft oxen. The mean utilization of draft oxen per year was found to be 43.7 days. About 30% of the farmers used their oxen for more

Table 5.10: Stem-and-leaf plot of the annual DAP utilization in days (pooled for Machakos and Mbeere districts).

| | DAP utilization, days | |
|---|---|---|
| Frequency | Stem (x10 days) | Leaf (x1 day) |
| 2.00 | 0 . | 58 |
| 3.00 | 1 . | 024 |
| 13.00 | 2 . | 0000224455589 |
| 13.00 | 3 . | 0000455556668 |
| 12.00 | 4 . | 000000055559 |
| 17.00 | 5 . | 00000000000002255 |
| 11.00 | 6 . | 00000005556 |
| 5.00 | 7 . | 00005 |
| 2.00 | 8 . | 00 |
| 1.00 | 9 . | 0 |

Stem width: 10
Each leaf: 1 case(s)

*Source: Modified SPSS print-out.*

than 50 days per year as shown (Table 5.11). This low utilization rate is indicative of the fact that draft oxen are used primarily for tillage operations. This premise was confirmed by more than 98% of the farmers who reported that their main activity with oxen was plowing the land.

### *5.1.9 Draft oxen life-span*

One of the factors that determines the life span of draft oxen is the age at which the animal are trained to work. This varies from 2 to 4 years. According to the responses the null hypothesis that the two groups of farmers interviewed had the same mean working life-span of oxen could not be rejected. While the mean reported oxen working life-span for Machakos was 8.33 years. that of Mbeere was 8.03 years. The mean difference

Table 5.11: DAP annual utilization

| Annual DAP Usage | Frequency | Percent |
|---|---|---|
| Less than 50 days | 43 | 53.75 |
| 50 days | 13 | 26.25 |
| More than 50 days | 24 | 30.00 |

of 0.30 was expected to occur 63.6% (P>0.05) of the time if the two population means were equal. Most of the farmers reported that they use the animals for up to 10 years before they replace them. It is commonly documented in the literature that the longevity of working draft oxen is an average of 5 to 6 years as the reasonable working life-span. However, it is not unusual to find farmers that have used the same oxen pair for 15 years or more. The data obtained from the field had six farmers who had used their current draft oxen for 15 or more years.

### *5.1.10 DAP renting from others or hiring out.*

Renting out draft oxen or hiring draft oxen from other farmers for income generation was not a common practice. When farmers borrowed draft oxen from neighbors, friends or relatives, it was mainly to return a favor and not for income generation. Less than 29% of the farmers (Table 5.12) rented out their draft oxen to other farmers for income generation. These were primarily the farmers with more than one pair of oxen. The main limitation against hiring or renting practice is the timeliness of operation. Over 78% of the respondents indicated that they do not hire other farmers' oxen. When they are late for land preparation (and they always try not to be late), they borrow draft oxen from friends or relatives. Only 6% of the respondents indicated that they rented draft oxen from other farmers because their own oxen could not complete tillage in time for timely planting (low capacity).

Under the present level of management of draft oxen, most farmers do not seem to have the extra capacity that could be used for hiring out to other farmers due to the short duration of land preparation time. Improving the level of management of DAP can make available extra hours which can be used to earn extra income for the farmers and facilitate the promotion of mechanization for the farmers without draft oxen.

The number of years that the farmers have used DAP in the two districts had a mean difference of 11.9 (Machakos 28.3 and Mbeere 16.5). The 2-tail significance level for the number of years farmers have used oxen was small (P<0.0005) and the 95% confidence interval was 6.813 to 16.920. This result indicated that the farmers in the two districts have a mean DAP usage period that is significantly different. This finding was reasonable because the farmers in Machakos district have used DAP for a longer period than most of the other districts in the country.

Table 5.12: Hiring and renting of draft oxen in Machakos and Mbeere districts.

| Hiring from others | Frequency | % | Renting to others | Frequency | % |
|---|---|---|---|---|---|
| No renting | 63 | 78.80 | No renting | 32 | 40.0 |
| Low capacity of own oxen | 6 | 7.56 | Return favor | 25 | 31.3 |
| Miscellaneous Reasons | 11 | 13.75 | Earn Income | 23 | 28.8 |

## 5.2 Energy utilization data analysis

Data collection with the electronic instrumentation (DAS) was performed through experiments that were done at the University of Nairobi farm and in the farmers' fields in

Machakos and Mbeere (former Embu) districts. The DAP-SYS energy utilization data obtained from these field tests provided data for quantifying linkages and parameter estimates for the EUMDAP computer simulation model.

In general, all DAS experiments performed at the University of Nairobi and in the farmers' fields were performed using the same equipment and procedure. Only the draft animals, the time of the experiment and the soil type and conditions varied when the experiments were performed in the two districts with the farmers' animals at their farms. The same operator (an employee of the researcher) handled the implement (Victory plow) throughout all the experiments in order to maintain consistency in the control of the speed of operation, depth of tillage and the width covered.

The length and the number of "runs" in each of the fields depended on the size and configuration of the field. The length of the "runs" ranged between 14 m and about 57 m. A minimum of three "runs" was done in each of the farmers' fields. For each farmer's field a data file for saving the data was created and it contained all the individual "runs" performed at the site. A different record name identified the name of each "run". At the end of each "run" the data record was saved in the same file that was created for the field site. Initially the data were saved in the data logger's RAM until the memory was exhausted. The RAM had sufficient memory to store the data from five or more runs depending on the length of each run. The data were then dumped into a floppy diskette using an RS232 data transfer cable, and the PROLEC-TRA software. PROLEC-TRA software is the processing program for the RAMLOG EI9000 data logger allowing one to read and to process the measurements taken by the data logger. The software is a user-friendly menu driven program.

### 5.2.1 *Preliminary data analysis procedure*

The number of "records" contained in a file depended on the length and time of each of the field tests conducted. The naming of the files and the "records" was such that the researcher could identify from the file name the location and the field where the experiments were performed.

The preliminary data analysis software (PROLEC-TRA) was saved in the computer and used to review and inspect all the data files in graphical format. Tabular data was later retrieved in EXCEL for subsequent analysis and computation of the output values in physical units.

The process of data analysis using the data logger software started with a display on the computer screen of all records for the file selected to be analyzed. When a record was selected for analysis, a graphic presentation of the entire time span of the "run" was displayed. The graphic display showed all details of the displayed channels including: date and time of the experiments; name of the file and "record" name; the units of each sensor values; and a function-key menu for other options of viewing the data.

One of the options included the choice of the channels to be displayed, printed or exported; up to a maximum of 8 analog, digital or a combination of both. Viewing of the average, maximum and minimum values was provided in an overlay window in the graphics display. Zooming-in on the graphics over a selected "window" of the display was also an option that conveniently enabled sampling of short spans of data to be viewed in a magnified form. This was especially useful for the three physiological channels with both analog and digital data records (heart rate, respiration rate and stepping rate).

Channel 20 which had 8 digital inputs was used for the digital data monitoring and recording.

Various data output options were available for saving or printing the preliminary data: print-out (graphics, Tables or Math results); ASCII file saving (Text, Lotus 1-2-3, Dbase); and saving Graph files (.PCX) through the PROLEC-TRA program. However, only the 8 displayed channels were saved in any of the formats chosen which included the main channels needed for the analysis. The ninth channel was used for the battery power monitor, and was omitted in the subsequent files. The data were saved in ASCII and also in graphics mode for subsequent analysis in EXCEL and for export into word processing programs. A print-out of one of the raw field data files is shown in Appendix H which was imported into EXCEL from the PROLEC-TRA software. The print-out shows nine channels including the battery monitor channel.

### 5.2.2 *Experimental results*

The experiments conducted at the University of Nairobi were performed with one pair of oxen. The purpose of the experiments was to provide preliminary estimates for the relationships of the relative heart rate (RHR) versus the draft generated by the animals at work. This was done through varying the depth and width of the tillage implement. Three depths (5, 10 and 15 cm) were used at two widths of 20 cm and 30 cm. A total of eighteen test "runs" were performed in three blocks in a randomized block design format. Each block was done and completed in one day. The data sampling and recording rate used for all channels was 16.67 Hz (0.06 sec intervals). At this sampling rate the time taken for the 594 data points recorded for experiment number "5NRR1" was about one-half minute (35 seconds). The file names represent the depth of tillage (5 cm), narrow width (NR) and replication one (R1). The descriptive statistical results of the speed, draft force, depth and power of the university of Nairobi experiments are shown in Table 5.13 grouped according to the blocks of the experimental design. The results of the depth data shown in the table shows a variation of the recorded depth from the depth that was targeted. Although the implement operator attempted to maintain consistency of the depth of plowing, this discrepancy was consistent in all experiments. The depth sensor was properly calibrated and therefore the error was possibly due to the operator not maintaining the plow at a consistent depth.

The data were obtained in "snap-shots" of the test runs which lasted between about 20 seconds and two minutes - when the draft animals were in a steady working condition. Data collection was triggered by pressing the "F1" key, while pressing the "F2" key marked the completion of the data acquisition process. This ability to control the process of data acquisition was very important, especially when there was need to interrupt the process when the draft animals either stopped or instruments needed attention.

One of the outputs of the PROLEC-TRA data analysis software for an experiment at the university of Nairobi (Figure 5.1) shows one "run" that lasted for about 20 seconds. Two channels (6 and 20) out of the eight possible were chosen for this graphical display. The analog heart rate output (channel 6) is shown in the upper part of the graph in the form of a trace which is also represented as voltage on the left hand side vertical axis. The axis was, however, labeled "P" to represent the pulse rate of the heart. The label on the right hand side vertical axis represented the raw values of the step rate sensor before conversion to actual step rate in steps per minute.

Table 5.13: Summary of performance results for university of Nairobi experiments

| | | | Draft *(kN)* | | Speed *(m/s)* | | Depth *(cm)* | | Power *(Kw)* | | Mean | Gross Ener. | Work Ener. | Work Ener. | Step |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Experi-Ments.** | *N* | **Dist.** *(m)* | **Mean** | **Std. Dev.** | **Mean** | **Std. Dev.** | **Mean** | **Std. Dev.** | **Mean** | **Std. Dev.** | **Rel. Ht. Rate** | **Expend.** $W/Wt^{0.75}$ | **Expend.** $W/Wt^{0.75}$ | **for 2 oxen** *kW* | **Rate** *s/min* |
| 5NRR1 | 594 | 33.9 | 1.21 | 0.14 | 0.95 | 0.19 | 3.70 | 1.52 | 1.14 | 0.24 | 1.3 | 16.17 | 9.23 | 1.314 | 36 |
| 5WR1 | 490 | 28.2 | 1.11 | 0.10 | 0.96 | 0.16 | 3.30 | 0.32 | 1.70 | 0.20 | 1.4 | 18.67 | 11.73 | 1.669 | 32 |
| 10NRR1 | 656 | 34.6 | 1.24 | 1.12 | 0.88 | 0.22 | 4.55 | 1.30 | 1.09 | 0.27 | 1.2 | 13.68 | 6.74 | 0.959 | 37 |
| 10WR1 | 655 | 22.4 | 1.19 | 0.12 | 0.57 | 0.24 | 5.34 | 0.41 | 0.66 | 0.24 | 1.2 | 13.68 | 6.74 | 0.959 | 30 |
| 15NRR1 | 561 | 26.3 | 1.52 | 0.17 | 0.78 | 0.14 | 8.33 | 0.21 | 1.18 | 0.20 | 1.3 | 16.17 | 9.23 | 1.314 | 35 |
| 15WR1 | 497 | 27.4 | 1.46 | 0.14 | 0.92 | 0.19 | 9.24 | 3.28 | 1.34 | 0.25 | 1.3 | 16.17 | 9.23 | 1.314 | 38 |
| 5NRR2 | 550 | 32.3 | 1.19 | 0.13 | 0.98 | 0.19 | 3.56 | 1.57 | 1.16 | 0.23 | 1.3 | 16.17 | 9.23 | 1.314 | 38 |
| 5WR2 | 546 | 28.5 | 1.12 | 0.11 | 0.87 | 0.30 | 4.30 | 0.41 | 0.97 | 0.33 | 1.3 | 16.17 | 9.23 | 1.314 | 38 |
| 10NRR2 | 500 | 26.7 | 1.30 | 0.92 | 0.89 | 0.19 | 6.55 | 1.20 | 1.16 | 0.17 | 1.3 | 16.17 | 9.23 | 1.314 | 36 |
| 10WR2 | 543 | 21.2 | 1.29 | 0.23 | 0.65 | 0.35 | 6.50 | 0.52 | 0.84 | 0.34 | 1.2 | 13.68 | 6.74 | 0.959 | 36 |
| 15NRR2 | 600 | 29.5 | 1.65 | 0.20 | 0.82 | 0.15 | 9.12 | 0.23 | 1.35 | 0.45 | 1.2 | 13.68 | 6.74 | 0.959 | 39 |
| 15WR2 | 590 | 31.5 | 1.65 | 0.41 | 0.89 | 0.21 | 11.20 | 2.30 | 1.46 | 0.12 | 1.3 | 16.17 | 9.23 | 1.314 | 39 |
| 5NR3 | 580 | 33.4 | 1.12 | 0.12 | 0.96 | 0.17 | 4.00 | 1.21 | 1.07 | 0.24 | 1.3 | 16.17 | 9.23 | 1.314 | 40 |
| 5WR3 | 650 | 37.1 | 1.26 | 0.11 | 0.95 | 0.36 | 5.20 | 0.49 | 1.19 | 0.33 | 1.3 | 16.17 | 9.23 | 1.314 | 42 |
| 10NR3 | 550 | 31.4 | 1.33 | 0.45 | 0.95 | 0.20 | 7.30 | 0.90 | 1.26 | 0.19 | 1.3 | 16.17 | 9.23 | 1.314 | 42 |
| 10WR3 | 590 | 26.6 | 1.32 | 0.24 | 0.75 | 0.36 | 7.50 | 0.31 | 0.99 | 0.25 | 1.2 | 13.68 | 6.74 | 0.959 | 38 |
| 15NRR3 | 680 | 30.1 | 1.64 | 0.18 | 0.75 | 0.13 | 10.39 | 1.20 | 1.23 | 0.12 | 1.3 | 16.17 | 9.23 | 1.314 | 38 |
| 15WR3 | 650 | 37.4 | 1.68 | 0.42 | 0.96 | 0.23 | 12.56 | 2.10 | 1.61 | 0.31 | 1.4 | 18.67 | 11.73 | 1.669 | 39 |

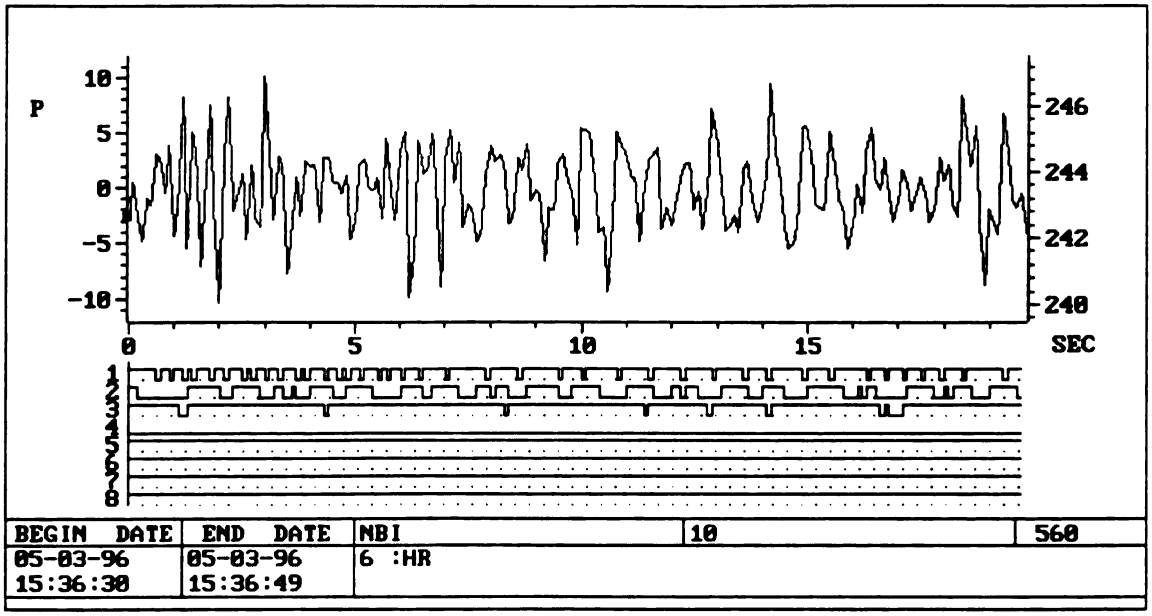


Figure 5.1: PROLEC-TRA graphical output for a Nairobi university experiment showing heart rate trace and three digital channels.

The heart rate, respiration rate and the stepping rate are represented in digital form (0,1) in the lower half of the graph as 1, 2, and 3 respectively. The analog graph of the heart rate represents the output of the infra-red absorption which registered the high and low (1, 0) peaks of the blood flow through the ear. It is worth noting that the heart rate trace in the upper half of the graph does not appear like a typical eletro-cardiogram (ECG) trace which clearly defines the three components of the cardiac cycle (P wave, QRS complex and T wave). The heart rate sensor picks the systolic or the ventricular depolarization phase (QRS complex) of the heart beat which is shown as the spike (peak) of the trace. The equivalent phase of QRS complex in the digital mode is represented by the number "1" of the binary digits. The raw data of the step rate is represented in the graph as pulses per minute on the right hand side of the vertical axis.

A graphic print-out showing two traces of the horizontal draft and depth of tillage are shown in Figure 5.2. The traces lasted for lasted 52 seconds recording a total of 866 data points. The left hand vertical axis represents the draft force in volts which

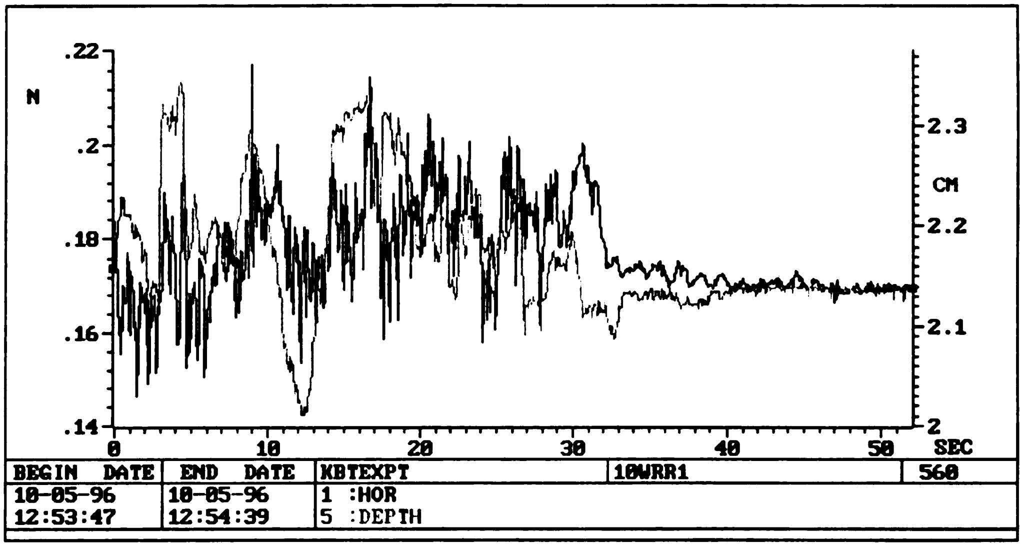


Figure 5.2: Graphic output for file number "10WRR1" showing the horizontal draft force and depth sensor traces.

were converted to force (N) with the sensor's transfer function. The right hand vertical axis represented the depth of tillage in analogous voltage readings which were computed into the actual depth in cm using the sensor's transfer function. The transfer functions for each mechanical sensors are tabulated in Table 3.1.

Two phases of the draft force are clearly seen in the graph. Both the depth of tillage and the draft force remained steady. The draft force generated by the implement was a factor of the depth to which the implement penetrated. In one section of the trace, the soil resistance was rapidly fluctuating as shown by the rapid changes of draft force and depth of tillage. The second section of the ground shows a more uniform and consistent soil resistance. Both sections of the graph show a more uniform and consistent soil resistance. In both sections of the graph, the depth of tillage and the draft force followed the same pattern in which the deeper tillage resulted in higher draft force.

**5.2.2.1 University of Nairobi experiments**

The summarized data obtained from the controlled experiments at the university of Nairobi were analyzed with the ANOVA procedures to obtain statistical validity. The observed difference between the F values of the blocks for the variables are as shown in Table 5.14. The mechanical variables measured with the DAS which included the draft force, depth of tillage, ground speed and the computed power were all found not to be significantly different. The respective probability of obtaining the F values shown for each of the variables if the means of the sampled populations were the same was far less than 5% value for which the ANOVA tests were performed. The largest F value was for the energy variable which was 0.0191. Therefore, the null hypothesis that the speed, draft force and power variables are the same were rejected at $P<0.05$. The P values obtained from SPSS for each of the variables indicate the probability of obtaining the computed F value if the null hypothesis of equal means is true. For example the probability of obtaining an F value of 20.464 for the draft force is 1.70263E-5 if the null hypothesis is true. The

Table 5.14: ANOVA results of the university of Nairobi experiments

| Variables | $df_1$ | $df_2$ | F | P value |
|---|---|---|---|---|
| Draft Force | 5 | 12 | 20.464** | 1.70263E-5 |
| Ground Speed | 5 | 12 | 16.783** | 4.74E-05 |
| Power | 5 | 12 | 4.218** | 0.019107 |
| Energy expenditure | 5 | 12 | 3.450** | 0.036581 |

** *significant at $P = 0.05$* [The critical value for $df_1 = 2$, $df_2 = 6$ and P (0.05)= 3.11]

results show that the variation of the draft force, ground speed, the energy expenditure and the power developed by the animals can be attributed to the varying depth and width of the implement. Hence the physiological response that the draft oxen were subjected to when working can be attributed to the draft force required by the implement at work in the prevailing soil conditions and setting of the tillage implement.

Likewise the energy expenditure of the draft oxen versus the power demand from the equipment that was monitored and recorded by the DAS shows that there is a relationship between the power output and the draft force generated. The ANOVA results show a statistically significant outcome from which the null hypothesis that the means of the energy expenditure of the animals subjected to different energy demand levels have the same values is rejected.

#### *5.2.2.2 Farmers' field experiments*

Out of the eighty farmers that were surveyed for the socio-economic data, 15 of them had their draft animals tested for the power output and energy consumption at their farms. The procedure of field tests with the farmers' draft animals was the same as that of the

University of Nairobi experiments. For each of the animal teams, six test runs of tillage were performed with the instrumented plow. Three depths (10, 15 and 20 cm) and two widths of tillage were used for each farm. Estimates of the width of tillage were done by the operator of the implement and an accurate measurement of the width done after the implement had passed. Three measurements of width were taken for each "run". The position of the preceding furrow was marked and used for measuring the actual width of tillage for the preceding "run".

A summary of the mean and standard deviation of four mechanical variables and corresponding values of the draft animal energy expenditure data is provided in Table 5.15. The energy expenditure calculations were performed with equation (3) of the model developed by Richards and Lawrence (1984) and which was discussed in section 2.5. According to the model, the power demand of oxen equivalent to relative heart rate of 1 (at rest) is 6.94 $W/Wt^{0.75}$. Hence the computation of the energy expenditure for work was done without the resting metabolism equivalent. The data were further analyzed with the one-way ANOVA procedures for each division. The test results analyzed were carried out in five administrative divisions three in Machakos and two in Mbeere. Data from each division consisted of three farm sites where the farmer's draft oxen were tested with the DAS instrumentation. Each division was considered as an experimental unit with three pairs of different teams of draft oxen for testing. From Table 5.16, the data for the three variables from Kalama division, the null hypothesis of equality of the means for draft force, depth of tillage and power was rejected. This means that the three variables in each of the test sites were significantly different due to other factors and not by chance. Hence, the different sites with different soil types have

Table 5.15: Summary of performance results for experiments on the farmers field in Machakos and Mbeere districts.

| Experiments (Division) | | *n* | Dist. *(m)* | Draft *(kN)* Mean | Draft Std. Dev. | Speed *(m/s)* Mean | Speed Std. Dev. | Depth *(cm)* Mean | Depth Std. Dev. | Power *(Kw)* Mean | Power Std. Dev. | Mean R. H. Rate | Energy Expenditure Gross $W/Wt^{0.75}$ | Energy Expenditure Work $W/Wt^{0.75}$ | Work Energy *kW* | Step Rate *s/min* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MACHAKOS:** | | | | | | | | | | | | | | | | |
| Kalama Division | | | | | | | | | | | | | | | | |
| R1 | Farm 1 | 970 | 53.1 | 0.81 | 0.07 | 0.91 | 0.09 | 8.19 | 1.83 | 0.74 | 0.09 | 1.3 | 16.17 | 9.23 | 0.909 | -- |
| R2 | | 1140 | 57.7 | 0.73 | 0.09 | 0.84 | 0.19 | 9.32 | 2.40 | 0.62 | 0.1 | 1.3 | 16.17 | 9.23 | 0.90 | -- |
| R3 | | 370 | 22.1 | 0.77 | 0.08 | 0.99 | 0.14 | 10.66 | 2.43 | 0.74 | 0.15 | 1.3 | 16.17 | 9.23 | 0.90 | -- |
| R1 | Farm 2 | 390 | 22.8 | 0.76 | 0.09 | 0.97 | 0.17 | 9.98 | 2.73 | 0.74 | 0.11 | 1.2 | 13.68 | 6.74 | 0.86 | 42 |
| R2 | | 360 | 20.1 | 0.75 | 0.09 | 0.93 | 0.28 | 9.72 | 2.87 | 0.71 | 0.25 | 1.2 | 13.68 | 6.74 | 0.86 | 40 |
| R3 | | 370 | 17.6 | 0.80 | 0.09 | 0.79 | 0.23 | 9.39 | 2.69 | 0.64 | 0.22 | 1.2 | 13.68 | 6.74 | 0.86 | 36 |
| R1 | Farm 3 | 466 | 22.7 | 1.38 | 0.11 | 0.81 | 0.18 | 5.04 | 3.42 | 1.12 | 0.02 | 1.2 | 13.68 | 6.74 | 0.88 | 38 |
| R2 | | 433 | 17.6 | 1.39 | 0.11 | 0.68 | 0.34 | 5.17 | 3.73 | 0.92 | 0.46 | 1.2 | 13.68 | 6.74 | 0.88 | 39 |
| R3 | | 416 | 22.8 | 1.29 | 0.10 | 0.91 | 0.16 | 5.04 | 1.86 | 1.18 | 0.22 | 1.2 | 13.68 | 6.74 | 0.88 | 40 |
| Central Division | | | | | | | | | | | | | | | | |
| R1 | Farm 1 | 1159 | 32.9 | 0.63 | 0.23 | 0.95 | 0.22 | 18.26 | 2.97 | 0.59 | 0.12 | 1.2 | 13.68 | 6.74 | 0.84 | 41 |
| R2 | | 440 | 14.1 | 0.51 | 0.16 | 0.75 | 0.17 | 17.04 | 3.51 | 0.41 | 0.12 | 1.2 | 13.68 | 6.74 | 0.84 | 36 |
| R3 | | 620 | 24.1 | 0.74 | 0.18 | 0.78 | 0.20 | 14.13 | 2.59 | 0.58 | 0.11 | 1.2 | 13.68 | 6.74 | 0.84 | 38 |
| R1 | Farm 2 | 550 | 12.8 | 0.82 | 0.24 | 0.77 | 0.20 | 17.29 | 3.39 | 0.63 | 0.09 | 1.3 | 16.17 | 9.23 | 1.12 | -- |
| R2 | | 380 | 13.6 | 0.65 | 0.17 | 0.84 | 0.18 | 14.82 | 3.84 | 0.55 | 0.13 | 1.3 | 16.17 | 9.23 | 1.12 | -- |
| R3 | | 680 | 22.2 | 0.61 | 0.19 | 0.85 | 0.21 | 15.13 | 3.91 | 0.52 | 0.14 | 1.3 | 16.17 | 9.23 | 1.12 | -- |
| R1 | Farm 3 | 600 | 21 | 0.67 | 0.23 | 0.98 | 0.25 | 15.56 | 3.45 | 0.65 | 0.15 | 1.2 | 13.68 | 6.74 | 0.66 | 38 |
| R2 | | 830 | 29.4 | 0.57 | 0.21 | 0.89 | 0.21 | 17.31 | 3.08 | 0.51 | 0.12 | 1.2 | 13.68 | 6.74 | 0.66 | 37 |
| R3 | | 730 | 30.1 | 0.73 | 0.22 | 0.70 | 0.27 | 13.90 | 3.30 | 0.51 | 0.19 | 1.2 | 13.68 | 6.74 | 0.66 | 41 |
| Mwala Division | | | | | | | | | | | | | | | | |
| R1 | Farm 1 | 350 | 22.1 | 0.52 | 0.18 | 1.05 | 0.19 | 16.08 | 4.06 | 0.55 | 0.25 | 1.3 | 16.17 | 9.23 | 1.00 | 42 |
| R2 | | 350 | 21.6 | 0.53 | 0.11 | 1.03 | 0.12 | 12.98 | 2.11 | 0.54 | 0.13 | 1.3 | 16.17 | 9.23 | 1.00 | 43 |
| R3 | | 360 | 22.8 | 0.49 | 0.17 | 1.06 | 0.18 | 13.61 | 2.40 | 0.54 | 0.21 | 1.3 | 16.17 | 9.23 | 1.00 | 44 |
| R1 | Farm 2 | 410 | 21.7 | 0.54 | 0.12 | 0.88 | 0.14 | 10.23 | 3.04 | 0.48 | 0.14 | 1.2 | 13.68 | 6.74 | 0.72 | 36 |
| R2 | | 620 | 25.2 | 0.80 | 0.10 | 0.68 | 0.35 | 10.88 | 2.37 | 0.54 | 0.19 | 1.2 | 13.68 | 6.74 | 0.72 | 37 |
| R3 | | 720 | 32.9 | 0.62 | 0.12 | 0.76 | 0.12 | 12.45 | 3.12 | 0.47 | 0.18 | 1.2 | 13.68 | 6.74 | 0.72 | 39 |
| R1 | Farm 3 | 625 | 27.2 | 0.58 | 0.11 | 0.73 | 0.21 | 11.23 | 2.13 | 0.42 | 0.11 | 1.2 | 13.68 | 6.74 | 0.78 | -- |
| R2 | | 580 | 34.1 | 0.68 | 0.13 | 0.98 | 0.13 | 12.45 | 3.13 | 0.66 | 0.21 | 1.2 | 13.68 | 6.74 | 0.78 | -- |
| R3 | | 480 | 24.5 | 0.75 | 0.16 | 0.85 | 0.12 | 13.22 | 2.13 | 0.64 | 0.19 | 1.2 | 13.68 | 6.74 | 0.78 | -- |

Table 5.15 *(cont'd)*

| Experiments (Division) | | n | Dist. (m) | Draft (kN) Mean | Draft (kN) Std. Dev. | Speed (m/s) Mean | Speed (m/s) Std. Dev. | Depth (cm) Mean | Depth (cm) Std. Dev. | Power (Kw) Mean | Power (Kw) Std. Dev. | Mean R. H. Rate | Energy Expenditure Gross $W/Wt^{0.75}$ | Energy Expenditure Work $W/Wt^{0.75}$ | Work Energy kW | Step Rate s/min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MBEERE** | | | | | | | | | | | | | | | | |
| Siakago Division | | | | | | | | | | | | | | | | |
| R1 | Farm 1 | 527 | 28.1 | 1.46 | 0.15 | 0.89 | 0.21 | 8.16 | 3.61 | 1.29 | 0.29 | 1.3 | 16.17 | 9.23 | 0.95 | -- |
| R2 | | 500 | 29.8 | 0.52 | 0.18 | 0.99 | 0.28 | 17.61 | 2.38 | 0.59 | 0.25 | 1.3 | 16.17 | 9.23 | 0.95 | -- |
| R3 | | 670 | 52.4 | 0.38 | 0.18 | 1.30 | 0.30 | 13.61 | 3.39 | 0.51 | 0.29 | 1.3 | 16.17 | 9.23 | 0.95 | -- |
| R1 | Farm 2 | 510 | 26.2 | 0.68 | 0.21 | 0.86 | 0.34 | 15.22 | 4.10 | 0.58 | 0.29 | 1.4 | 18.67 | 11.73 | 1.24 | -- |
| R2 | | 240 | 20 | 0.69 | 0.15 | 1.38 | 0.34 | 15.71 | 2.83 | 0.96 | 0.27 | 1.4 | 18.67 | 11.73 | 1.24 | -- |
| R3 | | 595 | 24.9 | 1.52 | 0.31 | 0.69 | 0.23 | 8.97 | 2.69 | 1.04 | 0.33 | 1.4 | 18.67 | 11.73 | 1.24 | -- |
| R1 | Farm 3 | 697 | 31.1 | 1.49 | 022 | 0.74 | 0.23 | 6.83 | 4.45 | 1.11 | 0.35 | 1.3 | 16.17 | 9.23 | 1.07 | -- |
| R2 | | 612 | 25.0 | 1.23 | 0.10 | 0.68 | 0.21 | 6.78 | 3.15 | 0.83 | 0.25 | 1.3 | 16.17 | 9.23 | 1.07 | -- |
| R3 | | 938 | 14.4 | 1.26 | 0.16 | 0.73 | 0.38 | 4.54 | 2.30 | 0.91 | 0.22 | 1.3 | 16.17 | 9.23 | 1.07 | -- |
| Gachoka Division | | | | | | | | | | | | | | | | |
| R1 | Farm 1 | 1200 | 49.0 | 1.65 | 0.18 | 0.68 | 0.22 | 15.39 | 3.72 | 1.11 | 0.36 | 1.3 | 16.17 | 9.23 | 1.07 | 42 |
| R2 | | 1050 | 34.8 | 1.73 | 0.17 | 0.55 | 0.23 | 14.79 | 3.75 | 0.95 | 0.39 | 1.3 | 16.17 | 9.23 | 1.07 | 40 |
| R3 | | 883 | 42.7 | 1.22 | 0.09 | 0.81 | 0.26 | 1.65 | 1.16 | 0.97 | 0.30 | 1.3 | 16.17 | 9.23 | 1.07 | 41 |
| R1 | Farm 2 | 980 | 15.0 | 1.26 | 0.16 | 0.76 | 0.38 | 4.54 | 2.30 | 0.95 | 0.52 | 1.3 | 16.17 | 9.23 | 1.12 | 43 |
| R2 | | 1020 | 58.3 | 1.21 | 0.11 | 0.95 | 0.18 | 6.74 | 2.57 | 1.15 | 0.24 | 1.3 | 16.17 | 9.23 | 1.12 | 44 |
| R3 | | 733 | 38.8 | 1.24 | 0.12 | 0.88 | 0.23 | 4.55 | 2.30 | 1.09 | 0.27 | 1.3 | 16.17 | 9.23 | 1.12 | 45 |
| R1 | Farm 3 | 750 | 25.8 | 1.19 | 0.12 | 0.57 | 4.42 | 8.42 | 1.24 | 0.66 | 0.24 | 1.3 | 16.17 | 9.23 | 1.17 | 38 |
| R2 | | 986 | 50.1 | 1.12 | 0.11 | 0.86 | 0.30 | 6.25 | 2.22 | 0.95 | 0.33 | 1.3 | 16.17 | 9.23 | 1.17 | 40 |
| R3 | | 697 | 39.6 | 1.12 | 0.10 | 0.95 | 0.18 | 8.33 | 0.33 | 1.16 | 0.23 | 1.3 | 16.17 | 9.23 | 1.17 | 43 |

varying soil resistance which caused the draft force as well as the power required to operate the tillage implement to be different. The computed F value was more than the critical value for all the three variables.

