PERFORMANCE EVALUATION OF AN ETHIOPIAN TRADITIONAL PLOW COMPARED TO AN AMERICAN SWEEP PLOW

BY

BEFEKADU WOLDE

Bachelor of Science

In Agriculture

Addis Ababa University

Alemaya College of Agriculture

Alemaya, Ethiopia

1982

Submitted to the faculty of the
Graduate College of the
Oklahoma State University
In partial fulfillment of
the requirements for
the degree of
MASTER OF SCIENCE
December, 1990

PERFORMANCE EVALUATION OF AN ETHIOPIAN TRADITIONAL

PLOW COMPARED TO AN AMERICAN SWEEP PLOW

Thesis Approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to express my appreciation to my major advisor Dr. Willard Downs for his great guidance and direction. I am also indebted to the other members of the advisory committee Dr. Marvin L. Stone and Dr. Thomas Esch for their help and guidance during the course of the project.

My great thanks goes to Mr. Conrad Evans for his valuable support. Great appreciation is extended to Rotary International Foundation for providing me full scholarship support during my stay in the USA.

Finally I would like to express my deepest appreciation to my wife Ethiopia Aklilu and my daughter Etsegenet Befekadu for their patience, understanding and moral encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

ADC	Analog to Digital converter
AME	American
cm	centimeter
COEFF.	coefficient
cu.ft	cubic feet
Dens.	density
DF	degree of freedom
Eth	Ethiopian
ft	feet
gm	gram
in	inch
Hz	hertz
kN	kilo newton
kPa	kilo pascal
kph	kilometer per hour
lbf	pound force
m	meter
mph	mile per hour
N	newton
OSL	ordinary significant level
psi	pound per square inch
rpm	revolution per minute
sec	second
sq.	square
STD	standard
°C	degree centigrade

CHAPTER I

INTRODUCTION

Since time immemorial, human beings have striven to fulfill their need for food and shelter. To ease the work and increase production, a number of small tillage implements were developed. The plow is a tillage tool that is highly associated with the development and history of human beings over the centuries. In recent decades, improvements and innovations in designs and materials have resulted in production of efficient modern implements.

Unfortunately, most developing countries still cultivate their land with primitive tools, and food productivity is low compared to developed countries. Agricultural production with these tools is insufficient to meet the increasing demand for food supplies. Farmers spend most of their time and energy plowing their land three or four times before planting. Besides inefficiency, this method of plowing leaves the depth of tillage very shallow due to limited animal power. Total working hours for the animals is another limitation. There are thus many constraints which hinder developing countries from being self sufficient in food production.

Ethiopia is a country where 90% of the agricultural practices are done using primitive tools and methods which have been in use for centuries. Though agriculture is the backbone of Ethiopia's economy, technological innovation to change the primitive method of cultivation is in its infancy. Most agricultural operations are still dependent on human and animal power using small implements manufactured by local blacksmiths.

Farmers have continued using primitive tools partly because little attention have been given to improving plow design and hitching. Other factors which contribute to use of the same plow for generations are its ease of manufacture and low cost. Moreover the implement is light in weight; farmers carry the plow home after work. The strength of social and cultural bonds also play a major role in introduction of new types of plows from other countries.

Even though the Ethiopian traditional plow has been in use for a long time, very little is known about its performance from an engineering point of view. There is an insignificant amount of written evidence documenting whether this traditional plow performs well in tilling the soil, or if it has some drawbacks in design or hitching method. Since the plow share is a very narrow, it does not invert or pulverize the soil mass, but simply breaks the soil. For these reasons farmers till their land three to four times before planting. As a result more time is required to plow a piece of land.

The draft requirement of a plow is one of the most important aspects to be considered for effective matching of implement and power source. Tillage tools have evolved from rudimentary units operated by humans to more sophisticated equipment powered by animals and, eventually, by machines. The majority of Ethiopian farmers still use oxen as their power source. A few farmers (approximately 5%) use donkeys and mules for plowing purposes (Huffnagel, 1961). Though there is some variation in the size of the share and landside of plows from region to region, the harnessing method to the animal is more or less similar across the country. Presently, Ethiopian farmers are using their own experience and skill to select an implement size that approximately fits their animal power source. There are no nomographs or functional relationships developed for best selection and matching of plow to draft requirement or speed of operation for primitive farming practices.

Draft requirements for the Ethiopian traditional plow compared to similarly sized American small sweep cultivators should be measured. The American sweep plow has extensive capability to be used as a primary and secondary tillage implement. Moreover, the plow weight and design may be well suited for use with an animal power source.

The scope of the research described in this report includes production, testing, and evaluation of an Ethiopian traditional plow. The traditional Ethiopian plow bottom was purchased from "Awassa", a southern region of Ethiopia. This metal point is tapered at one end and weighs 1.5 Kg (3.0 lb), and has a nose angle of 20°. At the widest point, it measures about 5.75 cm (2.25 in) and is 2.54 cm (1 in) thick. The frame and other accessories were made in the department of Agricultural Engineering research laboratory at Oklahoma State University. This plow was tested in one soil type at different tillage depths and travel speeds. An American sweep plow which is 11.43 cm (4.5 in) wide was purchased from a John Deere dealer in Stillwater, Oklahoma. This sweep bottom was attached to an Ethiopian frame and tested under the same conditions as for the Ethiopian plow bottom.

Objective of the Study

Evaluate the performance of an Ethiopian traditional plow and an American sweep plow of similar size in one soil type at three different tillage depths and speeds of operations.

CHAPTER II

LITERATURE REVIEW

Machinery Selection And Draft Measurement

Considerable work has been done in developed countries to evaluate implements under different working conditions. An aspect which has received much attention is the determination of power requirements for the plow. According to Harrison (1962), one of the basic considerations in selecting farm tillage machinery is unit draft. A desired ground speed then usually provides sufficient information to match implement size to the power unit and farming enterprise. The amount of power necessary for tillage is a function of forward speed and depth of tillage. Other factors that play an important role in the power requirement are soil density, soil texture, soil moisture content, surface condition, amount and type of weed growth, and the tension, compression and shear strength properties of the soils. Clevenger, (1964) also stated that draft of farm implements is an important factor influencing design, selection and use.

Draft is the component of the total pulling force that acts in the direction of travel. According to Harrison and Reed (1962), determination of the relationship between draft and depth at constant speed, and draft versus speed at constant depth provides a reliable method of comparing the draft requirements of two or more similar implements. Plows are frequently compared to each other in terms of their ability to invert the soil in addition to draft requirement per unit width of tillage. Ashby (1931), tested two plows in cornstalk fields and found that the shape of the plow bottom is a factor in both covering ability and draft. Reaves and Schafer (1975), compared three geometrically similar moldboard bottoms in four different soil types by varying speed and depth. They concluded for normal operating depths, 20 to 25 cm (7.87 to 9.84 in), the specific draft requirement changes little with depth. However, in clay soils some increase in draft requirement can be expected with depth.

With respect to power requirement for different soils, Upadhyaya et al. (1984) reported energy requirements for chiseling in coastal plain soils. The force required to move the subsoiler was dependant on soil type and condition, operating depth and speed, and geometry of the subsoiler. ASAE (1988) provides draft and power requirement prediction equations for tillage tools in several soil types. For chisel plows and field cultivators, predicted draft varies linearly with speed and the square of depth.

A typical method of increasing the capacity of farm machinery is through higher operating speeds. However, the draft increase associated with speed is a major factor limiting the speed at which it is feasible to use tillage tools (Rowe, et al. 1961). Furthermore, Rowe noted that draft increase resulting from higher operating speeds for tillage tools is primarily caused by an increase in shearing strength of the soil due to the higher rate of shear. While the same rate of work can be maintained by pulling either a wide implement at low speed or a narrower implement at a higher speed, the drawbar pull demand varies substantially. There is an optimum operating range for each type of plow which can be determined experimentally.

