METHODOLOGY FOR EVALUATING THE IMPACT OF ANIMAL TRACTION AT THE FARM LEVEL IN A SMALL-SCALE MULTI-CROPPING SYSTEM (BASSE CASAMANCE, SENEGAL)

Volume I

By

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A DISSERTATION

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

DOCTOR OF PHILOSOPHY

Agricultural Technology and Systems Management

Department of Agricultural Engineering

1997

ABSTRACT

METHODOLOGY FOR EVALUATING THE IMPACT OF ANIMAL TRACTION AT THE FARM LEVEL IN A SMALL-SCALE MULTI-CROPPING SYSTEM (BASSE CASAMANCE, SENEGAL)

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A methodology is presented along with an expert system program for evaluating the impact of animal traction at the farm level in a small-scale multi-cropping system. In its actual version, the expert system program applies to oxen cultivation using Ndama species in the Basse Casamance region situation. The evaluation is based on a number of models developed around the draft animals' daily energy balance. The energy available for the various field operations is calculated based on (1) the total liveweight of the oxen,(2) the daily amount of feed given to the oxen and (3) the level of draft and power required to perform the field operation. The liveweight of each ox is modeled by using an empirical equation relating the actual liveweight in kg to the circumference in cm of the thorax of the ox. The energy is estimated from the characteristics of the field operation (type of implement, draft, speed, field time) in association with the number of working days during the rainy season. An optimization module is used to model a cropping system in relation to the economical environment and endogenous constraints of the farm (land, labor and available energy). The expert system output agreed with current practices and values found in the literature.

To my father Macaty, to vieux Adama, to Odette and to Mabeye Sylla, gone too soon
(Peace Upon Them).
To my wife Mame Coumba, my son Ousmane and my mother Fatou Diagne.

ACKNOWLEDGMENTS

I would like to take this opportunity to gratefully acknowledge the assistance and trust of Dr. R.H. Wilkinson, my advisor and chairperson of my guidance committee. Also, the completion of this work would have not been possible without the attention and understanding of the members of my guidance committee, Dr. Burkhardt (AE), Dr. Harsh (Ag. Econ) and Dr. Harwood (CSS). Their suggestions and valuable ideas helped me finalize this dissertation and enjoy every moment of the work. Many thanks go also to Dick Roosenberg and Tillers International.

I would like to thank all the personnel at the ISRA/CRA Djibelor and CRZ Kolda research stations, for sharing with me ideas and research facilities during my fieldwork. Special thanks go to Dr. Khouma and Mme Sall, Abdou Fall, Adama Faye, Abibou Niang, Sabaly, Konte, Bolle, Tuti, Yafaye, Fode, Ba, Andre and Ibrahima Sonko.

I would like to express my gratitude to ISRA/DG, especially to J. Fayes and J.P. Ndiaye, to the NRBAR/OSU/AID Project, to CADEF, to vieux Diame (Boulom) and also to EATA through Mr. Konte for all the support provided to make the research possible.

Thanks to O. Fall, A.M. Mbaye, I. Diagne, Zeiman, Herman, B. Diagana, C. Babou, P. Diop, H. Diakhate, Amadou Fall, Dr. Sall, M. Havard, Sayon K., As Ndiaye, D. Coulibaly, M.L. Sonko, F. Diame, I. Thomas, M. Lo, S. Sall, H. Mbengue, S. Kante, M. Sene, Mme Badiane, D. Sidibe, S. Djiba, O. Ba, O. Diop, K. Toure, Ezabele, Brima, Pape Gueye, Aziz, Lopi's, and friends, and their respective families for the moral support.

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ABBREVIATIONS

AJAEDO: Association des Jeunes Agriculteurs et Eleveurs du Departement de Oussouye (Basse Casamance, Senegal).

AID : Agency for International Development (USAID).

ARC : Agricultural Research Council (England).

ASAE: American Society of agricultural Engineers.

ASCE: American Society of Civil Engineering.

CADEF: Comite d'Action pour le Developpement du Fogny (Basse Casamance, Senegal)

CEEMAT: Centre d'Etude et d'Experimentation en Machinisme Agricole Tropical (France).

CIRAD-SAR: Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement - Departement des Systemes Agro-alimentaires et Ruraux.

CPCS: Commission de Pedologie et de Cartographie des Sols (France).

CRA: Centre de Recherches Agricoles

CTVM: Center for Tropical Veterinary Medecine (England).

FAO: Food and Agriculture Organization.

IRAT: Institut de Recherches en Agronomie Tropicale(France).

ISRA: Institut Senegalais de Recherches Agricoles (Senegal).

MAC : Mission Agricole Chinoise (China).

NARS: National Agricultural Research System.

ORSTOM: Office de Recherches Scientifiques et Techniques dans les Territoires d'Outremer (France).

PIDAC: **Projet Integre pour le Developpement de la Basse Casamance (Senegal)**

SOMIVAC: **Societe pour la Mise en Valeur de la Casamance (Senegal)**.

LIST OF VARIABLES

AGETRAIN : Training age of draft animals

ANERGY : Energy Delivered by the Working animals in MJ.

ANIREL : Draft Animal Reliability in % or decimal.

ANNAVAIL: Probability of Draft animal Unavailability in %.

ANPOWER : Power Delivered by the working animals in J/sec.

ANSPEED : Draft animal Working Speed in m/sec.

ANWKGHR : Number of Hours Worked per Day.

AVGLW : Average liveweight in kg.

CI : Cone Index.

CIRCUMF : Animal thorax circumference or girth in cm.

CROPRICE : Market price or value of crop per kg.

DE : Digestable Energy in MJ.

DM : Dry Matter content in percent

DN : Soil Drainage in mm.

DEP : depth of penetration in the soil in cm(penetrometer).

DISTRAV : Distance Traveled in m.

DR : Draft required in daN.

DUL : Drained Upper Limit.

E_d : Penetration Energy of the penetrometer at depth in J.

EFC : Effective Field Capacity in ha/day

EFDTM: Effective field time in sec, min, or hr.

EPWD: Effective Probability of Working Day in %.

EQTYPE: Equipment type

ERI : Energy Required to pull the Implement in Joules (J).

ET : Evapotranspiration in mm per day.

FC : Field Capacity.

FDOP: Field Operation

FDTM: Field Time (hrs/ha).

FRFEED : Amount of fresh Feed Required in kg.

Fr : Frequency (decimal number) of precipitation occurence.

Fs : Soil resistance Force to the penetrometer bar in kgf.

FMSIZE : Farm Size in ha.

FU : Forage unit

FUM : Amount of Forage Unit for Maintenance.

NFWKERS : Number of Farm Workers.

GE : Gross Energy in MJ.

GSWC: Soil water content in g of water per g of soil.

HGT : height of falling weight in cm (penetrometer).

HI : Soil Hardening Index.

IMPFCOST: Implement fixed cost.

IMPLEFF : Implement Efficiency in %.

IMPLREL : Equipment reliability in %.

IMPLWDP : Implement Working Depth in cm.

IMPLWWD : Implement working width in cm.

LL : SWC Lower Limit in %

LW : Draft animal Liveweight in kg.

LWL : Liveweight Losses in kg/day

LWP : Percentage of LW used for traction in % or decimal.

MAE : Maintenance Energy in MJ.

MATURELW : Draft animal mature liveweight in kg.

ME : Metabolizable Energy in MJ.

NE : Net Energy in MJ.

PF : Draft animals Pulling Force in kgf or daN.

Pr : percentage probability of occurrence.

RF : Amount of rainfall in mm.

RO : Soil water runoff in mm.

SBD : Soil bulk density in g/cm^3.

SSR : Specific soil resistance in N/m^2.

SWC : Soil Water content in % g/g

SLWGHT : Penetrometer Sliding Weight in kg.

TDN : Total Digestible Nutrients in J per kg.

VSWC: Volumetric soil water content by volume in cm^3/cm^3.

NWDAYS : Number of Working Days in days.

SWHC : Water holding capacity.

SWP : Wilting Point in %.

WTM : Time to perform field operation in min

WWD : Implement Working Width in cm.

WWKGCOMP : Width of working component in cm.

YIELD : Crop Yield in kg per ha.

YRSEXP : Draft animal number of years of experience in years.

Chapter 1

INTRODUCTION

1.1. Mechanization overview

In contrast with farmers in industrialized countries, farmers in developing countries are generally small holders who must contend with increasing population pressure on the land and a low level of mechanization to promote effective crop intensification. Population pressure has changed most of the traditional farming systems by forcing short fallow and permanent cropping. These new practices have led to more soil degradation.

In order to absorb the impact of population growth, governments in developing countries urge farmers to produce more food by improving agricultural productivity. Such improvements depend in general, on the combination of a variety of energy sources: mechanical (machines, animals, humans), chemical (fertilizers, pesticides, herbicides, etc.) or biological (improved varieties, manure, compost, etc.). As pointed out by Esmay and Hall (1973), mechanization is one of the most critical production inputs to increase crop yields through better control of the soil water regime (runoff versus infiltration), better soil preparation for soil aeration and nutrients availability, more efficient weed control, and better timeliness. They defined agricultural mechanization as "the art and scientific application of mechanical aids for increased production and preservation of food and fiber crops with less drudgery and increased efficiency". Separate studies conducted in most of the developing countries in Asia, Africa and South America have shown that human and animal power are probably the most plentiful source of energy (Patrick, 1993; Campbell, 1990) towards the establishment of a sustainable mechanized production system. The switch from hand cultivation to an animal traction based production system is viewed by Jaeger (1984) as a significant step in creating more production opportunities and increasing returns for farmers through better land preparation and timeliness. The level of investment involved in the technology is low compared to tractorization. Draft animals are available and fed locally and thus save foreign exchange (Roosenberg et al, 1987). The energy provided by the combined two sources (draft animals and tractorization) represent 80% to 90% of the total energy used in agriculture throughout the world today (Campbell, 1990). The same study reported that there are over 1.5 billion animals used as working animals in the world compared to 22 million tractors. The species used to generate the energy needed for agriculture are mainly cattle, water buffalo, donkeys, mules, horses and camels.

The level of mechanization and intensity of draft animals' utilization is highly variable from one region of the world to another one. The focus of this research is the situation in Sub-Saharan Africa and in Senegal in particular.

1.1.1. Sub-Saharan Africa

In Sub Saharan Africa, animal traction is one of the most important energy sources for agriculture (**Table 1**). In some areas it provides up to 90% of the power required for crop production. The level of farmers' experience varies from one country to another. In

Table 1: Estimated numbers of draft animals in Sub-Saharan Africa

Region/Country	Numbers		
	Cattle	Donkeys	Horses
West-Africa			
Benin	30-40,000	-	-
Burkina Faso	75-80,000	50-60,000	3,000
Chad	105-130,000	-	-
Cote d'Ivoire	30-40,000	-	-
The Gambia	18-20,000	25-30,000	5-7,000
Ghana	20,000	1,000	-
Guinea	100,000	-	-
Guinea-Bissau	4,000	-	-
Mali	200-320,000	150,000	30,000
Niger	16-20,000	10,000	-
Nigeria	100-200,000	-	-
Senegal	130-140,000	140-180,000	200,000
Sierra Leone	1,000	-	-
Togo	9-10,000	-	-
East Africa			
Ethiopia	6,000,000	-	-
Kenya	700,000	-	-
Tanzania	600,000	-	-
Uganda	600,000	-	-
Central Africa			
Angola	300,000	5,000	-
Cameroon	50-55,000	4,000	-
C. Af. Republique	8-10,000	-	-
Zaire	1,000	-	-
South Africa			
Botswana	350-360,000	140,000	24,000
Lesotho	180,000	-	-
Madagascar	260-330,000	-	-
Malawi	50-70,000	1,700	-
Mozambique	100,000	-	-
Zambia	180-315,000	-	-
Zimbabwe	500-800,000	-	-

Source: Starkey and Faye (eds), 1990

Botswana, 80% of the farmers use animal traction for plowing. Zimbabwe has the largest draft animal population in the region (Starkey and Faye, 1988). Falvey (1986) pointed out also that one of the most significant impacts of the utilization of working animals is the increase of cultivated area per active household member: 30 to 40% in Senegal and 40 to 70% in Mali the neighboring country of Senegal.

In West Africa, animal traction was introduced before the era of independence in the early 1960s through the implementation of various agricultural projects oriented towards the production and export of cash crops (groundnuts in Senegal, cotton in Mali). The promotion of animal traction for cereal production at that time was almost non-existent. The introduction of the new technology by the colonial administrations took place between 1905 and 1945 in different places stretching between French Guinea, Senegal and Nigeria. The main actions taken were the integration of crop production and livestock husbandry (mixed farming) in northern Nigeria (1924), the introduction of plow farming in northern Ghana (1938), and the implementation of research on animal-drawn implements in Senegal (1928). In the process, most of the farm implements were originated from France or specifically manufactured and adapted for African conditions: the MANGA™ cultivator for Burkina Faso, the ARIANA™, TROPICANA™ and SINE™ for Senegal, the BAJAC™ moldboard plow for Mali.

Historical analysis shows that adoption rates by farmers were the greatest in the first 10 to 20 years after the independence (1960 - 1980). This period represents the most dynamic period in terms of animal traction projects implementation in the region (Le Moigne, 1981) (**Table 2**). This period was also characterized by the creation and development of animal-drawn equipment factories like SISCOMA (1961) in Senegal.

Table 2: Numbers of animal drawn implements in West Africa (1957 and 1980/84)

Country	Year	Plows	Brab. Plows	Hoes	Harrow	Seeder	MPT[1]	WTC[2]	Carts
Senegal	1957	1150	-	3700	-	41000	-	200	4000
	80/84	63000	-	340000	-	270000	9500[3]	n.a	135000
Mali	1957	25000	-	120	3700	30	-	-	2000
	80/84	170000	-	85000	15500	50000	-	-	110000
Guinea[4]	1957	10000	-	-	5000	-	-	5	5
		10000	-	-	5000	-	-	n.a	n.a
Nigeria	1957	627	4	1250	20	509	-	30	424
	80/84	13000	n.a	4000	n.a	4000	26300	n.a	31000
Burkina Faso	1957	1350	-	173	520	5	-	395	470
	80/84	61500	-	21000	n.a	n.a	26500	n.a	64000
Togo	1957	88	-	2	20	-	-	-	-
	80/84	6000	-	-	700	400	4700	-	2000
Benin	1957	33	-	2	4	7	-	1	30
	80/84	n.a	-	n.a	140	300	14600	n.a	1400
Cote d'Ivoire	1957	1000	-	130	130	-	-	-	-
	80/84	n.a	-	n.a	n.a	3100	15500	-	7000
Cameroon	1957	2000	14	2	2	6	-	-	1300
	80/84	30000	n.a	n.a	n.a	n.a	-	-	3500
Chad	1957	378	5	15	25	18	-	5	50
	80/84	75900	n.a	1,800		n.a	-	n.a	19800

[1] MPT: Multi-Purpose Toolbars
[2] WTC: Wheeled Tool Carriers
[3] Ariana multiculteur
[4] Figures from 1974
n.a: non available
Source: Extracted from Lawrence and Pearson, 1993

The major research issues addressed during this implementation and adoption phase to improve the technology were as follow:

- Draft animal selection (cattle, horse, donkey)
- Yoke design and fabrication (head, neck-yokes)
- Implement selection (single or multipurpose)
- Field operation techniques (tillage, weeding,)

1.1.2. Senegal

In the case of Senegal, cattle were the first option for energy supply to agriculture. The technology was tested in 1925 for the first time. In the castration and yoking of ox, farmers were introduced to a new technology that could generate much greater power than used previously. The technology was introduced through the French colonial research system IRAT. The main objective was to improve land and labor productivity, and to increase total cultivated areas and crop yield. The strategy was to produce enough groundnuts and/or cotton for export with regard to foreign exchange and also to use part of the production to supply the grain to the emerging national oil industry.

The major breakthrough in crop production with draft animals came around 1945 when equine and donkey traction were promoted at the farm level to perform light works like cultivation and transport. Along with groundnuts, the cereal production (millet, maize, and sorghum) reached satisfactory levels satisfying farm family consumption as well as supplying local markets with the production surplus. Progressively, bovine traction was oriented towards the execution of heavier tasks like plowing in medium and heavy soils, and carting of bulky loads.

The adoption of draft animal technology by farmers was mainly supported by the rapid increase in areas cropped with cash crops (major source of income), the availability of locally manufactured implements and the existence of credit programs to help farmers purchase their own equipment. The animal traction based production system appeared to be reproducible, as the major components involved were all readily available to farmers. Most importantly, draft animals like oxen were simply borrowed from the household or village herds.

However, the promotion of animal traction by governmental extension agencies must face regional, cultural and environmental diversities throughout the country. Constraints related to these aspects have delayed for many years its implementation in the Casamance area, located in the southern part of Senegal.

The latest survey conducted at the national level showed that the draft animals' population in Senegal was composed of 130-140,000 cattle, 140-180,000 donkeys and 200,000 horses (Lhoste, 1988). The Casamance province accounted for less than 15% of the national totals. Among other types of constraints to have delayed the implementation, were the animal sanitary conditions of the area in relation with the prevalence of the sleeping sickness. This characteristic has prevented until recently (in the 1990s) the introduction of donkeys and horses for draft purposes.

In the Basse Casamance region, the prevalence of trypanomiasis disease transmitted through the tse-tse fly turned out to be the major barrier as the sleeping sickness introduces a serious limitation in the working capacity of the draft animals. The most reliable source of draft energy is represented by the Ndama cattle, bos taurus, (87% of the total), while the utilization of horses and donkeys (3% and 10% respectively) is still marginal. The Ndama breed has more tolerance to the disease and is well-adapted to warm and humid climate. The castrated Ndama male oxen are used for traction while the cows are kept in the herd for their milk production. The draft team is always composed of two oxen of similar weight.

1.2. Statement of problem

To date in the Casamance province, agricultural production based on animal traction is below expectation. Its promotion initiated since the early 1960s did not bring about the expected increase in food production. In fact, the level of adoption of the technology by farmers appears to be very low for several reasons mostly sanitary and economical[1]. In the process of adoption, farmers are very selective in choosing implements in relation to the level of the first investment in terms of affordability (Ndiame, 1988). In general, farmers justify the use of animal traction for land preparation because it is faster and presents less drudgery than using hand tools (FALL, 1985).

Farmers in the South did not adopt the technology until some changes were made to the yoking system. Farmers use different size and multi-purpose yokes for both cropping (head yoke) and transportation (neck yoke). Among other factors, the design of the yoking system was found to affect the working capacity of oxen. In terms of efficiency, the fitness represents an important criterion when evaluating the work output of

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[1] The process and level of adoption of improved technologies by farmers in the Basse Casamance region is being investigated by a PhD student at Kansas State University.

draft animals. The yoking system assures compatibility in the link between the animals (power source) and the hitched farm equipment (implement or cart). A less effective yoking system is expected to turn into an appreciable source of potential energy wastage and to cause rapid fatigue if harnessed animals are not working together as a team. A poor teaming also, affects the quality of the field operation in terms of timeliness, effective field capacities, and poor work quality.

The real relationship between the design (width) of the yoke used and the working conditions (type of implement and soil) is not known well enough to help predict the amount of pulling force and energy required to performing the different field operations. In the decision-making process it is important to fit the job to the animals by choosing the more suitable team of oxen to perform the task. How does the size of a head yoke affect the draft required to pull different types of implement in a sandy textured soil at different moisture regimes? The determination of this type of relationship is very important in evaluating the expected role of draft animals in farmers' cropping system.

1.3. Objectives

The objectives of this study were as follows:

1. To develop a methodology that will better assess the impact of animal traction at the farm level.
2. To develop an expert system computer program to evaluate and predict the impact of animal traction at the farm level by using a Knowledge Base Management System (KBMS);

A significant amount of information on animal traction is available through the literature but is not systemized or structured into a standard form. The development of the expert system appears to be the start of such improvement to ease decision-making. In general, a fairly large number of technical parameters are involved in the decision making process. It is a real challenge for decision-makers to integrate local and scientific knowledge into an accessible structured database. The expert system is expected to provide the bridge between scientists and the rest of the community.

In combining artificial intelligence (AI) and conventional computer programming, expert systems have been used in a wide range of applications (Raman et al, 1992).

The work presented in this study is organized as follow:

- **Chapter 1**: Introduction.

The introduction presents an overview of agricultural mechanization in the world and specifically in the developing countries and in Senegal in particular, with a focus on small-scale farming systems. The statement of problem and the objectives of the study are also introduced.

- **Chapter 2:** Presentation of the area of study.

This chapter describes the production and cropping systems encountered in the area of study. The notion of agro-ecosystem is introduced and discussed from the point of view of animal traction utilization.

- **Chapter 3:** Determinants of performance of draft animals.

The discussion presents different relevant studies conducted on animal traction evaluation in various parts of the world with an emphasis on Senegal. The main determinants and parameters of performance are presented.

- **Chapter 4**: Materials and methods.

The organization of the field data collection along with the expert system building is presented chronologically with an emphasis on the different statistical designs.

- **Chapter 5:** Farm characteristics and system management.

- **Chapter 6:** Working capacities of draft animals.

- **Chapter 7:** Field operations and draft requirements

These three chapters deal with the presentation and discussion of the analysis performed. In the course of analysis, the results are compared to existing results in the literature for first hand validation.

- **Chapter 8:** Expert System to evaluate the impact of animal traction in the Basse Casamance region.

This chapter describes in details the process of building the expert system program. It shows how the collected data and models developed in the analysis part are used. In some cases, the collected data are reinforced by relevant secondary data from previous studies conducted in the area of study by the author or by the ISRA/CRA Djibelor's Farming Systems Research Team.

- **Chapter 9:** Conclusions and recommendations

What are the perspectives in animal traction studies in the Basse Casamance region and in Senegal in general? What are the expectations placed on the expert system program? Other similar questions are addressed.

Chapter 2

PRESENTATION OF THE AREA OF STUDY

2.1. Presentation of the area of study

The Basse Casamance region is located in the southern part of Senegal and covers 7,300 square kilometers (km^2), extending from the Soungrougrou Valley to the Atlantic Ocean (**Figure 1**). With population densities ranging from 27 to 60 inhabitants per square kilometer, there is increasing pressure on land use in relation to the weather (**Table 3**).

Table 3: Land distribution

Designation	Area occupied (ha)	Percent (%)
Cultivated areas	109,500	15
Mangrove (swamp wood)	124,100	17
Estuary and sediment	102,200	14
Forest	189,800	26
Residence area	204,400	28
Total	730,000	100

Source: PIDAC cited by A. FALL (1985)

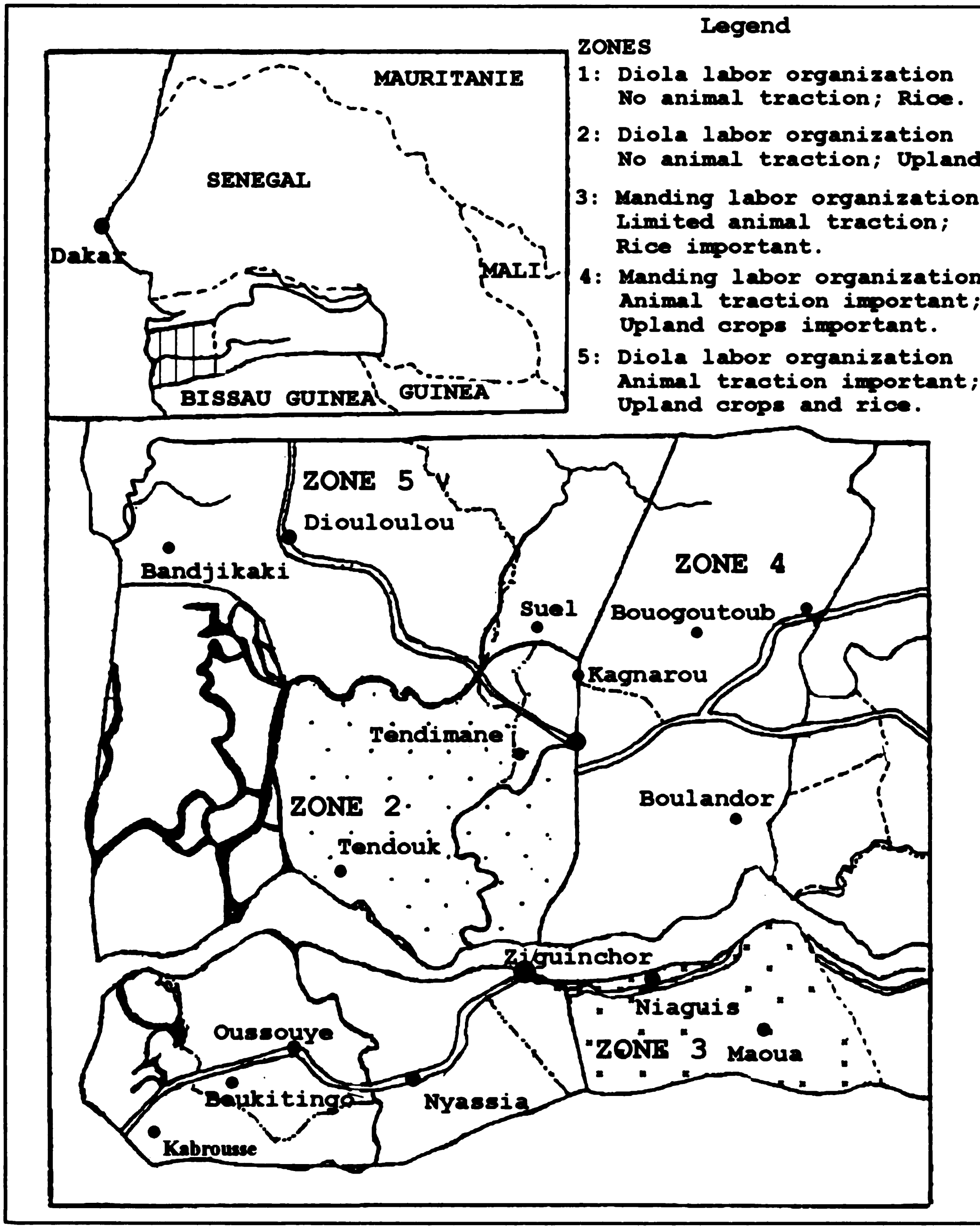

Figure 1: Agro-ecosystem zones in the Basse Casamance region

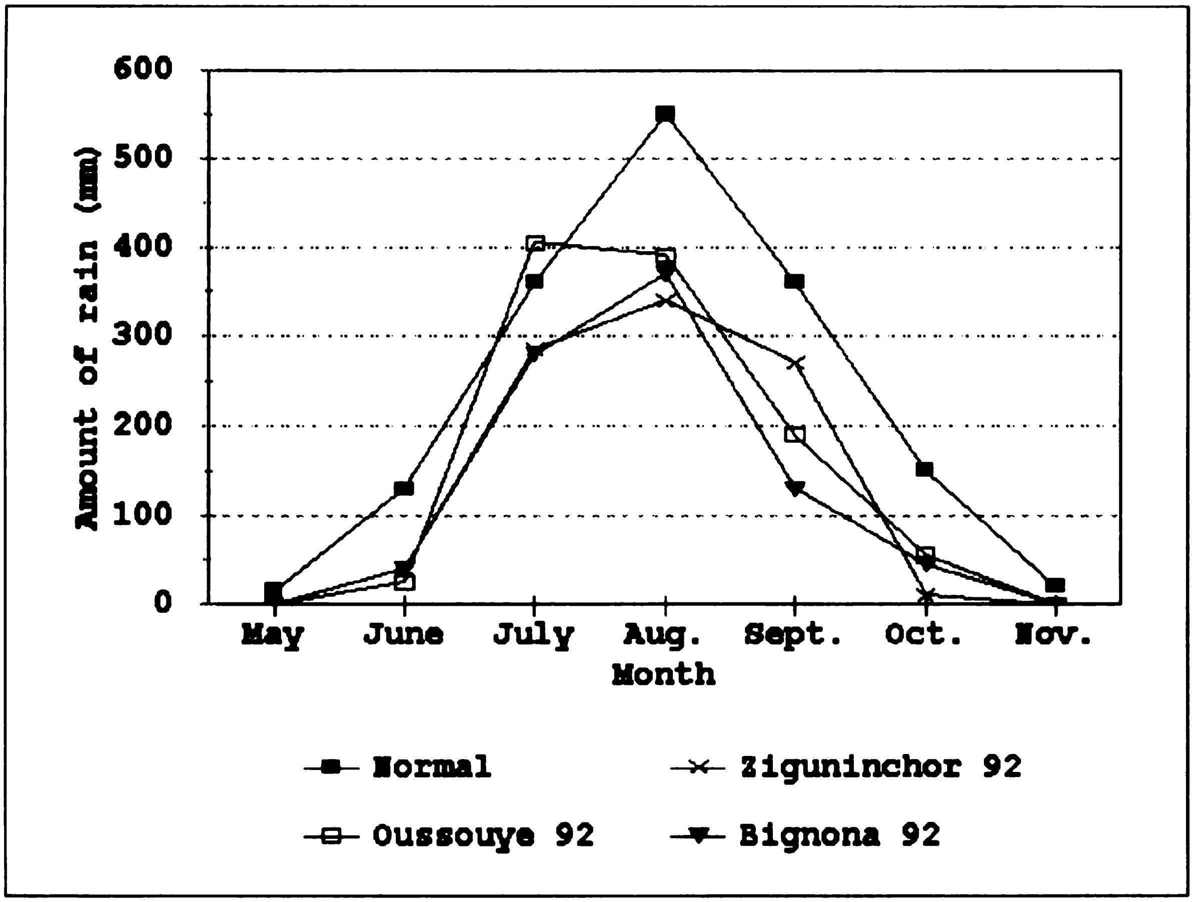

Figure 2: Rainfall distribution from North (Bignona) to South (Oussouye) and during normal years

The Diola ethnic group represents 83 percent of the total population, followed by Baïnouck (6%), the Manding (5%) and others (6%).

The climate is sub-Guinean type with a large maritime influence. The occurrence of one rainy season per year from the month of June to October represents the main characteristic.

The last two decades have witnessed a shortage of rainfall throughout the whole country and in the Basse Casamance region as well, where the type of landscape has induced significant changes in the cultural practices. The amount of rainfall decreased by an average of 33%, from 1,500 mm during normal years to 1,000 mm (39.4 in) (Figure 2). The lowest amount of rainfall, 800 mm (31.5 in) was recorded in 1983 in Ziguinchor, capital of the region.

The topography of Senegal is flat with an average land level elevation of 200 m. The physical aspect of the Basse Casamance region is characterized by a dense network of swamps and small streams flowing into the Casamance River. The landscape of the entire region is dominated by a succession of upland and lowland areas. During drought periods, the small streams offered privilege waterways to salt intrusion from the Atlantic Ocean through the Casamance River to the inland valleys following the upstream-downstream water movement.

With the increase in salt concentration throughout these years, combined with the low pH of soil and water, advanced chemical reactions started taking place in lowland areas to compromise their agricultural productivity (especially for rice production). Soil surveys conducted in the region yielded the tremendous figure of 180,000 ha non-productive, salty soils (Barry, 1986; ORSTOM, 1983). Most of these soils are located along the Casamance River and its main tributaries (Guidel, Kamoubeul, Soungrougrou, Baïla).

According to their position along the transect, crops are designated as either upland (groundnuts, maize, millet, sorghum) or lowland crops (mainly rice). All crops are rainfed.

Several field studies have been conducted to approach the agricultural and ethnic diversity of the area. One major finding was the identification of five agro-ecosystem zones offering different agricultural production and cropping opportunities. Three criteria were used to achieve this zoning (Equipe Systemes, 1984):

1. Labor organization at the farm level between male and female in relation to the crop to be grown and the agricultural operation to be performed (tillage, weeding, etc);
2. Ratio of upland and lowland areas in terms of relative importance of cultivated areas and types of crop;
3. Importance of animal traction utilization in the cropping system and the associated level of mechanization.

Each of these five agro-ecosystem zones presents different agricultural activities in relation to the type of the natural resources available (type of soil, water quantity and quality, forest) and the most dominant ethnic group (Equipe Systèmes, 1983).

In response to the decrease in productivity, farmers developed new strategies to meet their food security requirements (Posner et al, 1988). The coping strategies to deal with the new climatic conditions (drought, shortening of the rainy season and shortage of rainfall) were primarily based upon a progressive transfer of resources from lowland to upland areas. These major changes in farmer's traditional cropping system affected mostly the use and land tenure at the village level. The very first noticeable effect on the environment was the deforestation, which started taking place since the early 1970's to induce a disequilibrium in the land allocation process to different activities. The objective of the deforestation was to satisfy the increasing demand in cropping land. Through this type of management strategy, farmers tried in general to secure production through the expansion of upland crops rather than through intensification.

In an agro-ecosystem characterized by an availability of upland areas, the use of animal traction turned out to be the factor contributing most towards the expansion of fields cropped with cash crop (groundnuts) to the detriment of cereals such as millet and maize. The cereals are now mainly confined in backyards and compound fields. Within a short period of time (less than ten years), this type of cropping system affected the precarious equilibrium which has always existed between agricultural and livestock activities marked by the progressive disappearance of long term fallow along with village level grazing areas for livestock.

In the process, the mechanized field operations on newly cleared land brought about advanced stages of soil degradation to compromise land productivity. In most cases, the lack of good management practices has led to alarming soil losses.

2.2. Types of Production system

The agro-ecosystem zone is defined as a system in which farmers are carrying out productive agricultural activities within their natural environment. The environment is mainly composed of natural resources (soil, water, vegetative cover) and represents an area homogenous enough in terms of constraints and production opportunities. The most significant observation unit to evaluate interactions and performance of the system is the farm level (**Table 4**). This level of aggregation represents a finalized production system in itself as it comprises the center of the decision-making process which identifies agricultural production objectives and decisions upon resources allocation (Sonko and Fall, 1992).

Table 4: Average farm characteristics in the Basse Casamance region

Agro-ecosystem Zones	Village	Average farm size (ha)	Total population	Number of working adults	Cultivated area (ha/capita)	Cultivated Area (ha/adult)
Oussouye	Boukitingo	1.42	5.5	3.4	0.26	0.42
(Zone 1)	Loudia-Ouoloff	1.80	7.5	4.4	0.24	0.41
Blouf	Mahamouda	2.00	9.7	5.6	0.21	0.36
(Zone 2)	Tendimane	1.54	7.4	4.6	0.21	0.33
Niaguiss	Maoua	3.30	11.1	6.5	0.19	0.51
(Zone 3)	Boulom	1.88	8.1	5.0	0.23	0.38
Sindian-Kalounayes	Boulandor	5.01	11.0	6.3	0.45	0.79
(Zone 4)	Medieg	5.01	10.7	6.0	0.37	0.67
Fogni-Combo	Bandjikaki	3.20	9.1	5.0	0.35	0.64
(Zone 5)	Suel	4.41	7.5	4.4	0.59	1.00
Regional Averages		2.86	8.7	5.1	0.32	0.55

Source: Jolly et al, 1988

2.2.1. Agro-ecosystem 1 (Oussouye)

Located in the most southern part of the region, this agro-ecosystem is composed of a high proportion of lowland areas. The landscape is dominated by swamps, saline and acid soils ("sol de tannes"), and very few upland fields (village sites). The ratio of lowland to upland areas favors by far lowland areas. Transplanted rice is the major agricultural activity (Equipe Systemes, 1984).

Field operations are performed according to the Diola tradition of social labor division by gender: men perform land preparation while women perform rice nursery preparation, transplanting and harvesting. Women also help in weeding of upland crops confined in small fields.

Land preparation is manual and starts whenever enough water is stored in the rice fields. As the cumulative rainfall increases from the beginning of the rainy season, a network of small dikes dividing the main rice fields into small subplots, 10 m^2 to 30 m^2 in area, is used to capture water runoff. Farm sizes are generally small averaging 1.3 ha per household. More than 60% of the fields are cropped with rice.

Other non-agricultural activities contribute significantly to the total farm revenue: fishing, products from the forest (palm oil extraction for example).

Livestock activities are very important; cattle, poultry, swine are produced. Animal traction is not used in agricultural activities for different reasons. The primary constraint is sanitary with the prevalence of trypanomiasis (Pelissier, 1966; Traverse, 1974). The alternative to animal traction is to use rented power tillers from non-governmental organization (CADEF, AJAEDO). However, very few farm activities are mechanized through this rental scheme.

2.2.2. Agro-ecosystem 2 (Blouf)

Located in the northern part of the Casamance River, agro-ecosystem 2 represents a continuation of agro-ecosystem 1 but with more available upland areas. More than 80% of fields produce upland crops which are mainly groundnuts and millet.

The labor organization at the household level is the same as in agro-ecosystem 1. There is no use of animal traction since the big drought event in the late 1970s, which significantly reduced the availability of animals for draft purposes. Farmers are still very open to the technology (Fall, 1988).

2.2.3. Agro-ecosystem 3 (Niaguis)

Agro-ecosystem 3 is located eastward of agro-ecosystem 1. The population of the area is composed of a multitude of ethnic groups living in different villages, which continue to practice their original cropping system. Upland areas account for 60% of cropped fields.

The introduction of animal traction is still in progress: 30% of cropped areas are mechanically tilled with animal-drawn moldboard plows. It is important to mention that farmers located in this area were the first in the region to experience the use of motorized equipment for rice land preparation with the MAC project (1969-1973). The governmental regional extension service SOMIVAC-PIDAC took over the project in 1984 and pursued the rental of mini-tractors and power-tillers to farmers.

2.2.4. Agro-ecosystem 4 (Sindian-Kalounayes)

Agro-ecosystem 4 is located in the northeastern part of the region. This area has been culturally under Manding ethnic group influences even though the population was originally Diola. The social labor division according to gender is organized around the type of crop to be grown. Men are in charge of all upland crops which occupy more than 84% of cropped areas, while women are specialize in rice and vegetable production.

The use of animal traction is well implemented and most field operations, from land preparation to groundnut lifting, are mechanized. The average farm size is around 4 to 5 ha; more than 80% of croplands are mechanically plowed with draft animals, especially oxen.

Over the last five years, with the emergence of many local farmers' organizations, mechanization is becoming a major concern for the population. Farmers are getting more involved in the purchase of tractors of different sizes (used and new) within a wide power range (10 to 45 hp). The tractorization process is mainly oriented towards improving the timeliness of land preparation in the rice fields.

Different economical activities are conducted apart from the field crops. Livestock (cattle, sheep, poultry), tree cropping (fruit and palm) and vegetable gardens represent important sources of revenue.

2.2.5. Agro-ecosystem 5 (Diouloulou)

Agro-ecosystem 5 covers the northwestern part of the region. Upland crops are dominant, and occupy 75% to 80% of all cropland. The labor organization is Diola type based on division according to gender in relation to the type of field operation to be carried out. Men perform land preparation on both the upland and lowland areas.

The use of animal traction is also important but to a lesser extent than in the previous agricultural situation. The level of mechanization barely exceeds land preparation for 60% of all cropland.

2.3. Cropping systems

In normal rainfall conditions (1500 mm), the agricultural production of the Basse Casamance region is mainly oriented towards rice production. The amount of rice produced was estimated to be around 75,000 metric tons representing 30% of the national production. The shortage of rainfall by 20 to 45%, along with the correlated salinization process of most rice field soils, has compromised the regional production to the point that the region has become a net rice importer since 1978 (Equipe Systemes, 1983; Jolly et al, 1988). The coping strategies developed by farmers to counteract the decrease in rainfall were to move to more diversification at the regional agricultural production system level.

Table 5: Cereal yields in Casamance (kg/ha)

Crops	Average Yield (kg/ha)
Millet/Sorghum	730
Maize	950
Upland rice	750
Lowland rice	1,000
Aquatic rice	1,250
Swamp rice	750

Source: MDR, 1986 "Etude du Secteur Agricole: Plan Cérèalier."

A bigger emphasis was put on the cash crop (groundnuts) while areas cropped in maize increased by 19% between 1970 to 1982. Other crops grown are millet and sorghum. The yields measured in farmers conditions are generally low (**Table 5**).

2.3.1. Groundnut production

The draft animal based cropping system is mainly driven by groundnut production, the only cash crop supported by an organized market system at the national level. The cropping of groundnuts has significantly contributed to the extension of croplands gained by rapid deforestation and clearing of new lands: upland crops represent 75% to 80% of all croplands in the region and fields cropped with groundnuts alone accounts for 45% to 55% of all upland crops area. The average farm yield is 954 kg/ha (Posner et al, 1988).

In the agro-ecosystems located North of the Casamance River (zones 3, 4 and 5), groundnuts are grown either as the first crop in a 2 to 3-year rotation with millet/sorghum production following land clearing or alternating with an annual fallow (2-year rotation). Whereas in the South (zones 1 and 3), the cropping pattern is continuous (1-year rotation: groundnuts/groundnuts) as land availability is a major constraint.

Three varieties of groundnuts are grown: 28-206 and 69-101 (110 to 120 days/cycle). These are improved varieties introduced by agricultural research institutions and governmental extension agencies. The third variety is local and is called "Bourkouss" by the farmers. It is a short cycle variety (90 days/cycle) and is not supported by the official market system. The local variety is widely used for late seeding. The improved varieties are mostly grown for their high oil content and are cultivated as cash crops: 69-101 in the North and 28-206 mainly in the South.

Groundnuts are the only crop in the cropping system that is highly mechanized through animal traction. In some agro-ecosystem zones, the level of mechanization reaches the harvesting operation with the utilization of animal-drawn groundnut diggers or lifters. The main difference in the cropping pattern among farmers resides in the type of land preparation: either flat (with a moldboard plow) or ridged.

2.3.2. Cereals

Cereals (millet, sorghum, maize and rice) account for the remaining cropped area, 45% to 55%, of the total cropped area. Millet and sorghum can be in either a rotation with groundnut or alternate with annual fallow. Sorghum is very seldom in a mono-culture cropping pattern. It is generally intercropped with groundnuts. All varieties used are local.

Millet is important in agro-ecosystem zones with large Manding cultural influence. The seeding starts at the very beginning of the rainy season. The varieties used are local (Sanio) and have major pest management problems especially with birds and stem borers (Pentatomidae *Coreidae*). Millet is generally seeded on ridge plowed land to protect the seed and young emerged plants against excess moisture. The land preparation is either mechanically or manually performed in relation to the timeliness of groundnut field operations.

Maize production is crucial to farmers as it represents a relay food supply for their consumption. In general, the harvest takes place during the rainy season and before the end of the month of September. Maize is mainly grown in agro-ecosystem zones 3, 4 and 5. The cropping pattern is continuous mono-culture (1-year rotation) in soils rich in organic matter. Maize fields are mainly located in the backyards of the farmer's compounds on relatively small areas (less than 0.5 ha). Lately, there is a trend to cropping maize out of the backyard on newly cleared land, but the major concern to farmers is soil fertility and the need of field protection against pests to secure production.

During the last 10 to 15 years, high yielding varieties of 90 days/growing season have been provided to farmers by research institutions and governmental extension agencies: composite ZM 10 (yellow grain) and hybrid BDS (white grain). New high yielding varieties (Synthetic C, Makka, etc.) continue to be distributed.

Maize is the second most commonly mechanized crop after groundnuts. The level of mechanization involves land preparation, seeding and weeding. The intensity of mechanical cultivation is determined by the type of land preparation (flat or ridge). Ridging takes place generally when farmers are having weed problems or excess moisture in relation to the topography. Maize seems to be the crop that offers the largest margin of progress in terms of extension of cropped area and increase in level of production (Ndiame and Fall, 1989).

Most of the rice production is carried out in lowland areas. The cropping system is rainfed. There are three types of rice fields ranging from strictly rainfed (upland) to aquatic (lowland). The aquatic rice fields depend greatly on the accumulation of water from runoff within the watershed to low areas inside the valleys. The third type of rice field is assisted by the rising water table, which provides enough moisture to the rice plant. The types of soil used for rice production vary from sandy (upland) to clayey soil (lowland). A large number of rice varieties (local or improved 110 to 120 days/growing season) are used according to the field conditions in terms of soil moisture, salinity, pH, fertility, etc. Improved varieties are widely used by farmers: DJ 684D, IRAT 133, IR 8, DJ 12-519.

Historically, the mechanization of rice production in the region started with the introduction of the first series of power-tillers (DONG FENG™) from The Republic of China through the MAC project (1969-1973). One main objective of the project was to improve productivity through better timeliness and good quality land preparation (FALL, 1985). The major constraint was related to the size and shape of the plots, which were too small to facilitate the maneuverability of the power tillers.

The use of animal traction started earlier, in 1967-1968, but was mainly confined to areas where researchers and extension workers were conducting experimentation (TRAVERSE, 1974). Farmers try to combine animal traction for land preparation and seeding and tractors for land preparation whenever possible.

Rice is generally direct seeded by hand broadcasting right after land preparation except for the aquatic rice grown in lowland areas where transplanting is manually performed by women when water is still ponding. Rice production requires effective land preparation before seeding in order to improve weed control and to incorporate organic matter into the soil. This field operation depends largely on the water content of the soil.

Other crops are also important at the farm level for their economical and nutritional values. The area allocated to these types of crops is generally small: cow-pea, cassava, sweet potatoes and vegetables.

The Basse Casamance Agricultural Development Master Plan published the prediction of production trends for major crops in relation to extreme weather conditions scenarios (drought and normal) (**Table 6**). The potential increase in productivity to reach these predictions is real and depends mainly on how farmers will be able to improve their capacity for carrying out field activities on time

Table 6: Lower Casamance agricultural production trends in thousand metric tons

Conditions	Drought				Normal			
Year	1979	1985	1990	2000	1979	1985	1990	2000
I. Senegal								
Millet	407	419	430	452	415	497	577	779
Rice	68	70	72	76	77	93	109	151
Maize	32	35	38	44	34	41	47	64
Groundnuts	613	708	798	1015	749	946	1150	1699
II. L. Casamance								
Millet	25	26	26	28	26	31	36	49
Rice	22	23	23	24	38	46	54	74
Maize	6.6	7.2	7.8	9.0	6.8	8.1	9.5	12.8
Groundnuts	30	35	39	50	36	45	55	82

Source: Master Plan Report, Vol 1 by HARZA (1984).

2.4. Agricultural productivity

At the farm level, the increase in productivity to reach a sustainable cropping system is a major concern of farmers. A number of decisions are made towards meeting their production objectives. These decisions are of two kinds (Jouve, 1986):

- gathering and organizing available resources
- choosing the most appropriate production process and techniques in relation to the environmental conditions.

According to the resources available, farmers use different strategies to meet their needs. However, a number of limiting factors have an impact on their respective performances and help explain why farmers do what they are doing.

2.4.1. Land productivity

Three major soil types, with slopes ranging from 2 to 8%, have been identified through different studies, soil surveys and land evaluation in the region (Charreau, 1974). On upland areas, Oxisol and Alfisol soil types dominate whereas in lowland areas, there are three subclasses: Molisol (rice fields without salt), Entisol (sand deposit in the estuary of the Casamance river) and peatsol in swampy areas. The Oxisol soil type (Ferralsol according to FAO classification) is sandy-clay, red to reddish in color and characterized by the presence of kaolinite and a low cation exchange capacity (CEC= 11 mmol/g). Most of the upland crops are grown on this type of soil. The Alfisol soil type (beige in color) is mainly located on the transition zones (from upland to lowland) along the transect between the Oxisol (on top) and the Molisol types. Its organic matter content is low compared to the Molisol but has a more silty texture than the Oxisol type. It also has a higher clay content and is recognized by its grey to blackish color.

A number of studies have shown that the increase in land productivity is primarily bound by the drought situation as farmers do not use mineral fertilizers due to the shortage of rainfall (Equipe Systemes, 1984). In general, the fertility level of these soils is very low because of advanced weathering and lack of good management practices regardless the amount of manure provided by the livestock to the cropping system. The cereals grown in the farm backyard (maize) and at the village level (sorghum and millet) usually receive manure and organic matter from different origins, but most of the groundnut fields do not receive any type of fertilization. The extensive cropping on newly cleared lands has generated advanced levels of soil degradation. The sand deposit in the lowland areas by water runoff from upland fields tends to compromise rice productivity.

The amount, regularity and distribution of rainfall during the growing season represent important limiting factors towards reaching better land productivity. The decision to start field activities, in terms of working days, for example, is mainly subject to these two factors. The date at which the rainy season begins remains the most unpredictable factor.

The rain distribution pattern varies from North to South and from year to year. The state of drought has introduced a significant variation in the amount of rains received in different localities: 45% deficit in the northern areas and 26% in the southern areas. The year-to-year variation is the most commonly used indicator by farmers to decide about the cropping pattern (priorities) and the field operations scheduling towards minimizing risk. The soil moisture condition is one important parameter considered by farmers to decide when and how to carry out the field operations. The rainfall pattern is a key factor in the decision making process to meeting timeliness of farmers' field activities.

Agronomic trials conducted in on-station and on-farm conditions have demonstrated the benefits of plowing on land productivity through significant yield increases (Equipe Systemes, 1984). Usually, land preparation on all cropland begins after water has infiltrated the soil to a certain depth. The depth of the wetting front at which to start the plowing operation is mainly dictated by the amount of working power available at the farm level in relation to the soil consistency (physical and mechanical properties). On upland crops, draft animals are used when the wetting front is located at around 12 cm or more after the useful rain event (FALL, 1985). In lowland areas for rice production, this limit is different depending on the type of rice fields described earlier.

2.4.2. Manpower and labor productivity

The availability of manpower throughout the rainy season is the most important factor for success in carrying out field activities. The availability of manpower is mainly affected by the migration of the young and active population. One way for farmers to solve this problem is to turn to the mechanization of more and more field operations. However, the level of access to farm equipment and power units (animal or tractor) as factor of production differ from one agro-ecosystem to another and from one farmer to another (Fall, 1985; Sonko, 1986; Ndiame, 1987). This variation in production opportunities has induced very significant differences in farmers' performance across the region. Different studies used the level or degree of mechanization and the availability of manpower at the farm to divide farmers into three distinct categories at the regional level (Equipe Systemes, 1985; Fall, 1990; Sonko, 1990):

- Category 1: Non-equipped households (64%)

The manpower (men and women) ranges from 1 to 4. The peak labor demand is located at the beginning of the rainy season during land preparation and requires 40% of total farm seasonal labor demand.

The intensity of the labor constraint is different from one cropping system to another. In agro-ecosystems with important use of animal traction, zones 4 and 5 for example, some farmers rent a pair of oxen and plowing equipment for a day or two to meet their field schedule.

For this category of farmers, the area cropped with groundnuts (cash crop) is small compared to the cereals: rice fields can occupy up to 60% of all cropped areas.

- Category 2: Low-level-equipped households (29%)

This category of farmers is characterized by the amount of manpower, ranging between 5 and 8 farm workers. The average is 6 active workers per household.

Land preparation is generally the only mechanized field operation. The remaining field operations are manually executed which shifts the peak labor demand from land preparation to weeding and harvesting. The use of animal traction has a real impact on the amount of cropland reserved to groundnut production (5 to 8 ha). The majority of the available farm workers is generally directed to the groundnut fields and penalizes the cereals. Women involved in rice production according to the gender division of labor look more and more for other alternatives (power tillers or mini-tractors) to improve timeliness.

- Category 3: High-level-equipped households (7%)

The number of farm workers involved in production during the year is large, ranging from 9 to 21 persons. These households are well equipped and have 2 to 5 draft animals.

The area cropped with groundnuts is very important, and averages more than 8 ha. This crop receives the equipment priority. Farmers are sometimes forced to use supplemental external manpower to meet timeliness, as all the manpower is not available during the weeding operation of all cropped land.

2.5. Summary

The identification of the different agro-ecosystem zones at the regional level represents a major step toward the analysis and understanding of farmers' specific working conditions. The formulation of recommendations to improve their production techniques has more chance of success if based on existing opportunities. The factors involved in improving productivity in farmers' conditions are complex.

To increase productivity and sustainability, it is important to help farmers improve the soil management practices and conservation techniques. Improving tillage practices is an area to explore in order to reduce soil losses from upland areas and to mitigate the induced and rapid decrease in soil fertility. To meet these objectives, farmers must be involved at all phases of research and development. It is important, for example, that farmers be able to evaluate the physical properties of soils and select the right tool and implement to perform any given field operation in a timely manner (Henin, 1990). To achieve this level of decision-making involving prediction of the power required to carry out field activities on time, the physical and mechanical properties of the soils found in the region must be understood in terms of behavior under the influence of various factors.

Farmers in the same agro-ecosystem generally follow similar planting sequences as a village's coping strategy against major pests: maize-millet-groundnuts-sorghum with very little variation in the case of agro-ecosystems 4 and 5 (Equipe Systemes, 1983). The cropping practices usually differ from farmer-to-farmer in terms of type and amount of agricultural inputs used to carry out the field operations (Ndiame, Coulibaly and Fall, 1988). The degree of combination of these cropping practices also called "itineraire techniques" explains the differences in agricultural production performance among farmers.

The utilization of animal traction by farmers is viewed as an alternative to improving labor productivity. The potential behind the technology needs to be investigated more to optimize the output of the draft animals. It is important at this point to understand the difficulty and difference in levels of access to farm equipment and draft animals. As a factor of production, the utilization intensity of farm equipment is expected to be different from one agro-ecosystem to another and from one farmer to another. The variation in performance among farmers belonging to different mechanization categories needs to be better analyzed in order to be able to evaluate the impact of the technology at the farm level and to capture all of the information available in a knowledge-based system for later utilization.

Chapter 3

DETERMINANTS OF PERFORMANCE OF DRAFT ANIMALS

3.1. Constraints to animal traction utilization

Since the 1970s, development projects involving animal traction have flourished in many developing countries around the world. The utilization of animal traction appears to be very attractive for many small-scale farmers as an alternative way to agricultural mechanization (Starkey, 1989). A quick overview of the promotion and implementation of different animal traction-based projects has shown that the utilization of draft animals is not a panacea to solve the problem of all small-scale farmers in the Third World Countries. Eicher (1982) warned about the "maximum potential benefits" approach used by many agricultural researchers when carrying out animal traction project evaluation. He pointed out the tendency of the approach to inflate the projected returns and long-run economic profitability from the technology when data are mainly collected on experiment stations or demonstration farms.

The failure of different projects has demonstrated that the diffusion and implementation of animal traction have been limited by many factors. The most important are tradition, climatic conditions, diseases, poor infrastructure, lack of appropriate transportation and communication systems, inefficient marketing and credit systems, poor training, long duration of the learning process, inefficient extension services, cropping systems types, and inappropriate veterinary services (Pelissier, 1966; Munziger, 1982; Havard, 1987; Fall, 1990; Ndiame, 1990). Different studies have addressed these limiting factors and their impact on the implementation of animal traction throughout the world. One example reported by Starkey and Faye (1988) in relation to the sanitary constraints was the situation in Cameroon where the use of draft animals was confined to the Northern cotton producing areas of the country with low tse-tse flies infestation. Similar limitations are also described elsewhere: Central African Republic, Congo, Equatorial Guinea and Gabon where the use of animal traction is limited to a few mission stations; less than 1% of the farmers in Zaire make use of draft animals. In the Basse Casamance region the diffusion of animal traction from North to South had to face both traditions and sanitary constraints along with the cropping pattern (Pelissier, 1966; Traverse, 1974; Fall, 1985; Sonko, 1990;). Its utilization is mainly confined to the Northern part of the region where 18% (in the Northwest) to 68% (in the Northeast) of the farmers own at least one draft animal (Sonko, 1990). These general constraints explain most of the variability in the geographical distribution of draft animals in developing countries. A number of well-identified factors are involved in explaining the level of performance of small-scale farms that have adopted the technology.

3.2. Selection of draft animals

3.2.1. Availability

Farmers have a relatively wide variety of animal species to chose from for energy supply. Goe and McDowell (1980) in their guidelines for animal traction's utilization gave the p

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the potential of different species ranging from dog to horse. There was a large variation of daft potential among species. According to the survey carried out by Schmitz et al (1991) in 32 countries of Latin America, Africa and Asia, it appeared that cattle were the most commonly used animal breed for draft purposes.

An appreciable amount of quality research is being carried out throughout the world to increase the work output and efficiency of working animals. Crossbreeding within species is a widely used technique to improve draft potential. Different studies comparing breeds have shown that it was highly recommended to farmers to use local indigenous breeds as crossbred animal generally demonstrated inferior working performance. This was especially true for tasks of long duration. For extended periods of time, experience has shown the local breeds always produced the most steady output (Goe, 1983). Another important advantage of the local species described in the literature is their availability in numbers and accessibility to farmers, and their adaptability to the environment. An effective breeding program is always expensive to maintain in order to produce enough crossbred animals for a continuous supply of draft animals to the farmers. The supply aspect was found to be very important for the household in relation to the replacement of injured, dead or sold animals, and for the overall stability of the technology. In his investigation of the Basse Casamance situation, Sonko (1985) analyzed the diverse reasons of removing animals from service and the impact of the removal on the household performance (**Table** 7).

The analysis carried out showed that the technology was unstable for 71% of animal traction users who generally possessed one pair of oxen. The loss of one animal during the growing season (26%) was likely to compromise the objectives of the farmers'

Table 7: Reasons for removing animals from service

Reasons	Number of animals	Percentages (%)
Sales	93	46.5
Death	52	26.0
Trade	14	7.0
Slaughter	13	6.5
Theft	8	4.0
Rented out	7	3.5
Out for training	4	2.0
Return to herd	4	2.0
Gift	2	1.0
Unknown	3	1.5
Total	**200**	**100**

Source: Sonko, 1985

production systems, unless they decided to rent a team of oxen from better off farmers. For this reason, he suggested that the optimal number of oxen at the farm level is 3 to secure at least agricultural production.

3.2.2. Selection process

Specialists have agreed on most of the criteria used to select draft animals. Usually, draft animals for a given breed or species were either selected from the herd of the household or village, or bought from the market. The conformation (physical form, neck, legs and feet, horn, etc...), the character, the age, the sex and the weight were the major criteria for the selection. They also presented the most important factors affecting the work output and working career of a draft animal. The tractive potential of draft animals is generally determined by their liveweight LW in kg and their weight distribution. In comparing crossbred and indigenous cattle, Goe (1983) pointed out that the amount of weight distribution over the front legs should enable the crossbred animal to generate more power. The format and age at which an animal started its working career were determinant in its future performance.

The selection must be done from available species in relation to the expected task to be performed by the animals in the given environmental working conditions. Crosseley and Kilgour (1983) presented a list of advantages and disadvantages of the most commonly used draft animals in crop production: horse, ox, donkey and dromedary. Horses appeared to be very costly to maintain and easy to train while oxen were characterized as easy to feed and to acquire.

3.3. Training of draft animals

The working capability of animals is determined by in large by the quality and the level of training. An important number of publications on this topic are readily available to farmers. These publications are generally used as guidelines by numerous projects during their early implementation phases. The selection and training of animals are crucial for their working career. The main objective of the training sessions is to build a working behavior into the animals in terms of responsiveness and obedience. According to Conroy (1992), the trainer and the animals must develop a relationship based on respect and dominance, as animals deserve feed, rest, shelter and social interaction. During the training sessions, it is important to manage the temperament of the dominated animals. For this purpose, animals should not be frightened and negative aspects of the dominance reinf

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reinforcement must be avoided. One frequent negative aspect reported by Keith (1992) was to put the animals in discomfort while working which could cause them to associate the trainer or eventual driver presence with pain and upcoming punishment. The castration of bull is one common technique used by farmers to calm down the animal and to reduce their aggressiveness. The operation is performed between the age of 1 to 5 years in relation to the age of first selection and training.

The age at which animals are selected and trained varies among and within species: 1 to 8 years for buffaloes in Asian countries and 2 to 4 years for cattle in general (Goe, 1983). A good rule of thumb is to start the training when the body weight and physical development of the animals have reached 50% to 70% of the matured weight (Goe, 1983; Lee et al, 1993) (**Table 8**).

Lhoste (1990) reported that farmers with draft cattle in the Groundnut Basin (Sine Saloum) of Senegal used different management strategies in relation to the age of training and length of working career of the animals on-the-one-hand, and the existing marketing opportunities at the end of their career on the other. The training ages ranged from 2 to 5 years; the longest career was 6 years and the shortest 3 years.

In the Basse Casamance region, studies conducted by Sonko (1990) and Ndiame (1990) showed that the training age ranged from (AGETRAIN) 2 to 6 years and the average working career was 6 years. The training sessions were carried out one month before the rainy season. Keith (1992) working experience with cattle showed that weaned calves between the ages of 2 to 6 months were easy to train as they trusted and quickly accepted the trainer. In such cases, the training would require a firm commitment and planning from the trainer as the useful work would really begin at 3 to 4 years of age.

Table 8: Age and weight to initiate training of cattle for work

Breed or Type	Age Castrated (year)	Age trained (year)	Weight (kg) 1 year	2 year	Mature Weight (kg)
Adamawa	-	-	145	190	350-500
Azaouak	-	-	-	-	350-500
Maure	-	2.5-4.0	-	-	230-350
N. Soudan Shorthorn	-	1.5-4.0	80	135	300-410
Shuwa	-	2.5-3.0	145	240	350-400
N'Dama	1.5-2.0	2.0-3.0	84-136	200-300	280-410
Senegal Fulani	-	5.0	-	-	300-415
Ankole	-	2.2-5.0	140	225	300-410
Bukedi	-	2.0-3.0	90-120	160-175	350-450
Bororo	2.5-4.0	2.0-4.0	-	-	350-400
Lugware	-	3.0	85-100	150-200	300-350
Madagascar Zebu	-	4.0	175	260	300-450
Kankrej	0.5-1.0	3.0-4.0	175	250	360-550
Nagori	0.5-0.8	3.0	112	217	350-360
Ongole Sumba	-	3.0-3.5	215	350	540-680
Khillari	5.0-5.5	2.0-3.0	-	-	450-635
Lohani	3.0-3.5	3.0-3.5	-	-	270
Siri	4.0	4.0	150-185	200-230	315-540
Krishna Valley	3.0-4.0	2.5	150	250-275	490-519

Source: Goe and McDowell, 1980.

All these factors are highly interrelated and contribute significantly to building up the animals' willingness to work which turned out to be an important determinant of the animals' working performance. The willingness to work affects the percentage of the body weight (PF/LW in percent) available for potential power use. The willingness affects the efficiency of the draft animals teamed through the harnessing system.

3.4. Harnessing systems and team constitution

3.4.1. Types of harnessing systems

The main objective of a harnessing system is to allow better transmission of energy from the animal to the implement. The term "harnessing" is used in its general sense to mean yoking as well (Le Thiec, 1991).

A wide range of harnesses and yokes are being used around the world. This topic has been addressed in depth by different researchers (Hopfen, 1969; Starkey, 1989; Le Thiec, 1991).

Generally, harnessing systems are divided into two categories: horn or head yokes and withers or shoulders yokes. The first type of yoke is tied in front or behind the horns. In both cases ropes or leather straps are used to firmly secure the yoke around the horns. As mentioned by Le Thiec (1991) and Starkey (1989) a better fit could be guaranteed by carving the part of the yoke resting on the head of the animal. A head yoke must be strong and light for better comfort. The best features of cattle to fit the head yoke turned out to be a short and strong neck, and strong horns. Empirical experiences have shown that this type of harnessing system presented advantages of better coordinating the movements of working animals specially when instantaneous maximum draft is required, by allowing a rapid adjustment of the line of draft to reduce the angle of pull. The main disadvantage found for continuous work was the more rapid state of fatigue induced by the rigidity of the yoke attachment (Le Thiec, 1991). He warned also against the bad quality of some ropes used by farmers, which over time cut off the horns.

The shoulder yokes were mainly designed for forward motion. They are adjusted to pull against the shoulder muscles or the front base of the hump for Bos indicus cattle. The simplicity of fabrication has caused them to be widely used specially to pull different types and sizes of carts for transportation. The main advantage of this design allows the animals to move their heads freely which induces less fatigue than head yokes. Experience has shown that animals harnessed with withers yokes refused to pull and try to get away when maximum draft is required.

3.4.2. Efficiency of harnessing systems

The work efficiency of animals was found to depend primarily on the effectiveness of the energy transmission. A subjective evaluation technique of this effectiveness by animal traction users is the classification and codification of the energy transmission mode into (1) inefficient, (2) average and (3) efficient harnessing systems. According to Goe and McDowell (1990), a good and well-design harnessing system would help increase animal draft capacity by providing at the same time enough comfort to the animal. Starkey (1989) stressed the quality of a good harnessing system to maximize its positive effects in terms of mutual encouragement of teamed animals towards achieving a sustained work. Researchers have been focussing on animal factor ergonomics to improve the energy trans

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transmission for better efficiency. One major step was the improvement of the yoke design for a better attachment to the working animals (Le Thiec and Havard, 1995; Roosenberg, 1992).

The potential energy and pulling capacity were increased by teaming animals through a harnessing system which coordinates their movement. The process of teaming must start at the animal selection phase in relation to the task to be performed and the assessment of the expected draft requirements. According to Conroy and Rice (1992), oxen do not need to be identical in order to make up a successful working team. The suggested selection criterion to focus on was animals' ability to work together. They urged oxen team trainers to look for similar temperament, agility, size, conformation, and speed. This position was not far from the recommendation made by most animal traction specialists to select closely identical animals (CEEMAT, 1971; Watson, 1981). In the case of animals of different size, the strongest should always walk in the furrow when working with a moldboard plow in order to balance the draft demand between the two animals.

The pulling force potential expected from a team of animals was found to be less than the cumulative potential of individual animal making up the team. Marks (1951), cited by Goe (1983), reported the results obtained with different teaming scenarios. They showed that the harnessing system induced a loss of efficiency amounting to 7.5% for a pair, 15% for triplet, 20% for quadruplet, 30% for quintuplet, and 37% for sextuplet. The researchers of CEEMAT had specifically addressed the case of teaming oxen and found similar results (CEEMAT, 1972). Their findings showed that the potential of one animal must be multiplied by 1.9 to estimate the expected potential from the pair of oxen (10% of efficiency loss). Lee et al (1993) translated Marks findings into a general formula to evaluate

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evaluate the efficiency of the team (TE) in relation to the size of the team (TS):

$$TE = 1 - (TS - 1) * 0.075 \quad (1)$$

The average liveweight LW of each animal working in a team can be determined if the draft requirement DR for the task to be performed and the percentage of the body weight (BWP= PF/LW) that an animal could develop into pulling force (PF) were known. Watson (1981) proposed another formula by assuming a 15% loss of efficiency for a pair of oxen:

$$LW = \frac{DR}{0.85 * BWP} \quad (2)$$

The numerical default value of BWP used most often for cattle was 0.10 (10%) for long term traction (CEEMAT, 1975). This value needs to be validated with the local breed used for traction.