Table 5.16: ANOVA results of farmers' field experiments in Machakos and Mbeere districts.

| | Draft Force | | | Tillage Depth | | | Power | | |
|---|---|---|---|---|---|---|---|---|---|
| Division | $df_1$/ $df_2$ | F | P value | $df_1$/ $df_2$ | F | P value | $df_1$/ $df_2$ | F | P value |
| Kalama | 2/6 | 206.725** | 2.93E-06 | 2/6 | 37.470** | 0.00040 | 2/6 | 16.146** | 0.00384 |
| Central | 2/6 | 0.3069 | 0.74661 | 2/6 | 2.2494 | 0.18664 | 2/6 | 0.0729 | 0.93042 |
| Mwala | 2/6 | 5.5815** | 0.04272 | 2/6 | 4.2465 | 0.07095 | 2/6 | 0.6834 | 0.54024 |
| Gachoka | 2/6 | 4.8711 | 0.05536 | 2/6 | 25.242 | 0.00119 | 2/6 | 0.5799 | 0.58847 |
| Mbeere | 2/6 | 1.1435 | 0.37953 | 2/6 | 9.0240 | 0.01553 | 2/6 | 0.2067 | 0.81881 |

** *significant at* $P = 0.05$ [The critical value for $df_1 = 2$, $df_2 = 6$ and P (0.05)= 5.14.]

### *5.2.3 Use of field data for modeling*

The results of the data collected and analyzed were used as a comparing for the output of the simulation model. The EUMDAP simulation model was designed to make best estimates of the utilization of the DAP-SYSs in semi-arid lands of Kenya. The results of the data was used as guideline of the boundaries in which the DAP-SYSs operate. For instance the results of the data showed that the land holding size ranged between 1.21 and 8.0 ha per household. The simulations performed with the model were constrained within these land holding limits in order to represent the real world situation. The data also showed that about half of the land holdings are under crop and the rest is under natural forage which is harvested for feeding animals during the drier times of the year. This information was useful in determining the effect of expanding the cropped land beyond or reducing it below the average cropped land.

The data showed that the majority of farmers (about 70%) owned and used only one pair of oxen. The use of two animals for tillage only was therefore prevalent in the two administrative districts. The implication of this finding was that any improvement of the utilization of draft animals would be based mainly on the extensive use of the available oxen and not on acquisition of multiple teams. Since only less than 30% of the farmers train and use two pairs of oxen, simulations with more than one pair of oxen would be limited to farmers with larger farm sizes especially because of feed requirements.

The data on the availability and use of feed for the draft oxen showed that most of the farmers (85%) depend on the feed available from their own farms. One of the objectives of the research was to investigate ways of assisting the farmers to improve their ability to prepare their land in time for timely planting using their current resource endowments. Feed as an energy source is an important factor in the management of draft animals for work. There is little use of commercial feed for livestock in the research areas. Indigenous feeds (including maize stubble) were used for projecting the energy needs of the draft oxen for the simulation modeling using EUMDAP.

According to the data, the annual utilization of the draft animals during the cropping season was limited to only the short period of land preparation for planting and partly for inter-row weeding of single crop plantations of maize. Simulation of DAP-SYS utilization was done with the intention of utilizing the draft animals for longer periods than the current average of about 45 days per year. Draft animal power systems are not considered a source of generating direct income in semi-arid areas. Using draft animals between households is culturally acceptable on the basis of friendship and return of favors. Since over 70% of the farmers indicated that they do not rent other farmers' oxen, using "renting" in the EUMDAP simulation was an indicator of the extra capacity that the farmers may have and which may be used for expansion of their own cropped land if so desired.

The energy expenditure of the actual draft working animals in the farmers' fields was intended to be used for the validation of the simulation outputs obtained from the EUMDAP simulation modeling. Although the field data and the output of simulations may not be exactly the same, the range and variability that the field data provided for various soil types and conditions was important in comparing the simulation outputs with real world cases.

CHAPTER VI

# COMPUTER SIMULATION MODEL DEVELOPMENT

## 6.1 Systems approach and concepts

Application of systems science to solve problems of physical, biological or social nature continues to gain momentum in various disciplines. A "system approach" to the analysis of problems comprised of various components is used for analyzing systems with the aid of computers. Computer simulation models of a system are designed, implemented and used for analysis of a problem. Analysis is defined here as the determination of model outputs for a given set of inputs and for a given model structure which approximates the structure of the real world system being studied. Problems requiring analysis may arise from existing and operational systems or from entirely new concepts that address a new challenge arising from a felt need. Needs that arise from an existing system present a management decision-making problem. This type of systems approach is also referred to as management or control problems. In addressing a new and previously non-existent need requires that a new system is designed from scratch and implemented. In the latter case, a set of given system inputs and system outputs are available or perceived and a system structure that would predict values for the system desired outputs has to be designed and implemented.

A system is defined as a hierarchical structure with defined boundaries within which a combination of inter-related components are integrated to perform specific functions in order to achieve specific objectives (Ogata, 1978). There are two main types of systems: static and dynamic. Static systems operate in steady or equilibrium states with outputs being independent of the preceding values of variables. Dynamic systems on the other hand have memory. The system outputs change with time as system variables interact with each other. All systems have inputs and outputs and there are two types of inputs. Exogenous or environmental inputs are factors that are external to the system. Although this type of input may affect the system, they are not controllable by the analyst. The second type of inputs are called endogenous or controllable inputs. These are an integral part of the system and can be altered to determine the system behavior which in turn determines the outputs obtained.

The objective of a system analyst is to optimize the output of a system. Outputs are either used as inputs for subsequent system components or they can be used as performance measures of the system being studied. Since outputs can be both desirable and undesirable, optimization of a system requires minimizing the undesirable outputs while maximizing the desired outputs. This is achieved through varying or adjusting the levels and interactions of the endogenous input variables.

An example of an undesirable output is atmospheric pollution resulting from industrial production. In the farming environment, undesirable outputs may include chemical leaching into ground water or a disproportionate increase of labor requirement for hand weeding and hence the cost of crop production when draft animal power is used for tillage to expand the acreage of tillage.

The computer simulation model designed and developed by the researcher is derived from an existing real system of draft animal power (DAP-SYS). The DAP-SYS can be identified in terms of design parameters, inputs, outputs, and performance measures as shown in Figure 6.1.

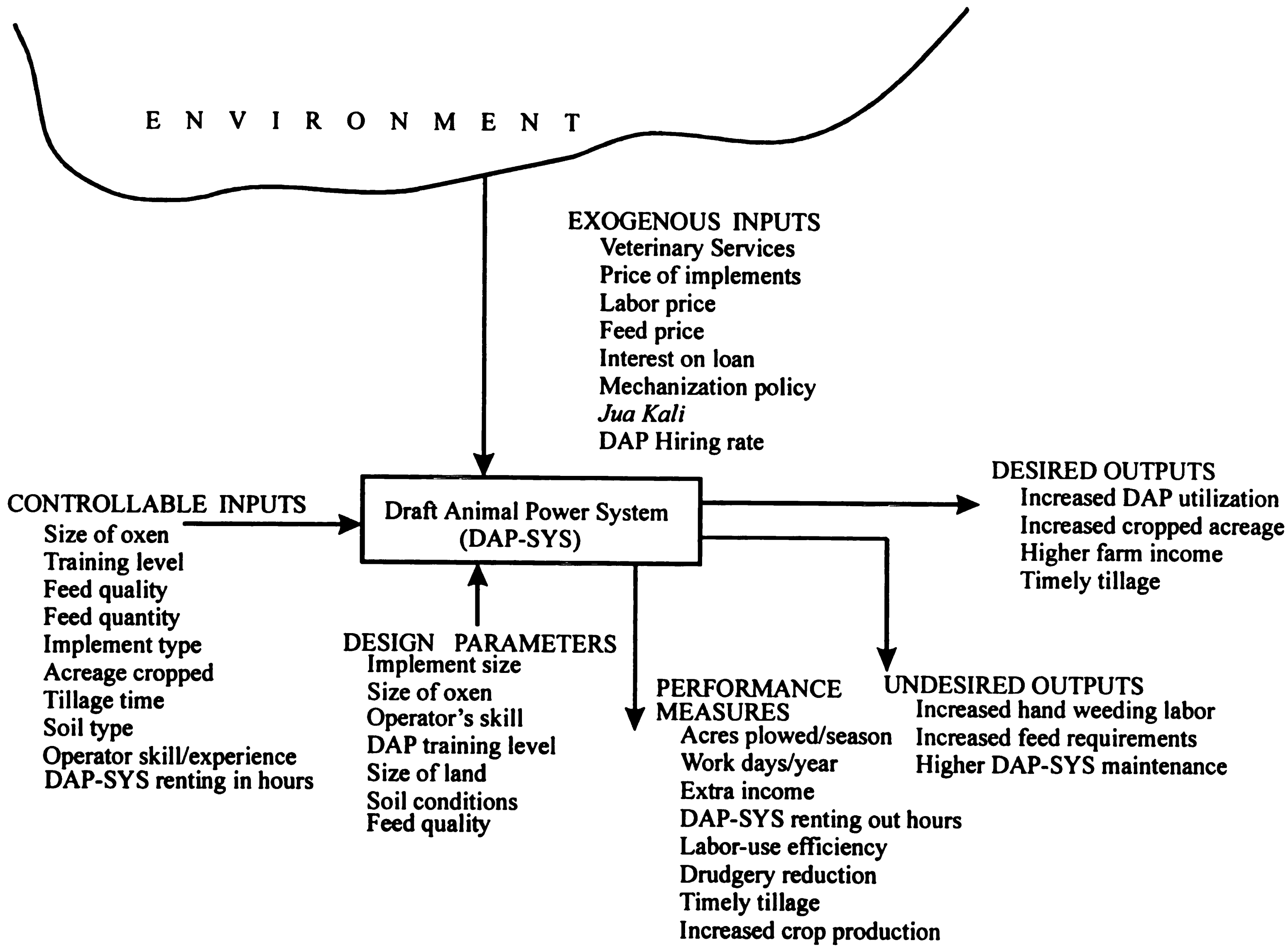


Figure 6.1: Draft Animal Power system identification diagram

The design parameters of a DAP-SYS are considered fixed and serve to define the structure of the system. They are the basis by which a particular DAP-SYS is identified in terms of the geographic location, acreage of the land, size of the implement, size of oxen, feed quality, and the harnessing technology used among others. The design parameters, of a particular DAP-SYS determine the ability of the system to efficiently produce the need-fulfilling desired outputs.

Examples of the controllable input variables that flow into the DAP-SYS include the training level of the system operator and animals, feed quality and quantity for the draft oxen, acreage under crops, DAP-SYS renting time in hours, and system utilization in hours per day. The DAP-SYS also is subjected to other inputs that are outside the control of the system. These are the exogenous inputs emanating from the “environment”. Some of these uncontrollable inputs include the weather, mechanization policy, draft oxen hiring rate, and the price of such inputs as feed and implements.

The objective of the DAP-SYS is to produce desired outputs while minimizing the undesired outputs. One of the main desired outputs is an increase in the annual utilization of the DAP-SYS in days per year. Increase in the cropped acreage, higher net farm income and timely tillage operations are other desired outputs expected from optimization of the DAP-SYS. Muchiri and Minto (1977) documented that timely tillage and hence subsequent timely planting enhances weed control as the crops get a head start. The crop also takes full advantage of the initial rainfall and therefore the probability of obtaining a crop and an improved yield is increased.

In the process of meeting the system objectives, some undesired outputs such as increased need for feed quality and or feed quantity, higher cost of DAP-SYS maintenance and increased demand for hand weeding are inevitable. These will tend to reduce the net benefits of the system and should, therefore, be minimized.

The measurement of the desired outputs is determined quantitatively by performance measures that include extra income generated, labor use efficiency, work days per year, acreage plowed per season, increased crop production (total cropped area and total yield), and the number of hours the DAP-SYS is rented out.

According to Manetsch and Park (1993), a systems approach to problem solving is a technique that is needs driven. The design of a system begins with identification of a need or needs from which a problem definition is formulated and subsequently a system structure is created. The boundaries of a system determine which components are included in the system. Once the boundaries are identified, other components outside the system are considered to be the environment with which the system interacts.

The DAP-SYS can be considered as a black box which receives both exogenous and endogenous inputs and which provides outputs, both desirable and undesirable. The simulation model developed is expected to behave as closely as possible to the real world DAP-SYS. When the system is operational, the level of outputs is determined through the system performance measures which are used to evaluate the performance of the system. When the system inputs of an operational simulation model are varied, the performance measures are used to determine and evaluate the change of outputs in response to changes of input type or level.

The design of the computer simulation model of the DAP-SYS involved the "dissecting" of the system to its bare constituent parts in order to build a "wholistic" simulation model consisting of the aggregate parts or components with linkages which represent directional flow rates of materials or services into and out of components. The preceding chapters I through V have dealt with the prerequisites that are necessary for the design, construction and implementation of a computer simulation model. Literature review and data collection and analysis established the foundation on which the analogous simulation model of DAP-SYS can be made, implemented and used for obtaining information about the performance of the real physical system, without the rigorous testing and evaluation of the biological (draft animals) and mechanical (implements) components of the real world system. The benefits of this type of approach in research cannot be overemphasized. Cost effectiveness notwithstanding, there is no limit of the possibilities that the simulation model can render to a researcher using a well designed and comprehensive computer simulation model.

## 6.2 Simulation modeling

A model is defined as a mathematical or physical system obeying certain specified conditions whose behavior is used to understand a physical, biological or social system to which it is analogous in some way. Simulation usually means that there exists a computer program or other functional model of a system on which different design and management strategies can be tried. Simulation modeling involves a model that is capable of performing in an analogous manner akin to an actual physical system. Analyzing a simulation model enables a system analyst to understand the effects that changes in system variables impose on the performance of a system without necessarily building the actual system.

Although systems analysis can be done without computers, the computational power of computers makes many system analysis tools easier to use. Simulation models are used to display the impacts of alternative decisions upon a number of measures of system performance which in turn can be used by decision makers to arrive at courses of action which are acceptable or "good". Two types of systems are commonly used in solving problems of physical or non-physical nature. The first is called the black box approach where inputs and outputs can be observed and measured, but the process of transformation of the inputs and outputs remains unknown or is of less importance to the user. The second type of a system is called the structural approach which begins with a careful examination of a system structure and theory to determine the basic system components and linkages. Both the black box and the structured approach can be used to simulate the same physical system.

The Energy Utilization Model for Draft Animal Power (EUMDAP) computer simulation model developed by the researcher in this project incorporated the two approaches. Essentially the computer simulation model developed was designed to be used for the modeling of a DAP-SYS operating in semi-arid lands. Energy utilization by draft animals for tillage purposes was the primary focus in developing the model. The objective of the exercise was to enhance the utilization of the energy from draft animals both in terms of the annual days the system is used and also the efficiency of using this power source for crop production. Although the conversion of feed to energy in animals is well understood, the modeling of energy production and utilization by draft animals was not done at the cellular level. Modeling the energy flow through the DAP-SYS was done at the macro level using the already established mathematical relationships of the feed energy values and the animals' metabolic rates for both maintenance and work and the existing models on energy used by animals at work.

Computer simulation models have been utilized for the design of new systems or for the management of existing physical systems. Principles of system analysis are used to determine how a set of components will behave in response to changes in the value of inputs or the interactions of inputs. In describing a system, consideration is given to the entities or components that would be included within the boundaries of the system. A detailed description of the components of the system and their linkages enables the design of the system to be done without making too many assumptions.

### 6.3 Computer simulation modeling

According to Neelamkavil (1987), a model is defined as a simplified representation of a system intended to enhance the ability to understand, predict, and possibly control the behavior of a physical system. Simulation has also been defined by Rockwell (1965) as meaning to duplicate the essence of a system without actually attaining reality. Hence a computer simulation model is one that is adapted for simulation on a computer. Computer simulation models have become useful tools in simulating biological and physical systems of agricultural production entities. The draft animal power (DAP-SYS) physical system was represented in abstract terms by the EUMDAP computer simulation model to achieve specific objectives. EUMDAP enables monitoring of the physiological response and interaction of the biological component (draft oxen) with the mechanical component (implements) of the DAP-SYS in an abstract setting. The purpose of the EUMDAP computer model was to simulate real DAP-SYSs by using varying rates and levels of input variables in order to achieve optimum energy utilization of draft animals in small-holder agricultural production systems in semi-arid areas.

Computer simulation models are used as alternatives to analytic solution methods using mathematical abstractions of the system to relate various functions that together affect each other in achieving a set of goals or objectives. The design of computer simulation models is preceded by graphical or conceptual models which provide the inter-relations between the various components, their linkages and direction of flow of materials or services.

Naylor et al. (1986) describes the purpose of a simulation model as being to enable the analyst to determine how one or more changes in aspects of a modeled system may affect other aspects of the system as a whole. Coefficients of equations used to relate system components are derived from empirical and historical data. The data used for the development and construction of the EUMDAP computer simulation model were collected in the field using socio-economic and DAS instruments to obtain first hand baseline and operational data from farmers that predominantly use draft animal power in Kenya. Historical and secondary data from literature were also used for parameters and variables that could not be obtained directly from the field surveys or energy utilization experiments.

### 6.4 EUMDAP computer simulation model development

In a system approach to problem solving, the process of developing a computer simulation model to solve a problem involves various stages which include:

- identification of needs
- formulation of the problem
- formulation of the conceptual model
- data collection and analysis
- formulation of the mathematical model
- model implementation
- verification of the model

- validation of the model
- sensitivity analysis
- evaluation of the simulation model

Each of these stages provides information that is used for the subsequent stage of model development. A checking process is used recursively to ensure that each stage is covered comprehensively before proceeding to the next one and that the desired structure of the model is progressively formulated. Figure 6.2 shows the step-by-step stages of the development of a simulation model. The dotted arrows from the left represent the flow and accumulation of information between iterations which is processed and used for the model development. This step-wise development process for EUMDAP computer simulation model of the DAP-SYS is described in the succeeding sections.

### 6.4.1 Identification of needs

Identifying the needs of the DAP-SYS used by the small-holder farmers of semi-arid areas of Kenya was the first stage of the process of formulating the computer simulation model. While other agronomic and socio-economic factors of agricultural production are important, the simulation model which was developed is hinged on the timing of tillage operations as critical in ensuring that farmers have a good chance of obtaining a harvest. The majority of farmers in the study area are largely subsistence growers producing mainly maize and beans as the primary seasonal crops. Maize, the staple food of Kenya is grown by virtually all small-holder farmers in the semi-arid lands. The primary objective of a subsistence farmer is to ensure food production (*food security*) for his

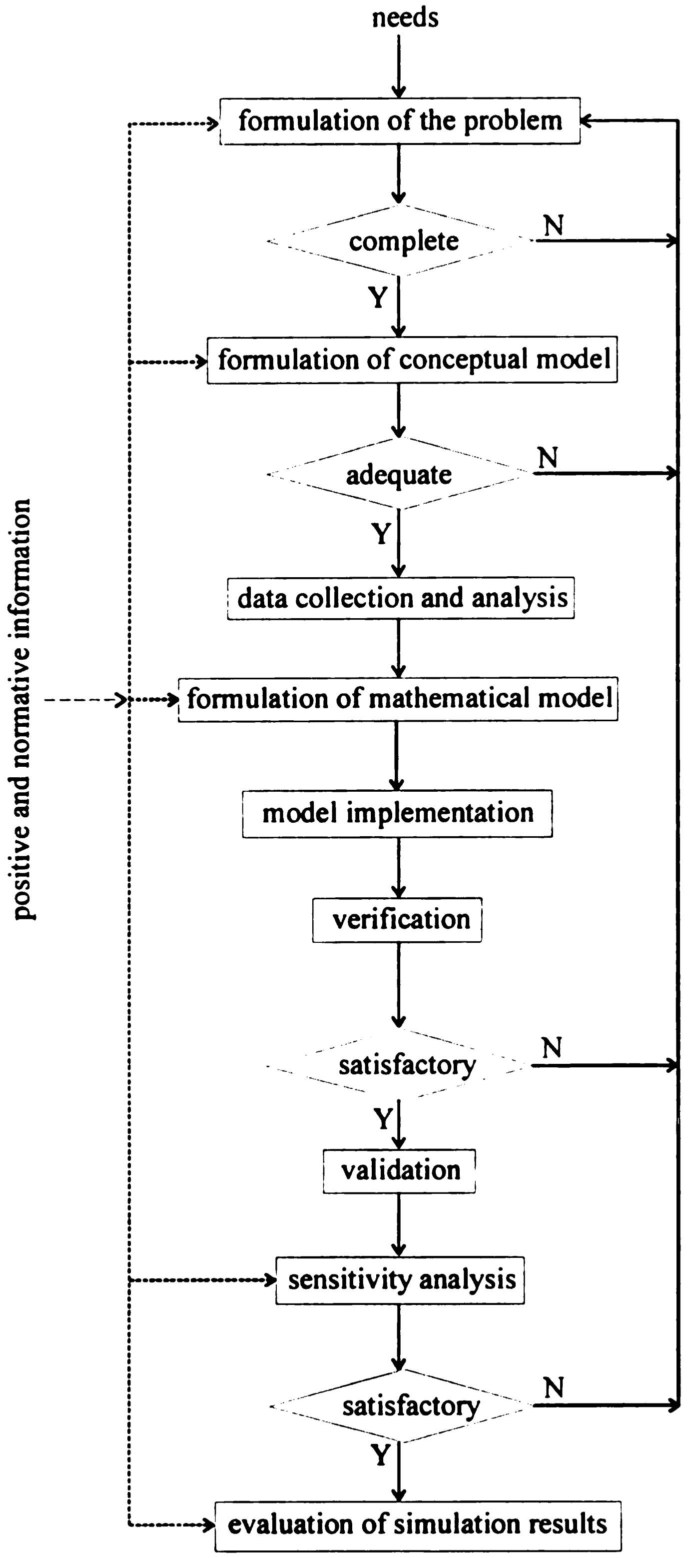


**Figure 6.2: Step by step simulation model development**

household. When maize is grown as a pure stand (single crop), limited post-planting mechanization like weeding can be done with draft oxen. Draft animals may be used for the first weeding of pure stand crops while the crops are small. Subsequent intra-row hand weeding is labor intensive. Expansion of cropped land is often constrained to the acreage that the family labor can handle in manual weeding. The EUMDAP simulation model implementation factors this limitation in projecting the land expansion possibilities.

Small-holder farmers in semi-arid areas face various food production challenges. Foremost among these is that the prevailing soil conditions during the optimum land preparation period are hard. More often than not farmers wait for the initial rain showers to soften the ground before they can embark on the tillage process. This delays land preparation which causes late planting and subsequently late weeding. Without timely planting and weeding, which are the main factors affecting yield, other recommended management practices and technological inputs such as improved seed, fertilizer, plant population and crop protection yield low returns. In semi-arid areas the loss of yield due to delayed planting is very substantial. According to experiments on yield of maize in semi-arid areas, up to 500 kg per hectare [5 quintals] loss of yield occurs per week of late planting or late weeding (Johnston, 1984). It is therefore imperative that timely planting in order to maximize on the scanty rainfall be given first priority in modeling for tillage with draft animal power systems.

The soils prevalent in the study area include the well-drained dark reddish Luvisols and heavy clay Vertisols, generally known as black cotton soils. These soils tend to be hard and impenetrable in the dry season due to "cementing" on the surface for the red soils and crusting for the black soils. On the other hand black soils become heavy and sticky when very wet but the red soils are manageable when wet. The results of the data collected indicated that about 55% of the farmers do the first plowing soon after harvest when the soils are neither too dry nor too wet. This post-harvest plowing enables tillage to take place before the rains and facilitates timely planting. The underlying need for the small-holder subsistence farmer is to produce sufficient food for the household despite the climatic and environmental odds operating against crop production. The problems sited above that hinder food production are factored into the EUMDAP simulation model in order to arrive at an optimum combination of resources and timing of operations for ensuring that the farmer obtains a crop.

### 6.4.2 Formulation of the problem

The process of formulation of the problem entails the identification or definition of the problem to be addressed and setting out the objectives to be realized in the simulation model. As stated earlier, DAP utilization in semi-arid lands of Kenya is bereft with many constraints. Some of the problems are associated with the harsh climatic and environmental conditions prevalent in this geographic area. The low productivity of the land makes the predominantly peasant farming community prone to chronic food shortages necessitating government food supply interventions during the drought stricken years. The main and most pressing limitations that the EUMDAP computer simulation model incorporates include:

- poor physical state of the draft oxen during the tillage season.
- low annual utilization of draft animal power
- inadequate quality and quantity of feed for draft oxen
- hard and dry soil conditions
- erratic and poorly distributed rainfall pattern

#### *6.4.2.1 Physical condition of draft animals*

The primary objective of the EUMDAP computer simulation model was to formulate a tillage system model that would utilize the current technological innovations at the farmer's disposal in such a way that land, draft power and labor productivity would be optimized. One of the main concerns at the outset was the prevalent and chronic loss of weight of the draft animals both before and during the tillage season. The optimum land preparation time of the two cropping seasons falls when the grazing fields have been depleted of adequate fodder for the livestock. About one third (30%) of the farmers surveyed harvest and store maize stover for the feed deficient periods. Data collected from the field by the researcher shows that commercial supplementary feeds are not readily available in the semi-arid areas. It is estimated that, in general, livestock in the semi-arid areas lose up to about 20% of their body weight by the end of the dry season. This situation invariably leads to the use of the draft animals at their worst physical condition. The draft requirements of the single bottom Victory plow commonly used by farmers does not justify the use of more than two oxen at a time. However, some farmers train more animals than they would normally need so that they are available to work together (in fours) during the peak power demand period if the need arises. Field data collected by the researcher found that although about 30% of all the farmers interviewed have four draft animals trained for work, only about 25% of all respondents actually use the two pairs together.

The use of multiple pairs of draft animals does not take full advantage of each animal's potential power output. The efficiency of multiple pairs of animals declines with each additional animal in the team. This loss of energetic efficiency is relative to the tractive effort of a single animal. The efficiency of utilization per animal declines with each extra animal used. Goe and McDowell (1980) documented this loss as amounting to 7.5% for two, 15% for three, 22% for four 30% for five and 37% for six animals. It is therefore desirable to utilize a single pair of oxen to its maximum potential to avoid the cumulative loss of power when multiple pairs of oxen are used in tandem. In order to enhance DAP utilization for farmers with four oxen the EUMDAP model simulates the use of single pairs intermittently in blocks of two or three hour intervals.

#### *6.4.2.2 Annual utilization of draft oxen*

The number of hours that oxen are utilized per year depends on the variety of activities in which the animals are engaged. Farmers with more than two trained oxen have a lower net annual draft oxen utilization rate per animal. The survey data obtained from the field also shows that farmers who use only a plow log relatively fewer hours per year when compared with farmers who use oxen for other purposes. The total average time that draft animals are used in the semi-arid areas was found by the survey to be about 58 hours per year. There is a substantial untapped potential for higher utilization of DAP-SYSs both during the tillage and post tillage periods. While tillage is the most important and the most energy demanding activity at the farm level, farmers with other implements such as ox-carts and improvised transport sleds log in more draft oxen hours per year than those with only a plow.

At the end of the plowing season the grazing fields have sufficient and nutritive forage. The oxen soon gain back their condition but unfortunately they are put to little use except for weeding and miscellaneous transportation like carting water, building materials, firewood and other items. The simulation model attempts to maximize the utilization of a single pair of draft oxen during and after the tillage season period. By so doing the annual utilization and the potential returns that the farmer can expect are increased. As noted in section 2.3, Indian draft power farmers use their animals almost three times as much per year as the Kenyan draft animal farmers.

#### *6.4.2.3 Quality and quantity of feed*

In general, farmers depend on natural grazing to feed their livestock including draft oxen. The milk producing cattle receive preferential feed regime (where available). The natural grazing fields in semi-arid areas have a very low livestock carrying capacity. Ideally 2 to 4 ha are required per livestock unit (LU) for adequate feeding (Silberfein, 1989). According to the findings of the data collected from the research areas, about half of the land owned by small-holder semi-arid farmers is used for crop production. The remaining land is barely enough to maintain the farmers' livestock. Hence the quantity of fodder available for livestock on natural grazing falls far short of the minimum required except after the rainy period.

The metabolizable energy (ME) feed value of natural pasture ranges between 4.0 and 8.5 MJ/kg DM (Zerbini et al. 1992). According to guidelines by ARC (1980) the ME available is attenuated by an efficiency of utilization factor ($K_m$) and also by the dry matter content of the feed ($DM_c$). Given an appetite limit or voluntary dry matter intake (VDMI) of 2.5% (ARC, 1980; NRC, 1996) per unit weight (kg) of the animal per day, draft animals are unable to ingest sufficient low quality feed to meet both maintenance and work energy needs. The amount of VDMI that a 350 kg ox can ingest per day is 8.75 kg of DM. From this amount of feed the ox would extract between 35.0 MJ and 74.38 MJ of metabolizable energy (ME) per day from natural grazing pasture. Using models developed by Brody (1964) and used in the EUMDAP simulation modeling (see equation 13 in section 6.4.5.2) the energy for maintenance ($E_m$) for a 350 kg ox would be 23.87 MJ per day.

### *6.4.2.4 Soil conditions*

The prevalent highly drained sandy soils of semi-arid lands and the less common black cotton soils are both difficult to work when dry. The high clay content of these soils causes hardening when the soil moisture declines with receding rain. This hardening increases the draft requirements of the tillage tools. Though timely land preparation is of prime importance in the semi-arid region, it is often not practical to engage animals in tillage operations when the soils are still dry. A characteristic shear resistance in these soils when dry is 50 kN per square meter. A pair of oxen (each weighing 350 kg) would develop a total force of 0.65 kN based on a 10% rule of thumb[1] for each animal and 92.5% "tractive efficiency" for a two-animal team[2] (Goe and McDowell, 1980). For a 25.4 cm (10 in) plow operating in a dry soil at a depth of 10 cm, the draft requirements of the plow would be about 1.27 kN which is beyond the maximum tractive force generated by a pair of 350 kg oxen.

### *6.4.2.5 Unreliable rainfall*

The minimum required moisture in rain-fed agriculture is 726 mm (30 in) of rainfall for crops to mature. In Machakos and Mbeere districts, the probability of obtaining more than 590.1 mm in the March-May season is only 10% while that of obtaining 670.5 mm

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[1] It is generally considered that oxen develop a pull force equivalent to 10% of their body weight (*rule of thumb*).

[2] If one ox is working, it is expected to develop a pull force approximately 10% of its body weight. When two oxen work in a team, the pair loses 7.5% of its potential pull force so that the total "tractive efficiency" or pulling ability is reduced to 92.5% of the potential pull force (Goe and McDowell, 1980)

or more is only 10% in October-December season. The two districts studied not only have erratic and poorly distributed rainfall but also the probability of drought is high, occurring about one in every ten years (Tiffen and Gichuki, 1994).

Some of the limitations of the expansion of land use for the small-holder farmer in the medium and low potential areas are the low livestock holding capacity, the small acreage of the land and the poor, and dry soil conditions. When the soils of semi-arid areas are dry, they tend to crust and harden. In the dry period the soils develop high implement draft force which is often beyond the capacity of the draft oxen. In addition, the physical condition of the draft animals is at its lowest at the time of tillage for the next season's planting due to inadequate fodder. The climatic conditions of these lands also pose a moisture supply problem due to poor distribution of rainfall during the crops' growing season. The basic need that the farmer has to meet given the economic and environmental scenario he is in is to produce enough food for his household. The needs and challenges stated above that the small-holder farmer faces are used for subsequent process of problem formulation. Better utilization of the DAP system is expected to provide increased returns for the household in order to improve the provision of food.

The problems that a farmer faces in trying to produce enough food for his family and preferably have some marketable produce left are technical and technological, as well as environmental and cultural. The implements available at the household level for the preparation of land by timely plowing are limited to mainly a moldboard plow which is incapable of penetrating the hard soils during the optimum land preparation period before the onset of rains. It is imperative that the land preparation is done in a timely manner to ensure that the planting is completed before the rains fall. Given the scanty rainfall that is prevalent in the semi-arid areas, the time of planting relative to the onset of rainfall can determine the success or failure of a cropping season. The problem to be addressed in attempting to assist the farmer can be defined as:

*How can the small-holder draft animal power farmer in the semi-arid area of Kenya combine the production resources at hand to prepare the land on time in order to: (a) maximize on the scarce and poorly distributed rain fall and (b) optimize on the available draft animal power so as to (c) produce enough food for his household?*

The simulation model addressed the following areas of the DAP-SYSs of semi-arid lands:

- the potential economic gain in increased utilization of draft animal power
- the potential of using only one pair of well trained oxen.
- multi-purpose use of draft animal power for increased income generation
- hiring draft animal power
- land-use expansion

### 6.4.3 Formulation of conceptual model

The DAP-SYS is comprised of both physical and biological components that work together as an entity to provide draft force to the soil in tillage operations. The oxen (*prime movers*) are the source of power for the system, while the operator(s) serve as the power controller. The animal, implement and soil interact together with each other to achieve the objective of accomplishing a task (tillage or transportation) within certain constraints of time and resources. The EUMDAP conceptual model shown in Figure 6.3 identifies five components of the system which include:

- draft oxen
- harness mechanism
- implement
- operator
- land (soil)

These components are interconnected through linkages which are services or materials flowing at varying flow rates. The draft oxen receive water, feed, management and training as inputs so that they can deliver the required energy to the harnessing mechanism that in turn delivers draft force to the implements. The ultimate objective is to manipulate the soil conditions to a suitable tilth for crop growth.

Detailed descriptions of the inputs and linkages are provided in the mathematical model development in section 6.4.5. The exogenous factors or inputs that affect the EUMDAP model are mainly institutional and environmental in nature and which are not influenced by the system. Four institutional factors that influence the EUMDAP system were identified. The government policy on agricultural mechanization can hinder

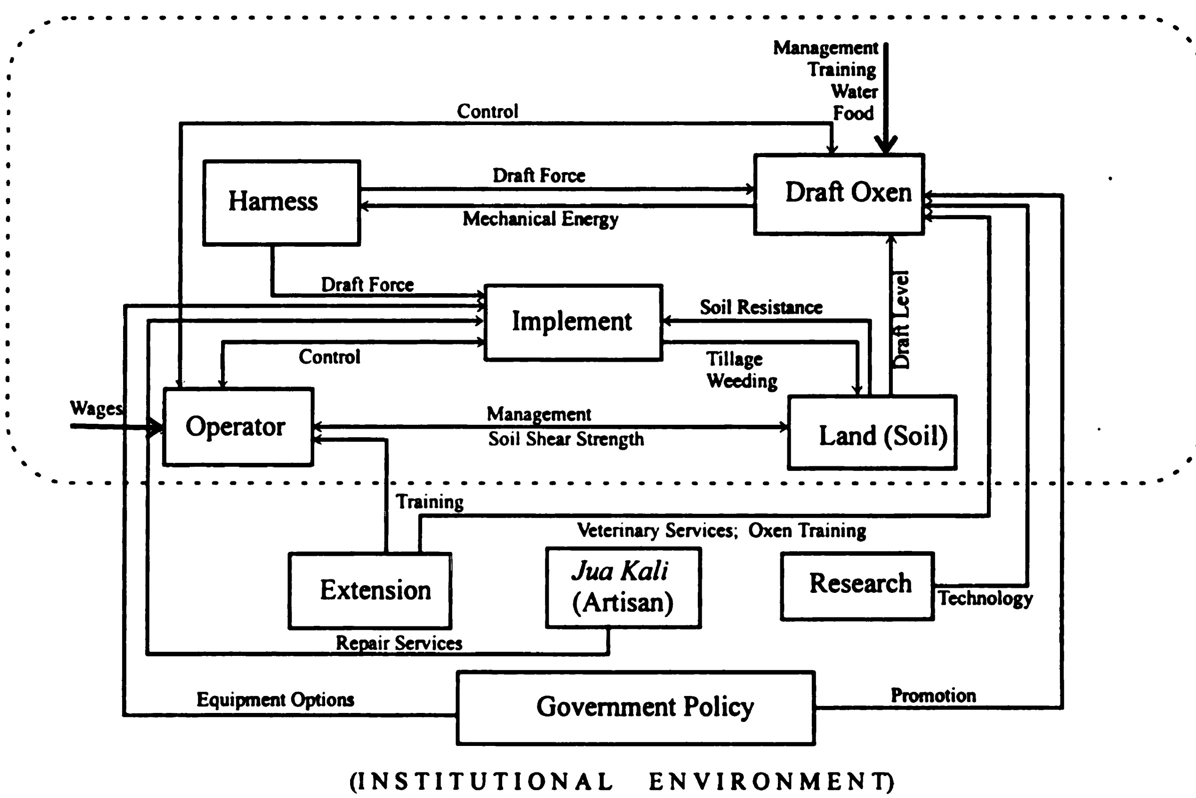


Fig. 6.3 Energy Utilization Model for Draft Animal Power (EUMDAP) conceptual model

or facilitate the promotion of draft animal power in semi-arid areas. As mentioned elsewhere, it was not until about 1975, that the government of Kenya explicitly enunciated a policy statement that considered draft animal power as a viable mechanization option for small-holder farmers. Both the promotion of DAP-SYS and the availability of alternative equipment for DAP-SYSs depend on the level of mechanization that the government supports. Implementation of government policy is channeled through agricultural extension services and the results of the research services provided by both the public and private sectors. The fourth exogenous input considered is the availability of artisans for the maintenance and repair of tillage implements.