Animal Power and Matching of Implements

The amount of draft effort required to pull an implement varies with the type of implement, soil type, and terrain. However, the most important part of power utilization is the relationship of implement size to output of the power source. According to Upadhyaya et al. (1985), draft and drawbar requirements are important performance characteristics of drawbar powered agricultural implements. These characteristics are useful in matching a power unit to the implement and improving implement design. According to Carl et al. (1971), performance evaluation may include force and power requirements, soil handling characteristics, excessive metal abrasion, structural damage to the machine, and other requirements.

Proper utilization of power sources will cut the cost of production and increase the available time for other operations. In this regard, Kyle (1962) emphasized that the greatest advantage of testing farm machinery accrues to the consumer. In addition to aiding the farmer in selecting a machine to suit his particular soil and climatic conditions, it helps him purchase a unit whose capacity matches the size of his enterprise. He also noted that field performance evaluations provide the user useful information on adjustment, and hints which allow him to get improved performance from the machine.

Power sources used in agriculture typically generate power within a wide range from 1 - 300 horsepower. In the same way, animal power is also available within a given range. A study by Smith (1981), has shown that draft animals generally pull about 10% of their body weight. In an article on animal power in agricultural production systems, Inns (1979) elaborated on the importance of assessment of machinery needs for developing countries with special reference to Tanzania. He mentioned that the type of farm machinery available has dictated the system of cultivation adopted, leading to sub-optimal crop production. He also stated that economic and social considerations should be an additional parameter added to technical considerations. In conclusion he noted that machinery can only be meaningfully selected after system requirements have been identified, and that it might be necessary to develop machinery to meet a specific need. This is best done after a thorough evaluation of existing machinery.

Smith (1981), in his article on draft animal research, "A Neglected Subject", emphasized the importance of improving simple implements, saying that equipment pulled by animals should be efficient. Generally the range of locally manufactured animal powered implements is too limited, and the equipment is poorly designed and made. Therefore, it is important that implements being introduced should be efficient and simple to maintain using locally available materials and skills.

CHAPTER III

EQUIPMENT AND METHODS

Background

Many types of measurement and instrumentation systems have been developed in recent years. They range in complexity from a simple spring dynamometer to sophisticated electronic measuring and recording devices. Instruments play an important part in helping the designer develop high performance machines. Moreover, instruments can be used to determine service loads in actual operation. An analysis can then be made to determine structural and other design requirements. Such analysis results in prototype machines with a much better chance of performing satisfactorily in the field than machines designed and fabricated by blacksmiths in a traditional way.

As has been mentioned by Harrison et al. (1962), obtaining measurements of draft, depth, and speed is complicated by difficulty in maintaining constant depth and speed under field conditions. Even though the plow is adjusted to work at a constant depth, there will be a variation in depth due to a change in the physical properties of the soil, unevenness of the ground, and vibration of the working tool. To accomplish measurement of power and speed, appropriate transducers and high frequency response recorders are necessary for all operating parameters which may influence performance calculations. Methods used to measure draft requirements for an animal drawn implement and a tractor drawn implement are technically the same.

Gunn et al. (1955) notes that the draft-speed characteristics of many tillage implements can be approximated by a straight line. This is particularly true for implements that do not move and accelerate large quantities of soil, and when the range of speeds involved is not large. Therefore this relationship holds true for animal drawn implements as well since their speed is limited to an average of 0.6 m/sec (1.5 mph) However, a drawback of using animals as a power source is the difficulty in maintaining constant power output through out the time of testing because of fatigue of the animals and plowman.

Earlier animal power research by Mukherjee, et al. (1961), has shown that pulse rate, respiration, and body temperature increase with increased hours of work. Devadattam, et al. (1978), studied the performance of harina bullocks at different loads. They observed that the optimum draft for an average pair was about 588 N (132.28 lbf). The correlation between power output, pulse rate, and body temperature indicated that higher power output caused early onset of fatigue in the bullocks. Breeding and quality of training also contributed to overall animal performance.

Design of a Hitching System

Unlike that of tractor drawn implements, an animal drawn implement requires a person to guide and maneuver the implement from behind. Thus it was necessary to develop a hitching system on a tractor which would be representative of oxen drawn type implements. The tractor attachment frame for both the Ethiopian traditional plow and American sweep plow was designed as shown in Figures 1, 2 and, 3.

The vertical frame was designed to fit the three point hitch of a 16 horsepower John Deere Model 318, hydrostatic drive tractor. The frame was maintained at the desired position by rotating the turn buckle of the upper link. The plow beam was attached to one end of the load cell with a loose cable to control plow bottom height during turning of the tractor.