3.5. Working capacities

In general, farmers intend to get the best performance out of their working animals. The handling and care of draft animals (health, housing, feed) were found to be an important consideration in order to keeping them in good working condition. When conditions were bad or the management poor, animals would become more sensitive to stresses and diseases.

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3.5.1. Climate effects

In the hot and humid climate of the tropics, exhausted animals will rapidly tend to lose their tolerance to trypanomiasis and mortality will increase. According to Crossley and Kilgour (1983), veterinary services must be made available especially to farmers. They must look daily for the more common symptoms related to the appearance and behavior of the animals: urination, mucous membrane, temperature, pulse and respiration rate. Only healthy animals were found to be able to produce the desired power output. Falvey (1986) defined health as the optimal functioning of animal body. This optimum could easily be offset by the effects of stress on the animal's immune system and by injuries caused by the harnessing and hitching system. He warned that stress could be created by overworking animals which are in a state of malnutrition. This would impair the immunoglobulin production due to deficiency of proteins.

Experience and tests conducted in different places suggests strict management practices to minimize the drastic effects of climate on the work output of draft animals. Besides the sanitary aspects, the environmental effects on working animals' needs to be investigated more to help farmers select the best animal. Draft animals do react to changes in working regime and environmental conditions by making physiological adjustments to maintain their body heat. These adjustments caused thermal stress on the animals reflected in their future behavior (Singhal and Tomar, -). A few studies have tried to show or quantify how much the temperature and the humidity really have affected the working efficiency. These two factors relate directly to the ability of the animals to dissipate the heat produced during the task performance. The heat transfer from the animal body to the environment is a natural phenomenon. The heat exchange is generally conveyed through conduction, convection, radiation and secretion of sweat. Reported results from Premi (1979) stipulated that the respiration rate of bullocks doubled with every 10°C rise in temperature. Goe (1983) reported similar results with the Hariana; the respiration rate and body temperature increased as the ambient temperature increased from 10 to 28°C. An increase in relative humidity reported in the same study affected the blood and respiratory system as it accelerated the pulse rate. Zander (1972) gave the range of 30 to 70% for air humidity to be a comfortable climate. The combination of these environmental factors was found to play an important role towards the animal's state of fatigue when at work (**Table 9**). Animal traction users agree that morning hours represented the best time period to carry out field operations. These important results need also to be validated in different working conditions.

Table 9: Environmental factors on draft animals

Type of Animal	Pulse Rate per minute under jaw bone	Respiration Rate per minute	Temperature °C
Cattle	40-50	10-30	38.5-39.5
Horses	36-42	8-16	37.5-38.5
Donkeys	40-60	40-56	36.0-38.0

Source: Crossley and Kilgour, 1983

The most detailed study available which reports the direct environmental factors affecting physiology deal with the human body (Essay, 1969). Essay developed a linear model to evaluate a parameter called the Temperature-Humidity Index (THI) which is related to the dry bulb temperature and dew point temperature. For THI values between 70% and 79%, 10% of 100 people were feeling uncomfortable. The THI can only be used as an indicator and must be set for draft animals working in a given environment. Other empirical methods based on management practices which included rest periods were recommended by field researchers to optimize the output of working animals in a given environmental condition. The level of fatigue of working animals was indicated through physiological and behavioral manifestations (Upadhyay, 1989): unwillingness to work, frequent stops, respiratory problems, etc. In tropical climates, the maximum working time ANWKHR in hours must not exceed 8 hrs per day. Devnani's (1981) investigation showed that bullocks' work time during the summer must be kept between 5 to 6 hrs per day and divided into two sessions (morning and evening). In the Basse Casamance region, Traverse (1974) suggested that the Ndama cattle could be managed in relation to the intensity of the work:

Light task: 7 hrs/day + rest at mid-day

Medium task: 7 hrs/day + rest at mid-day + 1 day off/week

Heavy task: 3.5 hrs/day from 8:00 to 11:30 am.

This classification was made possible in relation to the draft required to perform different tasks: transport, harrowing and weeding were considered as light jobs; plowing sandy soil (upland crops) as a medium jobs; and working clay soil (lowland rice fields) as heavy jobs. The most recent studies conducted by Fall (1985) and Sonko (1986) have shown that in fact, farmers in the Basse Casamance region used draft animals for less hours per day to perform field work.

3.5.2. Pulling force potential

The potential pulling capacity PF in N or daN of a working animal was found to be mainly determined by the animal species and breed, weight, age, nutritional and health condition, level of supervision and training, and methods of harnessing. A well documented research program showed that the pulling capacity was directly proportional to the animal body weight (CEEMAT, 1974; Goe and McDowell, 1983; Starkey, 1989; Campbell, 1990) which in turn was affected by the body condition of the animal and the harnessing system **(Table 10)**.

The potential was expressed in animal body weight percentage (BWP in %). The average long term pulling force (PF in N or daN) developed by working animals was found to be within the ranges of 15% to 20% for donkeys, 12% to 15% for horses and 9% to 12% for cattle (CEEMAT/FAO, 1972). Goe (1987) mentioned a draft potential of 18% to 23% of the body weight from Ethiopian draft oxen.

Table 10: Work potential of man and various animals

Item	Man	Horse	Ox	Donkey
Weight (kg)	80	400-700	300-900	100-300
Pull (N)	100	500	500	400
Speed (m/s)	1.0	1.0	1.0	1.0
Power (kW)	0.1	0.5	0.5	0.4
Daily work hours (h)	6	6	5	4
Daily work output(MJ)	2	10	9	6

Source: Crossley and Kilgour, 1983

Research findings showed that during their growth phase, the closer the draft animals' liveweight approached their mature, or genetic weight, MATURELW in kg, the heavier the type of work they could perform. This point has been emphasized by Upadhyay (1989) who stipulated that heavy animals possessed more pulling capacity than light animals but were less suited to speedy work. In evaluating this potential and taking into account the morphological aspects, Goe (1983) and Lee et al (1993) suggested a body weight parameter called the condition score CS. The condition score excludes from traction any animal scoring less than 1 (after rounding off). This corresponds to less than 50% of the body weight ratio depicted in the following equation where LW in kgf and MATURELW in kgf were respectively the animal live and mature weight:

$$CS = 5[(\frac{LW}{MATURELW}) - 0.4] \quad (3)$$

The liveweight LW could be measured by using proper scaling devices generally available at the veterinary services or the governmental extension agencies. In areas lacking infrastructure and effective technical support services to farmers, researchers have developed different models to help estimate the weight of cattle based on the morphological features of the animal (CEEMAT, 1974; Watson, 1981):

$$LW = \frac{(girth)^2 * L}{300} \quad (4)$$

Where the girth (in inches) represents the circumference (CIRCUMF) of the torso at the point of heart and L (in inches) represents the length of the animal from the point of shoulder to the rump. However the applicability of this formula was limited to non-castrated oxen. Cows were also used in areas where they were culturally accepted. The pulling capacity of cows was found to be approximately 5% lower than for male animals (Lindsay, 1986). Also cows needed special care and more attention than males in order to maintain their reproductive capacity and milk production. In the Sine Saloum region of Senegal (known as the Groundnut Basin), survey reports indicated cows were 26% of the draft cattle and were used as a second or third team member to support the already existing draft oxen (Lhoste, 1990). In the Basse Casamance area, only male cattle were used for traction (Sonko, 1985).

3.5.3. Work potential and energy requirements

3.5.3.1. Instrumentation

The evaluation of work output and energy expenditure was found to require from simple to highly sophisticated instrumentation in relation with the type of parameters to be included in the energy determination. Research efforts were mostly centered around the development of different sensors to help measure integrated parameters as heart beat, pulse rate, respiratory rate, draft, speed, oxygen consumption, body temperature, etc. Substantial resources were put into the development of new methods integrating physiological and physical parameters. At the same time, the classic approach using a simple dynamometer and integrating distance traveled DISTRAV with animal speed ANSPEED measurements was still widely used because of its simplicity compared to the new methods. The new methods were divided into direct and indirect measurements. These two techniques were well documented by Lawrence and Pearson (1989).

The direct method involved the measurement of heat output dissipated from the animal's body. The heat generated during the task performance was produced by the oxidation of carbohydrates, fats and proteins to carbon dioxide, water and urea. The method presented some serious limitations. The animals must be kept enclosed in a chamber. The theoretical and practical aspects of the measurement technique need to be investigated more in order to make the results usable in field operations.

The indirect method took the measurements one step further by addressing not only the heat production but also the amount and the quality of gaseous exchange involved. The technique was based upon the calculation of the heat dissipated by the body using a measurable parameter represented by the amount of gaseous exchange. The underlying principle was that no heat was produced without gaseous exchange. Oxygen (O_2), carbon dioxide (CO_2) and respiratory quotient were the parameters mostly concerned. Two types of apparatus were used by the Center for Tropical Veterinary Medicine (CTMV) at the University of Edinburg:

- Classic Open Circuit System for use on the animal at work and at rest. The system was not portable and the use of a treadmill was necessary to enable the animal to work while staying in one place.

- The Portable Breath-by-Breath Analyzer in the form of an airtight facemask fitted with a flow meter was to measure the volume of each breath. Samples of expired air were to be analyzed in the laboratory with the application of correction factors related to temperature, atmospheric pressure and humidity. The apparatus could not be used in the field because of the laboratory intervention, representing a serious disadvantage.

The AFRC instrumentation package was also developed for continuous measurement of both physiological and mechanical work performance variables (O'Neil et al, 1989). The data stored in the data logger during the work session were: draft force, angle of pull, speed, heart rate, breathing rate, body temperature and stepping rate. The only disadvantage resided in the non-availability and high cost of sensors used to collect the data. The CEEMAT package put more emphasis on the mechanical variables.

Other methods to estimate the different levels of energy required of working animals are indicated in the literature.

These levels of energy have been designated as maintenance, work and liveweight gain by many authors (CEEMAT/FAO, 1972; Goe, 1980; Lawrence, 1985; Falvey, 1986; Pearson, Lawrence and Ghimire, 1989; Lawrence and Zerbini, 1993).

3.5.3.2. Energy at work

FAO (1972) reported the energy requirements for ruminants at work to be about 2.6 fold the maintenance energy. Pearson and Fall (1993) believed that the FAO method overestimated the energy required. For the specific case of cattle, the values published by Lawrence and Zerbini (1989) were the most recent. The technique used the factorial method and was found to be feasible for long measurements in the field. It was based on deter

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determining the extra energy E used by working animals of liveweight LW (in kg) when walking on a horizontal distance HD (in km), carrying loads LC (in kg), doing work W (in kJ) while pulling loads, and walking uphill a vertical distance VD (in km):

$$E = A*(HD)*(LW) + B*(HD)*(LC) + \frac{W}{C} + \frac{9.81*(VD)*(LW)}{D} \quad (5)$$

The coefficients given by Lawrence and Zerbini (1989) were mainly for cattle:

A = 2.0 kJ/kg of LW per km of HD
B = 3.0 kJ/kg of LC per km of HD
C = 3.3 kJ/kJ of W
D = 0.033 kJ/kg of LW per km of VD

The values of the coefficients were obtained through laboratory experiments, which represented a major disadvantage compared to measurements performed in the field. The coefficients need also to be evaluated for local breeds.

3.5.3.3. Energy for growth

Most draft animals reached maturity during their working career. Energy was required to foster their growth while at work. The level of energy was found to vary in relation to the management practices and the task to be performed (work-only versus work and fattening). Goe (1983) warned that the energy used by working animals for growth needed more investigation as the values published in the literature presented important discrepancies. He presented research results obtained in West Africa reporting a rate of growth of 1 kg/day for cattle trained at 0.5 to 3 years of age. Experiences conducted in farmers□ condition in Senegal showed that the oxen used in the Groundnut

Basin areas gained an average liveweight of 33% per year or 0.16 kg/day, 25% per year or 0.11 kg/day and 17% per year or 0.05 kg/day. This was observed for draft animals trained at age 2-3 years and weighing 170 kg, 3-4 years and weighing 220 kg and 5-6 years and weighing 300 kg (Lhoste, 1990).

3.5.3.4. Energy for maintenance

The energy required for maintenance has been investigated by numerous scientists and appears in most animal traction manuals and guidelines. Lawrence and Zerbini (1993) presented MAFF (1984)'s contribution in evaluating the energy required for maintenance MAE (in MJ/day) for cattle of liveweight LW (in kg):

$$MAE = 0.36 * (LW)^{0.73} \quad (6)$$

The working capacity and the source of energy required for draft animals at work were described to be largely dependent upon the availability of quality feed and the efficiency with which this feed was transformed into potential energy.

3.6. Feeding systems

3.6.1. Feed quality and availability

An important amount of information was published in the literature to present research carried out towards improving draft animal feeding systems. The rationale behind providing working animals access to better feed was the maximization of the amount of work obtained from the limited available resources. Feed is the main source of energy for animals. One important aspect of that research was to increase the nutritional value in order to provide the nutrients required for the execution of various physiological functions as work. As presented earlier, working animals rely on feed to provide energy for maintenance, growth and work. The necessary amount of feed for a working animal could be calculated if all the required energies were known. The only limiting factor identified in the literature was the non-availability of a reliable feed supply (Eicher, 1982). This was found to be a major technical constraint as feeding practices commonly used by smallholder farmers were simple and dependent on naturally available feed resources: grazing and utilization of seasonal crop residues and by-products. But most crop residues were regarded by nutritionists as poor quality feed (Wanapat, 1989). Ffoulkes and Bamualim (1989) suggested that the quality of straw feed must be improved by the addition of urea. A limited number of natural forages species were found to be high protein: Leucaena, Cassava, sweet potato and banana (**Table 11**). Beside the mineral requirements, draft animals need high energy feed mainly based on glucose and fat to satisfy the energy demand of different physiological functions as sustained muscular activity. According to Teleni and Hogan (1989), work was achieved through the combination of various systems based on adenosine triphosphate (ATP) generation, respiratory and cardiovascular functions.

3.6.2. Diet for working animals

Current research results on nutrition are yet to be transferred to farmers. In the West African region with a long dry season, reports show that farmers are still experiencing a shortage of energy as land preparation occurs at the end of the long dry season when animals are in their poorest condition. For most farmers, the diet of working

Table 11: Composition and digestibility of feeds (DM basis)

Types of feed	DM %	CP %	CF %	Fat %	Minerals (g/kg DM)				DMD %
					Ca	P	Na	S	
Crop residues									
Rice straw	33-95	4-6	33	1	5	2	1	1	38-55
Maize stover	85	6	32-46	1	4	2	0	2	54
Sorghum straw	91	4-8	33	2	3	2	1	-	42-48
Sugarcane tops	28	6	35	2	5	2	1	4	62
Cassava leaves	26	20	21	4	20	3	1	2	72
Banana leaves	24	12	23	4	7	3	1	2	45-66
Potato forage	11	13	14	4	14	3	<1	3	93
Tree legumes									
Leucaena	30	29	21	4	19	3	1	4	51-60
Glyricidia	27	24	18	4	7	2	1	3	67
Concentrates									
Rice grain	86	10	10	2	1	3	1	-	63-95
Rice bran	86	10	20	11-22	1	18	1	2	43
Maize grain	86	10	2	5	0	3	1	1	65
Soya bean meal	90	37-48	5	4	3	6	<1	3	25
Kapok seed meal	90	31	30	8	5	13	-	-	50
Cotton seed meal	86	44	14	8	4	11	-	-	28-50
Molasses	75	4	0	0	11	1	9	9	100
Tapioca waste	90	2	3	4	6	2	-	-	69
Palm kernel cake	89	19	13	5	3	7	2	2	-

DM: Dry Matter; CP: Crude Protein; CF: Crude Fiber;
DMD: Dry Matter digestibility.
Source: Extracted from Ffoulkes and Bamualim, 1989

animals is mainly based on roughage and browse. The loss of weight during this dry period represents a serious limitation to performing heavy fieldwork at the beginning of the cropping season (Starkey, 1989). As pointed out by Wapanat (1989), very few experiments on feed rations were conducted in on-farm conditions, in order to evaluate the feasibility and acceptance of the rations by the farmers.

The literature is documented well in methods and techniques of evaluating the amount of feed necessary for working animals. In general, all the authors take into account all forms of energy involved in satisfying the demand of physiological functions. Lawrence and Zerbini (1989) included in their estimation the energy for milking cows at work based on MAFF (1984)'s model. Crossley and Kilgour (1983) partitioned the energy content of feed into gross energy (GE), digestible energy (DE) and metabolizable energy (ME). It was only at the stage of metabolizable energy that the animal could really use the energy to perform work. All these levels of energy were interconnected:

$$ME = 0.8 * DE \qquad (7)$$

For poor feed (straw for example):

$$DE = 0.45 * GE \qquad (8)$$

For good feed (grains for example):

$$DE = 0.85 * GE \qquad (9)$$

The energy content of feed was generally determined on a dry matter basis (DM) and largely depended on the percentage of digestible dry matter (DMD). Crossley and Kilgour (1983) indicated in their analysis that the approximate maximum amount of DM called the Appetite Limit (AL in kg of DM per day), was related to its liveweight:

$$AL = 0.025 * LW \tag{10}$$

3.6.3. Forage Unit

Goe and McDowell (1980) reporting different nutritional research activities conducted around the world used the concept of total digestible nutrient (TDN) and forage unit (FU) to convert the amount of feed into GE and the ME[1]. For the West African region, most of the research activities have been performed by the French institutions CEEMAT and IEMVT. A comprehensive list of nutrient sources for working animals and their energy content using the feed unit (FU) concept has been published (CEEMAT, 1975). Average estimates of feed unit for maintenance (FUM in kg) published by CEEMAT (1975) could be modeled (R^2= 0.999) into a relation between the liveweight (LW in kg) and the number of forage unit FU to provide the required level of energy[2]:

$$FUM = 6.321 * 10^{-3} * (LW) + 0.7089 \tag{11}$$

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[1] TDN = carbohydrate + protein + 2.25 * fat
1 kg of TDN = 4.409 Mcal or 18.447 MJ of DE
= 3.615 Mcal or 15.125 MJ of ME
1 kg of FU = 0.74 kg of Barley

[2] The raw data used to develop the linear model are presented in the appendices.

The model output gave the same TDN results as the values published by Goe and McDowell (1980) and Goe (1983) for West Africa.

3.7. Implements selection and characteristics

Implement selection described by different authors was revealed to be as important as the selection of draft animals (Le Moigne, 1981; Starkey, 1989). For many farmers, at the earlier stage of adoption, the selection could be very complicated, as a variety of equipment designs are available on the market. The introduction of farm equipment in the cropping system by development agencies was not neutral and was done as a means towards achieving production objectives. The major challenge in the process was to fit most of the tasks to the draft animals by selecting the right implements. Once the implement was selected, its utilization would likely predetermine the execution mode of all the following field operations.

Animal-drawn implements were generally designed with ergonomic considerations for comfort and efficiency. They were mainly composed of three major parts: working components (moldboard, ridger, tines, and shares), frame or beam (equipped with or without wheels) and handles. The shape and sharpness of the working components were mostly responsible of the draft required (DR in kgf or daN) to move the implement in the soil in the horizontal direction of travel. Each farm implement had its own requirements in terms of draft and energy in relation to the type of soil. A number of draft tests conducted in different areas of the world have been reported in the literature (CEEMAT, 1975; Goe and McDowell, 1980) (**Table 12**).

Table 12: Draft requirements for farm implements (Equatorial Africa)

Implement	Draft	Speed (km/hr)
Plow		
Indigenous	0.14-0.70 kg/cm^2	1.61-2.42
Moldboard	0.21-1.12 kg/cm^2	2.42-4.84
Disc	0.31-1.00 kg/cm^2	2.42-5.65
Disc harrow		
single action	0.45-1.50 kg/cm	1.61-4.03
double action	1.20-2.70 kg/cm	1.61-4.03
Rotary tiller	0.70-3.50 kg/cm	0.81-2.42
Harrow		
spike or peg	1.80-2.70 kg/peg	1.61-4.84
spring tine	10.0-25.0 kg/tine	1.61-4.84
Roller or puddler	0.15-0.90 kg/cm	0.8-4.03
Leveler, float	0.30-0.70 kg/cm	1.61-4.84
Row-crop planter	30.0-70.0 kg/row	1.61-4.84
Grain drill	6.0-22.0 kg/row	1.61-4.84
Transplanter	10.0-20.0 kg/row	0.8-2.42

Source: Goe and McDowell, 1981.

For given working conditions, the draft required was found to depend on the type and condition of soil, and the angle of pull (γ in degree angle). All farm equipment involved in crop production were mainly characterized by working width (IMPLWWD in cm) and depth (IMPLWDP in cm). If PF in daN is the animal pulling force, the draft required DR in daN can be expressed as:

$$DR = (PF) * \cos(\gamma) \quad (12)$$

Different studies have shown the importance of the angle of pull γ and its dependency on the type of draft animal and the harnessing system (Dibbits, 1993; Le Thiec and Havard, 1995). The optimum angle of pull was found to give the true line of draft. The line of draft or traction was defined as the straight line connecting the point of draft located at the harness level (yoke clevis) and the center of soil resistance on the working component of the implement (Watson, 1981). Le Thiec and Havard (1995) found the angle of pull for Ndama cattle to be between 15° to 18° and 19° to 23° for Zebu. The variable horizontal and vertical hitch points located on the implement hitching bar are used to adjust the line of draft and the pulling angle in order to balance the soil forces acting upon the working components and the weight of the implement.

The utilization of animal-drawn implements requires skilled operators to minimize energy losses. Different studies found farmers differing in skills and years of experience. Eicher (1982) reporting Barrett et al in a study conducted in Burkina Faso pointed out that there was a slow learning process for farmers who were using donkeys or oxen for the first time. It took about three to four years before a farmer knew how to use a complete package of equipment. Implements were provided with different control systems and adjustment devices. Besides the horizontal and vertical adjustments previously mentioned to adjust the working width and depth, the wheel was designed to provide better stability. Adjustments by trial and error were commonly used to reach the point where the wheel was not pressing too hard on the soil surface and cutting into the ground to increase the soil resistance (rolling resistance and bearing friction) or not lifting off the soil surface (Watson, 1981). Handles were also provided to help steer and tilt the implement to correct the line of draft while in motion. A good adjustment was achieved if no force was felt at the handles to prevent the operator from steering the implement and controlling the working animals (Crossley and Kilgour, 1983).

3.8. Soils

3.8.1. Soil types

The draft DR in daN is mainly defined in relation to the resistance of the soil against advancing implements' working components (WKGCOMP). In other words, draft is the force required in the horizontal direction of travel as stipulated by ASAE Standards (1984) to initiate and sustain movement. In crop production, the physical characteristics of the soil were found determinant in the evaluation of the amount of force required for pulling a given implement.

In the US system, soils are generally classified into textural classes or orders. There are 12 major textural classes according to the size and distribution of the primary particles (percentage of sand, silt and clay). Soil structure relates to the arrangement of the particles into peds or aggregates (shape and size) (Foth, 1990). The different soil classes are summarized in the commonly used textural triangle. Within the categories of soil taxonomy, soil orders represent the highest category. There are 11 orders divided into subgroups, family and series.

As pointed out by Charreau (1974), the soil survey and classification of the West African region had been made possible by a group of more than twenty French researchers (IRAT and ORSTOM) who helped train African soil scientists during a twenty-year period. They used the French system elaborated in 1967 by the CPCS to develop the West African soil map. The classification was made of 12 classes subdivided into subclasses, groups and subgroups, families, series and types. The family was composed of soils formed from the same kind of parent material. The series related to the position on the toposequence and the types relate to the texture of the surface horizon. They also presented five vast zones originated from the following parent materials:

" **a.** In the northern part of Senegal, Mali, Niger and Chad: sands and sand dunes.

b. In the Niger River's arc and a great part of the Chad basin: alluvial deposits ... ranging from pure sand to fine clay.

c. Westward, south-westward, and eastward of the Niger River's arc in Burkina Faso, in two-thirds of Senegal and in Southern Chad are found the Terminal Continental formations. ... The materials generally went through a strong ferralitic alteration. ...

d. In the southern part of Niger River's arc, in the central part of Mali, and in the western part of Burkina Faso is a vast area of Combro-Ordovician sandstones overlanded by an ancient "lateritic" iron pan ...

e. In the southern part of Mali, in Burkina Faso, in the central part of Chad: crystalline shield made up of plutonic rocks, metamorphic rocks and volcanic rocks. ..."

The soil map showed that large areas were occupied by grey and yellow-to-beige ferrugineous soils, and red ferralitic types of soil. The soils were also characterized by a field capacity (SFC) of 15 to 20% v/v and a wilting point (WP) of 7 to 9% v/v.

The oxic horizon of the ferrugineous and ferralitic soils are mainly made of a mixture of three elements: kaolin, amorphous hydrated oxides (iron and/or aluminum), and quartz. The amount of kaolinite is highly variable. The soils are desaturated and characterized by a low cation exchange capacity CEC due to the presence of kaolinite. As described by many soil scientists, they have almost reached the end point of weathering in their evolution (Charreau, 1974).

These two types of soil are dominant in the southern part of Senegal (Ducreux, 1984). The gray ferruginous soils ("Beige soil") presents a sandy to coarse loamy texture in the upper horizon with a subangular blocky structure and a fine loam to fine clayey texture in the deeper horizon with angular blocky structure.

The ferralitic soils also called "Red soil" (due to the presence of amorphous iron oxides) present some Alfic characteristics with subsurface horizons of clay accumulation and medium base supply. The texture and structure are similar to the grey type.

3.8.2. Mechanical and physical properties

3.8.2.1. Physical properties

Nicou (1975) and Ducreux (1984) presented, in their respective studies, the ferrugineous and ferralitic soils to derive their physical characteristics and mechanical behavior from the predominance of kaolinite and sandy to sandy-clayey texture of the surface horizon. The dry climate through the wetting and drying cycles had significantly affected the aggregates and structure stability. The stability refers to the ability of the soil aggregates to resist the disintegrating effects of water and mechanical manipulation (Jury et al, 1991). The low clay content in the upper horizons (8 to 12%) and the presence of kaolinite were described to confer to the soil surface a massive to structureless behavior when dry. In this situation, the aggregates tended to harden and a cementation of the whole soil mass takes place (Charreau, 1974). This process of increasing cohesion called "prise en masse" during the drying phase of the cycle is a well-known soil characteristic of the dry tropical regions. The phenomenon has been studied mainly by penetrometry by different researchers, in relation to the soil texture, water content and porosity. The soil cone penetrometer was designed and validated as a standard device used to measure the penetration resistance of soils called the "cone index" (CI in kgf or daN per cm^2). The cone index CI is used to compare mechanical properties of different soils, and to develop performance and prediction relationships. ASAE Standard (1984) has recommended two cone base diameter sizes: 20.27 mm with 15.9 mm shaft diameter for soft soils, and 12.83 mm with 9.5 mm shaft diameter for hard soils. The hand-operated cone penetrometer used by Charreau (1974), Nicou (1975) and Ducreux (1984) is described as a simple graduated and sharp metallic shaft (15 to 20 mm in diameter) with a 60° cone and a sliding weight

(SLWGHT in kgf or daN). The sliding weight falling from a given height (HGT in m) drives the shaft into the soil to a certain depth (DEP in m) (Ducreux, 1984). If SR in kgf or daN is the soil resistance to the shaft penetration, then the penetration energy E_{DEP} corresponding to the depth DEP is given by:

$$E_{DEP} = (SWGHT) * (HGHT) = (SF) * (DEP) \quad \textbf{(13)}$$

The penetration forces were found to be 5 to 10 times higher when the soil was dry than wet. At various moisture regimes above the wilting point, field observations and soil manipulation in the laboratory showed that the sandy texture of the surface horizons tends to give to these tropical soils a non-sticky, non-plastic and friable state of consistency (Charreau, 1974; Ducreux, 1984). The mechanism involved in this hardening process during the dry season and after intermittent rainfalls followed by dry spells during the wet season is still under investigation. Nicou (1975) and Ducreux (1984) defined a textural index called the "hardening index" HI to characterize this physical behavior. The index was expressed as the ratio of the clay content over the coarse fraction (coarse silt + coarse sand). They found that there was a linear relationship between the hardening of the soil upper horizons and the index HI for soils studied in Senegal and Niger: the higher the index, the higher the tendency of the soils to harden during the drying cycle. The phenomenon was found to be important in relation to crop production (tillage and root penetration). For land preparation, Charreau (1974) warned that during this hardening process, the draft required by these ferrugineous and ferralitic soils appeared to be too high for draft animals found within the area of study (donkeys, horses or cattle). A draft value of 240 kgf or daN from a plow working at a depth of 15 cm in a ferrugineous soil was recorded in the southern part of Senegal.

3.8.2.2. Resistance to traction

The most frequent parameter used to characterize the mechanical behavior of different soils is the specific soil resistance SSR in kgf or daN/cm^2. It represents the sum of the soil and crop resistance and the implement rolling resistance. The draft per unit of furrow cross-section given by the ASAE Standard (1984) relates high-speed (greater than 3 km/h) field operations with implement types and soil types. With animal power, experience has shown that draft depends mainly upon the soil moisture conditions and the type of implements used.

The specific resistance was found to be highly variable among soils. Smith and Mullins (1991), cited by Lee et al (1993), classified the soil specific resistance in relation to their textural characteristics. They used the clay content as a criterion to divide the soils into 5 classes of specific resistance, ranging from 30,000 N/m^2 for coarse sandy soils (0% to 8% of clay) to 130,000 N/m^2 for clayey soils (50% to 100 % of clay). In these conditions, the draft required (DR in daN) to pull an implement with working width (IMPLWWD in cm) and depth (IMPLWDP in cm) in a soil of known specific resistance (SSR in daN/cm^2) is as follows:

$$DR_{soil} = (IMPLWWD) * (IMPLWDP) * (SSR)_{soil} \quad (14)$$

The main limitation of this approach was found to be that the soil specific resistance was not correlated to the soil moisture regime. Different studies on monitoring field activities revealed that farmers carried out field operations at non-optimal soil water content in order to meet their production objectives through better timeliness (Charreau, 1974; Fall, 1985; Lee et al, 1993).

The occurrence of the first useful rain event is usually a signal for farmers to schedule their field activities according to the number of working days available during the cropping season. The number of working days was considered to be highly determinant in the process of evaluating how farmers achieved their production strategies in relation with the climate and soil type.

3.9. Working days

3.9.1. Soil moisture regime

The soil moisture regime described by many authors as the main criterion is used to evaluate a working day in relation to the type of soil and weather. It is generally described by soil physicists to be highly dependent on temperature through evapotranspiration (ET in mm/day), rainfall (RF in mm), slope of the soil surface through runoff (RO in mm), drainage characteristics (DN in mm) and type of field operation to be performed (ASAE Standards, 1984). For every soil, a characteristic curve can be developed to relate the soil matrix potential Ψ_m in MPa or bar and the soil moisture by volume θ_v in %v/v. The soil water content can be determined either by in-situ measurements or estimated by using prediction models.

The first technique described in many procedures of determining soil water content in-situ involves the use of either soil moisture sensors (tensiometer, porous blocks, psychrometer, TDR) for volumetric soil water content (VSWC in % cm^3/cm^3), or soil samples with laboratory facilities for gravimetric soil water content (GSWC in % g/g). These methods are complementary. Once the soil particle density (SPD in g/cm^3), the soil bulk density (SBD in g/cm^3) and the water density (WAD in g/cm^3) were known it becomes easy to determine the other related soil parameters (Hanks, 1992).

The second technique used by crop modelers was mainly based on equations (soil water balance) to predict on a daily basis the soil moisture status. The prediction equations were generally derived from the hydrologic balance which states that the water stored in a given volume of soil (root zone) is equal to the difference between the amount of water added (rain and/or irrigation) and the amount of water withdrawn (evapotranspiration, runoff, drainage) (Hillel, 1982). In absence of irrigation, Hunt (1986) proposed the following equation to determine the soil water content (SWC in mm) during day n (the other variables have been previously defined):

$$SWC_n = (SWC_{n-1}) - (ET_n) + (RF_n) - (RO_n) - (DN_n) \quad \textbf{(15)}$$

Two main characteristics of the soil water system given as boundary values, are the field capacity (SFC in % or mm) and the wilting point (WP in % or mm). The field capacity is defined in the literature as the soil water content, sometimes called drained upper limit (DUL in % or mm), reached in a few days after wetting of the soil layers located near the soil surface (Ritchie, 1972).

At field capacity, the soil water drainage DN from the lowest soil layer of the root zone is generally considered negligible. Jury (1991) argued that a true field capacity does not exist, as water will always continue to drain under gravity reaching an insignificant level after a few days (two days for most sandy soil). The water content at field capacity corresponds to a soil matrix potential ranging from Ψ_m= -0.1 bar (-0.01 MPa) to Ψ_m= -0.33 bar (-0.03 MPa). During the desiccation process, the wilting point is described as the lower limit (LL in % or mm) of soil moisture at which water is not available to plant. Only adhesion water around the soil particles is retained by the soil matrix (Foth, 1990). The soil matrix potential at this stage of desiccation is Ψ_m= -15 bar (-1.5 MPa).

The soil water balance can be determined with the measurement in-situ of the soil volumetric water content at DUL and LL. The soil water holding capacity (SWHC in % or mm), sometimes called extractable water is defined as the difference between the soil water content at field capacity (SFC) and the soil water content at wilting point (WP):

$$SWHC = (SFC) - (WP) \qquad (16)$$

The average extractable water in the root zone is 13% for most mineral soils. This is related to the texture, as plant water uptake also takes place during the drainage process (Ritchie, personal communication). The soil water content at which the execution of different animal traction field operations are recommended lies within the soil water holding capacity range in the upper 30 cm of soil and 15 cm.

3.9.2. Weather factors

The weather related factors induce a probabilistic aspect into the evaluation of the number of working days. The technique developed was based on determining the precipitation probabilities (P_{rain} in percent) or frequency (F_{rain} in decimal). The probabilities of occurrence was calculated by using the empirical equations adopted by the American Society of Civil Engineering (ASCE) and referred to as the Gumbel's equation (AID, 1977; Schwab G.O., Fangmeir D.D., Elliot W.J. and Frevet R.K., 1993):

$$F_{rain} = \left(\frac{m}{n+1}\right) \qquad (17)$$

$$P_{rain} = 100 * (1 - F_{rain}) \qquad (18)$$

Where m is the order assigned to the precipitation event ranked in ascending order and n is the total number of data points. The associated return period is the reciprocal of the frequency F_{rain}.

The probability values for working days (PWD in decimal) during chosen period intervals (weekly, bi-weekly or monthly) have been calculated and tabulated according to different geographical locations. The probabilities are used to help estimate the number of working days (NWDAYS in days) a specific field operation can be performed within the time intervals at a certain level of confidence.

Le Moigne (1981) had carried out a similar analysis for the West African region. He proceeded by determining the number of non-working days. For monthly period intervals, he based his analysis on hypotheses built around soil/tool relationships. He identified four large zones characterized by one rainy season within Senegal, Mali, Niger, Burkina Faso and Chad. For each zone he used the number of rainy days per month **(Table 13)** with the following hypotheses:

Scenario 1:

He considered two predominant types of soil: sandy and clay soils. The sandy soils are located at the highest position of the toposequence and are mainly used for upland rainfed crops. Their physical characteristics are the same as the ferrugineous and ferralitic soil types described earlier. Generally, these sandy soils have a good drainage systems. They drain well and fast. In contrast, the clay soils are found in lowland areas located within the watersheds along the main West African rivers (Niger, Senegal, Volta, Lake Chad, Casamance, Gambia). They can stay saturated for longer periods of time compared to the sandy soils and prevent any tillage operation.

Scenario 2:

He identified the different field operations and cropping practices that are significantly affected by the amount of rainfall in terms of soil-implement working component interactions and ground trafficability.

In sandy soils, all fields operations involving the utilization of cultivator tines were classified as quasi-impossible to carry out for rainfall events amounting to more than 50 mm/day. For plowing and ridging, the execution was difficult for rainfall between 30 mm/day to 50 mm/day. Seeding and weeding required 1 day of drainage after rainfall

Table 13: Non-working days for the West African region

Zones (rain) /Field operations	Sandy soils											
	J	F	M	A	M	J	J	A	S	O	N	D
<= 350 mm												
Plowing	0	0	0	0	0	0	0.5	1.5	1	0.5	0	0
Tines land preparation	0	0	0	0	0	0	0	0.5	0.5	0	0	0
Seeding	0	0	0	0	0.5	1	2	4.5	3	1	0	0
Weeding - Ridging	0	0	0	0	0	1	2	4	3	1.5	0	0
350 to 600 mm												
Plowing	0	0	0	0	0.5	1	2	3	2.5	0.5	0	0
Tines land preparation	0	0	0	0	0	0.5	1	1.5	2	0.5	0	0
Seeding	0	0	0	0.5	1	2	5	5.5	5	2	0.5	0
Weeding - Ridging	0	0	0	0	0.5	1.5	3.5	5	3.5	1.5	0	0
600 to 800 mm												
Plowing	0	0	0	0	0	1	2.5	4	3	1	0	0
Tines land preparation.	0	0	0	0	0	0.5	1	1.5	1	0.5	0	0
Seeding	0	0	0	0.5	1	2.5	5.5	6	5.5	2	0.5	0
Weeding - Ridging	0	0	0	0	1	2	4	5	4	1.5	0	0
800 to 1200 mm												
Plowing	0	0	0	0.5	1	1	3	4.5	3.5	1.5	0	0
Tines land preparation	0	0	0	0.5	0.5	1	1.5	2	1.5	0.5	0	0
Seeding	0	0	0.5	1	2.5	3	5.5	7	6	4	0.5	0
Weeding - Ridging	0	0	0	0.5	2	2.5	4.5	6	4.5	2.5	0	0
	Clay soils											
<= 350 mm												
Plowing	0	0	0	0	0.5	1	1.5	3	2	1	0	0
Tines land preparation	0	0	0	0	0	0.5	1	2	1.5	0.5	0	0
Seeding	0	0	0	0	0.5	1.5	3	5.5	3.5	1.5	0.5	0
Weeding - Ridging	0	0	0	0	0.5	1.5	3	5	3.5	1.5	0.5	0
350 to 600 mm												
Plowing	0	0	0	0.5	1	1.5	3	4	3.5	1.5	0	0
Tines land prepar.	0	0	0	0	0	0.5	1.5	2	3	1	0	0
Seeding	0	0	0.5	0.5	1.5	3	6	7.5	6	3	0.5	0
Weeding - Ridging	0	0	0.5	0.5	1	2	4	7	5	2	0.5	0
600 to 800 mm												
Plowing	0	0	0	0.5	1	2	4	5	4	1.5	0.5	0
Tines land preparation	0	0	0	0	0.5	0.5	1	2	1	0.5	0	0
Seeding	0	0	0.5	0.5	1.5	4	7.5	9	6.5	3	0.5	0
Weeding - Ridging	0	0	0	0.5	1	3.5	5	6.5	5.5	3	1	0
800 to 1200 mm												
Plowing	0	0	0.5	1	1.5	2.5	5	6	5	2.5	0.5	0
Tines land preparation	0	0	0	0.5	1	1.5	2	3	1.5	1	0	0
Seeding	0	0	1	2	4	5	8	11	9	5	1	0
Weeding - Ridging	0	0	0.5	1	3	3.5	5	8	6	4	0.5	0

Source: Extract from Le Moigne, 1981 events between 10 to 50 mm. In clay soils, he found that trafficability was greatly limited by the level of soil wetness near saturation. For field operations, the amount of all rainfall event thresholds found for the sandy soils were shifted upwards by 10, 20 and 30 mm.

The major limitation of his work resided in the fact that detailed studies on rainfall incidence on the execution of field operation did not exist. He did not consider the limitations induced by the soil desiccation and hardening processes near the lower limit of soil water content (LL in %). The 30 to 50 years rainfall data collected in research stations throughout the region have never been analyzed in terms of linking amount and distribution of rainfalls to limitations in using the different farm implements present at the household level.

3.10. Land use and cropping systems

3.10.1. Animal traction and cropping systems

The main objective of the implementation of animal traction projects around Third World Countries was to increase agricultural productivity through yield increases and labor savings. The challenge facing many agricultural policy makers was to produce more than subsistence production levels. The transition from hand hoe to animal-drawn implements has led to an increase of farming intensity. New cropping scenarios and agricultural production opportunities have been created as more energy has been made available to farmers through the utilization of draft animals. At the same time, timeliness of field activities has improved. Farmers view the labor savings objective in another way, a means of reducing drudgery (Campbell, 1990; Ndiame, 1988). Ndiame (1988) reported that the majority of farmers (79%) in the Southern part of Senegal were using animal traction for plowing because it was easier and faster than hand tools.

Animal traction has made significant progress and has produced changes in cropping systems driven at least by one cash crop. The fast spread of animal traction in different parts of the world was mainly due to the introduction and expansion of cash crops (Eicher, 1982). In the Sub-Saharan region most of the cash crops were introduced and developed by the colonial system for export: groundnuts in Senegal, cotton in Mali, Burkina Faso, and Ivory Coast, etc... These cash crops represented the main source of revenue to farmers involved in these cash crop oriented cropping systems.

Also, animal traction has brought about significant changes in cropping patterns. Two non-desirable major effects have been the decrease in fallow through the extension of cropped areas and the acceleration of land degradation process through erosion. The extension of cultivated areas was made possible by the capacity to do more work in the time available (Crossley and Kilgour, 1983). In order to use animal-drawn implements on new fields, not only must the land be cleared, but stumps and big roots also must be removed which resulted in accelerating water and wind erosion (Pingall et al, 1987). More detailed studies on the impact of animal traction utilization on the environment need to be made.

The literature is rich in experiences showing that working animals were involved in different field operations at the farm level: primary tillage, ridging, seeding, weeding, harvesting, transport, etc. Farmers have found the utilization of animal traction for field activities very attractive. Spencer (1988) pointed out that the degree of adoption by farmers was limited by the availability of the different components making up the package and by the production costs involved in their utilization.

To carry out all field operations required to grow a given crop, farmers must make strategic decisions in allocating available resources in combination with a variety of implements present at the farm level to achieve a finalized production system (Equipe Systemes, 1984). Sebillote (~1983) addressed this question in terms of cropping practices and introduced the terminology of "itineraire technique". The "itineraire technique" was defined for a given crop cycle as the combination of different cropping practices executed in sequence, from tillage to harvest. Two "itineraires techniques" were considered different if a change was made in the mode of execution of any field operation. An "itineraire technique" involving the use of a ridge or moldboard plow for land preparation with the remaining post-tillage operations manually executed would be different from another "itineraire technique" using a moldboard plow and a seeder, or a moldboard plow with a seeder and a cultivator (Equipe Systemes, 1984). The level of energy and amount of labor used were found to be significantly different among "itineraires techniques".

3.10.2. Field performance and crop yields

Different field studies have tried to correlate the level of energy used for crop production and yield. The power used per unit of cultivated area was a common indicator used to demonstrate the benefit of animal traction over hand tools. Morris (1983) argued that the yield increase induced by more energy per hectare was mainly due to improved timeliness and better quality or precision of the field operation execution. Most agricultural policies and decision-makers have always looked at mechanized cultivation as an effective way to significantly increase the income of the household. To this perspective many African governments have encouraged the permanent occupation of land by farmers but prevented at the same time any form of private ownership of the land. As pointed out by Charreau (1974), the Government of Senegal, for instance, passed a legislation to declare the Law of National Domain stating that any land in the country is nationally owned. The main objective of this government legislation was to give incentives to farmers involved in the national agricultural program of intensification through animal traction utilization. They urged farmers to remove all the stumps in their fields in exchange of 400 kg of rock phosphate (produced in Senegal) for each hectare cleared.

Agronomic research institutions have carried out field investigations to establish and quantify the benefits of the technology. The introduction of the animal-drawn plow for land preparation had given more opportunities to farmers to perform deeper tillage to a depth of 10 to 20 cm compared to the superficial traditional hand cultivation. The yield increases brought about by this cropping technique were mainly due by the combination of different factors. These factors are related to the improvement of the soil structure for better water infiltration and root development: better weed control and crop residues incorporation into the soil, better seed bed preparation for good conditions of plant germination and emergence, and better plant use of water stored in the soil. A fairly large number of technologies have been developed and, as shown by the percentage of yield increase over traditional practices, and most of them make significant contributions to productivity. Jaeger (1985) presented a summary of station findings widely used to demonstrate these beneficial effects (**Table 14**).

Table 14: Percent yield increase with animal traction plowing.

Sources	Millet	Sorghum	Maize	Cotton	Groundnuts	Rice
Senegal						
Charreau and Nicou In Sergent (1981)	30	30	30	27	19	50
Nicou In Le Moigne (1979)	19	24	50	17	24	103
Charreau (1971)	24	25	35	25	23	-
Ramond and Tournu (1973)	-	50	-	130	-	-
Tourte (1971)						
- Plowing only	25	44	43	41	20	-
- Plowing + OM	49	42	85	39	9	-
Mali						
SRCVO (1978) In Sergent (1981)						
- Donkey	-12	24	18	-2	-2	-
- Oxen	6	36	37	9	17	-

Source: Jaeger, 1985

The benefits gained from the utilization of the plow have been demonstrated in different parts of Africa. Especially in French-speaking countries of West Africa, plow use appears to be highly variable depending on the type of soil, the year and the type of crop. The depressive effects of plowing were mainly explained by poor plowing.

Field experiments conducted in farmers' conditions in the Casamance region for 8 to 10 years showed a modest trend of benefits (Equipe Systemes, 1984) when plowing was complemented with different levels of mechanized post-tillage operations like seeding, weeding, and harvesting. For groundnut production for example, the combination of mechanized plowing, seeding and weeding ("Itineraire 4") gave 59% more yield than plowing ("Itineraire 1 or 2") alone while mechanized plowing and seeding ("Itineraire 3") gave 13% more. These yield improvements were essentially due to better timeliness of the field operations, the efficient eradication of weeds and the physical stirring of soil for better aeration and water distribution in the root zone. In this process, labor input per hectare was also reduced by, as much as, 20% to 25% (Sonko and Fall, 1992).

3.11. Summary

The exhaustive review of literature presented on the determinants of performance of animal traction's utilization for crop production has shown a variety of research activities carried out in different parts of the world. Most of the well-published research activities and results found in the literature were from French (CEEMAT, IRAT), English (ARC, AFRC, CTVM) and German (GTZ) institutions, American universities (Department of Animal Science at Cornell University) and NARS in Third World countries. Investigations were conducted in different directions without really following any predetermined standard or procedure. The area of research appears to be new and open to more investigations. Lawrence and Pearson (1993) have addressed the issue of standardization in terms of (a) length of pre-experimental periods to allow draft animals to reach a 'steady state' (training, fitness, diet and climate) before measurements can be performed, (b) number of animals needed in an experiment for level of statistical significance of the results, (c) work and performance tests to evaluate continuous and instantaneous maximum efforts, (d) instrumentation and units to be used, and (e) physiological tests to understand the difference in draft animal performance when at work. The lack of standards in the measurement procedures introduced a factor of variability to explain the discrepancies found in published research results. The nature of the study involving living species made the task difficult for all researchers to agree upon the default values of different indicators used to predict working animal performance.

The main constraints limiting animal traction utilization and implementation around the world has been presented under different aspects, from climatic conditions related to the cultural behavior of target groups. The difficulty in laying out experimental designs involving weather as a variable made it quasi-impossible to rigorously compare draft animals working in different environmental settings. Along with weather, local sanitary conditions were described as a major issue in promoting animal traction. The prevalence of trypanomiasis in many wet and warm areas of the tropical region for example, has been considered by many authors to be a significant factor which slowed down the diffusion of the technology. The recommendation gained from the literature was to help farmers develop well-organized and feasible work plans to avoid over working their animals. More important was fitting the job to the draft animals' capacity in relation to the draft requirements and working conditions, the type of implement, the efficiency of the harnessing system, the type of soil (SWC) and its resistance to traction, and the probabilities of working days.

The new methods of energy evaluation presented have been mainly impaired by the laboratory determination of important parameters. This fact was described to represent a major disadvantage in the evaluation of some components of the energy balance in comparison to field measurements. For non-field measurable amounts of energy required from working animals, these parameters can be used to calculate the default values until the development of new, more realistic methods.

The quantity and quality of feed given to animal must meet the draft animal nutritional needs. In general, the right amount and composition of feed stuff was often reported not available to farmers. Most of the feed was mainly obtained through grazing on natural pasture. As pointed out by Ffoulkes and Bamualim (1989), when browsing, animals naturally tended to select feeds that were likely to enhance their body condition. Nevertheless, additional feed must be given on working days to avoid weight loss during peak work demand.

The use of draft animals for field work (plowing, seeding, weeding and harvesting) has demonstrated opportunities and potentials to generate substantial revenue to farmers through better productivity (yield increase and labor saving). This is made possible through better seed bed preparation, weed control, timeliness of field operation, improvement of soil moisture regime, reduction of labor.

Chapter 4

MATERIALS AND METHODS

4.1. Research sites

This study was conducted in distinct phases including both on-station and on-farm sites and focussed on the use of a pair of oxen as draft animals. Part of the human resources (animal scientist and soil scientist) needed to conduct the field work were provided by the Senegalese Agricultural Research Institute (ISRA) through its local Agricultural Research Center (CRA) of Djibelor located 7 kms South of the regional capital city Ziguinchor.

4.1.1. On-station

The on-station facilities were mainly used for the evaluation of the draft requirements of different field operations (plowing, ridging, seeding and weeding).

The Djibelor Agricultural Research Station (ISRA/CRA research center) is the major research station in the southern part of Senegal. Until 1979, research activities were mainly oriented towards the development of rice production techniques in relation to the amount of rainfall, the type of relief and the importance of hydro-agricultural production potential of the region. Since the events of the drought situation (1978-82), research activities were adjusted to reflect the new production strategies developed by farmers to counteract the effects of the shortage of rain. Multidisciplinary research teams were constituted at the station level to approach the diversity of the production systems found in the region from the perspectives of integrated agricultural and livestock activities, and mixed cropping systems. Following the new dynamic, research operations on upland crops (cereals and cash crops) and animal traction were given more emphasis at both on-station and on-farm levels.

Djibelor research station has several research facilities: soil and water laboratory, equipped farm shop, experimentation plots, pest management and plant genetics laboratories. The experimental units of the research station are located along the toposequence. The lowland plots are mainly used for the development of rice cropping techniques and the upland plots for the improvement of the rain-fed cropping systems (maize, millet, groundnuts, and sorghum). For this study, the on-station's research activities were conducted on the upland areas in the way animal traction is mainly used by farmers' circumstances (Posner, Kamuanga and Sall, 1988). The soils are "red soil" of the ferrallitic type, representative of most upland soils found in the region.

4.1.2. On-farm

Two research activities were programmed on-farm: survey on animal-drawn implements and test for maximum pulling performance along with a follow up of the draft animals' activities during the rainy season.

The on-farm target group was represented by farmers located in the two agro-ecosystem zones 4 and 5 in the northern part of the Basse Casamance region where animal traction is well established. A sample of farmers using animal traction for cultivation from four representative villages (two from each zone) was drawn for the field research activities. An important database about the target group is readily available which consists of information collected by the Farming System Research team (Equipe Systemes) of the Agricultural Research Center (CRA) of Djibelor during several years since 1982. Data are mainly related to field operations, production techniques, cropping systems, and calendar of agricultural production activities (Posner et al, 1985; Ndiame, 1990; Equipe Systemes, 1983). This database will be used as a reliable secondary data source.

The villages of Boulandor and Bougoutoub in agro-ecosystem zone 4, and Kagnarou and Suel in agro-ecosystem zone 5 were chosen for this on-farm study consisting of equipment survey and maximum performance trials.

4.2. On-farm equipment survey

As part of the methodology, an animal traction survey was conducted at the farm level (unit of observation). The farm is defined as an autonomous family composed of members who produce and consume together (Jolly, Kamuanga and Sall, 1988). The farm can be made of different dependent households. The center of decision making process in terms of management and resources allocation is located at the main farm level.

The focus of this study was put upon different aspects related to the use of animal-drawn equipment at the farm level. This type of survey could easily fit into a Rapid Rural Appraisal (RRA) approach (PRAAP, 1992). It was important to complete this survey in order to identify the range of implements used by farmers before any draft measurements and other energy estimation was performed.

The enumerators to conduct this survey had to undergo technical training to be able to identify the implements currently used by farmers.

4.2.1 Objectives

The objectives of the survey were:

1. Identify the types of equipment actually involved in field operations for which more detailed technical information was needed towards energy requirement estimates.
2. Evaluate farmers' learning process for animal traction use.

The null hypothesis (Ho) was that there was no difference in farmers' level of equipment. A farmer was considered to be equipped as long as he owed at least one farm implement (moldboard plow, ridger, cultivator, seeder, cart, etc.). The level of equipment encompassed two aspects of the mechanization process. The first aspect dealt with the total number of implements possessed by farmers and used to carry out field operations. The second aspect specified the possible combinations of implements used to perform field operations from tillage, seeding, weeding to harvest. The higher was the number of different types of implements, the higher the level of mechanization. Farmers with higher level of equipment were expected to perform better in the production system in terms of quality and timeliness of field operation.

4.2.2. Data collection

The questionnaire was designed to help collect three categories of information: type, management, and utilization of animal-drawn implements present at the farm level (Questionnaire in Appendix A1).

4.2.2.1. Type of farm equipment and draft animals

The main characteristics of animal-drawn implements retained in this survey were the type and shape of the working components. The configuration and aspect of these components were generally described to be responsible for the draft required to pulling the implement in given working conditions (type of soil, moisture regime).

The most popular working components expected to be found at the farm level were the moldboard plow, ridger with adjustable wings, furrow opener, cultivator tines equipped with various size of sweeps, duck foot shovels, or chisel points, and groundnut lifters.

Multipurpose farm equipment is also available in the market for farmers. These were designed and used for different field operations from tillage to harvest (groundnut lifting). This was made possible by simply changing the type of working component attached to the tool-frame. These multipurpose types were also sized to fit the job to the draft animals through the selection of suitable working components. In general, they require more skill from farmers compared to an implement with a simple frame design.

A second important characteristic was the type of traction used to pull the implement (pair of oxen, horse or donkey). The stability coefficient of the technology (STABCOEF in percent) under farmers' conditions was determined by evaluating the difficulties felt by farmers who have the minimum number of draft animals for field operations and in particular when these animal are oxen. The technology is considered to be unstable for farmers with only one pair of oxen, as the loss or unavailability of one animal will compromise the production objectives. The stability coefficient can be expressed as one minus the probability of farmers of having only one pair of oxen (PBPAIR in decimal):

$$STABCOEF_{oxen} = [1-(PBPAIR)] \tag{19}$$

The readiness of draft animals at work time was considered as a determinant indicator for better timeliness of field operations. Draft animal reliability ANIREL in percent was introduced at this point to report the probability that the draft animals were not available to perform field operations on time. It was computed as one minus the probability of draft animal unavailability, which is the probability of farmers of having one ox only at the beginning of the rainy season (ANNAVAIL in percent) when both probabilities were expressed in decimal form:

$$ANIREL = [1-(ANNAVAIL)] \tag{20}$$

In general, farm implements are designed and built with ergonomic considerations to fit height and draft requirements for the working animals. Fortunately for the farmers, most implements are interchangeable among draft-animals species through simple adjustments of the harnessing system. Switching from a pair of oxen to a single draft animal (donkey for example) requires the use of an evener.

The types of harnesses used by farmers to hitch the implements for their fieldwork were characterized in terms of attachment and size to help analyze the efficiency of the energy transmission mode.

The third characteristic was the type of the design and the purpose of the implement. Animal-drawn implements are generally built to fulfill specific purposes like land preparation, secondary tillage, seeding, weeding, cultivation, groundnut lifting, transport, etc. The utilization of one type of implement usually predetermines the execution mode of the following field operations. For example, if the land preparation is done with a ridge plow, it is likely that all remaining field operations (seeding, weeding, etc.) will be manually executed. It is important at the farm level to identify the function of each piece of equipment.

4.2.2.2. Management

The status and utilization rate of each animal-drawn implement found at the farm level was diagnosed to help understand its working conditions. The farm structural characteristics in terms of family composition (number of farm workers NFMWKERS, household dependency) was expected to dictate the type of ownership and explain how priorities were set up in the process of allocating available farm implements to different fields and crops.

The mode and date of acquisition in relation to the benefits generated were expected to give indications of the number of years of farmers'experience.

4.2.2.3. Utilization and maintenance

The level of use of farm implements during the growing season was generally reflected by the wear and the number of maintenance performed every year. From this information it was expected to be able to determine the frequency of equipment breakdown or the probability of equipment failure or the reliability (IMPLREL in percent) for each type of implement. The farm equipment reliability is defined by ASAE (1984) as the "statistical probability that a machine will function satisfactory under specified conditions at any given time. It is computed as one minus the probability of a failure" (PBRKDOWN in decimal):

$$IMPLREL = [1 - (PBRKDOWN)_{implement}] \quad (21)$$

Farmers' skills in adjusting and using the implements, and the physical aspect and nature of the fields (presence of roots and stumps) are described in the literature. These working conditions shorten the life expectancy of farm equipment in farmers' conditions (FARMLIFE).

Blacksmiths established in the villages were also contacted to evaluate their capacities for maintaining implements used by farmers in good working conditions.

It was important at this point in the survey to have the farmers' opinion about the efficiency of the technical support provided by the extension service and farm equipment dealers in terms of training, spare parts availability, and access to any type of credit.

4.2.3. Sampling techniques

The first step in the process was to determine the sample size **n** in order to have a good estimation of the population mean μ. This must be done in relation to the amount of error **d** that can be tolerated and the level of probability that this error was expected to hold (Bhattacharyya and Johnson, 1977). Farmers equipped with animal-drawn equipment represented the target population. The sample was drawn at random in the four representative villages of agro-ecosystem zone 4 and 5. The sample size **n** for the survey was determined by using the concept of standard error (S.E) and length of confidence intervals (C.I). At this level of planning, the sample size must be calculated in order to achieve more precision in the estimation of the different statistics. In this procedure, it was kept in mind that in general, a survey using a large sample size was more costly to implement and much more time consuming in terms of data processing. Without loosing too much precision in the results, the sample was sized large enough for the Central Limit Theorem to apply. The theorem states that, if **n** is large enough the distribution of the sample mean is approximately normal. In the case of non-normal distributions because of small **n**, the Chebyshev's inequality is still applicable. It stipulates that the probability that the difference between the population mean μ and an observed random variable **X** mean is less than a constant **d**, is greater or equal than 1 minus the variance of the observed random variable mean divided by the square of the constant **d**.

$$P[(|\bar{X} - \mu|) \leq d] \geq 1 - (\sigma^2 \div nd^2) \quad \textbf{(22)}$$

If the level of confidence is $100(1-\alpha)\%$, then the upper bound of the sample size is:

$$n = \left(\frac{\sigma^2}{\alpha d^2}\right) \qquad \textbf{(23)}$$

In this present study, the standard deviation σ of the population was determined from previous studies conducted in the same area (FALL, 1985; Sonko, 1986). The amount of error **d** that could be tolerated was set to 10% or 0.1 as suggested by Le Moigne (1984). The probability that the error of estimation would not exceed 0.1 was put to 90% level for $\alpha = 0.10$. Since the population variance σ was equal to 0.2, one calculated upper bound of the sample size was:

$$n = \frac{0.2^2}{0.1 * (0.1)^2} = 40 \qquad \textbf{(24)}$$

To implement the survey, **n** (total number of observations per variable) was equally divided into the four villages: $\mathbf{n_i} = 10$ for $\mathbf{i} = 1$ to 4 (**i**= village number).

4.2.4. Data analysis

The data collected in this survey were analyzed with the package MINITAB Statistical Software of Release 8 PC version. MINITAB is a registered trademark™ of Minitab Inc. Basic statistics were performed on the data collected regarding each type of equipment: frequency and distribution, mean, standard deviation and standard error, 90% t-Confidence Interval for the mean (Bhattacharyya and Johnson, 1977).

The data analysis was oriented towards approaching the variability among farmers in terms of the different types of possible implement combinations to conduct field operations from land preparation to harvest.

4.3. Estimates of energy requirements

4.3.1. Objectives

The objective of this research activity was to estimate the average energy required in carrying out field operations at the farm level. It was performed through the measurement of the amount of draft needed to pull an implement in a given working condition. The draft evaluation was carried out at different soil moisture regimes.

The null hypothesis (Ho) was that the amount of draft required to pull farm implements in given working conditions was mainly affected by the soil moisture regime and did not depend on the type of energy transmission system used to hitch the implement (width of head yoke).

4.3.2. Experimental design

For this purpose, a 2 x 3 x 3 factorial in randomized blocks design was laid out to help determine the combined effects of three factors: A= soil water content SWC range, B= type of implement EQTYPE and C= size of YOKE on the amount of pull force PF in daN measured. The three factors had respectively **a**, **b** and **c** levels and **m** observations (number of repetitions) taken for each combination of the three factor levels, for a total of **abcm** observations.

The factor levels **b** (number of implement types for EQTYPE) and c (number of different yoke sizes for YOKE) were determined from the output of the survey. The factor level **a** (number of soil water content levels for SWC range) was function of the rainfall profile and the soil water status. The soil water content was determined by the gravimetric method (GSWC in % g/g) and was converted into the volumetric soil water content if necessary (VSWC in % v/v). Different studies on monitoring of field operations have shown that farmers never carried out field activities at optimal soil water content. Land preparation was generally performed at the beginning of the rainy season just after the first useful rain. Three levels of factor **a** were arbitrary chosen within the range of a working-day's soil-water content during the period allocated to land preparation and weed control. These three levels of soil water content corresponded to three days of fieldwork: one day was chosen in the month of June and two days in the month of July.

The analysis of variance was performed to determine the significance of each factor and combination of factors on the pull force PF (**Table 15**).

The overall F-test was performed to detect treatment differences along with 100(1-α)% simultaneous Confidence Interval (CI) to compare specific pairs of treatments.

$$F_{\alpha} = \frac{MS_{(A,B,C,AB,AC,BC,ABC)}}{MSE} \quad \textbf{(25)}$$

$$CI = (\overline{Y}_i - \overline{Y}_{i'})_{t\frac{\alpha}{2}} s\sqrt{\frac{1}{n_i} + \frac{1}{n_{i'}}} \quad \textbf{(26)}$$

Table 15: Analysis of Variance

Source of Variation	Df	Sum of Squares	Mean Square	F
A	(a-1)	SSA	SSA/Df(A)	MSA/MSE
B	(b-1)	SSB	SSB/Df(B)	MSB/MSE
C	(c-1)	SSC	SSC/Df(C)	MSC/MSE
AB	(a-1)(b-1)	SSAB	SSAB/Df(AB)	MSAB/MSE
AC	(a-1)(c-1)	SSAC	SSAC/Df(BC)	MSAC/MSE
BC	(b-1)(c-1)	SSBC	SSBC/Df(BC)	MSAC/MSE
ABC	(a-1)(b-1)(c-1)	SSABC	SSABC/Df(ABC)	MSABC/MSE
ERROR	abc(m-1)	SSE	SSE/Df(ERROR)	
Corr. Total	abcm-1			
Mean	1			
Total	abcm	TSS		

The general linear statistical model associated with this factorial experimental design was stated in the form of: (Stapleton, 1995):

$$\Sigma\alpha_i = \Sigma\beta_j = \Sigma\gamma_k = \Sigma(\alpha\beta)_{ij} = \Sigma(\alpha\gamma)_{ik} = \Sigma(\beta\gamma)_{jk} = \Sigma(\alpha\beta\gamma)_{ijk} = 0 \quad \textbf{(27)}$$

Where:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl} \quad \textbf{(28)}$$

and ε_{ijkl} are random errors independently distributed: $\varepsilon_{ijkl} \sim N(0,\sigma)$.

For **i**= 1, ..., **a**
j= 1, ..., **b**
k= 1, ..., **c**
l= 1, ..., **m**.

It was also assumed that the observations Y_{ijkl} (PF in daN) were normally distributed as $\mathbf{Y_{ijkl}} \sim \mathbf{N}(\mu_{ijk}, \sigma^2)$ and independent.

$\mathbf{Y_{ijkl}}$ represented the pulling force PF in daN or kgf and μ the expected average draft in daN or kgf. The parameters α, β, and γ were unknown parameters called the interaction effects of A, B and C respectively. The first and second order interactions among factors were also included in the formulation of the regression model as well.

The general mean μ was calculated:

$$E(\bar{Y}_{ijkl}) = \mu_{ijk} \qquad \textbf{(29)}$$

$$\mu = \frac{1}{abc} \Sigma_{ijk}\, \mu_{ijk} \qquad \textbf{(30)}$$

There were a total of 18 different combinations applied each to a 200 m^2 to 300 m^2-experimental unit.

Besides this experiment, additional draft measurements were performed to determine the power requirements and energy expenditure for other post-tillage field operations: seeding, weeding.

4.3.3. Draft measurements

The measurements performed on each experimental unit were:

. Weight of each animal LW in kgf,

. Amount of pulling force PF in daN or kgf,

. Angle of pull γ in degrees (^{o}d),

. Oxen working time or field time FDTIME in s,

. Oxen working speed ANSPEED in m/s,

. Distance traveled DSTTRAV in m,

. Implement working depth IMPLWDP in cm,

. Implement working width IMPLWWD in cm,

. Soil gravimetric water content GSWC in % g/g.

. Soil penetrometer Cone energy E_{DEP} in J/s.

The pulling force (PF) was measured at the hitch point on the implement and represented the amount of force developed by the pair of oxen to pull the implement on a continuous working rhythm. For each experimental plot, the range and the average pulling force were observed. Not all the pulling force developed by the draft animals was used to do useful work. Only the component in the direction of travel was converted into tractive force to pull the implement in the soil. The amount of tractive force, also called the draft required (DR) by the implement, was expressed as a function of the angle of pull γ in ^{o}degree:

$$DR = PF * (\cos\gamma) \tag{31}$$

This required draft DR was expected to be highly correlated to the effective working width (IMPLWWD in cm) and depth (IMPLWDP in cm). The effective working width (more or less than the measured implement working component width WWKGCOMP in cm) was the width over which the implement actually worked.