For each of the system components a set of input and output variables was identified. Some inevitable constraints limited a comprehensive inclusion of all possible exogenous and endogenous variables that would affect the EUMDAP system. However, inputs that had direct influence on the performance of the EUMDAP system were included to the extent that data were available for parameter and variable determination. In designing the model of the DAP-SYS, a careful consideration of the boundaries of the system was taken into account. Inputs that affect the system from outside the system boundaries are considered environmental inputs. An example of such an input is the agricultural extension officer and the government policy on small-holder agricultural mechanization.

An adequate conceptual model determines how well the final system model represents the actual or envisaged physical system. Determination of the required data and the form, type and method of obtaining them depends on how comprehensive and detailed the conceptual model is. Similarly, the validity and relevance of the mathematical relationships developed and used in the abstract modeling depend on the linkages shown in the conceptual model. The linkages between the components are the paths of the flow of material and services between the system components.

The EUMDAP computer simulation modeling program is interactive with the user. At the start of the program parameter and variable value entries are required from the user as shown in Figure 6.4a through Figure 6.4f of the algorithm or logic flow of the computer simulation model. The user is required to select from pre-determined parameter settings and variables for some of the input data such as the type of soil, implement types, and depth and width of operation of tillage. The listing of the QBasic computer code is provided in Appendix F.

### 6.4.4 Data collection and analysis

The process of obtaining DAP utilization data was done through the administration of a questionnaire with which socio-economic data from a cross-section of small-holder farmers in Mbeere and Machakos districts were obtained. The data collected through the questionnaire provided parameter estimators for the computer simulation model. Historical data were obtained where possible, otherwise best estimates were obtained from farmers on variables such as the life span of working oxen. The size of the holdings and time spent for tillage and other operation with draft oxen, as well as the labor used for weeding with and without oxen, was obtained from farmers through the questionnaire. Details of the procedure used and the data collected are covered in Chapter IV and the results of the data analysis are summarized in Chapter V.

The energy demand by the implement and the energy available from the animals were obtained through an electronic data collection system tailor-made for the research

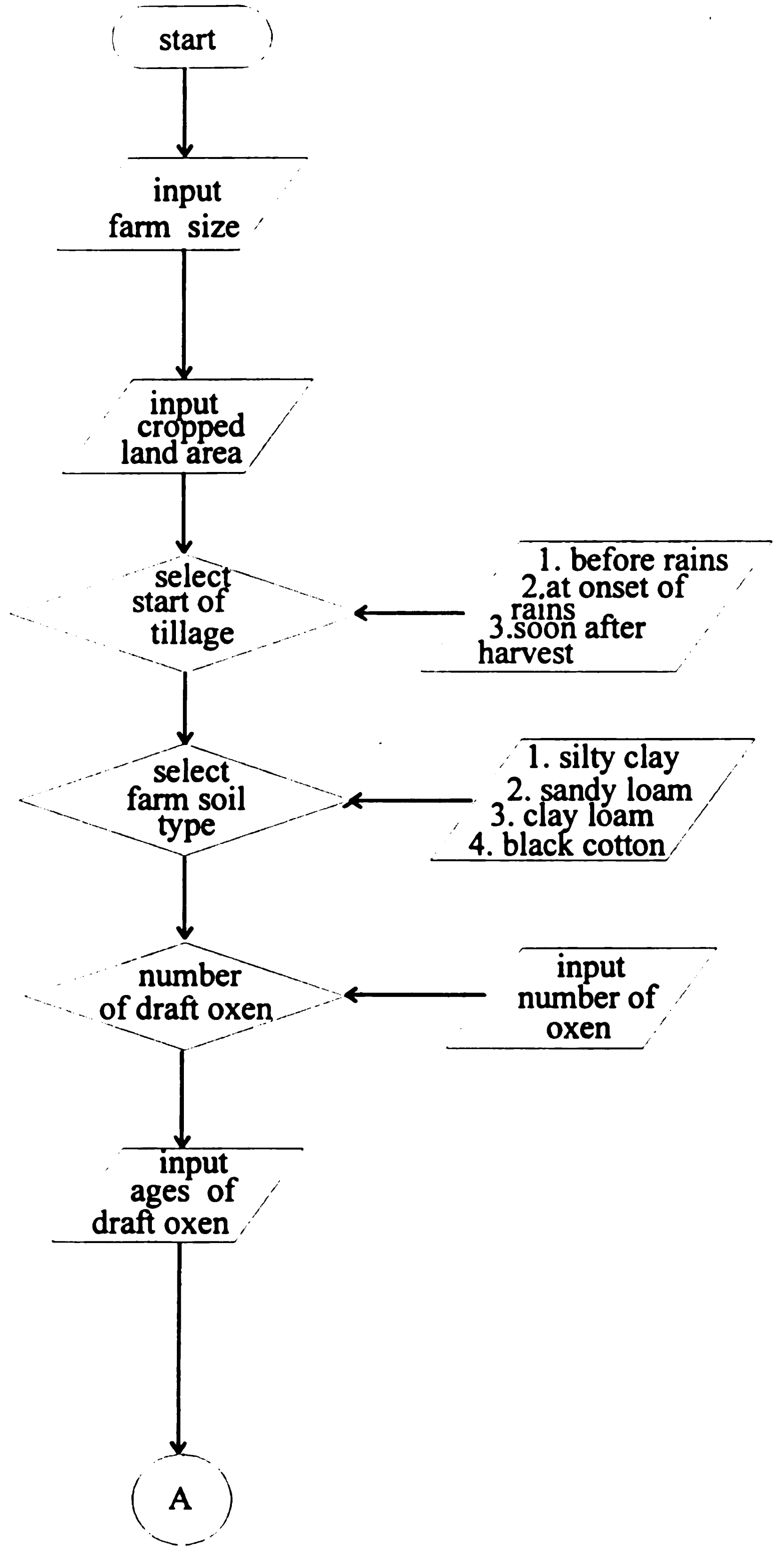


Figure 6.4a: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power.

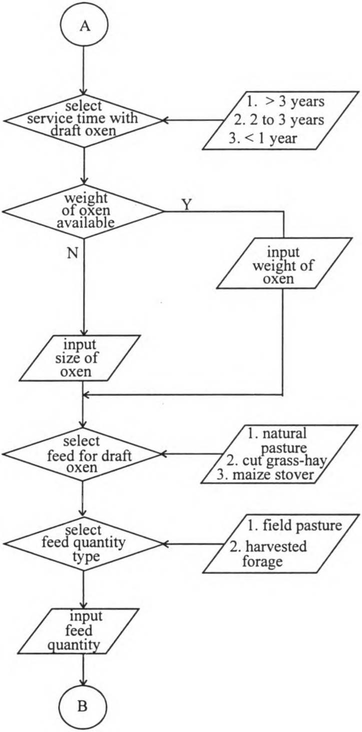


Figure 6.4b: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power *(cont'd)*.

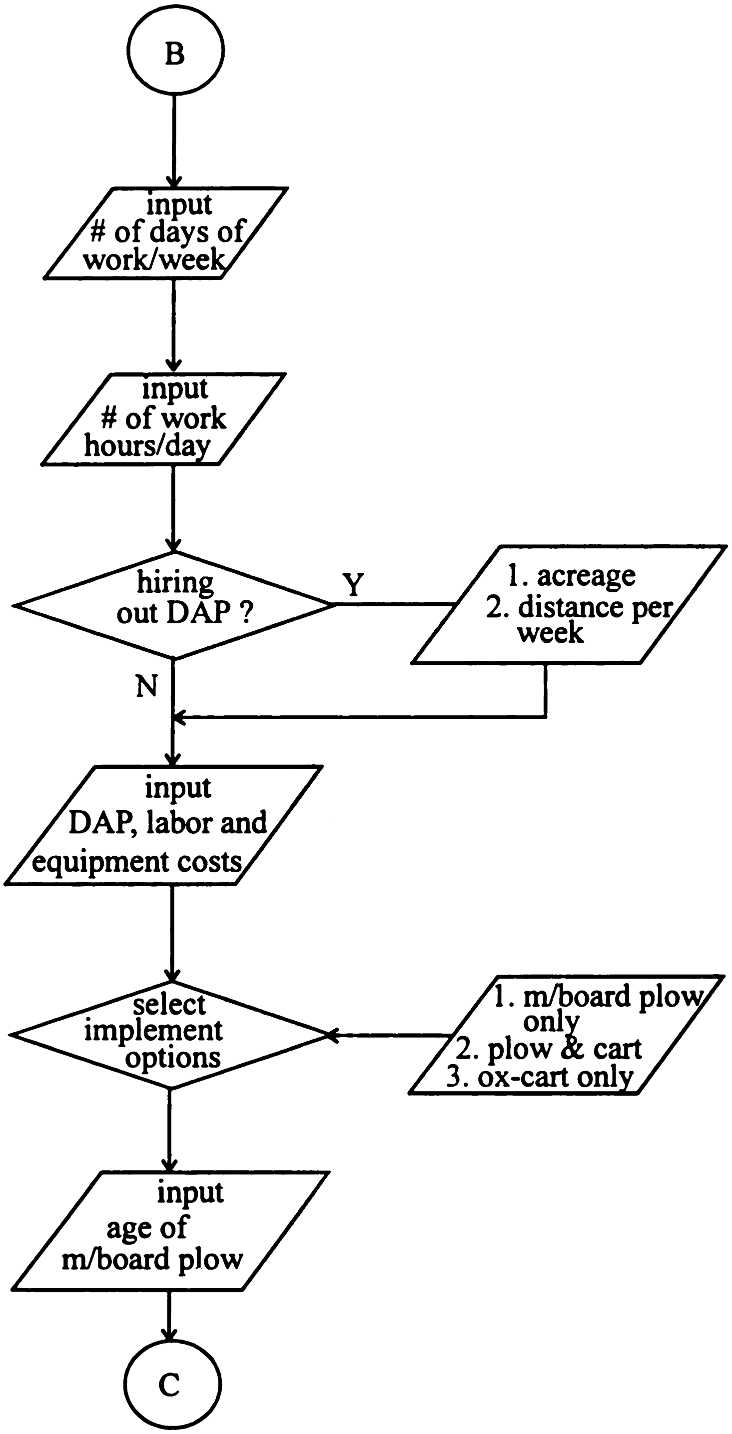


Figure 6.4c: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power (*cont'd*).

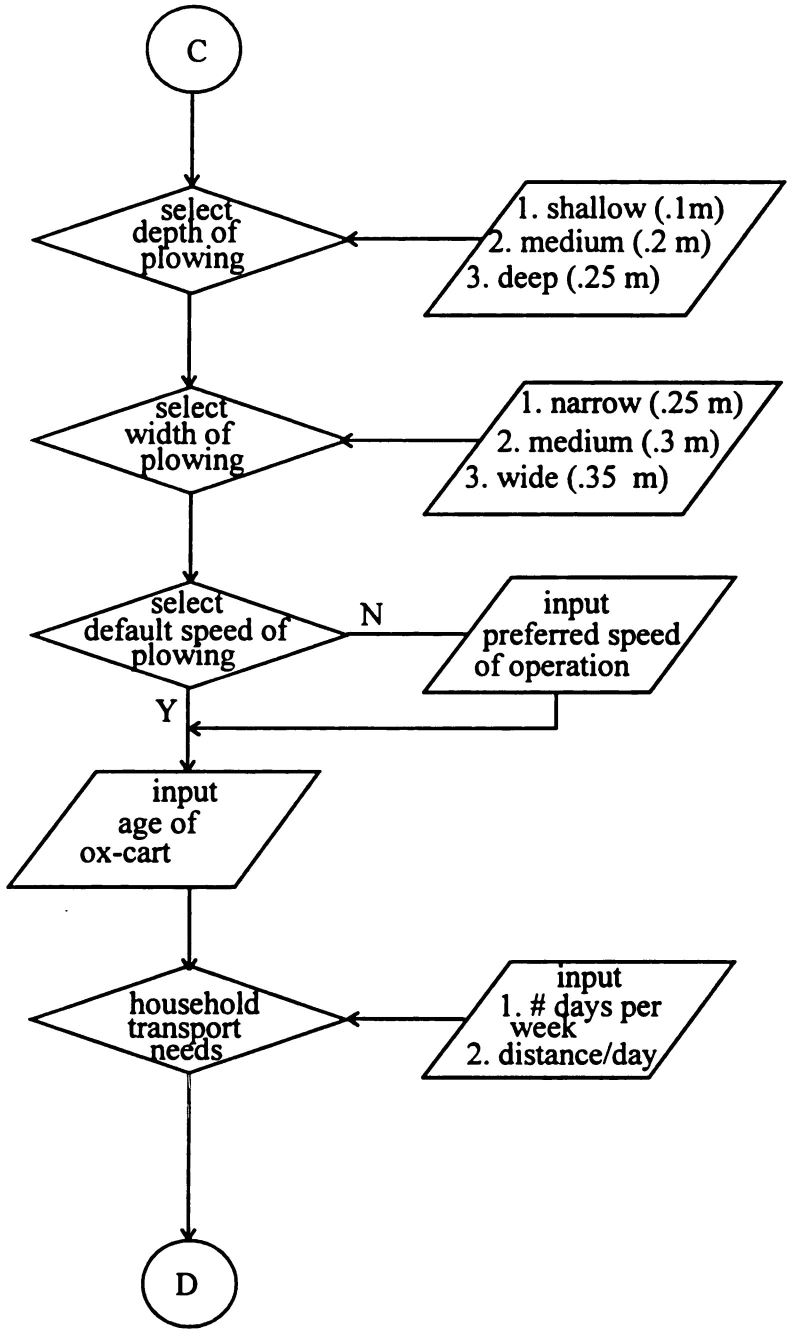


Figure 6.4d: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power (*cont'd*).

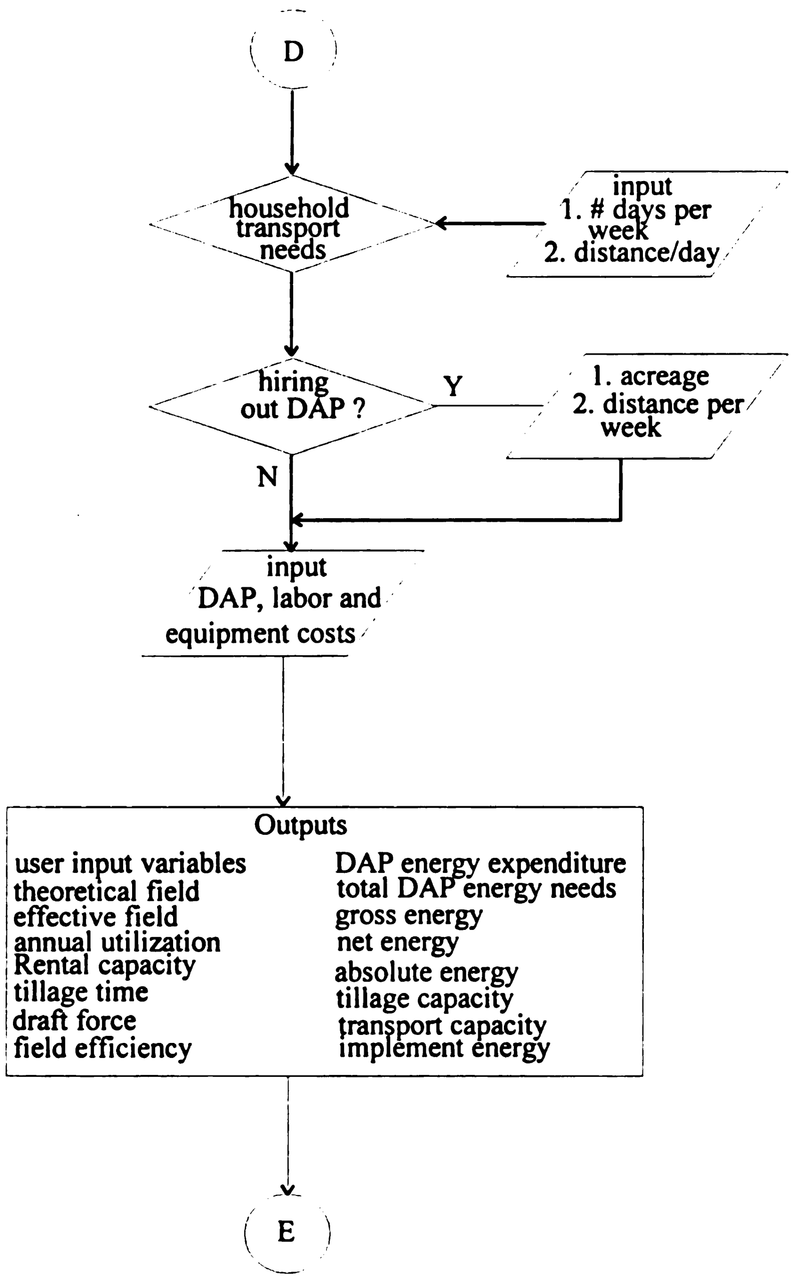


Figure 6.4e: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power (*cont'd*).

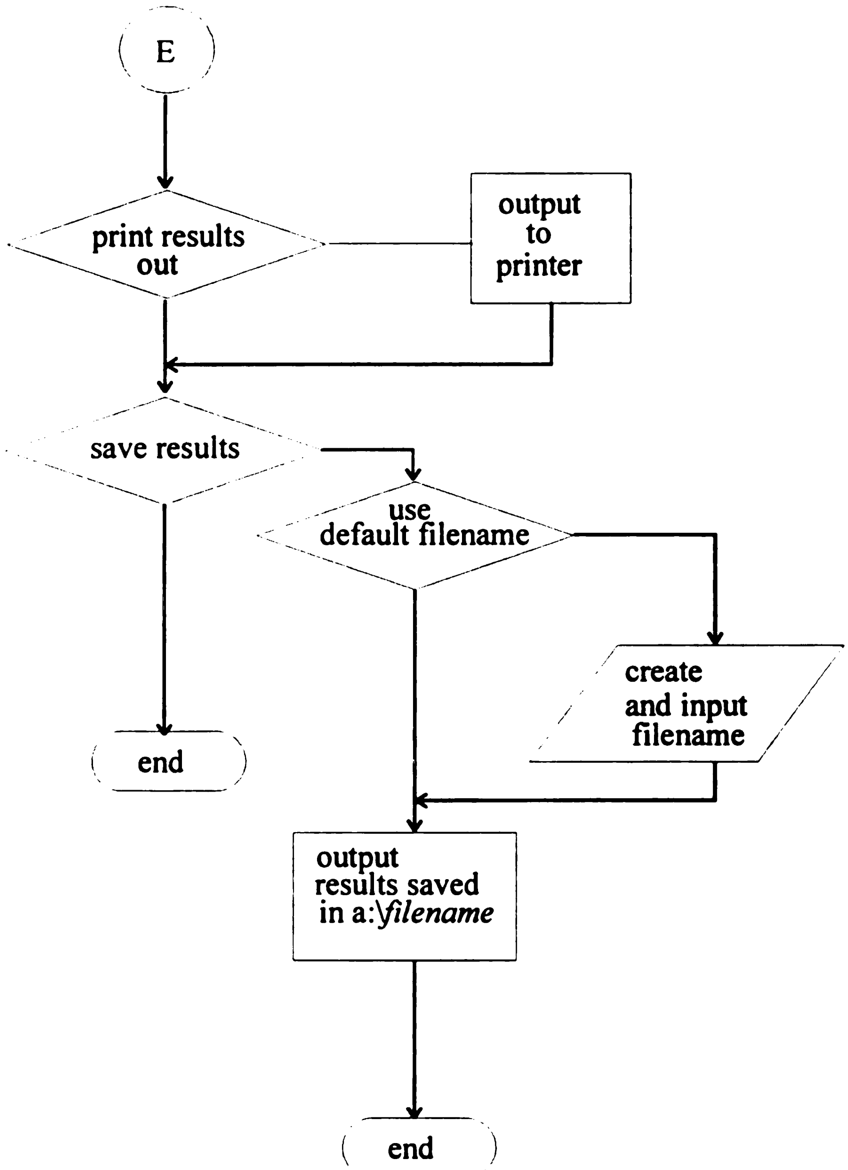


Figure 6.4f: Algorithm flow chart of the Energy Utilization Model for Draft Animal Power (*cont'd*).

project as described in sections 3.2 and 3.3. Four physiological parameters of the oxen at work were monitored with the farmers' animals at work. Using models developed by Richards and Lawrence (1984), estimation of the energy produced by working oxen was estimated from the heart rate of the animals at work including heart rate, stepping rate, breathing rate and body temperature. By simultaneous measurement of the mechanical energy output of the animal to the implement, it was possible to relate the energy provided by the animals to the specific draft force developed. Mechanical energy parameters monitored for the DAP-SYS included horizontal and vertical draft force, speed of working and depth of tillage as well as the width of tillage. A Victory plow was used for the whole exercise of electronic data collection. Detailed description of the data acquisition system is covered in Chapter III.

Soil and other environmental factors that influence the quality and rate of tillage work were measured in each field. These included the soil shear strength and the soil moisture content. From the contacts made with the farmers, it was possible to draw conclusions about the level of support that the extension officers give in the promotion of small-holder agricultural mechanization in both districts. This was especially noteworthy with respect to the training of the farmers' animals to adopt a better system of control of animals at work. In Mbeere district, a program of training both the farmers and animals was being promoted by a non-government organization using the agricultural extension officers to implement it. The use of a single pair of well trained draft oxen was a common feature in Mbeere district. There was no comparable program that helped farmers with DAP mechanization needs in Machakos district. The major distinction between the DAP management in Mbeere and Machakos districts is the handling of the animals. While farmers in Machakos use voice commands and prodding methods to get the animals to work, in Mbeere farmers have started adopting the nose-ring-and-reins control method which the government has been promoting. This method enables the oxen operator to make turns at the end of the field by simply pulling the rope (reins) of the right-hand ox.

There are limitations of measuring the power output from animals since it is not deterministic like the power from fossil-fueled machines. The output from animals varies in the short term (less than a day) due to both endogenous and exogenous factors. It was, therefore, necessary to ensure that the process of data collection for each farmer's location was completed in one working day so that each farm was treated as a block for data analysis purposes.

### 6.4.5 Construction of mathematical model

Mathematical relationships were used in the EUMDAP simulation program to represent the linkages between various components. Models of DAP energy utilization that have been used by other researchers were utilized for this purpose for some variables while new parameter values and relevant data from the research area were used for other variables. Parameter estimators used in other DAP research and animal nutrition literature provided a good basis for the development of the mathematical models. The EUMDAP computer simulation model puts emphasis on the energy production from the animals and the subsequent utilization of this energy by the implements during tillage and transportation.

Draft animals are isothermal energy converters with a maximal energetic gross efficiency of 25% that is comparable to that of heat engines (Brody, 1964). However as a source of energy, animals consume energy continuously as basal metabolism. The amount of energy they can produce for work depends on the quality and quantity of feed they take and also the energy stored in the body.

#### *6.4.5.1 Energy needs for draft oxen*

Animals provide the energy to do work by converting chemical energy stored in their bodies to mechanical energy. Unlike mechanical chemical energy converters (for example petroleum-based engines) which transform chemical fossil energy to mechanical energy at a predetermined rate, the type of feed that animals eat determines how much energy they can derive from it for maintenance and work. The energy so converted is in turn provided to the animals through feed ingested and digested to convert the gross energy (GE) to digestible energy (DE) and eventually to metabolizable energy (ME) available to exert movement of muscles when combustion takes place in the muscle cells. Gross energy also referred to as "heat of combustion" is the energy released as heat when an organic substance is completely oxidized to carbon dioxide and water. The relationships between the GE and the ME are well established.

The ME of draft animal feeds was used to estimate the quantity of feed required by draft animals for maintenance and work. ME is defined by Harris (1966) as the feed intake gross energy minus fecal energy, minus energy in the gaseous products of digestion, minus urinary energy as represented in equation (8).

$$ME = GE - FE - GPD - UE \tag{8}$$

where:

ME = metabolizable energy, MJ/ kg DM
GE = gross energy, MJ/kg DM

FE = fecal energy, MJ/kg DM
GPD = combustible gases produced in the digestive tract
UE = gross energy of urine, MJ/kg DM

The value of ME of feeds are documented in publications such as Agricultural Research Council (ARC, 1980) and National Research Council (NRC, 1996) and other animal nutrition publications. Natural grazing is the most common source of feed for draft animals in semi-arid areas. The ME energy value of natural forage is considered to be between 4.0 and 8.5 MJ per kg of dry matter (DM). In contrast, high energy feeds used for dairy cattle such as groundnut cake have a ME value of about 14.2 MJ per kg DM.

Due to the low quality of feed value available to draft animals and the intake constraint due to the appetite limit of the animal, draft animals fed on natural grazing hardly eat enough feed for maintenance and work especially during the dry spells between the two cropping seasons of semi-arid areas. Farmers salvage maize stover and harvest grass (natural hay) to provide feed for the animals for the dry periods of the year. Maize stover and harvested hay provide a more efficient energy source for animals because the animals are stall fed minimizing energy cost of walking. Commercial high energy value feeds are usually not easily available in semi-arid areas because of low demand but the prices are also prohibitive. While the energy availability from local feeds is a limiting factor, the appetite limit or the VDMI of animals also affects the energy intake of working animals. Generally VDMI is estimated at 2.5% of the animal's live weight (kg) per day (ARC, 1980). VDMI is also referred to as the animal's appetite limit. If the energy value of the feed is low, the animal may not obtain sufficient metabolizable energy for both maintenance and work. Hence most work animals lose weight during the working season and only regain it during off season when there is sufficient feed with high nutritive value.

Calculation of the daily feed intake by the animals is based on the metabolizable energy (ME) of the feed, weight of the animal, appetite limit and the dry matter content of the feed. Equation (9) developed by ARC (1980) was used to compute the maximum metabolizable energy ($ME_m$) intake for draft oxen per day:

$$ME_m = F_q * ME \quad (9)$$

where:

$ME_m$ = maximum metabolizable energy intake per day, MJ
ME = feed energy value, MJ per kg DM
$F_q$ = feed quantity per day, (0.025/$W_t$, kg of DM per day)

The maximum animal energy intake is further attenuated by the efficiency of utilization of metabolizable energy providing the net energy for maintenance and work ($NE_{mw}$). The efficiency of utilization factor ($K_m$) and the net energy for maintenance and work are computed as shown in equation (10) and (11) also developed by ARC (1980). Equation (12) computes the total energy need per animal per day for an animal at rest.

$$K_m = 0.019 * ME + 0.53 \quad (10)$$

$$NE_{mw} = ME_m * K_m \quad (11)$$

where:

$K_m$ = efficiency of utilization, decimal
$NE_{mw}$ = net energy available for maintenance and work per day, MJ
$ME_m$ = maximum metabolizable energy intake per day, MJ

The energy available for maintenance and work translates to about 60% of $ME_m$ whereas the rest is lost. Some of the "loss" is through the energy used for useless incidental motions associated with work. According to Brody (1964), most of the "lost" energy is expended for overcoming the internal resistance. Although the resistance of the body colloids is energetically wasteful it is biologically useful.

Each animal's $NE_{mw}$ is computed separately and the total of all the animals in the team is the total DAP-SYS energy needs. The gross quantity of feed required to provide this energy for maintenance and work is computed using the gross energy (GE) feed values and the corresponding digestible energy (DE) and metabolizable energy (ME) values as well as the dry matter content percentage. The simulations performed with the program used three different types of feeds commonly available in the semi-arid areas. The feed values and their corresponding ME and $DM_c$ values are shown in Table 6.1.

Table 6.1 Energy values of feeds

| **Feed Type** | **Dry Matter Content [$DM_c$]** *(%)* | **Metabolizable Energy [ME]** *MJ/kg DM* |
|---|---|---|
| Cut Grass (Natural Hay) | 85 | 9.0 |
| Maize Stover | 90 | 7.5 |
| Pasture | 75 | 11.0 |

#### *6.4.5.2 Work energy from draft oxen*

The energy that working animals need to exact a draft force to pull the implement is obtained from the feed that they eat. Work animals should be fed enough feed for their own maintenance and extra for doing work. Loss of body weight results when either the feed source has insufficient ME value or the maximum ME ($ME_m$) intake is inadequate to meet both maintenance and work energy requirements. The energy cost of maintenance is the net energy required to keep an animal in a "steady" energetic state. About 85% of the maintenance energy is expended through basal energy metabolism. By definition basal energy metabolism, also called post-absorptive metabolism or standard metabolism, is the heat production during complete rest of an animal in a thermo-neutral environment in a post-absorptive condition; it is the resting energy metabolism in a thermo-neutral environment uncomplicated by the heat increment of feeding (Brody, 1964).

The energy required for maintenance or basal metabolic rate (BMR) is a function of the animal's body weight and age. The BMR energy needs of cattle decreases exponentially with age at a rate of 3 per cent per year (NRC, 1996). On the other hand the energy for work depends on both the body weight, the type of work, and the rate of doing work (speed of operation). Equation (12) developed by Brody (1964) was used in the simulation modeling for the calculation of the maintenance energy needs of draft oxen.

$$^{3}\,BMR = \frac{70.5(W_t)^{0.73} * 4.184 * e^{-0.03Age}}{1000} \qquad (12)$$

where:

BMR = basal metabolic rate per day, MJ

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[3] The original equation by Brody (1964) for basal metabolism of mature animals of different species, from mice to elephants was in C per kg $(W_t)^{0.73}$ per day. 1 C (large calorie) = 4.184 J.

$W_t$ = weight of animal, kg
Age = age of the animal, yr

Equation (13) was used for the calculation of the net energy for work which is the energy needed above the maintenance energy level.

$$NE_w = NE_{mw} - BMR \tag{13}$$

where:

$NE_w$ = net energy for work per day, MJ

The total net energy needed by working animals is an aggregate of the basal or maintenance energy, energy needed for walking, carrying or pulling loads, raising loads and body weight up a slope as shown in equation (14) that was used by Lawrence and Stibbards (1990). This is the energy cost above the energy the animal uses when standing still or lying down.

$$E_t = E_m + E_w dW_t + E_c dW_t + W + \frac{9.81hW_t}{100\eta_h} \tag{14}$$

where:

$E_t$ = total energy used per day, kJ
$E_m$ = maintenance energy per day, kJ
$E_w$ = energy cost of walking, 2.0J/m kg weight
d = distance traveled horizontally, km
$W_t$ = live weight, kg
$E_c$ = energy cost of carrying, J/m per kg – used only for back packs
W = work done per day, kJ
h = vertical height traveled, m
$\eta$ = efficiency of doing work raising body weight, 0.35 for oxen

Generally for cattle the extra energy needed for walking above energy required for lying down is 9% and also the energy expenditure of walking decreases with the speed of walking (Brody, 1964 and Lawrence and Stibbards, 1990). Equation (15) by Brody (1964) is a model of the effect of speed on the overall cost of energy expenditure in cattle.

$$^{1}Y = 44e^{-0.268s} + 39.7 \qquad (15)$$

where:

Y = kcal per 45.45 kg weight per 1.6 km
S = speed of walking, km

*Adapted from Brody (1964)*

In order to compute the work that animals perform per day as provided for in equation (14), various field and operational parameters were estimated or computed from data obtained from field experiments and historical data.

Equation (16) was used for estimating the theoretical field capacity (TFC) for tillage operations. It is expected that the user of the EUMDAP program will provide operational data to enable the program to simulate the DAP system's performance. The input data is covered in the model implementation section (section 6.4.6).

Computation of implement field performance and the energy demand by tillage implements were done using equations 16 through 21 that were developed from field performance equations in the ASAE Yearbook (1995).

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[1] Conversion of this equation to *SI* units has been done in the modeling after the value of Y is calculated to maintain the original linearity of the equation.

$$TFC = \frac{S * W}{10} \tag{16}$$

where:

TFC = theoretical field capacity, ha/hr
S = speed of operation, km per hr
W = implement width, m

The total theoretical field time ($T_t$) for the field operations (17) was obtained by the inverse of equation (16) while the effective field time ($T_e$) was computed from equation (18) which took into consideration the percentage of the machine width that was used (k). The computation of the field efficiency (FE) was estimated with equation (19) which takes into consideration the total time lost ($T_{los}$) per hectare due to interruptions such as implement adjustments, turning at the headlands and lunch breaks. For DAP systems, it was estimated that the total time lost was about 8% of the total theoretical field time per hectare. This estimate was based on the assumptions that both the operator and the draft animals need to take a break for about ten minutes every one hour of work as observed during the field data collection.

$$T_t = \frac{1}{TFC} \tag{17}$$

$$T_e = \frac{100 * T_t}{k} \tag{18}$$

where:

$T_t$ = theoretical field time, hr/ha
$T_e$ = effective field time, hr/ha
k = percentage of implement width used

$$FE = \frac{T_t}{T_e - T_{los}} \tag{19}$$

where:

FE = field efficiency, decimal

$T_{los}$ = total time lost, hr/ha

The effective field capacity (EFC) in ha/hr was estimated by equation (20) which provides the actual total work done per unit hour. The equation was derived from the TFC and the efficiency of field work.

$$EFC = \frac{S * W * E}{10} \tag{20}$$

The draft developed by the soil (specific soil resistance) depends on the amount of moisture in the soil (moisture content), and the type of soil. The soil types covered in the two districts included silty clay, clay loam, sandy loam and black cotton soil. The estimated soil shear strength during the three possible periods of time of tillage were estimated using a hand penetrometer.

The computation of the total energy used for the field work per day required determination of the number of runs that the DAP-SYS does in completing a day's work. The average field length for the data collected in the farmers' field was 28.8 m with a standard deviation of 11.9 m. The minimum and maximum lengths recorded were 12.8 m and 58.3 m respectively. A computer random generator was used to determine the field length using the effective field capacity. This calculation also determined the field width from the area plowed. The actual working width of the tillage implement was determined by the implement size and the field efficiency factor (k). The computation of the total work done per day in MJ was done with equation (21) based on the specific soil resistance (kN/m$^2$), the hours worked per day, the EFC, and the actual width of tillage.

$$E_{total} = \frac{EFC * 10000 * SSR * hr * W * D}{1000 * W} \tag{21}$$

where:

$E_{total}$ = total work done per day, MJ
EFC = effective field capacity, ha/hr
SSR = specific soil resistance, kN/m$^2$
D = depth of tillage, m
hr = hours worked per day, hrs
W = width of tillage, m

The following set of equations were used for the computation of the power (or rate of working) and the implement energy (IE) of the tillage implement.

$$P = D * S \tag{22}$$

where:

P = power, kW
D = draft, kN
S = speed, m/sec

The draft force in equation (22) was based on the estimated soil resistance calculated using the depth and width of tillage and the specific soil resistance and the width and depth of tillage. The speed of operation is controlled by the draft oxen operator and depends on the level of experience of both the draft oxen and the operator. Adequate and consistent control of the DAP-SYS depends on the type of commands that the operator uses to drive the animals.