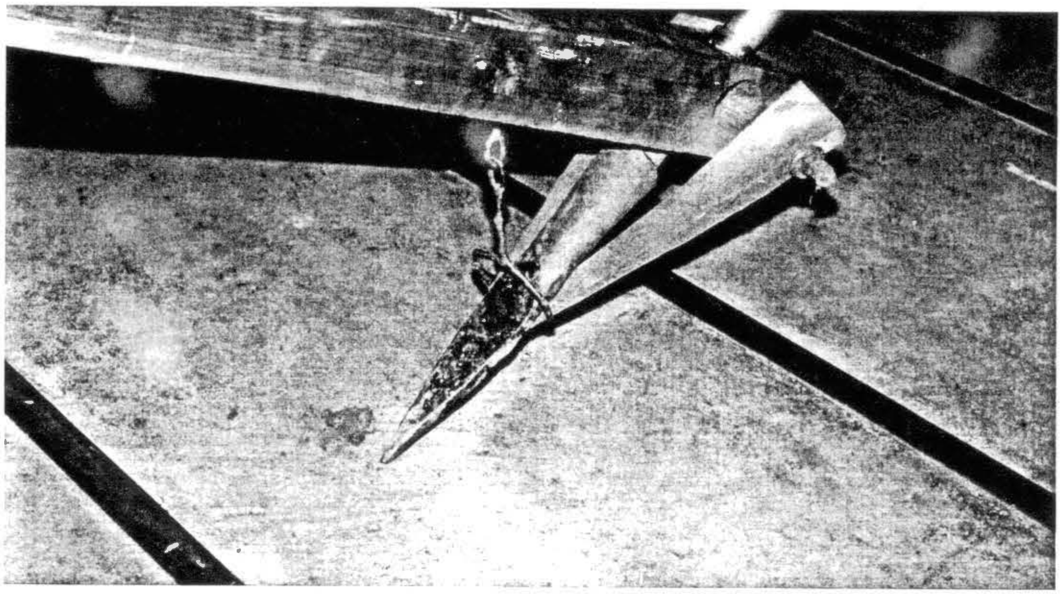

Figure 1. Ethiopian plow bottom

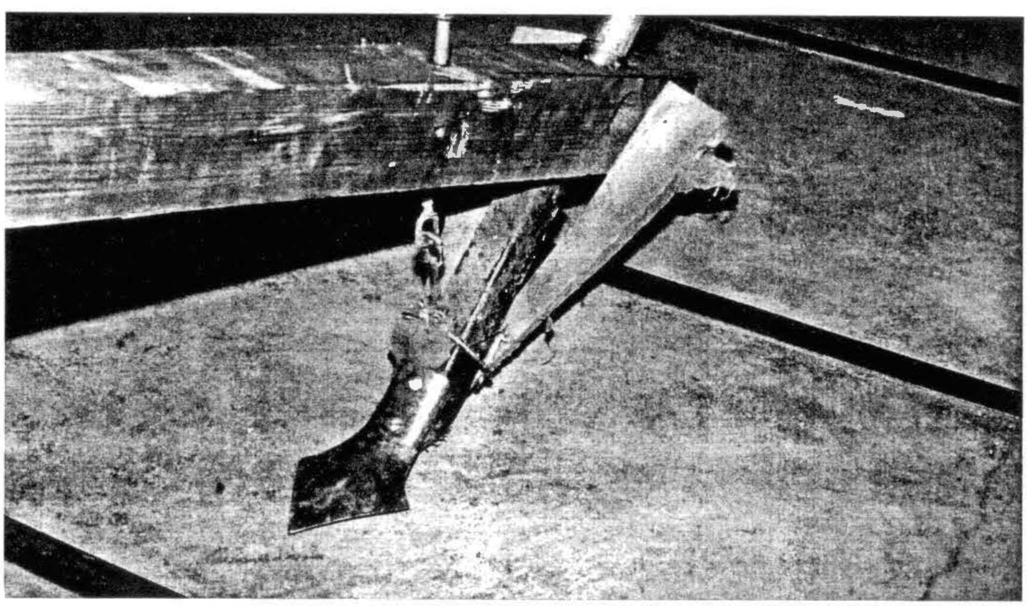

Figure 2. American sweep plow bottom

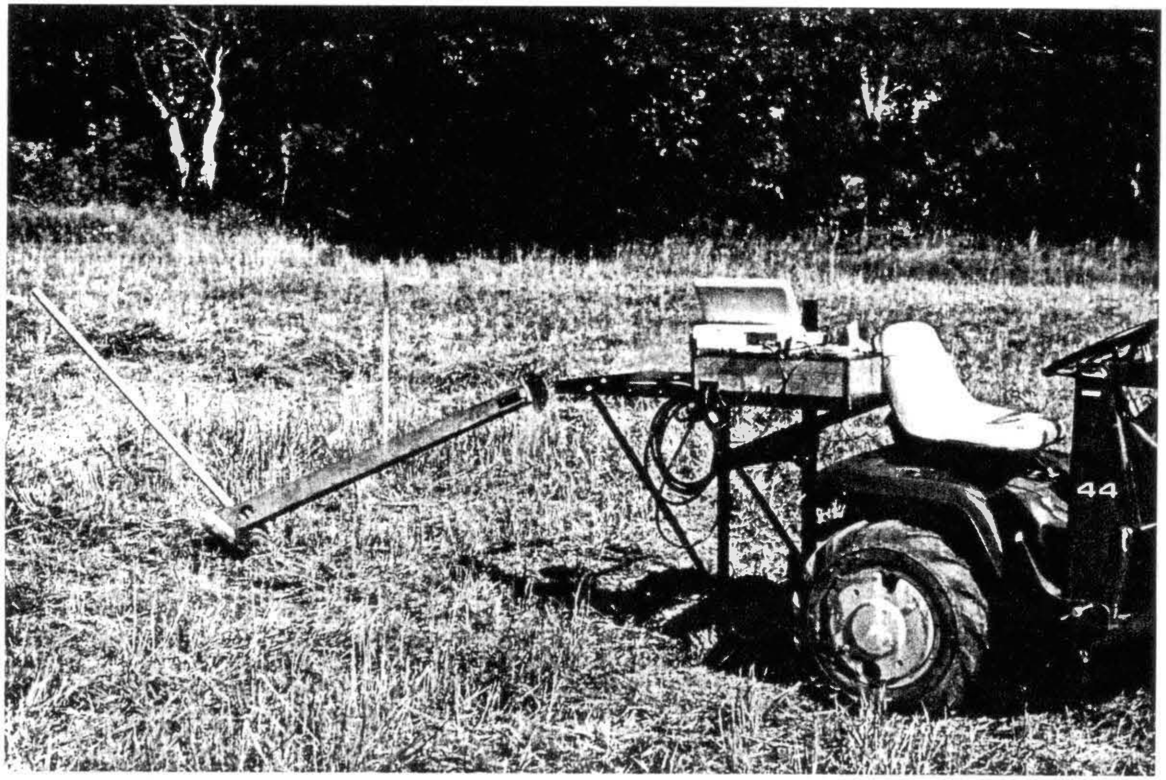

Figure 3. Tractor attachment and instrumentation set up

Draft Measurement

A drawbar (BLH) load cell with a manufacturers rated capacity of measuring up to 500 lb (2.224 kN) was used to measure the draft required to pull each of the two plows. The load cell as shown in Figure 3 was held in a horizontal position between a rectangular frame designed to slide along the vertical frame to vary the height of the hitch point from the ground.

The output of the load cell was logged with analog to digital converter (ADC-1 Remote Measurement Systems) via a low pass filter as shown in Figure 4. The first order low pass filter was designed using 10,000 ohm resistor and 1 μf capacitor for a cut off frequency of 15 hertz. Inside the ADC-1, analog signals are amplified and converted to digital signals. The converted signals are sent to a Tandy (Radio Shack) lap top computer via RS-232. This instrumentation was used to take continuous readings at a pre-set sampling frequency. Previous research results by Young et al. (1984), and Summers et al. (1985), indicated that the cyclic variations in the draft can be seen with a pattern of approximately 2 Hz and 10 Hz. Further research study conducted by Erickson et al. (1982), suggests that frequencies above 12 Hz are insignificant. Therefore a sampling frequency of 60 Hz at 11 bit resolution was used to collect data over a travel distance of 15.25 m (50 ft). Hence, 684 samples at the fastest speed of 1.33 m/sec

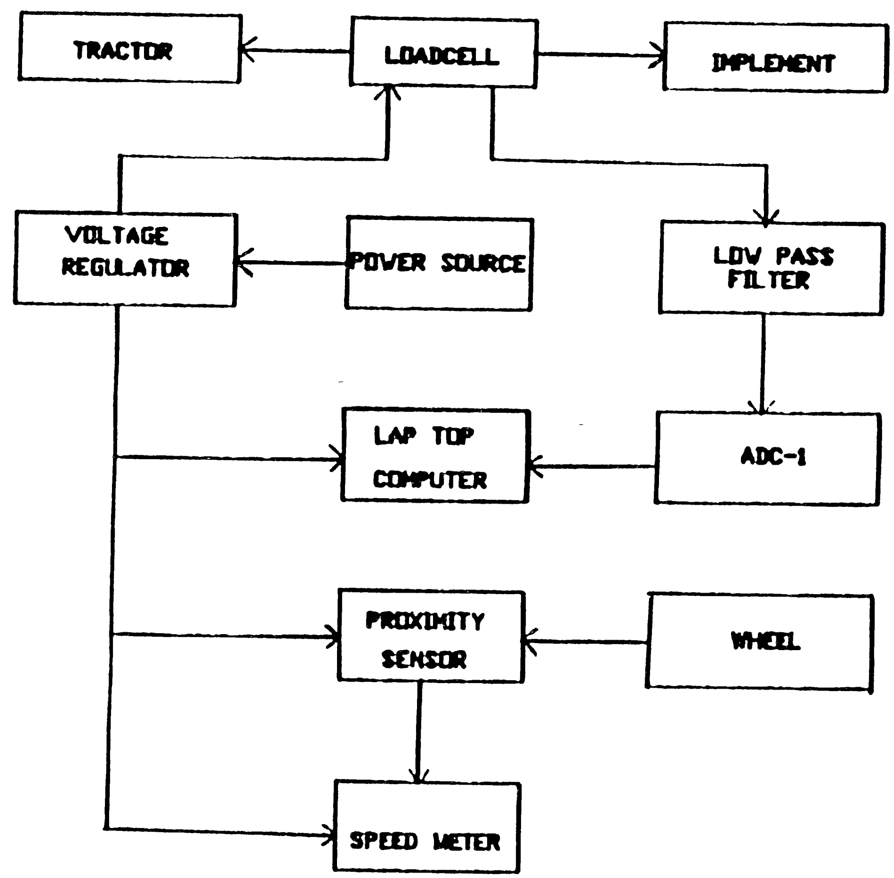

Figure 4. Block diagram of the instrumentation system

(3 mph), 1027 samples at 0.89 m/sec (2 mph), and 1364 samples at the slowest speed of 0.67 m/sec (1.5 mph) were recorded at intervals of 0.0166 seconds per sample. Data was collected three times for every 15.25 m (50 ft) long treatment plot to minimize error due to non-uniformity of the soil behavior.