4.3.4. Power and energy expenditure

The energy furnished by the working animals to perform the field operation was represented by the amount of energy needed to pull the implement and the distance walked from he beginning of the operation to the end. The energy delivered to perform the work ANERGY in MJ was estimated by multiplying the pulling force PF in daN by the distance traveled DSTRAV in m:

$$ANERGY = PF * (DISTRAV) \tag{32}$$

The energy required to pull the implement $ANERGY_{REQ}$ in MJ was calculated as the draft required DR in daN multiplied by the distance traveled DISTRAV in m:

$$ANERGY_{REQ} = DF * (DISTRAV) \tag{33}$$

Another approach to the energy evaluation was derived from the power concept defined as the rate of doing work. The animal power ANPOWER was calculated by multiplying the pulling force PF or the draft required (DR) and the animal field speed ANSPEED in m/s. The field speed was defined as the average rate of implement travel in the field during an uninterrupted period of functional activity (ASAE, 1984). The rate of travel was evaluated as the distance traveled (DISTRAV) divided by the field time (FDTM in sec) that the working component of the implement stayed in a non-stop working position.

$$ANERGY = k * (ANPOWER) * (ANWKGHR) \qquad \textbf{(34)}$$

The energy spent by the draft animals walking across the field while performing the work must be added to have a more complete formulation of the total energy (**Equation 5**).

The energy required and delivered to perform a given task was used to determine nutrient requirement by converting energy expenditure into amount of available feed to be supplied to the working animals.

4.4. Maximum performance

4.4.1. Objectives

The average available power was expected to increase as the body weight of the animals increased during the rainy season resulting from the availability of more grazing areas. The objective of this experiment was to measure the maximum effort developed by a pair of oxen and to determine the efficiency of energy utilization by comparing the energy used and the total energy available.

4.4.2. Procedure

The available animal power was measured at the beginning of the rainy season during the period allocated to land preparation. The power measurement was used to determine the maximum draft that a pair of oxen could develop during the growing season. As mentioned by Goe (1983), farmers are facing a problem of animal feed at the beginning of the cropping season when work labor demand is at its peak.

The research activities were divided into two parts:

- Measurement of the maximum pull force at the beginning of the rainy season;
- Follow-up with the selected draft animals to monitor the type of management used by farmers during the growing season (see Appendix A2 for follow-up guidelines).

The measurements were performed in each of the four previously mentioned villages located in the agro-ecosystems zone 4 and 5 and on-station. Two pairs of oxen were randomly selected per village to make a total of 9 pairs of oxen (18 draft oxen) to be used for the test and the follow up during the whole rainy season (June to October).

- Pulling trials for continuous maximum effort

The experiment consisted of pulling trials on soil ready for land preparation by a pair of oxen with a progression of known loads placed on a sledge. The variables observed were:

. Age of each animal AGE in years (yrs),

. Weight of each animal LW in kgf,

. Pulling force PF in daN or kgf,

. Angle of pull γ in ^{o}d,

. Distance traveled DISTRAV in m,

. Working time PULLTIME in s,

. Working speed ANSPEED in m/s.

For the data analysis, the following graphs were analyzed to determine the optimum power ($ANPOWER_{opt}$) delivered by the draft. A general linear modeling technique was used:

. Power output ANPOWER:

$$ANPOWER = f(PF) \quad \textbf{(35)}$$

. Specific power output $ANPOWER_{SPEC}$:

$$ANPOWER_{SPEC} = f(\frac{PF}{LW}) \quad \textbf{(36)}$$

The same analysis was conducted with the speed ANSPEED in m/s:

$$ANSPEED = f(PF) \tag{37}$$

$$ANSPEED = f(\frac{PF}{LW}) \tag{38}$$

Two identical sledges were locally fabricated for the pull trials.

- Follow up of draft animals

After the pulling trials, a follow up was agreed upon with the farmers to monitor all the activities performed by the 18 draft animals during the rainy season. Information collected were (Appendix A2):

. Liveweight (LW in kg) at the end of every month.

. Type of activities carried out during the given period.

. Feeding system (type of feed and amount given)

. Handling and care.

The follow-up was performed on a daily basis by two of the survey personnel who were in continuous contact with concerned farmers.

4.5. Instrumentation

The instrumentation used in this study was developed by CEEMAT and was designed for automatic field data collection (CIRAD-SAR, 1993). The animal-drawn system was composed of two basic elements: a data logger 21X (Campbell Scientific, Inc.) and a series of sensors to be mounted on the implement and connected to the data logger. The data measured by the sensors were made on real time basis through the internal clock of the data logger used for their storage. The main sensors used in this study were:

. 500 daN-dynamometer sensor for measuring the amount of pulling force (PF),

. Dickey John (registered trademark) radar to measure the working speed (ANSPEED) in m/sec,

. Internal clock of data storage unit to measure the working time (FDTM in s)

For later data processing, the data logger was downloaded to a computer with the support software EDLOG via a SC32A RS-232 interface using the software TERM or SC532 RS-232 interface from an auxiliary storage unit using the SMCOM. The RS-232 interface was to convert the CMOS logic levels of the data logger to the RS-232 levels of the computer. The SC32A and SC532 provided an effective isolation between the computer's and data logger's electrical system, protecting against normal static discharge, and noise (Campbell Scientific, 1992).

An additional mechanical dynamometer was also used to supplement the electronic system in the case it failed to operate properly. The dynamometer was a spring-loaded type made by PIAB™ and had a maximum force of 500 daN.

The additional field equipment used to carry out the field measurements were:

. Hand held stopwatch,

. Measuring tape,

. Rain gages,

. Soil penetrometer,

. AMS Soil samplers (Ben Meadows Company).

. Electronic weighing scales (Barlo Electronic Scale™ Model 2100).

The data collected during the season were used to develop a model to evaluate draft animals liveweight.

4.6. Expert System building

4.6.1. Objectives

The expert system model was built to help achieve an efficient utilization of animal traction for crop production through choice of animals and implements to perform specific field operations. It was designed for researchers, extension agents, farmers and policy makers to simulate different scenarios of animal traction utilization at the farm level.

By introducing a confidence threshold level set by the users for "fuzzy reasoning", the expert system model based on Knowledge Base Management System (KBMS) program was expected to yield more realistic results in farmers' conditions.

4.6.2. Knowledge Base Design and Development

4.6.2.1. Presentation of the expert system

The expert system was developed with the LEVEL 5 Object program (for Microsoft Windows™ Standard Edition Release 3.6 Copyright© 1995 Information Builders, Inc. NY). The selection of a suitable shell was considered to be the first step in developing an expert system.

LEVEL5 OBJECT is a software development tool kit. The program shell is able to activate external conventional programs called within the expert knowledge base and was able to perform mathematical operations, incorporate uncertainty and partial information, and explain its decision logic. The program was also user-friendly and composed of a built-in screen editor, a compiler for the inference engine and an interfacing mechanism with program written in TURBO PASCAL and Microsoft FORTRAN.

The program development was made by using a combination of decision-making rules, methods and demons with a high-level knowledge engineering language called PRL (Production Rule Language) based on inferences in linguistic form and written in IF-THEN rules.

Rules are used to express logic, cause-and-effect relationships, between the facts and conclusions, while a Demon proceeds by testing for patterns in data based on conditions and then executes an action based on the conditions. The method is similar to a macro with a number of commands associated with an attribute. It defines the attribute's behavior and executes a series of actions when the attribute value changes.

Rehak (1983), cited by Raman et al (1992), reported that there were three types of knowledge that could be integrated into an expert system: Heuristic (from experience), conventional (regarding facts) and inferential knowledge (study of results). They found that inferential knowledge was encountered in most of the engineering applications.

The representation of knowledge requires an efficient organization of the objectives or goals of the expert system and the supporting structure of information.

The inference engine of the shell evaluates the knowledge captured in the rules, demons and methods by exploring the problem space represented in a form of an IF-AND/OR-THEN structure.

The program was developed using a backward chaining control structure to connect the individual rules and forward for the methods. In the backward reasoning, the reasoning is performed starting from what the program wanted to prove towards the facts that are needed rather than beginning from the facts. This system of reasoning described by Jackson (1990) was more focused than forward chaining, because only potentially relevant facts are taken into consideration. An example of such reasoning:

Rule for draft animal selection:

RULE for Draft animal selection
IF the animal is trained
AND the animal liveweight > (Mature weight/2)
THEN the animal is a draft animal

RULE for trained animal
IF the animal is 2 years old
AND the animal has learned basic instructions
THEN the animal is trained CONFIDENCE 80

CONFIDENCE is used to quantify the degree to which one can be confident in the accuracy of the conclusion or to give an indication of the likelihood of occurrence. The lowest confidence level for LEVEL5 to reach a conclusion or goal is set up through the THRESHOLD statement.

With the command CHAIN, multiple knowledge bases can be linked if the domain of investigation can be partitioned into separate smaller knowledge bases. This procedure allows the building of programs of a virtually unlimited size program. It also improves the readability of the program by enabling the primary knowledge base to activate the necessary sub-knowledge base depending upon the context.

4.6.2.2. Expert system organization

The model was built around three major components.

- Field capacities evaluation
- Animal energy balance and feed ration
- Annual farm budget and Optimization

The values of the input variables required to run the model were either developed previously in the field experiments or taken from a reliable secondary database.

The data input system is composed of disk files and operator entered data through the user interface system. The model was designed to use different databases related to:

. Farm: farm size, number of farm workers,

. Farm implements: TYPE, WORKING COMPONENT, PF,

. Draft animals: SEX, LW, AGE,

. Available feeds: TYPE, NUTRIENTS, FU,

. Crops grown: TYPE, VARIETY, YIELD.

Validated default values are used to supplement for missing parameters. The data entered by the user was made possible by the capability of the expert system to use prompt boxes for all the information required from the user. The user could also query the program to know why a given information was needed and get the explanation, establishing very interactive communication.

4.6.2.3. Data processing

- Draft and power estimates, and field capacities

The statistical models developed in the second part of the methodology were used to evaluate the amount of traction delivered, the traction required, the energy delivered, and the energy required.

The pulling force PF in daN and draft DR in daN required were evaluated for every working day in relation with the type of implement used.

In relation to the pull force PF or draft required DR, the field capacities EFC in ha/day were evaluated along with the number of working days NWDAYS.

The soil water balance was used to estimate the number of working days NWDAYS affected with a level of probability (5 years out of 10 and 9 years out of 10).

The number of working days per month was evaluated by subtracting the number of non-working days from the total number of days of the corresponding month. The execution deadlines of specific field operations were taken into account. For each field operation, two soil moisture limits were considered: Drained Upper Limit (DUL) and Lower Limit (LL). The difference between DUL and LL was used to determine the soil field capacity and trafficability in relation to by the amount of rain. The lower limit was mainly indicated by the level of hardness of the soil during the drying process. At this level of soil water content, the implement working components were barely able to penetrate the soil surface.

The probability of a working day (PWD in percent) was calculated as the ratio between the number of working days (NWDAYS) over the total number of day (NDAYS) of the chosen period (month = 30 or 31 days, week = 7 days and so on). In this study the probability of a working day was evaluated on a monthly basis:

$$PWD = \left(\frac{NWDAYS}{NDAYS}\right)_{period} \quad (39)$$

A coefficient called effective probability of a working day (EPWD in percent) was introduced and defined as the PWD weighted by the draft animal reliability (ANIREL in decimal) and the farm implement reliability (IMPLREL in decimal):

$$EPWD = (PWD_{period}) * (IMPLREL) * (ANIREL) \quad (40)$$

- Energy and nutrient requirements

The nutrients required to carry out the field activities were evaluated from the energy balance equation or factorial method developed by Lawrence and Stibbards (1990) (**Equation 5**). It is quasi-impossible to determine directly in the field the total amount of energy used by a working animal (Falvey, 1986). The main components used for the energy balance were the net energy for the work performed by the draft animals and the net energy used for walking throughout the field.

The calculated energy represented the extra energy on top of the maintenance energy (MAE), supplied by the draft animal's body to perform the work required. In the process, the digestive system of the working animals converted the feed into digestible energy (DE). The part of the digestible energy used to perform the work is called metabolizable energy (ME), and is measurable in forage unit (FU). As defined by many researchers, the feed or forage unit represents the net energy of 1 kg of barley with no losses in the animal feces, urine, gas, etc. (CEEMAT, 1974; Goe and McDowell, 1980); Watson, 1981). The number of forage unit per day for maintenance was calculated by using **Equation 11**.

The program was designed to compose the ration from the variety of feed available to farmers, which could satisfy the daily total amount of forage unit. The amount of feed required $FRFEED_{DREQ}$ in kg of fresh feed per day can be calculated by converting the total FU into fresh feed (forage, grain, bran, straws) on a basis of 100% dry matter content (DM) and intrinsic value (FU) of each type of feed.

$$FRFEED_{RBQ} = (\frac{100}{DM}) * (\frac{TotalFU}{FU_{FEED}}) \quad (41)$$

The upper limit of the amount of feed an animal could take per day on a dry matter DM basis was set equal to the Appetite Limit (AL in kg of feed/day) for the corresponding animal of liveweight LW (**Equation 10**).

- Production costs and Optimization

Cropping system techniques ("Itineraire technique") were evaluated in relation with the level of energy used. The cost associated with animal and implement utilization, and man-labor used was included in the production cost evaluation with updated prices. For the benefit calculations, the average yield of the 10 past years' experience was used for each cropping technique and level of energy used for four "Itineraire techniques" using different implement's combinations.

It was assumed that the cropping system was driven by a cash crop (groundnuts) and marketed through the official network to help farmers cover all the production costs.

The optimization was formulated in terms of:

. Objective function: What is the crop mixture and hectarage that would maximize farmers' profit.

. Constraint functions: land availability, labor availability, available animal energy and required cereals consumption based on FAO standards.

4.6.2.4. Program output

The output of the expert system was oriented towards different aspects of farm equipment selection and management, and decision making process.

- Field Capacities
- Labor balance per ha (available vs required)
- Animal energy balance
- Feed ration
- Complete annual farm budget
- Optimization solution.

4.6.3. Program validation

The expert system was built around different statistical models and simple equations to evaluate or calculate variables involved in the decision-making process at the farm level in terms of resources allocation. The quality of the output is mainly related to the validity of the different equations used.

4.5. Summary

The methodology developed in this study was mainly oriented towards the building of an expert system that would really evaluate the impact of animal traction at the farm level. The evaluation was centered on crop production activities. The methodology was divided into three phases:

- Survey: the objective of the farm survey through a simple questionnaire was to identify all types of farm implements really involved in crop production at the farm level. This investigation technique offered an opportunity to select the implements along with the working animals on which more detailed technical information were needed in terms of power and energy requirements.

- Energy estimations: the energy estimations were performed on use field implements and working animals only. The pulling force delivered by the draft animals and measured with a dynamometer represented the core of these estimations. All the measurements were made in real working conditions in order to include as many variability factors as possible beside three major ones: type of implement and yoking system, and soil moisture regime. It was important to place the animals in their environment to avoid any extrapolated data. The model developed would be only applicable to the current soil and weather situation. The expert system program would offer possibilities to use the methods in other environments.

- Expert system building: the expert system was designed to integrate all aspects dealing with the technology evaluation at the farm level. The program can be used for calculating or predicting the draft requirements, the number of working days during the growing season, the cost of production and also for estimating the feed rations needed by the draft animals.

The validation of the expert system was mainly performed through the validation of the different models used to evaluate various aspects of the technology at the preset confidence level. The major outputs of the program are expected to compare with actual recommendations made to farmers in terms of resource management and allocation.

Chapter 5

FARM CHARACTERISTICS AND SYSTEMS MANAGEMENT

5.1. Farm equipment

The process to identify all the different farm implements used by farmers took two full weeks to inspect each item surveyed in detail. It required quite an expertise and patience to evaluate the quality of the implement, the effects of utilization and maintenance in farmers' condition, and to get the needed information from the users.

A total number of 126 implements belonging to 40 farmers located in agro-ecosystem 4 and 5 have been surveyed. All the implements involved in crop production were walking equipment with handles (**Figure 3 to 7**). At the 90% confidence level, the total number of implements consisted of the following (**Table 16**): 23% moldboard plow UCF (0.73 ± 0.19 per farm), 22% ARARA and EMCOT ridgers (0.70 ± 0.16 per farm), 9% cultivator Sine 9 (0.28 ± 0.13 per farm), 19% SUPER ECO seeders (0.60 ± 0.16 per farm), and 27% ox-cart (0.85 ± 0.16 per farm).

The distribution of each type of implement per agro-ecosystem shows that most of the UCF moldboard plows were located in zone 4 with an average of 1.25 per farm (CV = 43.2%) against 0.20 per farm in zone 5. On the other hand, most of the ridgers were confined in agro-ecosystem 5 with an average of 1.10 per farm (CV = 40%) against 0.30

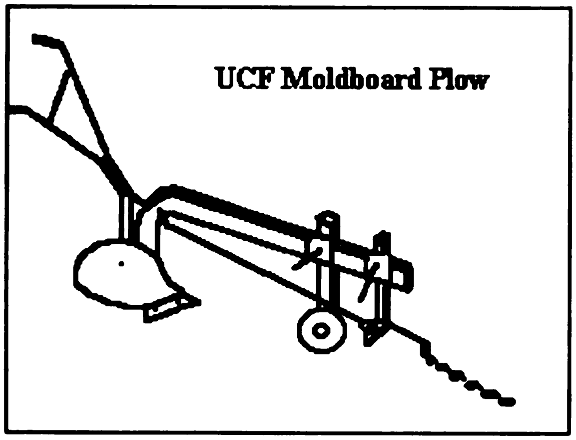

Figure 3: Moldboard plow UCF 10"

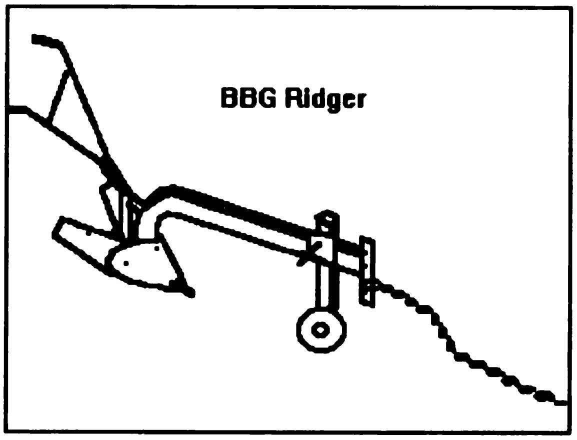

Figure 4: EMCOT Ridger (Gambia)

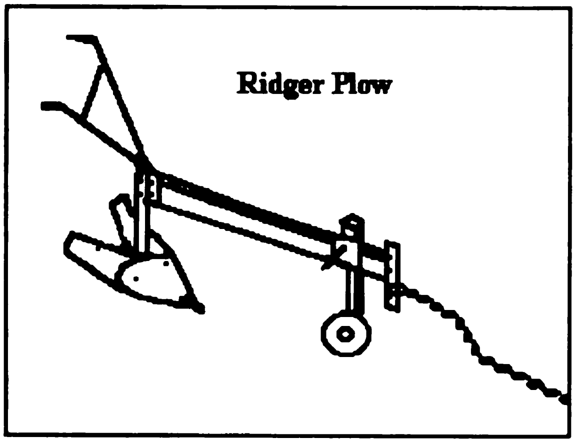

Figure 5: ARARA toolbar ridger

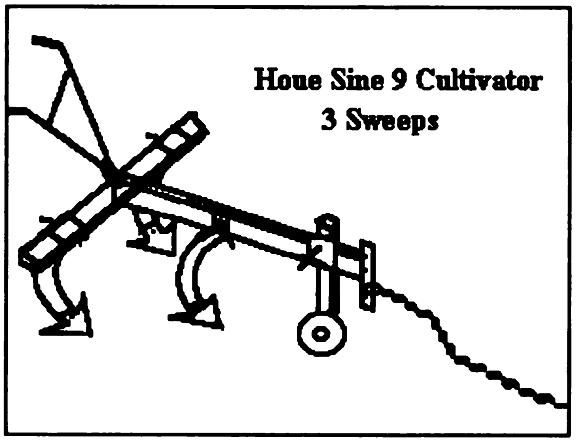

Figure 6: SINE 9 toolbar 3-tines

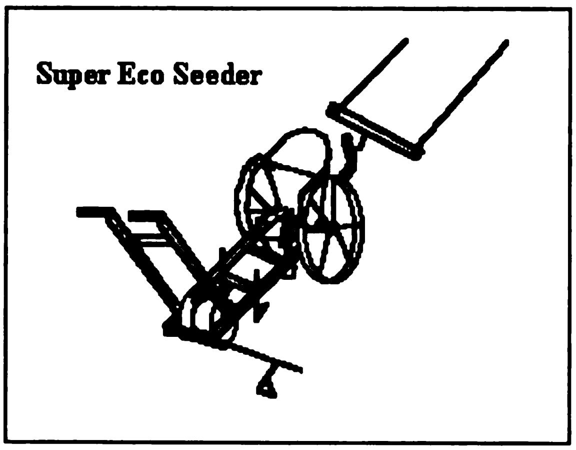

Figure 7: Seeder SUPER ECO

in zone 4. The same analysis shows also that the seeders SUPER ECO and cultivators SINE 9 were mainly used by farmers

located in agro-ecosystem 4 respectively with an average of 1.10 (CV = 40%) and 0.50 (CV = 118%) per farm. Ox-carts were mainly

Table 16: Farm characteristics

Statistics	Farm workers	Farm Size (ha)	Plow UCF	Ridger ARARA	Weeder SINE 9	Seeder SUPER ECO	Ox-Cart	Ox
Mean	10.53	4.03	0.73	0.70	0.28	0.60	0.85	2.23
Std Error	0.71	0.26	0.11	0.10	0.08	0.10	0.10	0.16
Median	9.50	4.00	1.00	1.00	0.00	1.00	1.00	2.00
Mode	9.00	4.50	0.00	1.00	0.00	0.00	1.00	2.00
Std Dev.	4.51	1.64	0.72	0.61	0.51	0.63	0.62	1.03
Variance	20.36	2.70	0.51	0.37	0.26	0.40	0.39	1.05
Kurtosis	-0.26	0.41	-0.89	-0.54	2.02	-0.54	-0.35	0.96
Skewness	0.50	0.63	0.46	0.25	1.66	0.56	0.10	0.87
Range	19.00	7.00	2.00	2.00	2.00	2.00	2.00	5.00
Minimum	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	21.00	8.00	2.00	2.00	2.00	2.00	2.00	5.00
Sum	421.00	161.35	29.00	28.00	11.00	24.00	34.00	89.00
Count	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
C.I.(0.90)	1.17	0.43	0.19	0.16	0.13	0.16	0.16	0.27
Zone 4								
Mean	11.60	4.26	1.25	0.60	0.50	1.10	0.65	1.95
Std dev.	4.71	1.54	0.54	0.30	0.59	0.44	0.57	0.92
Zone 5								
Mean	9.45	3.81	0.20	1.10	0.05	0.10	1.05	2.50
Std dev.	3.90	1.67	0.40	0.44	0.22	0.30	0.59	1.02

used for transport especially in agro-ecosystem 5 with an average of 1.05 (CV = 56%) per farm against 0.65 (CV = 88%) in zone 4.

It appears that farmers in the area of study were more concerned with the acquisition of tillage tools (57% of the total) **(Figure 8a)**. This was considered as a priority by farmers for a number of different reasons that previous studies have tried to show. Three main reasons need to be mentioned: the improvement of field operation timeliness, the extension of cropped areas, and the reduction of drudgery (Ndiame, 1986).

The geographical distribution of types of implements is an indicator of different cropping techniques used in relation to the resources available to the farmers (land, number of farm workers). The type and number of implements that exist at the farm level is also related to the agricultural practices. In other words, two farmers located in the same area may be expected to use different cropping techniques to produce the same crop.

5.1.1. Types of implements

Most of the implements are locally manufactured by SISCOMA (35%) created in 1963 which became SISMAR in 1984 under a new management staff (FALL, 1981). Since that time SISMAR has manufactured 49% of the implements actually used by farmers. The few implement imported (16%) are mainly found in agro-ecosystem 5 and originated from Gambia **(Figure 8b)**.

5.1.1.1. Moldboard plow UCF 10": Tillage

In the Basse Casamance region, a moldboard plow is one of the most important implements used for land preparation **(Figure 3)**. Besides breaking the soil for better

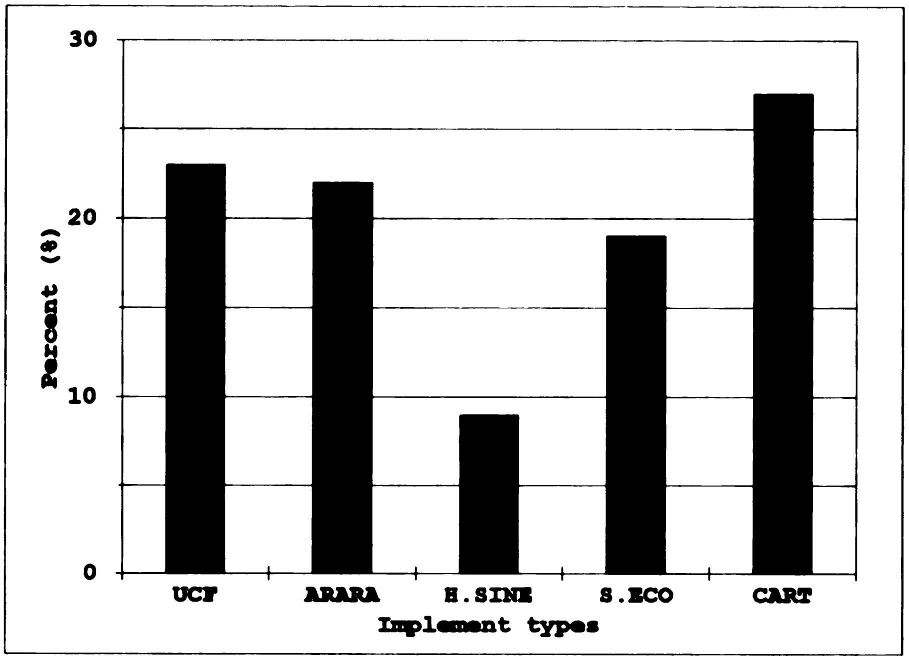

Figure 8a: Types of implement used by farmers

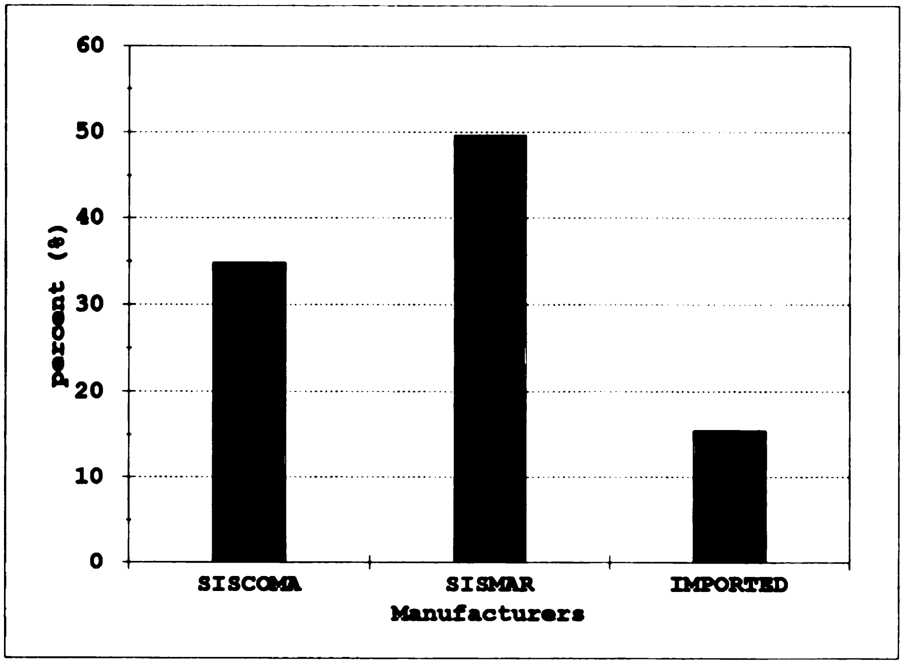

Figure 8b: Implement manufacturers

aeration, its main purpose is to plow under both weeds for better control, and manure for rapid decay. The better the bottom scour and turning the soil, the better the moldboard plow.

Designation: Moldboard plow CFOOOP UCF type.

Hitching system: chain.

Traction: oxen.

Stability: single wheel for longitudinal stability.

Reversibility: one way, right-hand plow.

Single bottom moldboard plow.

Nominal cutting width: 254 mm.

Total weight: 38 kg.

Working depth: 17 to 20 cm.

- Beam

The beam is made out of a 50x20 mm flat mild steel. The standardization test has shown resistance to effort as high as 950 daN. The maximum effort reached in farmers' conditions never attains this level, even when taking into account the presence of stumps scattered in their fields. In term of hardness, the value of the Brinell hardness test is 55 kg/mm^2.

- Share and landside

The share and landside are made of the same mild steel and tested 95 kg/mm^2. The general acceptable working component hardness recommended by research is within the range of 65 to 70 kg/mm^2. The share is a straight edge type and its main role is to cut the soil slice or furrow before sending it over the curved surface of the moldboard in order to be twisted and inverted or pulverized. The landside while riding along the furrow wall counteracts the throw or side pressure to help keep the plow steady while working.

- Moldboard

The moldboard is a universal type or cylindricol-helicoidal in design. This part of the bottom of the plow serves to break or invert the furrow slice. It plays an important role towards the quality of work to be done. It is also made of mild steel. The material used to make the moldboard is of great importance, the better the soil scour on its surface, the better the material.

These three working components along with the beam are bolted on top of a mild steel piece of irregular shaped metal called a frog.

- Hitching system:

The hitching system directly affects the maneuverability of the implement, as the handling and the draft depend to a great extent upon correct hitching adjustments. The hitching system consists of horizontal and vertical regulator to adjust the working depth IMPLWDP and the width IMPLWWD. It is important that the point of hitch be on a straight line with the center of draft or resistance and the center of power or yoke hitch point.

The implement is maneuvered by the plowman with the handles welded on the rear of the beam. The manufacturer SISMAR indicates an average theoretical field capacity of 0.45 to 0.50 ha/day in an 8 hr-day.

5.1.1.2. Imported ridger (EMCOT)

This farm equipment is imported from Gambia and is equipped with a bottom ridger **(Figure 4)**. The implement is also called a middlebreaker. The bottom is built with a double moldboard plow to invert the furrow slice, half to each side on every pass. Completing the operation in a-round-trip results into the formation of a ridge for planting crops. The winged designed moldboards are adjustable to control the height RIDGHGT and the spacing of the ridges RIDGDIST.

The implement is similar in design to the UCF plow described earlier except that the beam is made with an I-beam instead of flat steel and that the share is in one piece for the two moldboards.

The implement settings are performed through a clevis equipped with vertical and horizontal hitch adjustment. The adjustment rules are the same as the UCF 10" plow for obtaining a correct line of pull.

5.1.1.3. Seeding implement

The success to growing crops depends on the conditions the seed is placed in the soil in relation to different agronomic parameters along with the seeding equipment features: type of seed distribution and dropping mechanism, furrow opener and seed coverage system **(Figure 7)**.

Designation: Super Eco seeder.

One-row and multi-purpose seeder.

Hitching system: chain with or without evener.

Traction: pair of oxen, horse or donkey.

Nominal cutting width: 254 mm.

Total weight: 38 kg.

- Frame

The frame is made out of two 30x7 mm parallel flat mild steel runners, 1062 mm long and braced in the middle. The frame opens wide progressively towards the front end to allow the attachment of the hopper (galvanized zinc to protect from rust and corrosion). The runners are joined together at the forefront to form the hitching system made out of a 30x12 mm flat mild steel.

At the rear of the parallel runners two welded vertical standards, one on each runner, are used to fix and adjust a press wheel (two point-to-point conical elements) which firms the soil around the seed. The press wheel action is to complete the combined action of the seed shoe (furrow opener) and the set of two sweeps (30x12 mm flat, 1/2 solid steel) used to cover the seed with soil. The furrow opener and the sweeps are both clamped on the runners and are both adjustable in depth. At the very rear end, the runners are firmly joined by an angle iron brace used also to support the row marker.

- Handles

The user guides the seeder with a pair of handles, adjustable in height for better comfort. The handles are made with a 25x7 mm flat 1/2 solid steel.

- Metering wheel

The seeder is equipped with a pair of 400-mm diameter metering wheel made from a 40x4-mm 1/2 solid flat band- steel. When rolling on the soil surface, the wheels drive the distribution mechanism by means of an axle used as driving shaft. The distribution system is composed of a system of two gears (driving and driven) and a plateau located inside the hopper. The plateau is equipped with two pins which help hold the seed plates made of aluminum. Two types of seed plates are more common: full-drop round-hole and flat-drop types.

5.1.1.4. Multipurpose toolbar implements

Toolbar implements have been developed by French agricultural research institutions (IRAT, CEEMAT, MOUZON Mfg) working in West Africa to help farmers increase their field operational capacities **(Figure 5 and 6)**. The strategy behind the toolbar is to buy a single multipurpose frame and different attachments corresponding to specific tasks (tillage, weeding, groundnut harvesting). There are a large variety of toolbar implements available to farmers in the whole West African region.

5.1.1.4.1. Multipurpose frame ARARA

Designation: ARARA toolbar

Utilization: Tillage, weeding, ridging, lifting.

Traction: oxen, horse and donkey for light soil.

Weight: 31 to 46 kg with the attached working component.

Tillage attachments:

. 10" bottom

. 8" bottom

. 6' bottom

Ridging attachments

. 250 mm fixed wings

. 350 mm fixed wings

. Adjustable wings

Cultivator attachments:

. 3 full and half sweeps (left and right)

. 5 full and half sweeps (left and right)

. Optional: double reversible points

Groundnut lifting attachments

. 200 mm sweep

. 350 mm sweep

. 500 mm sweep

- **Frame**

The main beam consists of a straight squared shaped tube made of mild steel. The stability of the beam in the working position is provided by a wheel. The wheel standard is clamped at the front of the beam through a welded vertical adjustment device on which a vertical 5-hole hitching system is also welded.

A pair of 1/2 solid steel braced-handles is bolted at the other end of the beam to help the user guide the implement.

- **Equipment attachment**

The standard for either moldboard or ridger bottom and groundnut lifter is attached to the beam by bolts in a special groove located between the handles attachment and the rear end of the beam.

For the attachment of the other types of working components (spring tooth shanks or straight-stemmed), two cross bars are used to increase the versatility and working capacity of the implement. Up to 4 tine standards can be clamped on the cross bars and one under the main beam.

5.1.1.4.2. Multipurpose frame Sine 9

Designation: Sine 9 Cultivator or hoe

Utilization: secondary tillage, weeding, ridging, groundnut lifting

Traction mode: oxen, horse and donkey on light soil

Weight: 30 a 45 kg with the attachment.

- Frame

The main beam of the frame is made out of a 40x20 mm flat mild steel on which cross bars of the same materials can be added to increase its working capacity. The attachment system is very similar to the ARARA multipurpose toolbar described earlier. The handles are made out of 20x27 mm flat mild steel and designed wide enough over the frame to help its ease in use.

The stabilizing wheel standard is fixed on the main beam by means of a clamp equipped with a vise for easy continuous height adjustment.

- Attachments

. 10" plow equipped with a special shank and standard.

. Reversible point mounted on a 25 mm square straight-stemmed shank.

. 3-Canadian spring tines for weeding and stirring the soil.

The shovel and sweep attachment system is composed of one 160 mm central sweep and 2 half sweeps for weeding. Better action of soil stirring is performed with a system of 3 160 mm-full sweeps.

. Ridger: equipped with two adjustable or fixed wings with 250 mm and 360 mm options. The attachment to the main frame is made with a special standard.

. Groundnut lifter: The lifter knives or shovels are available in 3 sizes according to the traction mode and the soil type: 200 mm, 350 mm and 500 mm. The attachment is made with a standard constructed of matrix steel to better withstand the amount of draft required.

5.1.2. Cart

Designation: 1500 kg Grand-plateau cart

Traction mode: pair of oxen

Plateau: 2.40x1.50 m

Base: 1.40 m

Pneumatic 145x14 tires

Axle with conical roller bearings

Unladen weight: 220 kg

5.2. Repair and maintenance

The quality of repair and maintenance represents a key factor to the stability of the technology in farmers' conditions. The survey has revealed that the level of expertise of the local blacksmith was directly related to the farm implement working conditions and reliability. Most of the blacksmith were not equipped enough to solve all the maintenance and breakdown problems encountered by farmers on their piece of equipment **(Table 17)**.

5.2.1. Breakdown frequencies

5.2.1.1. Moldboard plow UCF 10"

The straight edge share supplied by the manufacturer (SISCOMA and SISMAR) to equip the plow lasts no more than two years. The locally manufactured share made of flatten truck springs by the blacksmith needs to be changed almost every year. Plow shares are damaged mainly by the presence of roots and stumps in newly cleared fields as farmers have the tendency to extend cropped upland areas. In agro-eco system 4 the high rate of

Table 17: Breakdown frequencies on farm equipment

Agro-eco zones	Location	Implement type	Repair and maintenance type	Freq (%)	Average distance (km)
4	Boulandor	Cropping	Working components: frog shares, landside, sweeps. Wheel bushings.	60	18 and On-site
		Transport	Tongue welding Tube and tires	40	20
4	Bougoutoub	Cropping	Working components: frog shares, landside, sweeps. Wheel bushings.	88	8
		Transport	Tongue welding Tube and tires	12	22
5	Kagnarou	Cropping	Working component: Wings shares, landsides. Wheel bushings. Adaptation and wing welding on EMCOT ridger	64	On-site
		Transport	Tongue welding Tube and tires	36	On-site 15
5	Suel	Cropping	Working component: Wings reversible shares, Wheel bushings Adaptation and wing welding on EMCOT ridger	42 45	8 and On-site
		Transport	Tongue welding Tube and tires	13	17

utilization of moldboard plows explains the high maintenance frequencies of 60 and 88%. The landside has a longer life than the share. In general, blacksmiths buy the raw material used to make the share and landside from junkyard retailers.

The share plays an important role in the amount of draft required to pull the plow, the penetration, and mostly the stability of the plow in working position. Different studies has showed that 75% of the draft is centered along a line passing across the plowshare and localized 1/3 from the landside.

The frog represents the central piece of the UCF plow. It holds the bottom parts (share, lanside, moldboard) and the beam together. It needs to be protected from any type of wear by replacing worn share and landside on time.

The majority of the implements that are in bad and very bad conditions **(Figure 9)** are made of implements with worn frogs. These implements need to be discarded and replaced as it can be more costly to fix a plow bottom at this level of wear than to purchase a new and complete implement.

According to the manufacturer SISMAR, UCF 10" plows are built to last at least for MANLIFE= 5 years against FARMLIFE= 15.30 years in farmers' condition. The study shows that farmers are still using plows more than 20 years old **(Table 18)**. If bad and very bad plows are removed from the analysis because of the worn frogs, the life expectancy of UCF plow, in farmers' condition becomes FARMLIFE= 8 years. This parameter is important in the process of evaluating the total number of plows for a given time period needed by farmers in order to replace existing plows. The implement's life expectancy in farmers' condition (FARMLIFE in years) can also be used to estimate the annual implement utilization fixed cost (IMPFCOST in local currency) when performing a farm budget analysis.

5.2.1.2. Seeder Super ECO

The seeder Super ECO requires more expertise from local blacksmiths to service because of the complexity of the seed distribution system. The mechanism housed in cast iron requires little servicing. The manufacturer SISMAR urges farmers to verify the quality and level of the anti-friction grease in the mechanism and to provide grease to gear system if necessary. The system is built strong enough to last the seeder's lifetime.

Most of the other seeder's working parts is serviceable by local blacksmiths. These parts include the furrow opener, and the two full sweeps used to cover the seed with soil.

The weak point of the seeder resides in the plateau which is unserviceable by local blacksmiths. The plateau made of brass is located inside the hopper and is part of the distribution system. Its role is to turn the seed plates held in place with a round brass nut, a spring and two anti-slide short pins. Two major problems are noticed: the nut and the spring are often lost or the pins are broken. An equivalent nut can be found in market places located in nearest biggest town; but the pins, when broken, are difficult to replace. In terms of breakdown frequencies, the seeder mainly contributed to the overall breakdown and maintenance frequencies of the shares and sweeps.

In relation to the level of utilization, seeders in working condition were found in the area of study older than FARMLIFE= 11.91 years. The manufacturer's specifications indicate a lifetime of MANLIFE= 10 years.

5.2.1.3. Toolbars and EMCOT ridger

There is little breakdown and maintenance on toolbars. The breakdowns identified in the course of data analysis are classified in the same category of breakdown as the attached working component. In all cases, farmers in the area of study considered the toolbars to be identified with the working component they came with originally. In other words, a multipurpose ARARA or SINE 9 equipped with plow bottom is no more than a plow, and the same for those equipped with ridgers. In the long run, the toolbars lose their original multipurpose characteristics. In general, an ARARA toolbar is considered to be a ridger as most of them are equipped with a ridger bottom and most of the SINE 9 toolbars are considered to be cultivators or weeders, generally equipped with 3-Canadian full sweep.

The breakdown rate of ridger bottoms appeared to be closely related to the type of wings they are equipped with. The EMCOT ridger from Gambia tends to break at the fixture level between the wing and the share. Most of these ridgers need welding to repair the damaged wing fixtures and account for 45% of the breakdown in agro-ecosystem 5. On the average, the lifetime of EMCOT ridger is FARMLIFE= 10.47 years (the manufacturer given lifetime MANLIFE was not available). If bad and very bad implements are not considered usable in the analysis, the lifetime decreases to FARMLIFE= 8 years.

The ridger bottom attached to the ARARA toolbar faces problems of wear on the reversible point and breakage or loss of the wing nuts. The wing nuts are important for the adjustment of their height in the process of monitoring the geometry of the ridges. This type of failure contributes to 42% of breakdowns mainly registered on ridgers in agro-ecosystem 5. The ARARA toolbar with its attachment has a farm lifetime of almost

FARMLIFE= 14.60 years and 8 years when the bad and very bad toolbars are not counted.

The sweeps used on the SINE 9 toolbar are also subject to the physical conditions of the fields in relation to the presence of roots and stumps. The rate of sweeps wear is similar to the plow share or ridger reversible point. The lifetime of toolbar SINE 9 in farmers' condition is around FARMLIFE= 6 years.

5.2.1.4. Ox-cart

Ox-carts are used year round by farmers. They mainly face problems of tires and tubes due to the poor quality of the farm roads. Flat tires on the road can be changed in the nearest town. They account for 12% and 13% of the total breakdowns respectively in agro-ecosystem 4 and 5.

The primary failure of the ox-cart is the breakage of the tongue, which generally occurs at least once in its lifetime. Tongue breakage in combination with the tire problem account for between 36 to 40% of the breakdowns. The lifetime in farmers' condition is close to FARMLIFE= 14.67 years in total and 10 years when poor quality carts are not counted (**Figure 9**).

5.2.2 Farm equipment reliability

The reliability of farm equipment is closely linked to the existing maintenance network and to the quality of technical services provided to farmers. The study shows that farmers rely on three categories of service providers: local blacksmiths, advanced shops located in nearest big towns and farm equipment dealers.

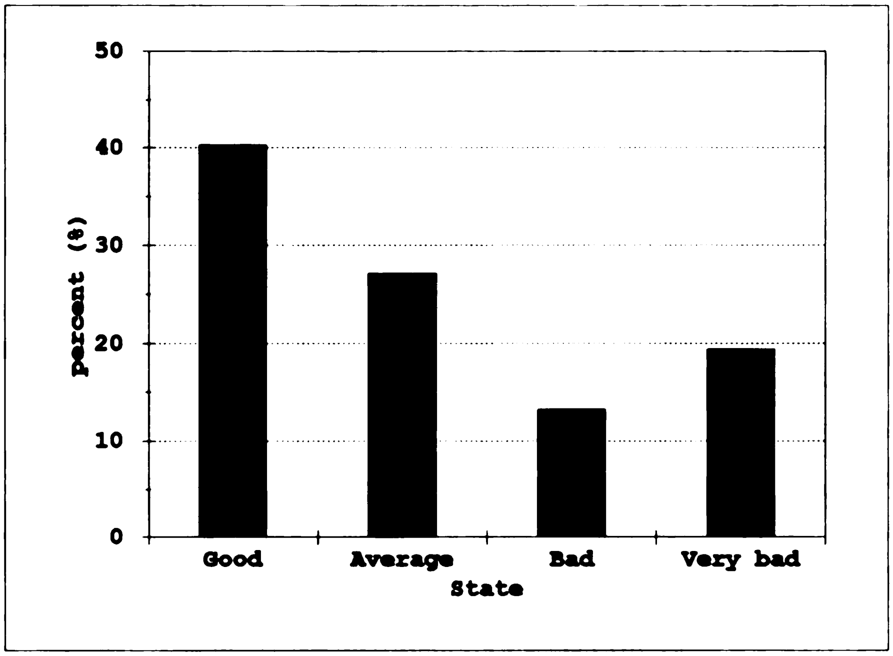

Figure 9: Implments' working conditions

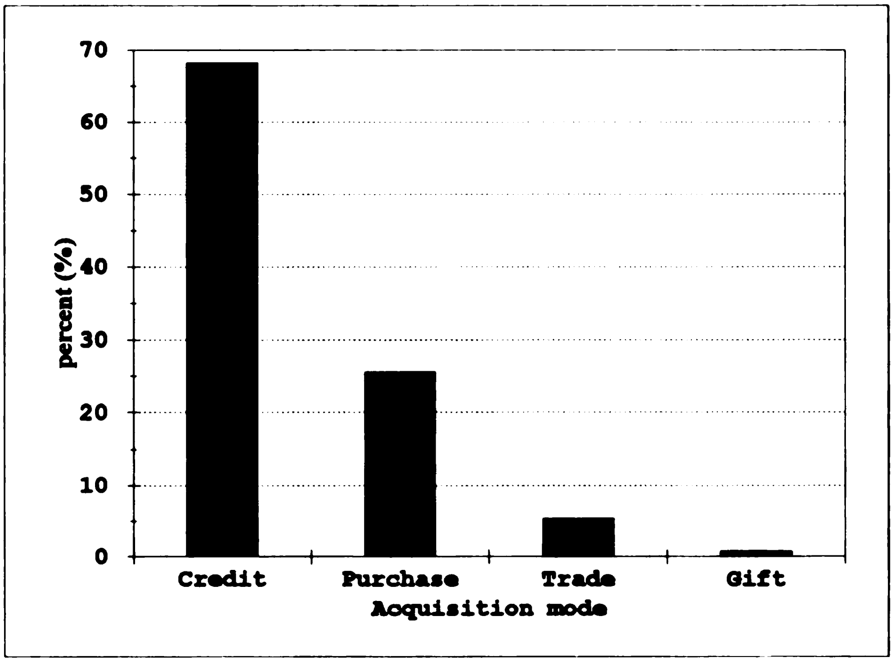

Figure 10: Acquisition mode

Until 1980, only governmental extension services were involved in making farm implements available to farmers through the ONCAD and SONADIS network. There were no private retailers involved in the process. One major advantage of this system was the quality control performed on implements and spare parts, but all the cost of distribution had to be supported by the Government. The system did not work well as farmers were not getting the spare parts on time.

The situation became worse after 1980, when the distribution system administered by extension agencies came to a complete stop: no more dealers or spare parts retailers. The only open alternative for the Government was to use the newly launched regional agricultural projects to support the distribution of implements and spare parts to farmers located in their geographical coverage. The PIDAC "Special Program" financed by USAID in 1979-80, was the only source of credit to farmers in the area of study. This new line of credit accounted for at least 20% of the UCF plows, 64% of the seeders and a little more than 3% of the ox-carts **(Figure 10)**. At the same time PIDAC tried to improve repairing capacities of selected blacksmiths willing to undergo some training and to purchase a set of tools at the end of the sessions. Currently, the local blacksmiths represent the central piece of the network of the farm equipment servicing by carrying out more than 80% of the repair and maintenance.

In this context, farmers do not rely completely on their farm implements. Hand tools are still ready to be used to compensate for any implement's failure.

In these conditions, the most often asked questions by animal traction practitioners are: How long will it take to fix a breakdown? How reliable is the technology to farmers?

There is no need to put stress on the importance of the reliability parameter when farmers are in the process of adopting a new technology. The parameter is determinant in evaluating the performance of households using animal traction implements for crop production. Timeliness is critical in the short period allowed for field operations.

The reliability of each farm implement or equipment (IMPLREL in percent) has been evaluated and tabulated **(Table 18)**. Two types of reliability coefficients are calculated, one on the yearly basis and the other on the implement lifetime basis. On the implement lifetime basis, two reliability coefficients are calculated, one on the manufacturer's given life expectancy ($IMPLREL_{man}$ in percent) and the second on the real farm lifetime ($IMPLREL_{farm}$ in percent). In any case, the reliability is given by following equations:

$$IMPLREL_{year} = 1 - \left(\frac{days_{Breakdown}}{NWDAYS}\right) \quad \textbf{(42)}$$

$$IMPLREL_{life} = 1 - \left(\frac{years_{Breakdown}}{IMPLLIFE}\right) \quad \textbf{(43)}$$

The real implement reliability per year IMPLREL in percent is expressed by the combined reliability of the two:

$$IMPLREL = (IMPLREL_{year}) * (IMPLREL_{life}) \quad \textbf{(44)}$$

Tableau 18: Implement repair and maintenance

Implement Types	Potential NWDAYS	Manufacturer Impl. Life	On-Farm Life	Potential On-Farm Life	Number of days of Breakdown: days/yr	(%)	Yrs/life	% Manuf	% On-Farm	Reliability (%): Manuf.	Farm
All Types				6.80							
Avg	-	-	12.91		13.98	-	2.90	-	-	-	
Min			1.00		1.00		1.00				
Max			25.00		182.50		7.00				
UCF 10"	45.00	5.00		8.00		7.44		45.80	28.62	50.16	66.07
Avg			15.30		3.35		2.29				
Min			7.00		2.00		1.00				
Max			25.00		5.00		4.00				
ARARA	45.00	5.00		8.00		8.33		40.00	25.00	55.00	68.75
Avg			14.60		3.75		2.00				
Min			1.00		2.00		1.00				
Max			25.00		5.00		4.00				
ECOMAT	45.00	5.00		8.00		6.40		40.00	25.00	56.16	70.20
Avg			10.47		2.88		2.00				
Min			6.00		1.00		2.00				
Max			18.00		5.00		2.00				
SINE 9	75.00	5.00		6.00		38.93		20.00	16.67	48.85	50.89
Avg			5.64		29.20		1.00				
Min			1.00		29.20		1.00				
Max			12.00		29.20		1.00				
Super ECO	40.00	10.00		10.00		7.50		25.00	25.00	69.37	69.37
Avg			11.91		3.00		2.50				
Min			1.00		3.00		1.00				
Max			22.00		3.00		5.00				
Ox-cart	365.00	10.00	14.67	10.00		22.38		33.50	25.00	51.62	58.21
Avg			1.00		81.68		3.35				
Min			23.00		1.00		1.00				
Max					182.50		7.00				

Among the most used farm equipment, the ox-cart appears to have the lowest overall reliability IMPLREL= 58.21%. The observed breakdowns are frequent and complex (pole welding, pneumatic problems) and require more time to repair in comparison with cropping implements (66.07% for UCF plow, 68.75% for ARARA, 70.20% for EMCOT ridger, 50.89% for SINE 9 and 69.37% for Super ECO seeder). According to the level of utilization, breakdowns on newly purchased farm equipment happen more often after 2 years of use for cropping implements and after 3 to 5 years for ox-cart, evaluated from their first date of service.

The longer the idling or immobilization time for breakdowns, the lower the reliability and therefore the higher the cost of utilization per year or per hectare.

5.3. Draft animal management

A total of 89 oxen were counted in the study for the 40 households. They represented more than 80% of the draft animals used in crop production. All the oxen belong to the Bos taurus breed commonly called Ndama. Small in size and trypanotolerent, they are physically characterized as humpless and have an optimal or mature weight MATURELW between 280 and 410 kg (Goe and McDowell, 1980). A mature weight value MATURELW= 360 kg is often used for practical applications.

The average number of oxen per farm is (2.23 ± 0.27) @ 90% confidence interval. The distribution is slightly different between the two agro-ecosystems with an average of 1.95 oxen per farm (CV= 47%) in zone 4 against 2.50 oxen per farm (CV= 41%) in the agro-ecosystem zone 5.

5.3.1. Availability of draft animals

Oxen used by farmers were either locally withdrawn from the farmer's own herd or purchased (50%) in the village from other farmers. Beside the withdrawal from the herd, the other 50% comprised exchanges against equivalent goods and gifts. It appears that the availability of oxen, for draft purposes is not viewed by farmers as a significant major constraint to adopting the technology.

In the selection process, only male oxen were selected as social and cultural standards of living prohibit the use of female animals for any physical activity.

5.3.2. Training and working career

Training of draft animals for teamwork as well as training of farmers to better use and adjust farm implements was revealed to be a serious concern to farmers. The only formal training sessions mentioned by very few farmers, occurred in the late 1970s. The sessions took place at the Guerina Training Center located South of Bignona. The center was created in 1964 as a pilot unit in the Basse Casamance region, financed by the UNDP. Its main objective was to train 32 farmers in the span of 9 months each year to acquire skills in using draft animals and the variety of implements. The training was stopped in 1980 when the administration lacked financing to support the activities. Nowadays, farmers are left to themselves to learn by doing. Common farming practices were to train animals at a much younger age. Most of the draft animals in the area of study were trained between the ages (AGETRAIN in years) of 2 to 3 years. On some rare occasions, older animals (5 to 6 years) were trained. The older the animal, the more difficult to be trained. Starting one month prior to the beginning of the rainy season, the draft animals were given names, and then taught basic moves through pulling and working as a team. During the cropping season, animals are literally forced to work together as a pair. It is only during their long working career that the pair of oxen begins to demonstrate more willingness to work. A minimum number of 3 years (YRSEXP) is generally accepted in the area as needed for a pair of oxen to respond correctly to commands. The average working experience of individual draft animal was found to be YRSEXP= 3.86 $\pm$ 0.79 years @ 90% confidence interval. The longest working career was 9 years.

Farmers are facing more technical learning problems. An early study conducted by the Farming System Research team of ISRA's Agricultural Research Center of Djibelor (Basse Casamance) reported in comparing farmers with and without animal traction that it took 5 to 6 years of experience for farmers to master the technology. The mastering is necessary before steady yield improvements becomes apparent. This includes implement hitching and adjustments, adjustment of line of draft, keeping plowshare sharp and moldboard in good scouring conditions, ox-team driving, resources allocation and choice of appropriate cropping techniques.

5.3.3. Stability

The key factor to a successful growing season is to maintain draft animals in good working condition. Stability of the technology from the draft animal perspective is what reliability is to farm implements.

A close look at the data shows that 13% of the farmers had only one draft animal **(Figure 11)**. They needed to borrow another animal to constitute a pair in order to carry out their field activities. This situation is risky, especially if the transaction takes place at

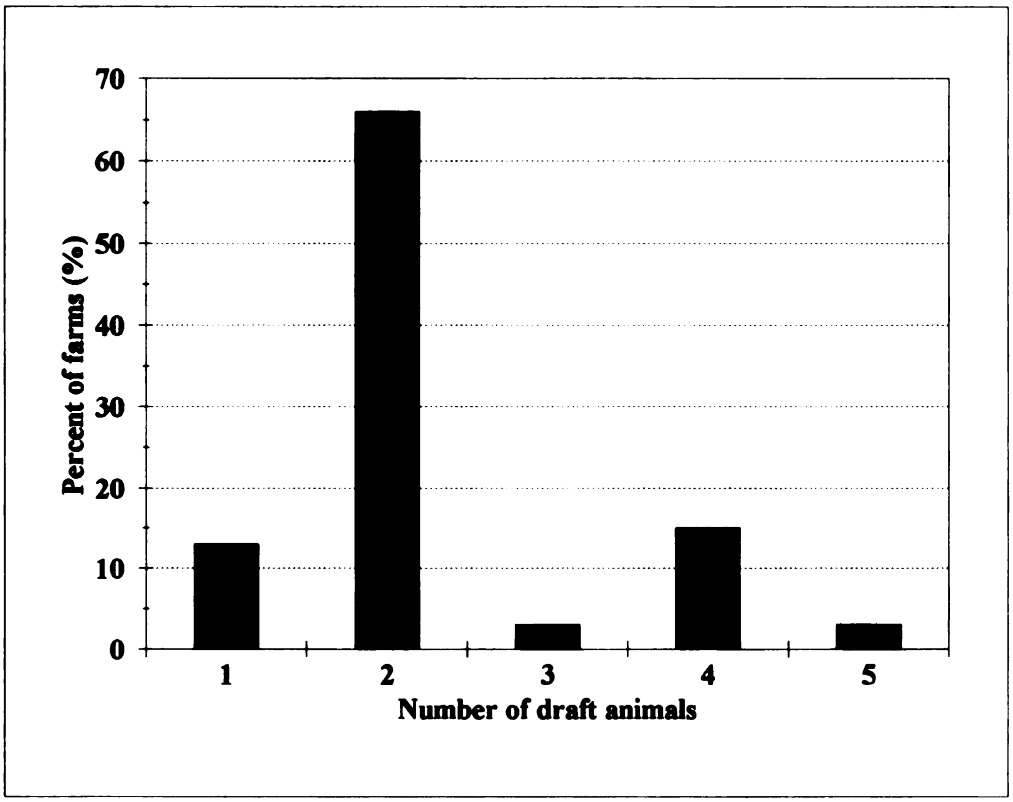

Figure 11: Draft animals' distribution (zones 4 qnd 5)

the beginning of the rainy season. A reliability factor on the draft animals' availability (ANIREL in decimal) is therefore attached to this situation. Using **Equation 20**, the value of ANIREL is equal to:

ANIREL= 0.87

The next group of farmers (66%) disposed of one pair of oxen. This represents also a risky situation. If one animal happens to be unavailable because of injury, disease, death, theft or some other reason, then the production objectives will be seriously compromised.

For these two groups of farmers (79%), the technology is not stable, associating a large amount of risk in the resource allocation process at the farm level. The coefficient of stability using **Equation 19** is equal to:

STABCOEF= 0.21

The third group of farmers (3%) showed more stability with 3 draft animals. The third animal was used to replace any unavailable one. The animal must be trained to work on both the left and right side. This aspect was the most difficult for farmers to achieve, as working draft animals need to be familiar to one another for better and sustained performance.

The fourth group (15%) was more concerned with continuity than anything else. Replacement of the actual working pair of draft animals was a concern and planned well ahead of time. With two pairs of oxen (4 draft animals), the second pair was trained to replace the first aging one. The average ages of the first and second pair of oxen were given as follow **(Table 19)**:

Agro-ecosystem 4:

1st pair of oxen

Right side: 6.79 years with a CV= 31%

Left side : 5.80 years with a CV= 33%

2nd pair of oxen

Right side: 4.33 years with a CV= 44%

Left side : 3.00 years with a CV= 0%

Agro-ecosystem 5:

1st pair of oxen

Right side: 8.15 years with a CV= 40%

Left side : 8.16 years with a CV= 37%

2nd pair of oxen

Right side: 4.20 years with a CV= 51%

Left side : 4.40 years with a CV= 47%

In any case, the second pair was not expected to yield the same productivity as the first pair. Switching to the second pair would slow down the working speed, causing both field capacity and quality of work to decrease.

Table 19: Average age of 1st and 2nd pair of oxen

Oxen	Average (years)	Standard Deviation	SE Mean	90% C.I
Ox 1	7.49	2.89	0.46	(6.71, 8.27)
Ox 2	7.12	2.89	0.50	(6.28, 7.96)
Ox 3	4.25	2.19	0.77	(2.78, 5.72)
Ox 4	4.00	2.00	0.76	(2.53, 5.47)

The fifth group of farmers (3%) had 5 draft animals to make up two pairs and one ready for replacement. They planned for both the future, by training younger animals and were ready for the replacement of any animal unable to work in the first pair.

The stability analysis shows that for the majority of the farmers the technology is unstable. In many cases they depend on their neighbors to borrow missing components or on community work organized at the village level to achieve their production objectives. It was not the focus of this study to analyze the alternatives but previous studies conducted in the same area have showed that in most cases, they still rely heavily on traditional hand tools to complete the unfinished work of the draft animals (Fall, 1985; Ndiame, 1986). This fact demonstrates the importance of the presence workers at the farm level for animal traction users until stability or reliability is improved.

5.4. Land and labor resources

5.4.1. Land availability

The average farm size in the area of study in terms of land area plowed by draft animals was FMSIZE= 4.03 $\pm$ 0.43 ha @ 90% confidence interval (CI) (**Figure 12**). The

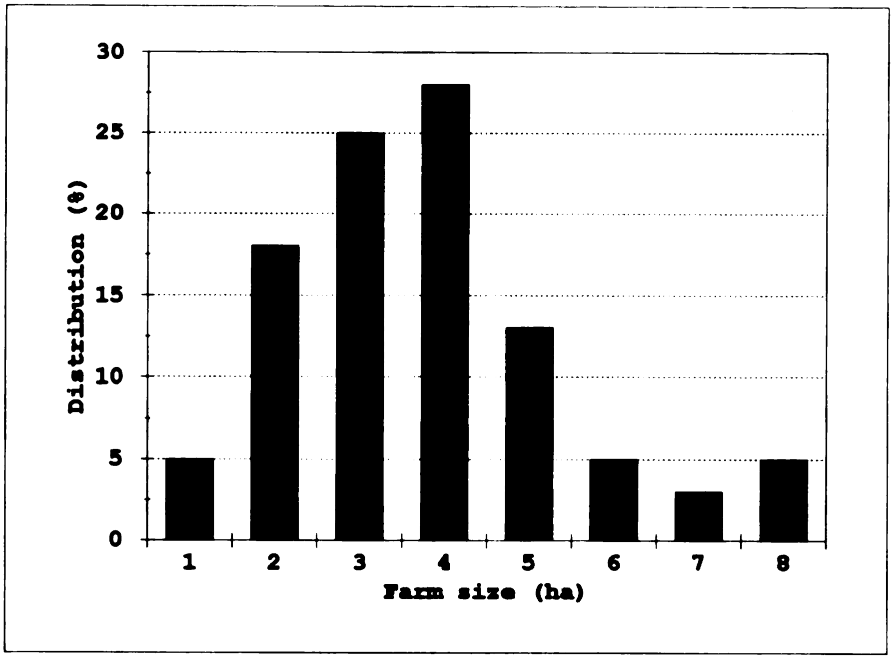

Figure 12: Farm size (ha) distribution

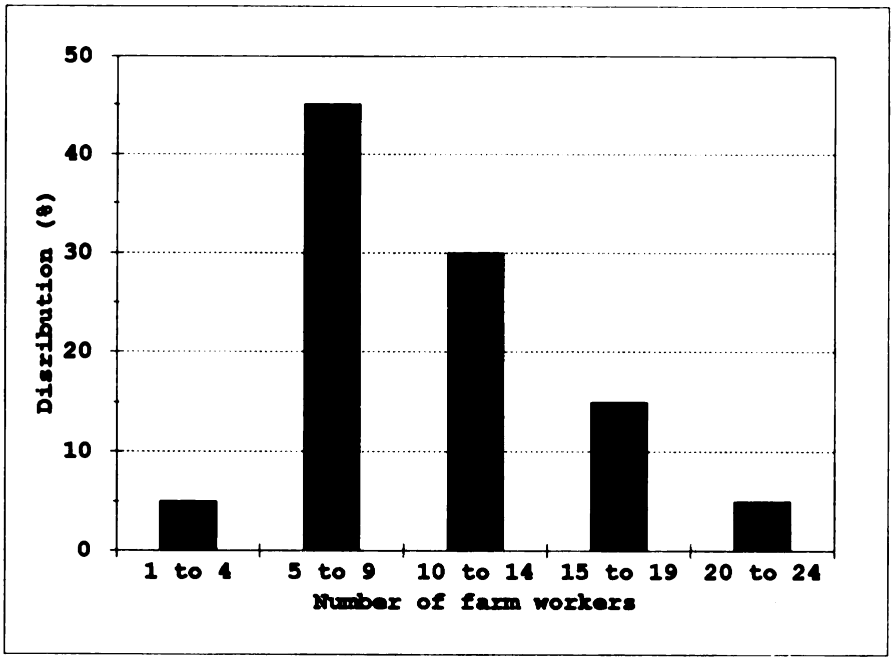

Figure 13: Farm labor distribution

average farm size is slightly different from agro-ecosystem 4 with FMSIZE= 4.26 ha (CV= 36%) to agro-ecosystem 5 with FMSIZE= 3.81 ha (CV= 44%). The potential for land extension is limited by the presence of valleys and lowland areas generally devoted to rice cultivation whenever possible.

5.4.2. Farm labor

Most farmers were equipped with tillage implements (57% of total farm equipment surveyed). The lack of post-tillage implements has relegated draft animals to a low level of utilization during the growing season.

The average number of farm workers NFWKERS present at the farm level during this study was NFWKERS= 10.53 ± 1.17 @ 90% probability level (**Figure 13**). The difference between the two agro-ecosystem zones were not significant with an average of NFWKERS= 11.60 farm workers (CV= 36%) for zone 4 and NFWKERS= 9.45 farm workers (CV= 41%) for zone 5. The availability of the farm workers throughout the growing season is crucial to meet the production objectives. The temporary absence of active family members was pointed out to be a constraint at weeding time.