Implement energy is a measure of the expected energy demand from the prime mover (draft oxen) per hectare. This was computed using equation (23). The capacity or the power required from the animals to provide the expected energy depends on the size of the animal (weight), the type, quality and quantity of feed available for them and the appetite limit of the animals. Equation (23) was based on the expected speed of operation of the DAP-SYS as well as the unit soil resistance.

$$IE = \frac{P}{EFC} \tag{23}$$

where:

IE = implement energy, kW-hr/ha
EFC = effective field capacity, ha/hr
P = implement power demand, kW

The theoretical total field energy required to complete the tillage work was computed as a factor of the acreage to be plowed and the implement energy as shown in equation (24).

$$T_{FE} = Lnd * IE \tag{24}$$

where:

$T_{FE}$ = theoretical field energy, kW-hrs
Lnd = the acreage for plowing, ha
IE = implement energy, kW-hrs/ha

The projected tillage time to complete the field work also referred to as the actual time in days to finish field work was computed using equation (25). The rate of energy consumption for work in animals at work was estimated by Abiye Astatke et al. (1986) as 3.85 MJ per hour. The DAP-SYS energetic capacity (hours/day) was calculated from the net energy available for work per day ($NE_w$) and the energy production capacity (hours per day) or tillage capacity of the oxen for work per day as shown in equation (26).

$$TDF_w = \frac{Lnd}{EFC * Hr} \tag{25}$$

where:

$TDF_w$ = actual time to finish field work, days
Lnd = land to be plowed, ha
EFC = effective field capacity, ha/hr
Hr = hours available for work per day, hr

$$DAP_c = \frac{NE_w}{3.85} \tag{26}$$

where:

$DAP_c$ = draft animal power working capacity, hrs/day
$NE_w$ = net energy for work, MJ/day

#### *6.4.5.3 Energy utilization efficiency*

The efficiency of utilization of energy by working oxen was determined for three levels based on Brody (1964). The gross energy efficiency was computed as the ratio of the work done per day and the total energy expenditure as shown in equation (27). The net energy efficiency of the draft animals was calculated as the ratio of the work done per day and the energy expenditure above the metabolic energy expenditure per day as shown in equation (28). Thirdly the absolute energy efficiency was computed as the ratio of work done per day and the energy expenditure above the energy expenditure of walking without a load as shown in equation (29). The net efficiency has a better estimation of the actual energy needed for work animals because it accounts for the energy needed above the basal or maintenance metabolism.

$$GrsEf = \frac{E_{total}}{TNE_{mw}} * 100 \quad (27)$$

where:

GrsEf = gross efficiency, %
$E_{total}$ = total work done per day, MJ
$TNE_{mw}$ = team total energy expenditure per day, MJ

$$NetEf = \frac{E_{total}}{TNE_{mw} - TBMR} * 100 \quad (28)$$

where:

NetEf = net efficiency, %
$E_{total}$ = total work done per day, MJ
$TNE_{MW}$ = total energy expenditure per day, MJ
TBMR = team total basal metabolic rate per day, MJ

$$AbsEf = \frac{E_{total}}{TNE_{mw} - EnWlk} * 100 \quad (29)$$

where:

AbsEf = absolute efficiency, %
$E_{total}$ = total work done per day, MJ
EnWlk = energy for walking per day, MJ

The total work done per day ($E_{total}$ ) was derived from equation (21). The energy for walking, however, was based on Lawrence and Stibbard's (1985) model which uses an estimate of 2 J per meter per km as the energy cost of walking for cattle.

The distance walked per day while plowing was computed using equation (30).

$$DstDy = \frac{EFC * TDapCap * 100000 * RDN_{dist}}{Wdth * RDN_{dst}} \qquad (30)$$

where:

| | | |
|---|---|---|
| DstDy | = | distance walked per day, m |
| TDapCap | = | total draft animal power capacity, hr/day |
| Wdth | = | width of tillage, m |
| $RDN_{dst}$ | = | randomly generated length of field, m |

#### *6.4.5.4 Crop yield and returns*

The survey carried out with the farmers showed that the average farmer allocates about 70% of their cropped land to the production of maize and about 30% of the land to the production of beans. The socio-economic data collected also included the data for yield of the main staple food crops (maize and beans). Estimates of the yield of maize and beans were obtained from the field extension officers. The average yield and the standard deviation of maize and beans were used for estimating the expected yields for the simulation model. The average values used for these estimates were 15 bags (90 kg) per hectare for maize with a standard deviation of 3 bags. The average yield used for beans was 6 bags (90 kg) per hectare and a standard deviation of 1.5 bags. For the simulation of the staple crop yields, a computer random number generator was used to obtain estimates using the average and standard deviation values.

The farmers' main concern is to provide sufficient food for his household. Hence, a reasonable quantity of the staple produce is kept for home use and the extra disposed of in the market. According to the data obtained from the farmers, an average of 10 bags of maize and 2 bags of beans are set aside for home consumption.

The income generated from the farm was estimated from the sale of the excess produce above the household food requirements. The price of maize and beans at the time of the research was estimated at KSh. 1,200 and KSh. 4,000 per 90 kg bag respectively. Computation of the gross net income per season was done for the costs of the DAP-SYS and the input costs of the crops are listed in section 6.4.6.7.

The majority of the farmers breed their own oxen which they train for draft purposes at the age of about 2 to 4 years. Farmers who buy draft oxen acquire them when they are young enough for training. The oxen resale value after they have been used for about ten years is always higher than the price originally paid for them. Hence, the acquisition cost and the salvage value of the oxen were not used in the computation of the seasonal variable expenses of DAP-SYS.

**6.4.6 Model implementation**

The implementation of the simulation model was done by writing a program in the computer language that is most widely used in Kenya. The computer language selected was QBASIC. However, after the program was completed verified and validated, it was compiled by QBASIC so that it could be used as a stand-alone program. Since the computer simulation program is geared for use by both extension officers and research workers in DAP in government institutions and NGOs, the choice of the language was an important consideration.

The EUMDAP program was tested and run for various scenarios in order to determine that it was computing as expected. This process also helped to determine whether there were other details or data omitted from the programming. The user of the program is expected to provide basic information that would be used to create a built-in DAP utilization scenario.

***6.4.6.1 Land and soil parameters***

The information required from the user about the land and soil parameters is as follows:

1. The size of the farm (land) in acres. Although official land adjudication measurements are in hectares, in most parts of Kenya land measurement is best understood in acres. The computer converts the land size to hectares for subsequent computation purposes.
2. The size of the cropped land that is to be prepared for crop growth in acres.
3. The time when the tillage is expected to be performed. A choice of three possibilities is provided for selection.

    3.i As soon as the rains come

    3.2 Soon after harvest

    3.3 Before the rains come.

4. The type of soil prevalent on the farm. There are mainly four types of soils in the areas covered by the research. The user is prompted to select one of the four:

4.1 Silty clay

4.2 Sandy loam

4.3 Clay loam

4.4 Black cotton

#### *6.4.6.2 Draft oxen parameters*

The following parameters and variables are required from the user.

1. Number of draft oxen used (choice of 2 or 4).
2. Age of each oxen
3. The experience of the current animals in terms of the period of time the animals have been in use. Three categories of experience for each ox were considered:

   3.1 Less than one year

   3.2 Between 2 and 3 years

   3.3 More than three years

4. The weight of each draft animal (kg) if known. Dimensions of the animals was given as an option if the weight was not known. The heart girth and the length of the animal are used to estimate the weight if the actual weight of the oxen was unknown .

#### *6.4.6.3 Feed for draft oxen*

Three feed types and quantity are considered for the simulation model. These are:

1. Maize stover
2. Cut grass or natural hay
3. Natural pasture

### *6.4.6.4 Operational inputs*

Operational inputs include:

1. Number of days draft oxen are used for tillage per week.
2. Number of hours that draft oxen work per day
3. Time (hours) used for transportation for the household.
4. Renting of DAP-SYS for tillage and or transportation work.

### *6.4.6.5 Implement usage*

1. The combination of implements used by the household. Three choices are offered by the program:
   - 1.1 Moldboard plow only
   - 1.2 Moldboard plow and ox-cart
   - 1.3 Ox-cart only.
2. The age of plow and or ox-cart.
3. Size of implement. (cm for plow and tonnage for ox-cart).
4. Depth of tillage preferred (cm).
5. Width of tillage preferred (cm).
6. Speed of operation.
   - 6.1 Default speed (0.75 m/s or 2.7 km per hour)
   - 6.2 Choice between 0.5 and 1.5 m/s

### *6.4.6.6 Renting out DAP-SYS*

1. Acreage plowed on rental basis.
2. Distances and loads carried in renting out ox-carts.
3. Rental rate cost for plowing and transportation.

#### *6.4.6.7 Costs of DAP System Usage*

The user provides the following costs of DAP system operation per season.

1. Feeding cost of oxen
2. DAP veterinary costs
3. DAP operator labor cost
4. Implement maintenance cost
5. Cost of planting per acre
6. Seeds and fertilizer cost per acre
7. Planting cost per acre
8. Weeding cost per acre
9. Harvesting costs per acre

#### ***6.4.6.8 Projected life-spans of implement and oxen***

1. Expected working life span of oxen
2. Life span of plow
3. Life span of ox cart

### **6.4.7 Model verification and validation**

In order to establish that the calculations and estimates that were performed by the model were accurate and within reasonable limits, each of the equations used for the model implementation was verified with a hand calculator. The equations that were either derived for the model or modified from existing ones were tested for consistency of units as shown in Appendix J. This process of verification of the equations used enabled correction of any errors discovered in the formulation of the mathematical relationships of the model.

On the other hand validation of the model involved ensuring that the output values obtained from simulations were consistent and reasonable for the DAP-SYSs simulated. Although not all equations used were validated, the experience of the researcher and the field data obtained from farmers both confirmed that the outputs obtained were within reasonable values. A few outputs were selected and used for validation purposes.

The effective field capacity (EFC) obtained from simulation for a pair of oxen weighing 250 kg was 0.06 ha per hour when the animals were walking at about 2.6 km per hour and working for 6.4 hours per day. At this working rate, it was expected that the oxen would take about 2.6 working days to complete plowing 1 ha of land. The data collected from the farmers indicated that farmers needed between 2 and 3 days to plow a hectare of land when the soil conditions were not too hard. From the researcher's experience in working with DAP-SYSs, the EFC obtained was within the expected rate of work in semi-arid lands.

The expected speed of walking of the DAP-SYS is between 0.5 and 1.5 m/sec (1.8 and 5.4 km per hr). The data obtained from the farmers field showed that the average rate of walking was between 0.55 and 1.30 m/sec. (1.98 and 4.68 km per hr) as shown in Table 5.15. A walking speed of about 0.72 m/sec (2.6 km per hr) for DAP-SYS was therefore within a comfortable range.

The power supplied from a pair of oxen weighing 250 kg each was estimated by the model as 0.32 kW and the power from a pair of oxen weighing 350 kg was estimated as 0.45 kW. The field data obtained from the farmers showed an average power rating of draft oxen that ranged between 0.42 to 1.2 kW. This range was for oxen that varied in size from about 280 to about 400 kg live-weight. The variability of the power supply from working oxen depends on a number of factors including training level and the ability of the operator to control the animals at work.

The simulated total time required to complete tillage operations ranged between 2.9 and 12.1 days with a pair of oxen weighing 250 kg and plowing between 1.2 and 4.7 ha of land. Many farmers reported that they spent between 4 and 15 days to complete the tillage operations depending on the size of the cropped land.

**6.4.8 Simulating DAP-SYSs**

The validity of the EUMDAP simulation model depends on the accuracy with which the model can predict or estimate the required parameter and variable values. The EUMDAP simulation model was tested by simulating various hypothetical scenarios. The real world DAP-SYSs in the area where the data was collected for the development of the modeling program were considered to be operating with land-holdings that were limited to a maximum of 8.1 ha (20 acres). Simulation runs were, therefore, performed for land sizes of 8.1 ha or less. The size of the oxen used by farmers range in size from about 200 kg to about 400 kg. Although training of oxen can start at the age of about two years, oxen weighing 200 kg are not powerful enough to be used for tillage. Farmers use them for tillage work as part of the training process. The simulations were performed for draft oxen weighing between 250 kg and 350 kg.

The preceding section (6.4.6) enumerated all the input variables that a user is expected to provide for the simulation in order for the model to provide the required outputs. After the entry of the inputs the user has the option of viewing the parameter values used (inputs) and the outputs on the computer screen (monitor), printing them directly or saving the data in the computer or on a floppy disk.

The format of data input and output print-out expected by a user from a simulation run is shown in Appendix G. Several simulations were done by varying the inputs that the user is expected to provide and also the choices provided in the program in order to evaluate and observe the performance of the model. In the simulations, the size of the cropped land was varied from 1.17 to 4.70 ha. The field data collection showed that about 58% of the total farm land is used for arable cropping while the rest is used for grazing purposes and also for the homestead.

#### 6.4.8.1 Scenario one

The majority of farmers use a single pair of oxen for tillage. The first simulation was performed with a single pair of oxen weighing 250 kg each and aged 3 years. At the beginning of the plowing season the oxen are usually in poor physical condition and weigh about 250 kg. This size represents the lower range of draft oxen used by farmers. The following parameters were kept constant for this simulation:

1. Soil type - Silty clay
2. Feed type - Maize stover
3. Depth of tillage - 10 cm
4. Width of tillage - 25 cm
5. Speed of tillage - 2.6 km per hour

The size of the land plowed was varied from 1.17 ha to 4.70 ha. The program computed and provided the user with the following categories of outputs which varied with the size of land plowed (see Appendix G):

- Draft oxen energy supply
- Implement energy demand

- Feed energy supply
- DAP system performance measures
- Random estimates of produce used in simulation
- Income variables

The results of the simulation shown in Table 6.2 indicate that the pair of oxen was capable of providing 0.32 kW of power while the implement energy demand was 0.28 kW. For the range of land sizes used for cropping the time needed for tillage was between 2.9 and 12.1 days for plowing 1.17 and 4.70 ha respectively. The energy needed to accomplish the tillage was between 5.38 and 22.26 kW-hrs when the animals were working at 2.6 km per hour at an effective rate (EFC) of tillage 0.062 ha per hour. The outputs from this simulation show the time required and the feed demand for a pair of oxen when used for plowing different sizes of land. The user of the DAP-SYS is provided with the performance information as well as the expected gross net returns based on the costs of running the DAP system and the crop production inputs provided by the user as shown in section 6.4.6.7. The gross net income represents the value of the disposable produce after the farmer's domestic home consumption needs are met. The user can also decide whether the DAP-SYS can be used for other tillage operations for the season based on the time required to complete the tillage work for the season.

The amount of feed required for tillage per day (above maintenance needs) was computed as about 3.6 kg of maize stover per day. The energy developed by the oxen for work was 24.8 MJ per day whereas the total energy for maintenance and work was 57.3 MJ per day. These energy values were constant for all iterations of this scenario. The feed ingested by the oxen was about 5.1 kg of maize stover per day which provided a

Table 6.2: Simulation #1 - Energy utilization per season with two oxen weighing 250 kg each.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.32 | 0.28 | 4.58 | 5.38 | 896.8 | 10.7 | 6.40 | 2.9 | 0 |
| 1.88 | 0.32 | 0.28 | 4.58 | 8.61 | 896.8 | 17.1 | 6.40 | 4.7 | 8,077 |
| 2.58 | 0.32 | 0.28 | 4.58 | 11.84 | 896.8 | 23.5 | 6.40 | 6.5 | 24,69 |
| 3.29 | 0.32 | 0.28 | 4.58 | 15.07 | 896.8 | 29.9 | 6.40 | 8.2 | 40,720 |
| 3.99 | 0.32 | 0.28 | 4.58 | 18.29 | 896.8 | 36.3 | 6.40 | 10.0 | 57,358 |
| 4.70 | 0.32 | 0.28 | 4.58 | 21.52 | 896.8 | 42.7 | 6.40 | 12.1 | 67,565 |

Ground speed = 2.6 km/hr; Working time = 6.43 hrs/day; Feed for work = 3.6 kg/day; Net work energy = 24.8 MJ/day.

Table 6.3: Simulation #2 - Energy utilization per season with two oxen weighing 350 kg each.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.45 | 0.28 | 4.58 | 5.38 | 1,154.2 | 10.7 | 10.01 | 1.9 | 0 |
| 1.88 | 0.45 | 0.28 | 4.58 | 8.61 | 1,154.2 | 17.1 | 10.01 | 3.0 | 3,028 |
| 2.58 | 0.45 | 0.28 | 4.58 | 11.84 | 1,154.2 | 23.5 | 10.01 | 4.9 | 18,600 |
| 3.29 | 0.45 | 0.28 | 4.58 | 15.07 | 1,154.2 | 29.9 | 10.01 | 5.3 | 32,840 |
| 3.99 | 0.45 | 0.28 | 4.58 | 18.29 | 1,154.2 | 36.3 | 10.01 | 6.4 | 47,745 |
| 4.70 | 0.45 | 0.28 | 4.58 | 21.52 | 1,154.2 | 42.7 | 10.01 | 7.5 | 59,010 |

Ground speed = 2.6 km/hr; Working time = 10.06 hrs/day; Feed for work = 5.6 kg/day; Net work energy = 38.7 MJ/day.

maximum of 85.1 MJ of energy per day as shown in simulation #1 in Appendix G.

In running the simulations it is assumed that the draft animals use only the energy available for work in performing the field work and that maintenance energy or body reserves are not used for work. Hence, the oxen are not expected to lose weight when used for draft purposes since simulated outputs utilize only the energy available for work to perform the field operations. However, in the farming conditions, farmers use their oxen without considering that the animals are not well nourished for the work they do. This causes the oxen to lose body condition as they utilize body reserves for work.

**6.4.8.2 Scenario two**

The majority of farmers' draft oxen do not exceed 350 kg of live weight. Table 6.3 shows scenario two which was done with oxen weighing 350 kg for comparison with the smaller oxen of scenario one. The same working conditions used in scenario one were simulated for the larger oxen so that only the oxen size was changed. The simulation showed that the larger oxen performed the same task of tillage in about 40% less time in total days of tillage at a working capacity of 10.06 hours per day. Although in reality farmers do not use their oxen for more than seven hours per day, this simulation showed that the larger oxen had the capacity to work for about 10 hours per day due to the higher available net work energy from the animals. The net energy for work for the larger oxen was 38.7 MJ/day while the smaller oxen had 24.8 MJ/day.

The amount of work done per day (MJ/day) was also estimated at about 40% more than the work done by the smaller oxen. The amount of feed required by the larger oxen for maintenance needs was estimated at about 30% more than the feed used by oxen weighing 250 kg (Table 6.3). The total implement energy demand for the two simulations was constant at between 5.38 and 21.52 kW-hrs for 1.17 ha and 4.70 ha respectively.

The two pairs of oxen in simulations 1 and 2 were subjected to the same amount of work and at the same speed of operation. The feed required to perform the work was, therefore, the same for the two teams (ranging from 10.7 to 42.7 kg). The amount of feed required for maintenance feed varied as it depends on the size of the animals. The feeding cost also reduced the net gross returns obtained from the larger ox team.

#### 6.4.8.3 Scenario three

Another simulation was performed with two pairs of oxen that were used alternately during the working day. The results of the simulation performed with four oxen weighing 250 kg each are shown in Table 6.4. Each pair of oxen provided 0.325 kW of power and a total of 0.65 kW for the two pairs. The working capacity of the oxen was 6.04 hours per day per pair and each pair of oxen in this simulation was expected to work for about 6 hours per day. The total tillage work per day is, therefore, doubled when compared with a single pair of oxen. The total work done per day is increased from 6.40 to 12.09 MJ. However, the feed required for maintaining the two pairs of oxen increased substantially from 896.8 for a single pair to 1793.6 kg of maize stover for two pairs of oxen per season.

The main advantage in using two pairs of oxen alternately is when the time for tillage is a constraint and the farmers wish to complete the work in time for planting. This is often the case in the semi-arid areas where the time available for seedbed preparation and subsequent planting is critical.

The feed requirement for maintenance of the oxen in both simulations is a major component of the cost of maintaining the oxen. The three simulations performed show

Table 6.4: Simulation #3 - Energy utilization per season with four oxen weighing 250 kg each.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.65 | 0.28 | 4.58 | 5.38 | 1,793.6 | 10.7 | 12.09 | 1.6 | 0 |
| 1.88 | 0.65 | 0.28 | 4.58 | 8.61 | 1,793.6 | 17.1 | 12.09 | 2.5 | 6,863 |
| 2.58 | 0.65 | 0.28 | 4.58 | 11.84 | 1,793.6 | 23.5 | 12.09 | 3.4 | 23,882 |
| 3.29 | 0.65 | 0.28 | 4.58 | 15.07 | 1,793.6 | 29.9 | 12.09 | 4.3 | 40,900 |
| 3.99 | 0.65 | 0.28 | 4.58 | 18.29 | 1,793.6 | 36.3 | 12.09 | 5.3 | 57,919 |
| 4.70 | 0.65 | 0.28 | 4.58 | 21.52 | 1,793.6 | 42.7 | 12.09 | 6.2 | 60,851 |

Ground speed = 2.6 km/hr; Working time = 12.15 hrs/day; Feed for work = 6.7 kg/day; Net work energy = 49.53 MJ/day.

Table 6.5: Simulation #4 - Energy utilization per season with four oxen weighing 350 kg each.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.91 | 0.28 | 4.58 | 5.38 | 2,308.4 | 10.7 | 18.91 | 1.2 | 0 |
| 1.88 | 0.91 | 0.28 | 4.58 | 8.61 | 2,308.4 | 17.1 | 18.91 | 1.6 | 1,063 |
| 2.58 | 0.91 | 0.28 | 4.58 | 11.84 | 2,308.4 | 23.5 | 18.91 | 2.2 | 17,981 |
| 3.29 | 0.91 | 0.28 | 4.58 | 15.07 | 2,308.4 | 29.9 | 18.91 | 2.8 | 31,650 |
| 3.99 | 0.91 | 0.28 | 4.58 | 18.29 | 2,308.4 | 36.3 | 18.91 | 3.4 | 47,219 |
| 4.70 | 0.91 | 0.28 | 4.58 | 21.52 | 2,308.4 | 42.7 | 18.91 | 4.0 | 52,711 |

Ground speed = 2.6 km/hr; Working time = 19.00 hrs/day; Feed for work = 10.6 kg/day; Net work energy = 77.45 MJ/day.

that the feed used for work is the same for each scenario. This is expected because the total work done in tillage is the same and the total demand for the "fuel energy' should be the same. The major difference between the single pair and the two pair teams is the time required to complete the work.

The net gross returns decreased slightly as compared to the single pair of ox teams due to the extra quantity of feed required for the second pair of oxen.

**6.4.8.4 Scenario four**

Using four oxen that weigh 350 kg each alternately further reduced the time required to complete the tillage operations (Table 6.5). Each pair developed about 0.455 kW of power. The total daily power available per day was 0.91 kW. The two pairs performed 18.91 MJ of work per day. The maintenance feed requirements increased to over 2,300 kg for the season. Since the work done in tillage remained the same the amount of feed required for the work was the same but the work could be completed in about 30% less days.

The simulation indicates that the two pairs were able to do a total of 19 hours of work per day. This may not be feasible because each team would have to work for a period of over 8 hours. However, farmers with sufficient labor and other resources can use multiple teams of oxen simultaneously and achieve the field time simulated. The researcher observed that some farmers with multiple teams of oxen engaged two or more teams at the same time and thereby increase their EFC.

The simulations with two pairs of oxen available have the potential of increasing the field time and also the actual acreage covered per day. The major drawback and often the major bottleneck is the extra feed required for the maintenance of the oxen. This is especially the case when the animals are used for owner-operator work only and no renting out for income generation.

The larger draft oxen have more work capacity but use more feed per day for work over a shorter period of time. As Tables 6.4 and 6.5 show, the smaller oxen need about 6.7 kg whereas the larger oxen need 10.6 kg of feed for work per day. The simulations of larger two pair teams show that the draft animals have both extra energy to work without straining themselves in the soil conditions simulated. They also have extra capacity because they are able to complete tillage in fewer days. This is achieved by increasing the field time due to the higher energy level and also utilizing "blocks" of time in which different pairs can work either alternately or simultaneously. This extra capacity can be utilized for generating income for the household through renting the oxen out for tillage and other activities. The quantity of feed required for the work done remained the same for the two types of DAP systems (simulations 1 through 4) because the computation is based on the total work done (hectares).

The gross net income from disposable produce ranged between zero for the smallest parcel of land tilled to KSh. 60,851 for 4.70 ha of land when using the smaller pairs of oxen and between zero and KSh. 52,711 for the larger team of ox teams. The larger ox teams required a larger amount of feed for maintenance. As in the preceding simulations, the quantity of feed used for work was the same for the two different oxen sizes because the amount of work performed was the same for each pair.

**6.4.8.5 Scenario five**

In some cases farmers tend to use two pairs of oxen in tandem particularly when working in heavier soils like black cotton soil (see table 6.8). When four oxen weighing

250 kg were used together in tandem the power generated by both oxen dropped from 0.65 kW to 0.55 kW. This was due to a “tractive efficiency” power loss factor of about 22% for a team of four oxen working together. This loss was not considered significant especially because the implement power demand was only 0.28 kW for the working conditions simulated. In heavy soils such as wet black cotton soils, the extra power from a team of four oxen can be useful. Farmers with soil conditions that demand extra “tractive force” from oxen usually use a team of two pairs in tandem (Table 6.6). However, this is only necessary when the tillage is done outside the ideal seed preparation period when the soil conditions are difficult.

Theoretically, the two pairs of oxen can do about 12.15 hours of work per day. Since the oxen have extra capacity to work beyond the demand from the implement, it is possible to use them for two blocks of time without sustaining loss in body weight.

The gross net income returns for simulation 5 and 6 were computed at the same input costs as in simulations 3 and 4. The returns were the same for respective ox teams as shown in Tables 6.4, 6.5, 6.6 and 6.7. The only factor that was varied in the income computation was the quantity of feed required for each team. Other input costs including DAP-SYS costs were held constant.

**6.4.8.6 Scenario six**

Four oxen weighing 350 kg each working in tandem experience a loss of power from 0.91 kW for a team of two oxen to 0.76 kW for a team of four oxen (Table 6.7). The total feed requirements and the total energy used for work remain the same like for two pairs of oxen used alternately.

Using four draft oxen in tandem does not provide much improvement in the overall

Table 6.6: Simulation #5 - Energy utilization per season with four oxen weighing 250 kg each working in tandem.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.55 | 0.28 | 4.58 | 5.38 | 1,793.6 | 10.7 | 12.09 | 1.6 | 0 |
| 1.88 | 0.55 | 0.28 | 4.58 | 8.61 | 1,793.6 | 17.1 | 12.09 | 2.5 | 6,863 |
| 2.58 | 0.55 | 0.28 | 4.58 | 11.84 | 1,793.6 | 23.5 | 12.09 | 3.4 | 23,882 |
| 3.29 | 0.55 | 0.28 | 4.58 | 15.07 | 1,793.6 | 29.9 | 12.09 | 4.3 | 40,900 |
| 3.99 | 0.55 | 0.28 | 4.58 | 18.29 | 1,793.6 | 36.3 | 12.09 | 5.3 | 57,919 |
| 4.70 | 0.55 | 0.28 | 4.58 | 21.52 | 1,793.6 | 42.7 | 12.09 | 6.2 | 60,851 |

Ground speed = 2.6 km/hr; Working time = 12.15 hrs/day; Feed for work = 6.7 kg/day; Net work energy = 49.53 MJ/day.

Table 6.7: Simulation #6 - Energy utilization per season with four oxen weighing 350 kg each working in tandem.

| Cropped Land ha | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Mainten-nance Feed Required kg | Feed for work kg | Work Done MJ/day | Tillage Time Days | Gross Net Income KSh |
|---|---|---|---|---|---|---|---|---|---|
| 1.17 | 0.76 | 0.28 | 4.58 | 5.38 | 2,308.4 | 10.7 | 18.91 | 1.2 | 0 |
| 1.88 | 0.76 | 0.28 | 4.58 | 8.61 | 2,308.4 | 17.1 | 18.91 | 1.6 | 1,063 |
| 2.58 | 0.76 | 0.28 | 4.58 | 11.84 | 2,308.4 | 23.5 | 18.91 | 2.2 | 17,981 |
| 3.29 | 0.76 | 0.28 | 4.58 | 15.07 | 2,308.4 | 29.9 | 18.91 | 2.8 | 31,650 |
| 3.99 | 0.76 | 0.28 | 4.58 | 18.29 | 2,308.4 | 36.3 | 18.91 | 3.4 | 47,219 |
| 4.70 | 0.76 | 0.28 | 4.58 | 21.52 | 2,308.4 | 42.7 | 18.91 | 4.0 | 52,711 |

Ground speed = 2.6 km/hr; Working time = 19.00 hrs/day; Feed for work = 10.6 kg/day; Net work energy = 77.45 MJ/day.

performance of the DAP-SYS except in heavier soils. Mechanization extension services recommend the use of only one pair of oxen at a time. When four oxen were used together in the two simulations (scenario five and six) the power generated was about 2.7 times more than the power demanded by the implement for the larger oxen and about 1.9 times for the smaller oxen. This excess power could only be effectively used if a larger implement was used.

**6.4.8.7 Scenario seven**

One of the major concerns for the farmers is the high draft force demand in heavier soils when wet in the case of black cotton soils and when the clay soils are dry. A simulation was performed for varying soil types and using oxen weighing 350 kg each as shown in Table 6.8.

The two heavier soils (clay loam and black cotton soils) generated draft power of 0.62 and 0.66 kW respectively while the team of oxen could only pull the plow at a maximum rate of 0.45 kW. The two oxen were only capable of generating sufficient power to plow in the lighter soils (silty clay and sandy loam). In the real world scenario, the researcher observed that farmers often subject their draft oxen to loads that are beyond their pulling capacity. The result is poor performance and low working efficiency as the animals are coerced to pull beyond their limit. The stress that the animals are subjected to leads to weight loss and bruises from the harnesses as the operators force them to work.

In simulation 6, two pairs of oxen weighing 350 kg working in tandem developed 0.76 kW of power which could be used for the higher energy demand of the clay loam and black cotton soils that require 0.62 kW and 0.66 kW respectively. A team of two pairs of oxen weighing 250 kg and working in tandem is only capable of providing a

Table 6.8: Simulation #7 - Tillage with two oxen weighing 350 kg each in different soils.

| Soil Type | DAP Power Supply kW | Implement Energy Demand kW | Implement Energy Expenditure kW-hr/ha | Total Implement Energy kW-hrs | Work Done MJ/day | Net Efficiency % |
|---|---|---|---|---|---|---|
| Silty clay | 0.45 | 0.28 | 4.58 | 21.52 | 10.01 | 27 |
| Sandy loam | 0.45 | 0.36 | 5.73 | 26.90 | 12.51 | 34 |
| Clay loam | 0.45 | 0.62 | 10.02 | 47.08 | 21.89 | 60 |
| Black cotton | 0.45 | 0.66 | 10.60 | 49.77 | 23.15 | 63 |

Ground speed = 2.6 km/hour; Working time = 10.06 hours/day; Net work energy = 38.73 MJ/day

maximum of 0.55 kW which is insufficient for the heavier soils depicted in Table 6.8.

**6.4.8.8 Scenario eight**

The type of feed and the quality of feed the animals are fed determines how much energy they can generate for both maintenance and work. Three different feed types were incorporated in the model based on the feeds available in semi-arid areas. A simulation of the feed type with a team of two oxen weighing 350 kg and plowing 4.7 ha at 2.6 km per hour generated the data shown in Table 6.9. The quantity of feed required per animal for each type of feed depends on the quality and the digestibility of the feed. Although draft animals are often used when the natural pasture is scarce, the feed value of natural pasture is higher than that of stored maize stover or harvested grass during the period after the rains have come.

The draft animals require a lesser quantity of the feed with a higher metabolizable energy value. The animals fed with better feed value have a higher work capacity per day because they generate more energy for work per day.

Table 6.9: Simulation #8 - Tillage with two oxen weighing 350 kg each using different feeds.

| Feed Type | Maximum Metabolizable Energy MJ/day | Net Energy for work MJ/day | DAP Power Supply kW | Work Done MJ/day | DAP Work Capacity hrs/day | Total Feed Required Per Season kg | Feed Required for Work kg |
|---|---|---|---|---|---|---|---|
| Natural pasture | 107.90 | 34.94 | 0.45 | 9.03 | 9.08 | 1,320 | 47 |
| Cut grass (hay) | 100.41 | 25.60 | 0.45 | 6.62 | 6.65 | 1,419 | 51 |
| Maize stover | 101.21 | 23.68 | 0.45 | 6.12 | 6.15 | 1,408 | 50 |

Ground speed = 2.6 km/hr

The net energy available for work depends on the quality of the feed, its digestibility and also the quantity that the draft oxen can eat per day (maximum metabolizable energy per day). The net energy for work is a direct relationship with the weight of the oxen. High quality feed is not readily available in semi-arid lands of Kenya due to high cost. Farmers preserve cut grass from rented or their own grazing fields for the dry periods of the year when the natural feed is scarce. This source of feed is considered important in making feed available in the lean periods of the season. Farmers who cannot afford supplemental feed are disadvantaged during the drier spells as their animals depreciate due to insufficient feed and are in poor physical state when the tillage season starts.

### 6.4.9 Application of EUMDAP model

The EUMDAP simulation model has been developed to enable estimation of energy requirements and utilization for DAP-SYSs in the semi-arid lands of Kenya. Since the use of draft power in the marginal lands continues to be the main mechanization option, farmers using the system need an improvement in the management and utilization of this power source.

The results obtained from simulations of the program are comparable with the real world scenario. The main application of the simulation results for real farming situations will be in the extension of DAP-SYS in terms of the utilization capacity of draft oxen. Currently the utilization of DAP-SYSs is about 60 days per year on average. The potential can be improved to about 180 days per year if the DAP-SYSs are used during the period after tillage work is over through transportation and other off-farm tasks. Increased use of DAP-SYSs in income generating activities has the potential of raising the farmers' economic level.

The model shows that the larger draft oxen have the capacity to work more hours per day, enabling farmers to complete tillage operations sooner. The model can be used to estimate and enable the extension workers to provide advice to farmers on the size of draft animals and the quantity of feed needed to be used for the field operations.

The program generates the quantity of feed required for performing tillage and other field work based on the type of feed at the farmers' disposal. A combination of the working capacity and the feed required as well as the size of draft oxen required would also facilitate the choice of the size of implement that can be used in order to perform the tillage work in time for timely planting.

The potential for generating extra income from renting the draft oxen has not been utilized sufficiently in the semi-arid areas. There are farmers that have two pairs of oxen that are under-utilized. The response received from the questionnaire indicated that farmers with two pairs of oxen only use them as stand-by in case they are needed.

For the farmers that prepare their land soon after harvest, there is sufficient capacity to generate more work among other farmers on rental basis since land plowed after harvest needs less time and energy at regular tillage time. Land plowed after harvest provides the farmer with two distinct advantages. The initial tillage after harvest makes the ground workable at the beginning of the tillage season because the ground has already been broken. Secondly, the stubble incorporated during the tillage provides humus enriching the nutritive value for the next crop. Water infiltration and timely land preparation give the crops an edge over weeds which compete for moisture and nutrients.

Post-harvest tillage also allows the use of the draft oxen when they are in prime physical condition. Feed is readily available and so the draft animals do not lose their weight during tillage. Consequently, during the final land preparation at the beginning of the season, the draft force demand by the soil is significantly less in land that had post-harvest tillage than the land being freshly plowed. It is expected that draft oxen's energy utilization efficiency is enhanced and less feed is required to complete tillage on time for the next cropping season.

CHAPTER VII

# DISCUSSIONS, CONCLUSIONS AND FUTURE RESEARCH

## 7.1 Discussions

The use of DAP-SYSs in semi-arid areas of Kenya will continue to fulfill the mechanization needs of small-holder farmers for many years. Since attempts to promote capital intensive mechanization strategies for small-holders have not succeeded, it is desirable to continue to promote DAP in the areas where it is currently used. Contacts made with farmers and mechanization extension workers by the researcher during the period of this study and earlier indicate that there is need for concerted efforts in enhancing the use of DAP for small-holder agriculture. Other developing countries like India that use DAP-SYSs utilize this power source for longer periods per year than the Kenyan farmers do. One of the reasons for this low utilization capacity is lack of a variety of implements that can be used to utilize DAP after tillage operations are over. There are various activities that DAP can be utilized for including transportation of water, firewood and farm produce as well as soil and water conservation practices.

DAP farmers are creative in developing cultural tillage practices that enable them to operate their limited tillage implements for a variety of purposes including weeding and implementation of soil conservation measures like terraces and dam construction. Since the oxen are idle most of the calendar year, the government and other non-government development agencies can encourage the use of DAP for soil conservation work. One farmer interviewed by the researcher uses his oxen for dam construction and repair after the tillage season is over. Semi-arid areas have chronic water shortage problems which need to be addressed through promotion of water conservation measures.

**7.1.1 DAS data**

The data collected with the questionnaire and those collected with the electronic DAS instrumentation were used for the development and implementation of the EUMDAP computer simulation model. The tillage depth and width were used for the computation of the draft force that the implement generated for each of the tests performed in the farmers' fields. The draft force measured was later used to validate the simulation outputs during the testing of the program as discussed in section 6.4.8.

The mechanical data were also used for the computation of the power demand from the oxen based on the ground speed and the draft force measured by the instrumentation. The power demand as computed from the actual field data collected and summarized in Table 5.16 provided data for comparison with the estimated power demand of simulated scenarios for validating the model.

The physiological data obtained with the DAS were needed to monitor the draft oxen's response to work. The primary variable for this purpose was the heart rate which was incorporated in the model developed by Richards and Lawrence (1984), equation (3) for the computation of the energy expenditure for work.

The other three variables, body temperature, respiration rate and the stepping rate were not utilized in the model. The body temperature did not vary within the time spans that the measurements were taken. The longest period of measuring the data in the field was about 120 seconds. The stepping rate was computed to estimate the rate of walking of the oxen as compared with the actual ground speed.