The power source was an automotive battery with an output of 12 volts. The source was connected to the tractor battery to keep it charged throughout data collection. A voltage regulator was built to reduce the 12 volts output of the battery to 10 volts used by the computer and ADC-1 and 9.7 volts used for excitation of the load cell.

Speed and Depth Measurement

Speed and depth are the most important parameters for evaluation of implement draft requirements. A digital speed measuring unit was assembled to measure the speed of the tractor. An optical proximity sensor GX-18H and a rate meter (speed meter) with a five digit display was purchased from Controlled Engineering Inc. to build the speed measuring unit. The sensor was attached to the bearing frame of a rubber wheel with a diameter of 30.48 cm (1 ft). The wheel and sensor assembly trailed the tractor. Each time the wheel rotated, the sensor perceived the head position of a bolt fixed to a rotating wheel. A signal was sent to the rate meter to display rotational speed, (rpm) of the rubber wheel. The sensor was activated by a 12 volt input from the tractor battery, and was reset by a single pole switch which could be turned "on" and "off" as required. Speeds selected were 0.66 m/sec (1.5 mph), 0.89 m/sec (2 mph), and 1.33 m/sec (3 mph). The speed of the tractor was regulated by adjusting the hand throttle till the required rpm of the speed sensing wheel was maintained.

The tractor and implements were run through a 15.25 m (50 feet) test section, and operated at depths of 7.62 cm (3 in), 10.16 cm (4 in), and 12.7 cm (4.5 in). For each furrow, depth measurements were taken at an intervals of 1.53 m (5 ft) using a steel ruler. Thus 11 depth measurements were taken for each pass and an average computed.

Field Layout and Land Preparation

The test area selected was at Oklahoma State University Blackwell farm 25.6 km (16 miles) west of Stillwater. Normally known as the Upper Lake Carl Blackwell watershed area, the geographical location is North 30° 03′ latitude and West 96° 40′ longitude. According to the United States Department of Agriculture (USDA) Soil Conservation Service, the area is dominated by Port Silty Loam, commonly known as Fine Silty, mixed, Thermic, Cumilic, Haplustoll. This area is generally good for cultivation of crops, though it is affected by occasional severe flooding (Soil survey of Payne county, Oklahoma, USDA soil conservation, 1987).

Land preparation and clearing of crop and weed residues were preliminary steps. Unlike moldboard and disk plows, small tools like the Ethiopian traditional plow 'Maresha' and the small American sweep bottom do not produce extensive soil breakup, inversion, or debris coverage. Rather, such small tools make a trench, throwing the furrow slices to either side. Therefore, the ground was first cleared to get rid of dense, tall weeds covering the plot.

A factorial experiment of 2 plow types, 3 depths and 3 speeds was planned for the silty loam soil. Three replications were made to minimize the variability of soil physical properties and the occurrence of an experimental error. A total of 2x3x3x3 = 54 experiments was carried out. The experimental area of each block was 10.98 X 15.25 sq. mt (36 X 50 sq. ft). Three blocks were randomly selected in-situ for three replications. Each block was divided in to nine small plots for each treatment. The treatments were randomly assigned to each plot. However, for simplicity, one type of plow was used continuously at different speeds and depths of tillage. This method minimized the time required to change plow bottoms after each pass.

Tilth Evaluation

One of the major quality evaluations for the plows was tillage quality. Measuring quality of tillage is subjective and varies with the objective of the tillage operation. For this experiment, the amount of soil loosened by each plow type was measured by clearing the loosened soil from

0.61 m (2 ft) long sections of each tillage trench. The approximate top width, depth, bottom width, and slope of the trench was measured at intervals of 10.16 cm (4 in) linearly along the cleared trenches as shown in Figure 5. The specific draft requirement (kPa or psi) of furrow cross section was used to compare the efficiency of the Ethiopian traditional plow and American sweep bottom.

Measurements of Soil Physical Properties

Soil is a granular medium that varies in composition from organic peat to gravel, and may contain various amounts of water. The soil physical system is continually subjected to external forces and is, therefore, dynamic. Draft requirements for any tillage tool depend on the moisture content of the soil, thus it was necessary to take soil samples each day of testing in the field. A 20.32 cm (8 in) long soil profile samples were taken with a soil tube each day at six different randomly selected locations. Each soil sample was trimmed and cut to a length of 5.08 cm (2 in) from the top, 7.62 cm (3 in) from the middle and 7.62 cm (3 in) from the bottom. The weight of the samples and the containers were recorded before drying them in an oven for 24 hours at 100 °c. Dried samples were then reweighed and moisture content determined. The bulk density of the soil samples as shown in Table I, was computed.

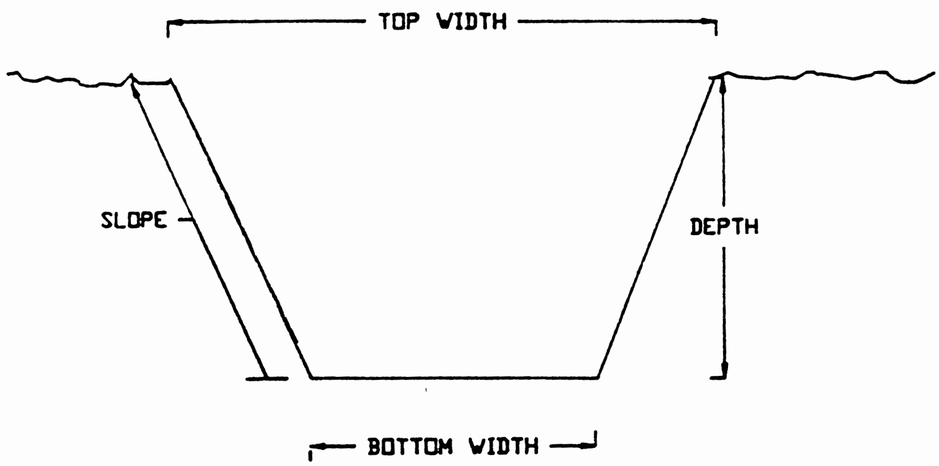

Figure 5. Cross section of a furrow

TABLE I

SOIL MOISTURE CONTENTS AND DENSITIES

WORKING DAY	DEPTH		AVERAGE MOISTURE CONTENT	WET BULK DENSITY		DRY BULK DENSITY	
	inch	cm	(%)	lb/cu.ft	gm/cc	lb/cu.ft	gm/cc
	0-2	0.00-5.08	17.01	91.5	1.464	78.25	1.252
1	2-5	5.08-12.7	15.09	101.12	1.618	87.88	1.406
	5-8	12.7-20.3	16.05	109.06	1.745	93.94	1.503
	0-2	0.00-5.08	14.95	103.94	1.65	89.94	1.439
2	2-5	5.08-12.7	16.04	113.88	1.822	98.13	1.570
	5-8	12.7-20.3	16.52	123.06	1.969	105.56	1.689
	0-2	0.00-5.08	20.30	110.25	1.764	91.63	1.466
3	2-5	5.08-12.7	17.04	122.00	1.952	104.25	1.668
	5-8	12.7-20.3	16.66	118.31	1.893	101.44	1.623
	0-2	0.00-5.08	18.84	117.63	1.882	99.00	1.584
4	2-5	5.08-12.7	17.18	123.88	1.982	105.75	1.692
	5-8	12.7-20.3	16.94	134.31	2.149	114.94	1.839

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

Draft for the plows was affected by the physical condition of the soil, tool size and shape, and depth and speed of operation. The draft required to pull the Ethiopian traditional plow and American sweep plow varied considerably over the 15.25 m (50 ft) test plots. Figures 6 and 7 show draft for an Ethiopian traditional plow and American sweep plow for a period of 8.25 seconds respectively. The draft requirement for the Ethiopian plow was significantly affected by the speed and depth of tillage. Draft for the American sweep plow was affected by the depth of tillage, the wet bulk density of the soil, and the interaction of the depth and bulk density.