5.5. Adoption dynamics

As expected during the implementation stage of many agricultural development projects around the world, three phases have been identified in the process of animal traction adoption in the Basse Casamance region **(Figure 14)**:

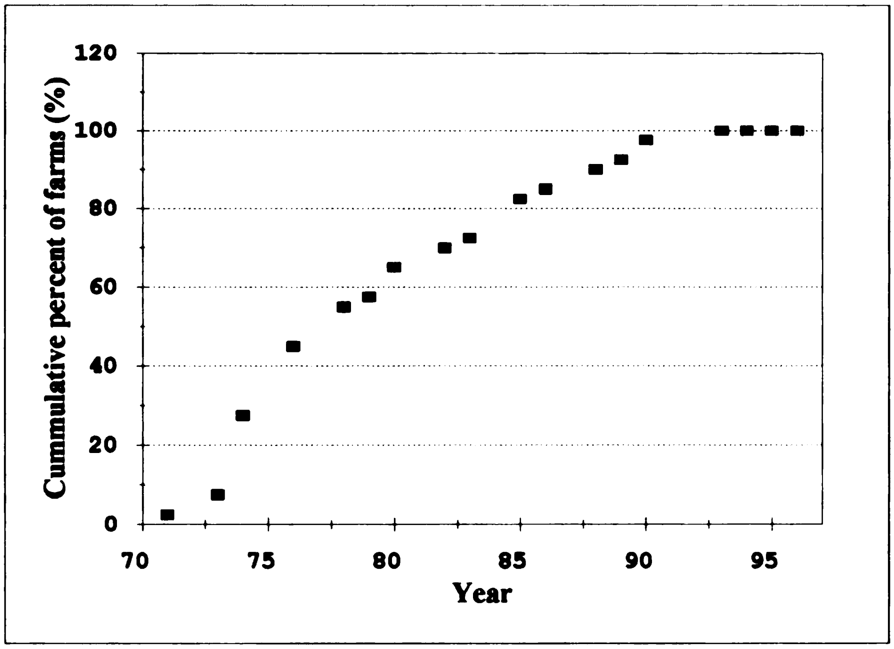

Figure 14: First year in animal traction

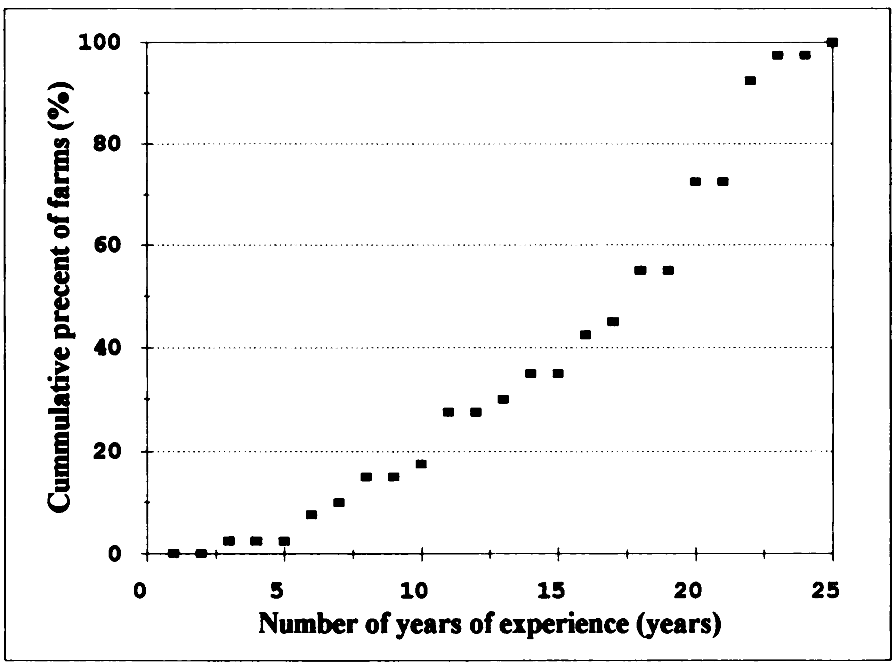

Figure 15: Number of years of experience

Early adopters:

This phase extended from the end of the 1960s to 1974. Animal traction adopters were made of farmers who accepted the challenge of securing agricultural production through diversification and extension of upland crops, mainly on groundnuts (cash crop). They represented no more than 15% of the farmers in the area of study. Farmers located in agro-ecosystem zone 4 were the first to adopt the new technology.

Adopters and innovators

The better performance of households using the new technology through the increase of gross cash crop production generated a lot of interest from manual farmers. The adoption rate was the highest between 1976 and 1980 when no less than 50% of the farmers became involved. This can be explained by two decisive factors. First, the incentives were put on groundnut production at the governmental level through the application of the National Agricultural Policy.

The policy was characterized by an easy access to credit and organized markets for this crop. The quasi-total groundnut production was used to supply the national oil industry. Second, the progressive encroachment of drought in the area forced farmers to look for other alternatives to better secure production at the household level. Rice production was reduced by the decrease in the amount of rainfall (30% to 40% in early 1980s) to the point that rice was no longer driving the farmers' production system in the area of study.

Late adopters

The decrease in the rate of adoption started in the early 1980s and went from 33% to an insignificant level of 2% in the early 1990s. The National Agricultural Policy administered through the governmental agencies was ended in 1980 at the national level for many reasons. The main reason was the inability of farmers to pay back the medium term (5 years) credit loans on farm implements after the long lasting drought of 1978-1982. The farmers' primary source to acquire farm equipment was put to an end and as was pointed out by Ndiame (1986) it is unlikely that a similar program will be initiated in the future. Following this, the credit systems fostered by the Government and policy makers to finance agriculture were merged into the collaboration with private banks and newly implementing rural development projects. Along with other reasons, the conditions for eligibility of the farmers to be part of the newly implemented credit systems were not expected to increase the number of new animal traction adopters.

The dynamics of adoption appeared to be very complex in regards to the variables involved. As the study showed, almost 70% of the farm implements actually used by farmers were financed through a credit system **(Figure 10)**. From 1980, most of the farmers who benefited from the newly formed credit lines, were already animal traction users. The rate of new adopters slowed down for different reasons that included the cost of transactions involved:

- Awareness of the credit system: farmers with a past credit system's experience were able to reduce the cost of transaction by getting correct information. Easy access to information helped them work their way through the system. Besides having easy access to information, they had strong connections for rapid administrative paper work and were also more aware of ways to avoid sanctions or penalties for no annuity payment.

- Members of farmers' production group or farmers' organization: There is more and more tendency for farmers' organization to guarantee the credibility of their members. They carry out preliminary negotiations on behalf of farmers to speed up the process of acquisition. Farmers' organizations administer have their own sanctions to default repayment in accordance with the organization bylaws. In the area of study and since 1988, the CADEF farmers' organization guaranteed 51% of the implements acquired by farmers.

- Conditions of eligibility: the involvement of private banks increased the cost of transaction. Interest went up and farmers were asked to constitute a down payment in order to be eligible for the credit. The National Agricultural Credit Bank of Senegal (CNCAS), the main actor in the credit system, was asking for a 20% down payment and 14% of interest on the capital. With these conditions, farmers generally believed the cost of money was just too high.

- Non existence of second hand implement markets: Only 26% of the implements used by farmers were purchased in cash **(Figure 10)**. These farm implements were mainly bought from out of state markets, across the Gambian border (16%). These implements imported by Gambian dealers were mainly ridgers fabricated by the English manufacturer EMCOT. Local markets, especially those located in North and South Central regions of Senegal accounted for nearly 10% of the purchases. It appears that there is a general tendency for farmers to keep their implements on the farm (19%) until they were completely worn out, out of service and finally discarded **(Figure 9)**. The very few occasions whereby farmers got rid of their implements were only when they traded them off against other equivalent goods (5%) or gave them away as gifts to relatives and friends (1%).

- Learning period: It required a long time for farmers to master the new technology (5 to 6 years). In agro-ecosystem 4 and 5, 10 to 15% of farmers were classified inexperienced **(Figure 15)**. In these conditions, a new adopter experienced mixed results of using animal traction. Animal cultivation can be very frustrating and using farm implements can appear to be a sum of tough skills to master. Lack of working skills can prevent farmers from performing proper adjustments, and identifying the signs of inefficiency.

Farmers located in the area of study do not have a long history of animal traction. The average number of years of experience was (16.43 ± 1.51) years @ 90% level of probability with a maximum of 25 years.

5.6. Summary

This broad overview of animal traction in the Basse Casamance region shows that many factors were involved in the implementation of the technology.

The quality of the implements made available to farmers is of major importance in relation to its life expectancy. Quality control is a must. The design also is as important. The simpler the implement, the better as farmers are not generally skillful in the handling and management of complex toolbars. The analysis shows that toolbars were generally identified with the working component that they were originally equipped with. The introduction of toolbars must go along with specific training to show their flexibility and to demonstrate how they can improve the overall farm working capacity.

The quality of maintenance and servicing is important to the viability of the technology. The skills and expertise of local blacksmiths must be improved through training and better tool supply. Increasing reliability of farm implements is likely to decrease production cost in the short run.

There is a need to improve performance by facilitating the adoption of complementary implements. This will help to avoid the side effects of the shifting of bottleneck to fill the labor deficits. To meet this need it is crucial to reduce the learning period by better training in order to achieve rapid returns on investments that can be reinvested.

In order to tie these different aspects together, it is important to carry out an analysis of actual and potential use of the technology. A correct evaluation of the impact of the technology will help farmers to have a better understanding of the effects of animal traction on the achievement of their production objectives. It will also help differentiate between yield increases and land extension effects. A good starting point is the evaluation of the working capacity of draft animals in the farmer's condition.

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METHODOLOGY FOR EVALUATING THE IMPACT OF ANIMAL TRACTION AT THE FARM LEVEL IN A SMALL-SCALE MULTI-CROPPING SYSTEM (BASSE CASAMANCE, SENEGAL)

Volume II

By

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A DISSERTATION

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

DOCTOR OF PHILOSOPHY

Agricultural Technology and Systems Management

Department of Agricultural Engineering

1997

Chapter 6

WORKING CAPACITY OF DRAFT ANIMALS

Two pairs of oxen per village and one pair on-station for control were used. A total number of 9 pairs were classified into 3 traction groups according to the pair's total liveweight LW:

Group 1: 600 to 700 kg

Group 2: 500 to 600 kg

Group 3: 400 to 500 kg

The 18 draft animals were monitored separately throughout the growing season: working schedule (type and time spent), liveweight follow up, disease, and feeding system.

6.1. Environmental conditions

In the Basse Casamance region, farmers are urged to carry out their field operations as early in the morning as possible to avoid heat stress and to rest the animals according to the level of intensity of the fieldwork. The heavier the work, the shorter the time allocated to the task and the longer the rest.

According to the weather data collected during the study, it shows that draft oxen in the Basse Casamance region faced the weather related fatigue between mid-July and the end of September when the average minimum relative humidity RH_{min} approached 70% **(Figure 16 and 17)**:

- From onset of rain to July 14
  - . Minimum Temperature $\mathbf{T_{min}}$: 24.21 °C
  - . Maximum Temperature $\mathbf{T_{max}}$: 33.73 °C
  - . Minimum Relative Humidity $\mathbf{RH_{min}}$: 52.56
  - . Maximum Relative Humidity $\mathbf{RH_{max}}$: 94.77
- From July 15 to end of September
  - . Minimum Temperature $\mathbf{T_{min}}$: 23.88 °C
  - . Maximum Temperature $\mathbf{T_{max}}$: 31.04 °C
  - . Minimum Relative Humidity $\mathbf{RH_{min}}$: 67.82
  - . Maximum Relative Humidity $\mathbf{RH_{max}}$: 99.49

The difference in RH_{min} shows that the oxen have a narrow window of working days before the draft animals entered the uncomfortable working period of the year. This situation dictates a working strategy based on the number of animal working hours ANWKGHR per day (in hrs/day) allocated to field operations: more working hours before mid-July and less working hours for the remaining of the growing season.

It must be noted that both minimum temperature T_{min} in °C and maximum temperature T_{max} in °C were on the decreasing phase from the onset of the rainy season and reach the minima towards the end of the year. Minimum temperature T_{min} was decreasing from 27.00 °C and maximum temperature T_{max} from 43.80 °C. Records show that the highest temperature has always been recorded during the month of May and the lowest in December-January. The effects of temperature alone need more investigation.

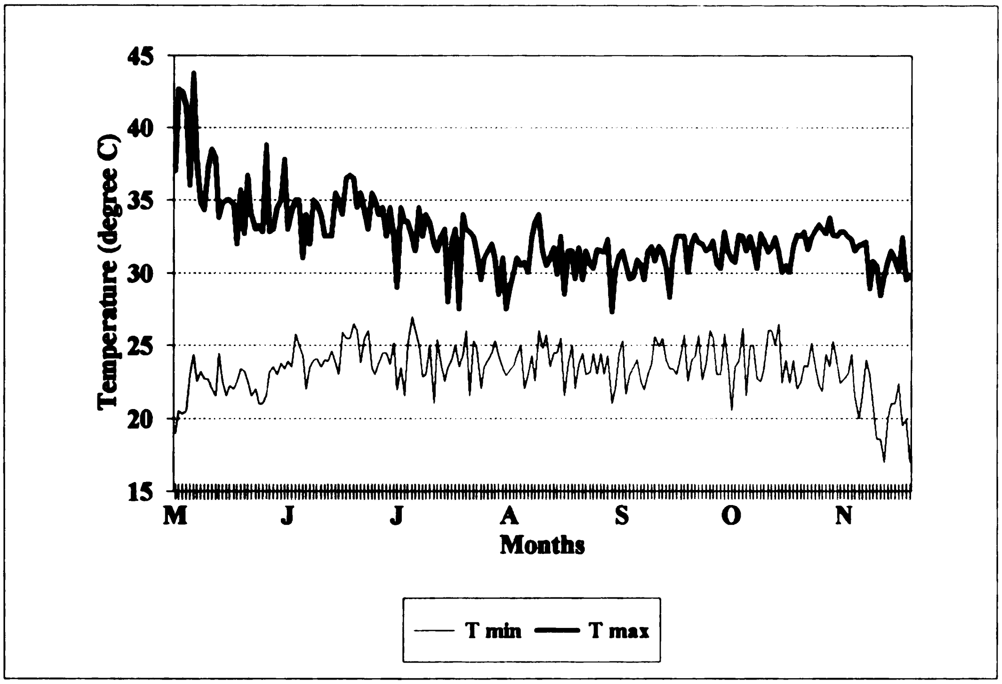

Figure 16: Temperatures (min and max) at Ziguinchor (1996)

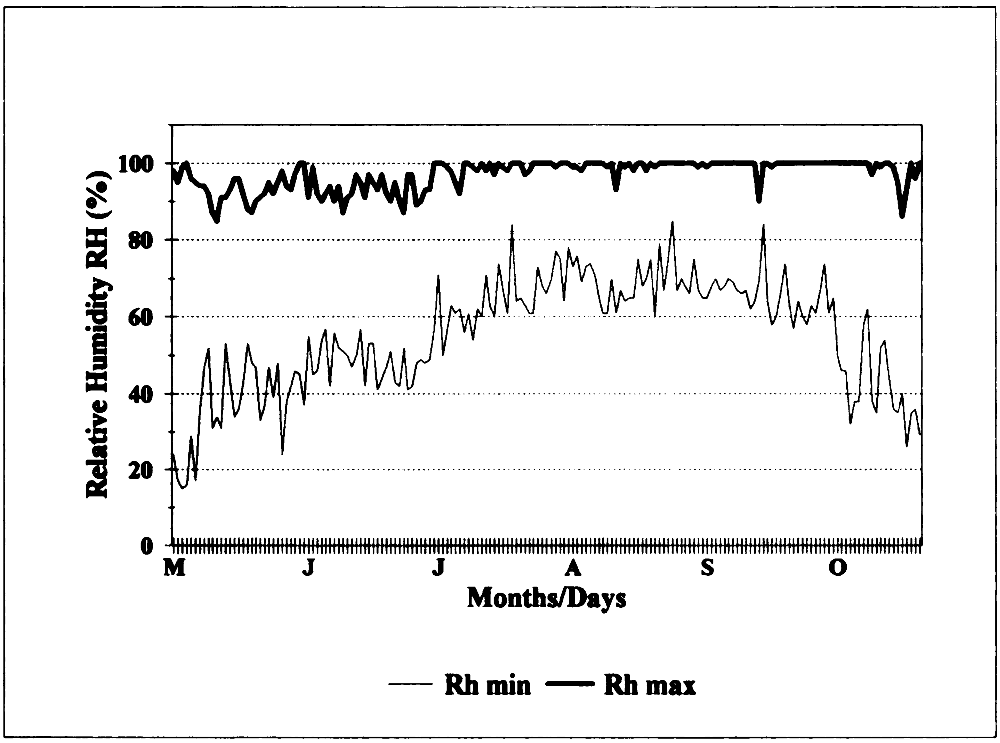

Figure 17: Relative humidity (min and max) at Ziguinchor (1996)

The main objective of the recommendations on working strategies is to optimize the energy available from the draft animals to yield a better efficiency. At this stage of investigation it is important to evaluate the level of animal energy output ANERGY in MJ/day that farmers can count on, especially at the beginning of the rainy season when it is needed the most.

6.2. Maximum performance

The maximum performance test was conducted on-farm during morning hours. The test took place on already cleaned fields and ready to be plowed for the cropping season. The time constraint was such that only two villages out of four could be visited per day.

The pair of oxen from each traction group used the same loaded sledge for each pulling trial. The pulling distance or distance traveled DISTRAV in m (100 to 200 m) was sometimes adjusted to fit the geometry of the fields. Each trial lasted approximately 2 hours starting with a warming up of the pair of oxen yoked to walk together without load for 10 to 15 min. The head yoke type was used for the trials. The characteristics of the draft animal's performance are given in **Table 20 and 21**.

Different adjustments by trial and error were performed at the sledge hitching point to reach an acceptable line of draft. Two variables were recorded during each repetition: the pulling force (PF in N) and the time (PTIME in s) to travel the given distance (DISTRAV in m). A regression analysis was run to model the power output of each pair (ANPOWER in J/s) in relation to the required pulling force PF in N to move the loaded sledge. The same analysis was carried out on the average performances.

6.2.1 Maximum performance

6.2.1.1. Optimum point

- Optimum power ($ANPOWER_{opt}$)

The optimum power $ANPOWER_{opt}$ in J/s is used to compare the performance of each pair of oxen. The power is calculated by multiplying the PF (N) and ANSPEED (m/s). A one-way analysis of variance is conducted with each of the factors contributing to

Table 20: Performance of team of oxen

Group[1]		LW (kg)	PF (N)	Std. dev.	Std Error	PF/LW	Speed (m/s)	Optimum power (J/s)	Max PF (N)
1	P 1	683	1408.32	65.92	9.83	0.21	0.90	1267.49	3531.60
	P 2	690[2]	1442.07	76.62	17.13	0.21	-	-	-
	P 2	648	1618.65	90.45	28.60	0.25	1.11	1796.70	3400.00
2	P 1	535	1379.19	71.12	17.25	0.26	0.90	1241.27	2256.30
	P 2	600	1409.11	75.64	22.80	0.24	0.91	1282.29	3256.00
	P 3	517	1471.50	65.43	21.81	0.29	1.09	1603.94	2950.00
3	P 1	469	924.40	98.75	19.37	0.20	1.01	933.64	1962.00
	P 2	435	950.79	126.78	24.86	0.22	0.86	817.68	2158.20
	P 3	441	1299.83	106.93	48.28	0.30	1.06	1377.81	2530.00

(1) P stands for pair of oxen

(2) The pair of oxen showed unwillingness to pull

Table 21: Average performance of team of oxen

Group	LW (kg)	PF (N)	PF/LW (daN/kg)	Speed (m/s)	Optimum power (J/s)	Max PF (N)
1	665.50[1]	1513.47	0.23	1.00	1532.09	3465.80
2	550.67	1419.93	0.26	0.97	1375.83	2820.77
3	448.33	1058.34	0.25	0.98	1043.04	2216.73

(1) The pair of oxen P2 of Group 1 was not included in the average

the power: the pull force PF in N and the draft animals speed ANSPEED in m/s (**Table 20 and 21**).

The analysis of variance on the optimum power $ANPOWER_{opt}$ in J/s shows that the difference among the 3 traction groups is not very significant **(Table 22)**. The arithmetic difference among the groups can help evaluate the energy balance involved in order to determine the exact amount of feed required for a given group.

Table 22: ANOVA of the Optimum Power (J/s)

SOURCE	DF	SS	MS	F	p
Group	2	322285	161142	2.05	0.224
ERROR	5	393748	78750		
TOTAL	7	716033			

```
                    INDIVIDUAL 95% CI'S FOR MEAN
                    BASED ON POOLED STDEV

LEVEL     N    MEAN    STDEV  -----+---------+---------+---------+-
 Group 1  2   1532.1   374.2            (----------*-----------)
 Group 2  3   1375.8   198.6          (---------*----------)
 Group 3  3   1043.0   295.7   (---------*---------)
                              -----+---------+---------+---------+-
   POOLED STDEV =   280.6         800      1200      1600      2000
```

- Optimum Pulling Force (PF_{Opt})

The arithmetic difference in optimum power $ANPOWER_{opt}$ is mainly due to the significant difference found between the pulling force PF_{opt} of the different traction groups at the optimum point. The 95% confidence level analysis shows that difference in PF_{opt} is significant between traction group 1/group 2 and traction group 3. The difference is not significant between traction group 1 and 2 **(Table 23)**.

The ratio of pulling force to liveweight $(PF/LW)_{opt}$ at the optimum point is the same for the 3 traction groups. The difference is not significant (Fisher-F= 0.92 and p= 0.45) and the average for the 3 groups is $(PF/LW)_{opt}$= 0.24 with a CV= 15% with pulled

Table 23: ANOVA of PF in N at Optimum point

SOURCE	DF	SS	MS	F	p
Group	2	321668	160834	8.19	0.019
ERROR	6	117780	19630		
TOTAL	8	439449			

```
                          INDIVIDUAL 95% CI'S FOR MEAN
                          BASED ON POOLED STDEV

LEVEL     N    MEAN    STDEV   ------+---------+---------+---------+
 Group 1  3   1489.7   113.0                  (-------*-------)
 Group 2  3   1419.9    47.1               (-------*-------)
 Group 3  3   1058.3   209.6   (-------*-------)
                               ------+---------+---------+---------+
 POOLED STDEV =  140.1              1000      1250      1500      1750
```

standard deviation Stdev= 0.036. Monnier (1965) and Nourrissat (1965) reported in different field trials that the Ndama cattle could pull continuously 10% to 14% of their body weight for a long period of time. Field operations requiring pulling 20% or more of the body weight were considered to be from medium to heavy work and could not be sustained for a long time. According to Goe and McDowell (1980), citing Swamy Rao (1964), an improved harness yielded a pull to weight ratio of 24%.

- Draft animals' speed $ANSPEED_{opt}$

The speed $ANSPEED_{opt}$ in m/sec is the most important factor in the power estimation. The significant difference in the pulling force PF is rapidly buffered by the level of low speed of the pairs of oxen across the groups. The analysis of variance shows that the speed of travel $ANSPEED_{opt}$ is almost the same for the traction groups **(Table 24)**.

Table 24: ANOVA of the walking speed (m/sec) (Optimum point)

SOURCE	DF	SS	MS	F	p
Group	2	0.0018	0.0009	0.07	0.935
ERROR	5	0.0666	0.0133		
TOTAL	7	0.0684			

INDIVIDUAL 95% CI'S FOR MEAN
BASED ON POOLED STDEV

```
LEVEL     N   MEAN     STDEV   ----+---------+---------+---------+--
Group 1   2   1.0050   0.1485        (-----------*----------)
Group 2   3   0.9667   0.1069   (------------*-----------)
Group 3   3   0.9767   0.1041    (-----------*------------)
                               ----+---------+---------+---------+--
POOLED STDEV =  0.1154            0.84      0.96      1.08      1.20
```

Considering the level of pulling force PF required for field activities, it would be a slight improvement to accept the level of significance of the optimum output. This can help to better allocate the length of time to perform field operations and also, to evaluate the amount of feed required for draft oxen to carry out specific field activities.

6.2.1.2. Maximum Pull force PF_{max}

The maximum pulling force PF_{max} in N represents the value for which the pair of oxen had difficulties in walking while pulling. It corresponds to the animals' speed ANSPEED almost equal to 0 m/sec. In other words, PF_{max} represents a continuous maximum pulling effort in comparison with the instantaneous maximum pull.

The analysis of variance shows that the difference is significant between the groups at $p = 0.038$ **(Table 25)**. The 95% confidence interval separates the means and shows that the maximum pull PF_{max} of group 1 is significantly different from group 3.

Table 25: ANOVA of maximum pull force (N)

SOURCE	DF	SS	MS	F	p
Group	2	1892816	946408	6.76	0.038
ERROR	5	700225	140045		
TOTAL	7	2593041			

INDIVIDUAL 95% CI'S FOR MEAN
BASED ON POOLED STDEV

```
LEVEL     N   MEAN    STDEV   -------+---------+---------+---------
Group 1   2   3465.8   93.1                   (---------*--------)
Group 2   3   2820.7  512.4          (-------*-------)
Group 3   3   2216.7  288.5   (-------*-------)
                              -------+---------+---------+---------
POOLED STDEV =  374.2              2100      2800      3500
```

The maximum pull force PF_{max} can be translated as the capacity of draft oxen to overcome the peak draft encountered in the fields while continuously working. The average ratio of pull force to liveweight $(PF/LW)_{max}$ at this point is 0.51 with CV= 14% and Fisher-F= 0.08 at $p = 0.923$. At this stage of the trial, the pairs of oxen were asked to give the maximum effort which yielded this high level of pull ratio PF/LW. The ratio corresponds to pulling force PF_{max} of almost half of the body liveweight LW. In any case, it is not expected in the real working situations that draft oxen be submitted to this level of pull on a regular basis.

Values found in the literature shows that the trial results for the Ndama breed are in the expected range. Goe and McDowell (1980) reported a ratio of 0.51 or 51% during tests conducted in India with different pairs of oxen.

6.2.2. Characteristics of power curves

A regression analysis was carried out to model the power output ANPOWER in J/s of each pair of oxen. The results are presented in the Appendices. A regression analysis was also performed on the average performance of each traction group. The different models are used in the expert system computer program to help evaluate and refine the energy balance at the farm level.

6.2.2.1. Power output model

The analysis was carried out on two determinant parameters directly involved in the performance of the cropping system: the power output ANPOWER in J/s of the draft animals (pair of oxen) and the level of speed ANSPEED in m/s at which the task was performed. Firstly, the parameters were estimated for the general linear regression, secondly an analysis of variance was performed, and thirdly, a look at the correlation coefficient **R** among variables to help explain the relationship. The $\mathbf{R}^2$ is also important as it helps to determine the amount of variation explained by the regression line. The best fit was obtained with the quadratic form of PF using the variables (PF/1000) and $(PF/1000)^2$.

A general comment: most of variation accounted in the linear regression was mainly due to the border values at:

PF = 0 and **PF** = PF_{max}

At **PF** = 0, the pair of oxen was walked without load to cover the path. Farmers had different feeling of walking with the draft animals in terms of how fast to perform the task. At the other end of the trial, pulling the maximum load depended on the willingness of the pair of oxen to do the job. It did not matter how well the oxen were trained, the greater the amount of draft required, the less the willingness of the oxen to pull. As a consequence, the pulling of the maximum load was put to an end to manage the temperament and excitement of the animals. In such cases, the value recorded for the maximum Pull force PF_{max} would be underestimated. The analysis is presented by traction group:

- Traction Group 1: 600 to 700 kg of LW

The average performance of the Traction Group 1 is summarized in **Table 26**. The regression equation is:

$$(ANPOWER)^{\frac{1}{2}} = 44.35*(\frac{PF}{1000})-12.69*(\frac{PF}{1000})^2 \qquad \textbf{(45)}$$

Table 26: Average performance of Traction Group 1

PF (N)	Speed (m/sec)	PF/1000 (N)	$(PF/1000)^2$ (N)	Power (J/s)	$(Power)^{1/2}$ (J/s)	PF/LW
0.00	1.33	0.00	0.00	0.00	0.00	0.00
259.70	1.17	0.26	0.07	303.85	17.43	0.04
517.60	1.14	0.52	0.27	590.06	24.29	0.08
920.40	1.09	0.92	0.85	1003.24	31.67	0.14
1052.40	1.11	1.05	1.20	1162.90	34.10	0.16
1232.80	1.04	1.23	1.52	1282.11	35.81	0.19
1408.30	0.90	1.41	1.98	1267.47	35.60	0.21
1531.40	0.75	1.53	2.35	1148.55	33.89	0.23
1618.70	1.11	1.62	2.62	1796.76	42.39	0.24
1866.80	0.53	1.87	3.48	989.40	31.45	0.28
2074.40	0.65	2.07	4.30	1348.36	36.72	0.31
2344.60	0.34	2.34	5.50	797.16	28.23	0.35
2452.50	0.53	2.45	6.01	1299.82	36.05	0.37
2811.00	0.34	2.81	7.90	955.74	30.92	0.42
3465.80	0.00	3.47	12.01	0.00	0.00	0.52

Table 27: Parameter estimates (Group 1)

Predictor	Coef	Stdev	t-ratio	p
No constant				
(PF/1000)	44.350	2.120	20.92	0.000
$(PF/1000)^2$	-12.6875	0.8319	-15.25	0.000
s = 4.454		R-squared = 0.88		

Table 28: Analysis of Variance (Group 1)

SOURCE	DF	SS	MS	F	p
Regression	2	13687.5	6843.8	344.96	0.000
Error	13	257.9	19.8		
Total	15	13945.4			

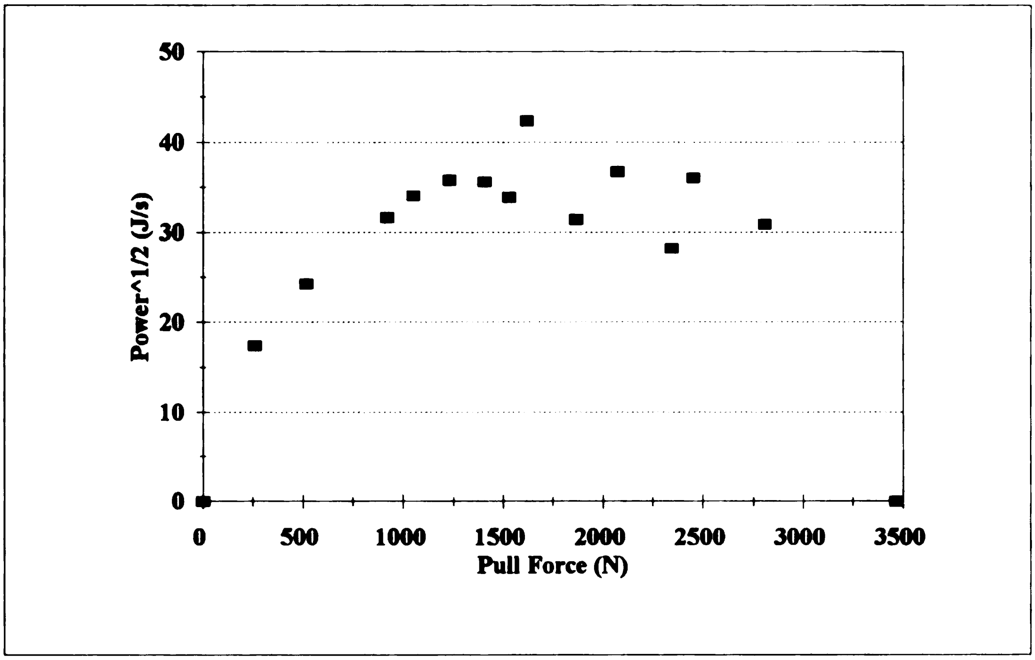

Figure 18a: Power curve of Traction Group 1

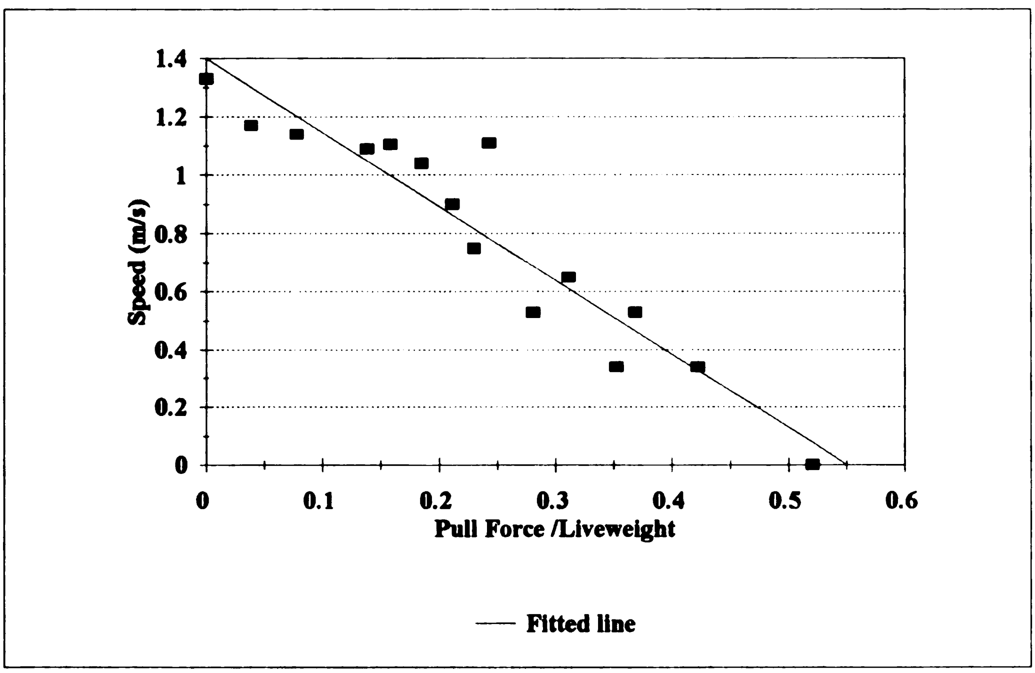

Figure 18b: Walking speed of Traction Group 1

The fitted linear regression equation $\mathbf{R^2}$ explains 88% of the total variation, which is very significant **(Table 27 and 28)**. Most of variation was mainly introduced by the border values at PF = 0 and PF = PF_{max} **(Figure 18a)**. According to this model, the unusual observation at PF_{max} suggests that the pairs of oxen in the Group 1 could have pulled more that was recorded. This influence is not negligible in the amount of variation translated into the value of the R^2.

In the region of the optimum power $ANPOWER_{opt}$, the amount of pull applied PF_{opt} = 1750 N started to become unsustainable and to induce the unwillingness to pull mentioned earlier. This fact indicates the needs for more studies to improve the harnessing systems.

- Traction Group 2: 500 to 600 kg of LW

The average performance of the Traction Group 2 is given in **Table 29**:

The regression equation is:

$$(ANPOWER)^{\frac{1}{2}} = 48.17 * (\frac{PF}{1000}) - 15.34 * (\frac{PF}{1000})^2 \quad \textbf{(46)}$$

The fitted regression equation shows a good coefficient of determination R^2= 0.93 which is very significant **(Table 30)**. However, the analysis of the data shows two singularities. Firstly, according to the model, the amount of maximum pull PF_{max}= 2013.9 N developed by the pair of oxen was also underestimated **(Figure 19a)**. Once again, the unwillingness to walk at this level of pulling induced part of the variation. Secondly, the value of the maximum pull force PF_{max}, influenced the trend of the curve.

Table 29: Average performance of Traction Group 2

PF (N)	Speed (m/sec)	PF/1000 (N)	$(PF/1000)^2$ (N)	Power (J/s)	$(Power)^{1/2}$ (J/sec)	PF/LW
0.00	1.32	0.00	0.00	0.00	0.00	0.00
868.90	1.25	0.87	0.75	1086.13	32.96	0.16
929.70	1.04	0.93	0.86	966.89	31.09	0.17
1209.90	1.11	1.21	1.46	1342.99	36.65	0.22
1285.10	0.89	1.29	1.65	1143.74	33.82	0.23
1409.10	0.91	1.41	1.99	1282.28	35.81	0.26
1471.50	0.99	1.47	2.17	1456.79	38.17	0.27
1917.40	0.76	1.92	3.68	1457.22	38.17	0.35
1970.10	0.75	1.97	3.88	1477.57	38.44	0.36
2013.90	0.35	2.01	4.06	704.86	26.55	0.37
2412.10	0.29	2.41	5.82	699.51	26.45	0.44
2452.50	0.42	2.45	6.01	1030.05	32.09	0.45
3103.00	0.00	3.10	9.63	0.00	0.00	0.56

Table 30: Parameter estimates (Group 2)

Predictor	Coef	Stdev	t-ratio	p
Noconstant				
(PF/1000)	48.167	2.009	23.97	0.000
$(PF/1000)^2$	-15.337	0.872	-17.58	0.000
s = 3.604		R-squared = 0.93		

Table 31: Analysis of Variance (Group 2)

SOURCE	DF	SS	MS	F	p
Regression	2	12505.1	6252.6	481.32	0.000
Error	11	142.9	13.0		
Total	13	12648.0			

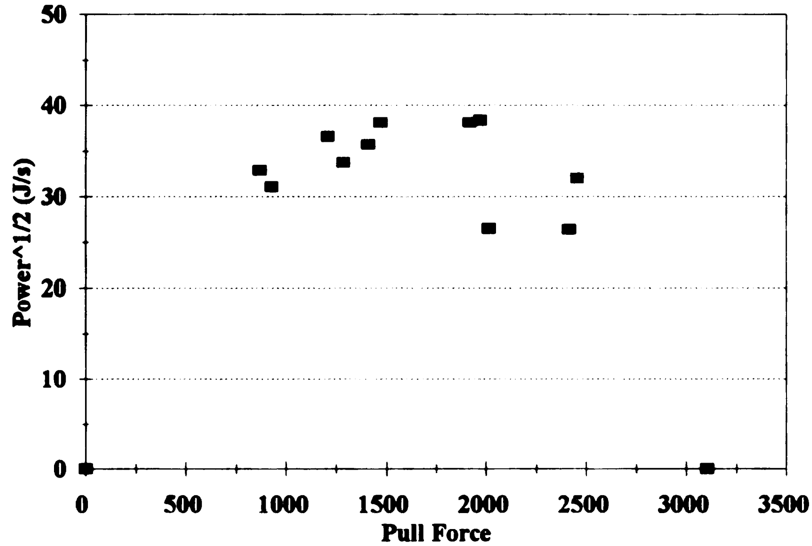

Figure 19a: Power curve of Traction Group 2

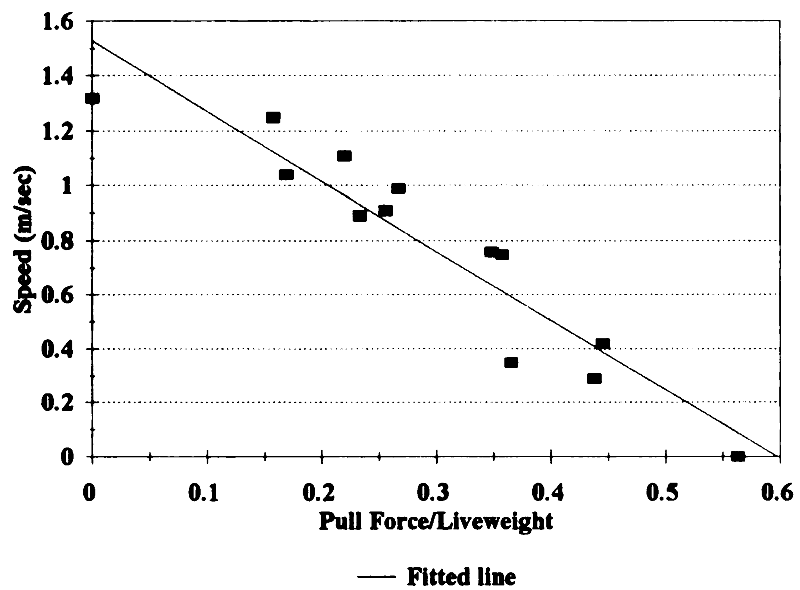

Figure 19b: Walking speed of Traction Group 2

- Traction Group 3: 400 to 500 kg of LW

The average performance of the Traction Group 3 is summarized in **Table 32**.

The regression equation is:

$$(ANPOWER)^{\frac{1}{2}} = 56.11 * (\frac{PF}{1000}) - 25.63 * (\frac{PF}{1000})^2 \qquad \textbf{(47)}$$

The parameter estimates and the analysis of variance show a very good fit with an $R^2 = 0.91$ **(Table 33 and 34)**. The draft animals had a tendency to walk fast in the area of lower required PF at the beginning of the trial. The unwillingness to pull appeared in the same region of the graph and mostly beyond the optimum power point **(Figure 20a)**. Most of the variation was introduced once again by the maximum pull force PF_{max}, underestimated according to the model.

6.2.2.2. Walking speed (ANSPEED in m/s)

The walking speed ANSPEED in m/s while performing a task is the second important parameter towards the evaluation of the power output ANPOWER. Regression analysis has also been performed to give more insight in order to explain the accounted variation in the power output models. The analysis has been conducted for each Traction Group. The best fit was obtained by plotting the speed ANSPEED as the dependent variable and the ratio of pull force PF over the average liveweight of the group PF/LW. The speed plotted against the PF/LW yielded a better correlation than the speed plotted against pull force PF.

Table 32: Average performance for Traction Group 3

PF (N)	Speed (m/sec)	PF/1000 (N)	$(PF/1000)^2$ (N)	Power (J/s)	$(Power)^{1/2}$ (J/s)	PF/LW
0.00	1.38	0.00	0.00	0.00	0.00	0.00
200.00	1.33	0.20	0.04	266.00	16.31	0.04
350.00	1.19	0.35	0.12	416.50	20.41	0.08
520.00	1.10	0.52	0.27	572.00	23.92	0.12
720.00	1.05	0.72	0.52	756.00	27.50	0.16
920.00	0.93	0.92	0.85	855.60	29.25	0.21
1270.00	0.76	1.27	1.61	965.20	31.07	0.28
1410.00	0.35	1.41	1.99	493.50	22.21	0.31
1500.00	0.39	1.50	2.25	585.00	24.19	0.33
1690.00	0.33	1.69	2.86	557.70	23.62	0.38
2220.00	0.00	2.22	4.93	0.00	0.00	0.50

Table 33: Parameter estimates (Group 3)

Predictor	Coef	Stdev	t-ratio	p
Noconstant				
(PF/1000)	56.111	3.106	18.06	0.000
$(PF/1000)^2$	-25.632	1.816	-14.11	0.000
s = 3.417		R-squared = 0.91		

Table 34: Analysis of Variance (Group 3)

SOURCE	DF	SS	MS	F	p
Regression	2	5362.4	2681.2	229.66	0.000
Error	9	105.1	11.7		
Total	11	5467.5			

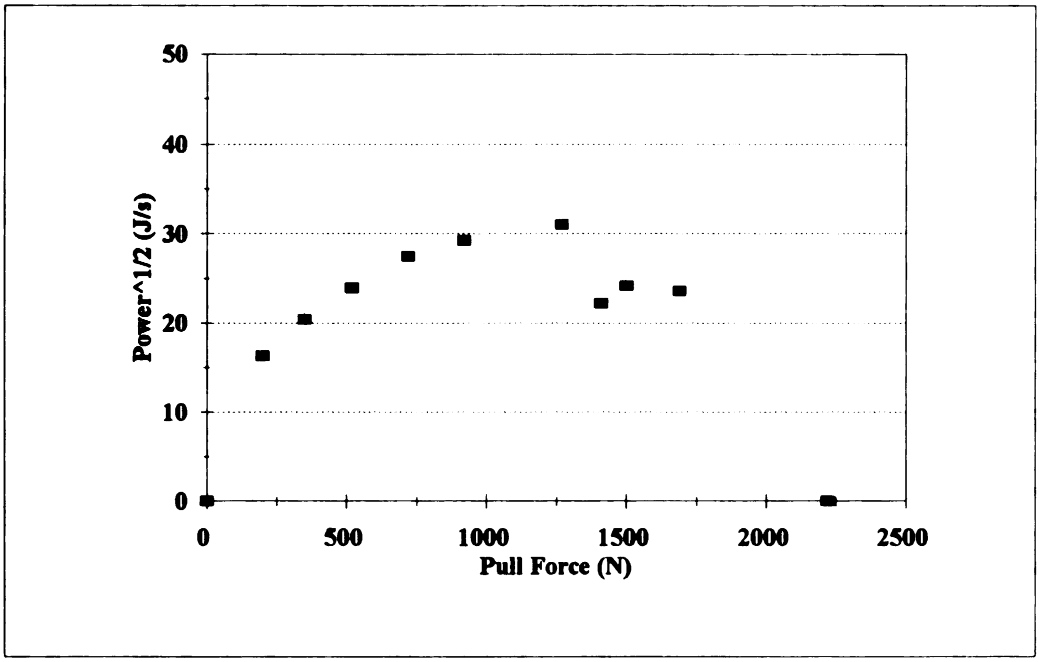

Figure 20a: Power curve of Traction Group 3

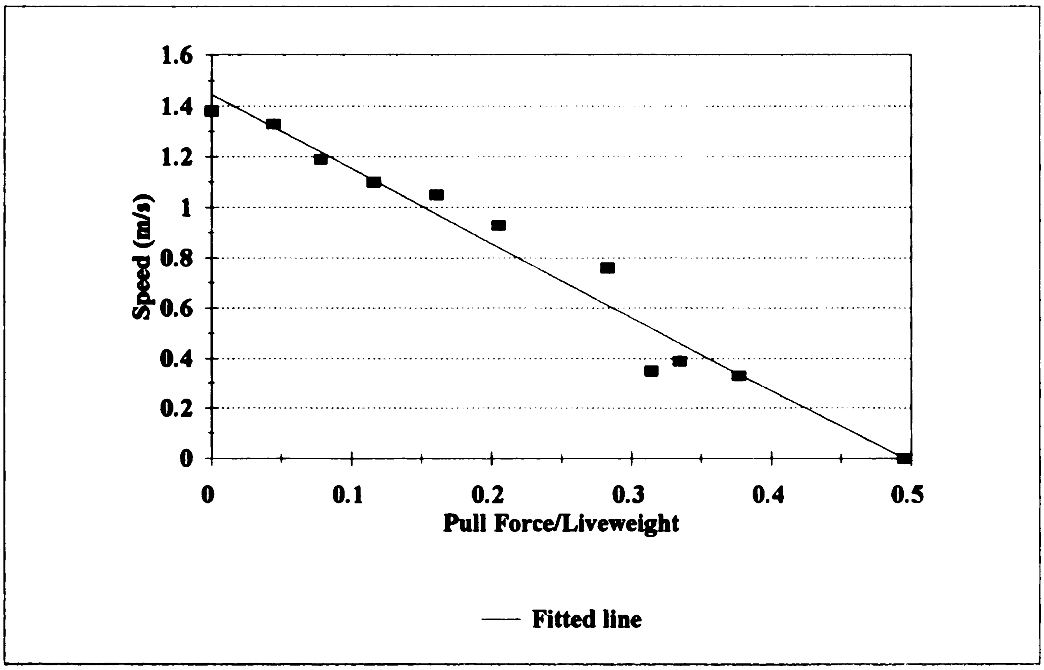

Figure 20b: Walking speed of Traction Group 3

Generally, the fitted straight lines with their respective negative slopes show that the speed ANSPEED of the pair of oxen was decreasing with higher required pull force. The higher the pull force PF, the lower the speed level. This speed reached the value of zero at the maximum pull PF_{max}.

- Traction Group 1

The regression equation is:

$$ANSPEED = 1.40 - 2.53 * (\frac{PF}{LW}) \tag{48}$$

The fitted straight line to model the speed is highly significant as the correlation coefficient R = 0.94 (with R^2= 89.2%) is very close to 1 **(Table 35 and 36)**. The relationship between the pull force PF and the speed ANSPEED

is very strong and in opposite direction **(Figure 18b)**. The straight line accounts for 89% of the variation. One observation at PF = 1618.7 seems to be high and introduces part of the total variation. The high value of the speed at this point gives the impression that the pair of oxen could have develop more power than actually delivered. The unwillingness factor induced by the amount of pulling seems to be the only reason they did not.

Table 35: Parameter estimates of walking speed (Group 1)

Predictor	Coef	Stdev	t-ratio	p
Constant	1.39930	0.06719	20.82	0.000
(PF/LW)	-2.5326	0.2450	-10.34	0.000
s = 0.1326	R-sq = 89.2%		R-sq(adj) = 88.3%	

Table 36: Analysis of Variance of walking speed (Group 1)

SOURCE	DF	SS	MS	F	p
Regression	1	1.8795	1.8795	106.86	0.000
Error	13	0.2287	0.0176		
Total	14	2.1082			

- Traction Group 2

The regression equation is:

$$ANSPEED = 1.53 - 2.56 * (\frac{PF}{LW}) \quad \textbf{(49)}$$

The parameter estimates and the analysis of variance shows that the fit is good with a negative slope and a high correlation coefficient of **R** = 0.94 (with $\mathbf{R}^2$= 88.5%) **(Table 37 and 38)**. The model explains more than 88% of the variation.

Table 37: Parameter estimates of walking speed (Group 2)

Predictor	Coef	Stdev	t-ratio	p
Constant	1.52727	0.09084	16.81	0.000
(PF/LW)	-2.5580	0.2784	-9.19	0.000
s = 0.1421	R-sq = 88.5%		R-sq(adj) = 87.4%	

Table 38: Analysis of Variance of walking speed (Group 2)

SOURCE	DF	SS	MS	F	p
Regression	1	1.7040	1.7040	84.40	0.000
Error	11	0.2221	0.0202		
Total	12	1.9261			

The low speed ANSPEED = 0.29 m/sec recorded at PF = 2412.1 N was not singled out by the analysis even though it introduces part of the variation. This low speed is also due to the unwillingness to pull under heavy load regardless of the quality and level of training (**Figure 19b**).

- Traction Group 3

The regression equation is:

$$ANSPEED = 1.45 - 2.95 * (\frac{PF}{LW}) \quad \textbf{(50)}$$

Table 39: Parameter estimates of walking speed (Group 3)

Predictor	Coef	Stdev	t-ratio	p
Constant	1.44785	0.04920	29.43	0.000
(PF/LW)	2.9540	0.1862	15.86	0.000
s = 0.09128		R-sq = 96.5%	R-sq(adj) = 96.2%	

Table 40: Analysis of Variance of walking speed (Group 3)

SOURCE	DF	SS	MS	F	p
Regression	1	2.0969	2.0969	251.69	0.000
Error	9	0.0750	0.0083		
Total	10	2.1719			

The best fit line for the Traction Group 3 is shown in **Figure 24**. The parameter estimates and the analysis of variance **(Table 39 and 40)** shows a very good correlation **R = 0.98** (with R^2= 96.5%) to translate the close relationship between the amount of pull required and the speed. There is still a certain amount of unexplained variation related to the unwillingness factor under heavy load, which leads to more energy losses.

6.3. Draft animal liveweight model

The liveweight LW in kg of draft animals is a required input in all models developed to this point. It is important to be able to evaluate this parameter before using any of these models. The simpler the way to do this the better. The liveweight of draft animals is generally unknown to the majority of farmers. During this field study none of them was able to give the liveweight of their draft animals. Also, weighing scales are not generally available to farmers to help them determine the weight of their animals.

In order to develop the model at this stage of the research, more draft animals were included in the sample to have enough point to generate a better fit. The extra draft animals used belonged to the farmers in the 4 villages visited during the maximum pull trials. The simplicity and speed of the measurement technique allowed this increase in number of oxen, from 18 (original sample) to 73 cases. The technique consisted of measuring the circumference at the point of heart (in cm) of individual animal and determining the liveweight LW with an electronic weighing scale (Barlo Electronic Scale™ Model 2100).

The regression analysis performed with the first 18 draft oxen gave a coefficient of determination of **R^2= 0.87** which is an acceptable level of significance. The correlation coefficient between liveweight LW in kg and circumference CIRCUMF in cm was **R = 0.93** to demonstrate a close relationship between the two variables **(Figure 21a)**.

The regression equation is:

$$LW = -467.80 + 4.78 * (CIRCUMF) \qquad \textbf{(51)}$$

The parameter estimates and analysis of variance are presented in the Appendices. Only, the complete statistical analysis of the broadened base sample (73 oxen) is given.

The corresponding regression equation is:

$$LW = -515 + 5.11 * (CIRCUMF) \qquad \textbf{(52)}$$

The broadened base sample gave a better correlation **R= 0.97** and explained more of the variation observed. The coefficient of determination **R^2 = 0.94** shows a better fit (**Table 41**). Most of the variation is due to the errors

Table 41: Parameter estimates for liveweight vs circumference

Predictor	Coef.	Stdev	t-ratio	p
Constant	515.13	23.88	-21.57	0.000
CC (cm)	5.10	0.15	33.41	0.000
s = 14.97	R-sq = 94.0%		R-sq(adj) = 93.9%	

Table 42: Analysis of Variance (LW, CC)

SOURCE	DF	SS	MS	F	p
Regression	1	250037	250037	1116.48	0.000
Error	71	15901	224		
Total	72	265938			

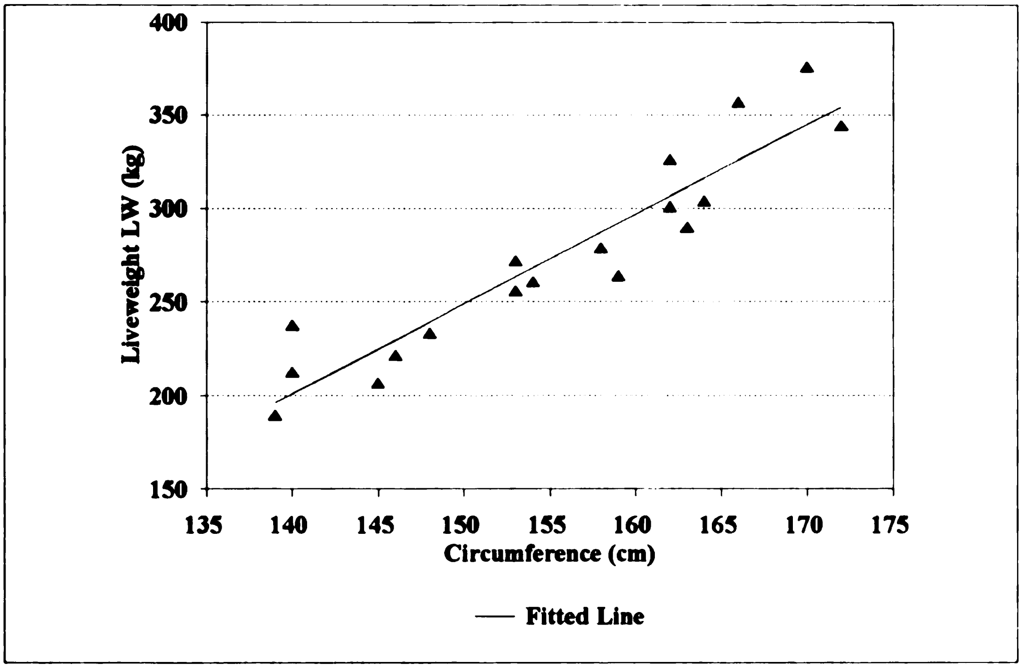

Figure 21a: LW= f(CIRCUM) regression line (18 oxen)

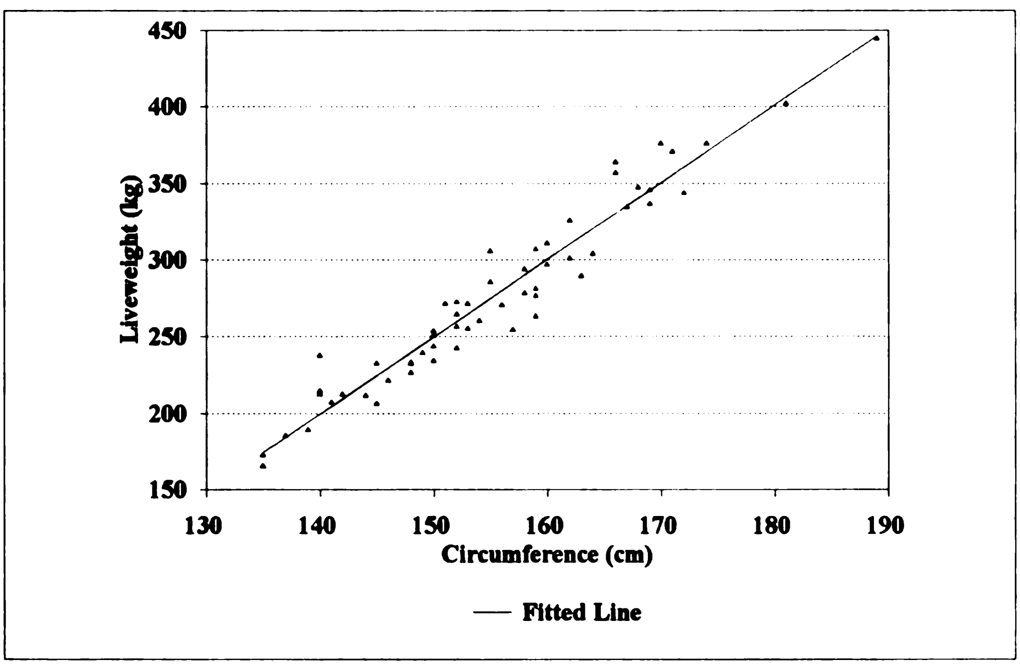

Figure 21b: General regression line (73 oxen)

committed when performing the measurements of the thorax circumference (**Table 42**). Draft animals do not appreciate being touched by outsiders. The measurement had to be made with the collaboration of the farmers. The best solution was to put them under a yoke before making the measurement. The coefficient of correlation **R= 0.97** demonstrates the positive close relationship between the two variables.

Figure 21b shows that a couple of points are unusual observations. They deviate from the line and present a fairly large standard residuals. Those points are represented at location (CC, LW) = (140, 238), (157, 255), (159, 264), (155, 306), (166, 364). Two other observations need to be pointed out at (CC, LW) = (188, 442), (189, 445) as they are located at the extreme end of fitted regression line. They have a real influence on the line even with their small standard residuals.

The fitted regression line works well in predicting liveweight of humpless Ndama breeds. Caution must be taken when performing the measurements. It must be done as early as possible, in morning hours. It is better to do the measurement before the draft animals go for grazing, to avoid introducing an extra source of variation. The more feed they take before the measurements, the more the variation is introduced in the model.

The liveweight LW model developed in this study needs to be validated for specific applications. The model will be very useful in future calculations of draft animal energy balance and feeding system evaluation.

6.4. Management of draft animals

According to their production objectives, the farmers' systems management of draft animals was mainly oriented towards minimizing risk and securing cash crop production. Farmers pointed out that the strategy of using draft oxen on different crops depended greatly on the timeliness of the rainy season onset. Two main allocation patterns are used:

- If the rainy season is on time: The cereals (maize and millet) will receive the draft animals first. Afterwards, they are allocated to the cash crop (groundnuts) for the time remaining. Their utilization on sorghum and rice fields is occasional depending on the pattern of rain distribution and on the number of working days.

- If the rainy season is late: The cash crops (groundnuts) are given priority in using the draft animals. The remaining crops (cereals) are usually manually cultivated.

In general, the amount of area for cereal production is fixed compared to the cash crops. The total cereal production is mainly used for the farmers' own consumption. On the other hand, the amount of land allocated to the cash crops depends on the size of the farm in hectares. In agro-system 4, for instance, the groundnut field can occupy 65% to 70% of the farm (Equipe Systemes, 1983; 1986; Fall, 1986).

The management of the draft animals during the rainy season deals mainly with the following questions: What type of field work can be performed?; How many days per week can the draft animals be used?; What type of feeding system is used?; How are the problems that affect the animal's health resolved?

The type of management has an impact on the liveweight and the working capacity of the oxen during the rainy season. The working schedule of the 18 draft oxen was monitored throughout the rainy season on a daily basis to better understand the type of management practices.

6.4.1. Field work

During the rainy season (June to October), the draft animals were mainly used for three major field operations (tillage, seeding and weeding) besides transport. For the rest of the season (November), the draft animals were idling or used occasionally for transport. They were not used for harvesting as groundnut diggers were almost non existent at the farm level.

Table 43: Repartition (%) of draft oxen time

Field Operations	June-July	August	September	October
Tillage	83.33	66.72	22.22	0.00
Seeding	38.95	11.13	0.00	0.00
Weeding	5.56	33.33	0.00	0.00
Harvesting	0.00	0.00	0.00	0.00
Not used	0.00	22.22	72.22	77.78
Transport	27.78	22.22	5.56	22.22

It appeared that most of draft animals working time was used for tillage activities, especially in the months of June and July where 83.3% of the oxen were used for seedbed preparation purposes **(Table 43)**. After plowing, seeding (38.9%) was the second most important field operation carried out by farmers. The concomitance of these two first field activities was such that farmers with more than one pair of oxen were better off. In contrast, weeding was not as mechanized (5.5%) in favor of transport (27.8%).

During the month of August, more weeding took place with 22.2% but plowing remained the most important activity. After the cash crop, sorghum and rice fields were the crops to receive the oxen. Starting the month of September, most of the draft animals stopped being used for crop production as 72.2% were just idling, 22.2% used for tillage on other secondary crops and 5.6% for transport. When the growing season reached the month of October, more oxen were idling (77.8%) and the rest were used for transport.

6.4.2. Daily working hours

The level of intensity of draft oxen utilization was very high at the beginning of the rainy season, during the months of June and July. Farmers were working the draft animals for an average of 7 hours per day with a minimum of 5 hours and a maximum of 9 hours. This number of hours included the time spent to travel to and from the field location and the time spent yoking the animals and hitching the farm implements. This working intensity was repeated 6.47 days per week with little rest, 0.53 day per week (1 day maximum) **(Table 44)**.

An average field time of 6 hours per day were used by farmers to perform field operations. Field time was adjusted according to corresponding field operation efficiency E in percent (plowing, seeding, weeding). A little time was left for other activities like transport.

Table 44: Management and Handling of Draft Animals @ the farm level

Draft animals' activities	Mean	Median	TRmean	Stdev	SEmean	Min	Max	Q1	Q3
A. Draft Animal Age (yrs)	7.94	7.75	7.84	2.54	0.60	4.50	13.00	5.87	9.25
Experience (yrs)	4.00	3.50	4.00	2.30	4.00	1.00	9.00	2.00	5.00
B. Field Work									
Days worked_June-July	19.47	15.00	19.38	8.65	19.38	7.00	33.00	14.00	26.50
Days worked_August	10.86	10.00	10.83	5.13	1.37	4.00	18.00	5.00	15.00
Days worked_September	2.00	2.00	2.00	1.15	0.58	1.00	3.00	1.00	3.00
Hours worked/day_June-July	7.00	7.00	7.00	1.19	0.31	5.00	9.00	6.00	8.00
Hours worked/day_August	5.21	5.00	5.08	1.24	0.33	4.00	8.00	4.50	5.00
Hours worked/day_September	5.50	5.50	5.50	1.73	0.87	4.00	7.00	4.00	7.00
C. Custom work									
Rental days_June-July	3.47	3.00	3.23	3.54	0.91	0.00	10.00	0.00	7.00
Rental days_August	2.00	2.00	2.00	1.15	0.58	1.00	3.00	1.00	3.00
Local Rent_Rate/day(CFA)	3500	2750	3500	1558	551	1000	6000	1000	6000
Outside Rent_Rate/day(CFA)	3500	3500	3500	2887	1443	1.00	3.00	1.00	3.00
Transp. Rent_Rate(CFA)/day	6500	6500	6500	0.00	0.00	6500	6500	-	-
D. Days @ rest									
Days rested/week_June-July	0.53	1.00	0.54	0.52	0.13	0.00	1.00	0.00	1.00
Days rested/week_August	6.22	7.00	6.56	0.26	0.53	0.00	7.00	7.00	7.00
Days rested/week_September	7.00	7.00	7.00	0.00	0.00	7.00	7.00	7.00	7.00
Days rested/week_October	7.00	7.00	7.00	0.00	0.00	7.00	7.00	7.00	7.00
E. Feeding system									
Grazing hrs/day_June-July	5.58	5.50	5.59	0.61	0.17	4.50	6.50	5.50	6.00
Grazing hrs/day_August	9.06	9.00	9.18	2.40	0.60	4.50	12.00	8.00	11.50
Grazing hrs/day_September	9.61	10.00	9.69	1.28	0.30	6.50	11.5	9.50	10.00
Grazing hrs/day_October	9.50	9.50	9.50	2.89	1.44	7.00	12.00	7.00	12.00
Complement Feed(kg)/day_June-July	2.50	2.50	2.50	1.73	0.87	1.00	4.00	1.00	4.00
Complement Feed(kg)/day_August	2.00	2.00	2.00	0.00	0.00	2.00	2.00	2.00	2.00
Complement Feed(kg)/day_September	0.98	1.00	0.94	0.57	0.73	0.30	2.00	0.60	1.00
Complement Feed(kg)/day_October	1.50	1.50	1.50	0.52	0.15	1.00	2.00	1.00	2.00
Complement Feed(kg)/day_Dry season	8.07	8.00	8.00	1.49	0.38	6.00	11.00	7.00	9.00
F. Days with Diseases	7.13	7.00	7.08	5.63	1.45	0.00	15.00	2.00	15.00

6.4.3. Feeding system

Two types of feeding systems were identified: one corresponding to the rainy season and the other, to the dry season. The main focus was on the growing season's feeding system.

According to farmers, the feeding system of the oxen during the dry season was mainly extensive grazing, along with the whole farm or village herds. A complement of feed based on crop residues, especially groundnut hays was given late in the afternoon.

During the rainy season, draft oxen were kept separate from the herd at the farm level. To complement the natural grazing, during the breaks oxen were given a daily ration of cereal grain (maize, millet) or cereal by-products (stover). Farmers across agro-ecosystems 4 and 5, used the same strategies as the resources available for feed were the same: 2.5 kg of corn per animal in June-July and part of August, and 2 kg of millet for the remaining of the month of August. The amount of complementary feed decreased along with the decrease in amount of work to be performed towards the end of the rainy season, as natural grasses were more abundant. The natural grazing played a key role in the feeding system of working animals. The grazing time passed from 5.58 hours per day at the beginning of the growing season to more than 9 hours per day towards the end. The most important grass species found for grazing are given in **Table 45.**

In addition to the grass species, a number of tree leaves were also used to complement the grass:

- Vene (pterocarpus eraniceus)
- Bu pumbapumb (calotropis procera Ait)

Table 45: Pasture grass species in zone 4 and 5

Grass local names	Corresponding Scientific names
Elimpey djikel	cyperus rotundus
Edjilangaye	panicum maximum
Eboussaye	digitaria ciliaris
Enoname	bracharia plantaginea
Ebongaye	chloris pilosa
Kohing kohing	desmodium hirtum
Essabay	urena lobota
Ebucay	bracharia pallide-fusca
Essoulangay	pennissetum pedicellatum
Baarafita	Oryza species
Essiteye	Acanthospermum hispidum

In general, the quality of feed given to draft animals is ranked according to the energy content expressed in forage unit (FU). The total forage unit FU is converted into energy by the draft animals digestive system, based on the total digestible nutrient (TDN) content of the feed. Pasture grasses are generally considered as poor feed. Based on the work carried out in Senegal by CEEMAT (french research institution), grass cut has only 0.14 FU whereas feed used for complement have a higher FU: groundnut hay = 0.35, maize grain = 1.10, for example.

In the energy evaluation, the number of FU used to provide the energy required for the maintenance of the draft animal were used to evaluate the energy balance in relation to the intensity of the task to be performed **(Equation 11)**. The lack of the energy required to perform the task will impact growth, health and liveweight LW of the working animals. The health problem is translated into the loss of resistance to sleeping sickness.

6.4.4. Liveweight changes and body condition

In order to evaluate the impact of the intensity of work on the draft animal body and health, the liveweight of each draft animal of the 18-base sample was monitored by means of weighing with an electronic scale (Barlo Electronic Scale□ Model 2100). This measurement was made at the end of every month throughout the growing season.

The measurements performed on the pairs of draft oxen are shown in **Tables 46 and 47**.