### 7.1.2 Socio-economic data

The socio-economic and DAP operational system data that were obtained from the farmers in the two districts enabled the development of the mathematical models of the computer simulation model. The relationships of the components of the real world DAP system were used to formulate the linkages of the computer model. For instance the data obtained for the land size and the amount of land used for cropping were used to compute the probable land size of the farms used for the simulations.

Other data that included the actual yield from the farms and the sale price of the farm produce were also used to make estimates of the expected returns (net gross income) to the farmer. It was noted that only a fraction of the produce was marketed. The main concern for any farmer is to provide adequate food for their household. Hence, certain quantities of both maize and beans (the staple foods) are retained for family use. This was taken into consideration in the computation of the gross net returns.

Though most of the farmers had only one pair of oxen, those farmers with four trained oxen had excess DAP working capacity that could have been utilized for rental purposes to bring more income into the household. In particular, the low annual usage of DAP means that there is untapped capacity which can be used for other non-farm activities after the tillage season is over. There is potential for improving the utilization of DAP-SYS in semi-arid agriculture of Kenya through extensive and intensive use of the currently available energy source and resources at the farmers' disposal.

### 7.1.3 Development of DAS

The DAS developed in collaboration with other researchers was a good prototype that performed as well as expected. The mechanical sensors had been perfected through earlier research done by researchers at Swedish University of Agricultural Sciences, Uppsala, Sweden. The mechanical sensors worked very well but the physiological sensors had to be handled carefully and checked regularly to ensure that data was being received by the logger as required.

Although there were some practical difficulties with the physiological data sensors, the data obtained enabled the researcher to make conclusive inferences about the energy that the animals expend and the amount of work they do. Simultaneous collection of mechanical and physiological data is the most suitable way of relating the energetic capacity of draft animals and their actual work performance.

### 7.1.4 Implementation of DAP-SYS data acquisition system

The data obtained with the use of electronic DAS were useful in providing the required estimates for the energy used for tillage and other activities. The mechanical data provided valuable estimates of the draft requirements in different soils and using different size of draft animals. The speed of operation and the actual amount of work done per unit time (EFC) were used for the modeling program to maintain real field situations in making simulations.

The design and the construction of a tailor-made electronic DAS for mechanical and physiological data of DAP-SYSs was successful. This instrumentation package and variations of it are currently being used for research in Kenya by the University of Nairobi. There is need for improving the way the physiological sensors are connected to the animal particularly the heart rate sensor, the temperature probe and the breathing rate sensor. The heart rate was the most important physiological parameter monitored. Since getting the best position in order to obtain a reading was very challenging, it will be necessary to improve the sensing mechanism of the heart rate sensor.

### 7.1.5 Development and implementation of EUMDAP simulation model

A computer simulation model was developed and tested. The EUMDAP simulation model performed well and was demonstrated through simulations of various scenarios of DAP-SYSs.

This version of the program has the capacity of being improved for greater versatility and use by a wider range of users and not restricted to semi-arid draft animal power. The Energy Utilization Model for Draft Animal Power provided useful data on the simulation of working draft animal power systems in various field scenarios and with different sizes of draft oxen. The program is DOS (disk operating system) based and operates as a stand-alone program which makes it easier to apply and be used with minimum computer skills and expertise. In order to have the program provide the user with the required simulations, the program requests operational and resources data from the user. These data include the size of the farm, the resources available from the farmer, the potential feed and the operational variables that include the time the animals are used for tillage and transportation. The costs involved in DAP-SYS management and the cost of inputs for the crop production are also requested for in order to estimate the expected returns to the farmer.

The user has the option of saving the data in a floppy disk or in a computer. Alternatively, print-outs of the input and output data are provided at the end of the simulation. The user is furnished with DAP-SYS performance data including the potential capacity for using the draft animals to log more working time (days per season).

## 7.2 Conclusions

This research project set out several objectives which were fulfilled in varying degrees of success. The first objective was to develop, design and build an electronic DAS that would collect simultaneously both physiological and mechanical data from working DAP-SYSs. This exercise used the expertise from several sources including the work done at the Silsoe Research Institute, Bedford, England and the on-going project work at the Swedish Agricultural Engineering Department in Uppsala, Sweden. A working prototype of DAS was built to project specifications and was successfully used to obtain useful data used for validating the EUMDAP simulation model developed. Improvements of the working model will be a continuous process as the need for this type of applied and basic research is gaining momentum.

The data collected from the farmers' field with both the DAS and the questionnaire was useful in developing and validating of the EUMDAP computer simulation program. The computer program was tested for validity using the field data obtained with both the DAS and the questionnaire. The program will be utilized for simulations of DAP-SYSs in the semi-arid areas of Kenya for increasing utilization of DAP as a power source. The physiological data obtained was only useful for the energy utilization estimates using the heart rate of the working oxen. The other three physiological variables were not used. However, the mechanical data obtained provided a basis on which the simulated output of the EUMDAP program was compared for validity in the semi-arid areas setting.

Baseline data collection was done for a total of 80 farmers in five administrative divisions in two Districts in semi-arid Kenya. The objective was to obtain sufficient data that would be used for the parameter and variable estimates to be used for the computer simulation model. The data obtained were useful in the somputer model development which was implemented successfully and used for simulations that monitored the energy utilization of draft oxen for semi-arid areas.

The ultimate objective was to develop and implement a working computer simulation model for DAP-SYS energy utilization. The model (code-named EUMDAP) was successfully developed and implemented. It is available for use in extension and research services in DAP mechanization in semi-arid areas with the potential for expanding for other areas where DAP utilization is prevalent. In the process of implementing the model, various scenarios were simulated that included sole use of DAP by owner-operator and owner-operator/hiring out to other farmers.

### 7.3 Limitations of the study and future research

The research work done for this study was limited to obtaining authentic data for validating a computer simulation program that was developed. The study did not address many issues that farmers grapple with for their mechanization needs. Some of the issues include the need for suitable implements that would enable the farmers to engage the DAP-SYSs before the onset of rains in order to prepare their land in time for timely planting. Due to constraints of time, adequate data for weeding operations and transportation could not be collected. Weeding is a major consideration when farmers consider expanding their cropped land size. Transportation is also an important factor in expanding the use of DAP after tillage operations are done. The instrumentation used for the data collection did not include measurements for transportation energy use.

Since the government of Kenya has realized the importance of DAP-SYS in small-holder agriculture, it is time that the opportunity was utilized to advance the cause of DAP mechanization systems. This research exercise was unique and paves the way for similar work in the future. Primary data in DAP-SYS is hard to come by as the researcher experienced in the process of obtaining authentic data for Kenayan DAP-SYS. Although other researchers have performed similar type of data collection on DAP-SYS, this was the first time that such experiments were conducted in Kenya. Building on the experience gained from this exercise, it is recommended that the following be undertaken in order to strengthen and augment the current eforts in DAP-SYS research:

- perform more extensive research with wider spectrum of farmers in the semi-arid regions of the country.
- conduct more controlled experiments on the feeding regime of draft oxen in order to establish the energy relationships of current local feeds and energy demand of draft oxen.
- carry out similar experiments in other high potential provinces of Kenya where DAP is used.
- perform further research on the harnessing mechanism and the effect of the same on transmission of draft animal power implements.
- develop a national data base for DAP-SYS and make it available to researchers in this area.
- the DAS can be used for a variety of research undertakings including monitoring of better harnessing systems to improve the power delivery to implements.

# APPENDIX A

# APPENDIX A

Appendix A provides empirical values for factors used for the computation of extra energy used by draft oxen at work. These factors were obtained from various sources as shown in the comments column. The numerical values of the factors include the standard deviation and the actual value used for the energy data computation. Application of the factors in the simulation model was done in equation (1) as shown in section 2.5. The four factors included:

| ***Factor*** | ***Units*** |
|---|---|
| A | Joules per kg live weight per m traveled |
| B | Joules per kg carried per m traveled |
| C | Ratio of work done raising body weight per energy used. |

**Empirical Values for factors used to calculate the extra energy consumption of draught animals for work.** ***Adapted from Lawrence (1985)***

| Factor and units | Numerical value ± S. E. | Type of animal | Comments |
|---|---|---|---|
| A: Joules per kg live weight per m traveled | 2.09 ± 0.062 | Brahman cattle | Walking speed range 0.4 - 1.6 m/sec |
| " | 2.0 | Cattle | |
| B: Joules per kg carried per m traveled | 2.60 ± 0.19 | Cattle | Load placed on saddle over animal's shoulders |
| C: Ratio work done pulling/energy used | 0.298 ±0.006 | Brahman Cattle | Data for animals in double and single yokes + a few for single animals with collars |
| D: Ratio work done raising body weight/energy used | 0.35 | Cattle | A.R.C. (1980) |

## APPENDIX B

# APPENDIX B

Appendix B provides the calorific equivalent of the respiratory exchange ratios (RER) and the relative percentages of kcal of carbohydrates and fats. The energy release from the food substrates depends on the relative combinations of carbohydrates and fats. The values of RER ranges from 0.71 to 1.0. The lower end of the RER scale (0.71) represents the energy released when 100% fats are burned in oxygen releasing 4.69 kcal of energy per liter of oxygen consumed whereas the RER ratio of 1.0 represents the energy released when 100% of carbohydrates are burned in oxygen releasing 5.05 kcal of energy per liter of oxygen consumed.

**Calorific Equivalent of the Respiratory Exchange Ratio and % kcal from CHO and Fats.** ***Adapted from Wilmore and Costill (1994)***

| | Energy | % kcal | |
|---|---|---|---|
| Respiratory Exchange Ratio | kcal . $L^{-1}O_2$ | Carbohydrates | Fats |
| 0.71 | 4.69 | 0 | 100 |
| 0.75 | 4.74 | 15.6 | 84.4 |
| 0.80 | 4.80 | 33.4 | 66.6 |
| 0.85 | 4.86 | 50.7 | 49.3 |
| 0.90 | 4.92 | 67.5 | 32.5 |
| 0.95 | 4.99 | 84.0 | 16.0 |
| 1.00 | 5.05 | 100.0 | 0 |

**APPENDIX C**

# APPENDIX C

Appendix C gives technical details for the RAMLOG EI-9000 data logger. These data were obtained from the operation manual of the logger and serves as a guide in determining the number and type of channels that the logger uses for data collection. Operational parameters including the range of the power supply and the memory capacity of the mini-computer of the logger are provided for quick reference.

## RAMLOG EI-9000 Data Logger Technical Details

| | |
|---|---|
| Inputs: | 16 analog single ended inputs or 8 differential inputs.<br>2 counters<br>8 digital inputs |
| Memory: | 128 kb RAM in standard version.<br>77,500 measurements (analog - 12 bits) for 128 kb version. |
| Analog inputs: | Individually programmable scales for every input.<br>Scales: ±100mV, ±200mV, ±500mV,±1V,±2V,±5V,±10V.<br>Resolution ±200 points.<br>Calibration error: 0.1% FS<br>Over-voltage protection: max ±200 V DC<br>Maximum common mode voltage (differential inputs): ±35V DC<br>Input impedance: > 100MΩ<br>Input numbers: single ended - channel 1 to 16<br>differential - channels 1 to 8 |
| Counter inputs: | Choice - two 8 bits counters (standard) or one 16 bits counter (option)<br>Maximum frequency - 1 MHz<br>Counter range - 255 (8 bits) or 65,535 (16 bits)<br>Signal TTL/CMOS level, Vmax = 5V<br>Input numbers - channels 17 and 18 (8 bits), channel 19 (16 bits) |
| Digital inputs: | TTL/CMOS level, Vmax = 5V<br>Input number - channel 20 binary values stored over 8 bits $d_0$ to $d_7$ |
| Real time clock: | Maximum drift 2 sec/day at 20 °C. |

| | |
|---|---|
| Sampling frequency: | 100 Hz on 1 channel<br>10 Hz on 16 channels. |
| Programmable range: | ±100 mV to ±10 V |
| Display: | LCD 2 lines of 16 characters.<br>Engineering units before, during and after recording. |
| Power supply: | Working range - 4.2 V to 7 V<br>4 alkaline batteries type LR6 (AA)<br>Option 4 NiCd accumulators<br>External power supply connector 6.7 V DC 200 mA |
| Battery econmy: | "STANDBY" current drain - 50 µA<br>Auto switch to "STANDBY" mode if:<br>• > 30 seconds of keyboard inctivity<br>• between measurements in recording mode. |
| Connections: | Communication - Dsub 9 pins connector<br>Measure - Dsub 37 pins connector<br>External sensor power supply - Dsub 37 pins connector (pin 4) |
| Temperature range: | - 10°C to + 60°C |
| Humidity: | 0 to 95% RH no condensation. |
| Case: | Plastic ABS |
| Dimensions: | 180 x 100 x 45 mm |
| Weight: | 500 grams (batteries included) |

**APPENDIX D**

# APPENDIX D

## Kistler Accelerometer

The accelerometer used for the measurement of the step rate of the working animals was a commercially available sensor manufactured by Kistler. Appendix D provides the technical details of the sensor. These details include the operational range as well as the sensitivity and the type electrical supply and the current outputs.

**Kistler Accelerometer**

| | | |
|---|---|---|
| Type: | | 8308A K-BEAM |
| Range: | g | ±10 |
| Sensitivity(±5%): | *mV/g* | 100 |
| Frequency range (±5%): | *Hz* | 0 - 150 |
| Mass without cable: | *g* | 10 |
| Operating temperature range: | °C | -20 to 85 |
| Linearity: | *% FSD* | <°±2 |
| Supply current: | *mV* | 9 - 20 |
| Output: | | |
| Voltage (full scale) | *V* | ±1 |
| Bias voltage (±5%): | *V DC* | 2. |
| Impedance: | Ω | 10 |

## Appendix E

The soil moisture content was monitored with an electronic sensor that measured the soil moisture content *in situ.* Appendix E provides the technical details of the Time Domain Reflectometry instrument. The technical details include the range of operation, the power supply, memory capacity and the electronic particulars of the instrumentation.

### Time Domain Reflectometry Instrument

| | |
|---|---|
| Model: | 6050X1 Trace System |
| Measuring range: | 0 - 100% Volumetric moisture content |
| Measuring accuracy: | ± 2% or better |
| Operating temperature: | 0 - 45 °C |
| Power supply: | 2 each 6 amp-hr, sealed, gelled electrolyte batteries<br>Supply recharge time, 9 hours.<br>Auxiliary power input 18-24 volts AC or DC amp, for battery recharge or independent operation.<br>External battery input: 12 volts for independent operation. |
| Connecting ports: | BNC port for wave guide connection.<br>RS 232 serial port for data transfer.<br>Multiplex port - 15 pin D-SUB for sequence Switch access for unattended logging of multiple sites using external equipment.<br>Power port - 8 pin DIN |
| Memory: | Standard 256 kb memory board with storage for at least 166 graphs/6000 readings.<br>Optional 256 kb memory board additions to maximum of 1 Mb storage.<br>Automatic data tagging of reading time/date/reading number plus use defined label.<br>Autologging capability with reading interval range from one day to one per minute. |

Electronic particulars: Measuring pulse rise time less than 200 picoseconds.
Sampling resolution, 10 picoseconds.
Graphic display - 128 x 256 dot super twist matrix, back-lighted LCD.
Battery charge status indicator light (3)
Circuit breaker protection.
Hardware - 8 slot card cage construction, 4 system boards, 4 optional slots.