Effect of Speed on Draft

Though many researchers have observed the dependency of draft on speed, the effect was minimal for the test conditions of this study. Tables II-VII show the average draft requirement for the two plows at different speeds and depths of operations.

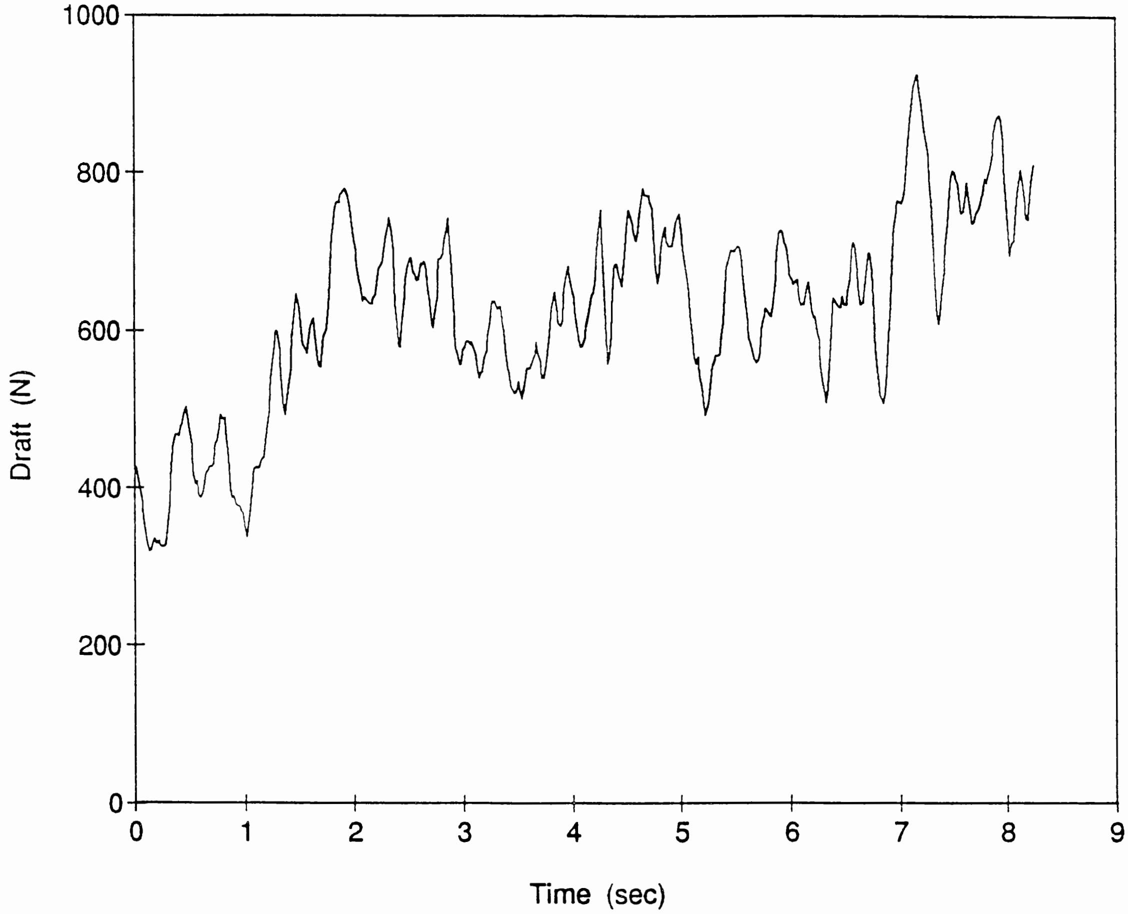

Figure 6. Draft vs. Time for an Ethiopian plow at 0.67 m/sec (1.5 mph).

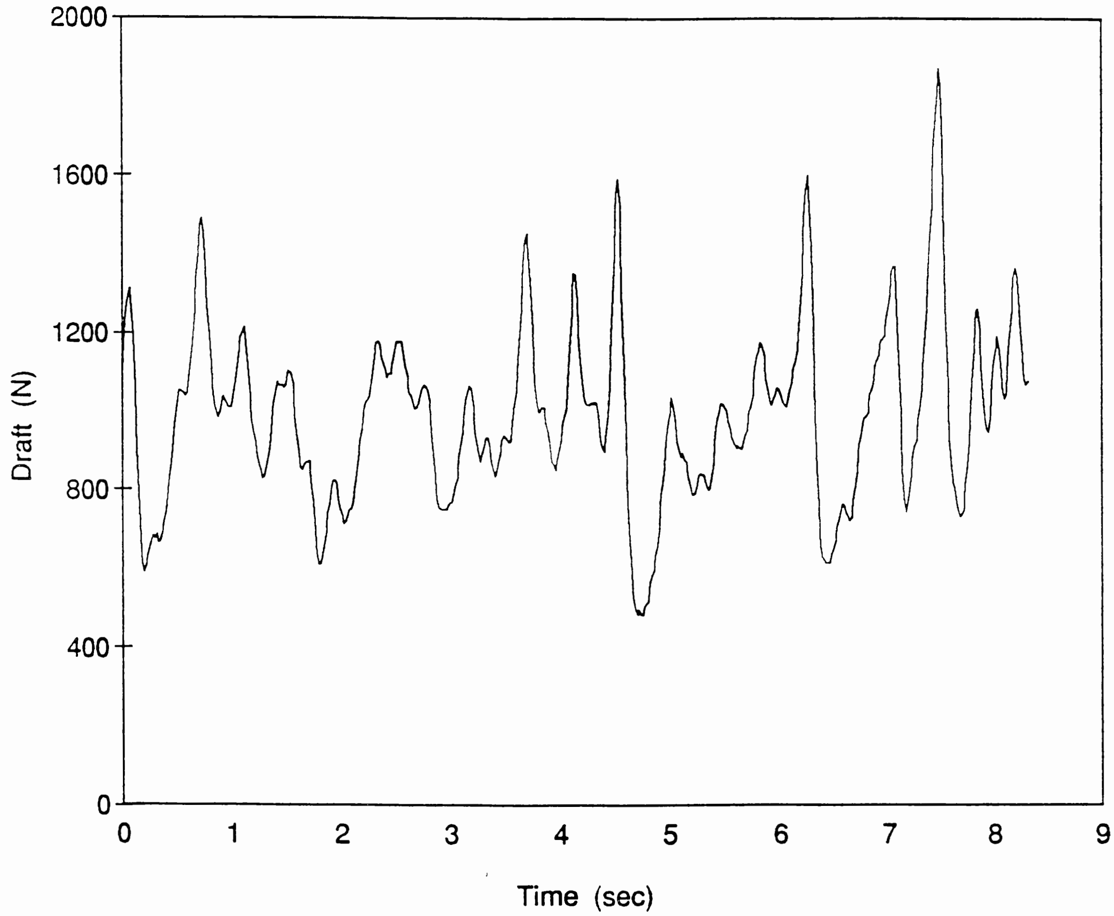

Figure 7. Draft vs. Time for an American sweep plow at 0.67 m/sec (1.5 mph).