6.4.4.1. Body weight losses (LWL in kg/day)

The analysis of the variation of the liveweight shows that both individual ox and pairs of oxen across the traction groups lost weight during the period of intense work in June-July. The recovery period started at the end of August and corresponded to the decrease in field work demand. The coefficient of variation CV ranged from 2% to 9% for Group 1, 2% to 6% for Group 2 and 1% to 3% for Group 3 **(Figure 22a and 22b)**.

The average liveweight variation LWV in kg and in percent per Traction Group was calculated and summarized in **Table 48**.

From June to July, each pair of oxen went through high level of utilization. The amount of body weight lost during the process was converted into energy (15 MJ/kg of LWL given in the literature) towards the accomplishment of the job. This means that the execution of most field operations required more energy than available from the feeding system. This effect of work on body weight has been reported in many publications but needs to be evaluated for different species.

Table 46: Liveweight (kg) variation of pair of oxen

Month	G 1			G 2			G 3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
June	683	690	648	535	600	517	469	435	441
July	699	673	583	522	544	499	438	427	419
Aug.	713	755	605	567	571	523	423	441	461
Sept.	717	742	635	580	600	537	472	456	487
Oct.	718	753	668	598	605	538	486	466	505

Table 47: Average Liveweight variation of Traction Group

Month	G 1		G 2		G 3	
	Avg (kg)	std (kg)	Avg (kg)	std (kg)	Avg (kg)	std (kg)
June	673.67	18.37	550.66	37.96	448.33	14.82
July	651.67	49.70	521.67	18.37	428.00	7.79
Aug.	691.00	63.18	553.67	21.75	441.67	15.52
Sept.	698.00	45.70	572.33	26.28	471.67	12.66
Oct.	713.33	34.88	580.33	30.07	485.67	15.92

Table 48: Liveweight losses and gained (June to October)

Period	G 1		G 2		G 3	
	LWV (kg)	%	LWV (kg)	%	LWV (kg)	%
June-July	-22.00	3.27	-28.99	5.56	-20.33	4.53
July-Aug.	39.33	6.03	32.00	6.13	13.67	3.19
Aug.-Sept.	7.00	1.01	18.66	3.37	30.00	6.79
Sept.-Oct.	15.00	2.15	8.00	1.40	14.00	2.97

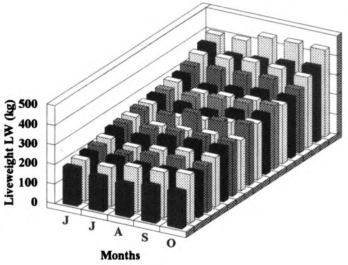

Figure 22a: Liveweight Variation (LWV) of individual ox

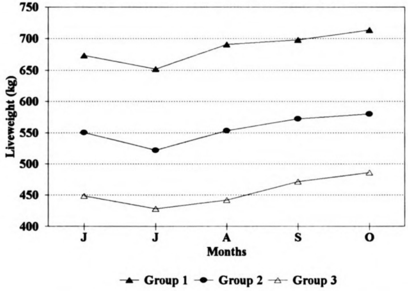

Figure 22b: Liveweight Variation (LWV) of Traction Groups

The average number of days worked during this period was 19.47 with a CV= **44% (Table 44)**. Based on this number of worked days, the liveweight losses LWL in kg/day per traction group were:

- **Group 1 LWL= 1.13 kg/day**
- **Group 2 LWL= 1.47 kg/day**
- **Group 3 LWL= 1.04 kg/day**

In accord with a number of cases observed throughout the world, animal traction researchers agree on the fact that even a good feeding system would not prevent draft animals from losing weight during this peak working time of the season. The body weight losses converted into energy

must be taken into account when calculating the daily energy balance of draft animals.

6.4.4.2. Health and care

In the majority of cases, farmers benefited from the veterinary services from the local governmental extension agency. Vaccines were given twice a year to protect oxen from losing tolerance to sleeping sickness and treatments were used against other different parasites. Cases of diarrhea have been mentioned by farmers in relation to the changes of the feeding system from the dry season to newly growing grasses after the first rains. This never stopped farmers from using the animals as cases were not very serious and were treated quickly.

6.5. Summary

This study showed with detailed calculations that the difference in optimal performance among the weight classes of draft Ndama cattle were not very significant. A further analysis would have showed that the coefficients or parameters estimated for the different model developed were also not very significant. It means that one equation can be used to model the working output of Ndama cattle in the Basse Casamance region environment. The level of significance can be used, if needed, to differentiate specific behavior between traction groups in order to make marginal improvements on the energy balance calculations. This can be done with consideration given to the cost and amount of human resources available to conduct the study. The nature of the problems may play a role in keeping the three groups separate. The difference in farmers' circumstances required to satisfy both animals needs (feeding and care) and production objectives may justify the treatment of each pair of oxen as belonging to a traction group that has specific needs in relation to their body weight.

The Ndama is a well-adapted species to the Basse Casamance region and needs to be properly managed in order to satisfy the level of energy required. It is important to monitor the feeding system and the amount of work demand. Draft animals need at least 1 day off per week for better efficiency. Body weight losses LWL per working day are expected from working draft animals but the amount in kg/day can be kept to a minimum through good management. Farmers need to develop expertise in fitting the job to the animals by being more aware of their maximum working capacity. This objective can only be achieved if they know their animals well. One major improvement would be for a farmer to follow up on the liveweight of his draft animals throughout their working career.

The means of doing this follow up using weighing scales is not always possible in the local areas, however other means can be used. The model developed in this study is significant and can be used by any farmer equipped with a simple measuring tape.

In addition to the liveweight, it is important for farmers to develop strategies and set up priorities in the execution of the field operations in relation to the specific energy requirements. This can be achieved by planning activities during the working days and in selecting the appropriate implements to carry out the field operation.

Chapter 7

FIELD OPERATIONS AND DRAFT REQUIREMENTS

The evaluation of the pull force PF in daN and draft DR in daN was conducted on station to better control the variables involved. The technique of land preparation used was the same as farmers' and the size of experimental plot was in the range of field plot unit delimited by farmers for plowing.

7.1. Field operations characteristics

7.1.1. Soil characteristics

The soil type is the primary factor in the process of evaluating the draft required to move different farm implements through the soil. The physical and mechanical properties of the soil are the most important parameters involved in its behavior at different water content levels (SWC). These two characteristics were used in selecting the sites for the pull force trial and draft measurements. The physical properties were: soil texture, bulk density, and soil moisture. The soil resistance to cone penetrometer was also used to minimize variability among plots.

A field of 2 ha was cleaned of natural vegetation composed of grasses (Pennisetum Polystachyon, Eragrotris tremula) and small trees. The area was characterized for mechanical and physical homogeneity. After the measurements and analysis, only 1/2 ha was found uniform enough to be used for the trial, with the following characteristics.

7.1.1.1. Physical properties

- Soil Description

The identification of the site was done using a soil map made available by the soil scientists of the Djibelor's research station. The soil type is representative of the dominant upland soil type found in the Basse Casamance region, according to studies conducted by ISRA/ORSTOM research teams (Niane A. B. 1884; Montoroi, 1991).

The soils were described as ferrallitic, red and highly weathered. Ferrugineous soil type was also found in very localized small upland areas.

The soil water regime was reported to be hydromorphic and requires drainage before being subject to any field traffic. They were also characterized to be very sensitive to water erosion especially if the cropping techniques were not appropriate. Erosion was given to range from 8.5 to 14 t/ha per year (Roose, 1967).

- Soil texture and bulk density

The soil texture of the trial site can be described as a sandy clay soil, especially for the horizons under the soil surface **(Table 49)**. The soil textural analysis was performed on the 0 - 60 cm profile even though field operations with animal traction are limited to the first horizon (0 - 16 cm). The total sand represents more than 80% of the texture.

Table 49: Average soil texture of the trial site

Soil depth (cm)	0 - 16	16 - 58 cm
% Clay < 2 µm	7.6	16.7
% Silt 2 - 20 µm	3.5	8.0
% Very fine sand 20 - 50 µm	6.2	6.5
% Fine sand 50 □ 200 µm	47.9	38.3
% Sand 200 - 2000 µm	34.8	30.5
% Organic matter	0.9	0.8

Source: Extract from Niane A., 1984

In the American soil classification, the very fine sand is called coarse silt, combined with the silt to represent 9.7% and 7.6% for the clay. In the USDA textural triangle, the type of soil corresponds to sand. The high soil groundmass which is the ratio between coarse to fine particles shows that the soil matrix tends toward low soil water holding capacity and high permeability (7 cm/hr).

The clay mineral (1:1) is kaolinite type and is mainly responsible of the soil red color. The presence of kaolinite and Fe sesquioxides act as bridges between adjacent particles and play the role of cement in the soil aggregation processes. The level of organic matter is too low (0.9%) to provide enough cement to the particles. These linkages are weak in general and confer a massive character to the soil structure that becomes hard when dry and very malleable when wet. The wetting-drying cycles in relation with the frequency of dry spells during the rainy season play an important role in the determination of the number of working days for different field operations (FDOP).

Beside the soil texture, the soil bulk density SBD in g/cm^3 of the trial site was also determined with the aid of a core sampler. Several sets of three undisturbed cores were sampled from the field in the first 10 cm-horizon, weighed, oven dried and weighed again. On a dry weight basis the average soil bulk density SBD in g/cm^3 was calculated:

SBD= 1.40 g/cm^3 std dev. = 0.01, CV= 1%

The average value of SBD found by Montorio (1991) in the Djguinoum watershed (agro-ecosystem zone 4) was 1.45 g/cm^3. He used in his investigation a gamma-ray attenuation densitometry (CAMPBELL type CPN 507-1.5)

7.1.1.2. Water holding capacity

The soil water holding capacity SWHC in % g/g was determined at the ISRA/Djibelor station soil laboratory. The values obtained from this experiment were used only for indication purposes. The real soil water regime must be evaluated in-situ for better results. For the laboratory determination, three weighed undisturbed soil core samples were taken from the trial sites in the first 10 cm-horizon and brought to saturation by capillarity. After all the initial weights were measured, the soil samples were left to drain for a number of days. The weight of each core sample was determined on a regular basis (every hour, every two-hours, every day) until the samples were completely air-dried. The recorded data were used to calculate the soil gravimetric water content SWC in % g/g. The SWC was plotted against number of days (NDAYS) to have a drainage curve **(Figure 23 and 24)**.

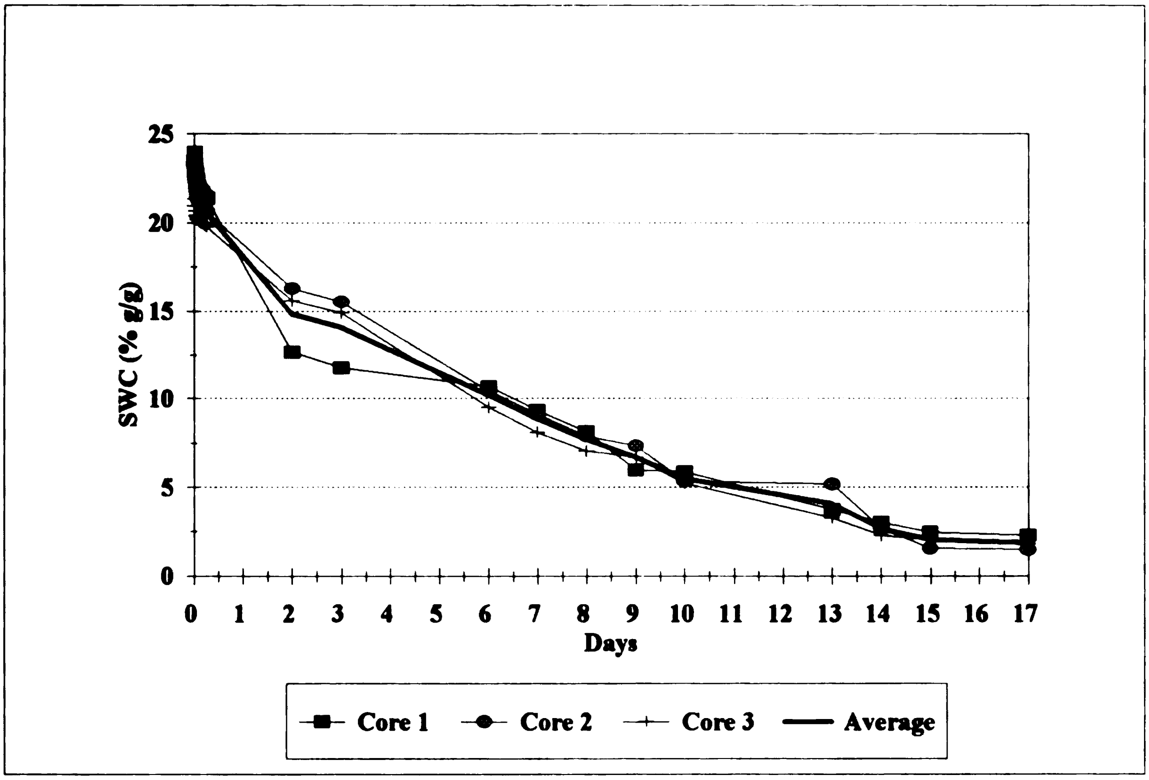

Figure 23: Drained soil water content (undisturbed cores)

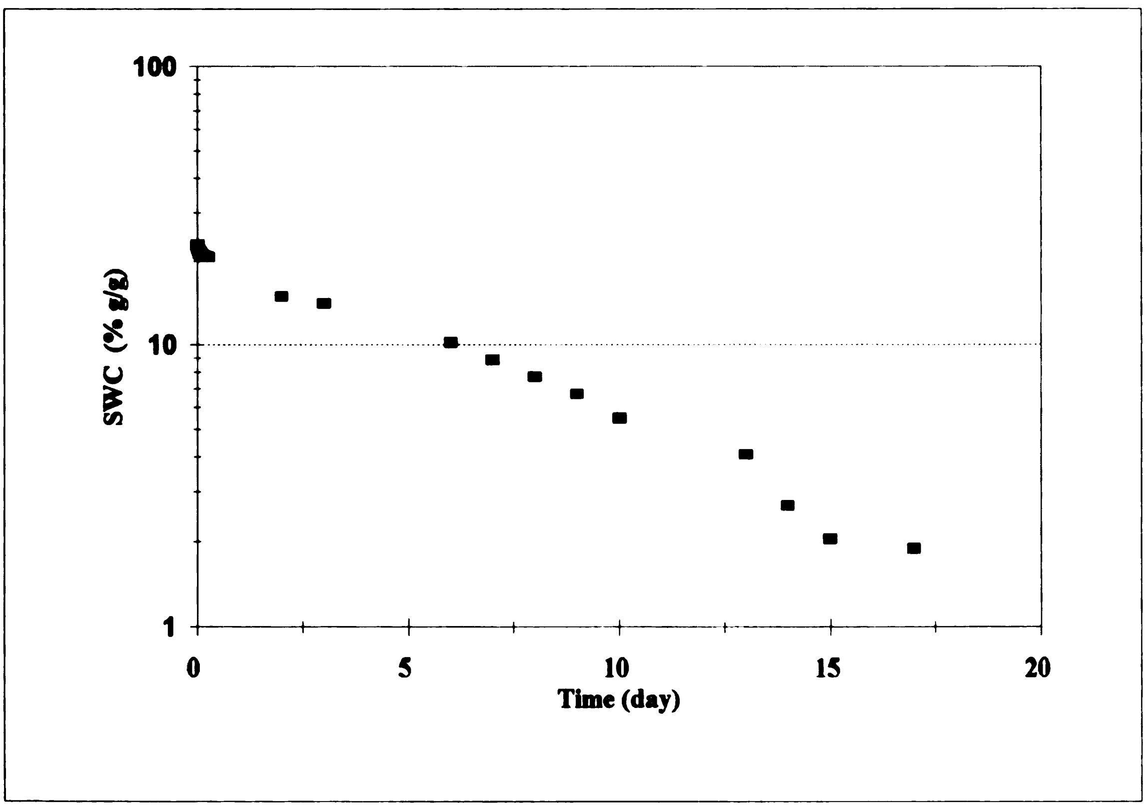

Figure 24: Log-SWC vs time

The analysis of the graphs shows that the 1/2 ha plot was uniform as regards to the drainage profile and soil water content SWC. One soil core showed a preferential flow at the beginning of the experiment but quickly followed the two other cores drainage pattern. The SWC in % g/g at characteristic points were calculated:

. @ Saturation (SAT) : **SWC_{sat}**= 23.69% (CV= 5.28%)

. @ Upper Limit (DUL) : **SWC_{DUL}**= 20.00% (CV= 4.08%)

. @ Wilting point (LL) : **SWC_{LL}**= 6.00% (Charreau, 1974)

. @ Air-dry (AD) : **SWC_{AD}**= 3.00% (CV= 13.60%)

The DUL in % g/g corresponding to a point close to the field capacity SFC in % g/g was reached about 1 day after saturation while the air-dry moisture level under ambient air temperature was reached after 14 days. As defined by Ratliff et al (1983), the DUL is the highest field-measured soil water content after being saturated and allowed to drain until drainage becomes practically negligible. The soil water holding capacity SWHC is the difference between SWC_{DUL} and air-dry SWC_{AD}.

The SWC at which, field operations FDOP are performed is an important factor towards the evaluation of the amount of energy required for the task. Farmers are expected to schedule field operation so soil is worked at a moisture close to the optimum soil water content SWC_{opt}.

7.1.1.2. Penetrometry

The penetrometry described earlier was the investigation tool used to evaluate the mechanical properties of the trial site. The dynamic method was used whereby a known weight falling from a predetermined height hammered the 50 cm long cone penetrometer rod into the soil. The depth of cone penetration was measured and the associated energy calculated using **Equation 13**.

Three locations were chosen at random along one diagonal of the 1/2 ha plot. Along with the soil resistance to penetration measurement, the SWC profile of the spot was also determined at the same time.

The graphs of the Cone energy in J against the depth in cm and the SWC profile helped describe the soil resistance to penetration at the given SWC levels **(Figure 25 and 26)**. It appeared that the 1/2 ha plot was uniform enough to minimize the amount of variation expected in the pull force **PF** and draft requirement DR trials.

7.1.2. Field operations

In relation to the monitoring of the utilization of draft animals (previous chapter), a number of field operations performed by farmers to meet their production objectives were characterized. Among those, plowing was the most important followed by seeding.

7.1.2.1. Tillage

Two types of implements were used for seedbed preparation: moldboard and ridger plows. In the Basse Casamance region, plowing was recommended as a method to control and slow down weed pressure at the beginning of the rainy season.

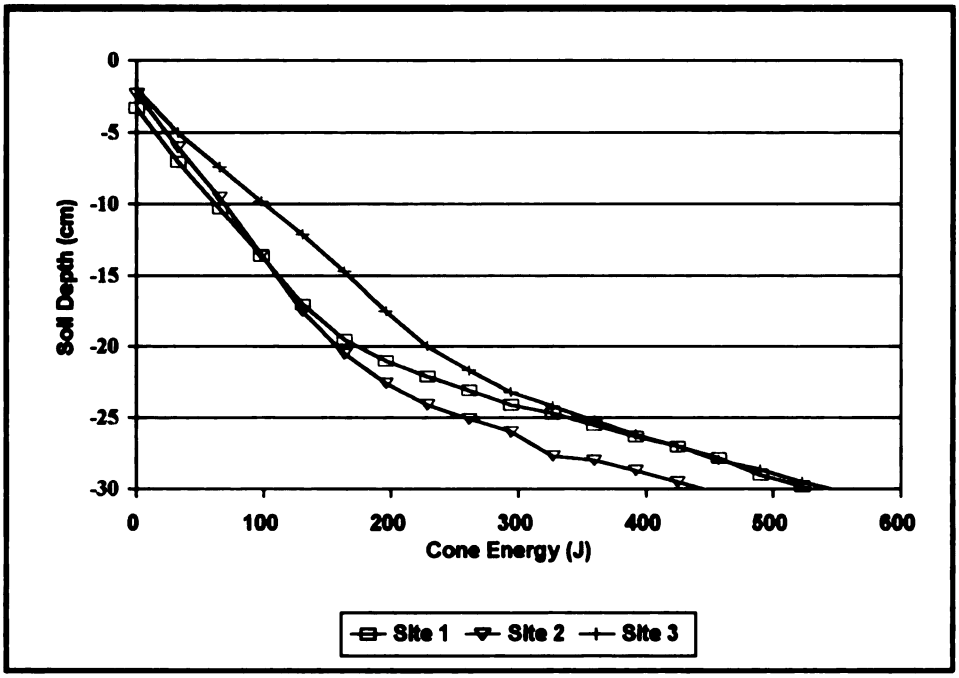

Figure 25: Penetrometry energy

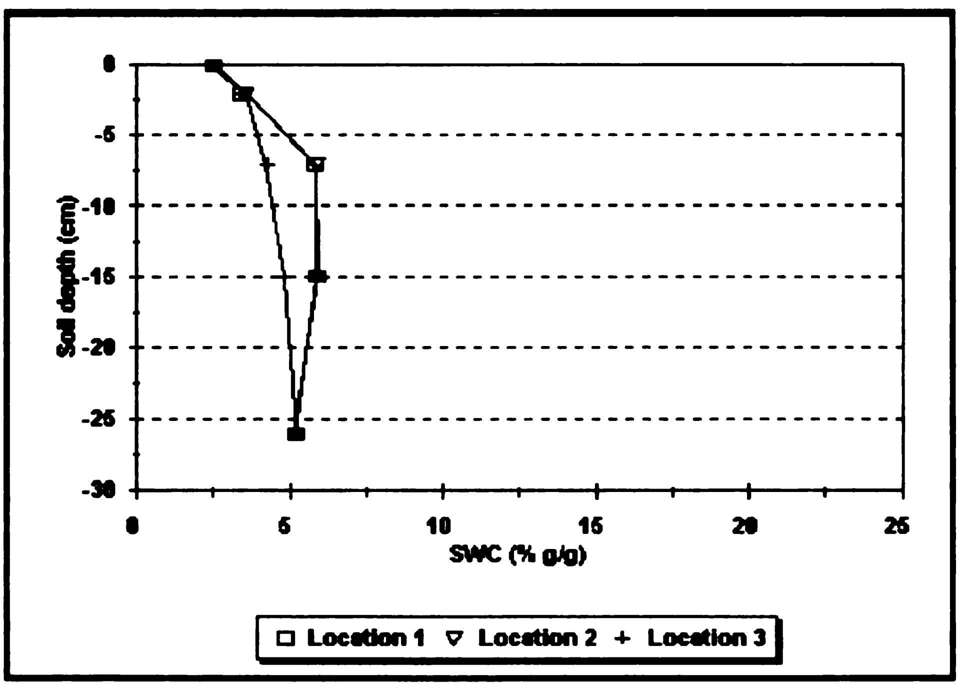

Figure 26: SWC at penetrometry sites

- Flat land preparation

The most common method of flat land tillage performed by farmers with the moldboard plow (UCF 10") is to divide the field into small plot units of 0.6 ha in average size and to plow each plot until the total field is done. The technique also known as the Fallenberg method consists of starting at one corner of the delimited plot and of plowing around the perimeter with the pair of oxen. In the process, the furrows are turned outward on one side of the delimited plot and adjoined side by side until the center of the plot is reached. The majority of the farmers prefer this technique because it is faster than other techniques like plowing in lands or by starting from the middle of the plot.

The average plowing depth in farmers' field was 10-12 cm and the width 23 cm. These two parameters depended greatly on the pulling capacity of the pair of oxen and on the level of expertise of the farmers to properly adjust the farm implements.

- Ridging techniques

The second most common technique of land preparation is ridging. The data analysis shows that farmers used two techniques of ridging. The first technique was performed with the ridger equipment attached to the ARARA toolbar or with the EMCOT ridger imported from Gambia **(Figure 4 and 5)**. The technique of ridging is similar to the plowing in lands technique with the difference that equi-distant ridges parallel to one side of the plot are made.

The second ridging technique was executed by means of UCF 10" moldboard plow. In this case, the making of a good standing ridge required two furrows placed back to back to create a crest of soil narrow enough to be planted with a single row crop. This method seems to be too slow to farmers who are concerned with timeliness. The common practice with a moldboard plow is to make one-way ridges instead of a back to back ridges. This technique is faster as only half of the total field is plowed. With this practice, the ridge quality is very poor as the height subsides faster with rainfall and water erosion.

The characteristics of the ridges made were highly variable depending on the piece of implement used and also on the ability of the farmers to properly use the pair of oxen. The average depth and ridge height, and between ridge distance were 12 cm, 15 to 18 cm and 50 to 60 cm respectively.

7.1.2.2. Seeding

The seeding equipment that farmers used was the Super ECO one row seeder (**Figure 7**). The seeder was designed for flat land preparation. This represents a major limitation in its utilization. All the fields that have been ridged were manually seeded.

It appears that seeding was not felt as a major constraint as the surplus of labor generated by the mechanization of the land preparation was mainly used to hand seed plowed areas. During the rush period in the months of June and July, only 38.7% of the pairs of oxen were used for mechanical seeding and it shows the importance of hand seeding. Most of the seeding was performed on the cash crop fields (groundnuts) which occupied more than 50% of all cropped land. All the Super ECO seeders were equipped with at least one groundnut seed distribution plate and 59.9% were equipped with groundnut seed plates only. After groundnuts, maize was the second most mechanized crop with 31.82% of the seeders equipped with maize seed plates, followed by sorghum (18.18% of the seeders) and millet (13.64%).

7.1.2.3. Weeding

Mechanical weeding was not found to be as important as plowing and seeding. The cultivator SINE 9 was the only implement used by farmers for weeding purposes. All the SINE 9 toolbars were equipped with 3-Canadian full sweep tines. For better efficiency, the type of sweep used to equip the cultivator must be able to stir the soil surface at a certain depth to destroy young weeds in favor of crop growth. The average depth in farmers conditions was around 8 cm. The weeding period generally starts about 20 days after seeding (DAS) and constitutes a peak activity for the available farm labor. The extension of cropped areas through mechanized plowing and seeding has created a labor bottleneck's shifting situation that needs to be properly managed. The analysis shows that the weeders owned by farmers were mainly used on part of the cash crop fields (groundnuts) while the rest of the crops were manually weeded. The level of utilization of the weeders was not enough to complete the field operation on all crops. The low level of utilization was mainly due to a lack of expertise and to a fear of damaging the crops at advanced growing stage when the weeding operation was not scheduled on time.

7.1.2.4. Harvesting

Farmers were not equipped with animal-drawn harvesting equipment. Harvesting of all crops is still manually performed. The only available animal-drawn harvester is the groundnut digger built by SISMAR. The timeliness of the field operation in terms of satisfying the labor demand is not critical according to the farmers' point of view. Farm labor is generally available in numbers sufficient to carry out the field operations by hand in time for upland crops. Only rice harvesting is felt to be a problem.

7.1.3. Soil water balance and Working days

Since 1960, the Sahel is globally experiencing an overall drying of the climate. Following the two major droughts in 1970s and 1980s, farmers' behavior in resources allocation have shown that the year-to-year variation in total amount of precipitation is an important and determinant factor in planning field activities. Under these conditions over the years, farmers have developed a risk aversion attitude towards investment.

The weather in the area of study is mainly characterized by the seasonality of the precipitation. During the wet season (June to October), rainfall does not occur every day making daily rainfall highly variable.

The intra-annual variation of precipitation dictates in general the farmer's strategy to decide on the types of crops to grow and the corresponding field operation to perform in relation to the types of implement available at the farm level. The analysis of daily precipitation amount is important to soil water balance calculation to help predict runoff and drainage and to help evaluate the field trafficability and determines the suitability for performing daily field operations.

The most important factor in determining the number of working days (NWDAYS in days) is the soil moisture regime. This factor significantly influences the timeliness of performing field operations. The soil water content is generally influenced by highly stochastical weather variables such as rainfall, relative humidity, temperature, wind speed, solar radiation, etc. The main effect of the weather variables is to associate a certain level of uncertainty in the process of scheduling farm operations.

The method applied in this analysis is based on the approach using probability levels. The probability level represents a degree of certainty. Two probability levels are considered 90% (9 years out of 10) and 50% (5 years out of ten). A database of 37 years (1960 to 1996) of daily rainfall for the region of Basse Casamance was used **(Table 50)**. The data was pulled from the Ziguinchor Weather Station database which is part of the National Weather Stations Network. The town of Ziguinchor is 50 km away from the on-farm research sites. The Gumbel (1941) approach is used (**Equation 17 and 18**).

Table 50: Annual rainfall (mm)/rank for Ziguinchor (1960-1996)

Year	Amount (mm)	Rank	Year	Amount (mm)	Rank	Year	Amount (mm)	Rank
1960	1274.60	16	1972	951.80	31	1985	1379.90	10
1961	1549.30	5	1973	1289.40	14	1986	975.20	29
1962	1567.50	4	1974	1240.40	17	1987	1042.60	28
1963	1429.40	9	1975	921.90	32	1988	1310.60	12
1964	1222.80	20	1976	1297.10	13	1989	1175.40	24
1965	1756.60	2	1977	790.30	36	1990	1114.30	25
1966	1603.80	3	1978	1512.10	6	1991	1223.00	19
1967	2006.50	1	1979	1187.30	23	1992	967.10	30
1968	882.50	34	1980	698.50	37	1993	1481.70	7
1969	1460.70	8	1981	1221.50	21	1994	1204.20	22
1970	1282.00	15	1982	897.80	33	1995	1095.40	27
1971	1098.60	26	1983	817.20	35	1996	1310.90	11
			1984	1236.00	18			

To determine the number of working days, the days suitable for field operations are counted for every month of the rainy season for each of the 37 years. The counting is manual and complex in relation to the main characteristics of a working day (see ASAE

Standard D230.4, Agricultural Management Data, Section 8-Working Days, Timeliness). In addition to the scenarios introduced by Le Moigne (1981), the following empirical assumptions for the Basse Casamance region were used:

. Data collected are normally distributed for the long period of 37 years.

. Onset of the rainy season is "the date after 1 May when rainfall accumulated over 3 consecutive days is at least 20 mm and when no dry spell within the next 30 days exceeds 7 days" (Sivakumar, 1988).

. Plowing and Ridging are difficult to perform after a 10-day dry spell.

. Seeding and Weeding are difficult to perform after a 2-week dry spell.

. The pair of oxen is at rest 1 day per week.

The confidence limits were used to estimate the range for the 90% and 50% probability levels. Assuming a normal distribution (mean annual rainfall = 1229.08 mm and standard deviation= 274.77 mm), the 9 years out of 10 for Ziguinchor lies within the limits given by the mean plus and minus 1.6440*standard deviation (777.36, 1680.88) mm. The 5 years out of 10 limits are within the mean plus and minus 0.6745*standard deviation (1043.88, 1414.27) mm.

The number of working days NWDAYS and their associated probabilities (PWD in percent) (TILLWDY for tillage and SWWDY for seeding and weeding) are summarized in **Table 51**.

Table 51: Probability (PWD) and number of working days (NWDAYS)

Month	%Rain /yr	Tilldays (days)	TILLWDY (%)	Swdays (days)	SWWDY (%)
			50% Confidence level		
June	8.20	12.18	0.41	9.18	0.31
July	26.44	25.53	0.82	16.88	0.54
August	32.18	26.12	0.84	15.59	0.50
September	25.16	26.82	0.89	17.76	0.59
October	7.07	18.88	0.61	15.88	0.51
			90% Confidence level		
June	7.85	11.59	0.38	8.82	0.29
July	25.03	25.85	0.83	17.09	0.54
August	31.02	25.41	0.82	14.88	0.48
September	26.74	26.76	0.89	17.03	0.58
October	8.38	19.94	0.64	16.26	0.52

The probabilities are monthly averages. To adjust for the 1-day rest per week, the PWD must be multiplied by an average coefficient of 0.86 (6 days per week). In the Basse Casamance region, the rest day is usually on Fridays.

The difference is not very significant between the 50% and 90% confidence levels in relation to the rainfall distribution and intensities during the rainy season **(Figure 27 and 28)**.

7.2. Pull force and draft requirements

The total draft animals' liveweight used for the trial was 683 kg with an average age of 7 years and 5 years of working experience. The pair of oxen belonged to the Traction Group 1.

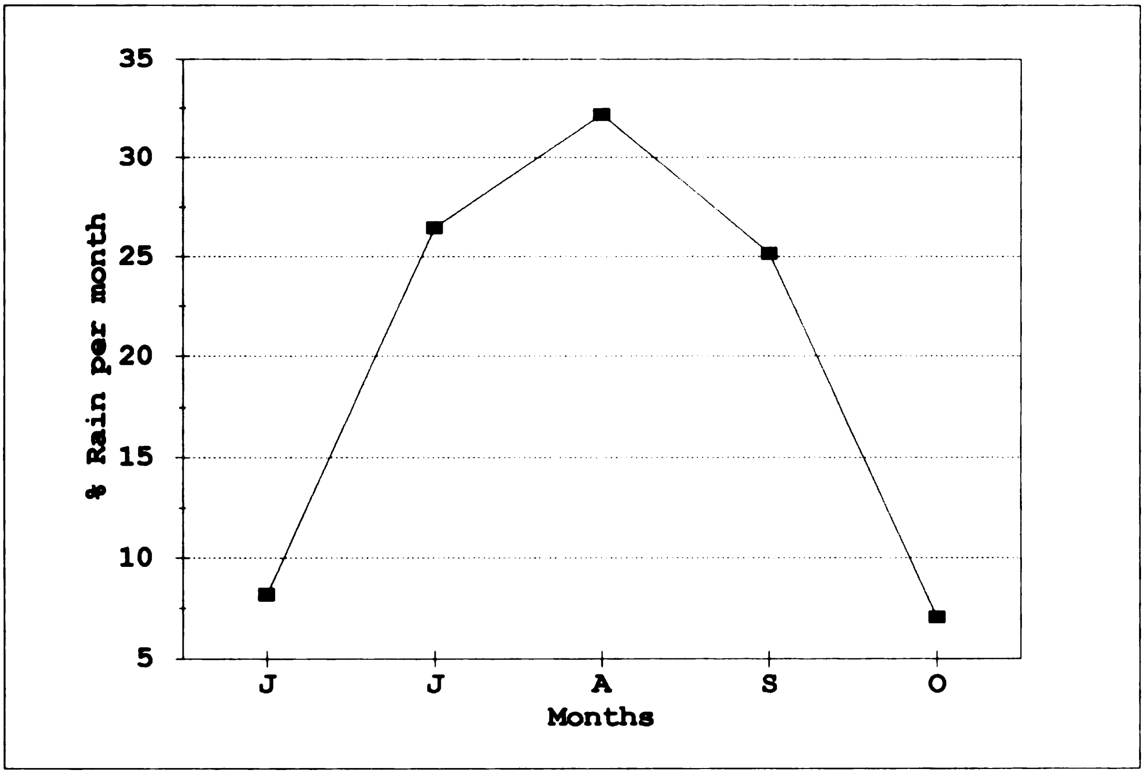

Figure 27a: Monthly rain distribution (5 years out of 10)

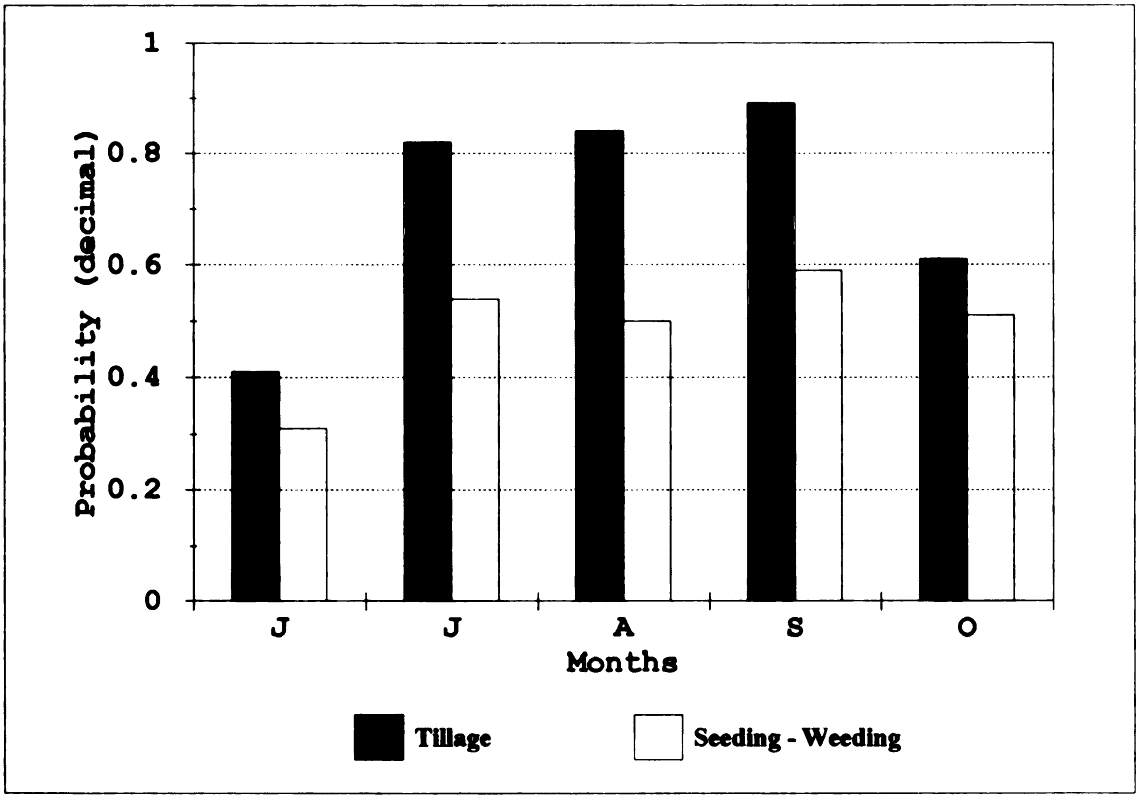

Figure 27b: PWD at 50% probability level

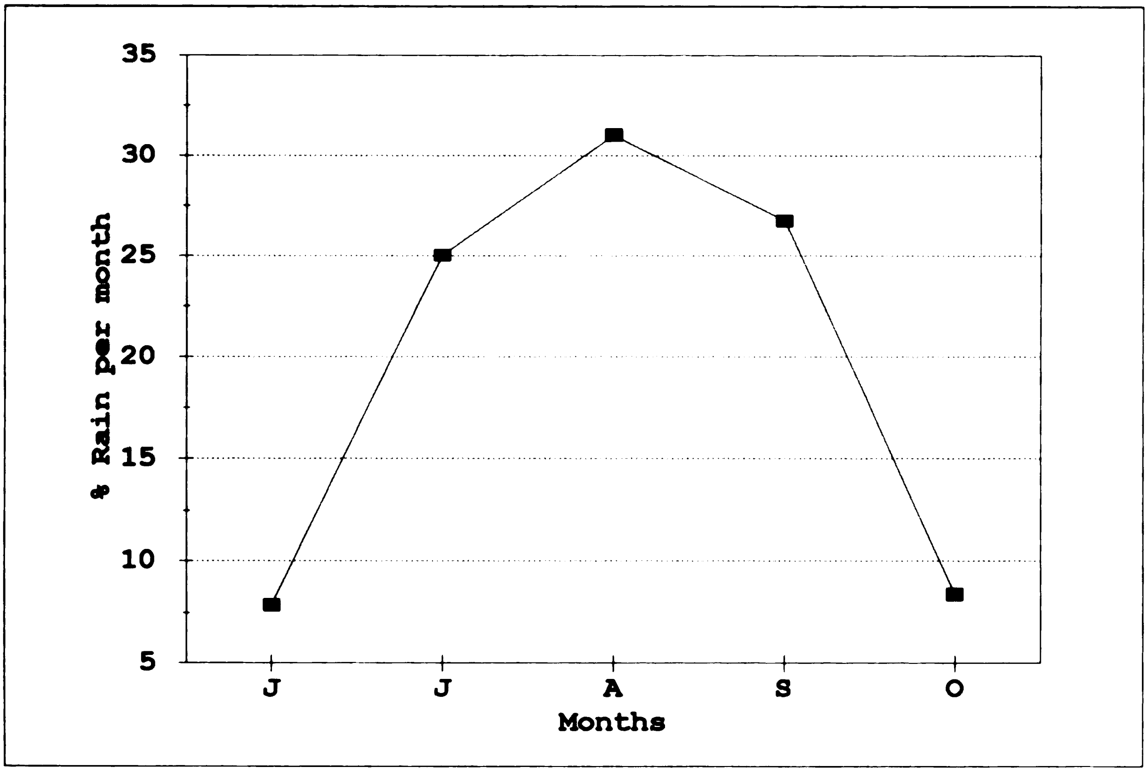

Figure 28a: Monthly rain distribution (9 years out of 10)

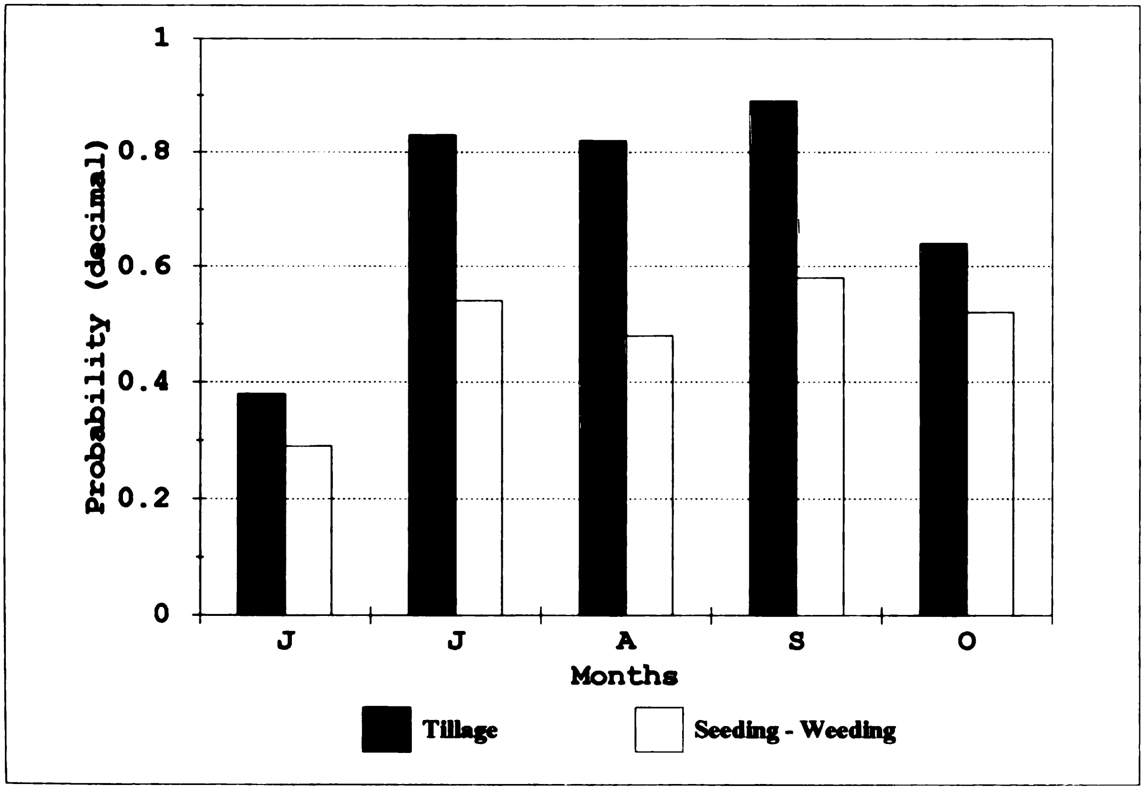

Figure 28b: PWD at 90% probability level

7.2.1. Statistical design

The 3-way factorial statistical design (2x3x3 Factorial in Randomized Blocks) was laid out within the 1/2 ha plot already tested for homogeneity in soil moisture regime and mechanical properties.

A certain number of studies have indicated that choosing the right type of harnessing system could improve the pulling capacity and the energy output of draft animals. The head yokes used by farmers for their pair of oxen can be classified into two groups according to the length: 90 cm and 120 cm **(Table 52)**.

Table 52: Dimension of yokes used by farmers (survey results)

Yoke type	N	MEAN	MEDIAN	STDEV	S.E MEAN
YOKE 1	16	0.9694	0.9500	0.1080	0.0270
YOKE 2	29	1.2069	1.2000	0.1043	0.0194

Table 53: Two-sample t-test for YOKE 1 vs YOKE 2

Yoke type	N	MEAN	STDEV	SE MEAN
YOKE 1	16	0.969	0.108	0.027
YOKE 2	29	1.207	0.104	0.019

95% C.I for $\mu_{YOKE1} - \mu_{YOKE2}$: (-0.305, -0.170)
T-test $\mu_{YOKE1} = \mu_{YOKE2}$ (vs N.E): T= -7.15 P=0.00 DF= 30

The average dimension of YOKE 1 (96.9 cm with CV= 11.14%) was found to be slightly different from the 90 cm-head yoke recommended by Research over the years.

The comparison between the number of the two sizes of yokes (90 cm and 120 cm), using the t-test distribution has showed that the difference is highly significant **(Table 53)**.

The factors and their levels used in the 3-way factorial experimental design are summarized in **Table 54**.

Table 54: Factors' levels in a 2x3x3 Randomized Block design

SWC (% g/g)	Implement type	Head yoke (cm)
6 to 8%	UCF 10" plow	90
8 to 10%	3-Canadian tines on SINE 9 Toolbar	120
10 to 13%	Ridger equipment on ARARA Toolbar	

A total number of 18 treatments were blocked by SWC in % g/g. Each treatment was performed on a 200 m^2 size plot. The whole experiment was conducted on 4590 m^2 with alleys between elementary plots included.

7.2.2. Required Pull force

The pull force PF in daN was the observed or dependent variable measured by means of 500 daN dynamometer (PIAB™).

7.2.2.1. Data collected for UCF 10" plow

The distribution of the data with the 90 cm-yoke at SWC= 6-8% (avg SWC= 7.01% g/g) is slightly skewed to the left **(Figure 29a)** compared to the distribution at SWC= 8-10% (avg SWC= 9.34% g/g) and SWC= 10-13% (avg SWC= 11.97% g/g). The SWC= 8-10% distribution presents two peaks, the first at PF= 100 daN and the second at PF= 160 daN (Figure 29b). The first peak (less than 5% of the data) is not as significant. The distribution at SWC= 10-13% seems to be more normal than the first two **(Figure 29c)**.

With the 120 cm-yoke, the tendency in the data distribution looks the same. A slight skewness to the right at SWC= 6-8% **(Figure 30a)** must be noted. The most normal distribution was achieved at SWC= 8-10% **(Figure 30b)** and the most skewed at SWC= 10-13% **(Figure 30c)**.

The data collected for the moldboard plow UCF 10" are summarized in **Table 55**. The average PF values shows that the lowest required PF for the UCF 10" plow was obtained within the 8-10% SWC range. The 90 cm-yoke gave slightly higher values, about 5.29 % more than the 120 cm-yoke type. The 90% Confidence Interval for the average PF required by the UCF 10" moldboard plow is:

$$\mathbf{PF_{UCF10"} = (146.98,\ 168.03)\ daN}$$

The corresponding implement average working width and depth were respectively IMPLWWD= 23.17 cm and IMPLWDP= 10.62 cm.

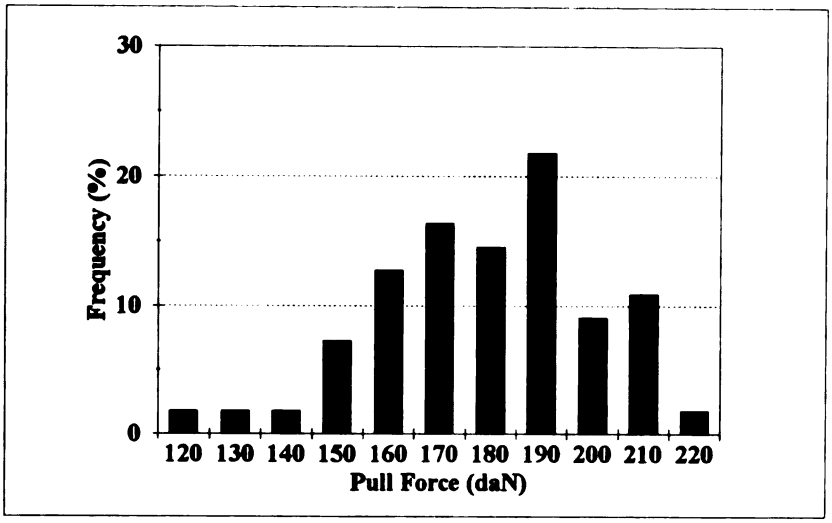

Figure 29a: PF with UCF 10" at SWC=6-8% Yoke= 90 cm

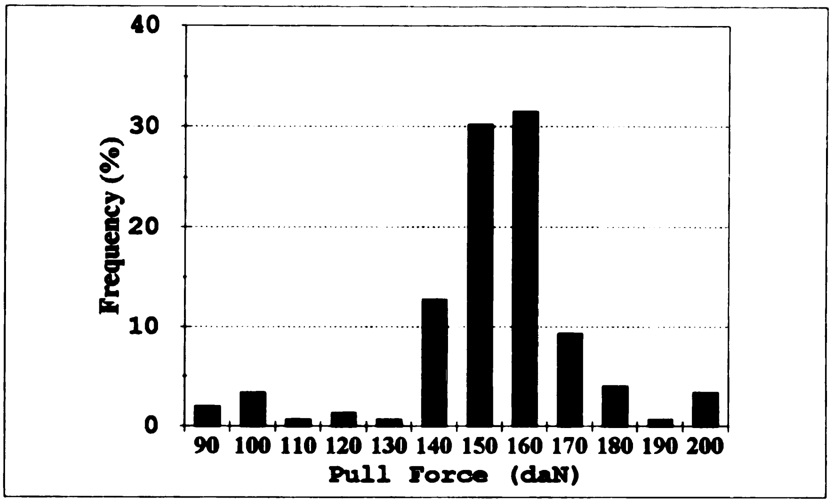

Figure 29b: PF with UCF 10" at SWC=8-10% Yoke= 90 cm

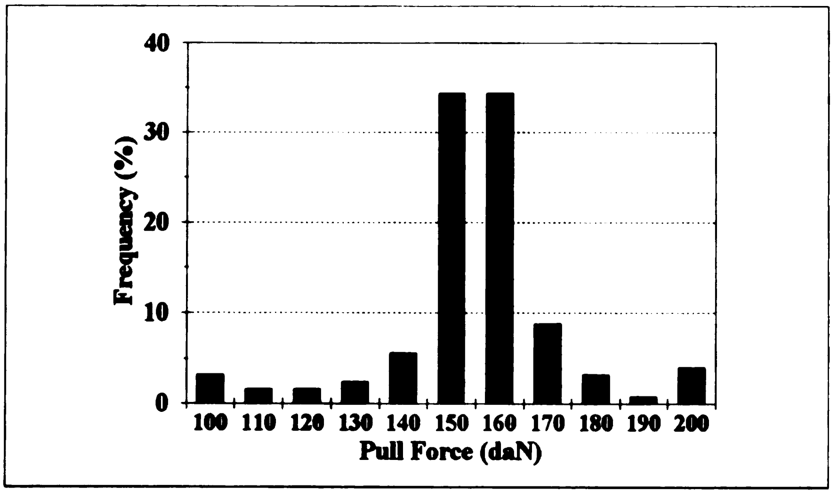

Figure 29c: PF with UCF 10" at SWC=10-13% Yoke= 90 cm

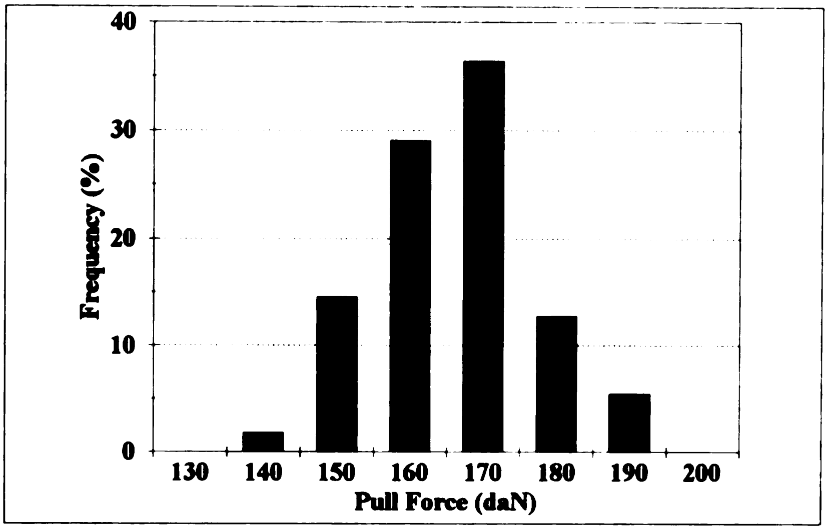

Figure 30a: PF with UCF 10" at SWC=6-8% Yoke= 120 cm

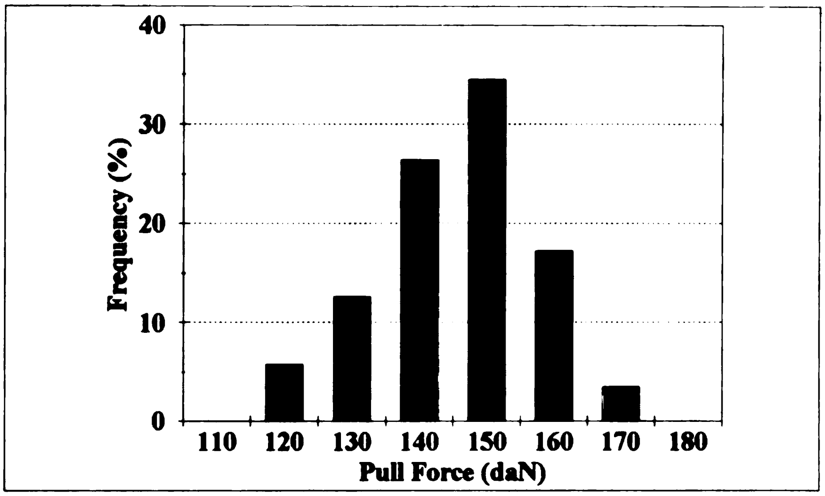

Figure 30b: PF with UCF 10" at SWC=8-10% Yoke= 120 cm

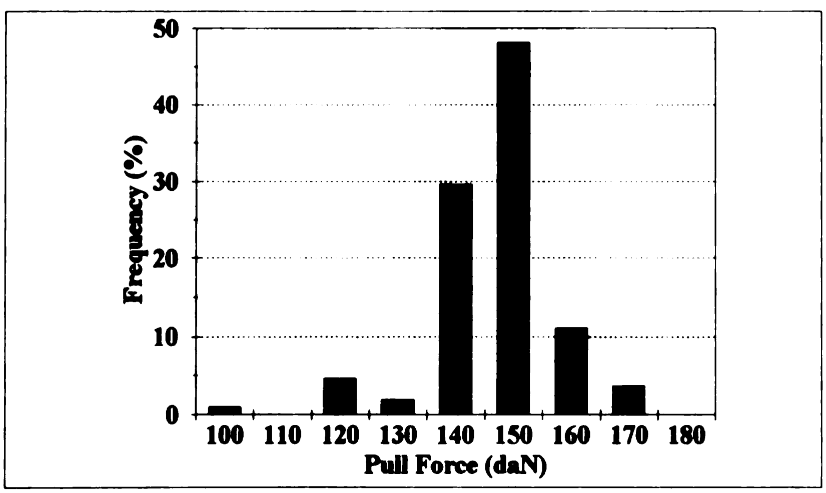

Figure 30c: PF with UCF 10" at SWC=10-13% Yoke= 120 cm

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Table 55: Pull Force PF (daN) with the UCF 10" plow

Yoke (cm)	90			120		
SWC-range SWC(%g/g)	6-8% 7.01	8-10% 9.34	10-13% 11.97	6-8% 7.01	8-10% 9.34	10-13% 11.97
Mean	178.91	153.22	154.72	166.00	145.52	146.67
S.E	2.91	1.61	1.62	1.50	1.27	1.04
Median	180.00	150.00	160.00	170.00	150.00	150.00
Mode	190.00	160.00	150.00	170.00	150.00	150.00
Std dev.	21.57	19.67	18.08	11.16	11.89	10.85
Min	120.00	90.00	100.00	140.00	120.00	100.00
Max	220.00	200.00	200.00	190.00	170.00	170.00

7.2.2.2. Data for 3-Canadian tines on SINE 9

The distribution of the data collected with the 120 cm-yoke is more normal than the 90 cm-yoke. However, the variation between the graphs is not significant. Only two of the six are negatively skewed **(Figure 31a and 32c)** while the other three are slightly positively skewed **(Figure 31b, 31c and 32a).** The distribution at SWC= 8-10% with the 120 cm-yoke is normal **(Figure 32b)**.

The statistics on the data collected with the SINE 9 cultivator are summarized in **Table 56**. It appears from the data table that the lowest PF required correspond to the 8-10%-SWC range for the 90 cm-yoke type. For the 120 cm-yoke, the difference between the 8-10% and 10-13% SWC range is not significant. Higher SWC has the tendency to generate more pulling effort as the wet soil adhered to the sweeps. The 90% Confidence Interval of the average pulling force, required by the 3-tine SINE 9 across the SWC (6-13%) is equal to:

$$\mathbf{PF_{SINE9} = (102.84, 135.20)\ daN}$$

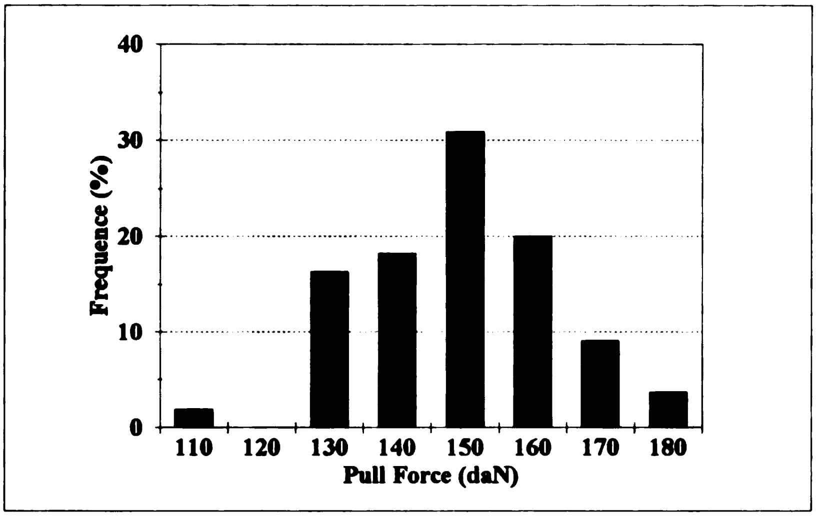


Figure 31a: PF with SINE 9 at SWC=6-8% Yoke= 90 cm

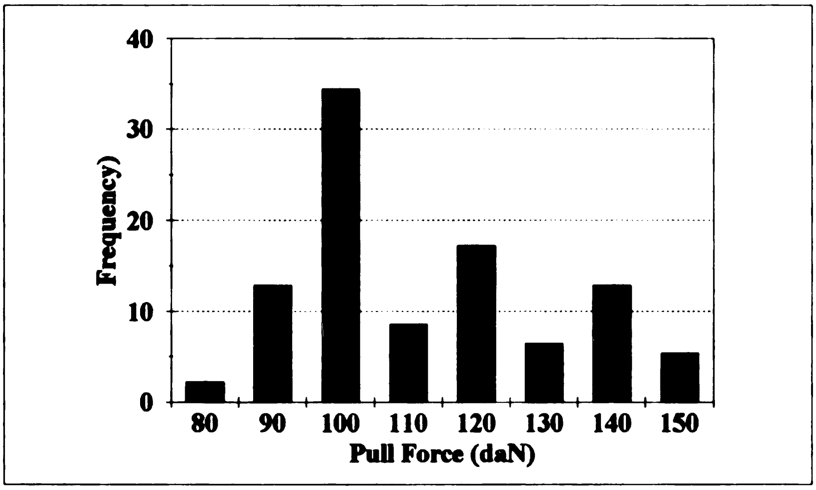


Figure 31b: PF with SINE 9 at SWC=8-10% Yoke= 90 cm

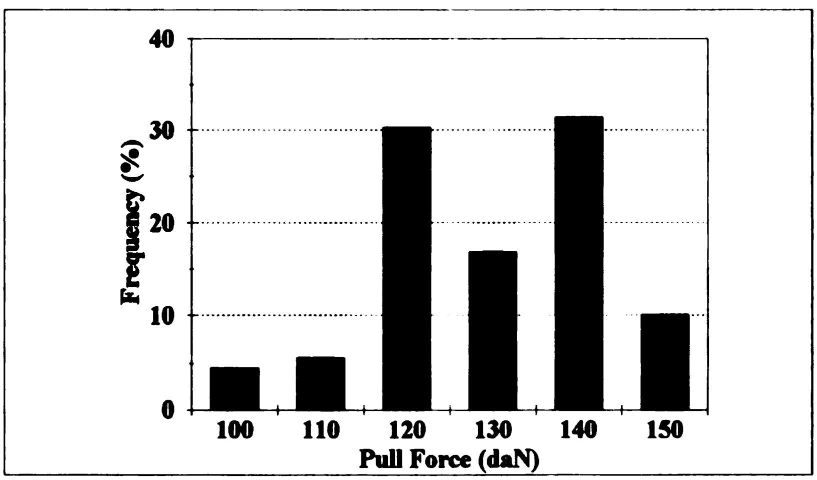


Figure 31c: PF with SINE 9 at SWC=10-13% Yoke= 90 cm

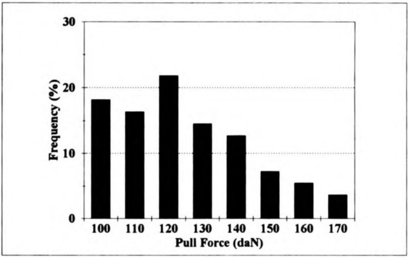


Figure 32a: PF with SINE 9 at SWC=6-8% Yoke= 120 cm

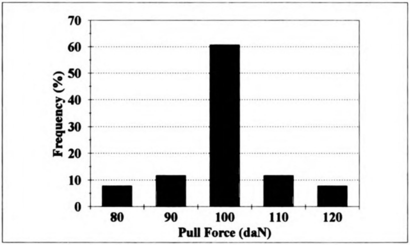


Figure 32b: PF with SINE 9 at SWC=8-10% Yoke= 120 cm

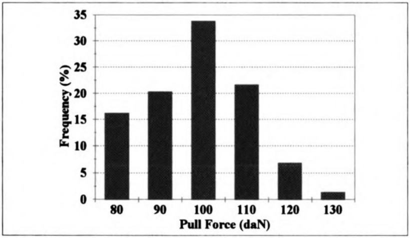


Figure 32c: PF with SINE 9 at SWC=10-13% Yoke= 120 cm

Table 56: Pull Force PF (daN) with the 3-tine SINE 9

Yoke (cm)	90			120		
SWC-range SWC(%g/g)	6-8% 7.01	8-10% 9.34	10-13% 11.97	6-8% 7.01	8-10% 9.34	10-13% 11.97
Mean	149.09	111.91	130.45	124.91	100.00	97.76
S.E	1.93	1.97	1.58	2.63	1.31	1.51
Median	150.00	105.00	130.00	120.00	100.00	100.00
Mode	150.00	100.00	140.00	120.00	100.00	100.00
Std dev.	14.31	19.08	14.92	19.52	9.38	13.12
Min	110.00	70.00	100.00	100.00	80.00	60.00
Max	180.00	150.00	200.00	170.00	120.00	130.00

The average implement working width for this PF range was IMPLWWD= 52.08 cm and the depth, IMPLWDP= 9.60 cm.

7.2.2.3. Data for ridger attached to the ARARA

A similar analysis of the graphs shows that most of observed data distribution are slightly positively skewed **(Figure 33a, 34a and 34b)**. The skewness coefficients of the distribution corresponding to the 10-13% SWC range are positive and greater than 1 (1.18 for 90 cm-yoke and 1.57 for 120 cm-yoke) to witness higher frequency values towards the low required pull force PF **(Figure 33c and 34c)**. Only one set of data is slightly negatively skewed with the 90 cm-yoke at 8-10% SWC range **(Figure 33b)**.

The lowest required PF with the ridger working component attachment was recorded within the 10-13% SWC range different from the UCF 10" plow and the 3-tine SINE 9 **(Table 57)**. The 90% Confidence Interval for the average required PF in daN is:

$$\mathbf{PF_{ARARA} = (109.57,\ 135.29)\ daN}$$

Table 57: Pull Force PF (daN) with the ARARA ridger

Yoke (cm)	90			120		
SWC-range SWC(%g/g)	6-8% 7.01	8-10% 9.34	10-13% 11.97	6-8% 7.01	8-10% 9.34	10-13% 11.97
Mean	130.18	118.50	109.88	138.36	137.64	100.00
S.E	2.65	1.97	1.63	2.80	3.18	1.37
Median	130.00	120.00	100.00	140.00	140.00	100.00
Mode	130.00	120.00	100.00	130.00	140.00	100.00
Std dev.	19.67	17.65	14.93	20.80	23.57	12.97
Min	100.00	80.00	90.00	100.00	100.00	80.00
Max	180.00	150.00	150.00	180.00	200.00	150.00

The average corresponding implement working width and depth were IMPLWWD= 22.59 cm and IMPLWDP= 10.44 cm respectively.

7.2.3. Regression analysis

The general linear regression model for this analysis uses different levels of qualitative independent variables: equipment types, soil water content ranges and yokes type. The following dummy variables were used to describe these levels: SWC2 (1 if SWC range is 8-10% and 0 otherwise), SWC3 (1 if SWC range is 10-13% and 0 otherwise), HS (1 if the equipment type is SINE 9 and 0 otherwise), ARA (1 if the equipment type is ARARA with ridger and 0 otherwise) and YK120 (1 if the YOKE is 120 cm and 0 otherwise).