**APPENDIX F**

## APPENDIX F

# EUMDAP Computer Program Listing

```
COLOR 7, 1, 1
CLS
LOCATE 9, 2
LOCATE 10, 8
PRINT
PRINT "                    ENERGY UTILIZATION MODEL "
PRINT "                           FOR"
PRINT "                  DRAFT ANIMAL POWER-SYSTEMS"
PRINT
PRINT "                     (E U M D A P - S Y S)"
LOCATE 19, 24
PRINT "PRESS ANY KEY TO CONTINUE";
1 a$ = INKEY$: IF a$ = "" THEN 1
CLS
LOCATE 10, 10
PRINT "        This program simulates the utilization of draft"
PRINT "                    animal power (DAP) system in "
PRINT "                    small-holder agriculture of"
PRINT "                     Semi-Arid areas of Kenya."
LOCATE 20, 24
PRINT "PRESS ANY KEY TO CONTINUE";
2 a$ = INKEY$: IF a$ = "" THEN 2

CLS
LOCATE 10, 10
PRINT "        Three DAP Systems are used for the simulations:"
PRINT
PRINT "              1. Sole Owner-operator of DAP System."
PRINT "              2. Owner-operator plus renting out of DAP System. "
PRINT "              3. None DAP System owners renting oxen."
PRINT
LOCATE 19, 24
PRINT "PRESS ANY KEY TO CONTINUE";
3 a$ = INKEY$: IF a$ = "" THEN 3

CLS
LOCATE 10, 5
PRINT " The following categories of information are required from the user"
PRINT "      in order to compute the utilization data of the DAP system:"
PRINT
PRINT "       1. Land and soil parameters        4. Draft oxen usage data"
PRINT "       2. Ox feed quality and quantity     5. Operational parameters "
PRINT "       3. Implement type and size"
PRINT
PRINT "                After each entry press the <ENTER> key."
PRINT
LOCATE 20, 14
PRINT "           PRESS ANY KEY TO CONTINUE";
4 a$ = INKEY$: IF a$ = "" THEN 4
```

```
'-------------------------LAND  AND SOIL PARAMETERS-----------------------
CLS
100
PRINT
LOCATE 12, 15
INPUT " What is the size of your farm in acres? ", Land
CLS
LOCATE 10, 10
IF Land > 20 OR Land < 0 THEN GOTO 10
  INPUT " How much of this land is under crop (acres)? ", CrpLnd
IF CrpLnd > Land THEN
10
BEEP

CLS
LOCATE 8, 5
PRINT "OUT OF RANGE: Cropped land is more than available land."
LOCATE 9, 5
PRINT "                 Or Land should be 20 acres or less."
PRINT "                                 Try again."
PRINT
GOTO 100
END IF
Land! = Land! / 2.47
CrpLnd! = CrpLnd! / 2.47                              'acres to hectares

200 CLS
LOCATE 10, 10
PRINT "   When do you start tillage? Choose from below (1 to 3)"
PRINT
PRINT "                        1. As soon as the rains come"
PRINT "                        2. Soon after harvest"
PRINT "                        3. Before the rains"
INPUT "                Tillage Start = ", TilSt$
IF TilSt$ < "1" OR TilSt$ >= "4" THEN
  BEEP
  PRINT
  PRINT "            Try again. Enter 1 to 3"
  GOTO 200
END IF

CLS
300 LOCATE 10, 10
PRINT " What type of soil do you have? Choose from 1 to 4."
PRINT "                            1. Silty Clay"
PRINT "                            2. Clay Loam"
PRINT "                            3. Sandy Loam"
PRINT "                            4. Black Cotton"
INPUT "                     Soil Type =", SolTy$
PRINT
IF SolTy$ < "1" OR SolTy$ >= "5" THEN
     BEEP
     LOCATE 8, 20
     PRINT "Try again, Enter 1 to 4."
     GOTO 300
```

```
END IF

IF TilSt$ = "1" AND SolTy$ = "1" THEN SoilStr = 15
IF TilSt$ = "1" AND SolTy$ = "2" THEN SoilStr = 20
IF TilSt$ = "1" AND SolTy$ = "3" THEN SoilStr = 30
IF TilSt$ = "1" AND SolTy$ = "4" THEN SoilStr = 40

IF TilSt$ = "2" AND SolTy$ = "1" THEN SoilStr = 20
IF TilSt$ = "2" AND SolTy$ = "2" THEN SoilStr = 25
IF TilSt$ = "2" AND SolTy$ = "3" THEN SoilStr = 35
IF TilSt$ = "2" AND SolTy$ = "4" THEN SoilStr = 45

IF TilSt$ = "3" AND SolTy$ = "1" THEN SoilStr = 25
IF TilSt$ = "3" AND SolTy$ = "2" THEN SoilStr = 35
IF TilSt$ = "3" AND SolTy$ = "3" THEN SoilStr = 40
IF TilSt$ = "3" AND SolTy$ = "4" THEN SoilStr = 50

'--------------------------DRAFT OXEN--------------------------
CLS
400 LOCATE 10, 10
INPUT " How many trained oxen do you have (2 or 4)? ", Oxen
IF Oxen = 2 OR Oxen = 4 THEN GOTO 500
IF Oxen < 2 OR Oxen > 4 OR Oxen = 3 THEN
  BEEP
  CLS
  LOCATE 8, 22
  PRINT "                  TRY AGAIN"
  GOTO 400
END IF

500
LOCATE 10, 10
PRINT "How many years have you used the current oxen (1 to 3 years)."
PRINT
INPUT "                              Level of training =", OxTr
IF OxTr <= 0 OR OxTr >= 4 THEN
  BEEP
  CLS
  LOCATE 8, 20
  PRINT "Try again. Enter between 1 and 3 years"
  GOTO 500
END IF

CLS
600
LOCATE 10, 6
INPUT "        Do you have the weights (kg) of the oxen (Y or N)"; WtOx$
    IF WtOx$ = "Y" OR WtOx$ = "y" THEN GOTO 610
    IF WtOx$ = "N" OR WtOx$ = "n" THEN GOTO 620
    BEEP
    CLS
    LOCATE 8, 50
    PRINT "Enter Y or N "
    GOTO 600

610 CLS
```

```
IF Oxen = 2 THEN GOTO 611
IF Oxen = 4 THEN GOTO 612
611
LOCATE 12, 10
PRINT
PRINT "     Enter weight (200 to 400 kg) and age of each ox:"
PRINT
INPUT "                    Weight of Ox1 =", WtOx1
INPUT "                    Weight of Ox2 =", WtOx2
PRINT
IF WtOx1 < 200 OR WtOx1 > 400 OR WtOx2 < 200 OR WtOx2 > 400 THEN
  CLS
  BEEP
  LOCATE 9, 7
  PRINT "Ox weight must be more than 200 kg and less than 400 kg"
  PRINT
  PRINT "                    TRY AGAIN"
  GOTO 611
END IF

613
INPUT "                      Age of Ox1 =", AgeOx1
INPUT "                      Age of Ox2 =", AgeOx2
IF AgeOx1 <= OxTr OR AgeOx2 <= OxTr THEN
  BEEP
  CLS
  LOCATE 9, 10
  PRINT "Age of oxen MUST be more than years of training (Training level)."
  GOTO 613
END IF
GOTO 700

'weight data for 4 oxen

612
LOCATE 10, 10
PRINT "          Enter weight (kg) and age of each ox:"
INPUT "                      Weight of Ox1 =", WtOx1
INPUT "                      Weight of Ox2 =", WtOx2
INPUT "                      Weight of Ox3 =", WtOx3
INPUT "                      Weight of Ox4 =", WtOx4
IF WtOx1 < 200 OR WtOx1 > 400 OR WtOx2 < 200 OR WtOx2 > 400 THEN
BEEP

CLS
LOCATE 7, 10
PRINT "Ox weight must be more than 200 and less than 400"
  PRINT " TRY AGAIN"
  SLEEP 3
  GOTO 612
END IF
IF WtOx3 < 200 OR WtOx3 > 400 OR WtOx4 < 200 OR WtOx4 > 400 THEN
  BEEP
  CLS
  LOCATE 7, 10
  PRINT "Ox weight must be more than 200 and less than 400"
```

```
  PRINT " TRY AGAIN"
  SLEEP 3
  GOTO 612
END IF

614
INPUT "                    Age of Ox1 =", AgeOx1
INPUT "                    Age of Ox2 =", AgeOx2
INPUT "                    Age of Ox3 =", AgeOx3
INPUT "                    Age of Ox4 =", AgeOx4
IF AgeOx1 <= OxTr OR AgeOx2 <= OxTr OR AgeOx3 <= OxTr OR AgeOx4 <= OxTr THEN
  BEEP
  LOCATE 9, 10
  PRINT "Age of oxen MUST be more than years of training (Training level)."
  SLEEP 2
  GOTO 614
END IF
GOTO 700

620 CLS
IF Oxen = 2 THEN GOTO 615
IF Oxen = 4 THEN GOTO 616

'measurements of 2 oxen

615
LOCATE 10, 8
PRINT "        Enter the measurements of the 2 oxen in cm:"
PRINT
PRINT "            (Heartgirth should be AT LEAST 125 cm)"
PRINT "            (Length should be AT LEAST 145 cm)"
LOCATE 14, 10
INPUT "Ox1 Heartgirth and length (HeartGirth, Length) =", HrtGrOx1, LntOx1
LOCATE 16, 10
INPUT "Ox2 Heartgirth and length (HeartGirth, Length) =", HrtGrOx2, LntOx2
WtOx1 = (HrtGrOx1 / 2.54) ^ 2 * (LntOx1 / 2.54) / 660
WtOx2 = (HrtGrOx2 / 2.54) ^ 2 * (LntOx2 / 2.54) / 660
GOTO 613

'measurements of 4 oxen

616
LOCATE 12, 10
PRINT "Enter the measurements of the 4 oxen in cm:"
PRINT "           Heartgirth should be at least 125 cm"
PRINT "           Length should be at least 145 cm"
INPUT "Ox1 Heartgirth and length (HeartGirth, Length) =", HrtGrOx1, LntOx1
INPUT "Ox2 Heartgirth and length (HeartGirth, Length) =", HrtGrOx2, LntOx2
INPUT "Ox3 Heartgirth and length (HeartGirth, Length) =", HrtGrOx3, LntOx3
INPUT "Ox4 Heartgirth and length (HeartGirth, Length) =", HrtGrOx4, LntOx4
WtOx1 = (HrtGrOx1 / 2.54) ^ 2 * (LntOx1 / 2.54) / 660
WtOx2 = (HrtGrOx2 / 2.54) ^ 2 * (LntOx2 / 2.54) / 660
WtOx3 = (HrtGrOx3 / 2.54) ^ 2 * (LntOx3 / 2.54) / 660
WtOx4 = (HrtGrOx4 / 2.54) ^ 2 * (LntOx4 / 2.54) / 660
GOTO 614
```

```
'------------------------FEED FOR THE OXEN----------------

700 CLS
LOCATE 10, 10
PRINT "    What is the Primary feed for the draft animals?"
PRINT "                        Choose from 1 to 3"
PRINT "                       1. Maize stover"
PRINT "                       2. Cut grass (Hay)"
PRINT "                       3. Natural pasture"
INPUT "             Primary Feed =", PryFd$
IF PryFd$ <= "0" OR PryFd$ > "3" THEN
  BEEP
  PRINT "          Try again. Enter 1, 2, or 3"
  GOTO 700
END IF

IF PryFd$ = "1" THEN ME = 7.5
IF PryFd$ = "1" THEN DMc = .9
IF PryFd$ = "2" THEN GE = 9!
IF PryFd$ = "2" THEN DMc = .85
IF PryFd$ = "3" THEN GE = 11
IF PryFd$ = "3" THEN DMc = .75

'------------------OPERATIONAL INPUTS--------------------

800 CLS
LOCATE 10, 10
PRINT "    How many days do you use oxen for tillage per week?"
PRINT
INPUT "                   Number of days per week? =", NdWk%
IF NdWk% <= 0 OR NdWk% > 7 THEN
     BEEP
     LOCATE 13, 15
     PRINT "          Out of Range. Try again."
     INPUT "              Days worked per week (1 to 7)? =", NdWk%
END IF

CLS
LOCATE 12, 10
PRINT "    How many hours do oxen work on tillage per day?"
PRINT
INPUT "                  Number of hours per day =", HrDy!

'-----------------------IMPLEMENT USAGE-----------------------

CLS
900 LOCATE 10, 10
PRINT "    Which of the following implements do you use?"
PRINT "                       Choose one combination:"
PRINT "                       1. Moldboard plow only"
PRINT "                       2. Moldboard plow and Ox-Cart "
PRINT "                       3. Ox-Cart only"
INPUT "          Type of implements ="; Impl$
IF Impl$ = "1" OR Impl$ = "2" THEN GOTO 910
IF Impl$ = "3" THEN GOTO 920
IF Impl$ <= "0" OR Impl$ > "3" THEN
```

```
  BEEP
  CLS
  GOTO 900
END IF

910 CLS
LOCATE 10, 14
PRINT "Select depth of tillage:"
PRINT "                    1. Shallow (.10 m)"
PRINT "                    2. Medium ( .15 m)"
PRINT "                    3. Deep (.20 m)"
INPUT "        Depth of tillage =", Dpth
IF Dpth = 1 THEN Dpth = .1
IF Dpth = 2 THEN Dpth = .15
IF Dpth = 3 THEN Dpth = .2

IF Dpth < 0 OR Dpth > 3 THEN GOTO 1010 ELSE 1100
1010
BEEP
LOCATE 10, 14
PRINT "Depth is out of range!"

1100 CLS
LOCATE 10, 14
PRINT "Select width of tillage:"
PRINT "                    1. Narrow (.25 m)"
PRINT "                    2. Medium (.30 m)"
PRINT "                    3. Wide (.33 m)"
INPUT "        Width of tillage =", Wdth

IF Wdth = 1 THEN Wdth = .25
IF Wdth = 2 THEN Wdth = .3
IF Wdth = 3 THEN Wdth = .33

IF Wdth < 0 OR Wdth > 3 THEN GOTO 1120 ELSE 1200
1120 BEEP
  LOCATE 10, 14
  PRINT "Width is out of range!"
GOTO 1100
IF Impl$ = "2" THEN GOTO 920
920

1200 CLS
LOCATE 10, 14
INPUT "Use default tillage operation speed (Y or N)"; DefSpd$
  IF DefSpd$ = "Y" OR DefSpd$ = "y" THEN
    Spd = .75
    GOTO 1300
  END IF
  IF DefSpd$ = "N" OR DefSpd$ = "n" THEN GOTO 1220
    BEEP
    PRINT "Enter Y or N "
    GOTO 1200
1220
CLS
LOCATE 10, 14
```

```
INPUT "Speed of operation (0.5 to 1.5 m/s) =", Spd
IF Spd < .5 OR Spd > 1.5 THEN
  BEEP
  CLS
  LOCATE 8, 10
  PRINT "Try again"
  GOTO 1220
END IF

1300 CLS
LOCATE 10, 10
INPUT "Days per week of household transportation with DAP =", TrDys
INPUT "       Number of weeks of transportation per season =", WksTr
CLS
LOCATE 10, 10
INPUT "Distance (km) per day of household transportation =", TrKm
INPUT "            Pay load per trip of transportation (tons) = ", PyLd
DstT = WksTr * TrDys * TrKm * 1000          'Distance per season m
'HseLoad = DstT * PyLd * 9.81 * 1000 / 1000                'Annual transport energy, MJ

IF OxTr = 1 THEN Spd = Spd * .95
IF OxTr = 2 THEN Spd = Spd * .85
IF OxTr = 3 THEN Spd = Spd * .8

'--------------------COSTS of DAP SYSTEM USAGE------------
CLS
PlwCst = 3500
PlCstSn = PlwCst - (.1 * PlwCst) / 10 * 2       '10% salvage value after 10 years
OxCtCst = 4000
OxCtCstSn = OxCtCst - (.1 * OxCtCst) / 10 * 2     '
LOCATE 11, 10
INPUT "Feeding cost of each oxen per season =", FdgCstOx
FdgCstOx = FdgCstOx * Oxen
LOCATE 12, 10
INPUT "DAP veterinary costs per draft oxen per season = ", VetCst
VetCst = VetCst * Oxen
LOCATE 13, 8
INPUT "DAP operator cost per season (KSh) = ", DapOpCst
CLS
LOCATE 8, 8
INPUT "Implement maintenance cost (Ksh) per season = ", ImpCst
LOCATE 9, 8
INPUT "Hand Weeding cost per acre (Ksh)=", WdgCst
WdgCst = (WdgCst / 2.47) * CrpLnd            'weeding cost per ha
LOCATE 10, 8
SdFtCst = 2500
SdFtCst = (SdFtCst / 2.47) * CrpLnd
LOCATE 12, 8
INPUT "Planting cost per acre per season (Ksh)=", PlgCst
PlgCst = (PlgCst / 2.47) * CrpLnd
LOCATE 14, 8
INPUT "Harvesting cost per acre per season=", HvstCst
HvstCst = (HvstCst / 2.47) * CrpLnd           'cost per ha
'Seasonal returns

SnVbCst = VetCst + DapOpCst + ImpCst + WdgCst + SdFtCst + PlgCst + HvstCst
```

```
SnFxCst = PlwCstSn + OxCtCstSn + FdgCstOx              'plow dep; oxcart dep; Oxenfeeding
TtCst = SnVbCst + SnFxCst

'------------------INCOME - RETURNS------

MnMzYld = 15
StdMzYld = 3
MnBnYld = 6
StdBnYld = 1.5
MzYld = (MnMzYld + (RND * StdMzYld))
BnYld = (MnBnYld + (RND(0) * StdBnYld))
IF TilSt$ = "3" THEN
  MzYld = MzYld * .9
  BnYld = BnYld * .9
END IF
IF TilSt$ = "2" THEN
  MzYld = MzYld                    '90 kg bags
  BnYld = BnYld
END IF
IF TilSt$ = "1" THEN
  MzYld = MzYld * .8                 '20% reduction in yield
  BnYld = BnYld * .8
END IF
TMzYld = CrpLnd * .7 * MzYld         '90 kg bags of maize on 75% of land
TBnYld = CrpLnd * .3 * BnYld          '90 kg bags of beans
MzSl = TMzYld - 10
BnSl = TBnYld - 2
CrpInc = (MzSl * 1800) + (BnSl * 5000)   'gross income per season
HirInc = HirAc * 600                'income from rental plowing
TotInc = CrpInc + HirInc             'gross total income
GrsNtRtn = TotInc - TtCst

' -----------------HIRING OUT AND RENTING IN OF DAP-SYSTEM
CLS
8000
LOCATE 12, 10
INPUT "Is DAP hired out to other farmers (Y or N) ="; HirOut$
  IF HirOut$ = "Y" OR HirOut$ = "y" THEN GOTO 8600
  IF HirOut$ = "N" OR HirOut$ = "n" THEN GOTO 5000
  CLS
  BEEP
  LOCATE 8, 10
  PRINT "                Enter Y or N "
  GOTO 8000

8600 CLS
LOCATE 11, 10
PRINT "Enter  'zero (0)' if no hiring out done"
CLS
LOCATE 12, 10
INPUT "Acreage (acres) plowed for hire per season =", HirAc
HirAc = HirAc / 2.47

CLS
LOCATE 10, 10
PRINT
```

```
INPUT "    Hired out transportation distance (km per week) on hire =", HirKm
HrDstT = HirKm * 1000

5000 CLS
LOCATE 10, 10
INPUT "Do you hire DAP System from others (Y or N)? ", Hir$
IF Hir$ = "Y" OR Hir$ = "y" THEN GOTO 5100
IF Hir$ = "N" OR Hir$ = "n" THEN GOTO 6100
BEEP
GOTO 5000
5100 CLS
LOCATE 10, 10
INPUT "How much land do you plow with hired oxen (acres)? =", HirAcPl
HirAcPl = HirAcPl / 2.47
6100

'-----------------------------------1. ENERGY DEMAND FROM OXEN
CLS
TDpth = Dpth * 100
TWdth = Wdth * 100
'999
TCrpLnd = CrpLnd + HirAc
k = 90                          'k = % of implement width used
TFC = Spd * Wdth * 3.6 / 10          'TFC  = theoretical field capacity (ha/hr)
 Tt = 1 / TFC                      'Tt  = Theoretical field time (hr/ha)
 Te = 100 * Tt / k                 'Te  = Effective field time (hr/ha)
 Tlos = .08 * Tt                   'Tlos = total time lost (8% of Tt)
 FE = Tt / (Te - Tlos)               'FE  = Field efficiency (dec)
 EFC = Spd * Wdth * FE * 3.6 / 10       'EFC = Effective field capacity (ha/hr)"
 ATimTil = TCrpLnd / (EFC * HrDy)      'TimTil = Time to complete tillage (days)
 Drft = Wdth * Dpth * SoilStr         'kN
 Pwr = Drft * Spd                    'kW = (kN * m/s) /1000
 ImplEn = Pwr / EFC    'ImpEn = specific energy in kW-hr/ha
 TrsEn = HseLoad * 9.81 / 1000       'transport energy per year,  MJ

'-------------2. DAP-SYS ENERGY SUPPLY & PERFORMANCE

IF Oxen = 2 THEN GOTO 1400
IF Oxen = 4 THEN GOTO 1500

1400 'Two oxen teams

'Energy from Ox1

Fq1 = .025 * WtOx1            'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
'  ME = GE * .45 * .8 * .85
 ' ELSE
  '  IF PryFd$ = "1" OR PryFd$ = "2" AND TilSt$ = "2" THEN
   '    ME = GE * .45 * .8
    ' END IF
'END IF
MEM1 = Fq1 * ME * DMc       'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
Km = .019 * ME + .53      'Km = efficiency of utilization (ARC standard)
NEmw1 = MEM1 * Km        'NEmw = net energy for maintenance and work per day
BMR1 = (70.5 * WtOx1 ^ .75 * 4.184 * EXP(-.03 * AgeOx1)) / 1000 'Basal Metabolic rate MJ/day
```

```
NEw1 = NEmw1 - BMR1        'NEw = net energy for work, MJ/day

'Energy from Ox2

Fq2 = .025 * WtOx2          'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
' ME = GE * .45 * .8 * .85
 ' ELSE
  '  IF PryFd$ = "1" OR PryFd$ = "2" AND TilSt$ = "2" THEN
  '    ME = GE * .45 * .8
   ' END IF
'END IF
MEm2 = Fq2 * ME * DMc       'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
Km = .019 * ME + .53        'Km = efficiency of utilization (ARC standard)
NEmw2 = MEm2 * Km           'NEmw = net energy for maintenance and work per day
BMR2 = (70.5 * WtOx2 ^ .75 * 4.184 * EXP(-.03 * AgeOx2)) / 1000 'Basal Metabolic rate MJ/day
NEw2 = NEmw2 - BMR2         'NEw = net energy for work, MJ/day
TBMR = BMR1 + BMR2

'total energy of two oxen

TNEmw = NEmw1 + NEmw2              'total net energy for team/day: MJ/day
TMEm = MEM1 + MEm2                 'max ME/day
TNEw = NEw1 + NEw2                 'net energy for work/day
TNEw = TNEw
TDapCap = TNEw / 3.85              'capacity in hrs of work per day at 3.85 MJ/hr
TATimTil = TCrpLnd / (EFC * TDapCap)   'actual time to finish work: days
'Wks = TATimTil / NdWk%
OxPwr = ((WtOx1 + WtOx2) * 9.81 * .1 * .925 * Spd) / 1000'power kW from two oxen

Etot = EFC * 10000 * SoilStr * Wdth * Dpth * TDapCap / (Wdth * 1000)   'total work done per day MJ
GrsEf = (Etot / TNEmw) * 100          'gross efficiency %
NetEf = (Etot / (TNEmw - TBMR)) * 100    'net efficiency %
DstDy = EFC * TDapCap * 10000 / Wdth   'distance traveled per day working, m
OxWt = WtOx1 + WtOx2
EnWlk = OxWt * 2! * DstDy / 1000000      'energy for walking for both oxen, MJ
AbsEf = (Etot / (TNEmw - EnWlk)) * 100      'absolute efficiency %
FdMn = TBMR * 180 / (DMc * ME)  'seasonal maintenance feed needs kg
FdWk = TNEw * TATimTil / (DMc * ME)
'TrsFd = HseTrLd / (DMc * ME )
GrsFdRqd = FdMn + FdWk + TrsFd
GrsEnRqd = GrsFdRqd * DMc * ME
PotWkT = GrsEnRqd / TNEmw                  'potential work time, days

GOTO 3600

1500 'Four oxen team

'energy from Ox1

Fq1 = .025 * WtOx1           'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
' ME = GE * .45 * .8 * .85
 ' ELSE
  '  IF PryFd$ = "1" OR PryFd$ = "2" AND TilSt$ = "2" THEN
  '    ME = GE * .45 * .8
```

```
   ' END IF
'END IF
MEM1 = Fq1 * ME * DMc        'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
Km = .019 * ME + .53      'Km = efficiency of utilization (ARC standard)
NEmw1 = MEM1 * Km         'NEmw = net energy for maintenance and work per day
BMR1 = (70.5 * WtOx1 ^ .75 * 4.184 * EXP(-.03 * AgeOx1)) / 1000 'Basal Metabolic rate MJ/day
NEw1 = NEmw1 - BMR1         'NEw = net energy for work, MJ/day

'Energy from Ox2

Fq2 = .025 * WtOx2          'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
 ' ME = GE * .45 * .8 * .85
  ' ELSE
  '  IF PryFd$ = "1" OR PryFd$ = "2" AND TilSt$ = "2" THEN
   '    ME = GE * .45 * .8
   ' END IF
'END IF
MEm2 = Fq2 * ME * DMc        'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
Km = .019 * ME + .53      'Km = efficiency of utilization (ARC standard)
NEmw2 = MEm2 * Km         'NEmw = net energy for maintenance and work per day
BMR2 = (70.5 * WtOx2 ^ .75 * 4.184 * EXP(-.03 * AgeOx2)) / 1000 'Basal Metabolic rate MJ/day
NEw2 = NEmw2 - BMR2        'NEw = net energy for work, MJ/day

'computation from one half team

TtNEmw = NEmw1 + NEmw2        'total MJ/day for team 1
TtMEm = MEM1 + MEm2           'max ME, MJ/day
TtNEw = NEw1 + NEw2          'net work energy MJ/day
TtDapCap = TtNEw / 3.85       'number of hours per day
TtOxPwr = ((WtOx1 + WtOx2) * 9.81 * .1 * .925 * Spd) / 1000'power kWfrom two oxen

'energy from ox3

Fq3 = .025 * WtOx3           'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
 ' ME = GE * .45 * .8 * .85
  ' ELSE
  '  IF PryFd$ = "1" OR PryFd$ = "2" AND TilSt$ = "2" THEN
   '    ME = GE * .45 * .8
   ' END IF
'END IF
MEm3 = Fq3 * ME * DMc        'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
Km = .019 * ME + .53      'Km = efficiency of utilization (ARC standard)
NEmw3 = MEm3 * Km         'NEmw = net energy for maintenance and work per day
BMR3 = (70.5 * WtOx3 ^ .75 * 4.184 * EXP(-.03 * AgeOx3)) / 1000 'Basal Metabolic rate MJ/day
NEw3 = NEmw3 - BMR3        'NEw = net energy for work, MJ/day

'Energy from Ox4

Fq4 = .025 * WtOx4          'Fq  = Voluntary dry matter intake (kg of Dry Matter per day)
'IF PryFd$ = "3" AND TilSt$ = "1" OR TilSt$ = "3" THEN
 ' ME = GE * .45 * .8 * .85
  ' ELSE ME = GE * .45 * .8
'END IF
MEm4 = Fq4 * ME * DMc        'Max Metabolizable energy per day; DMc=Dry matter  content (dec)
```

```
Km = .019 * ME + .53        'Km = efficiency of utilization (ARC standard)
NEmw4 = MEm4 * Km           'NEmw = net energy for maintenance and work per day
BMR4 = (70.5 * WtOx4 ^ .75 * 4.184 * EXP(-.03 * AgeOx4)) / 1000 'Basal Metabolic rate MJ/day
NEw4 = NEmw4 - BMR4         'NEw = net energy for work, MJ/day

'calculation for second pair of oxen

T2NEmw = NEmw3 + NEmw4      'total MJ/day for team 1
T2MEm = MEm3 + MEm4         'max ME, MJ/day
T2NEw = NEw3 + NEw4         'net work energy MJ/day
T2DapCap = T2NEw / 3.85
T2OxPwr = ((WtOx3 + WtOx4) * 9.81 * .1 * .925 * Spd) / 1000'power kW from two oxen

'computation of totals

TBMR = BMR1 + BMR2 + BMR3 + BMR4
TNEmw = TtNEmw + T2NEmw
TMEm = TtMEm + T2MEm
TNEw = TtNEw + T2NEw
TNEw = TNEw * EXP(.08 * Spd)
TDapCap = TtDapCap + T2DapCap
TATimTil = TCrpLnd / (EFC * TDapCap)
Wks = TATimTil / NdWk%
OxPwr = TtOxPwr + T2OxPwr

FtdMn = (BMR1 + BMR2) * 180 / (DMc * ME) 'seasonal maintenance feed needs kg
F2dMn = (BMR3 + BMR4) * 180 / (DMc * ME)
FdMn = FtdMn + F2dMn

FtdWk = TtNEw * TATimTil / (DMc * ME)     'per season
F2dWk = T2NEw * TATimTil / (DMc * ME)
FdWk = FtdWk + F2dWk
'TrsEn = HseLoad * 9.81 / 1000       'transport energy per year, MJ
TrsFd = TrsEn / (DMc * ME)
GrsFdRqd = FdMn + FdWk
GrsEnRqd = GrsFdRqd * DMc * ME

3600 'general for both

Etot = EFC * 10000 * SoilStr * Wdth * Dpth * TDapCap / (Wdth * 1000)   'total work done per day MJ
GrsEf = (Etot / TNEmw) * 100              'gross efficiency %
NetEf = (Etot / (TNEmw - TBMR)) * 100     'net efficiency %
DstDy = EFC * TDapCap * 10000 / Wdth   'distance traveled per day working, m
'OxWt = WtOx1 + WtOx2 + WtOx3 + WtOx4
EnWlk = OxWt * 2! * DstDy / 1000000       'energy for walking for both oxen, MJ
AbsEf = (Etot / (TNEmw - EnWlk)) * 100     'absolute efficiency %

'probability oif working days

IF TilSt$ = "1" THEN SnTlDys = 10
IF TilSt$ = "2" THEN SnTlDys = 25
IF TilSt$ = "3" THEN SnTlDys = 20

PotWkT = GrsEnRqd / TNEmw
ExCap = PotWkT - SnTlDys            'extra work potential in days
TFEnD = TCrpLnd * ImplEn            'total field implement energy demand
```

```
'-------------------------4. PREPARATION OF DATA FOR PRINTOUT OF OUTPUT

Spdd = Spd * 3.6
DMcc = DMc * 100
Dpthh = Dpth * 100
Wdthh = Wdth * 100
IF TilSt$ = "1" THEN TilSt$ = "'as soon as rains come'"
IF TilSt$ = "2" THEN TilSt$ = "'soon after harvest'"
IF TilSt$ = "3" THEN TilSt$ = "'before the rains'"
IF SolTy$ = "1" THEN SolTy$ = "'Silty clay.'"
IF SolTy$ = "2" THEN SolTy$ = "'Clay loam.'"
IF SolTy$ = "3" THEN SolTy$ = "'Sandy loam.'"
IF SolTy$ = "4" THEN SolTy$ = "'Black cotton.'"
IF PryFd$ = "1" THEN PryFd$ = "'maize stover'"
IF PryFd$ = "2" THEN PryFd$ = "'cut grass (hay)'"
IF PryFd$ = "3" THEN PryFd$ = "'natural pasture'"
IF Impl$ = "1" THEN Impl$ = "'moldboard plow.'"
IF Impl$ = "2" THEN Impl$ = "'moldboard plow and ox cart.'"
IF Impl$ = "3" THEN Impl$ = "'Ox cart only.'"
2650 CLS
LOCATE 10, 12
INPUT "Do you want to print out the outputs on a printer (Y/N)"; PrtOut$
IF PrtOut$ = "Y" OR PrtOut$ = "y" GOTO 2700
IF PrtOut$ = "N" OR PrtOut$ = "n" THEN GOTO 2710
BEEP
GOTO 2650
2710
'------------------CREATING NEW FILE NAME--------------------

LOCATE 10, 10
PRINT "      Creating a file for saving the results"
PRINT
LOCATE 12, 8
PRINT "The default file name is 'A:\z\1.dat'"
FileName$ = "A:\z\1.dat"
4000

LOCATE 14, 8
INPUT "      Use default file name? (Y/N):", DeFNme$
IF DeFNme$ = "Y" OR DeFNme$ = "y" GOTO 4200
IF DeFNme$ = "N" OR DeFNme$ = "n" THEN GOTO 4100
BEEP
CLS
GOTO 4000
4100
CLS
LOCATE 10, 14
INPUT "Enter New File Name: ", FileName$
LOCATE 13, 10
PRINT "File Name ="; FileName$
'OPEN FileName$ FOR OUTPUT AS #1


999 '---------------------SAVING THE RESULTS IN A FILE----------------------
4200
```

```
PRINT "            Please wait"
PRINT "      Saving Results to the File"
PRINT #1,
"++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
PRINT #1,
PRINT #1, "              Energy Utilization Model for Draft Animal Power"
PRINT #1, "                   for Small-holder Agriculture"
PRINT #1, "                      (E U M D A P)        "
PRINT #1,
PRINT #1, "                                                   George S N Mungai "
PRINT #1,
"++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
PRINT #1,
PRINT #1, "   Herebelow are the results of the DAP-SYS simulation performed based on the",
PRINT #1, "   inputs provided."
PRINT #1, ""
PRINT #1, "            I N P U T S   P R O V I D E D"
PRINT #1,
PRINT #1, USING "1. The land size of the farm is #.## ha out of which"; Land!;
PRINT #1, " the cropped land for each"
PRINT #1, USING "    season is #.## ha. with a soil type of"; CrpLnd;
PRINT #1, " "; SolTy$
PRINT #1, "2. The number of oxen used by system is"; Oxen
IF Oxen = 4 GOTO 992
PRINT #1, "  with the following weights:"
PRINT #1, USING "      Ox1 is ###.# kg."; WtOx1
PRINT #1, USING "      Ox2 is ###.# kg."; WtOx2
PRINT #1, "  Their ages are:"
PRINT #1, "     age of Ox1 is "; AgeOx1;
PRINT #1, "  years"
PRINT #1, "     age of Ox2 is "; AgeOx2;
PRINT #1, "  years"
GOTO 993
992
PRINT #1, USING "      Ox1 is ###.# kg"; WtOx1
PRINT #1, USING "      Ox2 is ###.# kg"; WtOx2
PRINT #1, USING "      Ox3 is ###.# kg"; WtOx3
PRINT #1, USING "      Ox4 is ###.# kg"; WtOx4
PRINT #1, "  Their ages are:"
PRINT #1, "       age of Ox1 is "; AgeOx1;
PRINT #1, "  years"
PRINT #1, "       age of Ox2 is "; AgeOx2;
PRINT #1, "  years"
PRINT #1, "       age of Ox3 is "; AgeOx3;
PRINT #1, " years"
PRINT #1, "       age of Ox4 is "; AgeOx4;
PRINT #1, "  years"
993
PRINT #1, "3. The type of feed available was"; PryFd$
PRINT #1, "4. The implement(s) used were: "; Impl$
PRINT #1, "5. Tillage was started "; TilSt$;
PRINT #1, " and the plowing was done at a"
PRINT #1, "    depth of"; Dpthh; "cm. and";
PRINT #1, " a width of"; Wdthh; "cm."
PRINT #1, "6. The speed of operation was"; Spdd; "km per hour"
PRINT #1, "7. The oxen were used for"; NdWk%; "days per week";
```

```
PRINT #1, " and for"; HrDy!; "hours per day."
PRINT #1, ""
PRINT #1, "            O U T P U T S"
PRINT #1,
PRINT #1, "1. Draft oxen energy supply"
PRINT #1,
PRINT #1, ; USING "  1.1 Maximum metabolizable energy (MJ/day):        #,###.## "; TMEm
PRINT #1, USING "  1.2 Total net energy (maintenance and work-MJ/day): #,###.## "; TNEmw
PRINT #1, USING "  1.3 Net energy for work (MJ/day):                ###.## "; TNEw
PRINT #1, USING "  1.4 DAP-SYS power supply (kW):                  #.## "; OxPwr
PRINT #1, USING "  1.5 DAP-SYS work capacity (hours/day):           ###.## "; TDapCap
PRINT #1,
PRINT #1, "2. Implement energy demand"
PRINT #1,
PRINT #1, USING "  2.1 Implement power demand (kW):                 #.## "; Pwr
PRINT #1, USING "  2.2 Implement energy expenditure (kW-hr/ha):     ###.## "; ImplEn
PRINT #1, USING "  2.3 Total field implement energy demand (kW-hrs):  ##.## "; TFEnD
PRINT #1,
PRINT #1, "3. Feed energy supply"
PRINT #1,
PRINT #1, USING "  3.1 Gross total season's maintenance feed (kg):   #,###.## "; FdMn
PRINT #1, USING "  3.2 Total feed required for tillage work (kg):   #,###.## "; FdWk
PRINT #1, USING "  3.3 Gross feed required per season (kg):        ##,###.## "; GrsFdRqd
PRINT #1,
PRINT #1, "4. DAP System performance measures"
PRINT #1,
PRINT #1, USING "  4.1 Effective field capacity (ha/hr):            #.### "; EFC
PRINT #1, USING "  4.2 Total daily energy expenditure (MJ):         #,###.## "; TNEmw
PRINT #1, USING "  4.3 Actual time to finish work (days):           #,###.## "; TATimTil
PRINT #1, USING "  4.4 Potential work time (days):                  #,###.## "; PotWkT
PRINT #1, USING "  4.5 Total daily tillage work done (MJ):          ##.##"; Etot
PRINT #1, USING "  4.6 Gross eficiency of DAP-SYS (%):              ##.##"; GrsEf
PRINT #1, USING "  4.7 Net efficiency of DAP-SYS (%):               ##.##"; NetEf
PRINT #1, USING "  4.8 Excess potential DAP-SYS work capacity (days):  #,###.##"; ExCap
PRINT #1,
PRINT #1, "5. Random Estimates of produce used in simulation"
PRINT #1,
PRINT #1, USING "  5.1 Maize yield per hectare (90 kg bags):        ##.##"; MzYld
PRINT #1, USING "  5.2 Total maize yield of farm (90 kg bags):      ###.##"; TMzYld
PRINT #1, USING "  5.3 Quantity of maize sold (90 kg bags):         ###.## "; MzSl
PRINT #1, USING "  5.4 Beans yield per hectare (90 kg bags):        ##.##"; BnYld
PRINT #1, USING "  5.5 Total beans yield of farm (90 kg bags):      ###.##"; TBnYld
PRINT #1, USING "  5.6 Quantity of beans sold (90 kg bags):         ###.## "; BnSl
PRINT #1,
PRINT #1, "6. Income sources"
PRINT #1,
PRINT #1, USING "  6.1 Income from sale of crops (KSh):             ###,###.##"; CrpInc
PRINT #1, USING "  6.2 Income from rental of DAP-SYS (KSh):         ###,###.##"; HirInc
PRINT #1, USING "  6.3 Gross net income for season (KSh):           ###,###.##"; GrsNtRtn
888
CLS
PRINT "Etot"; Etot
PRINT "TDapCap"; TDapCap
PRINT "TCrpLnd"; TCrpLnd
PRINT "ATimTil"; ATimTil
PRINT "MEm1"; MEM1
```

```
PRINT "Km"; Km
PRINT "BMR1"; BMR1
PRINT "BMR2"; BMR2
PRINT "NEmw1"; NEmw1
PRINT "EFC"; EFC
PRINT "Hrdy"; HrDy
PRINT "TBMR"; TBMR
PRINT "TNEmw"; TNEmw
PRINT "GrsFdRqd"; GrsFdRqd
PRINT "GrsEnRqd"; GrsEnRqd

CLOSE #1
END

2700
LPRINT
"+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
PRINT
LPRINT "            Energy Utilization Model for Draft Animal Power"
LPRINT "                 for Small-holder Agriculture"
LPRINT "                    (E U M D A P)        "
LPRINT
LPRINT "                                                      George S N Mungai "
LPRINT
"+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
LPRINT
LPRINT "   Herebelow are the results of the DAP-SYS simulation perfomed;"
LPRINT "     based on the inputs provided."
LPRINT ""
LPRINT "           I N P U T S   P R O V I D E D"
LPRINT
LPRINT USING "1. The land size of the farm is #.## ha out of which"; Land!;
LPRINT " the cropped land for each"
LPRINT USING "    season is #.## ha. with a soil type of"; CrpLnd;
LPRINT " "; SolTy$
LPRINT "2. The number of oxen used by system is"; Oxen
IF Oxen = 4 GOTO 994
LPRINT "  with the following weights:"
LPRINT USING "     Ox1 is ###.# kg."; WtOx1
LPRINT USING "     Ox2 is ###.# kg."; WtOx2
LPRINT "  Their ages are:"
LPRINT "    age of Ox1 is "; AgeOx1;
LPRINT " years"
LPRINT "    age of Ox2 is "; AgeOx2;
LPRINT " years"
GOTO 995
994
LPRINT USING "     Ox1 is ###.# kg"; WtOx1
LPRINT USING "     Ox2 is ###.# kg"; WtOx2
LPRINT USING "     Ox3 is ###.# kg"; WtOx3
LPRINT USING "     Ox4 is ###.# kg"; WtOx4
LPRINT "  Their ages are:"
LPRINT "      age of Ox1 is "; AgeOx1;
LPRINT " years"
LPRINT "      age of Ox2 is "; AgeOx2;
LPRINT " years"
```

```
LPRINT "      age of Ox3 is "; AgeOx3;
LPRINT " years"
LPRINT "      age of Ox4 is "; AgeOx4;
LPRINT "  years"
995
LPRINT "3. The type of feed available was"; PryFd$
LPRINT "4. The implement(s) used were: "; Impl$
LPRINT "5. Tillage was started "; TilSt$;
LPRINT " and the plowing was done at a"
LPRINT "    depth of"; Dpthh; "cm. and";
LPRINT " a width of"; Wdthh; "cm."
LPRINT "6. The speed of operation was"; Spdd; "km per hour"
LPRINT "7. The oxen were used for"; NdWk%; "days per week";
LPRINT " and for"; HrDy!; "hours per day."
LPRINT ""
LPRINT "             O U T P U T S"
LPRINT
LPRINT "1. Draft oxen energy supply"
LPRINT
LPRINT USING "  1.1 Maximum metabolizable energy (MJ/day):        #,###.## "; TMEm
LPRINT USING "  1.2 Total net energy (maintenance and work-MJ/day): #,###.## "; TNEmw
LPRINT USING "  1.3 Net energy for work (MJ/day):              ###.## "; TNEw
LPRINT USING "  1.4 DAP-SYS power supply (kW):                  #.## "; OxPwr
LPRINT USING "  1.5 DAP-SYS work capacity (hours/day):          ###.## "; TDapCap
LPRINT
LPRINT "2. Implement energy demand"
LPRINT
LPRINT USING "  2.1 Implement power demand (kW):                 #.## "; Pwr
LPRINT USING "  2.2 Implement energy expenditure (kW-hr/ha):     ###.## "; ImplEn
LPRINT USING "  2.3 Total field implement energy demand (kW-hrs): ##.## "; TFEnD
LPRINT
LPRINT "3. Feed energy supply"
LPRINT
LPRINT USING "  3.1 Gross total season's maintenance feed (kg):  #,###.## "; FdMn
LPRINT USING "  3.2 Total season's feed required for work (kg):  #,###.## "; FdWk
LPRINT USING "  3.3 Gross feed required per season (kg):        ##,###.## "; GrsFdRqd
LPRINT
LPRINT "4. DAP System performance measures"
LPRINT
LPRINT USING "  4.1 Effective field capacity (ha/hr):          #.## "; EFC
LPRINT USING "  4.2 Total daily energy expenditure (MJ):        #,###.## "; TNEmw
LPRINT USING "  4.3 Actual time to finish work (days):          ##.## "; TATimTil
LPRINT USING "  4.4 Potential work time (days):               #,###.## "; PotWkT
LPRINT USING "  4.5 Total daily tillage work done (MJ):         ##.##"; Etot
LPRINT USING "  4.6 Gross eficiency of DAP-SYS (%):             ##.##"; GrsEf
LPRINT USING "  4.7 Net efficiency of DAP-SYS (%):              ##.##"; NetEf
LPRINT USING "  4.8 Gross net return per season (KSh):          ##,###.##"; GrsNtRtn
LPRINT USING "  4.9 Excess DAP-SYS work capacity (days):        #,###.##"; ExCap
LPRINT #1,
LPRINT #1, "5. Random Estimates of produce used in simulation"
LPRINT #1,
LPRINT #1, USING "  5.1 Maize yield per hectare (90 kg bags):       ##.##"; MzYld
LPRINT #1, USING "  5.2 Total maize yield of farm (90 kg bags):     ###.##"; TMzYld
LPRINT #1, USING "  5.3 Quantity of maize sold (90 kg bags):        ###.## "; MzSl
LPRINT #1, USING "  5.4 Beans yield per hectare (90 kg bags):       ##.##"; BnYld
LPRINT #1, USING "  5.5 Total beans yield of farm (90 kg bags):     ###.##"; TBnYld
```

```
LPRINT #1, USING "   5.6 Quantity of beans sold (90 kg bags):          ###.## "; BnSl
LPRINT #1,
LPRINT #1, "6. Income sources"
LPRINT #1,
LPRINT #1, USING "   6.1 Income from sale of crops (KSh):            ###,###.##"; CrpInc
LPRINT #1, USING "   6.2 Income from rental of DAP-SYS (KSh):          ###,###.##"; HirInc
LPRINT #1, USING "   6.3 Gross net income for season (KSh):           ###,###.##"; GrsNtRtn

END
```

# APPENDIX G

# APPENDIX G

Appendix G shows three print-outs of simulations ran with the EUMDAP computer simulation program. This print-out is the same as the user would obtain after simulations are carried out. The data input by the user and the output values of the simulation are shown in the print-outs. The simulations were performed for two oxen weighing 250 kg each and plowing between 1.17 to 3.29 ha of land with silty clay soil type at a speed of 2.6 km per hour.

Simulation #1:

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                    Energy Utilization Model for Draft Animal Power
                             for Small-holder Agriculture
                                  (E  U  M  D  A  P)

                                                      George S N Mungai
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     Herebelow are the results of the DAP-SYS simulation performed
based on the inputs provided.

                   I  N  P  U  T  S   P R O V I D E D

1. The land size of the farm is 5.67 ha out of which the cropped land
   for each season is 3.29 ha. with a soil type of 'Silty clay.'
2. The number of oxen used by system is 2
   with the following weights:
       Ox1 is 250.0 kg.
       Ox2 is 250.0 kg.
   Their ages are:
     age of Ox1 is  3   years
     age of Ox2 is  3   years
3. The type of feed available was'maize stover'
4. The implement(s) used were: 'moldboard plow.'
5. Tillage was started 'as soon as rains come' and the plowing was done
   at a depth of 10 cm. and a width of 25 cm.
6. The speed of operation was 2.565 km per hour
7. The oxen were used for 5 days per week and for 6 hours per day.