TABLE II

DRAFT REQUIREMENT FOR ETHIOPIAN PLOW AT 0.67 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
4.35	11.05	91.5	1.464	266.17	1.184
4.39	11.15	91.5	1.464	248.59	1.106
4.10	10.41	91.5	1.464	242.49	1.079
4.53	11.51	110.25	1.764	287.24	1.278
3.97	10.08	110.25	1.764	220.44	0.981
4.16	10.57	110.25	1.764	204.38	0.909
4.00	10.16	117.63	1.882	204.83	0.911
4.43	11.25	117.63	1.882	261.31	1.162
4.25	10.79	117.63	1.882	225.17	1.002

TABLE III

DRAFT REQUIREMENT FOR ETHIOPIAN PLOW AT 0.89 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
3.55	9.02	91.5	1.464	160.41	0.714
4.11	10.44	91.5	1.464	261.67	1.164
4.00	10.16	91.5	1.464	255.18	1.135
3.85	9.78	110.25	1.764	212.37	0.945
4.35	11.05	110.25	1.764	275.83	1.227
4.45	11.30	110.25	1.764	281.89	1.254
4.02	10.21	117.63	1.882	261.05	1.161
4.86	12.34	117.63	1.882	281.87	1.254
4.04	10.26	117.63	1.882	263.00	1.170

TABLE IV

DRAFT REQUIREMENT FOR ETHIOPIAN PLOW AT 1.33 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
3.56	9.040	91.500	1.464	198.02	0.881
4.50	11.43	91.500	1.464	305.97	1.361
3.90	9.910	91.500	1.464	303.64	1.351
3.00	7.620	110.25	1.764	145.30	0.646
4.18	10.62	110.25	1.764	225.05	1.001
3.50	8.890	110.25	1.764	214.14	0.953
3.50	8.890	117.63	1.882	192.66	0.857
3.82	9.700	117.63	1.882	296.13	1.317
4.52	11.48	117.63	1.882	306.88	1.365

TABLE V

DRAFT REQUIREMENT FOR AMERICAN SWEEP PLOW AT 0.67 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
3.84	9.750	103.44	1.655	217.15	0.97
4.93	12.52	103.44	1.655	326.76	1.45
5.20	13.21	103.44	1.655	410.54	1.83
3.97	10.08	110.25	1.764	186.32	0.83
4.91	12.47	110.25	1.764	338.84	1.51
4.72	11.99	110.25	1.764	262.74	1.17
3.75	9.530	117.63	1.882	263.10	1.17
3.59	9.120	117.63	1.882	224.60	1.00
3.68	9.350	117.63	1.882	256.74	1.14

TABLE VI

DRAFT REQUIREMENT FOR AMERICAN SWEEP PLOW AT 0.89 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
3.90	9.910	103.44	1.655	255.59	1.14
4.29	10.90	103.44	1.655	317.31	1.41
3.98	10.11	103.44	1.655	311.00	1.38
4.20	10.67	110.25	1.764	303.46	1.35
4.73	12.01	110.25	1.764	336.54	1.50
5.00	12.70	110.25	1.764	381.63	1.70
3.36	8.530	117.63	1.822	270.48	1.20
3.29	8.360	117.63	1.822	268.26	1.19
4.00	10.16	117.63	1.822	317.90	1.41

TABLE VII

DRAFT REQUIREMENT FOR AMERICAN SWEEP PLOW AT 1.33 m/sec

DEPTH		BULK-DENSITY		AVERAGE DRAFT	
inch	cm	lb/cu.ft	gm/cc	lbf	kN
3.40	8.640	103.44	1.655	217.67	0.97
4.79	12.17	103.44	1.655	402.87	1.79
4.47	11.35	103.44	1.655	327.46	1.46
3.66	9.300	110.25	1.764	249.20	1.11
4.41	11.20	110.25	1.764	273.98	1.22
4.25	10.80	110.25	1.764	245.74	1.09
3.71	9.423	117.63	1.822	250.25	1.11
3.87	9.830	117.63	1.822	266.77	1.19
3.56	9.042	117.63	1.822	249.62	1.11

Draft response to speed was more significant for the Ethiopian traditional plow than the American sweep bottom as shown in Figures 8 and 9. This is probably due to the difference in design of each plow. The Ethiopian plow has evolved to be used for a slow speed operation between 0.67 to 0.89 m/sec (1.5 to 2 mph). The American sweep plow is designed for operation over a range of 6.4 to 12.8 kph (4 to 8 mph). The sensitivity of the Ethiopian plow to speed could thus be a result of its geometry which makes it more suitable if drawn by animals. The effect of speed on the American sweep plow is insignificant over a lower speed range of 0.67 to 1.33 m/sec (1.5 to 3 mph). This condition has also been observed by other researchers when studying the effect of sweep design parameters on draft. Clark et al (1981), noted that for very shallow depths, speed had almost no effect on draft of sweep plows.

Furthermore, the width of the point has a considerable impact on the speed and depth effect and their interaction. Since the American sweep plow is bulldozing a large amount of soil compared to Ethiopian traditional plow, the speed effect on this tool will be comparatively less.

Effect of Depth on Draft

Depth was the dominant single factor affecting draft during the experiment. It was difficult to keep the tools at uniform depth during testing. This was mainly because

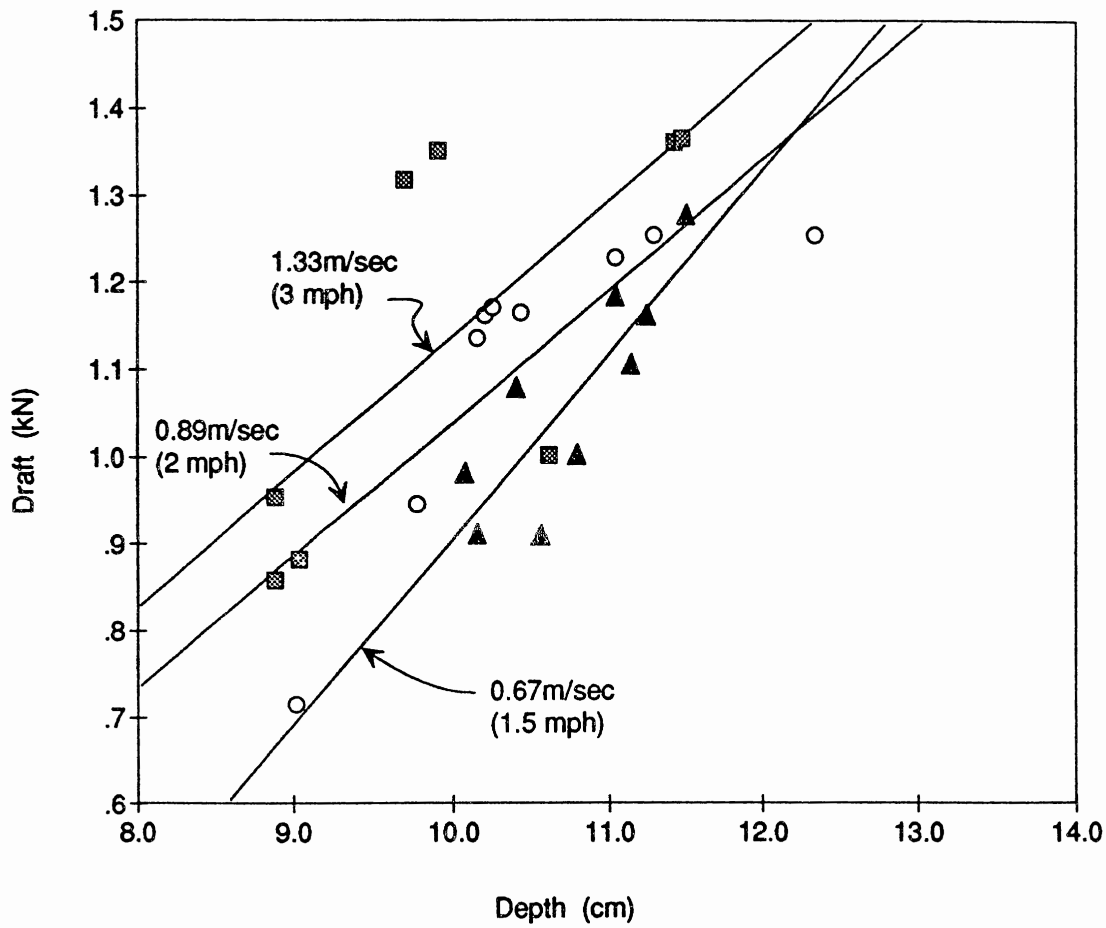

Figure 8. Draft vs. Depth at different speeds for an Ethiopian plow.