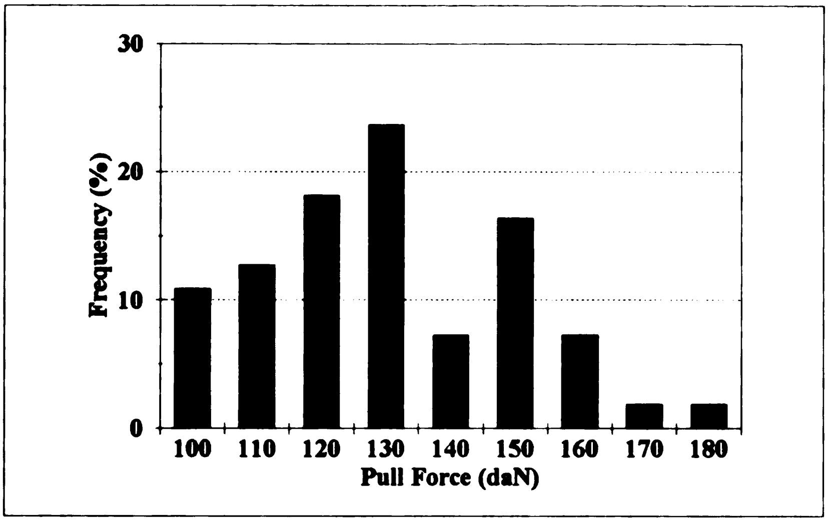


Figure 33a: PF with ARARA at SWC=6-8% Yoke= 90 cm

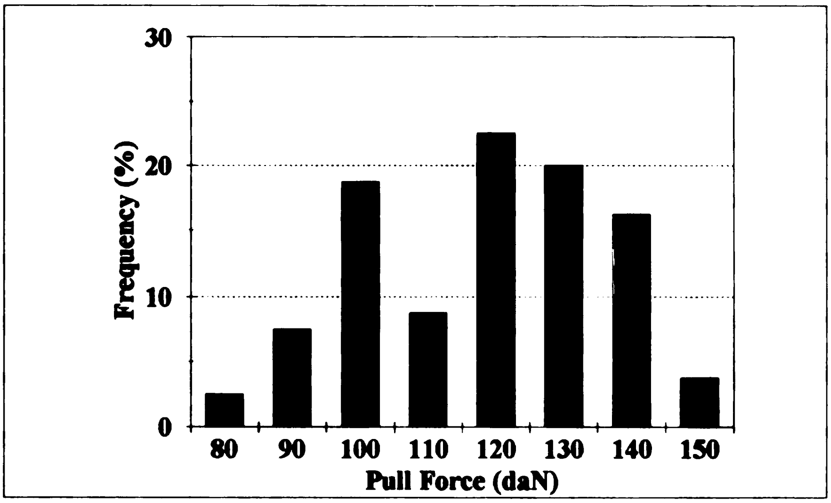


Figure 33b: PF with ARARA at SWC=8-10% Yoke= 90 cm

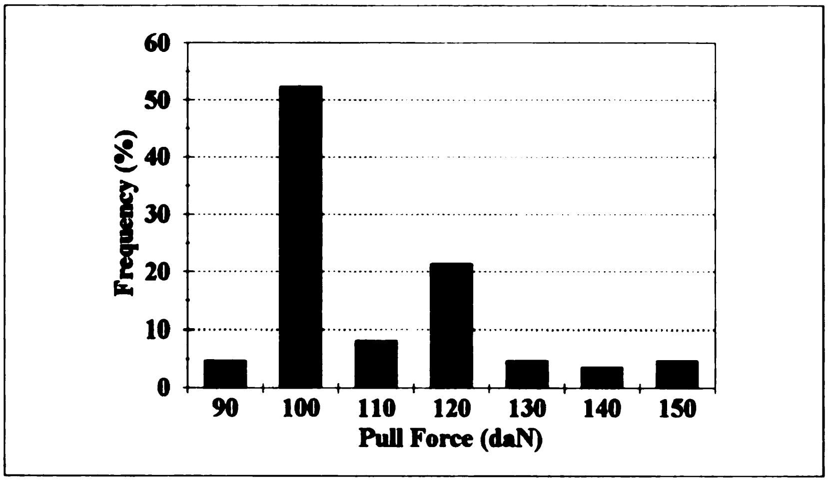


Figure 33c: PF with ARARA at SWC=10-13% Yoke= 90 cm

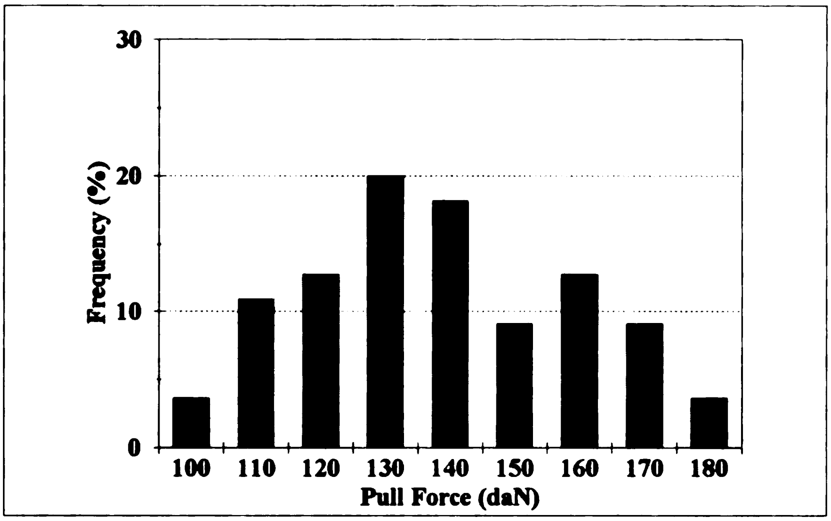


Figure 34a: PF with ARARA at SWC=6-8% Yoke= 120 cm

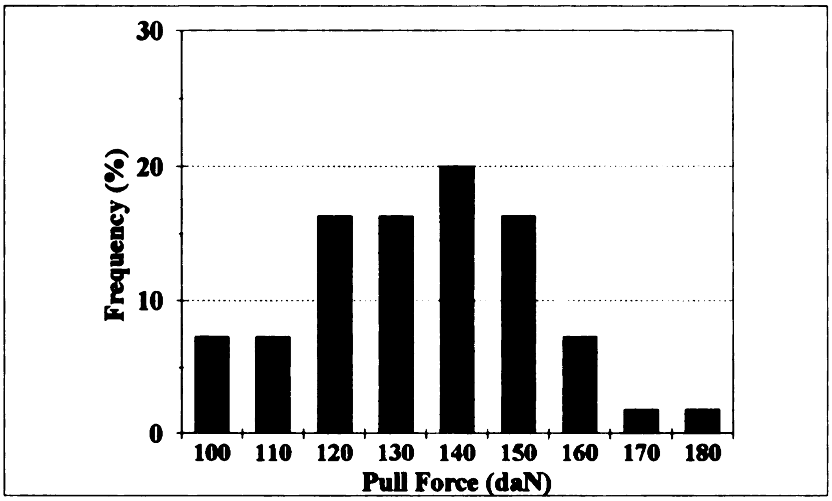


Figure 34b: PF with ARARA at SWC=8-10% Yoke= 120 cm

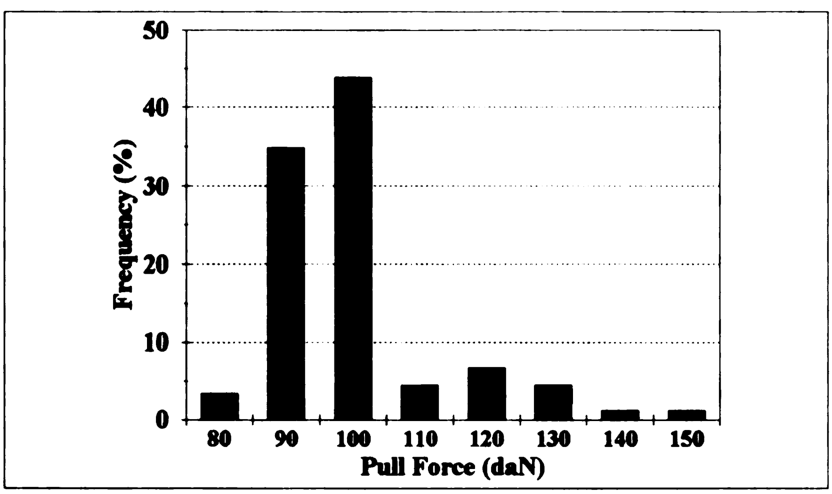


Figure 34c: PF with ARARA at SWC=10-13% Yoke= 120 cm

- Full model with interactions

$$PF = 177 - 23.1*(SWC2) - 17.5*(SWC3) - 35.5*(HS) - 38.2*(ARA) - 9.99*(YK120) - 8.0*(SWC2HS) + 16.9*(SWC2ARA) - 2.0*(SWC3HS) - 11.0*(SWC3ARA) \quad \textbf{(53)}$$

The regression equation explains a significant part of the total variation (**R^2**= 88.5%) **(Table 58 and 59)**. Most of the non-explained variation comes from the lack of normality in the distribution of data collected within some elementary plots. One part of the variation is also induced by the variation of the different implements' working width (IMPLWWD) and depth (IMPLWDP). The low values of the skewness coefficients, less than or equal to 1 in absolute value for 88.89 % of the observed distribution, did not strongly indicate a need for data transformation. The assumption of normal distribution

Table 58: Parameter estimates of PF regression

Predictor	Coef	Stdev	t-ratio	p
Constant	177.45	8.77	20.22	0.000
SWC2	-23.08	11.77	-1.96	0.086
SWC3	-17.54	11.77	-1.49	0.174
HS	-35.46	11.77	-3.01	0.017
ARA	-38.19	11.77	-3.24	0.012
YK120	- 9.99	5.55	-1.80	0.109
SWC2HS	- 7.96	16.65	-0.48	0.645
SWC2ARA	16.89	16.65	1.01	0.340
SWC3HS	- 2.00	16.65	-0.12	0.907
SWC3ARA	-10.99	16.65	-0.66	0.528

s = 11.77 R-sq = 88.5% R-sq(adj) = 75.6%

Table 59: Pull force PF Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	9	8561.0	951.2	6.86	0.006
Error	8	1108.6	138.6		
Total	17	9669.7			

Variables	DF	SEQ SS
SWC2	1	336.5
SWC	1	1435.8
HS	1	1708.0
ARA	1	3936.0
YK120	1	449.3
SWC2HS	1	292.9
SWC2ARA	1	334.0
SWC3HS	1	8.2
SWC3ARA	1	60.4

holds as the central limit theorem allows when the number of observation **n** from the random variable PF in each elementary was large (**n**= 51 to 149).

The probability values in **Table 58** of testing the hypotheses that the interaction coefficients are equal to zero are quite large. This implies to remove the interaction terms as they are not very important. The same analysis for the yoke suggests its removal from the model.

- No-interaction model

$$PF = 173 - 20.1 * (SWC2) - 21.9 * (SWC3) - 38.8 * (HS) - 36.2 * (ARA) \quad \textbf{(54)}$$

This new linear equation simple to use explains 76.7% of the variation and has slightly higher probability levels (**Table 60**). However, it also has a slightly larger standard error.

Table 60: Analysis of Variance (SWC and EQTYPE)

SOURCE	DF	SS	MS	F	p
Regression	4	7416.3	1854.1	10.70	0.000
Error	13	2253.4	173.3		
Total	17	9669.7			

Variables	DF	SEQ SS
SWC2	1	336.5
SWC3	1	1435.8
HS	1	1708.0
ARA	1	3936.0

The PF averages corresponding to the SWC-range and EQTYPE factors are of particular interest in the evaluation process of the PF required to perform a given field operation.

7.2.4. Draft requirements

Another approach to the evaluation of the working capacity of draft animals is to start from the draft requirements DR in daN of a given field work (**Equation 12 or 31**). The draft is defined as the force needed to move the farm implement in the direction of travel. The conversion factor between the pull force PF in daN and the required draft DR in daN is the angle of pull γ at the implement hitching point. During the trials, the angle of pull, which gave the best line of traction, was maintained throughout the experiment. The average γ was **22.22** degrees with a **CV**= 1.15% and a 95% CI of (22.09, 22.35), with a coefficient of traction **cos** γ = 0.9257 **(Table 62)**.

For the type of sandy soil in the Basse Casamance region, a more interesting parameter in relation to the working width (IMPLWWD in cm) and depth (IMPLWDP in cm) is the draft required per unit cross-section of furrow slice at low speed . This parameter is called the specific soil resistance SSR in daN/cm^2 **(Table 61)**.

Table 61: Analysis of variance of Specific Soil Resistance SSR (daN/cm^2)

SOURCE	DF	SS	MS
SWC	2	0.10629	0.05315
EQTYPE	2	1.62410	0.81205
ERROR	13	0.03464	0.00266
TOTAL	17	1.76503	

```
            Individual 95% CI

SWC         Mean    -+---------+---------+---------+-------
6-8%        0.704                            (------*-----)
8-10%       0.562        (-----*------)
10-13%      0.526    (-----*------)
                    -+---------+---------+---------+--------
                   0.490     0.560     0.630     0.700

EQTYPE      Mean    -+---------+---------+---------+-------
UCF 10"     0.613                        (--*-)
SINE 9      0.222   (-*-)
ARARA       0.957                                      (-*-)
                    -+---------+---------+---------+-------
                   0.200     0.400     0.600     0.800
```

The difference in SSR in daN/cm^2 at the higher SWC ranges is not significant, 0.56 daN/cm^2 for the 8-10% SWC versus 0.53 daN/cm^2 for the 10-13% SWC range. The difference is highly significant between the lower and higher SWC ranges.

The implements show also a highly significant difference between their respective draft requirements per unit area within the whole 6-13% SWC range. In relation to the characteristics of the field operation performed, the ridger attached to the ARARA toolbar has the highest draft requirements, followed by the moldboard plow. The sweeps attached to the SINE 9 toolbar required less draft. A good estimate of the SSR daN/cm^2 for common use when evaluating the draft required DR in daN or the required pull force PF in daN during an average working day (8-13% SWC range) is:

Moldboard plow: 0.55 daN/cm^2

Ridger plow : 0.89 daN/cm^2

Full Sweep : 0.20 daN/cm^2

From this perspective, it will be important to know ahead of time the implement working width IMPLWWD in cm and depth IMPLWDP in cm in order to use **Equation 14**. The value of the pulling angle γ will also be needed. After calculating the corresponding traction coefficient **cos** γ, it will be possible to determine the required PF in daN to be developed by the pair of oxen (**Equation 31**). Other important field performance characteristics must also be taken into account in order to achieve a good evaluation of the draft animals working capacity.

Table 62: Field work characteristics and Field efficiencies

SWC range	6 to 8%					
Implement	UCF 10" plow		3-tine SINE 9		ARARA with ridger	
Yoke (cm)	90.00	120.00	90.00	120.00	90.00	120.00
Width (cm)	23.00	23.50	50.00	51.50	23.00	22.50
Depth (cm)	9.50	9.00	9.33	9.00	10.00	10.10
TFDTM(sec)	1366.67	840.00	774.75	520.00	710.00	480.00
EFDTM(sec)	740.00	460.00	490.00	350.00	390.00	340.00
Eff. E(%)	54.15	54.76	63.25	67.31	54.93	70.83
Angle γ	22.00	22.00	22.50	22.50	22.00	22.00
SWC range	8 to 10%					
Implement	UCF 10" plow		3-tine SINE 9		ARARA with ridger	
Yoke (cm)	90.00	120.00	90.00	120.00	90.00	120.00
Width (cm)	23.43	24.44	54.50	52.00	21.57	22.50
Depth (cm)	12.11	9.33	10.25	9.00	11.00	11.33
TFDTM (sec)	2050.00	1033.00	1342.00	954.00	1120.00	910.00
EFDTM (sec)	1374.00	710.00	956.00	916.00	624.00	690.00
Eff. E(%)	67.02	68.73	71.24	96.02	55.71	75.82
Angle γ	22.50	22.50	22.50	22.50	22.00	22.00
SWC range	10 to 13%					
Implement	UCF 10" plow		3-tine SINE 9		ARARA with ridger	
Yoke (cm)	90.00	120.00	90.00	120.00	90.00	120.00
Width (cm)	22.75	22.50	52.50	52.00	23.00	23.00
Depth (cm)	11.80	12.00	10.00	10.00	10.33	10.00
TFDTM (sec)	2308.00	2472.00	1480.00	1332.00	1520.00	1238.00
EFDTM (sec)	1262.00	1634.00	1116.00	986.00	890.00	920.00
Eff. E(%)	54.68	66.10	75.41	74.02	58.55	74.31
Angle γ	22.00	22.00	22.50	22.50	22.00	22.00
Avg E (%)	58.62	63.20	69.96	72.19	56.40	73.66
Stdev.	5.95	6.06	5.05	12.96	1.56	2.09
CV (%)	10.15	9.59	7.22	15.49	2.77	2.84

7.3. Implement Field capacities

7.3.1. Field efficiencies

The field efficiency E (in percent) of a farm implement is defined as the ratio of the implement's effective field capacity (EFC in ha/day) to its theoretical field capacity (TFC in ha/day). An equivalent approach is to determine the ratio in percent of effective field time (EFDTM in hrs) to total field time (TFDTM in hrs). The effective field time of an implement is the time spent performing a functional activity.

$$E = \left(\frac{EFDTM}{TFDTM}\right) \tag{55}$$

Table 63: ANOVA of E(%)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SWC	2	378.08	378.08	189.04	4.74	0.030
EQTYPE	2	571.56	571.56	285.78	7.16	0.009
YOKE	1	480.09	480.09	480.09	12.03	0.005
Error	12	478.86	478.86	39.90		
Total	17	1908.58				

Table 64: Average implement efficiency E (%)

EQTYPE	N	MEAN	MEDIAN	STDEV	SEMEAN	CV(%)
UCF 10"	6	61.07	60.93	6.87	2.81	11.25
SINE 9	6	74.54	72.63	11.43	4.67	15.33
ARARA	6	65.19	64.69	9.46	3.86	14.51

The summary in **Table 62** suggests that the field efficiencies E depend not only on the type of implement but also on the type of yoke used. The analysis of variance shows that the difference in E is highly significant **(Table 63)**.

Field efficiencies are best given in terms of field operation. It makes more sense to use the efficiency attached to the type of implement to perform the field activities (**Table 64**).

The effective field time (EFDTM) to perform a field operation is affected by the losses of time when turning at the end of the furrow and when the implement is grounded because of continuous high draft requirements caused by the rooting system of tree stumps scattered across the fields.

Another source of variation was introduced by the reluctance to pull on a continuous basis of the pair of oxen and their. They often made frequent stops to cope with the draft requirements close to their optimum draft performance, with an average PF/LW in the following ranges:

UCF 10" plow : PF/LW = (0.21, 0.24)

3-tine SINE 9 : PF/LW = (0.15, 0.20)

ARARA with ridger : PF/LW = (0.16, 0.20)

7.3.2. Field capacities

Based on the field efficiency E in percent, the effective field capacity EFC in ha/day is equal to the theoretical field capacity TFC in ha/day times the efficiency E:

$$EFC = (WWKGCOMP * ANISPEED) * (E) * (\frac{ANWKGHR}{day}) * 36 * 10^{-4} \quad (56)$$

Where the WWKGCOMP in cm is the width of the implement's working component; ANISPEED in m/s is the animal walking speed and ANWKGHR in hrs/day is draft animal daily field working time. The coefficient $36*10^{-4}$ is used to convert the units into ha/day.

The field capacity depends significantly on the number of hours ANWKGHR the draft animals are effectively used in the field to perform a task. The time spent traveling to the field and yoking the pair of oxen are not included in the number of animal-work-hours.

The total area cropped in ha during the season is calculated using the EFC (ha/day) and the number of days worked in relation to the probability of working day (PWD in percent).

7.4. Summary

A number of decision variables are involved in farmers' daily activities during the rainy season. Some of the variables are weather related, therefore out of the farmer's control. The soil moisture regime SWC (% g/g) remains the most determinant factor when it comes to performing farm activities. From the onset to the end of the rainy season, farmers rely on their good judgement to decide when to perform a field operation in relation to the available resources at the farm level.

The number of days suitable for tillage and other field operations is dictated by the type of soil along with the configuration of the rainy season. One of the best approaches to predict the number of working days NWDAYS is to use the level of probability or level of certainty. Two levels are generally used the 50% or 5 years out of 10 and the 90% or 9 years out of 10.

It is unfortunate that precipitation data are not always normally distributed. The duration of the period to analyze is important to draw acceptable statistical inferences: the shorter the duration, the less the likelihood of a normal distribution. Long duration periods are preferred as the World Meteorological Organization WMO recommends a minimum of 30-years data. Even with this range of data, annual rainfall data are still skewed (positively), with fewer totals significantly greater than the mean. Sometimes the use of the median instead of the mean can provide a more realistic and usable results especially for the 50% level of occurrences (Sumner, 1988).

During a suitable day for fieldwork, the level of intensity of the draft animals utilization represents a determinant factor in the evaluation of their field working capacity. At the beginning of the rainy season, the work demand is always high and farmers consequently try to maximize their utilization for greater output. The number of working hours per day ANWKGHR along with the speed ANISPEED to perform the work will determine the farmer's capacity to meet his cropping objectives. It is important to choose the correct combinations of implements, which will manage the available working capacity of the draft animals. As demonstrated in previous chapters, farmers do not have a wide range of implements to select from to carry out the field operations. Only the expected draft required DR in daN from the working component-soil relationships would help make a decision. The amount of draft found in this study shows that farmers normally use the draft oxen within the area of their optimum energy output (PF/LW= 0.20). This level of utilization corresponds to medium-to-heavy work intensity. Working an average of 6 hours/day in these conditions reinforces the management strategy of 1 day-rest per week. It is important to fit the job to the draft animals in terms of workload to improve their efficiency and productivity.

The use of different size head yokes does not seem to have a significant effect on the pull force PF developed by the pair of oxen. It is a good management practice to look after draft animal's comfort by fitting the yokes to the animal as energy is converted to useful work through the yoking system. A poorly fitted yoke will reduce power output. On the other hand, the type of yoke has a significant effect on the field efficiency E. The use of a larger yoke has the tendency to increase the working width without really performing a better quality job. In order to use realistic parameters, the use of the implement field efficiency (highly significant) is recommended in the process of field working capacity evaluation.

Chapter 8

EXPERT SYSTEM TO EVALUATE THE IMPACT OF ANIMAL TRACTION IN THE BASSE CASAMANCE REGION

8.1. Organization of the expert system program

The expert system developed in this study is aimed at evaluating the working capacity of a pair of draft oxen in the Basse Casamance region conditions. The program is built with flexibility in order to be expanded in the future to include other draft species and other geographical regions.

The program is organized around different modules **(Figure 35)**.

- Field capacities module
- Energy module
- Feeding system module
- Farm budget module
- Optimization module

The main module (Energy module) is used to calculate the traction potential and the traction delivered in terms of energy.

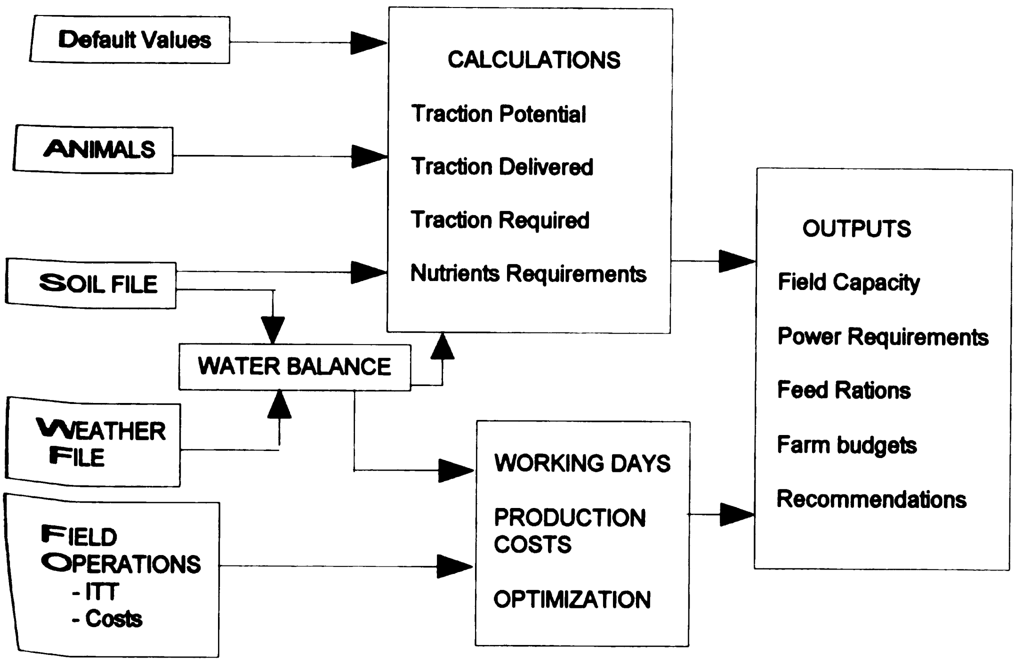


Figure 35: Animal Traction Evaluation Model Diagram

The program was built with the LEVEL5 Object Oriented 3.6 for Microsoft Windows Copyright 1995, Information Builders. The language is a high-level knowledge engineering language called Production Rule Language (PRL). The syntaxes are organized within Methods (When changed and When needed), Rules, and Demons which contain commands that tell the inference engines to initiate one or more actions at run time.

The program at run time needs a certain number of external files made with the DBASE III program and graphic files made with the Paintbrush software of the Microsoft Windows 3.1 package.

Most of the information and default values supplied to the program were data gathered from the field or models developed in the previous chapters.

For the Optimization module the program is set to use the Optimizer tool of an external Windows spreadsheet server program like Microsoft Excel, Lotus 123 version 3 or later versions, and Quattro Pro.

8.2. Database Files' structures

8.2.1. Farm location and characteristics

Name of the file: **FARM.DB3**
Fields Name:

COUNTRY	: Senegal.
COUNTPIC	: Country picture (Senegal.bmp).
REGION	: Basse Casamance.
REGPIC	: Region picture (Basse.bmp).
SITE	: Southwest (Geographical Location).
NZONE	: 5 (Number of Agro-ecosystem zones).
ZONE	: Agro-ecosystem zone
VILLAGE	: Village name (optional).
FMSIZE	: Farm Size in ha.
NFWKERS	: Number of Farm Workers (active workers).
MCASCROP	: Groundnuts (Main Cash Crop).
TYPESOIL	: Sandy clay (Type of dominant upland soil).

It is assumed that small-scale farms' production systems are in general driven by at least one main cash crop (MCASCROP). The information is needed for the program to execute the energy evaluation module and the optimization.

Two types of information need to be input in the program at this point by the user:

- The types of crops grown at the farm level which make up the cropping system (Groundnuts, Maize, Millet, Sorghum, Cotton and Rice).
- The First year the farmer started using animal traction. The name of the farmer is optional (first screen of the program).

8.2.2. Farm implement

Name of the file: **EQUIP.DB3**

Fields' Name:

NAME	: UCF 10" (Current Name of the implement)
WKGCOMP	: Moldboard (Working component)
NWKGCOMP	: 1 (Number of working component)
WWKGCOMP	: 25 cm (Working component Width)
WKGDEP	: 12 cm (Avg Working component depth)
AVGPF	: 145 daN (Average Pull force required)
RETPRICE	: Retail market Price
IMPLPIC	: Implement picture (*.BMP)
MANLIFE	: Years Life according to Manufacturer
FARMLIFE	: Years Life in Farmer's conditions
IMPLEFF	: Field Efficiency (in percent)
IMPLREL	: Implement Reliability (in percent)

The program will use the given average pull force (AVGPF in daN). The model developed in the study (**Equation 54**) is used to supplement a default value for AVGPF.

The efficiency IMPLEFF in percent and reliability IMPLREL in percent were determined previously. New data entered by the user will overwrite the current ones.

Information on the price of the implement (RETPRICE in local currency) can be supplemented at run time.

A bitmap filename with extension .BMP for the implement picture IMPLPIC is needed to be loaded for display to the user.

8.2.3. Draft animals

Name of the file: **DRAFTANI.DB3**

Fields' Name:

TYPE	: Ox.
BREED	: Ndama.
SEX	: Male.
AGE	: Age of the younger animal if in pair.
CIRCUMF	: Circumference at point of heart in cm.
AVGLW	: Average Liveweight in kg.
MATURELW	: Mature Liveweight in kg.
NDRFTANI	: Number of draft animals.
MKTPRICE	: Market price.
MATPRICE	: Mature draft animal's market price.
AGETRAIN	: Age trained.
YRSEXP	: Number of years of experience.
ANWKGHR	: Animal number of field work hours per day.
ANIPIC	: Animal Picture (*.BMP).

- Readiness for traction

The liveweight LW of draft animals are not generally known or readily available from the majority of farmers. The model developed previously **(Equation 52)** is used by the program to estimate the value of the liveweight LW in kg. The information needed is the average value of the circumference CIRCUM in cm, measured at the point of heart of each draft animal. The average liveweight (AVGLW in kg) is used by the program to evaluate the pulling capacity of the draft animals. For the specific case of cattle, different studies have shown that oxen with a liveweight less than half of the value of the species' optimal or mature liveweight (MATURELW in kg) must be excluded from traction (Lee et al, 1993). When a pair of oxen is rejected on the basis of that rule, the program will display a message and will not proceed further:

Not ready for traction

- Age versus Years of experience

The program will use the AGE in years of the younger animal (if a pair of draft animals is used) to test the readiness for traction in terms of capacity to perform field activities. The average training age (AGETRAIN in years)'s threshold of draft animals of current species are usually well known to animal traction users. In the Basse Casamance region, oxen are trained when they are two years of age. To be ready for field work an ox must be at least more than 2 years. The threshold can be overwritten.

The number of years of experience (YRSEXP in years) is used to rate the field working capacity of the draft animals. In the Basse Casamance region 3 years of experience is an accepted number of years to carry out good quality fieldwork. The number of years of experience and the age for training are compared to the age of the animal to verify the consistency of the data entered in the session. The program will reject inconsistencies and ask for new data. If a draft animal with correct liveweight has less experience than required, the program will inform the user through a displayed message that:

Need more training

The program will proceed from that point but will treat the draft animals as inexperienced.

- Working potential

Draft animals with correct liveweight and adequate working experience, are characterized by the program as:

Good for Field work

The average number of working hours (ANWKGHR in hrs/day) expected from the draft animals in relation to their pulling capacity is needed to evaluate the effective field capacity EFC **(Equation 56)**.

Information on draft animals' market prices MKTPRICE and MATPRICE in local currency are used in the cash flow analysis in the farm budget module. This information can also be supplemented at run time.

The draft animal's picture ANIPIC is a bitmap file type with .BMP extension.

8.2.4. Feeding System

Name of the file: **FEED.DB3**

Fields' name:

MAINFD : Main feed (Pasture grazing, cut grass, ...)
MFDQUANT : Quantity of main feed in kg
DMCMFD : Dry Matter content of the main feed in %
ERGCMFD : Main Feed Energy Content (in MJ NE/kg DM)
SUPLFD : Supplemented Feed in kg (Grain, stover, ...)
SFDQUANT : Quantity of Supplemented feed in kg
DMCSFD : Supplemented Feed Dry Matter Content in %

ERGCSFD	: Supplemented Feed Energy Content in MJ/kg DM
SFDPRICE	: Price of Feed per kg

In farmers' conditions, the main feeding type (MAINFD) during the rainy season is the natural grazing system. The quantity and quality of feed (MFDQUANT in kg) from the natural grazing is never enough at the beginning of the rainy season to provide enough energy to the draft animals. Farmers use different sources for feed supplement (SUPLFD in kg) like maize grain, sorghum grain or stover. The groundnut hay is generally used during the dry season along with the other crop residues. Feed information during working days is required.

The price of the supplement feed (SFDPRICE in local currency) is used to evaluate the cost of the daily maintenance of the draft animals.

8.2.5. Crops grown at the farm level

Name of the file: **CROPS.DB3**

Fields' name:

TYPE	: Type of Crop (Groundnuts, maize, millet, ...)
VARIETY	: Variety of crop grown (69-101, ZM 10, ...)
CYCLE	: Number of days from seeding to harvest
SDRATE	: Quantity of seed in kg/ha
SDLINE	: Distance in between rows in cm.
RIDGDIST	: Distance in between ridges in cm.
FTRATE	: Fertilizer rate in kg/ha.
SDLIMIT	: Date limit of Seeding for potential yield
SDPRICE	: Seed Market price per kg.
FTPRICE	: Fertilizer Market Price per kg.
CROPRICE	: Crop Market Price per kg.
YIELD	: Avg Yield without animal traction in kg/ha
LABCDAY	: Farm labor cost per day

Only information related to the types of crops grown at the farm level are entered in the current session. The program will not recognize a crop that has not been selected at the beginning of the session. Most of the variables are used for the elaboration of the farm budget.

Some variables listed in the file are not activated in the current version of the program but will be in the near future. Variable such as SDLIMIT (date limit of seeding for a given crop) are used to evaluate the timeliness cost, and the variable FTRATE (fertilizer rate) to include farmers that use fertilizers. The majority of farmers in the Basse Casamance region do not use fertilizers. Different studies have showed that the actual average rate of fertilizer is under 10 kg/ha of NPK (8:18:27).

The YIELD in kg required by the program corresponds to the level of yield observed before the utilization of animal traction. In the process of evaluating the yield, the program assumes that farmers with less than 6 years of experience or using non-experienced draft animals will not benefit from the yield increase induced by the mechanical plowing. The yield increments given to experienced farmers come from the average results of past experiences on animal traction induced yield increases over manual farming. A percentage increase on yield is used for different level of mechanization for each crop grown at the farm level. The yield increases generated by the mechanization of land preparation were found to be most significant and consistent according to Tourte (1971), Nicou (1979), Charreau and Nicou (1981) cited by Jaeger (1985) **(Table 14).** Results from field work carried out by the FSR team (Equipe Systemes, 1982-90) in the Basse Casamance region were also used. Rice is the crop with the highest yield increase (50.00%), followed by cotton (48.00%), maize (46.71%), Sorghum (34.60%), groundnuts

(25.67%) and millet (21.54%). The mechanization of the post tillage field operations (seeding and weeding) tends in general to increase the labor productivity more than the yield, except in few cases where non sustained yield increases were generated (Ndiame, 1988; Fall and Sonko, 1992).

8.3. Program modules

All the modules are used to run specific routines and the outputs are displayed to the end user after completion of each series of calculations. A printout of the output can be obtained with the print screen function from the computer keyboard.

8.3.1. Field capacities module

The effective field capacities EFC in ha/day are evaluated for each crop using **Equation 56**. After this operation, the EFC is converted into number of man-days per ha in order to evaluate the labor requirement per ha of crop (LABOREQ in man-days/ha).

The total number of working days is calculated using the probability of working day (PWD in percent) applied to each month and evaluated for each field operation according to the formula:

$$NWDAYS_{FDOP} = \left(\sum_{Month} (NDAYS * PWD)\right) * 0.86 \qquad \textbf{(57)}$$

The number of working days NWDAYS in days for a given field operation FDOP is equal to the sum of the product of number of days (NDAYS) in the month times the probability of working day in that month **(Table 51)** for the given FDOP. The sum is adjusted by a coefficient (0.86) for the 1 day of rest per week.

The farm labor balance ($LABORBAL_{ha}$ in man-days/ha) is carried out for each crop and for each field operation at given probability level: 5 years out of 10 and 9 years out of 10. The $LABORBAL_{ha}$ in man-days/ha is the difference between the labor available ($AVLABOR_{ha}$ in man-days/ha) minus the labor required ($LABOREQ_{ha}$ in man-days/ha) to perform the field operation FDOP (evaluated for each ha of crop):

$$((LABORBAL_{ha} = AVLABOR_{ha} - LABOREQ_{ha})_{FDOP})_{CROP} \quad (58)$$

The output on the farm labor shows the potential trade- offs and the labor effects of each level of mechanization for each crop. The farmer must choose among the trades-off, towards meeting his production objectives. One major strategy often performed by farmers is to use the labor surplus generated by the mechanization of land preparation to perform seeding operation instead of using seeders.

8.3.2. Energy module

The energy balance uses the most recent scientific work on animal energy evaluation. The factorial method **(Equation 5)** is used to perform the different energy calculations. The coefficients used in the equation for this study are mainly pulled from the dissertation work carried out on cattle in the West African region by Abdou FALL (1995) a ISRA's researcher, in partial fulfillment of his degree of Doctor of Philosophy submitted to the University of Edinberg (England). Four levels of energy are calculated:

- Energy doing work (pulling farm implements).
- Energy spent walking while pulling.
- Daily energy for Maintenance.
- Energy from body weight losses

8.3.2.1. Energy doing work (WRKERG)

The amount of energy used to do the task is directly related to the amount of pull force PF required. The energy for fieldwork (WRKERG in MJ NE/day) is evaluated using the power model developed in the previous chapters. In relation to the traction groups, the corresponding **Equation (45, 46 or 47)** is converted to energy by multiplying the power with the number of animal-work-hours per day (ANWKHR), adjusted by the field efficiency E in percent of the given implement used to perform the given field operation FDOP.

$$WRKERG = (Power^{1/2})^2_{Group} * (\frac{ANWRGHR}{day}) * E * (\frac{3600 * 1.075 * 10^{-6}}{0.32}) \quad \textbf{(59)}$$

The coefficients in the equation are used to convert the work energy WRKERG into net energy expressed in MJ NE/day. The coefficient 1.075 compensates for the energy losses due to the yoking system. Different authors suggest an average of 7.5% (=0.075) of energy loss due to the yoke (Goe and McDowell, 1980). The coefficient 0.32 is called the mechanical efficiency.

8.3.2.2. Energy spent walking (WALKERG)

While pulling implement, the draft animals move their own body across the field spending another level of energy. An energy coefficient is often used to compensate for the extra effort spent by the draft animal when walking while pulling (Lawrence and Zerbini, 1989; Fall, 1995). The recent energy coefficient used by Fall (1995) is equal to 1.59 compared to 2.00 from Lawrence and Zerbini (1989).

The walking energy (WALKERG in MJ NE) is equal to the distance traveled (DSTRAV in m) to perform a field operation FDOP times the total LW of the draft animals and multiplied by the energy coefficient. For any field operation FDOP on any crop, the distance traveled DSTRAV can be evaluated in two ways. One way uses the walking speed (WALKSPD in m/s) and the other, the effective field capacity (EFC in ha/day):

$$\textbf{DISTRAV = WALKSPD * EFDTM} \qquad (60)$$

$$\textbf{DISTRAV = EFC / WWKGCOMP} \qquad (61)$$

This program uses the EFC method as it was already calculated in previous routines:

$$WALKERG = 1.59 * \left(\frac{EFC_{FDOP}}{WWKGCOMP}\right) * TotalLW \qquad (62)$$

The WALKERG is expressed in MJ NE/day, the EFC_{FDOP} in ha/day and the Total LW in kgf.

The WALKERG is summed to the WRKERG to yield the total energy (TWERG in MJ NE/day) used to perform the field operation for the day. This energy can in turn be converted into total energy $TWERG_{ha}$ in MJ NE per ha by dividing with the corresponding field operation EFC.

8.3.2.3. Energy for maintenance (MAE)

The energy for maintenance MAE in MJ NE/day is highly dependent on the quality of feed given to the draft animals. The feed is converted into potential energy to be mainly used for fieldwork and to satisfy the demand for the metabolic activities of the draft animals. The energy should be enough to compensate for the increase in metabolic rate observed during workdays. The maintenance energy for cattle has been evaluated by different scientists. Each scientist accounts for various aspects (AFRC, 1993; Lawrence and Zerbini, 1993; Fall, 1995). In his latest research, Fall (1995) improved the AFRC (1993)'s method by including a coefficient that reflects the work done and not explicitly accounted for:

$$MAE = (0.53 * (\frac{TotalLW}{1.08})^{0.67}) * a * b * c \qquad (63)$$

The coefficient **a**= 1.15 is to adjust for male oxen, **b**= 1.10 to compensate for increased metabolic rate during work days and **c**=1.05 to reflect the work done and not accounted for (Fall, 1995). The MAE can be converted into MAE_{ha} in MJ NE/ha by dividing with the corresponding field operation EFC.

8.3.2.4. Energy from LW losses (LWLERG)

The beginning of the rainy season represents a peak energy demand period because of intense field activities. These activities especially tillage, take place within the number of workings days in the months of June and July. The level of draft oxen utilization is often so intense that draft oxen uses their body reserves to meet energy needs, resulting in a loss of body weight (LWL in kg/day). Animal traction researchers in general, have reported negative LW changes during this time of the year. Even well fed draft animals were found to lose weight (Goe, 1983).

The analysis of field activities in farmers' conditions have shown in previous chapters that draft oxen in the Basse Casamance region lost an average of LWL = 1.21 kg/day. Lawrence and Becker (1994) suggested the use of a coefficient of 15 MJ NE/kg to convert every kg of LWL into usable energy by the draft animals. The energy (LWLERG in MJ NE/day) is calculated as followed:

$$LWLERG = (LWL_{Group}) * 15 \qquad \textbf{(64)}$$

The **LWLERG** is expressed in MJ NE/day and LWL_{Group} in kg/day.

8.3.3. Feeding system module

The calculation of the feeding system is based on the ratio k of the energy used during every working day (daily maintenance + work done) over the daily maintenance.

8.3.3.1. Energy from the feed (FEEDERG)

The energy from the feed (FEEDERG in MJ) is calculated starting with the level of metabolizable energy ME contained in the feed on a dry matter DM basis. The appetite limit in **Equation 10** represents the maximum dry matter DM a draft animal can take per day. It is directly proportional to the draft animal LW.

- Metabolizable Energy (ME) in feed (FEEDME)

The FEEDME in MJ ME is the sum of the ME in each feed composing the total diet made of the main feeding system (grazing) and the supplement feed (grain, stover, etc.).

$$FEEDME = (MFDQUANT * DMCMFD * ERGCMFD) + (SFDQUANT + DMCSFD + ERGCSFD) \quad \textbf{(65)}$$

- NE available for maintenance and work (MNWRKNE)

The ME in order to be usable by draft animals for maintenance purposes and to perform work must be converted into net energy MJ NE. A mechanical efficiency k_m developed by MAFF (1975) is applied to the ME to yield the available NE in MJ NE:

$$MNWRKNE = (k_m) * (FEEDME) \quad \textbf{(66)}$$

$$k_m = 0.019 * (x) + 0.503 \quad \textbf{(67)}$$

where **x** in MJ/kg DM is the equivalent energy content of the total diet.

$$x = \frac{(MFDQUANT * ERGCMF) + (SFDQUANT * ERGCSFD)}{(MFDQUANT * DMCMFD) + (SFDQUANT * DMCSFD)} \quad (68)$$

- NE available for work from the feed (FDWRKNE)

Only part of the energy made available from the metabolizable energy ME is used to perform work and the remaining part used for maintenance purposes. The net energy available for work from the feeding system (FDWRKNE in MJ NE/day) is calculated by subtracting the required energy for maintenance per day MAE from the total net available energy (MNWRKNE in NJ NE):

$$FDWRKNE = (MNWRKNE) - (MAE) \quad (69)$$

According to the farmers' systems management of draft animals, the pair of oxen may be used 6 days a week. The amount of energy available for work WRKNE in MJ NE/day is evaluated for the working days only and adjusted to take into account the energy available from LW losses LWLERG in kg/day:

$$WRKNE = FDWRKNE * (\frac{7}{6}) + LWLERG \quad (70)$$

This level of energy is available and expected to be expended from the pair of oxen. It is important to mention that the quantity of feed used to carry out all these calculations corresponds to the total amount given to both animals working in the team.

- Energy expenditure ratio (k_{exp})

The ratio of energy expenditure calculated on a daily basis is determined by evaluating the part of the energy required for maintenance MAE in MJ NE from the effective total energy used per day:

$$k_{exp} = (\frac{MAE + WRKNE}{MAE}) \quad (71)$$

The energy requirements for the pair of oxen working at this level of intensity would be k_{exp} times the energy required for maintenance (Goe, 1980; Lee et al, 1993).

8.3.3.2 Feed rations (FDRATION)

The amount of feed supplied to draft animals is evaluated from the quantity of feed required for the daily maintenance. The quantity of feed given to working animals will greatly depend on the intensity of utilization. The ratio of energy expenditure k_{exp} is a good measure of the current utilization intensity level. Based on k_{exp}, the program will evaluate the number of forage units (FU) to meet the minimum needs of the working animals. The daily ration FDRATION in FU will be equal to k_{exp} fold the quantity of forage units (FU) required for maintenance. The daily maintenance is evaluated using the model formulated in **Equation 63**:

$$FDRATION = (k_{exp}) * (6.321 * 10^{-3} * TotalLW + 0.7089) \quad (72)$$

A list of available feed stuffs along with their FU content per kg of DM (Table 65) is presented for the user to select and make up his own ration FDRATION expressed in FU.

Table 65: FU contained in some available feed

Available Feed	FU/kg
Sorghum grain	0.90
Millet grain	0.70
Maize grain	1.10
Cow peas grain	1.00
Cotton grain	1.10
Groundnut cake	1.00
Millet/Sorghum stover	0.85
Cut grass	0.14
Pasture grazing	0.06 - 0.19
Good quality hay	0.29
Groundnut hay	0.35
Rice straws	0.26

Source: CEEMAT, 1975.

Most of these feeds are available on a yearly basis. It is important to select the feed available during the intense working period, mainly June, July and August.

The program will present to the user a calculator type of display to sum the FU of the selected feed.

8.3.4. Farm budget module

The farm budget module uses the available information to carry out a yearly budget on each crop according to the following format (the local currency is used for the farm budget (**$1 US= 560 CFA**):

Production value (PRODVAL in CFA/ha)):

$$\mathbf{PRODVAL = YIELD * CROPRICE} \quad (73)$$

Variable Cost :(SDCOST= seed cost; FERCOST= fertilizer cost in CFA/ha)

$$\mathbf{SDCOST = SDRATE * SDPRICE} \quad (74)$$

$$\mathbf{FERCOST = FERTRATE * FERPRICE} \quad (75)$$

Labor cost (LABCOST in CFA/ha)

$$\mathbf{LABCOST = LABOREQ * LABCDAY} \quad (76)$$

Total variable cost with labor (TVCWLAB in CFA/ha)

$$\mathbf{TVCWLAB = SDCOST + FERCOST + LABCOST} \quad (77)$$

<u>Total variable cost wo labor</u> (TVCWOLAB in CFA/ha)

TVCWOLAB = SDCOST + FERCOST **(78)**

<u>Total fixed cost</u> (TFCOST in CFA/ha)

TFCOST = IMPFCOST + ANIFCOST **(79)**

<u>Total cost</u> (TCWLAB; TCWOLAB with and without labor in CFA/ha):

TCWLAB = TVCWLAB + TFCOST **(80)**

TCWOLAB = TVCWOLAB + TFCOST **(81)**

<u>Gross Margin GM per ha</u> (**GMWLABha**; **GMWOLABha** w and wo labor in CFA/ha)

GMWLABha = PRODVAL - TVCWLAB **(82)**

GMWOLABha = PRODVAL - TVCWOLAB **(83)**

<u>Net Margin NM per ha</u> (**NMWLABha**; **NMWOLABha** w and wo labor in CFA/ha)

NMWLABha = PRODVAL - TCWLAB **(84)**

NMWOLABha = PRODVAL - TCWOLAB **(85)**

Margin per man-day (in CFA/man-day):

GMmanday = GMWOLABha / LABOREQ (86)

NMmanday = NMWOLABha / LABOREQ (87)

Production cost/kg (PRODCOST in CFA/kg)

PRODCOST = TCWLAB / YIELD (88)

Two separate displays are used to present the output of the farm budget. All marginal analyses are presented in one display. Only the budget related to the crops selected at the beginning of the program is processed.

It is left to the user to make good interpretations of the farm budget output.

8.3.5. Optimization module

The optimization module is executed by using the optimizer tool of a Windows spreadsheet server. The program becomes the client and sends the needed information to the server by means of DDE links and receives the result back after calculations are completed. The server is required for the program to run properly.

Linear programming is used for the optimization. The program will display the constraints' matrix to the user before sending the information to the server. It is up to the user to verify its consistency before action is taken.

The objectives of the optimization problem can be expressed as followed:

8.3.5.1. Optimization objectives

Goal 1: Maximize revenue from the cash crop

Goal 2: Produce enough cereals for farmer's own consumption.

Instead of using a goal programming approach, the second objective of the problem is considered as a constraint in the search of solutions to producing cereals corresponding to no less than the farmer's needs.

In small-scale farming system, farmers' objectives are not always monetary. Trades-off are sometimes possible in relation to the current economical production environment. A major adjustment performed in the Basse Casamance region was to sacrifice the cereals' production in general and rice in particular, in favor of the groundnut cash crop. Rice was kept to a minimum and was allocated the least resources compared to other upland crops. The main reason was the risky weather situation characterized by a persistent shortage of rainfall. Among the cereals produced by farmers to meet their own consumption, rice production always plays a role of regulator and occupies a fixed percentage of land in the low land areas according to the spatial distribution of crops.

8.3.5.2. Constraints and objective function

8.3.5.2.1. Decision variables

The decision variables used in the program, in the form of area allocated to a crop (CROPAREA in ha) are defined as follow:

GNAREA = Area cropped with Groundnuts GN in ha.

MZAREA = Area cropped with Maize MZ in ha.

MLAREA = Area cropped with Millet ML in ha.

SGAREA = Area cropped with sorghum SG in ha.

CTAREA = Area cropped with Cotton CT in ha.

RCAREA = Area cropped with Rice RC in ha.

Among the crops listed, only cotton is not part of the cropping system of a common farmer in the Basse Casamance region. Cotton is considered as a cash crop in other regions.

8.3.5.2.2. Objective function

The objective function which maximizes the net profit (NPROFIT in CFA) is written as:

$$\text{Max}(NPROFIT) = \Sigma_{CROP}(NMWOLAB_{ha} * CROPAREA) \quad \textbf{(89)}$$

8.3.5.2.3. Statements of the constraints

The constraints to small-scale production systems are in general the same throughout the region: land (FMSIZE in ha), labor (LABOR in man-day), animal energy (ANERGY in MJ NE), own consumption (CONSUMP in kg) and minimum of rice (MINRICE in ha).

. **Land constraints**

$$\Sigma_{CROP}(CROPAREA) \leq FMSIZE \qquad (90)$$

. **Farm labor constraints**

$$\Sigma_{CROP}(LABOREQ_{ha} * CROPAREA) \leq AVLABOR \qquad (91)$$

The available farm labor (AVLABOR in man-days) is evaluated in relation to the number of active farm workers NFWKERS at the farm level multiplied by the number of working days during the growing season.

The labor required per $LABOREQ_{ha}$ in man-days/ha corresponds to the total amount of man-days per ha needed to conduct the crop from tillage to harvest.

. **Animal energy constraints**

The animal energy must be evaluated for the time the field operation FDOP lasts and for as many field operations FDOP as performed (tillage, seeding, weeding). If the pair of oxen is used for plowing only then the competition between different crops becomes a constraint in relation to the total energy available for the number of working days (NWDAYS in days) for tillage field operation.

The available animal energy (AVANERG in MJ NE) is equal to:

$$AVANERG = (k_{exp}) * (MAE) * (\Sigma_{FDOP} NWDAYS) \qquad (92)$$

The constraint on animal energy utilization is given by:

$$\Sigma_{CROP} [\Sigma_{FDOP} (TERG_{ha} + MAE_{ha})] * (CROPAREA) \leq AVANERG \qquad \textbf{(93)}$$

. **Consumption constraints**

The consumption constraints are evaluated using the FAO standards for food energy intake per year. The equivalent cereal for that requirement is 200 kg per year and per active farm worker. An extraction coefficient (EXTCOEF in percent) is applied to each cereal type to convert the amount of production needed into consumable food form. The value of EXTCOEF is closely related to the quality of the post-harvest operations through handling and processing. For cereals, maize, millet and sorghum, EXTCOEFF is equal to 0.83 (MBENGUE, 1986). Rice harvested from the field for example needs to be dried, threshed, de-hulled and milled. After processing, only approximately 65% of the original quantity can be used as food supply for human consumption (Equipe Systemes, 1983). The extraction coefficient takes into account all the losses observed during the processing from harvest to the final stage for consumption. The cotton is not edible (0%). Studies conducted in the region by socio-economists, researchers of the Djibelor FSR team have reported that most farmers provide more than 60% of their groundnut seed, around 30 to 50 kg per ha. The total household use for groundnuts is estimated to be 5% of the harvest per year.

The constraint on consumption can be formulated as follow: The sum of consumption value from each crop (CONSVAL in kg) must at least be equal to the household total consumption needs (CONSNEED in kg).

$$CONSVAL_{CROP} = (EXTCOEF_{CROP}) * (YIELD_{CROP}) \tag{92}$$

$$CONSNEED = 200 * (NFWK) \tag{93}$$

The consumption constraints can be written as follow:

$$\Sigma_{CROP} (CONSVAL * CROPAREA) \geq CONSNEED \tag{94}$$

. **Cropping system constraints**

The cropping system constraints are expressed in terms of minimum area of the farm land to be reserved to specific crops. Rice production in the Basse Casamance region carries a heavy load of cultural behavior as the traditional cropping systems in the past was mainly centered around this crop. A number of social science researchers refer to the Basse Casamance population as the "Rice Civilization" people (Pelissier, 1966).

For the Basse Casamance region, the percentage of land allocated to rice production (RCPCENT in percent) varies on the basis of type of agro-ecosystem. In agro-ecosystem zone 4, for example an average of 15% of the farm land FMSIZE are used for rice production against 20% in the agro-ecosystem zone 5.

The value of RCPCENT in percent is expected to be different for individual farmers but the present version of the program is designed to use a default value per agro-ecosystem zone.

The cropping system constraint is expressed as followed:

$$RCAREA \geq (RCPCENT) * (FMSIZE) \quad \textbf{(95)}$$

The cropping system constraint is not included in the table of constraints presented to the user before optimization. The constraint equation is directly written to the spreadsheet as a condition to be met.

. Decision variables constraint

$$(CROPAREA_{CROP}) \geq 0 \quad \textbf{(96)}$$

The amount of land resources allocated to a crop (CROPAREA in ha) must be positive or equal to zero. When using the CROPAREA variable in the equation, CROP has to be replaced by GN for groundnuts, MZ for maize, ML for millet, SG for sorghum, CT for cotton and RC for rice. This general condition on the decision variable also called the non-negativity restrictions will guarantee a real value to the solution.

8.4. Optimization output

The optimization output is bound by the amount and quality of information the server is able to process. The Solver tool from Microsoft Excel or Optimizer from Quattro

Pro for Windows have their own technique to handle such problems. The current version of the expert system program is designed to fit the Quattro Pro for Windows' format.

8.4.1. Server solution

It is important to mention at this point that the solution to the optimization problem refers to the combination of the different decision variables and not to the maximum value of the net profit (NPROFIT in CFA). The main concern for the user is to determine the crop mix to be grown and the area of land that will maximize the profit, using the available resources.

The solution is given in ha of cropped land for each crop. A zero value means that the crop must not be included in the cropping system. As the decision-maker, the user must weigh all the information given by the optimization output before formulating a decision. The cropping system chosen should reflect the specificity of his farm. Qualitative variables not used in this analysis can help reach a better viable solution.

8.4.2. Interpretation of Coefficients

A number of information items are given along with the solution to the problem. The information items are presented to the user on the same display. The main coefficients given are:

- Slack/Surplus

The coefficients represent the difference between the level of utilization of a given resource and its availability.

A resource with a positive coefficient also called slack is not fully utilized and is considered a "free good". A free good means that an increase in its availability will not increase or change the profits. The slack must always be zero or positive. Slack is better represented in a greater than or equal to type of relationship in formulating the constraints equations.

In surplus situations, the difference between the level of utilization of a resource and a minimum requirement is positive. This difference is used to measure how much the requirements are exceeded.

- Shadow prices

Different names are used to represent the same coefficient, like opportunity cost, marginal or dual values in relation to the way the optimization problem is stated. Shadow prices are applied to resources to estimate their opportunity cost when not one unit of the corresponding resource is included in the solution. In other words, it expresses the change in the value of the objective function when one additional unit of the resource is added to evaluate its effects. In purely economical terms, it represents the net marginal contribution to the profit. A negative value of a shadow price means that if the availability of the resource is increased by one unit, the corresponding value of the objective function will decrease. This variable is important and can be used to examine the profitability of using additional resources and to evaluate possible trades-off.

The opportunity cost of resources is also used to perform a test for optimality. If all the opportunity costs of the resources are either zero or negative then the solution can be considered as optimal. In this situation, the resources are fully utilized meaning that, if any other variable enters the basis, it can only either decreases the profit or leave it unchanged.

- Reduced cost

The reduced cost for the decision variables represents the amount by which the objective function will be reduced if the variable is introduced into the optimal solution. In other words, it expresses the penalty imposed on the objective function if one unit of the variable not currently accounted is entered into the optimal solution.

- Binding status

A fully used resource is "binding". It constitutes a bottleneck for any improvement or reorganization of the environment. The Kuhn-Tucker conditions stipulate that if the shadow price is nonzero then the resource is fully utilized meaning there is no slack or surplus (Turban and Meridith, 1994).

8.4.3 Sensitivity analysis

An explicit module to run a sensitivity analysis is not included in this version. The program must be re-run in order to change the parameter and observe its effect on the optimal solution. The purpose of the sensitivity analysis is to give to the user additional decision making information.

8.5. Program validation

In the process of continuous validation, the expert system program is built to work with validated input data. Built-in messages guide the execution of the program. The error trapping system can still be improved to better handle certain type of "wild" data. Program routines execute and verify at the same time the quality of the data entered. In case of inconsistencies, the program will prompt the user to enter correct data. The amount of data to be provided directly by the user during the session is kept to a minimum.

Two modules need to be tested and validated against other methods of evaluation: the field capacities module and the animal energy module.

8.5.1. Example of one Session

- Data input

Farm characteristics

First year in animal traction : 1990

Agro-ecosystem zone : 4

Farm size : 6

Number of farm workers : 5

Crops grown : Groundnuts, Maize, Millet, Sorghum, Rice

Implements and draft animals selection

Implement type : UCF 10" moldboard plow

Draft animals : Pair of oxen

Average LW : 200 kg

Age (younger animal) : 6 years Working Experience : 4 years

- Program output

Effective field capacities (ha/day)

	GN	MZ	ML	SG	RC
Tillage	0.18	0.18	0.18	0.18	0.18
Seeding	0.04	0.07	0.05	0.07	0.05
Weeding	0.03	0.03	0.05	0.06	0.05
Harvesting	0.05	0.08	0.08	0.10	0.02

Energy evaluation module (MJ NE/day)

	GN	MZ	ML	SG	RC
Tillage	39.69	39.69	39.69	39.69	39.69
Weeding	-	-	-	-	-
Seeding	-	-	-	-	-
Harvesting	-	-	-	-	-

Maintenance (MJ NE/day) = 37.02

Energy evaluation module (MJ NE/ha)

	GN	MZ	ML	SG	RC
Tillage	223.78	223.78	223.78	223.78	223.788
Weeding	-	-	-	-	-
Seeding	-	-	-	-	-
Harvesting	-	-	-	-	-

Maintenance (MJ NE/ha) = 208.76

Annual Farm budget

	GN	MZ	ML	SG	RC
NMWOLABha (CFA/ha)	154669	144477	106645	106646	164412
PRODCOST CFA/kg)	103.88	86.11	107.63	94.07	205.57

The prices used are the official market prices of year 1995 (CSA, 1995)

Optimization output

Crops	Land (ha)	Reduced cost (CFA/ha)
Groundnuts	4.75	0.00
Maize	0.35	0.00
Millet	0.00	-34264.31
Sorghum	0.00	-43607.64
Rice	0.90	0.00
Resources	Slack	Shadow prices
Land	0.00	108154.90
Labor	0.00	509.51
Energy	1017.40	0.00
Consumption	44.24	0.00
Rice land	0.00	-54468.06

The units of the shadow prices are the objective function unit (CFA) per unit of the constraints (ha, man-day, MJ NE, kg equivalent-cereal and ha of rice in the order written).

8.5.2. Discussion on Optimization output

Field capacities

In this farmer's situation, only land preparation is mechanized with the UCF 10" moldboard plow. All the post-tillage field operations are manually performed.

According to the tillage effective field capacity EFC in ha/day, it will require from the pair of oxen an average of 5 days (6 hours/day) to plow one hectare of land. It is assumed that flat land preparation is executed with the moldboard plow.

In comparison with the values published in the literature, the program output for each operation is within acceptable range. For example, Le Moigne (1981) gave the range of 6 to 8 days for a pair of oxen, working 4 to 5 hrs per day to complete the task.

Draft animals Energy balance

The validation of the animal energy balance is more difficult in terms of finding similar utilization environment. For testing the consistency of the information given by the program, the output is compared to the experiment reported by Falvey (1986) in terms of procedure. All the steps were followed to reach the energy balance for each field operation. The value given in the output is mainly related to the level of confidence given to the raw data and to the validity of the different equations used.

Optimization output

The solution of the optimization recommends that the user grow 79% of the farm with groundnuts which is consistent with the practices in agro-ecosystem zone 4. In terms of cash flow, it was expected from the program to allocate more land resources to the cash crop. In a small-scale farming system, the value attached to the cash crop represents the driving force for trades-off in relation to the price levels of goods in the official market. Such decisions in turn can reshape the type of cropping system to the point that they become the determinant factor in the evolution of the global production system.

The general formulation of the objective in terms of profit maximization and the equations used to formulate the constraints on the available resources do not specify which crop is driving the profit. It is important to leave it that way in order to take into account a farmer who decides not to grow cash crop in consideration of particular constraints at the farm level (farm size, consumption required for the family members).

In the decision making process the opportunity cost of resources and the reduced cost of the decision variables must help to find a better organization of farm operations.

8.6. Summary

The building of a decision support system program must be performed around good first hand information. There are some advantages but also some disadvantages to using expert systems. The advantages of an expert system over a human expertise are primarily in the facts that expert system knowledge is permanent, easy to transfer, consistent and easy to access. The main disadvantages are the lack of creativeness, the required symbolic type of input, the narrow focus and the high level technical knowledge.

The main limitation of designing and building an expert system is the cost of getting the needed information to run the program. As this study has shown, the evaluation of the different variables and parameters required considerable time and human resources. The good news is that once the data are validated and tested for stability, they remain consistent and ready to be used.

Expert systems in agriculture represent a valuable tool to conduct farming system diagnostics, field operations scheduling and management. The existence of such programs gives opportunity to farmers, government servants, non-governmental organizations, to access technical information and to interpret simulation in relation to the socio-economical environment.

The organization of the program in modules makes information flow and outputs easy to interpret. The energy evaluation module uses in its important routines, animal energy equations developed elsewhere by other researchers. This approach is aimed to stimulate the continuity of the research on that topic. The factorial method developed by Lawrence (1985) to evaluate the extra energy used by draft animals to perform work is actually widely used around the world. An effort has been made in this study to use coefficients validated in the West African region with cattle.

The annual farm budgeting and the linear optimization are classic tools used in decision-making problems. The program output was designed to furnish as much decisional information as possible to the user.

As a general comment, this version of the program needs to be used for more validation and improvement. Some actions are going to be taken in the near future to expand the versatility and the geographical coverage to other regions of Senegal and, possibly to other countries.

Chapter 9

CONCLUSIONS AND RECOMMENDATIONS

9.1. Conclusions

In developing countries, farmers are generally confronted with a variety of agricultural technologies. These technologies have the common characteristics of being not well adapted to their new environment. Most of them have proven their merits elsewhere, and are possibly being penalized by the transfer process. Animal traction has to undergo the same constraints. Its utilization presents some advantages and disadvantages which need to be correctly evaluated. One main advantage over human energy is that it provides more power to help farmers improve the timeliness of their daily agricultural activities.

Animal traction is providing more than 80% of the energy needed in the agricultural activities, in Senegal in particular. The animal species used for traction are mainly cattle, horse and donkey. In the Southern part of Senegal, in the Basse Casamance region, cattle are the main source of power. The Ndama breed is well adapted in the environment characterized by harsh sanitary conditions for working animals. The level of utilization is highly variable across the region, and yet it needs to be evaluated at the farm level. The purpose of the evaluation is to estimate its potential and current impact. It represents an important factor of evolution of the cropping systems and towards farmers' achievements in building up a sustainable production system.

In this study, the evaluation technique used was built around an expert system to simulate different levels of utilization of animal traction in different agro-ecosystem zones in the Basse Casamance region. The expert system was structured according to modules linked by routines and subroutines using a high-level language called PRL (Program Rule Language). The PRL language is similar to natural language (like natural English) with interactive editors for more flexibility and accuracy in building applications. The LEVEL5 OBJECT™ (Release 3.6 for Microsoft Windows, Copyright© 1995 by Information Builders, Inc.) shell was used as the main programming environment and development tool kit. As any expert system derived from the artificial intelligence (AI) domain, it needs a considerable amount of quality information in order to be used for decision making. The information supplied to the expert system can be performed through a well-organized knowledge base management system (KBMS).

The knowledge gathered from animal traction utilization in the area of study was processed into 5 modules:

- Field capacities calculations
- Animal Energy evaluation
- Feeding system
- Annual Farm budget
- Optimization of farm resources' utilization.

Information fed in the program has been collected directly from the fields in farmers' conditions and from reliable sources in the existing scientific literature. A methodology of data collection on animal traction was proposed through surveys and field trials. To carry out the field activities, the farm was considered to be the unit of observation and was viewed as the basic element of the production system.

The surveys were divided into two types. The first type focussed on the inventory of the different types of farm implements currently used by farmers for crop production. The second was a follow up of different field operations performed with the draft oxen.

The field trials were designed to evaluate two things: (1) The amount of power and energy required to perform different field operations; and (2) To measure the maximum and optimum power that the draft oxen could develop at the beginning of the rainy season.

9.1.1. Surveys

- Farm implements

It was possible in a relatively short period of time (two weeks for 40 farmers) to identify all the implements actually used by farmers. The data collected ranged from the type and number of implements, the acquisition mode, the system management, the repair and maintenance problems, the type and number of draft animals to the local blacksmith activities. These data were analyzed to better understand the agricultural cropping system alternatives available to farmers in relation to the opportunities offered by the type of agro-ecosystem zones.

It appears that the range of implements is not very large. Only one model per type of implement was used: UCF 10" moldboard plow was the only type available; the same for the cultivators including the SINE toolbar; also one type of one-row seeder (Super ECO). Only the ridging implements were available in two versions. One was attached to the ARARA toolbar and the second, imported from Gambia.

All the farm implements experienced several breakdowns. This was associated with the quality of the materials used to make the working components and the conditions of use. Most of the soil working components were victims of the natural wear and of the presence of roots and stumps scattered in farmers' fields. The problems were aggravated by the absence of technical support. The local blacksmiths were not able to handle some types of breakdown. The unavailability of required tools and good quality raw materials prevented timeliness of the services. In these conditions the reliability, evaluated for each piece of farm equipment was generally found to be low.