                   O  U  T  P  U  T  S

1. Draft oxen energy supply
```

| | |
|---|---|
| 1.1 Maximum metabolizable energy (MJ/day): | 85.05 |
| 1.2 Total net energy (maintenance and work-MJ/day): | 57.29 |
| 1.3 Net energy for work (MJ/day): | 24.77 |
| 1.4 DAP-SYS power supply (kW): | 0.32 |
| 1.5 DAP-SYS work capacity (hours/day): | 6.43 |

2. Implement energy demand

| | |
|---|---|
| 2.1 Implement power demand (kW): | 0.28 |
| 2.2 Implement energy expenditure (kW-hr/ha): | 4.58 |
| 2.3 Total field implement energy demand (kW-hrs): | 15.07 |

3. Feed energy supply

| | |
|---|---|
| 3.1 Gross total season's maintenance feed (kg): | 896.8 |
| 3.2 Total feed required for tillage work (kg): | 29.9 |
| 3.3 Gross feed required per season (kg): | 926.7 |

4. DAP System performance measures

| | |
|---|---|
| 4.1 Effective field capacity (ha/hr): | 0.062 |
| 4.2 Total daily energy expenditure (MJ): | 57.29 |
| 4.3 Actual time to finish work (days): | 8.2 |
| 4.4 Potential work time (days): | 110.05 |
| 4.5 Total daily tillage work done (MJ): | 6.40 |
| 4.6 Gross efficiency of DAP-SYS (%): | 11 |
| 4.7 Net efficiency of DAP-SYS (%): | 27 |
| 4.8 Excess potential DAP-SYS work capacity (days): | 100.1 |

5. Random Estimates of produce used in simulation

| | |
|---|---|
| 5.1 Maize yield per hectare (90 kg bags): | 13.7 |
| 5.2 Total maize yield of farm (90 kg bags): | 31.5 |
| 5.3 Quantity of maize sold (90 kg bags): | 21.5 |
| 5.4 Beans yield per hectare (90 kg bags): | 5.4 |
| 5.5 Total beans yield of farm (90 kg bags): | 5.4 |
| 5.6 Quantity of beans sold (90 kg bags): | 3.4 |

6. Income sources

| | |
|---|---|
| 6.1 Income from sale of crops (KSh): | 55,546 |
| 6.2 Income from rental of DAP-SYS (KSh): | 0 |
| 6.3 Gross net income for season (KSh): | 40,720 |

Simulation #2:

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Energy Utilization Model for Draft Animal Power
for Small-holder Agriculture
(E U M D A P)

George S N Mungai

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Herebelow are the results of the DAP-SYS simulation performed based on the inputs provided.

I N P U T S P R O V I D E D

1. The land size of the farm is 4.45 ha out of which the cropped land for each season is 2.58 ha. with a soil type of 'Silty clay.'
2. The number of oxen used by system is 2
   with the following weights:
   Ox1 is 250.0 kg.
   Ox2 is 250.0 kg.
   Their ages are:
   age of Ox1 is 3 years
   age of Ox2 is 3 years
3. The type of feed available was'maize stover'
4. The implement(s) used were: 'moldboard plow.'
5. Tillage was started 'as soon as rains come' and the plowing was done at a depth of 10 cm. and a width of 25 cm.
6. The speed of operation was 2.565 km per hour
7. The oxen were used for 5 days per week and for 6 hours per day.

O U T P U T S

1. Draft oxen energy supply

| | |
|---|---|
| 1.1 Maximum metabolizable energy (MJ/day): | 85.05 |
| 1.2 Total net energy (maintenance and work-MJ/day): | 57.29 |
| 1.3 Net energy for work (MJ/day): | 24.77 |
| 1.4 DAP-SYS power supply (kW): | 0.32 |
| 1.5 DAP-SYS work capacity (hours/day): | 6.43 |

2. Implement energy demand

| | |
|---|---|
| 2.1 Implement power demand (kW): | 0.28 |
| 2.2 Implement energy expenditure (kW-hr/ha): | 4.58 |
| 2.3 Total field implement energy demand (kW-hrs): | 11.84 |

3. Feed energy supply

| | |
|---|---|
| 3.1 Gross total season's maintenance feed (kg): | 896.8 |
| 3.2 Total feed required for tillage work (kg): | 23.5 |
| 3.3 Gross feed required per season (kg): | 920.3 |

4. DAP System performance measures

| | |
|---|---|
| 4.1 Effective field capacity (ha/hr): | 0.062 |
| 4.2 Total daily energy expenditure (MJ): | 57.29 |
| 4.3 Actual time to finish work (days): | 6.5 |
| 4.4 Potential work time (days): | 109.29 |
| 4.5 Total daily tillage work done (MJ): | 6.40 |
| 4.6 Gross efficiency of DAP-SYS (%): | 11 |
| 4.7 Net efficiency of DAP-SYS (%): | 27 |
| 4.8 Excess potential DAP-SYS work capacity (days): | 99.3 |

5. Random Estimates of produce used in simulation

| | |
|---|---|
| 5.1 Maize yield per hectare (90 kg bags): | 13.7 |
| 5.2 Total maize yield of farm (90 kg bags): | 24.8 |
| 5.3 Quantity of maize sold (90 kg bags): | 14.8 |
| 5.4 Beans yield per hectare (90 kg bags): | 5.7 |
| 5.5 Total beans yield of farm (90 kg bags): | 4.4 |
| 5.6 Quantity of beans sold (90 kg bags): | 2.4 |

6. Income sources

| | |
|---|---|
| 6.1 Income from sale of crops (KSh): | 38,541 |
| 6.2 Income from rental of DAP-SYS (KSh): | 0 |
| 6.3 Gross net income for season (KSh): | 24,969 |

Simulation #3:

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Energy Utilization Model for Draft Animal Power
for Small-holder Agriculture
(E U M D A P)

George S N Mungai

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Herebelow are the results of the DAP-SYS simulation performed based
on the inputs provided.

I N P U T S   P R O V I D E D

1. The land size of the farm is 2.02 ha out of which the cropped land for each season is 1.17 ha. with a soil type of 'Silty clay.'
2. The number of oxen used by system is 2
   with the following weights:
   Ox1 is 250.0 kg.
   Ox2 is 250.0 kg.
   Their ages are:
   age of Ox1 is 3 years
   age of Ox2 is 3 years
3. The type of feed available was'maize stover'
4. The implement(s) used were: 'moldboard plow.'
5. Tillage was started 'as soon as rains come' and the plowing was done at a depth of 10 cm. and a width of 25 cm.
6. The speed of operation was 2.565 km per hour
7. The oxen were used for 5 days per week and for 6 hours per day.

O U T P U T S

1. Draft oxen energy supply

| | |
|---|---|
| 1.1 Maximum metabolizable energy (MJ/day): | 85.05 |
| 1.2 Total net energy (maintenance and work-MJ/day): | 57.29 |
| 1.3 Net energy for work (MJ/day): | 24.77 |
| 1.4 DAP-SYS power supply (kW): | 0.32 |
| 1.5 DAP-SYS work capacity (hours/day): | 6.43 |

2. Implement energy demand

| | |
|---|---|
| 2.1 Implement power demand (kW): | 0.28 |
| 2.2 Implement energy expenditure (kW-hr/ha): | 4.58 |
| 2.3 Total field implement energy demand (kW-hrs): | 5.38 |

3. Feed energy supply

| | |
|---|---|
| 3.1 Gross total season's maintenance feed (kg): | 896.8 |
| 3.2 Total feed required for tillage work (kg): | 10.7 |
| 3.3 Gross feed required per season (kg): | 907.5 |

4. DAP System performance measures

| | |
|---|---|
| 4.1 Effective field capacity (ha/hr): | 0.062 |
| 4.2 Total daily energy expenditure (MJ): | 57.29 |
| 4.3 Actual time to finish work (days): | 2.9 |
| 4.4 Potential work time (days): | 107.77 |
| 4.5 Total daily tillage work done (MJ): | 6.40 |
| 4.6 Gross efficiency of DAP-SYS (%): | 11 |
| 4.7 Net efficiency of DAP-SYS (%): | 27 |
| 4.8 Excess potential DAP-SYS work capacity (days): | 97.8 |

5. Random Estimates of produce used in simulation

| | |
|---|---|
| 5.1 Maize yield per hectare (90 kg bags): | 13.7 |
| 5.2 Total maize yield of farm (90 kg bags): | 11.3 |
| 5.3 Quantity of maize sold (90 kg bags): | 1.3 |
| 5.4 Beans yield per hectare (90 kg bags): | 5.7 |
| 5.5 Total beans yield of farm (90 kg bags): | 2.0 |
| 5.6 Quantity of beans sold (90 kg bags): | 0.0 |

6. Income sources

| | |
|---|---|
| 6.1 Income from sale of crops (KSh): | 2,246 |
| 6.2 Income from rental of DAP-SYS (KSh): | 0 |
| 6.3 Gross net income for season (KSh): | 0 |

**APPENDIX H**

# APPENDIX H

**Raw data printout of File #: Musau2**

One of the files containing raw field data is provided with slight modifications to indicate the eight channels used for data collection and the real time lapse. Also included is a count of the data points and statistical calculations for each channel values at the end of the file. The file printed out was File number Musau2 for one of the farmers in Kalama division.

| | | TRANSDUCER OUTPUT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chan. # | 1 | 2 | 5 | 6 | 7 | 8 | 9 | 19 | 20 |
| Data Points | Time Csec | Horizontal Draft V | Vertical Draft V | Depth V | Heart Rate P | Respiration Rate P | Body Temp. V | Battery V | Ground Speed P | Step Rate (Digital) P |
| 1 | 0.00 | 0.1873 | -0.0335 | 2.2725 | 0.035 | 3.045 | 0.512 | 6.995 | 22 | 11110001 |
| 2 | 0.06 | 0.1978 | -0.0343 | 2.3000 | 0.140 | 3.045 | 0.512 | 6.997 | 28 | 11110001 |
| 3 | 0.12 | 0.1930 | -0.0365 | 2.3150 | 0.215 | 3.045 | 0.512 | 6.995 | 22 | 11110001 |
| 4 | 0.18 | 0.1928 | -0.0335 | 2.3600 | 0.205 | 3.065 | 0.512 | 6.995 | 22 | 11110001 |
| 5 | 0.24 | 0.1970 | -0.0303 | 2.4325 | 0.155 | 3.070 | 0.512 | 6.995 | 25 | 11110001 |
| 6 | 0.30 | 0.1813 | -0.0163 | 2.4275 | 0.095 | 3.055 | 0.512 | 7.005 | 20 | 11110001 |
| 7 | 0.36 | 0.2030 | -0.0165 | 2.4225 | 0.050 | 3.055 | 0.512 | 6.985 | 15 | 11110001 |
| 8 | 0.42 | 0.2255 | -0.0095 | 2.4100 | 0.005 | 3.060 | 0.512 | 6.995 | 20 | 11110001 |
| 9 | 0.48 | 0.2340 | -0.0108 | 2.3775 | -0.030 | 3.050 | 0.512 | 6.975 | 24 | 11110001 |
| 10 | 0.54 | 0.2110 | -0.0228 | 2.3500 | 0.000 | 3.055 | 0.512 | 6.995 | 24 | 11110001 |
| 11 | 0.60 | 0.2068 | -0.0270 | 2.3250 | 0.025 | 3.060 | 0.512 | 6.995 | 27 | 11110001 |
| 12 | 0.66 | 0.2065 | -0.0273 | 2.2650 | 0.095 | 3.085 | 0.512 | 6.995 | 28 | 11110001 |
| 13 | 0.72 | 0.1955 | -0.0363 | 2.2225 | 0.155 | 3.065 | 0.512 | 6.995 | 18 | 11110001 |
| 14 | 0.78 | 0.1918 | -0.0328 | 2.3025 | 0.230 | 3.075 | 0.512 | 6.995 | 18 | 11110001 |
| 15 | 0.84 | 0.1858 | -0.0318 | 2.3250 | 0.155 | 3.095 | 0.512 | 6.995 | 19 | 11110001 |
| 16 | 0.90 | 0.1933 | -0.0308 | 2.3350 | 0.020 | 3.090 | 0.512 | 6.995 | 17 | 11110001 |
| 17 | 0.96 | 0.2043 | -0.0248 | 2.3775 | 0.030 | 3.095 | 0.512 | 6.995 | 19 | 11110101 |
| 18 | 1.02 | 0.2123 | -0.0238 | 2.4175 | 0.000 | 3.115 | 0.512 | 6.995 | 25 | 11110001 |
| 19 | 1.08 | 0.2113 | -0.0195 | 2.4375 | 0.170 | 3.105 | 0.512 | 7.005 | 23 | 11110001 |
| 20 | 1.14 | 0.2148 | -0.0250 | 2.4250 | 0.190 | 3.110 | 0.512 | 6.995 | 24 | 11110001 |
| 21 | 1.20 | 0.2198 | -0.0175 | 2.4075 | 0.315 | 3.125 | 0.512 | 6.995 | 24 | 11110001 |
| 22 | 1.26 | 0.2018 | -0.0145 | 2.3725 | 0.440 | 3.120 | 0.512 | 6.995 | 26 | 11110001 |
| 23 | 1.32 | 0.2013 | -0.0200 | 2.3100 | 0.220 | 3.120 | 0.512 | 7.000 | 17 | 11110000 |
| 24 | 1.38 | 0.1945 | -0.0265 | 2.3075 | 0.010 | 3.130 | 0.512 | 6.995 | 18 | 11110001 |
| 25 | 1.44 | 0.2020 | -0.0275 | 2.2700 | 0.000 | 3.120 | 0.512 | 6.995 | 24 | 11110001 |
| 26 | 1.50 | 0.2008 | -0.0325 | 2.2275 | 0.100 | 3.120 | 0.512 | 6.995 | 27 | 11110001 |
| 27 | 1.56 | 0.1960 | -0.0333 | 2.1650 | 0.085 | 3.110 | 0.512 | 6.995 | 29 | 11110001 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 1.62 | 0.1905 | -0.0415 | 2.1500 | 0.150 | 3.115 | 0.512 | 6.995 | 21 | 11110001 |
| 29 | 1.68 | 0.1885 | -0.0398 | 2.2050 | 0.235 | 3.105 | 0.512 | 6.995 | 25 | 11110001 |
| 30 | 1.74 | 0.1925 | -0.0398 | 2.2125 | 0.330 | 3.105 | 0.512 | 7.005 | 21 | 11110001 |
| 31 | 1.80 | 0.1825 | -0.0388 | 2.2725 | 0.255 | 3.065 | 0.512 | 6.995 | 21 | 11110001 |
| 32 | 1.86 | 0.1960 | -0.0273 | 2.3150 | 0.010 | 3.065 | 0.512 | 6.995 | 19 | 11110001 |
| 33 | 1.92 | 0.2045 | -0.0278 | 2.3200 | -0.045 | 3.075 | 0.512 | 6.995 | 25 | 11110001 |
| 34 | 1.98 | 0.2155 | -0.0218 | 2.3275 | 0.000 | 3.070 | 0.512 | 6.995 | 24 | 11110001 |
| 35 | 2.04 | 0.2318 | -0.0100 | 2.3125 | 0.090 | 3.075 | 0.512 | 6.995 | 23 | 11110001 |
| 36 | 2.10 | 0.2255 | -0.0185 | 2.3050 | 0.080 | 3.070 | 0.512 | 6.995 | 25 | 11110001 |
| 37 | 2.16 | 0.2078 | -0.0308 | 2.2650 | 0.185 | 3.095 | 0.512 | 6.995 | 24 | 11110001 |
| 38 | 2.22 | 0.1985 | -0.0353 | 2.2675 | 0.440 | 3.090 | 0.512 | 6.995 | 21 | 11110001 |
| 39 | 2.28 | 0.2040 | -0.0300 | 2.2625 | 0.245 | 3.095 | 0.512 | 6.995 | 20 | 11110000 |
| 40 | 2.34 | 0.2055 | -0.0353 | 2.2575 | 0.070 | 3.105 | 0.512 | 6.990 | 26 | 11110000 |
| 41 | 2.40 | 0.2033 | -0.0323 | 2.2325 | -0.015 | 3.105 | 0.512 | 6.995 | 27 | 11110001 |
| 42 | 2.46 | 0.2013 | -0.0328 | 2.1950 | -0.060 | 3.095 | 0.512 | 7.005 | 28 | 11110001 |
| 43 | 2.52 | 0.1950 | -0.0365 | 2.1825 | 0.000 | 3.105 | 0.512 | 6.990 | 28 | 11110001 |
| 44 | 2.58 | 0.1925 | -0.0383 | 2.1700 | 0.140 | 3.070 | 0.512 | 6.995 | 26 | 11110001 |
| 45 | 2.64 | 0.1948 | -0.0380 | 2.1575 | 0.300 | 3.120 | 0.512 | 6.995 | 26 | 11110001 |
| 46 | 2.70 | 0.1945 | -0.0390 | 2.1675 | 0.525 | 3.105 | 0.512 | 6.970 | 27 | 11110001 |
| 47 | 2.76 | 0.1915 | -0.0390 | 2.1625 | 0.090 | 3.120 | 0.512 | 6.995 | 24 | 11110000 |
| 48 | 2.82 | 0.1923 | -0.0375 | 2.1850 | -0.115 | 3.115 | 0.512 | 6.990 | 27 | 11110000 |
| 49 | 2.88 | 0.1950 | -0.0350 | 2.1950 | -0.115 | 3.120 | 0.512 | 6.975 | 30 | 11110001 |
| 50 | 2.94 | 0.1913 | -0.0353 | 2.1950 | -0.005 | 3.105 | 0.512 | 6.995 | 31 | 11110001 |
| 51 | 3.00 | 0.1908 | -0.0383 | 2.1675 | 0.000 | 3.095 | 0.512 | 6.995 | 29 | 11110001 |
| 52 | 3.06 | 0.1895 | -0.0400 | 2.1575 | 0.195 | 3.085 | 0.512 | 6.995 | 29 | 11110001 |
| 53 | 3.12 | 0.1800 | -0.0375 | 2.1900 | 0.135 | 3.095 | 0.512 | 6.995 | 30 | 11110001 |
| 54 | 3.18 | 0.1723 | -0.0378 | 2.2050 | 0.020 | 3.095 | 0.512 | 6.990 | 27 | 11110001 |
| 55 | 3.24 | 0.1878 | -0.0360 | 2.2375 | 0.080 | 3.090 | 0.512 | 7.000 | 24 | 11110001 |
| 56 | 3.30 | 0.1783 | -0.0303 | 2.2425 | 0.160 | 3.090 | 0.512 | 6.995 | 24 | 11110001 |
| 57 | 3.36 | 0.1895 | -0.0358 | 2.2975 | 0.305 | 3.080 | 0.512 | 6.985 | 29 | 11110001 |
| 58 | 3.42 | 0.1888 | -0.0358 | 2.3050 | 1.035 | 3.085 | 0.512 | 6.990 | 31 | 11110000 |
| 59 | 3.48 | 0.1860 | -0.0438 | 2.2650 | 1.285 | 3.085 | 0.512 | 6.980 | 25 | 11110000 |
| 60 | 3.54 | 0.1805 | -0.0315 | 2.3150 | -0.220 | 3.090 | 0.512 | 6.990 | 28 | 11110001 |
| 61 | 3.60 | 0.1870 | -0.0360 | 2.3075 | -0.195 | 3.100 | 0.512 | 6.995 | 24 | 11110001 |
| 62 | 3.66 | 0.1915 | -0.0353 | 2.3150 | -0.135 | 3.085 | 0.512 | 6.990 | 25 | 11110101 |
| 63 | 3.72 | 0.1958 | -0.0300 | 2.3150 | -0.280 | 3.085 | 0.512 | 6.990 | 24 | 11110001 |
| 64 | 3.78 | 0.1975 | -0.0308 | 2.3250 | -0.175 | 3.090 | 0.512 | 6.995 | 24 | 11110001 |
| 65 | 3.84 | 0.2013 | -0.0280 | 2.3100 | -0.190 | 3.085 | 0.512 | 6.985 | 22 | 11110001 |
| 66 | 3.90 | 0.1980 | -0.0278 | 2.3175 | 0.120 | 3.085 | 0.512 | 6.990 | 23 | 11110001 |
| 67 | 3.96 | 0.1935 | -0.0293 | 2.3250 | 0.135 | 3.095 | 0.512 | 6.995 | 24 | 11110001 |
| 68 | 4.02 | 0.1945 | -0.0360 | 2.3175 | -0.280 | 3.080 | 0.512 | 6.995 | 25 | 11110001 |
| 69 | 4.08 | 0.1980 | -0.0325 | 2.3125 | -0.275 | 3.120 | 0.512 | 6.995 | 25 | 11110001 |
| 70 | 4.14 | 0.1963 | -0.0333 | 2.2975 | -0.215 | 3.130 | 0.512 | 6.995 | 25 | 11110001 |
| 71 | 4.20 | 0.1965 | -0.0360 | 2.2750 | 0.020 | 3.125 | 0.512 | 7.000 | 23 | 11110001 |
| 72 | 4.26 | 0.1988 | -0.0315 | 2.2975 | 0.225 | 3.130 | 0.512 | 6.990 | 25 | 11110001 |
| 73 | 4.32 | 0.2010 | -0.0310 | 2.2975 | 0.370 | 3.135 | 0.512 | 6.995 | 28 | 11110001 |
| 74 | 4.38 | 0.2003 | -0.0355 | 2.2975 | 0.640 | 3.140 | 0.512 | 6.990 | 30 | 11110001 |
| 75 | 4.44 | 0.1950 | -0.0370 | 2.2750 | 0.800 | 3.105 | 0.512 | 6.985 | 28 | 11110000 |
| 76 | 4.50 | 0.1920 | -0.0368 | 2.2825 | 0.210 | 3.125 | 0.512 | 6.995 | 29 | 11110001 |
| 77 | 4.56 | 0.1883 | -0.0388 | 2.2750 | -0.095 | 3.120 | 0.512 | 6.985 | 24 | 11110101 |
| 78 | 4.62 | 0.1673 | -0.0275 | 2.2800 | -0.195 | 3.110 | 0.512 | 6.995 | 25 | 11110001 |
| 79 | 4.68 | 0.1900 | -0.0325 | 2.3075 | 0.000 | 3.110 | 0.512 | 6.990 | 21 | 11110001 |
| 80 | 4.74 | 0.2038 | -0.0260 | 2.3150 | 0.330 | 3.110 | 0.512 | 6.990 | 24 | 11110001 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 4.80 | 0.2210 | -0.0160 | 2.3250 | 1.010 | 3.110 | 0.512 | 6.990 | 30 | 11110000 |
| 82 | 4.86 | 0.1998 | -0.0333 | 2.3150 | 0.890 | 3.105 | 0.512 | 6.990 | 33 | 11110000 |
| 83 | 4.92 | 0.2010 | -0.0350 | 2.2700 | -0.265 | 3.100 | 0.512 | 6.995 | 28 | 11110001 |
| 84 | 4.98 | 0.1880 | -0.0288 | 2.2325 | -0.420 | 3.100 | 0.512 | 6.995 | 25 | 11110001 |
| 85 | 5.04 | 0.1820 | -0.0358 | 2.2325 | -0.260 | 3.105 | 0.512 | 7.000 | 20 | 11110001 |
| 86 | 5.10 | 0.1930 | -0.0333 | 2.2500 | -0.235 | 3.105 | 0.512 | 6.990 | 19 | 11110001 |
| 87 | 5.16 | 0.1998 | -0.0278 | 2.2625 | 0.000 | 3.105 | 0.512 | 7.000 | 21 | 11110001 |
| 88 | 5.22 | 0.2040 | -0.0240 | 2.3150 | 0.035 | 3.105 | 0.512 | 6.995 | 25 | 11110001 |
| 89 | 5.28 | 0.2025 | -0.0220 | 2.3450 | 0.555 | 3.115 | 0.512 | 6.995 | 25 | 11110001 |
| 90 | 5.34 | 0.2018 | -0.0255 | 2.3575 | 0.385 | 3.110 | 0.512 | 6.995 | 25 | 11110000 |
| 91 | 5.40 | 0.1980 | -0.0283 | 2.3475 | -0.270 | 3.110 | 0.512 | 6.995 | 27 | 11110000 |
| 92 | 5.46 | 0.1845 | -0.0258 | 2.3075 | -0.305 | 3.115 | 0.512 | 6.990 | 17 | 11110001 |
| 93 | 5.52 | 0.1945 | -0.0275 | 2.3450 | -0.250 | 3.120 | 0.512 | 6.995 | 20 | 11110001 |
| 94 | 5.58 | 0.2033 | -0.0215 | 2.3475 | -0.125 | 3.120 | 0.512 | 6.995 | 22 | 11110001 |
| 95 | 5.64 | 0.2038 | -0.0208 | 2.3550 | 0.150 | 3.120 | 0.512 | 7.000 | 25 | 11110001 |
| 96 | 5.70 | 0.2083 | -0.0208 | 2.3600 | 0.325 | 3.130 | 0.512 | 6.995 | 25 | 11110001 |
| 97 | 5.76 | 0.2105 | -0.0238 | 2.3650 | 0.355 | 3.135 | 0.512 | 6.995 | 28 | 11110001 |
| 98 | 5.82 | 0.2143 | -0.0280 | 2.3675 | 1.015 | 3.150 | 0.512 | 7.005 | 28 | 11110000 |
| 99 | 5.88 | 0.1935 | -0.0335 | 2.3475 | 0.485 | 3.165 | 0.512 | 6.990 | 31 | 11110000 |
| 100 | 5.94 | 0.1815 | -0.0258 | 2.3125 | -0.205 | 3.175 | 0.512 | 6.990 | 21 | 11110001 |
| 101 | 6.00 | 0.1928 | -0.0240 | 2.3250 | -0.290 | 3.170 | 0.512 | 6.995 | 21 | 11110001 |
| 102 | 6.06 | 0.2193 | -0.0175 | 2.3500 | -0.045 | 3.170 | 0.512 | 6.990 | 25 | 11110001 |
| 103 | 6.12 | 0.2233 | -0.0135 | 2.3550 | 0.510 | 3.175 | 0.512 | 7.000 | 28 | 11110001 |
| 104 | 6.18 | 0.2153 | -0.0215 | 2.3350 | 1.100 | 3.165 | 0.512 | 6.985 | 28 | 11110000 |
| 105 | 6.24 | 0.2008 | -0.0303 | 2.3250 | 0.695 | 3.140 | 0.512 | 6.985 | 29 | 11110000 |
| 106 | 6.30 | 0.2033 | -0.0273 | 2.3075 | 0.455 | 3.175 | 0.512 | 7.000 | 22 | 11110001 |
| 107 | 6.36 | 0.2105 | -0.0238 | 2.3300 | -0.160 | 3.160 | 0.512 | 6.995 | 19 | 11110001 |
| 108 | 6.42 | 0.2155 | -0.0178 | 2.3350 | -0.735 | 3.160 | 0.512 | 6.990 | 23 | 11110001 |
| 109 | 6.48 | 0.2180 | -0.0153 | 2.3325 | -0.730 | 3.130 | 0.512 | 6.995 | 26 | 11110001 |
| 110 | 6.54 | 0.2153 | -0.0175 | 2.3350 | -0.405 | 3.130 | 0.512 | 6.990 | 27 | 11110001 |
| 111 | 6.60 | 0.2060 | -0.0253 | 2.3275 | -0.095 | 3.115 | 0.512 | 6.995 | 28 | 11110001 |
| 112 | 6.66 | 0.2035 | -0.0293 | 2.3025 | 0.335 | 3.110 | 0.512 | 6.995 | 29 | 11110001 |
| 113 | 6.72 | 0.1860 | -0.0288 | 2.3100 | 1.105 | 3.125 | 0.512 | 6.985 | 25 | 11110000 |
| 114 | 6.78 | 0.1870 | -0.0358 | 2.3500 | 0.580 | 3.135 | 0.512 | 6.980 | 19 | 11110000 |
| 115 | 6.84 | 0.1838 | -0.0303 | 2.4175 | -0.190 | 3.150 | 0.512 | 6.990 | 16 | 11110001 |
| 116 | 6.90 | 0.2103 | -0.0230 | 2.4750 | -0.395 | 3.145 | 0.512 | 6.990 | 21 | 11110001 |
| 117 | 6.96 | 0.2300 | -0.0125 | 2.4850 | -0.325 | 3.140 | 0.512 | 7.005 | 27 | 11110001 |
| 118 | 7.02 | 0.2210 | -0.0178 | 2.4825 | 0.015 | 3.140 | 0.512 | 6.990 | 27 | 11110001 |
| 119 | 7.08 | 0.2318 | -0.0075 | 2.4775 | 0.475 | 3.145 | 0.512 | 6.995 | 28 | 11110001 |
| 120 | 7.14 | 0.2265 | -0.0063 | 2.4500 | 0.690 | 3.145 | 0.512 | 6.990 | 31 | 11110000 |
| 121 | 7.20 | 0.2043 | -0.0048 | 2.3800 | 0.520 | 3.155 | 0.512 | 6.995 | 28 | 11110000 |
| 122 | 7.26 | 0.2153 | -0.0183 | 2.3250 | 0.690 | 3.185 | 0.512 | 6.990 | 22 | 11110001 |
| 123 | 7.32 | 0.2293 | -0.0058 | 2.2625 | -0.225 | 3.185 | 0.512 | 6.985 | 20 | 11110101 |
| 124 | 7.38 | 0.2243 | -0.0123 | 2.2525 | -0.455 | 3.185 | 0.512 | 6.995 | 22 | 11110001 |
| 125 | 7.44 | 0.2043 | -0.0310 | 2.2275 | -0.360 | 3.180 | 0.512 | 6.990 | 24 | 11110001 |
| 126 | 7.50 | 0.1965 | -0.0345 | 2.2000 | -0.165 | 3.185 | 0.512 | 6.990 | 26 | 11110001 |
| 127 | 7.56 | 0.1970 | -0.0348 | 2.1875 | 0.060 | 3.190 | 0.512 | 6.995 | 18 | 11110001 |
| 128 | 7.62 | 0.1995 | -0.0340 | 2.2525 | 0.165 | 3.185 | 0.512 | 6.995 | 22 | 11110001 |
| 129 | 7.68 | 0.1670 | -0.0188 | 2.2875 | 0.335 | 3.160 | 0.512 | 6.985 | 25 | 11110001 |
| 130 | 7.74 | 0.1850 | -0.0295 | 2.2925 | 0.100 | 3.155 | 0.512 | 6.995 | 16 | 11110001 |
| 131 | 7.80 | 0.1893 | -0.0235 | 2.2950 | 0.240 | 3.170 | 0.512 | 7.000 | 17 | 11110001 |
| 132 | 7.86 | 0.2135 | -0.0213 | 2.3250 | 0.030 | 3.180 | 0.512 | 7.000 | 21 | 11110001 |
| 133 | 7.92 | 0.2180 | -0.0180 | 2.3500 | 0.000 | 3.145 | 0.512 | 6.995 | 27 | 11110101 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 134 | 7.98 | 0.2105 | -0.0268 | 2.3475 | 0.210 | 3.140 | 0.512 | 6.990 | 26 | 11110001 |
| 135 | 8.04 | 0.2028 | -0.0265 | 2.3175 | 0.440 | 3.135 | 0.512 | 6.985 | 30 | 11110001 |
| 136 | 8.10 | 0.1855 | -0.0268 | 2.2625 | 0.415 | 3.140 | 0.512 | 6.995 | 30 | 11110001 |
| 137 | 8.16 | 0.1933 | -0.0348 | 2.1950 | 0.550 | 3.150 | 0.512 | 6.990 | 19 | 11110001 |
| 138 | 8.22 | 0.1930 | -0.0343 | 2.2175 | 0.735 | 3.160 | 0.512 | 6.990 | 18 | 11110000 |
| 139 | 8.28 | 0.1980 | -0.0283 | 2.2625 | 0.410 | 3.145 | 0.512 | 6.990 | 21 | 11110000 |
| 140 | 8.34 | 0.2020 | -0.0290 | 2.2700 | -0.045 | 3.160 | 0.512 | 6.995 | 19 | 11110000 |
| 141 | 8.40 | 0.2148 | -0.0208 | 2.2925 | -0.325 | 3.160 | 0.512 | 6.995 | 21 | 11110001 |
| 142 | 8.46 | 0.2185 | -0.0218 | 2.2775 | -0.230 | 3.145 | 0.512 | 6.995 | 25 | 11110001 |
| 143 | 8.52 | 0.2110 | -0.0258 | 2.2775 | -0.055 | 3.150 | 0.512 | 6.995 | 20 | 11110001 |
| 144 | 8.58 | 0.2103 | -0.0220 | 2.3075 | 0.000 | 3.155 | 0.512 | 6.970 | 19 | 11110001 |
| 145 | 8.64 | 0.2075 | -0.0210 | 2.3100 | 0.455 | 3.155 | 0.512 | 6.995 | 23 | 11110001 |
| 146 | 8.70 | 0.1895 | -0.0223 | 2.2900 | 0.980 | 3.150 | 0.512 | 6.985 | 17 | 11110000 |
| 147 | 8.76 | 0.2028 | -0.0178 | 2.3175 | -0.260 | 3.180 | 0.512 | 6.990 | 14 | 11110000 |
| 148 | 8.82 | 0.2103 | -0.0210 | 2.3300 | -0.365 | 3.180 | 0.512 | 6.995 | 20 | 11110001 |
| 149 | 8.88 | 0.2073 | -0.0235 | 2.3400 | -0.295 | 3.190 | 0.512 | 6.990 | 19 | 11110001 |
| 150 | 8.94 | 0.2060 | -0.0273 | 2.3550 | -0.470 | 3.185 | 0.512 | 6.995 | 19 | 11110001 |
| 151 | 9.00 | 0.2058 | -0.0243 | 2.3750 | -0.460 | 3.195 | 0.512 | 6.995 | 19 | 11110001 |
| 152 | 9.06 | 0.1853 | -0.0243 | 2.3600 | -0.185 | 3.190 | 0.512 | 6.995 | 24 | 11110001 |
| 153 | 9.12 | 0.1928 | -0.0373 | 2.3350 | 0.160 | 3.180 | 0.512 | 7.000 | 27 | 11110001 |
| 154 | 9.18 | 0.1805 | -0.0320 | 2.2725 | 0.325 | 3.175 | 0.512 | 6.990 | 24 | 11110001 |
| 155 | 9.24 | 0.1828 | -0.0308 | 2.2625 | 0.630 | 3.140 | 0.512 | 6.995 | 23 | 11110001 |
| 156 | 9.30 | 0.1883 | -0.0310 | 2.2650 | 0.625 | 3.125 | 0.512 | 6.990 | 19 | 11110000 |
| 157 | 9.36 | 0.1903 | -0.0333 | 2.2650 | 0.095 | 3.130 | 0.512 | 6.995 | 22 | 11110000 |
| 158 | 9.42 | 0.1980 | -0.0328 | 2.2700 | -0.130 | 3.120 | 0.512 | 6.990 | 26 | 11110000 |
| 159 | 9.48 | 0.1890 | -0.0275 | 2.2250 | -0.015 | 3.130 | 0.512 | 6.985 | 25 | 11110001 |
| 160 | 9.54 | 0.1930 | -0.0365 | 2.2250 | 0.215 | 3.115 | 0.512 | 6.990 | 22 | 11110001 |
| 161 | 9.60 | 0.1998 | -0.0320 | 2.2225 | 0.340 | 3.090 | 0.512 | 6.990 | 18 | 11110001 |
| 162 | 9.66 | 0.2065 | -0.0310 | 2.2625 | 0.525 | 3.110 | 0.512 | 6.990 | 20 | 11110001 |
| 163 | 9.72 | 0.2073 | -0.0300 | 2.3125 | 0.420 | 3.110 | 0.512 | 6.995 | 19 | 11110000 |
| 164 | 9.78 | 0.2180 | -0.0200 | 2.3300 | 0.215 | 3.120 | 0.512 | 6.990 | 14 | 11110000 |
| 165 | 9.84 | 0.2208 | -0.0115 | 2.3950 | 0.080 | 3.120 | 0.512 | 6.990 | 21 | 11110001 |
| 166 | 9.90 | 0.1938 | -0.0130 | 2.3725 | -0.050 | 3.120 | 0.512 | 6.990 | 19 | 11110001 |
| 167 | 9.96 | 0.2130 | -0.0120 | 2.3500 | -0.250 | 3.125 | 0.512 | 6.995 | 18 | 11110001 |
| 168 | 10.02 | 0.2148 | -0.0083 | 2.3325 | 0.025 | 3.120 | 0.512 | 6.990 | 16 | 11110001 |
| 169 | 10.08 | 0.2248 | -0.0108 | 2.3125 | 0.300 | 3.130 | 0.512 | 6.995 | 16 | 11110001 |
| 170 | 10.14 | 0.2210 | -0.0218 | 2.3150 | 0.180 | 3.130 | 0.512 | 6.990 | 21 | 11110001 |
| 171 | 10.20 | 0.2008 | -0.0298 | 2.3150 | 0.310 | 3.130 | 0.512 | 6.995 | 21 | 11110001 |
| 172 | 10.26 | 0.1840 | -0.0283 | 2.3300 | 0.305 | 3.130 | 0.512 | 6.995 | 19 | 11110001 |
| 173 | 10.32 | 0.1890 | -0.0240 | 2.3225 | 0.135 | 3.140 | 0.512 | 6.985 | 16 | 11110101 |
| 174 | 10.38 | 0.1993 | -0.0258 | 2.3250 | -0.065 | 3.145 | 0.512 | 6.990 | 16 | 11110001 |
| 175 | 10.44 | 0.1940 | -0.0323 | 2.3175 | -0.140 | 3.150 | 0.512 | 6.985 | 18 | 11110001 |
| 176 | 10.50 | 0.1945 | -0.0280 | 2.3575 | -0.055 | 3.165 | 0.512 | 6.995 | 19 | 11110001 |
| 177 | 10.56 | 0.1923 | -0.0240 | 2.3525 | 0.110 | 3.175 | 0.512 | 6.995 | 21 | 11110001 |
| 178 | 10.62 | 0.2023 | -0.0313 | 2.3525 | 0.275 | 3.190 | 0.512 | 6.995 | 19 | 11110001 |
| 179 | 10.68 | 0.2028 | -0.0303 | 2.3225 | 0.365 | 3.170 | 0.512 | 7.000 | 22 | 11110001 |
| 180 | 10.74 | 0.2005 | -0.0308 | 2.2825 | 0.460 | 3.170 | 0.512 | 6.990 | 24 | 11110001 |
| 181 | 10.80 | 0.1890 | -0.0280 | 2.2425 | 0.565 | 3.190 | 0.512 | 6.990 | 20 | 11110001 |
| 182 | 10.86 | 0.1858 | -0.0320 | 2.2650 | 0.275 | 3.170 | 0.512 | 6.990 | 15 | 11110000 |
| 183 | 10.92 | 0.1988 | -0.0230 | 2.2850 | -0.110 | 3.165 | 0.512 | 6.995 | 16 | 11110000 |
| 184 | 10.98 | 0.2100 | -0.0228 | 2.2875 | -0.375 | 3.170 | 0.512 | 6.990 | 16 | 11110001 |
| 185 | 11.04 | 0.2130 | -0.0195 | 2.3275 | -0.580 | 3.155 | 0.512 | 7.000 | 21 | 11110001 |
| 186 | 11.10 | 0.2088 | -0.0248 | 2.3350 | -0.480 | 3.180 | 0.512 | 6.990 | 18 | 11110001 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 187 | 11.16 | 0.2075 | -0.0260 | 2.3600 | -0.075 | 3.165 | 0.512 | 6.995 | 19 | 11110001 |
| 188 | 11.22 | 0.2078 | -0.0245 | 2.3700 | 0.165 | 3.150 | 0.512 | 6.995 | 19 | 11110001 |
| 189 | 11.28 | 0.2103 | -0.0208 | 2.3875 | 0.455 | 3.160 | 0.512 | 6.995 | 19 | 11110001 |
| 190 | 11.34 | 0.2178 | -0.0223 | 2.3675 | 0.940 | 3.140 | 0.512 | 6.985 | 20 | 11110000 |
| 191 | 11.40 | 0.2013 | -0.0300 | 2.3525 | 0.695 | 3.160 | 0.512 | 6.985 | 21 | 11110000 |
| 192 | 11.46 | 0.2018 | -0.0223 | 2.3375 | 0.275 | 3.165 | 0.512 | 6.990 | 17 | 11110001 |
| 193 | 11.52 | 0.2083 | -0.0265 | 2.3150 | -0.075 | 3.170 | 0.512 | 6.995 | 19 | 11110001 |
| 194 | 11.58 | 0.2048 | -0.0250 | 2.2850 | -0.215 | 3.180 | 0.512 | 6.990 | 22 | 11110001 |
| 195 | 11.64 | 0.1990 | -0.0305 | 2.2475 | -0.180 | 3.185 | 0.512 | 6.985 | 23 | 11110001 |
| 196 | 11.70 | 0.1980 | -0.0333 | 2.2125 | -0.145 | 3.180 | 0.512 | 6.995 | 20 | 11110001 |
| 197 | 11.76 | 0.1890 | -0.0295 | 2.1800 | -0.055 | 3.205 | 0.512 | 6.990 | 20 | 11110001 |
| 198 | 11.82 | 0.1950 | -0.0290 | 2.1900 | 0.085 | 3.185 | 0.512 | 6.980 | 17 | 11110001 |
| 199 | 11.88 | 0.1940 | -0.0345 | 2.2200 | 0.240 | 3.180 | 0.512 | 7.000 | 17 | 11110001 |
| 200 | 11.94 | 0.1925 | -0.0368 | 2.2600 | 0.160 | 3.180 | 0.512 | 6.990 | 18 | 11110001 |
| 201 | 12.00 | 0.1993 | -0.0350 | 2.2775 | 0.010 | 3.200 | 0.512 | 7.000 | 19 | 11110001 |
| 202 | 12.06 | 0.2015 | -0.0310 | 2.2950 | 0.010 | 3.210 | 0.512 | 6.995 | 19 | 11110001 |
| 203 | 12.12 | 0.2003 | -0.0323 | 2.3300 | 0.290 | 3.225 | 0.512 | 6.995 | 16 | 11110001 |
| 204 | 12.18 | 0.1918 | -0.0288 | 2.3975 | 0.500 | 3.220 | 0.512 | 6.990 | 17 | 11110001 |
| 205 | 12.24 | 0.2065 | -0.0215 | 2.4525 | 0.415 | 3.225 | 0.512 | 6.970 | 16 | 11110001 |
| 206 | 12.30 | 0.2153 | -0.0125 | 2.4975 | 0.705 | 3.225 | 0.512 | 6.990 | 17 | 11110000 |
| 207 | 12.36 | 0.2113 | -0.0140 | 2.5225 | 0.575 | 3.230 | 0.512 | 6.990 | 18 | 11110000 |
| 208 | 12.42 | 0.2085 | -0.0148 | 2.5225 | 0.160 | 3.225 | 0.512 | 6.990 | 13 | 11110000 |
| 209 | 12.48 | 0.2123 | -0.0053 | 2.5325 | -0.170 | 3.215 | 0.512 | 6.990 | 14 | 11110000 |
| 210 | 12.54 | 0.2220 | -0.0080 | 2.5300 | -0.320 | 3.215 | 0.512 | 6.985 | 13 | 11110001 |
| 211 | 12.60 | 0.2413 | 0.0003 | 2.5175 | -0.230 | 3.205 | 0.512 | 6.990 | 10 | 11110001 |
| 212 | 12.66 | 0.2560 | -0.0125 | 2.5225 | -0.130 | 3.210 | 0.512 | 6.995 | 11 | 11110001 |
| 213 | 12.72 | 0.2305 | -0.0028 | 2.5300 | 0.050 | 3.210 | 0.512 | 7.000 | 15 | 11110001 |
| 214 | 12.78 | 0.2030 | -0.0008 | 2.5175 | 0.020 | 3.200 | 0.512 | 6.990 | 14 | 11110001 |
| 215 | 12.84 | 0.2010 | -0.0145 | 2.5100 | 0.025 | 3.190 | 0.512 | 6.995 | 15 | 11110001 |
| 216 | 12.90 | 0.2100 | -0.0070 | 2.4675 | 0.170 | 3.175 | 0.512 | 7.005 | 15 | 11110001 |
| 217 | 12.96 | 0.2148 | -0.0068 | 2.4425 | 0.335 | 3.180 | 0.512 | 6.990 | 15 | 11110001 |
| 218 | 13.02 | 0.2148 | -0.0060 | 2.3975 | 0.220 | 3.185 | 0.512 | 6.995 | 14 | 11110001 |
| 219 | 13.08 | 0.2175 | -0.0198 | 2.3575 | 0.110 | 3.210 | 0.512 | 6.995 | 12 | 11110001 |
| 220 | 13.14 | 0.2055 | -0.0303 | 2.3175 | 0.080 | 3.215 | 0.512 | 7.005 | 13 | 11110001 |
| 221 | 13.20 | 0.1815 | -0.0355 | 2.2975 | 0.075 | 3.190 | 0.512 | 6.990 | 16 | 11110001 |
| 222 | 13.26 | 0.1845 | -0.0340 | 2.3150 | 0.170 | 3.170 | 0.512 | 6.990 | 15 | 11110001 |
| 223 | 13.32 | 0.2030 | -0.0323 | 2.3175 | 0.195 | 3.165 | 0.512 | 6.985 | 17 | 11110001 |
| 224 | 13.38 | 0.2133 | -0.0303 | 2.3025 | 0.135 | 3.165 | 0.512 | 6.990 | 21 | 11110001 |
| 225 | 13.44 | 0.2055 | -0.0318 | 2.2850 | 0.300 | 3.165 | 0.512 | 6.995 | 22 | 11110001 |
| 226 | 13.50 | 0.2060 | -0.0343 | 2.2900 | 0.225 | 3.160 | 0.512 | 6.985 | 16 | 11110101 |
| 227 | 13.56 | 0.2078 | -0.0333 | 2.3550 | -0.080 | 3.155 | 0.512 | 6.995 | 19 | 11110001 |
| 228 | 13.62 | 0.2145 | -0.0243 | 2.3625 | -0.170 | 3.155 | 0.512 | 6.995 | 24 | 11110001 |
| 229 | 13.68 | 0.2180 | -0.0253 | 2.3575 | -0.080 | 3.155 | 0.512 | 6.975 | 23 | 11110001 |
| 230 | 13.74 | 0.2113 | -0.0210 | 2.3800 | 0.105 | 3.155 | 0.512 | 6.990 | 27 | 11110001 |