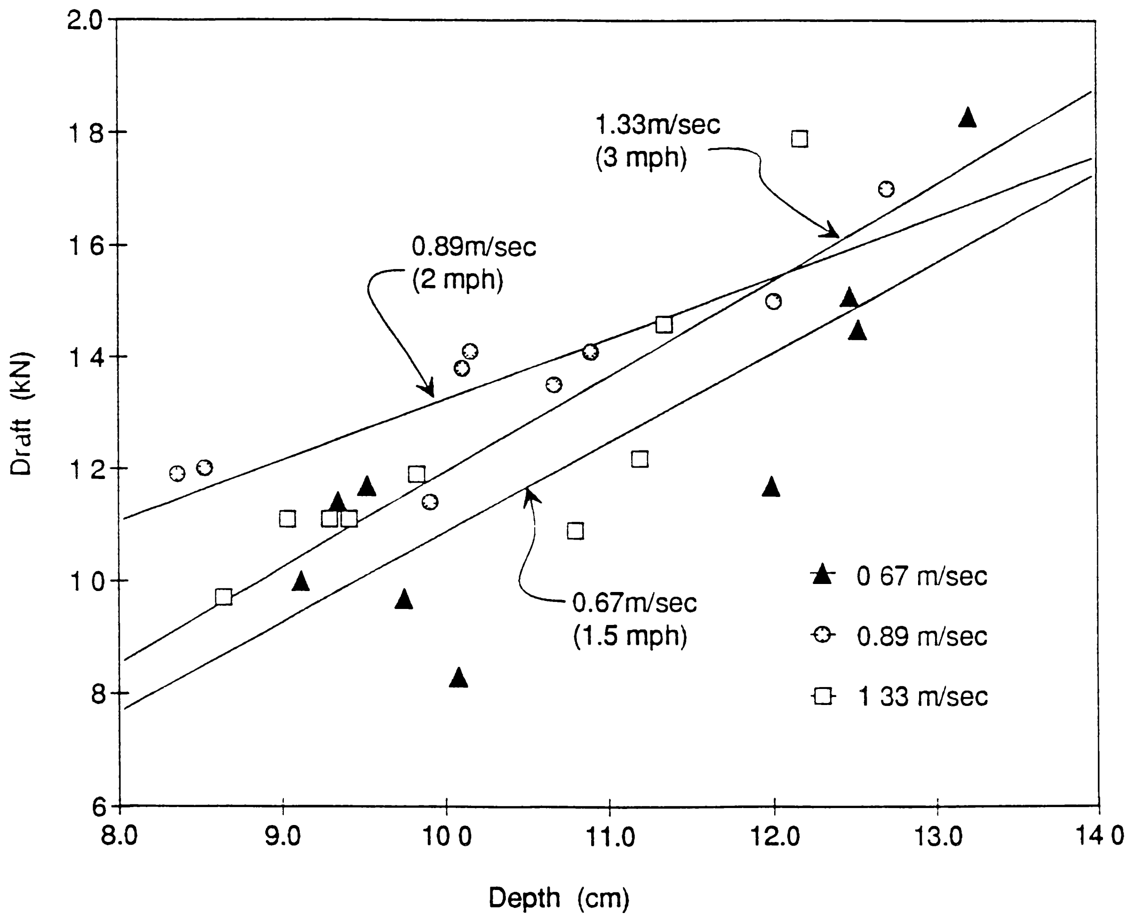

Figure 9. Draft vs. Depth at different speeds for an American sweep plow.

the implements were tested as animal drawn implements requiring the presence of a person to guide and maneuver the plow bottom. Maintaining uniform depth of tillage by hand is very difficult and tiresome. The ability to accurately control the plow varies from individual to individual depending on size, weight, and experience. This fact contributed significantly to variation in depth for both plows. Though, the proposed depths of tillage were 7.62, 15.24, and 22.86 cm (3, 6, and 9 in), it was not possible to obtain these depths consistently. Therefore, the analysis for draft was conducted based on actual depths achieved in the field.

A regression analysis was done for each plow, keeping the speed terms constant. The analysis indicated a linear relationship between tillage depth and draft requirements. Furthermore, the closeness of the draft vs depth graph lines indicate that speed and draft are not strongly correlated. As the lines get farther apart, the dependency of the draft on speed becomes greater and vice versa.

Effect of Experimental Blocking

Blocking of test plots was done because small variations in soil texture or moisture could cause large differences in draft. The test area was divided in three blocks in order to minimize soil physical variations.
For this experiment, statistical analysis did in fact show that variation between blocks was significant.

Effect of Moisture Content on Draft

There was no large variation in soil moisture content during the testing period (soil moisture varied from 15% to 20%). The effect of moisture content on draft was statistically insignificant for the Ethiopian traditional plow and very significant for the American sweep plow.

The wet bulk density of the soil was used as a prediction parameter during development of a draft equation for the American sweep plow. This parameter was not used in the prediction equation for the Ethiopian plow. Soil information data is tabulated in Table I.

Curve Fitting of Draft Versus Speed and Depth

Development of prediction equations for draft prediction is difficult. Most equations are valid only for a given machine in given soils, over a narrow range of operating conditions. Difficulties in development of prediction equations for performance of complex systems is well explained by Reaves et al. (1971). A lack of understanding of the many interactions of tools with soil is the main problem. Development of comprehensive prediction equations for even relatively simple soil-machine system is very complex. Hence, the most frequent approach is to develop partial prediction equations valid for a particular system over a limited range of conditions.

A multiple regression and nonlinear regression was used to fit a smooth curve to the data. The best-fit equation for both the Ethiopian and American sweep bottom was developed for speeds within a 0.67 m/sec (1.5 mph) to 1.33 m/sec (3 mph) speed range, and a 7.62 cm (3 in) to 12.7 cm (5 in) depth range. This prediction equation is valid only for a fine silty loam soil. Extrapolating for depths and speeds outside this range may not be valid.

Model of Draft For an Ethiopian Plow

A regression analysis was made between draft vs speed, depth, and wet bulk density. The correlation matrix, Table VIII, shows no strong correlation among the independent variables of speed, depth, and bulk density. However, the dependant variable draft was correlated to speed by 0.010, to depth by 0.715, and to bulk density by -0.008.

TABLE VIII

CORRELATION MATRIX FOR DRAFT OF AN ETHIOPIAN PLOW

	Speed	depth	bulk density	Draft
Speed	1.000			
Depth	-0.466	1.000		
Bulk dens.	0.000	0.087	1.000	
Draft	0.010	0.715	-0.008	1.000

Furthermore, tests of significance of the independent variables was done to select those variables contributing significantly to draft response. The test of significance was taken at the 95% level. For the Ethiopian traditional plow, the parameters chosen for the model were depth and speed; bulk density was insignificant at the 95% confidence interval.