- Draft animals

Even though oxen were available to farmers, the distribution was found to be highly variable. The main source of draft animals remained the herds in the village. The analysis shows how unstable the technology was as the majority of farmers relied on only one pair of oxen. They represented more than 70% of the farms. One pair of oxen will not protect farmers from production losses in case of animal injuries, diseases or deaths. In such cases the only alternative is to borrow another animal, if available, or to rent for a day or two, or to simply use hand tools. The majority of the farmers in that situation use hand tools. For some farmers, this situation can last a longtime before they find a replacement. The frequency of these types of event placed a certain level of unreliability in the utilization of draft animals for a given year.

9.1.2. Follow up of field operations

How the technology was helping farmers to fulfil their production needs was the main concern of the follow up. The aspects included in the daily follow up were: type of field operations performed, how it was performed in relation to the type and amount of resources involved, the health and care of the animals and, the feeding system used to maintain their working capacities. The draft animals were weighed every month to evaluate the liveweight LW variation during the rainy season.

To get the best performance from the animal, farmers had to manage the oxen working time in relation to the climatic conditions. They mainly used their animals during morning hours. An average of 6 to 7 hours of fieldwork per day put a lot of physical stress on the animals, to the point that they lost weight to cover the level of energy demand. The main feeding system through natural grazing after work or during breaks was not enough to supply the energy necessary for the tasks. Feed was supplemented early in the morning on a daily basis. The supplement was mainly made of maize, millet, sorghum grain or stover.

The liveweight of draft animals is a needed parameter in the process of evaluating the impact of animal traction. The model developed herein can be used to estimate the liveweight through the measurement of the circumference or girth. The circumference and the liveweight are highly correlated.

9.1.3. Maximum working capacity

The maximum working capacity was evaluated through the amount of power developed to pull different loads. The pull force PF developed was measured along with the speed used to pull the load. These two variables were combined to evaluate the power output of the draft animals at different level of utilization intensities. Draft animals were classified by liveweight into traction groups and the power output of each group modeled using a linear regression. The results showed that there was no significant difference in the power output among the traction groups, therefore one general model could be used to model the power output.

Two interesting points on the power curve were analyzed to compare the groups' performance: the optimum and maximum power. The amount of pull force PF corresponding to the optimum power revealed the existence of a range of forces too difficult to sustain. All pairs of oxen used in the pulling trial showed a certain level of unwillingness to pull in that range and induced an underestimation of the corresponding power output. At the maximum point, it was found that a pair of oxen could develop around 50% of its liveweight into force. This level of pull was an extreme and was not expected on a regular basis in farmers' working conditions.

9.1.4. Energy required for field operations

The different implements in the repertories at the farm level were tested to evaluate the level of energy required for their daily utilization. The amount of pull force generated for moldboard and ridger plows corresponded closely to the optimum area of the power curve. The level of working intensity could be classified in the range of medium to heavy job.

The effective field capacity EFC of each field operation was calculated along with the number of working days during the rainy. Two levels of probability were used: 5 years out of 10 and 9 years out of 10.

The amount of energy delivered by the pair of oxen was evaluated using the factorial method with rh use of local coefficients. The animal energy balance was determined by taking into account the energy used for working, for walking, for liveweight losses, and for the daily maintenance.

A main output of the energy balance was the calculation of the feed ration from feed available to farmers.

This methodology will need more refinements in the future to better evaluate the information needed to build up the KBMS.

9.2. Recommendations

The first recommendation is to improve the methodology of collecting information from farmers, in particular, data on animal traction. The technology is widely used in developing countries and need more attention. The other aspects to investigate further are as follow:

- Animal farming systems

The technology has brought about significant changes to farmers' cropping systems. The level of utilization is still low as many farmers use draft animals for land preparation only. There is room for improvement by designing better equipment to carry out post-tillage field operations. Weeding is a serious problem which farmers are faced every year due to fluctuation of available family labor during the season.

The use of draft animals for fieldwork is very attractive to farmers as their utilization can generate substantial revenue. By raising the level of utilization of the draft animals, it will be possible to increase the rate of adoption of the technology. One aspect that will increase adoption of animal traction is the reduction in production costs resulting from mechanization.

- Draft animal selection

The environmental effects on working animals need to be better addressed to help farmers select the right format of draft animals and to fit the job to their pulling capacity. The stress generated by the local climate has an effect on their efficiency. The only existing recommendation is to work morning hours but farmers' working needs go beyond morning hours.

The format and the age to start working draft animals are determinant for future performance through better training. Farmers are not generally consistent on these two factors because of lack of technical information.

- Feeding system

Meeting the feeding requirements of their working animals at the beginning of the rainy season is a serious concern for farmers. The state of the art shows that agro-ecosystem zones offer very limited possibilities. It is important to focus on what is feasible in farmers' conditions. More research is needed.

- Harnessing system

Different trials showed that draft animals are wasting considerable amount of energy in relation to the high level of pulling intensity. Regular field working conditions will require pull force around the optimum power output level. One aspect to consider in the future is the improvement of the yoking system to have animals pull in a more comfortable and efficient way. The loss of the willingness to pull by the ox-team does help the farmer or improve the quality of the fieldwork.

- Implement selection and design

The major challenge is to fit the job to the working animals. This can be done, by designing and adapting implements to better fit the working conditions. This must be done in consideration with the ergonomic factors involved in the implement design to account for the animal format, the soil characteristics, and the user.

- Learning period

It is crucial to find ways to reduce the learning period. Farmers do not see the benefits of using animal traction because they do not master the technology. The lack of skills shows that most of the advantages of using animal traction are offset. One alternative is to reinforce the capacity of the farmers' organization to train farmers on a regular basis. The classic approach of regional training centers depends to a large extent on external funding sources.

- Instrumentation

The evaluation of work output and energy expenditure still requires highly sophisticated instrumentation. The factorial method developed by Lawrence from treadmill and laboratory measurements is almost the only technique used. It should be possible to develop portable inexpensive sensors to measure integrated parameters used in the energy evaluation: draft, speed, heat, temperature, and heart rates. The instrumentation developed by the French research institution CEEMAT needs to be completed with a computer software capable of analyzing data recorded in the data logger and carrying out basic power and energy calculations.

- Computer programs

More computer programs dealing with animal traction management need to be developed. This will enable information to be shared by different users through a common database and to better simulate conditions of utilization. The present expert system is expected to be improved, to be validated, and to be extended to other regions in Senegal, and to the West African region.

APPENDIX A

APPENDIX A1

ANIMAL TRACTION QUESTIONNAIRE

Objectives

As part of the methodology, the animal traction questionnaire is conducted at the household level in order to evaluate the type and number of farm equipment available to farmers. This survey must be completed before any draft and other energy evaluation is performed. The main focus of the questionnaire deals with different technical aspects related to the utilization of animal drawn-equipment at the household level.

The objectives of this survey are:

1. To identify the types of equipment actually involved in field operations for which more detailed investigations are needed to determine power requirements.

2. To evaluate the learning process for animal traction use by correlating performance at the farm level against years of experience.

Methodology

The target group include farmers equipped with and using animal traction implements. The enumerator for this survey must undergo technical training in identifying the different pieces of equipment and their use by farmers.

The questionnaire addresses a limited number of variables:

1. **Agro-ecosystem zone**: There exists five agro-ecosystem zones in the area of study and farmers located in two of them are considered effective animal traction users.

2. **Location**: By location it is understood villages within the identified agro-ecosystem zone.

3. **Household**: Identification of the chief of the household.

4. **Number of family workers**: number of persons belonging to the household and carrying out field activities (labor force).

5. **Equipment type**: equipment must be identified properly. A variety of farm implements are used by farmers. The most common items are:

. Moldboard plow UCF 10"
. Multipurpose beam ARARA

. Multipurpose beam SINE
. Ridger EMCOT
. Seeder SUPER ECO
. Transport cart

6. **Field operation**: this variable relates to the piece of equipment and its use in the field for land preparation, weeding, groundnuts lifting.

7. **Working tools**: this variable is typical of the multipurpose tool bar, which can be equipped with moldboards, ridgers or cultivator tines.

8. **Traction mode and age of the animal(s)**: Three species are used: donkey, horse and cattle as source of energy.

9. **Yoke type**: in relation to the field operations, the activity and the species, yokes are designed to provide efficient transfer of energy from the animal to the implement. The type will be described by its name and length.

10. **Acquisition of the equipment**: information is collected as regard to the Date of acquisition, Mode (credit, cash payment, gift), State (new, used), Price if bought.

11. **Origin**: farmers use equipment of different trade names (locally made or imported).

12. **Management**: what is the status of the equipment at the household level: does the farmer own the equipment? Is he co-owner with a neighbor? Is he borrowing, renting, long term leasing?

13. **Actual condition of the equipment**: Is the equipment in good condition (working parts must be checked), does it need repair and maintenance ? Should it be discarded ?, ...

14. **Repair and maintenance**: what repair has been performed and at what cost? Who took care of the maintenance?

15. **Observations**: important information coming up during the survey

Table A1: ANIMAL DRAWN EQUIPMENT QUESTIONNAIRE

1. Agro-ecosystem zone:
2. Location:
3. Household:
4. Number of family workers:

	1	2	3	4	5	6	7	8
5. Type								
6. Field operations . Land preparation . Seeding . Cultivating . Harvesting								
7. Working Components . Moldboard . Ridger . Tines . Lifter								
8. Animal age . Cattle . Donkey . Horse								
9. Yoke dimension . Head . Neck								
Observations								

(Table A1 continued)

10.**Acquisition**: . **Date** . **Mode** . **State 1 = new** **2 = used** . **Price**								
11.**Origin/Manufacturer** . **SISCOMA** . **SISMAR** . **Blacksmith** . **Imported**								
12.**Management** . **Owner** . **Co-Owner** . **Borrower** . **Others**								
13.**Actual cond.** . **Good** . **Medium** . **Bad**								
14.**Repair/maintenance**								
Observations								

APPENDIX A2

Draft Animal Follow Up Guidelines

I. Draft animals utilization

1. Utilization Timeframe (hours per day)

1.1. Field work

- Tillage
- Seeding
- Weeding
- Harvesting

1.2. Transport

- Destination
- Distance
- Rate (paid or non-paid)

1.3. Custom work

- Number of days
- Type of field work
- Site
- Rental rate

2. Draft animal feeding system

2.1. Dry season

- Types of feed
- Daily Quantity (average)
- Origin

2.2. Rainy season

- Types of feed
- Daily Quantity (average)
- Supplement (type, quantity)
- Origin (For natural grazing, sample the type of grasses and hays for identification and evaluate its proportion in the feeding system),

II. <u>Health</u>

1. Health Problems and diseases

- Dry season
- Rainy season

2. Manifestations / Identification / Frequency

3. Length of immobilization

4. Care

5. Housing

III. ADDITIONAL OBSERVATIONS

APPENDIX B

APPENDIX B

SUMMARY OF THE DIFFERENT MAXIMUM PERFORMANCE TRIALS

Table B1: Maximum draft trial (G1 P1)

DATE :	June 25,1996	
LOCATION :	Djibelor Station	
ZONE :	1	
DRAFT ANIMAL NAME :	Etoile	Double Les
SIDE :	Right	Left
LENGTH (cm) :	85.00	82.00
CIRCUMFERENCE (cm) :	166.00	162.00
WEIGHT (kg) :	357.00	326.00
AGE (yrs) :	8.00	7.50
EXPERIENCE (yrs) :	5.00	5.00
Path Length (m) :	200.00	

Avg. Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.28	0.00	0.00	0.00
259.67	46.89	11.37	18.06	196.20	294.30	1.17	303.81	0.04	0.05
517.58	50.82	9.44	9.83	392.40	588.60	1.14	590.04	0.08	0.09
920.37	62.98	10.80	6.85	784.80	981.00	1.09	1003.21	0.14	0.15
1086.95	91.53	16.18	8.44	981.00	1275.30	1.02	1108.69	0.16	0.17
1270.49	83.78	13.08	6.59	1079.10	1471.50	0.92	1168.85	0.19	0.17
1408.32	65.92	9.83	4.68	1275.30	1569.60	0.90	1267.49	0.21	0.19
1531.44	66.51	9.05	4.34	1373.40	1667.70	0.75	1148.58	0.23	0.17
1866.84	155.59	27.08	8.33	1667.70	2452.50	0.53	989.43	0.28	0.15
2138.09	145.97	23.37	6.83	1962.00	2452.50	0.49	1047.66	0.32	0.16
2344.59	68.67	21.72	2.93	2256.30	2452.50	0.34	797.16	0.35	0.12
2777.01	351.39	97.46	12.65	2452.50	3433.50	0.34	944.19	0.41	0.14
3531.60	-	-	-	3531.60	3531.60	0.00	0.00	0.53	0.00

Table B2: Maximum draft trial (G1 P2)

DATE :	June 27,1996	
LOCATION :	Bougoutoub	
ZONE :	4	
DRAFT ANIMAL NAME :	Bahanga	Bolong
SIDE :	Right	Left
LENGTH (cm) :	118.00	99.00
CIRCUMFERENCE (cm) :	181.00	163.00
WEIGHT (kg) :	400.00	290.00
AGE (yrs) :	12.00	9.00
EXPERIENCE (yrs) :	9.00	5.00
Path Length (m) :	100.00	

Avg.Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.33	0.00	0.00	0.00
999.44	99.47	24.87	9.95	882.90	1177.20	0.61	609.66	0.14	0.11
1442.07	76.62	17.13	5.31	1275.30	1569.60	0.49	706.61	0.21	0.13
1680.75	123.41	31.86	7.34	1471.50	1962.00	0.38	638.68	0.24	0.12
2060.10	-	-	-	2060.10	2060.10	0.00	0.00	0.30	0.00

Table B3: Maximum Draft trial (G1 P3)

DATE :	June 28,1996	
LOCATION :	Suel	
ZONE :	5.00	
DRAFT ANIMAL NAME :	Amerique	Gaston
SIDE :	Right	Left
LENGTH (cm) :	97.00	105.00
CIRCUMFERENCE (cm) :	153.00	170.00
WEIGHT (kg) :	272.00	376.00
AGE (yrs) :	13.00	12.00
EXPERIENCE (yrs) :	7.00	8.00
Path Length (m) :	100.00	

Avg.Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.39	0.00	0.00	0.00
1017.79	84.07	29.72	8.57	882.90	1177.20	1.19	1211.17	0.16	0.19
1195.05	100.94	30.44	8.44	1079.10	1471.50	1.16	1386.26	0.19	0.22
1618.65	90.45	28.60	5.59	1471.50	1765.80	1.11	1796.70	0.25	0.28
2011.05	100.55	31.80	5.00	1863.90	2158.20	0.81	1628.95	0.32	0.26
2452.50	92.51	30.84	3.77	2354.40	2648.70	0.53	1299.83	0.39	0.20
2844.90	120.17	60.09	4.22	2648.70	2943.00	0.34	967.27	0.45	0.15
3400.00	-	-	-	3400.00	3400.00	0.00	0.00	0.53	0.00

Table B4: Maximum draft trial (G2 P1)

DATE :	June 28,1996	
LOCATION :	Kagnarou	
ZONE :	5	
DRAFT ANIMAL NAME :	Balla	Kumukor
SIDE :	Right	Left
LENGTH (cm) :	93.00	95.00
CIRCUMFERENCE (cm) :	149.00	159.00
WEIGHT (kg) :	250.00	285.00
AGE (yrs) :	8.00	7.00
EXPERIENCE (yrs) :	5.00	2.00
Path Length (m) :	100.00	

Avg. Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.00	0.00	0.00	0.00
928.71	60.63	15.65	6.18	784.80	981.00	0.88	817.27	0.18	0.16
1379.19	71.12	17.25	5.16	1275.30	1471.50	0.90	1241.27	0.26	0.24
1809.95	113.89	25.47	11.61	1667.70	1962.00	0.56	1013.57	0.34	0.19
2256.30	-	-	-	2256.30	2256.30	0.00	0.00	0.43	0.00

Table B5: Maximum draft trial (G2 P2)

DATE :	June 27,1996	
LOCATION :	Bougoutoub	
ZONE :	4	
DRAFT ANIMAL NAME :	Afrique	Senghor
SIDE :	Right	Left
LENGTH (cm) :	96.00	92.00
CIRCUMFERENCE (cm) :	164.00	162.00
WEIGHT (kg) :	299.00	301.00
AGE (yrs) :	7.00	8.00
EXPERIENCE (yrs) :	2.00	2.00
Path Length (m) :	100.00	

Avg.Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.33	0.00	0.00	0.00
931.95	121.55	32.48	13.04	686.70	1177.20	1.04	969.23	0.16	0.16
1409.11	75.64	22.80	5.37	1275.30	1471.50	0.91	1282.29	0.24	0.22
2013.89	202.18	49.04	10.04	1569.60	2452.50	0.35	704.86	0.34	0.12
2412.08	111.93	27.15	4.64	2158.20	2648.70	0.29	699.50	0.41	0.12
3256.00	-	-	-	3256.00	3256.00	0.00	0.00	0.54	0.00

Table B6: Maximum Draft trial (G2 P3)

DATE :	June 28,1996	
LOCATION :	Suel	
ZONE :	5.00	
DRAFT ANIMAL NAME :	Ndioley	Babou Raw
SIDE :	Right	Left
LENGTH (cm) :	95.00	93.00
CIRCUMFERENCE (cm) :	153.00	154.00
WEIGHT (kg) :	256.00	261.00
AGE (yrs) :	10.00	9.00
EXPERIENCE (yrs) :	5.00	4.00
Path Length (m) :	100.00	

Avg.Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.32	0.00	0.00	0.00
868.87	62.69	23.69	7.21	784.80	981.00	1.25	1086.09	0.17	0.21
1209.87	92.51	37.77	7.64	1079.10	1373.40	1.11	1342.95	0.24	0.26
1471.50	65.43	21.81	4.44	1373.40	1569.60	1.09	1603.94	0.29	0.32
1970.14	93.59	27.02	4.75	1863.90	2158.20	0.75	1477.61	0.39	0.29
2452.50	69.36	34.68	2.83	2354.40	2550.60	0.42	1030.05	0.48	0.20
2950.00	-	-	-	2950.00	2950.00	0.00	0.00	0.57	0.00

Table B7: Maximum draft trial (G3 P1)

DATE :	June 27,1996	
LOCATION :	Boulandor	
ZONE :	4	
DRAFT ANIMAL NAME :	Robert	Iba Der
SIDE :	Right	Left
LENGTH (cm) :	99.00	90.00
CIRCUMFERENCE (cm) :	158.00	139.00
WEIGHT (kg) :	279.00	190.00
AGE (yrs) :	7.00	5.00
EXPERIENCE (yrs) :	3.00	2.00
Path Length (m) :	100.00	

Avg. Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
0.00	-	-	-	0.00	0.00	1.45	0.00	0.00	0.00
196.20	0.00	0.00	9.00	196.20	196.20	1.33	260.95	0.04	0.06
524.84	89.24	19.95	17.00	392.40	686.70	1.10	577.32	0.11	0.13
924.40	98.75	19.37	10.68	686.70	1079.10	1.01	933.64	0.20	0.20
1264.41	158.71	30.54	12.55	981.00	1471.50	0.57	720.71	0.27	0.16
1500.54	165.00	31.50	11.00	1200.60	1780.80	0.39	585.21	0.33	0.13
1962.00	-	-	-	1962.00	1962.00	0.00	0.00	0.43	0.00

Table B8-B9: Maximum draft trial (G3 P2, G3 P3)

	P2		P3	
DATE :	June 27,1996 (P2)		June 28,1996 (P3)	
LOCATION :	Boulandor		Kagnarou	
ZONE :	4.00		5.00	
DRAFT ANIMAL NAME :	Lena	Soulou	Bassene	Casa
SIDE :	Right	Left	Right	Left
LENGTH (cm) :	91.00	91.00	88.00	84.00
CIRCUMFERENCE (cm) :	146.00	140.00	145.00	148.00
WEIGHT (kg) :	222.00	213.00	207.00	234.00
AGE (yrs) :	4.50	4.50	6.00	5.50
EXPERIENCE (yrs) :	2.00	2.00	3.00	1.00
Path Length (m) :	100.00		100.00	

Draft N	STD N	S.E	CV %	Min N	Max N	Speed m/s	Power J/s	Draft/LW N/N	Power/LW J/s-N
(G3 P2)									
0.00	-	-	-	0.00	0.00	1.30	0.00	0.00	0.00
350.50	32.67	9.87	9.32	255.45	410.31	1.19	417.10	0.08	0.11
720.40	45.23	13.60	6.28	655.87	870.67	0.97	698.79	0.17	0.18
950.79	126.78	24.86	13.04	686.70	1177.20	0.86	817.68	0.22	0.19
1250.00	122.34	22.34	9.79	980.70	1340.77	0.65	812.50	0.29	0.19
1411.17	72.40	20.08	5.13	1275.30	1471.50	0.35	493.91	0.33	0.12
2158.20	-	-	-	2158.20	2158.20	0.00	0.00	0.51	0.00
(G3 P3)									
0.00	-	-	-	0.00	0.00	1.39	0.00	0.00	0.00
882.90	90.84	34.33	10.29	686.70	981.00	1.28	1130.11	0.20	0.26
1299.83	106.93	37.81	8.22	1079.10	1471.50	1.06	1377.81	0.30	0.32
1692.23	136.56	48.28	8.07	1471.50	1962.00	0.67	1133.79	0.39	0.26
2530.00	-	-	-	2530.00	2530.00	0.00	0.00	0.58	0.00

Table B10: Draft animals LW and CIRCUMF

Rec. #	LW (kg)	Length (cm)	CIRCUMF (cm)
1	166.00	96.00	135.00
2	173.00	90.00	135.00
3	186.00	89.00	137.00
4	186.00	94.00	138.00
5	190.00	90.00	139.00
6	207.00	88.00	145.00
7	208.00	99.00	141.00
8	212.00	95.00	144.00
9	213.00	93.00	142.00
10	213.00	91.00	140.00
11	215.00	89.00	140.00
12	222.00	91.00	146.00
13	227.00	88.00	148.00
14	228.00	91.00	148.00
15	233.00	89.00	145.00
16	233.00	95.00	148.00
17	234.00	96.00	148.00
18	234.00	84.00	148.00
19	235.00	94.00	150.00
20	238.00	90.00	140.00
21	238.00	96.00	150.00
22	240.00	93.00	149.00
23	243.00	95.00	152.00
24	244.00	98.00	150.00
25	251.00	91.00	150.00
26	254.00	92.00	150.00
27	255.00	100.00	157.00
28	256.00	95.00	153.00
29	257.00	111.00	152.00
30	261.00	93.00	154.00
31	264.00	95.00	159.00
32	265.00	100.00	152.00
33	271.00	100.00	156.00
34	271.00	102.00	156.00
35	272.00	97.00	153.00
36	272.00	94.00	151.00
37	273.00	87.00	152.00

Rec. #	LW (kg)	Length (cm)
38	273.00	100.00
39	277.00	95.00
40	278.00	101.00
41	279.00	99.00
42	282.00	95.00
43	286.00	103.00
44	290.00	99.00
45	294.00	98.00
46	297.00	103.00
47	300.00	102.00
48	300.00	99.00
49	301.00	92.00
50	304.00	96.00
51	305.00	101.00
52	306.00	103.00
53	307.00	99.00
54	311.00	97.00
55	311.00	106.00
56	322.00	104.00
57	325.00	103.00
58	326.00	82.00
59	335.00	100.00
60	337.00	100.00
61	344.00	99.00
62	346.00	97.00
63	348.00	107.00
64	357.00	85.00
65	358.00	108.00
66	364.00	105.00
67	371.00	107.00
68	376.00	105.00
69	376.00	105.00
70	379.00	108.00
71	402.00	118.00
72	442.00	114.00
73	445.00	119.00

Table B11: Regression analysis of the 18 draft oxen

LW (kg)	LENGTH (cm)	CIRCUMF (cm)	LW vs CIRCUMF		
190.00	90.00	139.00			
207.00	88.00	145.00	Constant		-467.80
213.00	91.00	140.00	Std Err of Y Est		19.48
222.00	91.00	146.00	R Squared		0.87
234.00	84.00	148.00	No. of Observations		18.00
238.00	90.00	140.00	Degrees of Freedom		16.00
256.00	95.00	153.00	X Coeff	4.78	
261.00	93.00	154.00	Std Err	0.45	
264.00	95.00	159.00			
272.00	97.00	153.00			
279.00	99.00	158.00			
290.00	99.00	163.00			
301.00	92.00	162.00			
304.00	96.00	164.00			
326.00	82.00	162.00			
344.00	99.00	172.00			
357.00	85.00	166.00			
376.00	105.00	170.00			

APPENDIX C

APPENDIX C

SUMMARY OF DATA COLLECTED DURING ON-STATION TRIALS

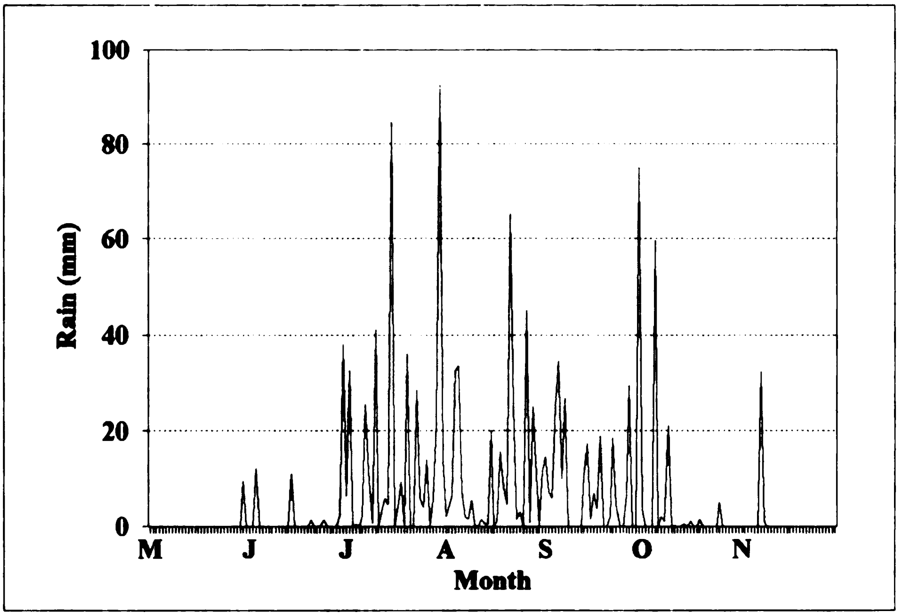


Figure C.1: Rainfall distribution at Djibelor Research Station (1996)

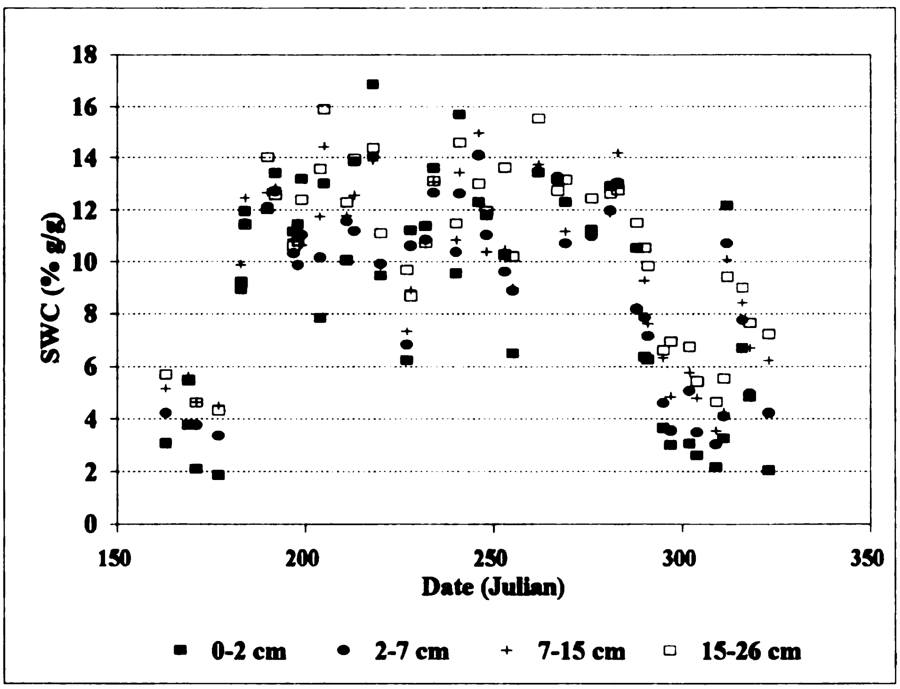


Figure C.2: Soil water content at Djibelor Research Station (trial site)

Table C1: UCF 10" Block I @ SWC-range 6 - 8 % g/g (Extract)

Implement	Plow UCF			
Width (cm)	23.00		23.50	
Depth (cm)	9.50		9.00	
Total time (s)	1366.67		840.00	
Effect. time (s)	740.00		460.00	
Efficiency (%)	54.15		54.76	
Angle of pull	22.00		22.00	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	130	120.53	160	148.35
	180	166.89	160	148.35
	150	139.08	160	148.35
	120	111.26	150	139.08
	190	176.16	170	157.62
	170	157.62	150	139.08
	210	194.71	140	129.81
	190	176.16	170	157.62
	180	166.89	180	166.89
	190	176.16	150	139.08
	180	166.89	160	148.35
	200	185.44	180	166.89
	170	157.62	180	166.89
	190	176.16	150	139.08
	180	166.89	150	139.08
	160	148.35	160	148.35
	150	139.08	170	157.62
	160	148.35	160	148.35
	180	166.89	150	139.08
	190	176.16	160	148.35
	190	176.16	170	157.62
	190	176.16	190	176.16
	210	194.71	170	157.62
	210	194.71	160	148.35
	210	194.71	170	157.62
	200	185.44	150	139.08
	160	148.35	180	166.89
	190	176.16	170	157.62
	220	203.98	170	157.62
	170	157.62	160	148.35

(Table C1 continued)

	160	148.35	170	157.62
	210	194.71	190	176.16
	160	148.35	170	157.62
	170	157.62	160	148.35
	160	148.35	170	157.62
	180	166.89	170	157.62
	200	185.44	180	166.89
	190	176.16	170	157.62
	170	157.62	180	166.89
	170	157.62	160	148.35
	150	139.08	170	157.62
	190	176.16	170	157.62
	180	166.89	160	148.35
	140	129.81	150	139.08
	180	166.89	190	176.16
	170	157.62	160	148.35
	150	139.08	180	166.89
	160	148.35	160	148.35
	170	157.62	160	148.35
	170	157.62	170	157.62
	190	176.16	170	157.62
	200	185.44	170	157.62
	190	176.16	170	157.62
	210	194.71	170	157.62
	200	185.44	160	148.35
Avg (daN)	175.71	165.88	166.00	153.91
Std dev.	31.78	19.82	11.05	10.25
CV(dec.)	0.18	0.12	0.07	0.07
Max (daN)	220.00	203.98	190.00	176.16
Min (daN)	0.00	111.26	140.00	129.81

Table C2: 'SINE 9 Block I @ SWC-range 6 - 8 % g/g (Extract)

Implement	3-tine SINE 9			
Width (cm)	50.00		51.50	
Depth (cm)	9.33		9.00	
Total time (s)	774.75		520.00	
Effect. time (s)	490.00		350.00	
Efficiency (%)	63.25		67.31	
Angle of pull	22.50		22.50	
Yoke (cm)	90.00		120.00	
Draft (kg)	Pull	Req.	Pull	Req.
	160	147.82	100	92.39
	110	101.63	170	157.06
	150	138.58	120	110.87
	140	129.34	150	138.58
	160	147.82	140	129.34
	140	129.34	130	120.10
	140	129.34	110	101.63
	130	120.10	140	129.34
	150	138.58	150	138.58
	160	147.82	110	101.63
	160	147.82	100	92.39
	140	129.34	120	110.87
	170	157.06	120	110.87
	150	138.58	100	92.39
	180	166.30	140	129.34
	130	120.10	130	120.10
	150	138.58	100	92.39
	140	129.34	130	120.10
	130	120.10	100	92.39
	140	129.34	130	120.10
	160	147.82	120	110.87
	130	120.10	130	120.10
	170	157.06	110	101.63
	150	138.58	130	120.10
	150	138.58	120	110.87
	140	129.34	100	92.39
	130	120.10	100	92.39
	150	138.58	140	129.34
	150	138.58	120	110.87
	180	166.30	120	110.87

(Table C2 continued)

	150	138.58	130	120.10
	150	138.58	110	101.63
	150	138.58	160	147.82
	140	129.34	170	157.06
	150	138.58	120	110.87
	140	129.34	100	92.39
	160	147.82	120	110.87
	160	147.82	160	147.82
	130	120.10	100	92.39
	130	120.10	110	101.63
	160	147.82	150	138.58
	150	138.58	110	101.63
	150	138.58	110	101.63
	170	157.06	140	129.34
	170	157.06	120	110.87
	150	138.58	100	92.39
	130	120.10	140	129.34
	150	138.58	150	138.58
	140	129.34	140	129.34
	170	157.06	110	101.63
	160	147.82	130	120.10
	130	120.10	160	147.82
	150	138.58	110	101.63
	160	147.82	120	110.87
	160	147.82	120	110.87
Avg (daN)	146.43	137.74	124.91	115.40
Std dev.	24.23	13.10	19.34	17.87
CV(dec.)	0.17	0.10	0.15	0.15
Max (daN)	180.00	166.30	170.00	157.06
Min (daN)	0.00	101.63	100.00	92.39

Table C3: 'ARARA Block I @ SWC-range 6 - 8 % g/g (Extract)

Implement		Ridger ARARA		
Width (cm)	23.00		22.50	
Depth (cm)	10.00		10.10	
Total time (s)	710.00		480.00	
Effect. time (s)	390.00		340.00	
Efficiency (%)	54.93		70.83	
Angle of pull	22.00		22.00	
Yoke (cm)	90.00		120.00	
Draft (kg)	Pull	Req.	Pull	Req.
	120	111.26	130	120.53
	120	111.26	170	157.62
	130	120.53	140	129.81
	100	92.72	120	111.26
	100	92.72	110	101.99
	120	111.26	110	101.99
	140	129.81	120	111.26
	100	92.72	140	129.81
	130	120.53	130	120.53
	110	101.99	120	111.26
	140	129.81	100	92.72
	130	120.53	120	111.26
	120	111.26	130	120.53
	150	139.08	140	129.81
	120	111.26	180	166.89
	100	92.72	160	148.35
	110	101.99	170	157.62
	130	120.53	120	111.26
	160	148.35	170	157.62
	110	101.99	130	120.53
	150	139.08	160	148.35
	130	120.53	160	148.35
	140	129.81	120	111.26
	150	139.08	130	120.53
	150	139.08	130	120.53
	130	120.53	150	139.08
	150	139.08	170	157.62
	160	148.35	130	120.53
	150	139.08	150	139.08
	130	120.53	140	129.81

(Table C3 continued)

	100	92.72	150	139.08
	120	111.26	170	157.62
	100	92.72	140	129.81
	150	139.08	130	120.53
	130	120.53	110	101.99
	110	101.99	140	129.81
	130	120.53	110	101.99
	130	120.53	140	129.81
	130	120.53	150	139.08
	120	111.26	140	129.81
	140	129.81	130	120.53
	170	157.62	140	129.81
	110	101.99	160	148.35
	130	120.53	110	101.99
	160	148.35	140	129.81
	160	148.35	160	148.35
	110	101.99	130	120.53
	150	139.08	160	148.35
	120	111.26	150	139.08
	130	120.53	120	111.26
	120	111.26	180	166.89
	180	166.89	160	148.35
	120	111.26	130	120.53
	150	139.08	110	101.99
	110	101.99	100	92.72
Avg (daN)	127.86	120.70	138.36	128.29
Std dev.	25.89	18.07	20.61	19.11
CV(dec.)	0.20	0.15	0.15	0.15
Max (daN)	180.00	166.89	180.00	166.89
Min (daN)	0.00	92.72	100.00	92.72

Table C4: 'UCF 10" Block II @ SWC-range 8- 10 % g/g (Extract)

Implement	Plow UCF			
Width (cm)	23.43		24.44	
Depth (cm)	12.11		9.33	
Total time (s)	2050.00		1033.00	
Effect. time (s)	1374.00		710.00	
Efficiency (%)	67.02		68.73	
Angle of pull	22.50		22.50	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	160.00	147.82	120.00	110.87
	160.00	147.82	150.00	138.58
	150.00	138.58	160.00	147.82
	170.00	157.06	170.00	157.06
	150.00	138.58	160.00	147.82
	160.00	147.82	150.00	138.58
	150.00	138.58	160.00	147.82
	150.00	138.58	160.00	147.82
	150.00	138.58	140.00	129.34
	150.00	138.58	140.00	129.34
	160.00	147.82	150.00	138.58
	200.00	184.78	140.00	129.34
	150.00	138.58	160.00	147.82
	150.00	138.58	150.00	138.58
	140.00	129.34	150.00	138.58
	150.00	138.58	150.00	138.58
	140.00	129.34	130.00	120.10
	150.00	138.58	150.00	138.58
	160.00	147.82	150.00	138.58
	170.00	157.06	150.00	138.58
	150.00	138.58	150.00	138.58
	150.00	138.58	160.00	147.82
	140.00	129.34	160.00	147.82
	160.00	147.82	140.00	129.34
	150.00	138.58	140.00	129.34
	180.00	166.30	140.00	129.34
	160.00	147.82	160.00	147.82
	180.00	166.30	140.00	129.34
	170.00	157.06	150.00	138.58
	150.00	138.58	130.00	120.10

(Table C4 continued)

	160.00	147.82	150.00	138.58
	160.00	147.82	150.00	138.58
	180.00	166.30	140.00	129.34
	160.00	147.82	150.00	138.58
	160.00	147.82	130.00	120.10
	160.00	147.82	160.00	147.82
	170.00	157.06	150.00	138.58
	180.00	166.30	160.00	147.82
	160.00	147.82	160.00	147.82
	160.00	147.82	130.00	120.10
	160.00	147.82	120.00	110.87
	160.00	147.82	120.00	110.87
	150.00	138.58	140.00	129.34
	160.00	147.82	150.00	138.58
	180.00	166.30	130.00	120.10
	170.00	157.06	130.00	120.10
	160.00	147.82	140.00	129.34
	170.00	157.06	150.00	138.58
	160.00	147.82	150.00	138.58
	170.00	157.06	140.00	129.34
	160.00	147.82	140.00	129.34
	160.00	147.82	150.00	138.58
	170.00	157.06	130.00	120.10
	150.00	138.58	150.00	138.58
	160.00	147.82	150.00	138.58
	180.00	166.30	140.00	129.34
	160.00	147.82	160.00	147.82
Avg (daN)	153.22	141.56	145.52	134.44
Std dev.	19.60	18.11	11.82	10.92
CV (%)	12.79	12.79	8.12	8.12
Max (daN)	200	184.78	170.00	157.06
Min (daN)	90	83.15	120.00	110.87

Table C5: 'SINE 9 Block II @ SWC-range 8- 10 % g/g (Extract)

Implement	Cultivator HS			
Width (cm)	54.50		52.00	
Depth (cm)	10.25		9.00	
Total time (s)	1342.00		954.00	
Effective time (s)	956.00		916.00	
Efficiency (%)	71.24		96.02	
Angle of pull	22.50		22.50	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	140.00	129.34	100.00	92.39
	130.00	120.10	80.00	73.91
	150.00	138.58	100.00	92.39
	140.00	129.34	110.00	73.91
	140.00	129.34	100.00	92.39
	140.00	129.34	90.00	83.15
	150.00	138.58	100.00	83.15
	140.00	129.34	100.00	92.39
	150.00	138.58	110.00	73.91
	140.00	129.34	100.00	92.39
	140.00	129.34	90.00	83.15
	140.00	129.34	100.00	83.15
	130.00	120.10	100.00	92.39
	150.00	138.58	100.00	92.39
	100.00	92.39	100.00	92.39
	140.00	129.34	100.00	92.39
	130.00	120.10	100.00	92.39
	100.00	92.39	120.00	83.15
	150.00	138.58	100.00	92.39
	120.00	110.87	110.00	73.91
	140.00	129.34	100.00	92.39
	140.00	129.34	90.00	83.15
	100.00	92.39	100.00	92.39
	120.00	110.87	110.00	73.91
	120.00	110.87	100.00	92.39
	100.00	92.39	110.00	73.91
	110.00	101.63	100.00	92.39
	100.00	92.39	80.00	73.91
	100.00	92.39	100.00	83.15
	130.00	120.10	80.00	73.91

(Table C5 continued)

	120.00	110.87	100.00	92.39
	120.00	110.87	80.00	73.91
	100.00	92.39	100.00	92.39
	140.00	129.34	100.00	83.15
	130.00	120.10	100.00	92.39
	100.00	92.39	120.00	110.87
	120.00	110.87	120.00	110.87
	100.00	92.39	100.00	92.39
	110.00	101.63	90.00	83.15
	100.00	92.39	100.00	92.39
	90.00	83.15	100.00	92.39
	110.00	101.63	110.00	73.91
	120.00	110.87	120.00	83.15
	90.00	83.15	90.00	83.15
	100.00	92.39	100.00	92.39
	120.00	110.87	100.00	92.39
	100.00	92.39	90.00	83.15
	120.00	110.87	100.00	92.39
	110.00	101.63	100.00	92.39
	110.00	101.63	100.00	92.39
	110.00	101.63	100.00	92.39
Avg (daN)	111.91	103.40	100.00	87.32
Std dev.	18.98	17.53	9.29	8.64
CV (%)	16.96	16.96	9.29	9.90
Max (daN)	150.00	138.58	120.00	110.87
Min (daN)	70.00	64.67	80.00	73.91

Table C6: ARARA Block II @ SWC-range 8- 10 % g/g (Extract)

Implement	Ridger ARARA			
Width (cm)	21.57		22.50	
Depth (cm)	11.00		11.33	
Total time (s)	1120.00		910.00	
Effective time (s)	624.00		690.00	
Efficiency (%)	55.71		75.82	
Angle of pull	22.00		22.00	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	100.00	92.72	160.00	148.35
	80.00	74.17	150.00	139.08
	90.00	83.45	170.00	157.62
	100.00	92.72	150.00	139.08
	100.00	92.72	180.00	166.89
	90.00	83.45	200.00	185.44
	120.00	111.26	200.00	185.44
	90.00	83.45	130.00	120.53
	100.00	92.72	200.00	185.44
	110.00	101.99	140.00	129.81
	120.00	111.26	150.00	139.08
	100.00	92.72	160.00	148.35
	120.00	111.26	150.00	139.08
	140.00	129.81	160.00	148.35
	100.00	92.72	150.00	139.08
	90.00	83.45	130.00	120.53
	100.00	92.72	140.00	129.81
	90.00	83.45	140.00	129.81
	90.00	83.45	150.00	139.08
	120.00	111.26	130.00	120.53
	80.00	74.17	120.00	111.26
	140.00	129.81	110.00	101.99
	150.00	139.08	130.00	120.53
	150.00	139.08	130.00	120.53
	100.00	92.72	100.00	92.72
	130.00	120.53	140.00	129.81
	150.00	139.08	140.00	129.81
	120.00	111.26	100.00	92.72
	110.00	101.99	110.00	101.99

(Table C6 continued)

	130.00	120.53	120.00	111.26
	100.00	92.72	130.00	120.53
	140.00	129.81	100.00	92.72
	130.00	120.53	110.00	101.99
	120.00	111.26	130.00	120.53
	120.00	111.26	140.00	129.81
	120.00	111.26	130.00	120.53
	110.00	101.99	140.00	129.81
	120.00	111.26	140.00	129.81
	120.00	111.26	150.00	139.08
	140.00	129.81	110.00	101.99
	130.00	120.53	120.00	111.26
	130.00	120.53	120.00	111.26
	100.00	92.72	150.00	139.08
	110.00	101.99	120.00	111.26
	130.00	120.53	140.00	129.81
	140.00	129.81	140.00	129.81
	120.00	111.26	130.00	120.53
	130.00	120.53	150.00	139.08
	130.00	120.53	120.00	111.26
	140.00	129.81	120.00	111.26
	140.00	129.81	120.00	111.26
	130.00	120.53	160.00	148.35
	100.00	92.72	140.00	129.81
	120.00	111.26	120.00	111.26
	110.00	101.99	100.00	92.72
Avg (daN)	118.50	109.87	137.64	127.61
Std dev.	17.54	16.27	23.35	21.65
CV (%)	14.80	14.80	16.97	16.97
Max (daN)	150.00	139.08	200.00	185.44
Min (daN)	80.00	74.17	100.00	92.72

Table C7: 'UCF 10" Block III @ SWC-range 10 - 13 % g/g (Extract)

Implement	Plow UCF			
Width (cm)	22.75		22.50	
Depth (cm)	11.80		12.00	
Total time (s)	2308.00		2472.00	
Effect. time (s)	1262.00		1634.00	
Efficiency (%)	54.68		66.10	
Angle of pull	22.00		22.00	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	140.00	129.81	140.00	129.81
	150.00	139.08	150.00	139.08
	150.00	139.08	150.00	139.08
	160.00	148.35	160.00	148.35
	160.00	148.35	150.00	139.08
	180.00	166.89	150.00	139.08
	190.00	176.16	140.00	129.81
	160.00	148.35	150.00	139.08
	200.00	185.44	150.00	139.08
	150.00	139.08	140.00	129.81
	160.00	148.35	150.00	139.08
	170.00	157.62	140.00	129.81
	160.00	148.35	150.00	139.08
	160.00	148.35	150.00	139.08
	150.00	139.08	140.00	129.81
	150.00	139.08	140.00	129.81
	160.00	148.35	140.00	129.81
	160.00	148.35	140.00	129.81
	150.00	139.08	140.00	129.81
	150.00	139.08	150.00	139.08
	150.00	139.08	150.00	139.08
	160.00	148.35	140.00	129.81
	150.00	139.08	170.00	157.62
	170.00	157.62	150.00	139.08
	180.00	166.89	150.00	139.08
	160.00	148.35	150.00	139.08
	200.00	185.44	150.00	139.08
	150.00	139.08	170.00	157.62
	160.00	148.35	160.00	148.35
	170.00	157.62	140.00	129.81

(Table C7 continued)

	160.00	148.35	140.00	129.81
	170.00	157.62	150.00	139.08
	160.00	148.35	140.00	129.81
	160.00	148.35	150.00	139.08
	120.00	111.26	150.00	139.08
	130.00	120.53	140.00	129.81
	150.00	139.08	150.00	139.08
	160.00	148.35	130.00	120.53
	170.00	157.62	140.00	129.81
	150.00	139.08	150.00	139.08
	170.00	157.62	150.00	139.08
	150.00	139.08	140.00	129.81
	170.00	157.62	150.00	139.08
	150.00	139.08	150.00	139.08
	200.00	185.44	140.00	129.81
	160.00	148.35	150.00	139.08
	150.00	139.08	160.00	148.35
	150.00	139.08	160.00	148.35
	140.00	129.81	150.00	139.08
	200.00	185.44	150.00	139.08
	180.00	166.89	160.00	148.35
	160.00	148.35	160.00	148.35
	160.00	148.35	160.00	148.35
	160.00	148.35	150.00	139.08
	160.00	148.35	170.00	157.62
	160.00	148.35	160.00	148.35
	180.00	166.89	150.00	139.08
Avg (daN)	154.72	143.45	146.67	135.99
Std dev.	15.99	14.82	8.46	7.84
CV(dec.)	9.93	9.93	5.68	5.68
Max (daN)	200.00	185.44	170.00	157.62
Min (daN)	120.00	111.26	130.00	120.53

Table C8: 'SINE 9 Block III @ SWC-range 10 - 13 % g/g (Extract)

Implement	3-tine SINE 9			
Width (cm)	52.50		52.00	
Depth (cm)	10.00		10.00	
Total time (s)	1480.00		1332.00	
Effect. time (s)	1116.00		986.00	
Efficiency (%)	75.41		74.02	
Angle of pull	22.50		22.50	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	130.00	120.10	80.00	73.91
	120.00	110.87	60.00	55.43
	140.00	129.34	70.00	64.67
	120.00	110.87	80.00	73.91
	130.00	120.10	90.00	83.15
	140.00	129.34	80.00	73.91
	140.00	129.34	90.00	83.15
	150.00	138.58	90.00	83.15
	150.00	138.58	80.00	73.91
	150.00	138.58	90.00	83.15
	130.00	120.10	90.00	83.15
	140.00	129.34	90.00	83.15
	130.00	120.10	110.00	101.63
	130.00	120.10	80.00	73.91
	120.00	110.87	100.00	92.39
	140.00	129.34	120.00	110.87
	150.00	138.58	120.00	110.87
	150.00	138.58	100.00	92.39
	140.00	129.34	110.00	101.63
	140.00	129.34	120.00	110.87
	140.00	129.34	110.00	101.63
	130.00	120.10	120.00	110.87
	150.00	138.58	110.00	101.63
	130.00	120.10	100.00	92.39
	130.00	120.10	100.00	92.39
	120.00	110.87	80.00	73.91
	120.00	110.87	100.00	92.39
	120.00	110.87	100.00	92.39
	140.00	129.34	100.00	92.39
	140.00	129.34	80.00	73.91

(Table C8 continued)

	150.00	138.58	120.00	110.87
	130.00	120.10	90.00	83.15
	140.00	129.34	80.00	73.91
	140.00	129.34	110.00	101.63
	140.00	129.34	110.00	101.63
	150.00	138.58	100.00	92.39
	140.00	129.34	110.00	101.63
	140.00	129.34	110.00	101.63
	110.00	101.63	100.00	92.39
	140.00	129.34	100.00	92.39
	200.00	184.78	80.00	73.91
	150.00	138.58	100.00	92.39
	140.00	129.34	110.00	101.63
	130.00	120.10	110.00	101.63
	140.00	129.34	110.00	101.63
	140.00	129.34	90.00	83.15
	120.00	110.87	90.00	83.15
	130.00	120.10	110.00	101.63
	120.00	110.87	80.00	73.91
	140.00	129.34	110.00	101.63
	140.00	129.34	110.00	101.63
	120.00	110.87	90.00	83.15
	130.00	120.10	100.00	92.39
	140.00	129.34	100.00	92.39
	140.00	129.34	130.00	120.10
	110.00	101.63	100.00	92.39
	110.00	101.63	90.00	83.15
Avg (daN)	130.45	120.52	97.76	90.32
Std dev.	13.22	12.21	14.53	13.43
CV(%)	9.67	9.67	14.80	14.80
Max (daN)	200.00	184.78	130.00	120.10
Min (daN)	110.00	101.63	60.00	55.43

Table C9: 'ARARA Block III @ SWC-range 10 - 13 % g/g (Extract)

Implement	Ridger ARARA			
Width (cm)	23.00		23.00	
Depth (cm)	10.33		10.00	
Total time (s)	1520.00		1238.00	
Effect. time (s)	890.00		920.00	
Efficiency (%)	58.55		74.31	
Angle of pull	22.00		22.00	
Yoke (cm)	90.00		120.00	
Draft (daN)	Pull	Req.	Pull	Req.
	90.00	83.45	100.00	92.72
	100.00	92.72	120.00	111.26
	110.00	101.99	100.00	92.72
	120.00	111.26	100.00	92.72
	100.00	92.72	100.00	92.72
	100.00	92.72	150.00	139.08
	120.00	111.26	120.00	111.26
	120.00	111.26	100.00	92.72
	150.00	139.08	90.00	83.45
	150.00	139.08	100.00	92.72
	150.00	139.08	100.00	92.72
	150.00	139.08	100.00	92.72
	100.00	92.72	100.00	92.72
	140.00	129.81	110.00	101.99
	130.00	120.53	100.00	92.72
	120.00	111.26	90.00	83.45
	110.00	101.99	100.00	92.72
	100.00	92.72	100.00	92.72
	120.00	111.26	100.00	92.72
	100.00	92.72	120.00	111.26
	110.00	101.99	90.00	83.45
	140.00	129.81	100.00	92.72
	120.00	111.26	90.00	83.45
	120.00	111.26	140.00	129.81
	100.00	92.72	100.00	92.72
	130.00	120.53	130.00	120.53
	100.00	92.72	100.00	92.72
	100.00	92.72	80.00	74.17
	120.00	111.26	100.00	92.72
	100.00	92.72	100.00	92.72

(Table C9 continued)

	130.00	120.53	100.00	92.72
	100.00	92.72	90.00	83.45
	100.00	92.72	90.00	83.45
	100.00	92.72	90.00	83.45
	100.00	92.72	90.00	83.45
	100.00	92.72	90.00	83.45
	100.00	92.72	100.00	92.72
	110.00	101.99	100.00	92.72
	100.00	92.72	100.00	92.72
	100.00	92.72	110.00	101.99
	100.00	92.72	100.00	92.72
	100.00	92.72	80.00	74.17
	100.00	92.72	100.00	92.72
	100.00	92.72	90.00	83.45
	90.00	83.45	100.00	92.72
	100.00	92.72	90.00	83.45
	90.00	83.45	100.00	92.72
	120.00	111.26	90.00	83.45
	100.00	92.72	130.00	120.53
	100.00	92.72	100.00	92.72
	100.00	92.72	90.00	83.45
	110.00	101.99	90.00	83.45
	120.00	111.26	100.00	92.72
	100.00	92.72	100.00	92.72
	100.00	92.72	90.00	83.45
	100.00	92.72	90.00	83.45
	110.00	101.99	100.00	92.72
Avg (daN)	109.88	101.98	100.00	92.72
Std dev.	16.16	14.99	13.19	12.23
CV(%)	14.60	14.60	13.10	13.10
Max (daN)	150.00	139.08	150.00	139.08
Min (daN)	90.00	83.45	80.00	74.17

Table C10: Output example of the CEEMAT data processing system (UCF plow -Bugutub rice field)

T1	T2	T3	T4	T5
#	hour:min	Second	Draft	Radar
	hr:mn	s	daN	pulse
0103.	12:36.	0000.	108.5	53.00
0103.	12:36.	002.0	131.9	138.0
0103.	12:36.	004.0	102.7	162.0
0103.	12:36.	006.0	135.8	126.0
0103.	12:36.	008.0	132.0	122.0
0103.	12:36.	010.0	131.8	099.0
0103.	12:36.	012.0	158.1	130.0
0103.	12:36.	014.0	122.3	115.0
0103.	12:36.	016.0	086.0	146.0
0103.	12:36.	018.0	152.6	147.0
0103.	12:36.	020.0	108.5	148.0
0103.	12:36.	022.0	094.4	140.0
0103.	12:36.	024.0	165.8	149.0
0103.	12:36.	026.0	117.2	134.0
0103.	12:36.	028.0	26.84	28.00
0103.	12:36.	030.0	23.49	0.000
0103.	12:36.	032.0	1.195	0.000
0103.	12:36.	034.0	2.690	0.000
0103.	12:36.	036.0	17.38	18.00
0103.	12:36.	038.0	23.62	48.00
0103.	12:36.	040.0	079.2	08.00
0103.	12:36.	042.0	099.4	48.00
0103.	12:36.	044.0	148.7	125.0
0103.	12:36.	046.0	101.0	096.0
0103.	12:36.	048.0	122.3	117.0
0103.	12:36.	050.0	097.4	143.0
0103.	12:36.	052.0	099.8	196.0
0103.	12:36.	054.0	092.0	104.0
0103.	12:36.	056.0	088.5	082.0
0103.	12:36.	058.0	085.2	102.0
0103.	12:37.	0000.	104.1	127.0
0103.	12:37.	002.0	131.8	134.0
0103.	12:37.	004.0	105.5	123.0
0103.	12:37.	006.0	136.7	181.0
0103.	12:37.	008.0	103.4	164.0

(Table C10 continued)

0103.	12:37.	010.0	132.7	139.0
0103.	12:37.	012.0	090.8	144.0
0103.	12:37.	014.0	117.8	143.0
0103.	12:37.	016.0	121.8	166.0
0103.	12:37.	018.0	096.8	138.0
0103.	12:37.	020.0	116.1	088.0
0103.	12:37.	022.0	158.8	113.0
0103.	12:37.	024.0	166.1	100.0
0103.	12:37.	026.0	169.7	40.00
0103.	12:37.	028.0	138.9	09.00
0103.	12:37.	030.0	108.3	094.0
0103.	12:37.	032.0	133.5	59.00
0103.	12:37.	034.0	146.6	144.0
0103.	12:37.	036.0	127.2	094.0
0103.	12:37.	038.0	180.8	110.0
0103.	12:37.	040.0	187.5	115.0
0103.	12:37.	042.0	142.8	092.0
0103.	12:37.	044.0	171.0	0.000
0103.	12:37.	046.0	165.7	0.000
0103.	12:37.	048.0	120.0	0.000
0103.	12:37.	050.0	130.1	0.000
0103.	12:37.	052.0	076.0	0.000
0103.	12:37.	054.0	103.1	08.00
0103.	12:37.	056.0	123.1	082.0
0103.	12:37.	058.0	115.4	073.0
0103.	12:38.	0000.	116.0	65.00
0103.	12:38.	002.0	079.0	137.0
0103.	12:38.	004.0	127.4	072.0
0103.	12:38.	006.0	130.5	090.0
0103.	12:38.	008.0	136.4	089.0
0103.	12:38.	010.0	162.0	071.0
0103.	12:38.	012.0	170.8	086.0
0103.	12:38.	014.0	134.1	085.0
0103.	12:38.	016.0	136.9	63.00
0103.	12:38.	018.0	147.9	39.00
0103.	12:38.	020.0	07.63	0.000
0103.	12:38.	022.0	3.016	0.000
0103.	12:38.	024.0	0.872	0.000
0103.	12:38.	026.0	43.77	0.000

(Table C10 continued)

0103.	12:38.	028.0	091.7	53.00
0103.	12:38.	030.0	099.9	114.0
0103.	12:38.	032.0	69.18	120.0
0103.	12:38.	034.0	090.4	114.0
0103.	12:38.	036.0	121.9	100.0
0103.	12:38.	038.0	096.5	100.0
0103.	12:38.	040.0	093.8	081.0
0103.	12:38.	042.0	106.9	45.00
0103.	12:38.	044.0	089.3	092.0
0103.	12:38.	046.0	104.8	101.0
0103.	12:38.	048.0	2.494	5.000
0103.	12:38.	050.0	10.81	0.000
0103.	12:38.	052.0	0.934	33.00
0103.	12:38.	054.0	0.414	63.00
0103.	12:38.	056.0	32.81	3.000
0103.	12:38.	058.0	078.6	132.0
0103.	12:39.	0000.	113.5	176.0
0103.	12:39.	002.0	107.1	182.0
0103.	12:39.	004.0	091.0	189.0
0103.	12:39.	006.0	075.9	183.0
0103.	12:39.	008.0	080.5	198.0
0103.	12:39.	010.0	088.5	184.0
0103.	12:39.	012.0	092.6	174.0
0103.	12:39.	014.0	110.8	167.0
0103.	12:39.	016.0	105.3	201.0
0103.	12:39.	018.0	086.7	154.0
0103.	12:39.	020.0	114.5	174.0
0103.	12:39.	022.0	092.6	191.0
0103.	12:39.	024.0	077.6	141.0
0103.	12:39.	026.0	080.8	144.0
0103.	12:39.	028.0	103.4	170.0
0103.	12:39.	030.0	109.1	169.0
0103.	12:39.	032.0	092.3	108.0
0103.	12:39.	034.0	078.6	108.0
0103.	12:39.	036.0	096.2	154.0
0103.	12:39.	038.0	089.9	121.0
0103.	12:39.	040.0	090.2	127.0
0103.	12:39.	042.0	084.3	176.0

(Table C10 continued)

0103.	12:39.	044.0	107.4	111.0
0103.	12:39.	046.0	67.62	130.0
0103.	12:39.	048.0	083.2	147.0
0103.	12:39.	050.0	071.3	140.0
0103.	12:39.	052.0	070.7	127.0
0103.	12:39.	054.0	60.34	120.0
0103.	12:39.	056.0	51.88	088.0
0103.	12:39.	058.0	65.32	084.0
0103.	12:40.	0000.	56.15	076.0
0103.	12:40.	002.0	071.2	101.0
0103.	12:40.	004.0	073.5	57.00
0103.	12:40.	006.0	30.47	31.00
0103.	12:40.	008.0	45.81	0.000

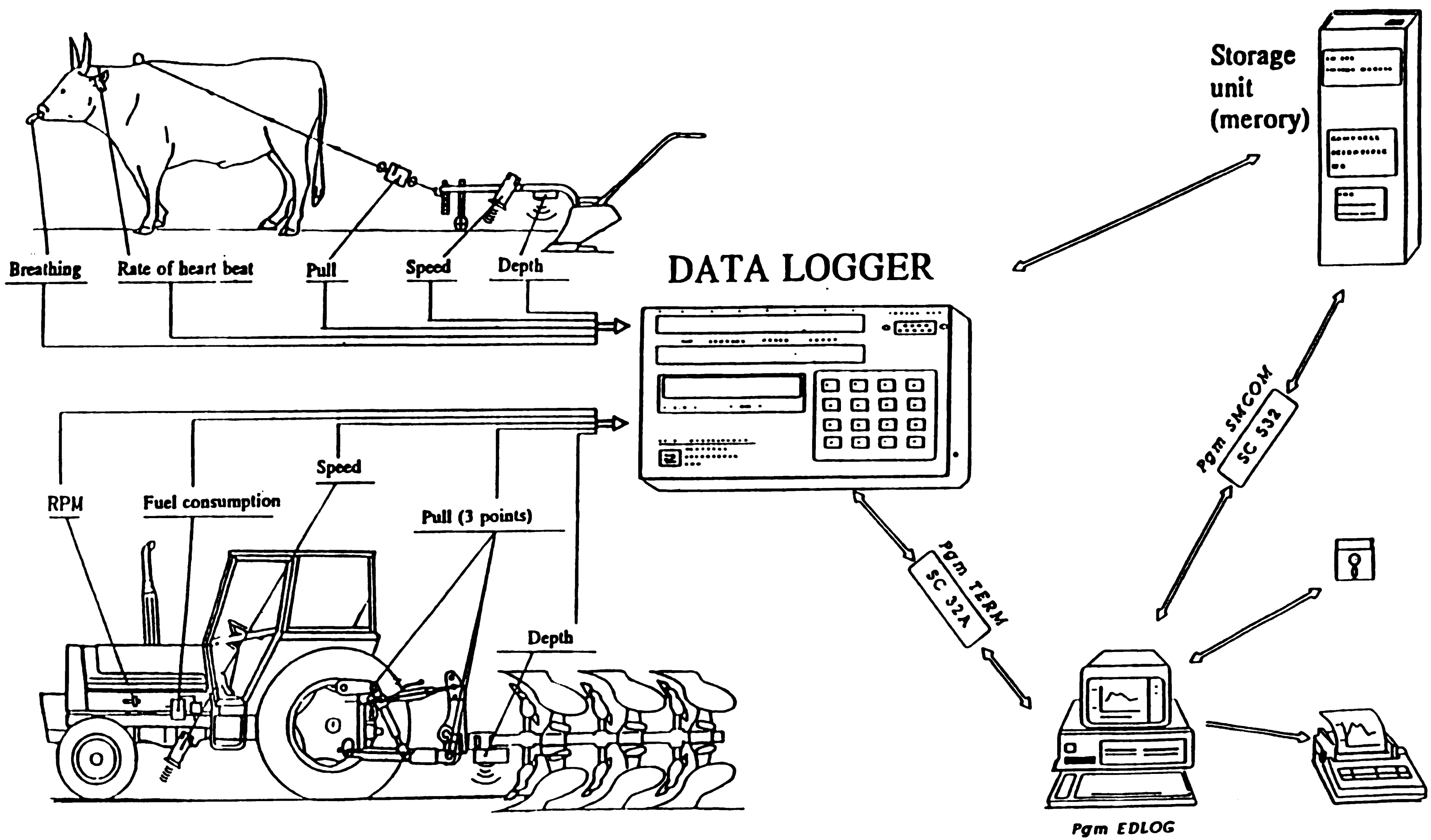


Figure C3: CEEMAT data recording and processing system

APPENDIX D

APPENDIX D

FEEDING SYSTEMS AVAILABLE IN WEST-AFRICA

Table D1: FU for maintenance FUM of working cattle

Weight (kg)	Feeding Units (FU)
200	1.95
250	2.30
300	2.60
350	2.95
400	3.25
450	3.55
500	3.85

Source: CEEMAT, 1975

Table D2: Composition of some African feeds (As-Fed Basis)

Feeds	DM	100 % DM basis			FU
		DP	P	Ca	
Green grass pasture					
Sudan (Andropogon gavanus)	18.0	6.2	0.02	0.35	0.66
Guinea (Panicum maximum)	16.6	6.7	0.27	0.45	0.57
Elephant (Pennisetum purpureum)	18.5	6.9	0.26	0.60	0.58
Digitaria	15.3	9.4	0.23	0.49	0.60
Mixed fresh shoots	17.7	18.2	0.45	0.29	0.77
Mixed young pasture	24.8	5.8	0.24	0.31	0.61
Mixed young pasture + legumes	25.6	7.5	0.10	0.87	0.72
Drier pasture (standing hay)					
Sudan #1	29.7	4.2	0.12	0.34	0.57
Sudan #2	34.6	3.5	0.15	0.39	0.63
Guinea	34.7	3.6	0.22	0.54	0.57
Digitaria	32.7	2.5	0.33	0.64	0.54
Mixed - average quality	30.8	3.2	0.18	0.30	0.48
Mixed - poor quality	39.6	2.0	0.10	0.48	0.35
Para grass (Brachiaria)	28.6	-	0.08	0.22	0.58
Cured hay - average quality	64.0	2.6	0.09	0.69	0.46
Straw					
Sudan	93.2	0.5	0.06	0.39	0.49
Guinea	95.7	0	0.08	0.48	0.49
Elephant	93.2	0	0.04	0.17	0.15
"Ivory Coast hay"	87.0	3.1	0.24	0.42	0.44
Brachiaria	94.1	0.1	0.06	0.62	0.37
Mixed (standing or cut)	96.4	0.4	0.10	0.40	0.30
Green legumes					
Stylosanthes gracilis	21.0	12.4	0.23	1.65	0.73
Stylosanthes gracilis - older	44.0	5.9	0.18	1.22	0.72
Centrosema pubescens	21.8	15.5	0.21	1.04	0.70
Centrosema pubescens - older	29.4	14.7	0.18	1.15	0.68
Legume hay					
Stylosanthes	92.8	6.1	0.17	0.85	0.54
Centrosema	87.0	12.5	0.27	1.88	0.54
Peanut hay (as-fed basis = afb)	92.1	6.3	0.13	1.19	0.40
Bean hay (Dolichos lablab)afb	93.9	14.2	1.2	0.15	0.56
Cowpea hay (Vignas sinensis)afb	89.0	7.6	0.26	0.57	0.61
Fodders					
Maize - whole young plant	21.9	4.8	0.20	0.34	0.89
Maize - same + cob forming	48.2	4.9	0.25	0.69	0.75
Maize - dry leaves+stalk+husk	93.6	0.8	-	-	0.53
Millet (Sorghum almum) - whole	27.4	16.9	0.54	0.62	0.70
Millet - whole plant - younger	15.0	4.7	0.35	0.30	0.41
Millet - same plant - older	30.9	2.7	0.28	0.23	0.42
Millet - dry leaves + stalks	85.0	1.9	0.14	0.55	0.36

Source: Watson, P.R. 1981.