| 231 | 13.80 | 0.2048 | -0.0130 | 2.3650 | 0.360 | 3.155 | 0.512 | 6.995 | 27 | 11110001 |
| 232 | 13.86 | 0.2125 | -0.0200 | 2.3400 | 0.535 | 3.155 | 0.512 | 6.990 | 25 | 11110001 |
| 233 | 13.92 | 0.2123 | -0.0190 | 2.3225 | 0.470 | 3.160 | 0.512 | 6.985 | 25 | 11110001 |
| 234 | 13.98 | 0.2040 | -0.0315 | 2.2900 | 0.335 | 3.165 | 0.512 | 6.985 | 21 | 11110000 |
| 235 | 14.04 | 0.2040 | -0.0253 | 2.2800 | 0.030 | 3.165 | 0.512 | 7.000 | 20 | 11110001 |
| 236 | 14.10 | 0.2098 | -0.0240 | 2.2850 | 0.030 | 3.170 | 0.512 | 6.995 | 25 | 11110001 |
| 237 | 14.16 | 0.2030 | -0.0300 | 2.2825 | 0.430 | 3.175 | 0.512 | 6.990 | 27 | 11110001 |
| 238 | 14.22 | 0.2010 | -0.0340 | 2.2625 | 1.020 | 3.180 | 0.512 | 6.985 | 24 | 11110000 |
| 239 | 14.28 | 0.2038 | -0.0373 | 2.1950 | 0.400 | 3.180 | 0.512 | 6.990 | 19 | 11110000 |

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|---|---|---|---|---|---|---|---|---|---|---|
| 240 | 14.34 | 0.1978 | -0.0353 | 2.2600 | -0.835 | 3.175 | 0.512 | 6.990 | 25 | 11110001 |
| 241 | 14.40 | 0.1993 | -0.0300 | 2.2800 | -0.875 | 3.180 | 0.512 | 6.970 | 23 | 11110001 |
| 242 | 14.46 | 0.2125 | -0.0248 | 2.3350 | -0.570 | 3.185 | 0.512 | 6.980 | 30 | 11110001 |
| 243 | 14.52 | 0.2133 | -0.0228 | 2.3500 | -0.175 | 3.190 | 0.512 | 6.995 | 31 | 11110001 |
| 244 | 14.58 | 0.2113 | -0.0160 | 2.3575 | 0.115 | 3.175 | 0.512 | 6.990 | 34 | 11110001 |
| 245 | 14.64 | 0.2010 | -0.0220 | 2.3200 | 0.305 | 3.200 | 0.512 | 6.990 | 29 | 11110001 |
| 246 | 14.70 | 0.2063 | -0.0260 | 2.3275 | 0.595 | 3.205 | 0.512 | 6.990 | 29 | 11110001 |
| 247 | 14.76 | 0.2100 | -0.0253 | 2.3275 | 0.155 | 3.210 | 0.512 | 6.995 | 23 | 11110000 |
| 248 | 14.82 | 0.2113 | -0.0240 | 2.3550 | -0.210 | 3.205 | 0.512 | 6.990 | 29 | 11110001 |
| 249 | 14.88 | 0.2048 | -0.0310 | 2.4025 | -0.095 | 3.200 | 0.512 | 6.990 | 26 | 11110001 |
| 250 | 14.94 | 0.2115 | -0.0285 | 2.4900 | 0.180 | 3.200 | 0.512 | 6.990 | 35 | 11110001 |
| 251 | 15.00 | 0.2218 | -0.0155 | 2.4900 | 0.835 | 3.215 | 0.512 | 6.990 | 34 | 11110000 |
| 252 | 15.06 | 0.2218 | -0.0200 | 2.4625 | 1.505 | 3.215 | 0.512 | 6.970 | 28 | 11110000 |
| 253 | 15.12 | 0.2428 | -0.0053 | 2.4575 | 0.230 | 3.210 | 0.512 | 6.985 | 27 | 11110001 |
| 254 | 15.18 | 0.2325 | -0.0098 | 2.4350 | -0.330 | 3.220 | 0.512 | 6.990 | 30 | 11110001 |
| 255 | 15.24 | 0.2360 | -0.0038 | 2.3850 | -0.510 | 3.230 | 0.512 | 6.985 | 22 | 11110101 |
| 256 | 15.30 | 0.2565 | -0.0100 | 2.3650 | -0.280 | 3.225 | 0.512 | 6.990 | 25 | 11110001 |
| 257 | 15.36 | 0.2420 | -0.0015 | 2.3525 | 0.045 | 3.220 | 0.512 | 6.995 | 27 | 11110001 |
| 258 | 15.42 | 0.2508 | -0.0023 | 2.3475 | 0.500 | 3.225 | 0.512 | 6.985 | 28 | 11110001 |
| 259 | 15.48 | 0.2353 | -0.0128 | 2.3575 | 0.910 | 3.220 | 0.512 | 6.985 | 30 | 11110000 |
| 260 | 15.54 | 0.2148 | -0.0245 | 2.3375 | 0.640 | 3.215 | 0.512 | 6.985 | 31 | 11110000 |
| 261 | 15.60 | 0.2105 | -0.0283 | 2.2850 | 0.150 | 3.205 | 0.512 | 6.995 | 29 | 11110001 |
| 262 | 15.66 | 0.2145 | -0.0275 | 2.2600 | -0.370 | 3.205 | 0.512 | 6.990 | 30 | 11110001 |
| 263 | 15.72 | 0.2185 | -0.0295 | 2.2250 | -0.385 | 3.195 | 0.512 | 6.995 | 34 | 11110001 |
| 264 | 15.78 | 0.2073 | -0.0313 | 2.1900 | 0.190 | 3.165 | 0.512 | 6.990 | 36 | 11110001 |
| 265 | 15.84 | 0.2118 | -0.0315 | 2.1525 | 0.360 | 3.185 | 0.512 | 6.990 | 33 | 11110001 |
| 266 | 15.90 | 0.1945 | -0.0388 | 2.1500 | 0.120 | 3.190 | 0.512 | 6.990 | 33 | 11110001 |
| 267 | 15.96 | 0.1893 | -0.0420 | 2.1275 | -0.680 | 3.190 | 0.512 | 6.990 | 29 | 11110001 |
| 268 | 16.02 | 0.1883 | -0.0418 | 2.1300 | -0.830 | 3.190 | 0.512 | 6.985 | 20 | 11110101 |
| 269 | 16.08 | 0.1980 | -0.0410 | 2.1800 | -0.460 | 3.185 | 0.512 | 6.995 | 25 | 11110001 |
| 270 | 16.14 | 0.1995 | -0.0418 | 2.1825 | -0.165 | 3.190 | 0.512 | 6.990 | 31 | 11110001 |
| 271 | 16.20 | 0.1920 | -0.0418 | 2.1650 | 0.095 | 3.195 | 0.512 | 6.990 | 31 | 11110001 |
| 272 | 16.26 | 0.1895 | -0.0435 | 2.1825 | 0.325 | 3.200 | 0.512 | 6.990 | 30 | 11110001 |
| 273 | 16.32 | 0.1820 | -0.0430 | 2.2075 | 0.140 | 3.200 | 0.512 | 6.990 | 32 | 11110001 |
| 274 | 16.38 | 0.1865 | -0.0435 | 2.2075 | 0.045 | 3.200 | 0.512 | 6.995 | 23 | 11110001 |
| 275 | 16.44 | 0.1638 | -0.0348 | 2.2150 | 0.130 | 3.210 | 0.512 | 6.990 | 24 | 11110001 |
| 276 | 16.50 | 0.1728 | -0.0393 | 2.2250 | 0.295 | 3.220 | 0.512 | 6.985 | 24 | 11110001 |
| 277 | 16.56 | 0.1693 | -0.0340 | 2.2375 | 0.485 | 3.210 | 0.512 | 6.985 | 24 | 11110001 |
| 278 | 16.62 | 0.1765 | -0.0340 | 2.2400 | 0.470 | 3.220 | 0.512 | 6.990 | 24 | 11110001 |
| 279 | 16.68 | 0.1943 | -0.0365 | 2.2200 | 0.555 | 3.240 | 0.512 | 6.990 | 20 | 11110001 |
| 280 | 16.74 | 0.1950 | -0.0368 | 2.2100 | 0.840 | 3.235 | 0.512 | 6.995 | 21 | 11110000 |
| 281 | 16.80 | 0.1905 | -0.0385 | 2.2125 | 0.320 | 3.200 | 0.512 | 6.990 | 19 | 11110001 |
| 282 | 16.86 | 0.1843 | -0.0285 | 2.2125 | -0.040 | 3.215 | 0.512 | 6.990 | 17 | 11110001 |
| 283 | 16.92 | 0.1928 | -0.0348 | 2.2000 | 0.075 | 3.205 | 0.512 | 6.995 | 16 | 11110001 |
| 284 | 16.98 | 0.1803 | -0.0315 | 2.1975 | 0.180 | 3.205 | 0.512 | 6.985 | 20 | 11110001 |
| 285 | 17.04 | 0.1770 | -0.0368 | 2.1875 | 0.140 | 3.200 | 0.512 | 6.995 | 16 | 11110001 |
| 286 | 17.10 | 0.1860 | -0.0375 | 2.1950 | 0.060 | 3.200 | 0.512 | 6.990 | 15 | 11110001 |
| 287 | 17.16 | 0.1733 | -0.0340 | 2.2100 | 0.130 | 3.185 | 0.512 | 6.990 | 15 | 11110001 |
| 288 | 17.22 | 0.1835 | -0.0395 | 2.2125 | 0.170 | 3.190 | 0.512 | 6.990 | 12 | 11110001 |
| 289 | 17.28 | 0.1793 | -0.0378 | 2.2150 | 0.115 | 3.195 | 0.512 | 6.990 | 11 | 11110001 |
| 290 | 17.34 | 0.1755 | -0.0335 | 2.2450 | 0.120 | 3.195 | 0.512 | 6.995 | 9 | 11110001 |
| | | TRANSDUCER OUTPUT | | | | | | | | |
| | Chan. # | 1 | 2 | 5 | 6 | 7 | 8 | 9 | 19 | 20 |

| | | TRANSDUCER OUTPUT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Channel # | 1 | 2 | 5 | 6 | 7 | 8 | 9 | 19 | 20 |
| Data | Time | Horizontal Draft | Vertical Draft | Depth | Heart Rate | Respiration Rate | Body Temp. | Battery | Ground Speed | Step Rate (Digital) |
| Points | Csec | V | V | V | P | P | V | V | P | P |
| 291 | 17.40 | 0.1815 | -0.0353 | 2.235 | 0.285 | 3.195 | 0.512 | 6.995 | 11 | 11110001 |
| 292 | 17.46 | 0.1830 | -0.0363 | 2.255 | 0.475 | 3.205 | 0.512 | 6.99 | 16 | 11110001 |
| 293 | 17.52 | 0.1843 | -0.0365 | 2.24 | 0.05 | 3.215 | 0.512 | 6.995 | 18 | 11110001 |
| 294 | 17.58 | 0.1888 | -0.0363 | 2.2525 | -0.165 | 3.21 | 0.512 | 6.995 | 20 | 11110001 |
| 295 | 17.64 | 0.1918 | -0.0378 | 2.2425 | -0.125 | 3.245 | 0.512 | 6.975 | 13 | 11110001 |
| 296 | 17.70 | 0.1878 | -0.0333 | 2.2425 | -0.005 | 3.215 | 0.512 | 6.99 | 15 | 11110001 |
| 297 | 17.76 | 0.1970 | -0.0335 | 2.2475 | 0.175 | 3.205 | 0.512 | 6.995 | 13 | 11110001 |
| 298 | 17.82 | 0.1905 | -0.0313 | 2.25 | 0.185 | 3.21 | 0.512 | 6.99 | 18 | 11110001 |
| 299 | 17.88 | 0.1935 | -0.0330 | 2.2425 | 0.135 | 3.22 | 0.512 | 6.995 | 17 | 11110001 |
| 300 | 17.94 | 0.1910 | -0.0378 | 2.245 | 0.16 | 3.25 | 0.512 | 6.99 | 14 | 11110001 |
| 301 | 18.00 | 0.1853 | -0.0353 | 2.26 | 0.165 | 3.25 | 0.512 | 6.995 | 15 | 11110001 |
| 302 | 18.06 | 0.1850 | -0.0360 | 2.26 | 0.03 | 3.25 | 0.512 | 6.995 | 18 | 11110001 |
| 303 | 18.12 | 0.1833 | -0.0358 | 2.2575 | -0.08 | 3.245 | 0.512 | 6.995 | 19 | 11110001 |
| 304 | 18.18 | 0.1853 | -0.0383 | 2.2625 | -0.06 | 3.175 | 0.512 | 6.995 | 13 | 11110001 |
| 305 | 18.24 | 0.1840 | -0.0370 | 2.2625 | 0.025 | 3.21 | 0.512 | 6.995 | 16 | 11110001 |
| 306 | 18.30 | 0.1853 | -0.0363 | 2.2625 | 0.095 | 3.165 | 0.512 | 6.985 | 13 | 11110001 |
| 307 | 18.36 | 0.1845 | -0.0365 | 2.26 | 0.155 | 3.175 | 0.512 | 6.99 | 17 | 11110001 |
| 308 | 18.42 | 0.1805 | -0.0395 | 2.255 | 0.18 | 3.17 | 0.512 | 6.995 | 12 | 11110001 |
| 309 | 18.48 | 0.1793 | -0.0425 | 2.255 | 0.2 | 3.155 | 0.512 | 6.995 | 16 | 11110001 |
| 310 | 18.54 | 0.1778 | -0.0435 | 2.2575 | 0.18 | 3.16 | 0.512 | 6.995 | 13 | 11110001 |
| 311 | 18.60 | 0.1780 | -0.0445 | 2.2625 | 0.16 | 3.15 | 0.512 | 6.975 | 15 | 11110001 |
| 312 | 18.66 | 0.1780 | -0.0445 | 2.255 | 0.15 | 3.15 | 0.512 | 6.985 | 16 | 11110001 |
| 313 | 18.72 | 0.1785 | -0.0430 | 2.255 | 0.145 | 3.14 | 0.512 | 6.99 | 17 | 11110001 |
| 314 | 18.78 | 0.1790 | -0.0433 | 2.255 | 0.225 | 3.15 | 0.512 | 6.995 | 14 | 11110001 |
| | Average | 0.1823 | -0.0277 | 2.3032 | 0.1249 | 3.152 | 0.5120 | 6.9918 | 22.1401 | |
| | Minimum | 0.1633 | -0.0445 | 2.1275 | -0.875 | 3.045 | 0.512 | 6.97 | 9 | |
| | Maximum | 0.2530 | 0.0003 | 2.5325 | 1.5050 | 3.2500 | 0.5120 | 7.0050 | 36.0000 | |
| | Std Dev | 0.0241 | 0.0095 | 0.0811 | 0.3507 | 0.0472 | 0.0000 | 0.0057 | 5.3634 | |

# APPENDIX I

# APPENDIX I

**Questionnaire on Draft Animal Power**

**(DAP) Energy Utilization**
**in Small-Holder Agriculture**
**in Kenya**

**Information about the respondent**

Respondent's name ________________________________

Province ____________________________________

District __________________ Division __________________
Location ______________ Sub-location ___________

**Information about the enumerator**

Enumerator's name ________________________________
Date of interview ____________________________________
Place of interview __________________________________
[*eg Respondent's house, farm, field*]
Time interview began ____________ am/pm *[check one]*
Time interview ended ____________ am/pm *[check one]*
*Comments (What was the respondent doing on your arrival?)*

______________________________________________

______________________________________________

**Terms of the interview**

***This questionnaire will be administered on a voluntary basis. The respondents will not be coerced to provide any of the information being asked for. The data collected will be used to develop programs for improving Draft Animal Power for small-holder farmers. Respondents will be clearly explained this purpose which is intended to help them in their mechanization needs. The researcher takes full responsibility on the data received and will not release the same to a third party without the respondents' permission.***

*The respondent's name, address and other personal/family data will be used only for identifying the source of the data. The family structure data, household income/expenditure data will be used with confidentiality.*

**Farm Map**

*Make a sketch of all the fields that were worked on during the "short" and "long" rains last year.*

**INSTRUCTIONS:**
*(To enumerator)*
*First* **draw the farmers house and reference marks like a major road, mountain, river.** *Secondly (a)* **draw all the fields that the family has.** *(b)* **include all the fields that the family rented or borrowed during the past year.** *Thirdly* **number all the fields.** *Fourthly* **write the size of each field in the sketch.** *Then* **list the principal crops planted during short and long rains in the space provided.** *Fifth* **if the family has other land located elsewhere, ask the farmer its location and make notes about it.**

*(For enumerator to the farmer)*

We would like to make simple sketches of your farm showing where the various fields you worked on last year were located for each of the two seasons.

***Farm Sketch:***

*North*

| | Field Number | Main Crops | | | |
|---|---|---|---|---|---|
| **Short Rains:** | | | | | |
| | 1. | ______ | ______ | ______ | ______ |
| | 2. | ______ | ______ | ______ | ______ |
| | 3. | ______ | ______ | ______ | ______ |
| | 4. | ______ | ______ | ______ | ______ |
| | 5. | ______ | ______ | ______ | ______ |

| | Field Number | Main Crops | | | |
|---|---|---|---|---|---|
| **Long Rains:** | | | | | |
| | 1. | ______ | ______ | ______ | ______ |
| | 2. | ______ | ______ | ______ | ______ |
| | 3. | ______ | ______ | ______ | ______ |
| | 4. | ______ | ______ | ______ | ______ |
| | 5. | ______ | ______ | ______ | ______ |

| | Field Number | Location | Terms (eg Rented, Borrowed) |
|---|---|---|---|
| **Other Land:** | | | |
| | 1. | ______ | ______ |
| | 2. | ______ | ______ |
| | 3. | ______ | ______ |
| | 4. | ______ | ______ |

**CHECK LIST:**

1) Did you include the farmer's house and major reference marks?
2) Did you include all the fields?
3) Did you number all the fields.
4) Did you indicate all the principal crops grown in short and long rains?
5) Did you make notes on the location of fields away from the "homestead"?

*Block I*

## I. Resources Inventory

[1.1] What is the size of your farm? ________Acres
[1.2] How many parcels of land did you work on (a) last season? (short rains) ______
[1.3] (b) the preceding season (long rains) ______

Table 1: **Field sizes and characteristics.**

| | Field No. | Rains (Season) | 0 own<br>1 rented<br>2 borrowed<br>3 communal | Size (Acres) | 1 flat<br>2 rolling<br>3 steep<br>4 very steep | 1 easy to work (soft)<br>2 medium soft<br>3 hard<br>4 very hard | Clearing<br>1 well cleared<br>2 trees/stumps<br>3 poorly cleared |
|---|---|---|---|---|---|---|---|
| | | | TENURE | AREA | SLOPE | SOIL | CLEAR |
| [1.4] | 1 | Short | | | | | |
| | | Long | | | | | |
| [1.5] | 2 | Short | | | | | |
| | | Long | | | | | |
| [1.6] | 3 | Short | | | | | |
| | | Long | | | | | |
| [1.7] | 4 | Short | | | | | |
| | | Long | | | | | |
| [1.8] | 5 | Short | | | | | |
| | | Long | | | | | |
| Total acreage | | | | | | | |

**Income and Draft Animal Power Costs**

**Production and Sales**

*We would like to ask some questions related to the crops grown and sold from the use of draft oxen.*

**Table 2: Short Rains Season**

| Crops Grown | | Area | Total Production | | Sales | | Price | |
|---|---|---|---|---|---|---|---|---|
| Field | Name of Crop | ACRES | UNITS | QTY | UNITS | QTY | UNITS | Ksh |
| C1 | | | | | | | | |
| C2 | | | | | | | | |
| C3 | | | | | | | | |
| C4 | | | | | | | | |
| C5 | | | | | | | | |
| [1.9] Totals | | | | | | | | |

**Table 3: Long Rains Season**

| Crops Grown | | Area | Total Production | | Sales | | Price | |
|---|---|---|---|---|---|---|---|---|
| Field | Name of Crop | ACRES | UNITS | QTY | UNITS | QTY | UNITS | Ksh |
| C1 | | | | | | | | |
| C2 | | | | | | | | |
| C3 | | | | | | | | |
| C4 | | | | | | | | |
| C5 | | | | | | | | |
| [1.9] Totals | | | | | | | | |

*Block 2*

**Prime Mover/Equipment.**

**Hand Tools:** How many of the following hand tools do you have?

| | | Number | | Other hand tools: Name | Number |
|---|---|---|---|---|---|
| [2.1] | Hand hoe | ______ | | | |
| [2.2] | Digging fork | ______ | [2.5] | ______________ | ______ |
| [2.3] | Machetes | ______ | [2.6] | ______________ | ______ |
| [2.4] | Axe | ______ | [2.7] | ______________ | ______ |

**Draft Animal Power**

[2.8] Do you own trained draft oxen? ______ [0 = no; 1 = yes]

[2.9] If yes, how many? ________

How many of the following DAP implements do you own?

| | | Number | | Other DAP implements: Name | Number |
|---|---|---|---|---|---|
| [2.10] | Moldboard plow | ______ | | | |
| [2.11] | Harrow | ______ | [2.14] | ____________ | ______ |
| [2.12] | Planter/Seeder | ______ | [2.15] | ____________ | ______ |
| [2.13] | Trailer/Cart | ______ | [2.16] | ____________ | ______ |

[2.17] What is the main activity for which you use the draft oxen?
***Enumerator:*** *Check one main activity.*
a) Plowing ______
b) Weeding ______
c) Haulage ______

[2.18] When do you start your land preparation for the following season?

***Enumerator:*** *Check one response.*
a) Soon after harvest ______
b) Just before rains come ______
c) After rains come ______
d) Other (*specify*) ______

[2.19] Why do you start at that time? ______

[2.20] Do you own a tractor? ______ [ 0 = no; 1 = yes]
[2.21] If yes, what is the size of the tractor? ______ HP.

*Block 3.*

**Draft Animal Power Operation**

[3.1] How many oxen do you use for plowing? ______

[3.2] If you use more than two, why?
***Enumerator:*** *Check items that apply.*
a) Oxen too weak ______
b) Ground too hard ______
c) Training other team ______
d) All oxen available ______
e) Other reason *(Specify)* ______

[3.3] How many persons operate the oxen team?______
[3.4] Who is the principal ox-team operator?
a) Self ____
b) Wife/Husband ____
c) Employee ____
d) Son/daughter ____

**Table 4: Use of draft oxen**

| Activities | Rains (Season) | Field Number | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| [3.5] How many days did it take to plow the field. | Short | | | | | |
| | Long | | | | | |
| [3.6] How many hours per day did the animals work when plowing? | Short | | | | | |
| | Long | | | | | |
| [3.7] How many days did it take to weed with oxen? | Short | | | | | |
| | Long | | | | | |
| [3.8] How many hours per day did the animals work during weeding? | Short | | | | | |
| | Long | | | | | |

[3.9] What other work did your oxen do on your farm in the two seasons?
*List the types of work:*

Short Rains Season — Time Used

| Type of Work | Days | Hours/day |
|---|---|---|
| a) ______ | ____ | ______ |
| b) ______ | ____ | ______ |
| c) ______ | ____ | ______ |

Long Rains Season — Time Used

| Type of Work | Days | Hours/day |
|---|---|---|
| a) ______ | ____ | ______ |
| b) ______ | ____ | ______ |
| c) ______ | ____ | ______ |

**[3.10]** Approximately how many days per season do you use the oxen for all work? _____ days
**[3.11]** About how many days do you use the oxen in-between the seasons? _____ days
**[3.12]** List three main activities that you use the oxen for in-between the seasons?
a) ______________________________
b) ______________________________
c) ______________________________
**[3.13]** What are the two most **ENERGY or POWER** demanding activities on your farm?
a) ______________________________
b) ______________________________

**[3.14]** During the farming season what activity takes up the greatest amount of time? ***(Enumerator:*** *not necessarily using oxen)*

*Block 4*

## II. Utilization of Draft Oxen

**Hiring Out Oxen**

**[4.1]** Did you hire out your oxen to other farmers last season? _______ [0 = no; 1 = yes]
**[4.2]** If yes, give the two most important reasons why you hired out your oxen.
a) ____________________________________________
b) ____________________________________________
**[4.3]** If you hired oxen out for plowing:
*Fill in the hiring details for each season below:*

| **Short Rains** | | | **Long Rains** | | |
|---|---|---|---|---|---|
| Number of days | Hours per day | Charges Ksh/acre | Number of days | Hours per day | Charges Ksh/acre |
| | | | | | |
| | | | | | |

**[4.4]** If you hired oxen out for haulage:
*Fill in the hiring out details for each season below:*

| **Short Rains** | | | **Long Rains** | | |
|---|---|---|---|---|---|
| Number of days | Hours per day | Charges Ksh/hr | Number of days | Hours per day | Charges Ksh/hr |
| | | | | | |
| | | | | | |

**[4.5]** If you hired out oxen for other activities:

| | Short Rains | | | Long Rains | | |
|---|---|---|---|---|---|---|
| *List activities below* | Number of days | Hours per day | Charges Ksh/hr | Number of days | Hours per day | Charges Ksh |
| a)________________ | | | | | | |
| b)________________ | | | | | | |
| c)________________ | | | | | | |

*Block 5.*

## III. Feed Sources & Usage

**[5.1]** What was your primary feed source?
a) Communal grazing ________
b) Own grazing field ________
c) Bought feed ________
d) Any other *(Specify)* ________________________________

**[5.2]** Did your oxen get enough feed from your farm? _______ [0 = no; 1 = yes]
**[5.3]** What was the acreage of your grazing land? _______ acres
**[5.4]** If answer to Q 5.2 is No did you use extra feed? ______ [0 = no; 1 = yes]
**[5.5]** If yes to Q 5.4, which extra feed did you use?

| Extra feed used | Source of feed | [2 = bought; 3 = free] |
|---|---|---|
| a) Hay | _____ | _______ |
| b) Silage (green fodder) | _____ | _______ |
| c) Farm waste | _____ | _______ |
| d) Concentrates | _____ | _______ |
| e) Any other (*Specify)* _____________ | | |

*Block 6.*

## IV. Renting of Draft Animals

**Renting oxen from other farmers.**
**[6.1]** Did you hire oxen from other farmers? _______ [0 = no; 1 = yes]
***Enumerator:*** *If answer is No go to question 6.11.*
**[6.2]** Which season did you hire other farmer's oxen? _______ [2 = short rains; 3 = long rains]
**[6.3]** For what activity did you hire the oxen?
a) Plowing ______
b) Haulage ______
c) Any other (*Specify)* ________________________________
**[6.4]** If hired for plowing, what acreage were they used for? _______ acres.
**[6.5]** If hired for haulage, how many hours were they used? _______ hours.
**[6.6]** If hired for other activity, how many hours were they used for? ______ hours.
**[6.7]** How was the cost computed? *Choose one.*
a) Per acre _____
b) Per hour _____
c) Per day _____
**[6.8]** What was the cost of plowing per acre? Ksh. _______ per acre
**[6.9]** What was the cost of haulage per hour? Ksh. _______ per hour.
**[6.10]** What was the unit charge for other activity? Ksh _____ per _____

**Farmers that did not rent oxen from other farmers.**

[6.11] Why did you not hire oxen from other farmers?
a) Had own capacity _____
b) Not available _____
c) Expensive _____
d) Poor workmanship _____
e) Available too late _____
f) Any other reason (*Specify*) ______________________________

[6.12] What other options do you have for tillage?
a) Hire tractors _____
b) Family labor _____
c) Hired labor _____
d) Friends _____

[6.13] Did you borrow oxen from friends or relatives? _____ [0 = no; 1 = yes]

[6.14] Why did you borrow oxen from friends or relatives?
a) They offered other services _____
b) In return for favor given earlier. _____
c) Other reasons (*Specify*) ________________________________

*Block 7*

7. **Maintenance Costs of Draft Oxen**

[7.1] In which year did you start using draft oxen? 19 _____

[7.2] For how many years have you been using oxen ? _____ years.

[7.3] How did you acquire the initial draft oxen?
***Enumerator***: *Choose one from respondent.*
a) Purchased _____
b) Inherited from parents _____
c) Other source (*Specify*)________________________________

[7.4] If purchased the oxen, when did you do so? 19 ________

[7.5] What was the price per animal at that time? Ksh. _______

[7.6] Who trained the oxen team for you?
***Enumerator:*** *Choose one that applies.*
a) Self ______
b) Friends ______
c) Employee ______

[7.7] For how long do you expect to use a team of oxen before replacement? _____years.

[7.8] How much would you expect each ox to fetch in the market currently? Ksh. ______

[7.9] What method would you use to replace the oxen?
a) Buy trained ones. ______
b) Buy and train ______
c) Select from old stock and train ____________________________
d) How much would a trained ox cost? Ksh. ______

[7.10] If you choose to buy, how much would you expect to pay? Ksh. ______

[7.11] Did you incur any veterinary costs on the animals last year? ______ [0 = no; 1 = yes]

[7.12] If yes, how much? Ksh. _______

[7.13] Were there any other maintenance costs on your animals? (*Specify*).

| Other maintenance costs | How much |
|---|---|
| a) ___________________________ | Ksh.________ |
| b) ___________________________ | Ksh.________ |
| c) ___________________________ | Ksh.________ |
| d) ___________________________ | Ksh.________ |

[7.14] When did you acquire the oxen implements that you have and at what price?

| Implements | Year acquired | Price paid |
|---|---|---|
| a) Moldboard plow | 19 _____ | Ksh. ____ |

b) Harrow 19 _____ Ksh. ____
c) Planter/seeder 19 _____ Ksh. ____
d) Trailer/cart 19 _____ Ksh. ____

*Block 8*

**Future Plans**

**[8.1]** Are you meeting all your farm energy needs? ______ [ 0 = no; 1 = yes]
**[8.2]** What are the two major energy constraints areas on your farm?
a) Plowing _____
b) Weeding _____
c) Haulage _____
d) Harvesting _____
e) Any other *(Specify)*___________________________________
**[8.3]** What would be the best three options that you would consider to improve your energy needs?
a) Hire tractor _____
b) Buy more oxen _____
c) Grow more feed _____
d) Buy quality feed _____
e) Hire more labor _____
f) Buy ox-cart _____
g) Hire oxen _____

*Block 9*

**Credit**

**[9.1]** Have you ever obtained a loan for mechanization needs? ______ [0 = no; 1 = yes]
**[9.2]** If yes, which year did you get one? 19 ______
**[9.3]** How much was the loan? Ksh _________
**[9.4]** If no to question 9.1, would you consider taking a loan to meet any of your energy needs?
______ [ 0 = no ; 1 = yes]
**[9.5]** What would be your best option for a loan?
a) Agricultural Finance Corporation (AFC) ______
b) Bank ______
c) Friends ______
d) Relatives ______
f) Village money-lender ______
g) Other *(Specify)*___________________________________________
**[9.6]** What would you use as security for the loan?
a) Title deed ________
b) Daft oxen _________
c) Other property (*Specify*) _____________________________________

## V. STRUCTURE OF THE FAMILY

**[10.1]** How many people currently live in your house (home)? _______

**Table 5: Family Structure**

| # | Name | **Relation**<br>1 head 2 spouse<br>3 child 4 cousin<br>5 aunt/uncle<br>6 employee | **Gender**<br>1 M<br>2 F | highest level of schooling completed | Does he/she work on the farm?<br>0 = no<br>1 = yes |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |

**[10.2]** What is the current wage rate per day for the following tasks?
a) Weeding Ksh _______
b) Harvesting Ksh. _______
c) Plowing with oxen Ksh. _______
d) Any other task *(Specify)* Ksh. _______

**[10.3]** What is the draft animal operator's wage rate? Ksh. _______ per month.

## APPENDIX J

# APPENDIX J

Glossary of equations derived for the EUMDAP simulation model.

| Equation # in text | Source | Equation | Derivation of units | Units |
|---|---|---|---|---|
| 9 | ARC (1980) | $ME_m = F_q * ME$ | Fq is 2.5 % of body weight | Max. metabolizable energy (MJ/day) |
| 10 | ARC (1980) | $K_m = 0.019 * ME + 0.53$ | Derivation of Km | Energy utilization factor (decimal) |
| 11 | ARC (1980) | $NE_{mw} = ME_m * K_m$ | $K_m$ is a derived decimal value as shown above | Net energy for maintenance and work (MJ/day) |
| 12 | Brody (1964) | $BMR = \frac{70.5(W_t)^{0.73} * 4.184 * e^{-0.03Age}}{1000}$ | Original model was in kcal per day<br>1 kcal=4.184 kJ | Basal metabolic rate (MJ/day) |
| 13 | Derived | $NE_w = NE_{mw} - BMR$ | All values in MJ per day | Net energy for work (MJ/day) |
| 16 | ATM 440 | $TFC = \frac{S * W}{10}$ | $\left(\frac{ha}{hr}\right) = \left[\frac{km}{hr}\right]\left[m\right]\left[\frac{ha}{10,000m^2}\right]\left[\frac{1000m}{km}\right]$ | Theoretical field capacity (ha/hr) |
| 17 | ATM 440 | $T_t = \frac{1}{TFC}$ | $\left(\frac{hr}{ha}\right) = \left[\frac{hr}{ha}\right]$ | Theoretical field time (hr/ha) |
| 18 | ATM 440 | $T_e = \frac{100 * T_t}{k}$ | $\left(\frac{hr}{ha}\right) = \left(\frac{100}{\%}\right)\left(\frac{hr}{ha}\right)$ | Effective field time (hr/ha) |

| Equation # in text | Source | Equation | Derivation of units | Units |
|---|---|---|---|---|
| 19 | ATM 440 | $FE = \frac{T_t}{T_e - T_{los}}$ | $(dec) = \left[\frac{hr}{ha}\right]\left[\frac{ha}{hr}\right]$ | Field efficiency (decimal) |
| 20 | ATM 440 | $EFC = \frac{S * W * E}{10}$ | $\left(\frac{ha}{hr}\right) = \left[\frac{km}{hr}\right]\left[\frac{1000m}{km}\right]\left[\frac{m}{-}\right]\left[\frac{ha}{10,000m^2}\right] * dec$ | Effective field capacity (ha/hr) |
| 21 | Derived | $E_{total} = \frac{EFC * 10 * W * D * SSR * DapCap}{W}$ | $\left(\frac{MJ}{day}\right) = \left[\frac{ha}{hr}\right]\left[\frac{10000m^2}{ha}\right]\left[\frac{1 furrw}{m}\right]\left[\frac{m^2}{1 slice}\right]\left[\frac{kN}{m^2}\right]\left[\frac{hr}{day}\right]\left[\frac{MJ}{1000kJ}\right]$ | Total field energy (MJ/day) |
| 22 | Derived | $P = D * S$ | $(kW) = kN\left[\frac{m}{\sec}\right]$ | Implement draft power (kW) |
| 23 | Derived | $IE = \frac{P}{EFC}$ | $\left(\frac{kW - hr}{ha}\right) = kW\left[\frac{hr}{ha}\right]$ | Specific implement energy (kW-hr/ha) |
| 24 | Derived | $T_{FE} = Lnd * IE$ | $kW - hr = ha\left(\frac{kW - hr}{ha}\right)$ | Total field energy (kW-hr) |
| 25 | Derived | $TDF_w = \left(\frac{Lnd}{EFC * DapCap}\right)$ | $days = \left(\frac{ha * day}{ha * hr}\right)$ | Theoretical days in field (days) |
| 26 | Derived | $DAP_c = \frac{NE_w}{3.85}$ | $\left(\frac{hrs}{day}\right) = \left[\frac{MJ}{day}\right]\left[\frac{hr}{MJ}\right]$ | DAP capacity (hrs/day) at 3.85 MJ per day |

| Equation # in text | Source | Equation | Derivation of units | |
|---|---|---|---|---|
| 27 | Brody (1964) | $GrsEf = \frac{E_{total}}{TNE_{mw}} * 100$ | Ratio of energy used | Gross efficiency (%) |
| 28 | Brody (1964) | $NetEf = \frac{E_{total}}{TNE_{mw} - TBMR} * 100$ | Ratio of energy used | Net efficiency (%) |
| 29 | Brody (1964) | $AbsEf = \frac{E_{total}}{TNE_{mw} - EnWlk} * 100$ | Ratio of energy used | Absolute efficiency (%) |
| 30 | Derived | $DstDy = \frac{EFC * DapCap * 10{,}000}{Wdth}$ | $\left(\frac{m}{day}\right) = \left[\frac{ha}{hr}\right]\left[\frac{hr}{day}\right]\left[\frac{10000m^2}{ha}\right]\left[\frac{1furrow}{m}\right]$ | Distance oxen walk per day (m/day) |
| | Derived | ATimTil=Lnd/(EFC*DapCap) | $(days) = \left[\frac{ha}{1}\right]\left[\frac{hr}{ha}\right]\left[\frac{days}{hr}\right]$ | Actual time for tillage (days) |

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