Table D3: Composition of some African feeds (As-Fed Basis)

Feeds	DM	100 % DM basis			FU
		DP	P	Ca	
Grains					
Maize (Coastal West Africa)	87.0	6.61	0.34	0.03	1.05
Maize (Savanna West Africa)	92.6	7.73	0.33	0.02	1.08
Millet (Burkina Faso)	91.8	7.3	0.37	0.40	0.97
Paddy rice	87.3	4.7	0.26	0.06	0.82
Sorghum	89.9	5.9	0.29	0.02	0.92
Fonio	88.4	3.6	0.06	0.07	0.86
Brans					
Maize (traditional milling)	86.0	6.23	0.72	0.06	0.92
Millet	92.3	9.0	0.61	0.09	0.86
Rice	88.6	4.16	0.41	0.09	0.42
Sorghum	90.7	6.8	0.64	0.09	0.78
Cakes and meals					
Peanut cake	92.7	47.3	0.65	0.11	1.13
Cottonseed meal (industrial)	-	21.2	1.2	0.15	0.56
Seeds					
Cottonseed (whole)	94.4	9.6	0.49	0.11	1.05
Peanuts	90.8	14.0	0.29	0.12	1.11
Cowpeas (Vigna)	90.4	19.1	0.42	0.17	1.06
Beans (Dolichos lablab)	89.6	19.9	0.29	0.26	-
Leaves					
Banana (Tanganyika)	16.2	1.26	0.03	0.17	0.14
Manioc (Cassava)	27.3	9.4	0.51	0.92	0.64
Sahel acacia	60.8	10.1	1.90	3.05	0.46
Acacia Albida - dry leaves	92.8	7.2	0.15	0.23	0.69
Baobab - dry, West Africa	91.0	5.7	0.40	1.08	0.41
Miscellaneous					
Brewers wet meal (local)	30.7	17.6	0.41	0.26	0.80
Brewers meal dried (local)	92.3	21.6	0.33	0.03	0.87
Breadfruit (Artocarpus com.)	30.0	0.0	0.04	0.02	0.31
Mango (green/pulp) (munis)	14.5	0.16	0.01	0.02	0.18
Yam (fresh)	36.8	0.0	0.05	0.11	0.39
Yam (dried)	89.6	5.04	0.12	0.19	0.59
Cassava (manioc) - fresh	34.2	0.0	0.04	0.04	0.34
Cassava - dried	88.0	0.0	0.08	0.09	0.98
Rice husks (chaff)	92.0	0.12	0.08	0.08	0.29
Bean hulls (Vigna sinensis)	39.3	5.60	-	0.44	0.85
Cocoa puds	92.1	4.13	0.15	0.20	0.46
Maize cobs	88.3	0.0	0.03	0.01	0.40
Maize - mature cob + grain chop	93.3	5.4	0.01	0.22	0.84
Whole banana	24.1	0.68	0.02	0.01	0.26
Banana pulp	24.1	0.55	0.02	0.02	0.25
Sugar cane molasses	83.3	0.9	0.03	1.49	1.04
Nere powder (Mali)	-	-	-	-	1.00
Rice straw	92.5	0.35	0.19	0.19	0.29

Source: Watson, P.R. 1981.

Table D4: Field operation execution time

1. Tillage

Manual: 28 a 35 man-days/ha (8 hrs/day)
Animal traction: 6 a 8 ox-team-day/ha (4 a 5 hrs/day)

2. Manual seeding

Millet	20 man-day/ha
Maize	15 man-day/ha
Sorghum	15 man-day/ha
Groundnut	24 man-day/ha

3. Manual Weeding

Millet	20 man-day/ha
Maize	32 man-day/ha
Sorghum	17 man-day/ha
Groundnut	38 man-day/ha

4. Manual Harvesting

Millet	13 man-day/ha
Maize	13 man-day/ha
Sorghum	10 man-day/ha
Groundnut	18 man-day/ha

(**Source:** Le Moigne, 1981)

APPENDIX E

APPENDIX E

ONE COMPLETE SESSION OF THE EXPERT SYSTEM PROGRAM

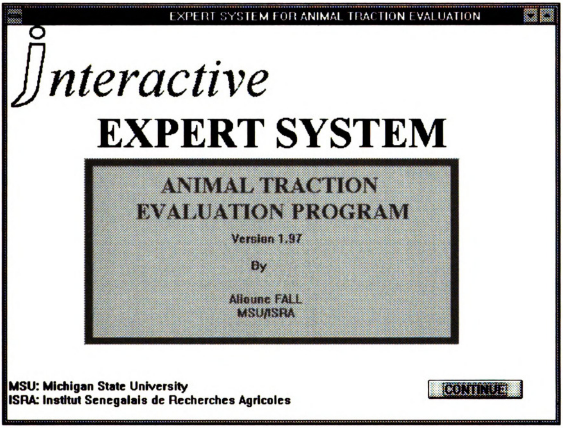


Figure E1: Screen 1

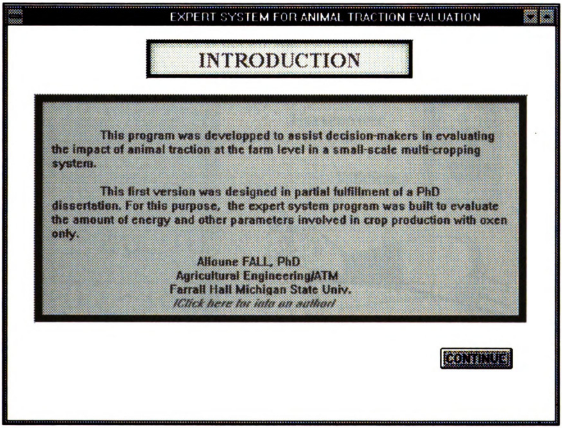


Figure E2: Screen 2

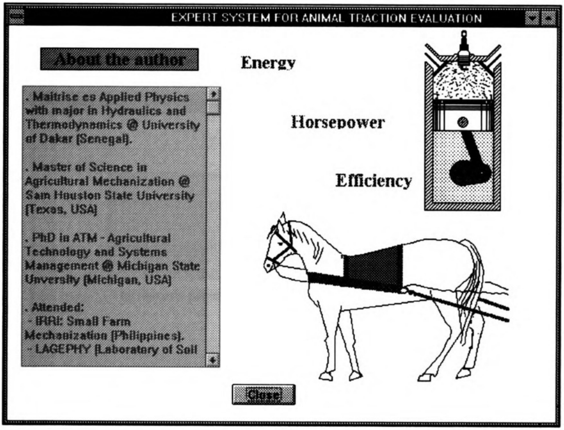


Figure E3: Screen 3

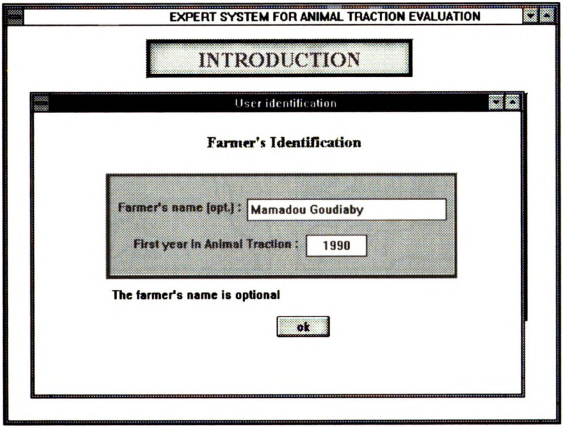


Figure E4: Screen 4

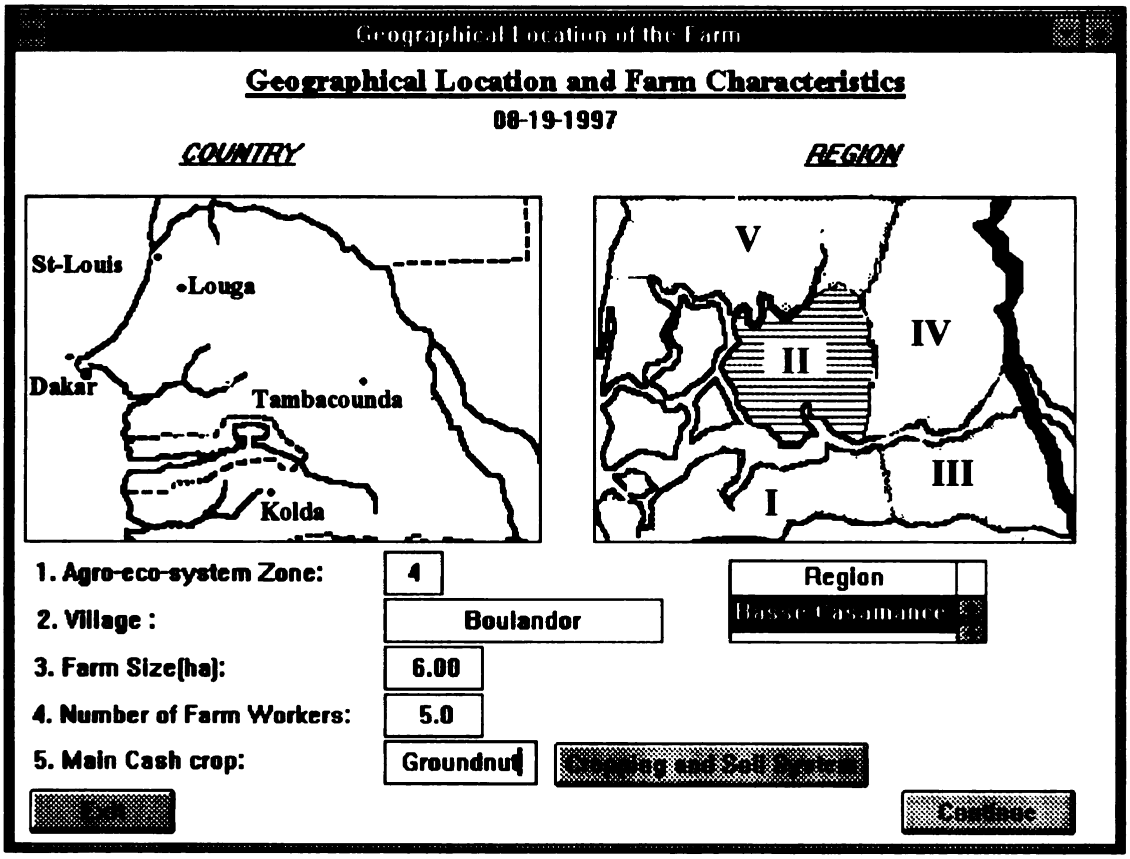


Figure E5: Screen 5

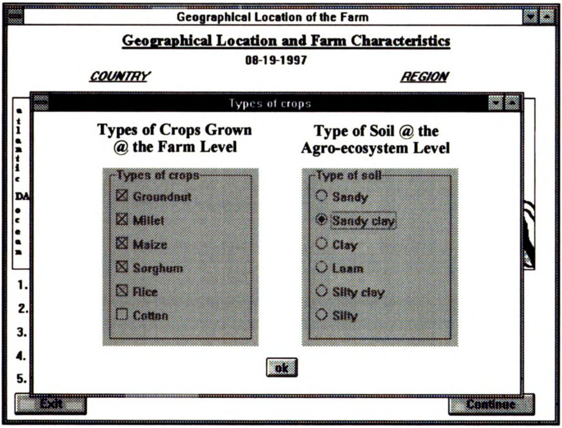


Figure E6: Screen 6

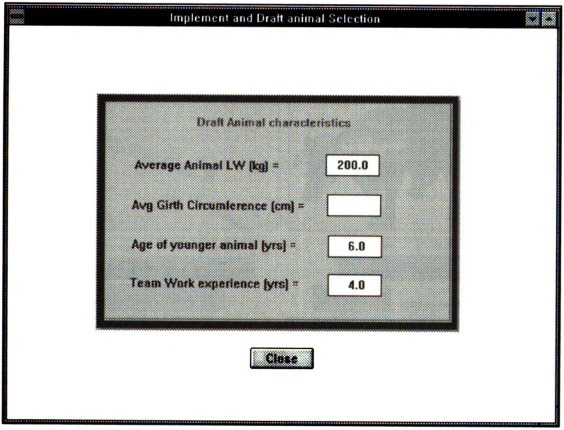


Figure E7: Screen 7

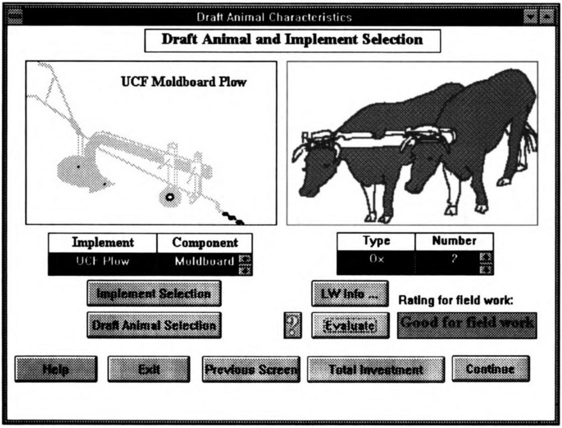


Figure E8: Screen 8

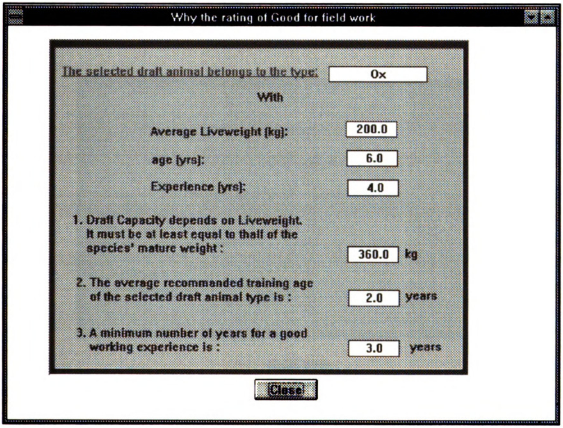


Figure E9: Screen 9

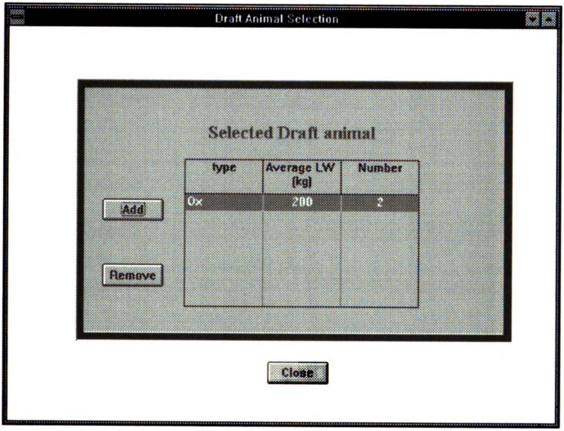


Figure E10: Screen 10

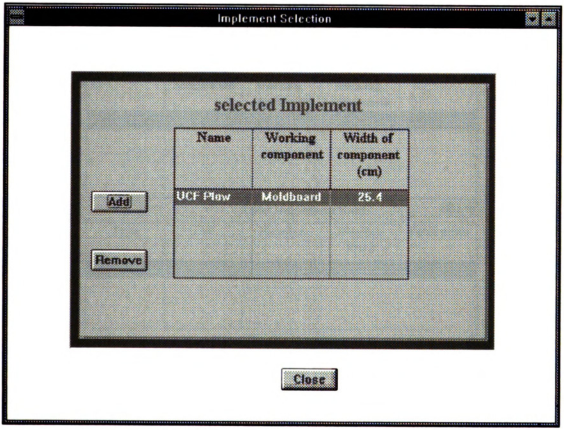


Figure E11: Screen 11

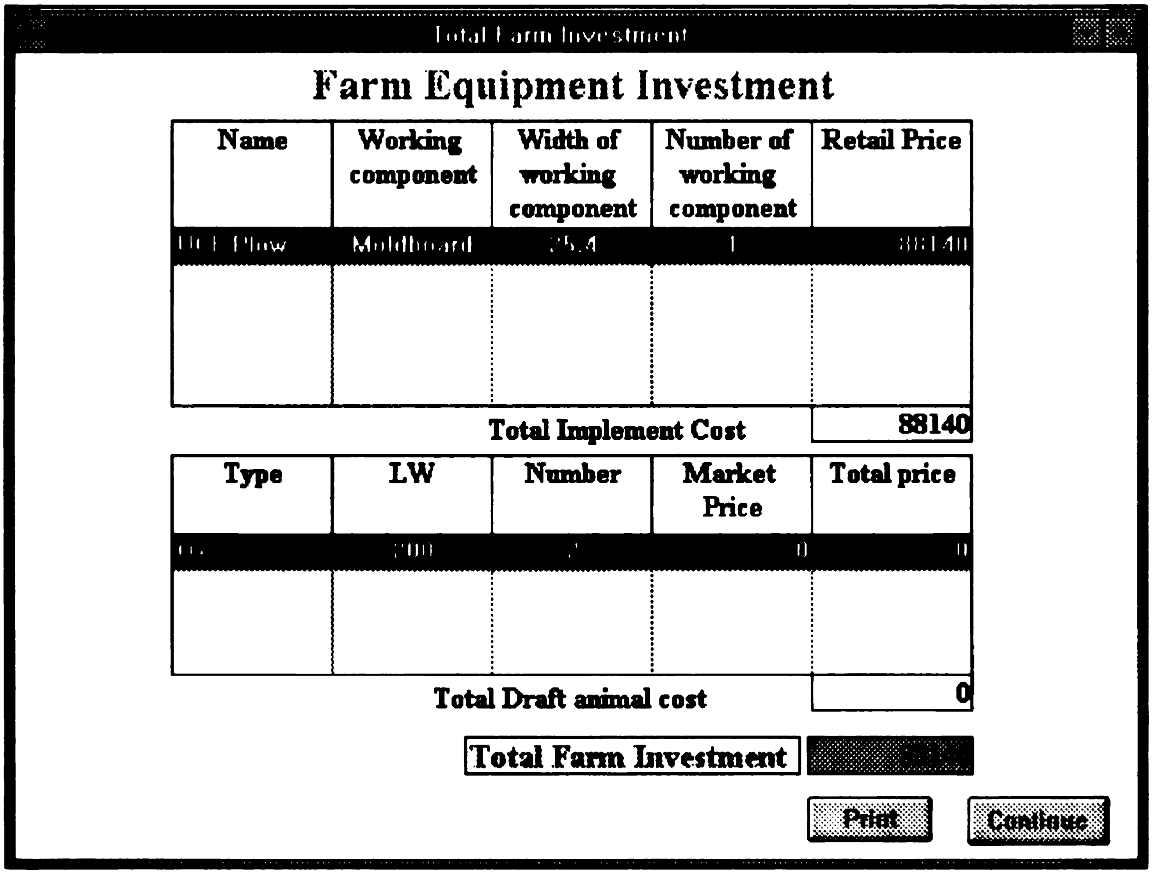


Figure E12: Screen 12

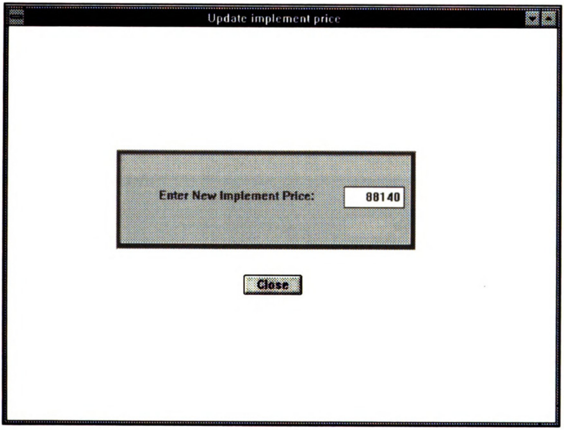
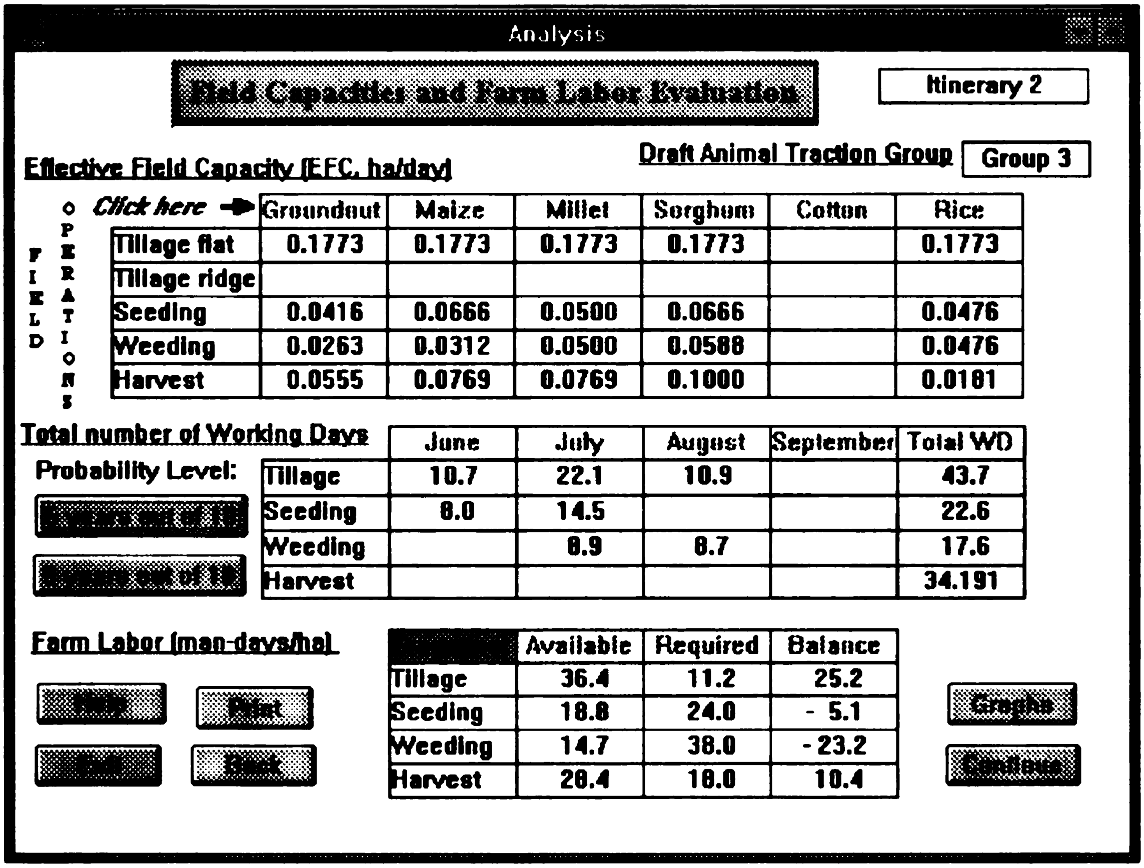


Figure E13: Screen 13

Figure E14: Screen 14



	Groundnut	Maize	Millet	Sorghum	Cotton	Rice
Tillage flat	0.1773	0.1773	0.1773	0.1773		0.1773
Tillage ridge						
Seeding	0.0416	0.0666	0.0500	0.0666		0.0476
Weeding	0.0263	0.0312	0.0500	0.0588		0.0476
Harvest	0.0555	0.0769	0.0769	0.1000		0.0181

	June	July	August	September	Total WD
Tillage	10.7	22.1	10.9		43.7
Seeding	8.0	14.5			22.6
Weeding		8.9	8.7		17.6
Harvest					34.191

	Available	Required	Balance
Tillage	36.4	11.2	25.2
Seeding	18.8	24.0	- 5.1
Weeding	14.7	38.0	- 23.2
Harvest	28.4	18.0	10.4

Figure E15: Screen 15

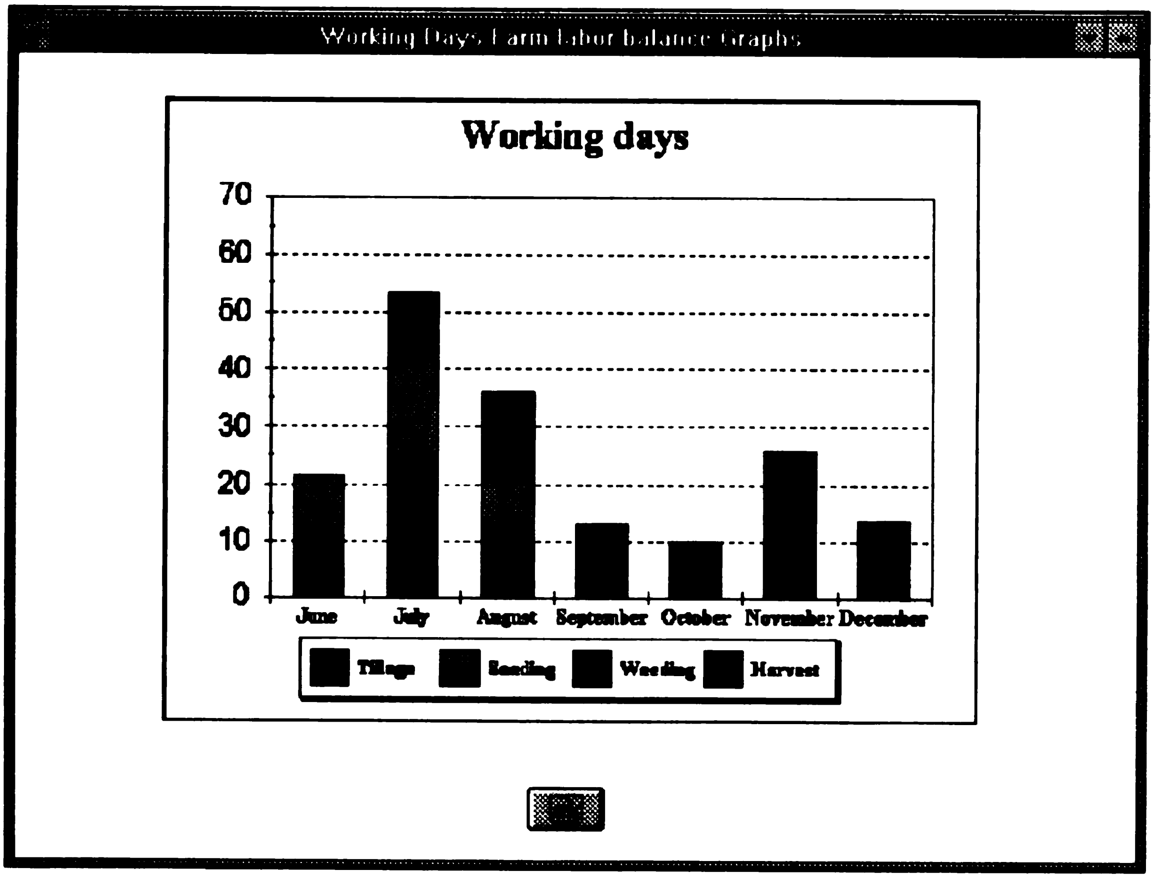
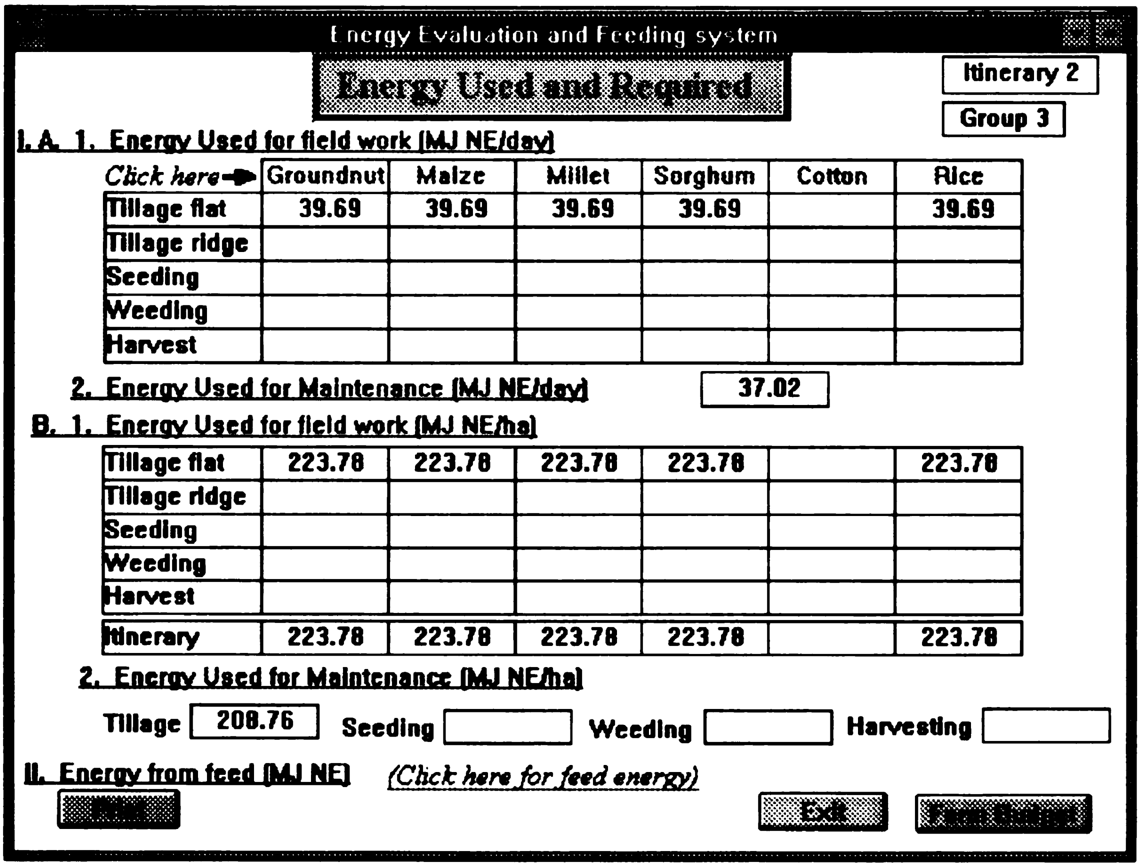


Figure E16: Screen 16



Energy Evaluation and Feeding system

Energy Used and Required

Itinerary 2

Group 3

I. A. 1. Energy Used for field work [MJ NE/day]

Click here ➡	Groundnut	Maize	Millet	Sorghum	Cotton	Rice
Tillage flat	39.69	39.69	39.69	39.69		39.69
Tillage ridge						
Seeding						
Weeding						
Harvest						

2. Energy Used for Maintenance [MJ NE/day] 37.02

B. 1. Energy Used for field work [MJ NE/ha]

Tillage flat	223.78	223.78	223.78	223.78		223.78
Tillage ridge						
Seeding						
Weeding						
Harvest						
Itinerary	223.78	223.78	223.78	223.78		223.78

2. Energy Used for Maintenance [MJ NE/ha]

Tillage 208.76 Seeding Weeding Harvesting

II. Energy from feed [MJ NE] *(Click here for feed energy)*

Exit

Figure E17: Screen 17

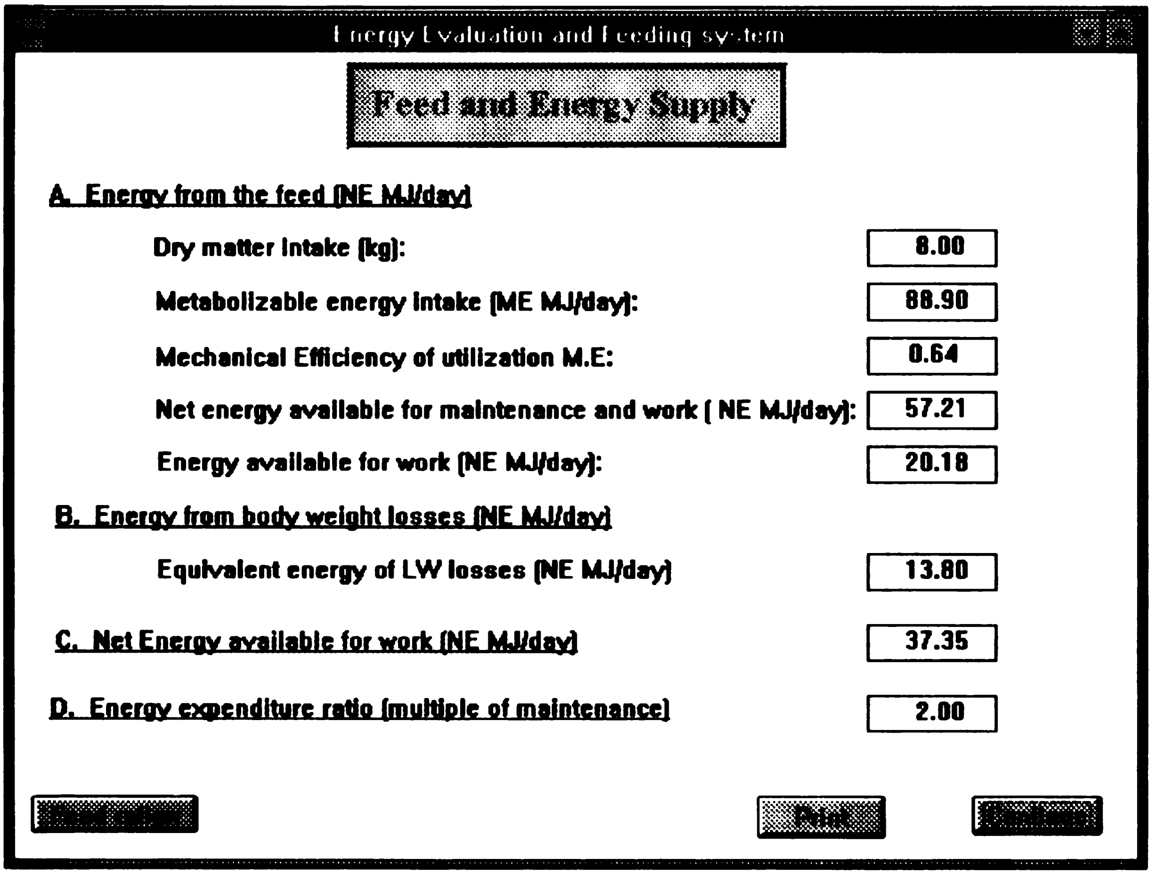


Figure E18: Screen 18

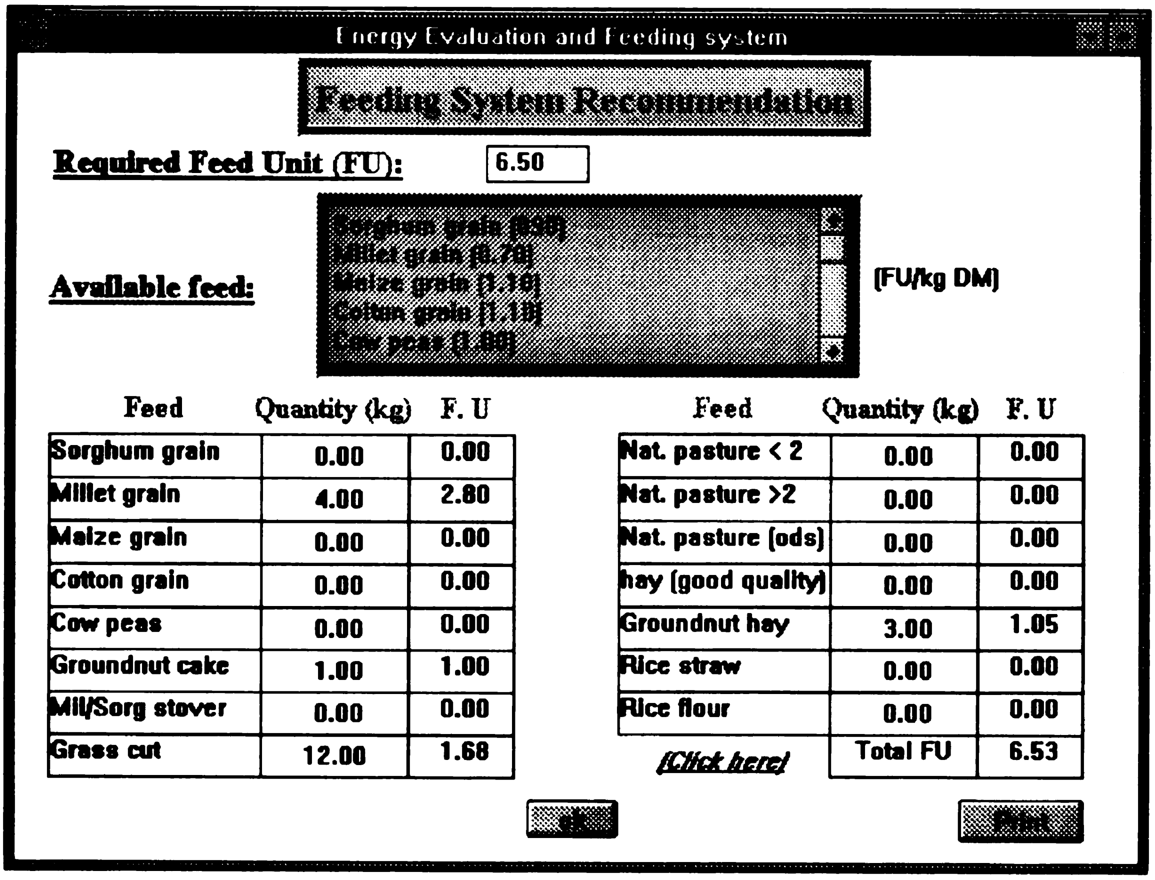


Figure E19: Screen 19

Farm Budget

Farm Budget

Itinerary 2

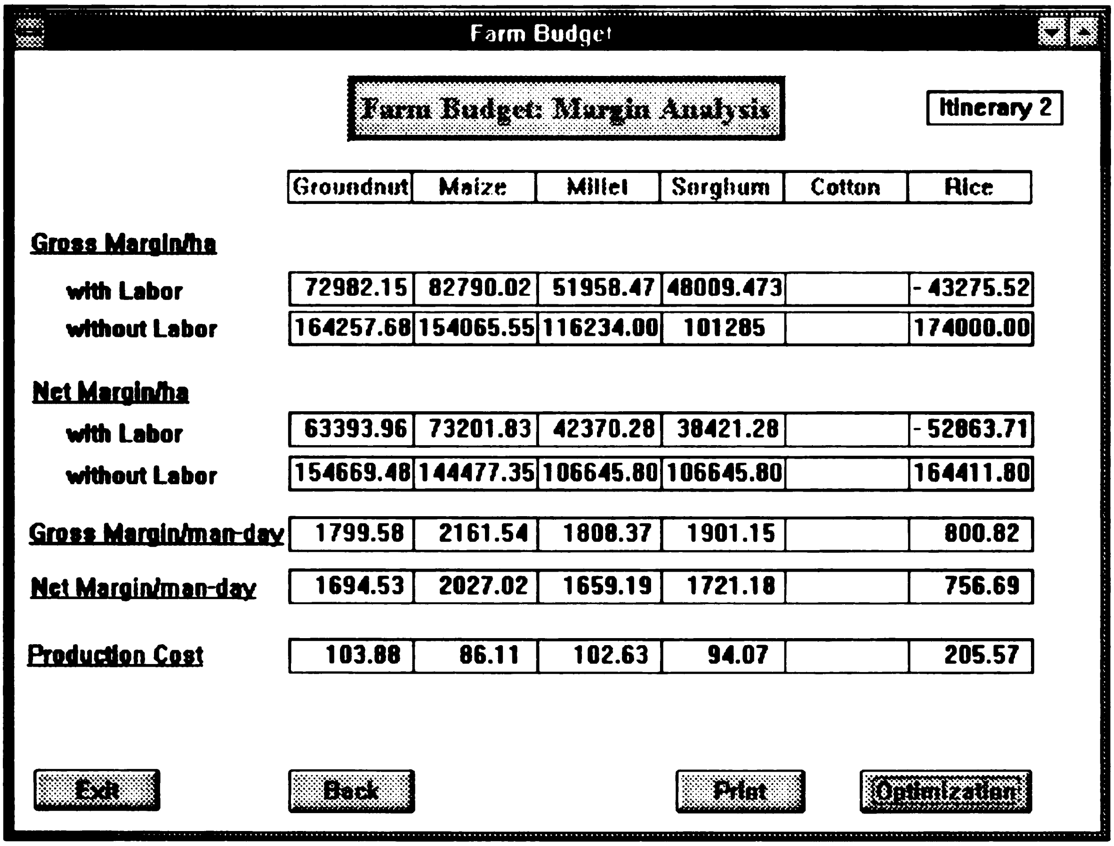
[CFA/ha]

Click here ➡	Groundnut	Maize	Millet	Sorghum	Cotton	Rice
I. Production value	172957.68	157385.55	116886.00	101925.00		185600.00
II. Variable cost						
Seeds	8700.00	3320.00	652.00	640.00		11600.00
Fertilizers	0.00	0.00	0.00	0.00		0.00
III. Farm Labor	91275.52	71275.52	64275.52	53275.52		217275.52
IV. Fixed cost						
Implements	7051.20	7051.20	7051.20	7051.20		7051.20
Draft Animals	2536.99	2536.99	2536.99	2536.99		2536.99
V. Total Cost						
With Labor	109563.71	84183.71	74515.71	63503.71		238463.71
Without Labor	18288.19	12908.19	10240.19	10228.19		21188.19

[Click here for Margin Analysis]

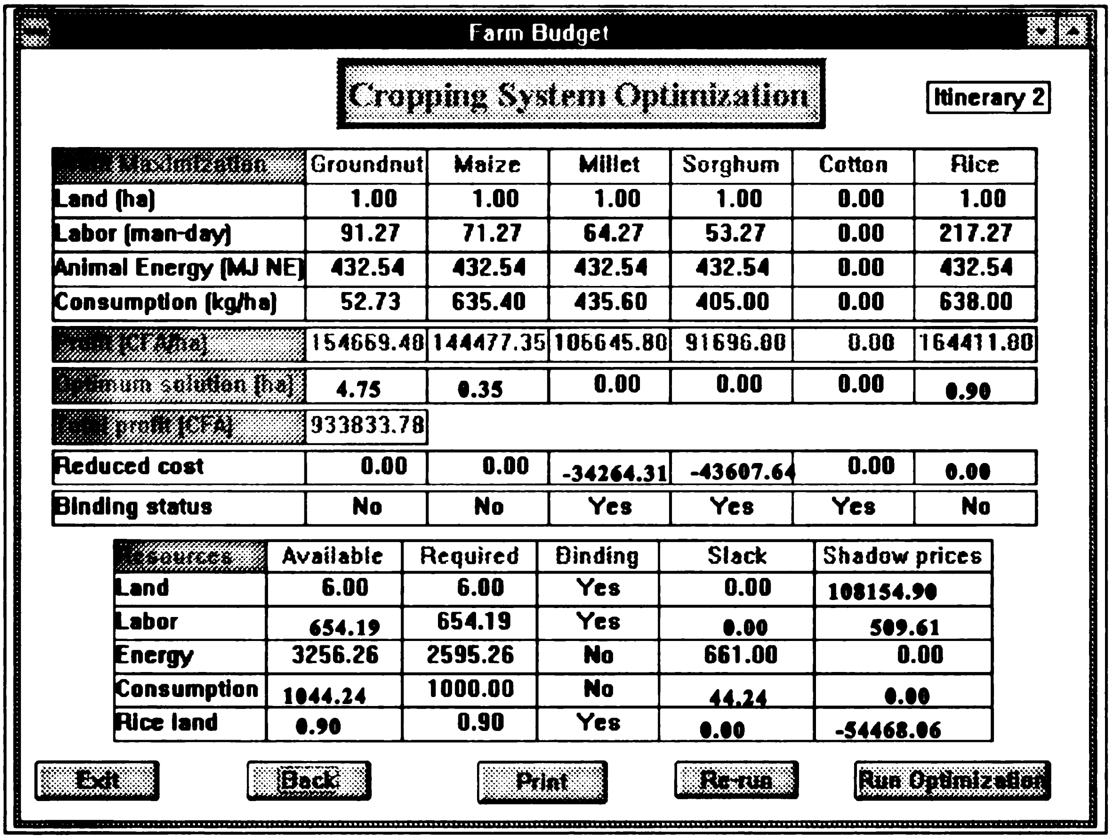
Print

Figure E20: Screen 20



	Groundnut	Maize	Millet	Sorghum	Cotton	Rice
Gross Margin/ha						
with Labor	72982.15	82790.02	51958.47	48009.473		- 43275.52
without Labor	164257.68	154065.55	116234.00	101285		174000.00
Net Margin/ha						
with Labor	63393.96	73201.83	42370.28	38421.28		- 52863.71
without Labor	154669.48	144477.35	106645.80	106645.80		164411.80
Gross Margin/man-day	1799.58	2161.54	1808.37	1901.15		800.82
Net Margin/man-day	1694.53	2027.02	1659.19	1721.18		756.69
Production Cost	103.88	86.11	102.63	94.07		205.57

Figure E21: Screen 21



Farm Budget

Cropping System Optimization

Itinerary 2

Profit Maximization	Groundnut	Maize	Millet	Sorghum	Cotton	Rice
Land (ha)	1.00	1.00	1.00	1.00	0.00	1.00
Labor (man-day)	91.27	71.27	64.27	53.27	0.00	217.27
Animal Energy (MJ NE)	432.54	432.54	432.54	432.54	0.00	432.54
Consumption (kg/ha)	52.73	635.40	435.60	405.00	0.00	638.00
Profit [CFA/ha]	154669.48	144477.35	106645.80	91696.80	0.00	164411.80
Optimum solution [ha]	4.75	0.35	0.00	0.00	0.00	0.90
Total profit [CFA]	933833.78					
Reduced cost	0.00	0.00	-34264.31	-43607.64	0.00	0.00
Binding status	No	No	Yes	Yes	Yes	No

Resources	Available	Required	Binding	Slack	Shadow prices
Land	6.00	6.00	Yes	0.00	108154.90
Labor	654.19	654.19	Yes	0.00	509.61
Energy	3256.26	2595.26	No	661.00	0.00
Consumption	1044.24	1000.00	No	44.24	0.00
Rice land	0.90	0.90	Yes	0.00	-54468.06

Exit | Back | Print | Re-run | Run Optimization

REFERENCES

REFERENCES

AID, 1977. World water for agriculture (Climate, Precipitation Probabilities and adequacies for rainfed agriculture). Agency of International Development, Washington DC. USA.

AIRIC. 1986. Field performance of maresha. Test report Nos 4, 16 and 18. AIRIC: Ethiopia.

Anderson, F.M. 1985. Draught animal power systems in Sub-Saharan Africa: their production impact and research needs. In Copland, J.W. (ed.) Draught Animal Power for production: Proceedings of an international workshop held at James Cook University, Townsville, Qld, Australia, 10-16 July 1985. Canberra: ACIAR Proceedings No. 10, 26-31.

Apathy, R.C. 1987. Factors limiting work capacity and fatigue assessment in draught animals. In: N.S.L. Srivastava and T.P. Ojha (eds). National seminar on Status of animal energy utilization. Central Institute of Agricultural Engineering: Bhopal, India.

ARC. 1980. The nutrient requirements of ruminant livestock. Slough: Commonwealth Agricultural Bureaux.

Barwell and Ayre, 1982. The harnessing of draught animals. Intermediate Technology Publications, Ardington.

Betker J. and Kutzbach H.D. 1991. The role of donkeys in Agricultural mechanization in Niger: Potential and limitations. In Fielding ad Pearson (eds), Donkeys, Mules, Horses in Tropical Agricultural Development, CTVM Edinburgh, 1991.

Campbell, J. 1990. Dipple sticks, donkeys and diesels. IRRI, Los Banos, Philippines.

CEEMAT. 1975. Manuel de culture avec traction animale: techniques rurales en Afrique. Centre d'Etude et d'Experimentation du Machinisme Agricole Tropical (CEEMAT) et Ministere de la Cooperation, Parc de Tourvoie, Antony, France. 336p.

CEEMAT. 1974. Aide memeoire du moniteur de la culture attelee. Centre d'Etude et d'Experimentation du Machinisme Agricole Tropical (CEEMAT) et Ministere de la Cooperation, Parc de Tourvoie, Antony, France.

CEEMAT/FAO. 1972. The employment of draught animals in agriculture. Rome, Italy.

CIMMYT. 1984. Report of a networkshop on draught power and animal feeding. 4-6 October 1983, Ezulwini, Swaziland. Networking workshop Report 2. CIMMYT Eastern and Southern Africa Economics Programme: Mbabane, Swaziland.

Charreau, C. and Nicou, R. 1971. L'amelioration du profil cultural dans des sols sableux et sablo-argileux de la zone Tropicale seche Ouest-Africaine et ses incidences Agronomiques (d'apres des travaux des chercheurs de l'IRAT en Afrique de l'Ouest). Agronomie Tropicale 26:903-978.

Conroy D. 1992. Advanced training techniques for oxen. Tiller's TechGuide. Tillers International. Kalamazoo Michigan, USA.

Conroy D and Rice P. 1992. Selecting and training oxen. Tiller's TechGuide. Tillers International. Kalamazoo, Michigan, USA.

Crossley, P. and Kilgour, J. 1983. Small farm mechanization for developing countries. John Wliley and Sons, Chichester, UK. 253p.

DERBAC. 1992. Rapport d'activites. Campagne agricole 1991-1992. Ziguinchor, Senegal.

Devnani, R.S. 1981. Design considerations for harnesses and yokes for draught animals. Technical bulletin n° CIAE/81/30.

Dibbits, H.J. 1993. Human and draught animal power in crop production. Past experiences and outstanding problems. In Human and Draught Animal Power in Crop production. Workshop proceedings, Harare, Zimbabwe, 18-22 January, 1993. Silsoe Research Institute-Agricultural Research Food Council. CEE-FAO, Rome 1993, Italy.

Ducreux, A. 1984. Caracterisation mecanique des sols sableux et sablo-argileux de la zone tropicale seche de l'Afrique de l'Ouest. Etude d'un prototype d'outils permettant de les travailler en periode seche. These de Docteur Ingenieur en Sciences Agronomiques-Option Pedologie. Academie de Montpellier, Universite des Sciences et Techniques du Languedoc. Montpellier, France.

Eicher, K.C. and Baker, D.C. 1982. Research on agricultural development in Sub-Saharan Africa: A critical survey. MSU International Development Paper n° 1.

Fall A. 1995. Factors affecting feed intake, energy expenditure and work output of oxen and bulls used for draught purposes in Semi-Arid West Africa. Submitted to the University of Edinburg in partial fulfillment of the requirements for PhD degree.

Fall, A. 1985. Situation actuelle de l'environnement et de l'utilisation du parc de materiels de culture attelee en Basse Casamance. Memoire de titularisation. Departement de Recherches sur les Systemes de Production et Transfert de Technologie en Milieu Rural. ISRA. (document interne).

Fall, A. 1990. Adoption et Principales contraintes a la diffusion des equipments de traction animale en Basse Casamance, Senegal. In: P. Starkey, M. Goe and A. Faye (eds), Animal traction for Agriculture Development. Wageningen: Technical Center for Agricultural and Cooperation (ACP-EEC Lome Convention).

FALL, A. 1990. Roles actuels et potentiels des forgerons traditionnels dans la maintenance du materiel agricole en Basse Casamance, Senegal. In: P. Starkey, M. Goe and A. Faye (eds), Animal traction for Agriculture Development. Wageningen: Technical Center for Agricultural and Cooperation (ACP-EEC Lome Convention).

Fall, B.N. 1981. Etude sur la situation et les perspectives de l'industrie du machinisme agricole au Senegal. Premiere consultation regionale pour le developpement de l'industrie du machinisme agricole en Afrique. ONUDI-OUA-CEA-FAO.

Falvey L.J. 1986. An introduction to working animals. MPW, Melbourne, Australia.

FAO. 1972. Manual on the Employment of draught Animals in Agriculture. CEEMAT

FAO. 1982. Report of the FAO Expert Consultation on Appropriate use of animal energy in Agriculture in Africa and in Asia. FAO. Rome.

Ffoulkes D. and Bamualim, 1989. Improving the nutrition level of draught animals using available feeds. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:134-145.

Foth, D.H. 1990. Fundamentals of soil science. 8th edition. Wiley & Sons Publisher. New York.

Goe, M.R. 1983. Current status of research on animal traction. World Animal Review, 45, 2-17

Goe, M.R. 1987. Animal traction on smallholder farms in Ethiopian highlands. University Microfilms International: Ann Arbor, Michigan.

Goe, M.R. 1990. Overcoming constraints to animal traction through a collaborative research network. In: P.H. Starkey, M.R. Goe and A. Faye (eds). Proceedings of the third WAATAN. 7-12 July 1988, Saly, Senegal. Animal Traction for Development. CTA.

Goe, M.R., and McDowell, R.E. 1980. Animal Traction: Guidelines to utilization. Cornell International Agriculture Mimeo. Ithaca, N.Y. Cornell University.

Havard, M. 1987. Le parc de materiels de culture attelee et des possibilites de sa maintenance dans le departement de Nioro: resultats d'enquetes. Document de travail 1987:3. Departement Systemes et Transfert, ISRA, Dakar, Senegal. 45p.

Havard M., Le Gal J.P. and Pirot R. 1994. Towards a decision support system integrating different kinds of knowledge to choose and manage field equipment. U.R. Genie Agronomique et Mecanisation, CIRAD-SAR, Montpellier, France.

Havard M and Le Thiec G. 1995. Animal traction in Western Africa and Madagascar. Influence of the environment on its development and use. Communication in The challenge of Animal Traction. ATNESA Network, 4-9 December 1995, Kenya. 11p.

Hillel, D. 1982. Introduction to soil physics. Academi Press, Inc. New York, USA.

Hopfen, H.J. 1960. Farm implements for Arid and Tropical Regions. Agricultural Development paper No 67. FAO, Rome, Italy.

Jaeger, K.W. 1985. Agricultural mechanization: The economics of animal traction in Burkina Faso. Doctor of Philosophy thesis submitted to IFPRI. Standford University.

Jackson, P. 1990. Introduction to Expert Systems (2nd ed.). Addison-Wesley Publishing Company, N.Y.

Jury W.A., Gardner W.R. and Gardner W.H. 1991. Soil physics. 5th Edition. Wiley & Sons. New York.

Kartiarso, M.D. and Teleni, E. 1987. Nutritional study using a treadmill at James Cook University. DAP Project Bulletin. 3:1-15.

Keith M. 1992. Training young steers. Tiller's TechGuide. Tillers International. Kalamazoo MI.

Kemp, D.C. 1987. Draught animal power: some recent and current work. World Animal Review. 63:7-14.

Lawrence, P.R. 1985. A review of the nutrient requirements of draught oxen. In Copland, J.W. (ed.) Draught Animal Power for production: Proceedings of an international workshop held at James Cook University, Townsville, Qld, Australia, 10-16 July 1985. Canberra: ACIAR Proceedings No. 10, 59-63.

Lawrence, P.R. and Pearson, A. 1985. Factors affecting the measurements of draught force, work output and power of oxen. J. agric. Sci. Camb. 105:703-714.

Lawrence, P.R. and Pearson A. 1989. Measurement of Energy Expenditure in working Animals: Methods for different conditions. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:155-165.

Lawrence, P.R. and Pearson R.A. 1993. Experimental methods in draught animal science: The need for standardization. In Human and Draught Animal Power in Crop production. Workshop proceedings, Harare, Zimbabwe, 18-22 January, 1993. Silsoe Research Institute-Agricultural Research Food Council. CEE-FAO, Rome 1993, Italy.

Lawrence, P.R. and Stibbards R.J. 1990. The energy costs of walking, carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffalo. Animal Production, 50: 29-39.

Lawrence P.R. and Zerbini E. 1993. Recent trends in research on draught animal nutrition. In Human and Draught Animal Power in Crop production. Workshop proceedings, Harare, Zimbabwe, 18-22 January, 1993. Silsoe Research Institute-Agricultural Research Food Council. CEE-FAO, Rome 1993, Italy.

Lee J. V. d., Udo H. M. J. and Brouwer B. O. 1993. Design and validation of an Animal Traction Module for a smallholder Livestock Systems Simulation Model. Agricultural Systems 43 (1993) 199-227.

Le Moigne, M. 1981. Contraintes posees par l'insertion de la mecanisation dans les unites de production agricole en zone sahelienne. Etude methodologique. CEEMAT. Paris, France.

Martin, D., and Teleni, E. 1989. Fatigue in buffaloes on different work loads. DAP Project Bulletin, 9, 2-6.

Le Moigne, M. 1984. Mission d'appui au programme Machinisme Agricole en Casamance. CEEMAT. 33p.

Le Thiec, G. 1991. Les harnachements pour bovins - "De l'Europe a l'Afrique". CIRAD-SAR, CEEMAT, Montpellier, France.

Le Thiec, G. and Havard M. 1995. Quels jougs pour les bovins de trait en Afrique Sub-Saharienne? Communication in The challenge of Animal Traction. ATNESA Network, 4-9 December 1995.

Le Thiec G and Havard M. 1995. Developing suitable yokes for draft oxen in Sub-Saharan Africa. Communication in Meeting the challenges of Animal Traction. ATNESA Network, 4-9 December 1995. 10p.

M.A.T. 1985. Special animal traction. No 91. Juillet-Septembre.

M.A.T. 1988. Activites CEEMAT 1986-87. CEEMAT. Parc de Tourvoie, Antony, France.

Matthews, M.D.P. and Pullen. 1975. Cultivation trials with ox-drawn implements using Ndama cattle in the Gambia. Tropical Agricultural Engineering Information, Report series; Overseas Department. NIAE, Silsoe, Bedford, England.

Mbengue H.M. 1986. LA mecanisation de la transformation des cereales au Senegal: Aspects techniques et nutritionnels. ISRA CNRA Bambey. DRSAEA. Dakar, Senegal.

MDR. 1986. Etude du Secteur Agricole: Plan Cerealier. Ministere du Developpement Rural, Senegal.

Monnier, J. 1983. Pour un nouveau developpement de la culture attelee en region. Lecons des experiences acquises au Senegal, Madagascar, Cote d'Ivoire. Les roles de la Recherche et de la Vulgarisation. Montpellier, France.

Morris J. 1983. The economics of small farm mechanization in Crossley P. and Kilgour J. (eds). Wiley and Sons. NY.

Montoroi J.P. 1991. Etude du comportement hydrique des sols rouge et beige du bassin versant de Djiguinoum (Basse Casamance - Campagne de mesures 1990). ORSTOM, Programme CEE DG XII, Contrat no TS2A-0216-M (CD).

Niane A. B. 1884. Etudes cartographiques et agro-pedologiques des sols de plateau de Basse Casamance. Memoire de confirmation. Cra Djibelor, ISRA. 110 pp.

Ndiame, F. 1986. Aspects economiques de l'utilisation de la traction animale bovine et de sa promotion par le biais du Credit Special du PIDAC pour le materiel agricole. ISRA. DRSAEA. Memoire de titularisation. Dakar, Senegal.

Ndiame, F. 1990. Animal traction in the Lower Casamance: Technical aspects and socio-economic implications. In: Paul Starkey and Adama Faye (eds), Animal traction for Agriculture Development. Wageningen: Technical Center for Agricultural and Cooperation (ACP-EEC Lome Convention).

Ndiame F. and Fall A. 1989. Par quelle cereale remplacer le riz ? Quelques problemes de la culture du maïs en Basse Casamance. In Economie des Filières en Regions Chaudes. Actes du X^{eme} seminaire d'economie et de sociologie. 11-15 Septembre 1989, Montpellier, France. Une publication du CIRAD.

Nicou, R. 1975. Le probleme de la prise en masse a la dessication des sols sableux et sablo-argileux de la zone tropicale seche. In Agronomie Tropicale XXX-4: 325-343.

Nolle, J. 1975. Le tracteur animal. M. A. T. 51:46-56

O'Neill, D.H., Howell P.J.L., Paice, M.E.R. and Kemp, D.C. 1987. An instrumentation system to measure the performance of draught animals at work. In: Proc. Natl. Seminar Animal Energy Utilization. 53-72. Central Institute of Agricultural Engineering: Bhopal, India.

O'Neill D, Hayton S. and Sims B. 1989. Measurement of draught animal performance. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:264-271.

Pearson R.A. and Fall A. 1993. Research on the nutrition of draught animals. In Human and draught animal power in crop production. Workshop proceedings 18-22 January, 1993, Harare Zimbabwe. Silsoe Research Institute and Agricultural Research and Food Council, CEE-FAO, Rome, Italy.

Pelissier, P. 1966. Les paysans du Senegal. Les civilisations agraires du Cayor a la Casamance. Saint Yrieux, France. ed. Fabreque.

Peret S., Pirot R. and Razaka B. 1994. In-field measurement of tillage implements performances: Practical applications in soil-tillage relations studies. Paper AG-ENG 94.

Pingall P., Bigot Y and Binswanger H. 1987. Agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. A World Bank Publication, John Hopkins Press, Baltimore, MD. USA.

Pirot, R. 1993. Automation of in-field data recording: Recent research work at CIRAD-SAR. CIRAD-SAR, Montpellier, France.

Posner, J.L. 1985. Contribution a la connaissance agronomique de la Basse Casamance (synthese bibliographique). Document de travail 1985:3. Departement Systemes et Transfert, ISRA, Dakar, Senegal.

Posner J.L. and al. 1988. Les systemes de production en Basse Casamance et les strategies paysannes face au deficit pluviometrique. ISRA/MSU International Development Papers.

Raman H., Mohan S., and Rangacharya N.C.V. 1992. Decision Support for Crop Planning during Droughts. In Journal of Irrigation and Drainage Engineering, vol 118 n° 2 :229-241.

Ratlif L.F, Ritchie J.T., and Cassel D.K. 1983. Field-meaasured Limits of Soil Water availability as Related to Laboratory-Measured Properties. In Journal of SSSA, vol 47 no. 4: 770-775.

Rehak, D.R. 1983. Expert systems for drought management. In proceeding of Conference on Emerging Computer Techniques in Storm Water and Flood Management. W James (ed), ASCE. New York, NY, 333-387.

Ritchie, J.T.1972. Model for predicting evapotranspiration from a row crop with incomplete cover. In Journal of Water resources Research October 1972, 8:1204-1213.

Roose E. 1967. Dix annees de mesure de l'erosion et du ruissellement au Senegal. Agronomie Tropicale 1967 2":123-152.

Roosenberg R. 1987. Updating animal-powered mechanization by building on history. ASAE proceedings: December 15 - 18, 1987 Winter meeting in Chicago IL.

Roosenberg R. 1992. Neck yoke design and fit: Ideas from dropped hitch point traditions. Tiller's TechGuide. Tillers International. Kalamazoo MI.

Sebillotte M. 1990. Les processus de decision des agriculteurs. Deuxieme partie: consequences pour les demarches d'aide a la decision. In modelisation systemique et systeme agraire. Decision et organisation, J. Brossier, B. Vissac et J.L. Le Moigne, eds., Paris, France, INRA: 103-117.

Sivakumar M.V.K. 1988. Predicting rainy season potential from the onset of rains in the Sahelian and Sudanian climatic zones of West Africa. Agricultural and Forest Meteorology 42: 295-305

Smith A. J. 1990. Using science to understand the biological constraints that limit work animal productivity. In: P. Starkey, M. Goe and A. Faye (eds), Animal traction for Agriculture Development. Wageningen: Technical Center for Agricultural and Cooperation (ACP-EEC Lome Convention).

Smith A. J. 1981. Draught animal Research: A neglected subject. World Animal review, 40, 43-48

Sonko, M.L. 1990. Disponibilite des animaux de trait et contraintes structurelles en Basse Casamance. In: P. Starkey, M. Goe and A. Faye (eds), Animal traction for Agriculture Development. Wageningen: Technical Center for Agricultural and Cooperation (ACP-EEC Lome Convention).

Sonko, M.L. and Fall, A. 1992. Budgets de culture: Recueil de donnees technico-economiques de production en Basse Casamance. FAO contrat d'auteur n° 7 CMT 37503.

Srivastava, N.S.L. and Ojha, T.P. (eds). 1987. Utilization and economics of draught animal power. Central Institute of Agricultural Engineering: Bhopal, India.

Stapleton, J.H. 1995. Linear Statistical Models. Wiley and Sons, New York. USA.

Starkey P. 1986. Draught animal power in Africa: priorities for development, research and training. Networking paper 14. FSSP, University of Florida: Gainsville, Florida.

Starkey, P. 1989. Harnessing for cattle and buffaloes: Options and research. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:280-291.

Starkey P. 1989. Harnessing and Implements for Animal traction - An animal traction resource book for Africa. GATE/GTZ, Vieweg and sons, Braunschweig, Wiesbaden. Germany.

Sumner G. 1988. Precipitation: Process and analysis. John Wiley and Sons. New York, USA.

Turban E. and Meredith J.R. 1994. Fundamentals of Management Science. 6th Edition. Irwin, Boston Ma. USA.

Teleni E. and Hogan J.P. 1989. Nutrition of draught animals. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:118-133.

Tourte, R. 1971. Themes legers - Themes lourds: Systemes intensifs; Voies differentes ouvertes au Developpement Agricole du Senegal, (Simple technical innovation, Sophisticated technical innovation, Intensive Systems; Three different Approaches to Agriculture Developpement in Senegal). Agronomie Tropicale, No 26 (5).

Traverse, S. 1974. Le boeuf Ndama et la riziculture en Basse Casamance. Station Rizicole de Djibelor. ISRA, Dakar, Senegal.

Upadhyay, R.C. 1989. Performance limiting factors in draught animals: Can they be manipulated to improve output? In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:166-173.

Uzureau, C. 1974. Animal draft in West Africa. World Crops. 26:112-114.

Wanapat, M. 1989. Supplementary feeds: Their effects on performance of draught animals and their acceptability to Southeast Asian farmers. In Hoffman D., Nari J. and Petheram R.J. (eds), Draught Animals in Rural Development. Proceedings of an Iternational Research Symposium, Cipansas, Indonesia. ACIAR Proceedings n° 27:146-153.

Willocks, T.J. 1979. Tillage energy requirements for semi-arid crop production in Botswana. In R. Lal (ed). Soil tillage and Crop production. Proceedings series No.2. 303-323. IITA: Ibadan, Nigeria.