TABLE IX

SUMMARY OF REGRESSION ANALYSIS OF DRAFT
MODEL FOR AN ETHIOPIAN PLOW

VARIABLE	REGRESSION COEFF.	STD ERROR	T	P (2 TAIL)
SPEED	30.078	9.214	3.264	0.003
DEPTH	98.130	14.335	6.846	0.000
CONSTANT	-221.251	70.268	-3.149	0.004

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	P
REGRESSION	32711.264	2	16355.632	23.435	0.000
RESIDUAL	16750.288	24	697.929		
TOTAL	49461.552	26			

R-SQUARED 0.661

* Dependant variable : Draft
* independent variables: Speed, depth, and bulk density

The mathematical model for these conditions is:

In the SI system

DRAFT = -0.990 + 0.003 * SPEED + 0.172 * DEPTH

Where,
SPEED is in cm/sec
DEPTH is in cm
DRAFT is in kN

Or,

DRAFT = -221.251 + 98.130 * DEPTH + 30.078 * SPEED

Where,
SPEED is in mph
DEPTH is in in
DRAFT is in lbf

The ANOVA table shown above (Table IX), shows the parameters involved in determining coefficients for the predictor variables and the coefficient of determination. The R-SQUARED value was 0.66. This indicates that 66% of the data could be explained by the prediction equation. This value is a little lower than is typical for similar laboratory tests conducted in the soil bin. This may be due to uncontrollable variations that occurs in the field. Therefore this value is significant for this experiment.

Model of Draft For an American Sweep Plow

Similar methods and procedures were used to develop a model for the American sweep plow. The correlation matrix in Table X indicates that the independent variables of speed, depth, and bulk density are less correlated to each other. Correlation of the dependant variable draft to speed, depth, and bulk density was -0.052, 0.764, and -0.343 respectively.

Test of significance were done for the American plow to develop the model. The significant parameters were depth, bulk density and the interaction between depth and bulk density. Speed was insignificant at the 95% significance level.

TABLE X

CORRELATION MATRIX FOR DRAFT OF AN AMERICAN SWEEP PLOW

	SPEED	DEPTH	BULK DENSITY	DRAFT
SPEED	1.000			
DEPTH	-0.191	1.000		
BULK DENS.	0.000	-0.508	1.000	
DRAFT	-0.052	0.764	-0.343	1.000

The ANOVA table in Table XI was used to develop the model and determine coefficients for the predictor variables. The coefficient of determination (R-squared) was 0.62. This partial predicting equation can be used for a limited range of speed from 0.67 to 1.33 m/sec (1.5 mph to 3 mph) and depths from 7.62 to 12.7 cm (3 to 5 in).

TABLE XI

SUMMARY OF REGRESSION ANALYSIS OF DRAFT MODEL FOR AN AMERICAN SWEEP PLOW

VARIABLE	REGRESSION COEFF.	STD. ERROR	T	P (2 TAIL)
DEPTH	804.259	285.560	2.816	0.010
BULK DEN.	26.442	10.280	2.572	0.017
DEP * BULK	-6.660	2.6260	-2.536	0.018
CONSTANT	-2928.435	1125.346	-2.602	0.016

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO	P
REGRESSION	55918.528	3	18639.509	16.084	0.000
RESIDUAL	26653.975	23	1158.868		
TOTAL	82572.503	26			

R - SQUARED 0.677

* Dependant variable: Draft

* Independent variables: Depth, bulk density, and the interaction between depth and bulk density (dep * bulk).

The mathematical model for an American sweep plow is:

In the SI system

DRAFT = -13.039 + 1.409 * DEPTH + 7.357 * BULK DENSITY

- 0.729 * DEPTH * BULK DENSITY

Where,
DEPTH is in cm
BULK DENSITY is in gm/cc
DRAFT is in kN

Or,

$$DRAFT = -2928.435 + 804.259 * DEPTH + 26.442 * BULK\ DEN. - 6.660 * DEPTH * BULK\ DENSITY$$

Where,

DEPTH is in inch
BULK DENSITY is in lb/cu.ft
DRAFT is in lbf

Specific Draft Requirement Evaluation

As far as performance evaluation of the two plows is concerned, the specific draft requirement is important since it is the amount of energy required to move a unit volume of soil mass. An analysis was done to develop a prediction equation for the specific draft requirement of each plow type. However, the analysis revealed that specific draft does not depend on either speed or depth of tillage. The specific draft for each plow over the tested range of speed and depth is nearly a unique value.

Therefore, the specific draft values for different plows and different replications were pooled together and an average of these values computed as shown in Table XII. A unique overall average specific draft is determined from these calculations. A scatter plot of specific draft vs depth and speed is shown in Figure 10 and 11 respectively.

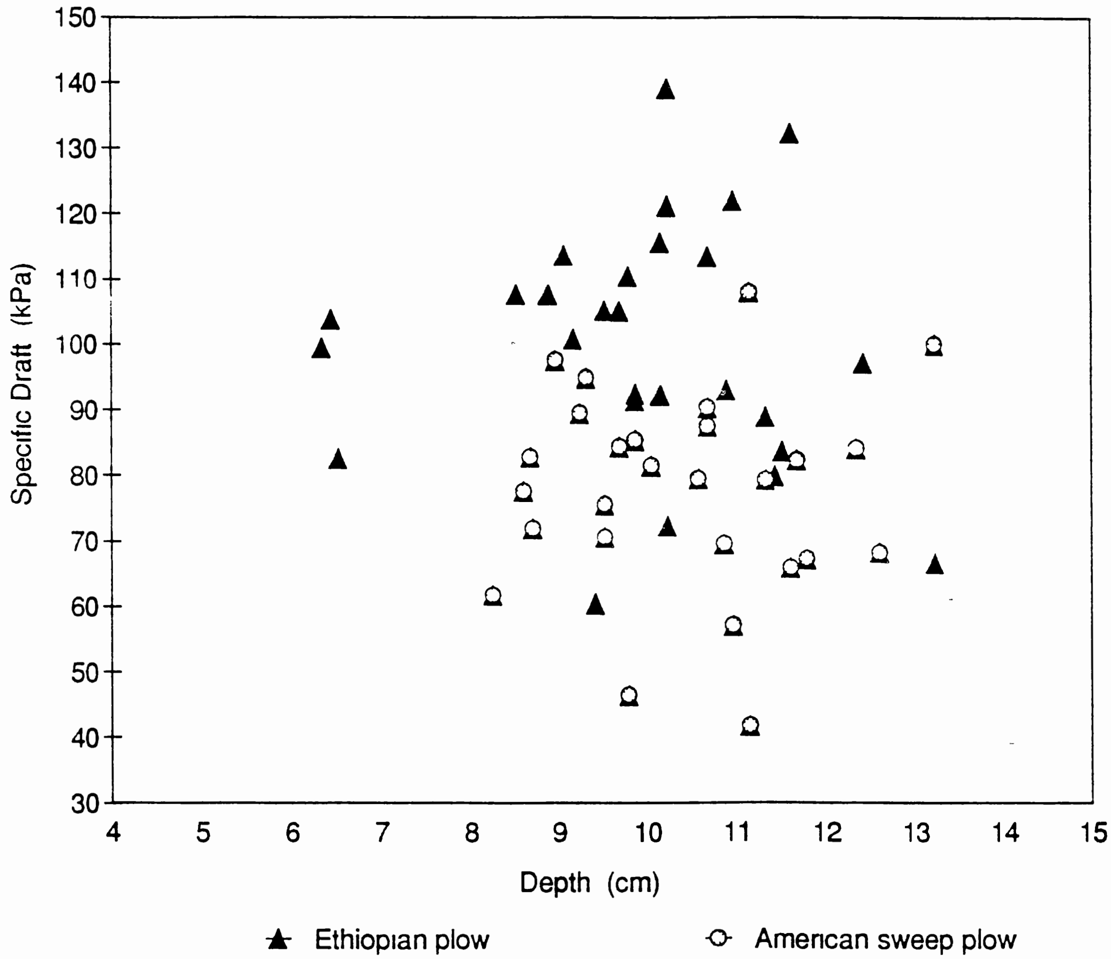

Figure 10. A scatter plot of a specific draft for an Ethiopian plow and an American sweep plow.

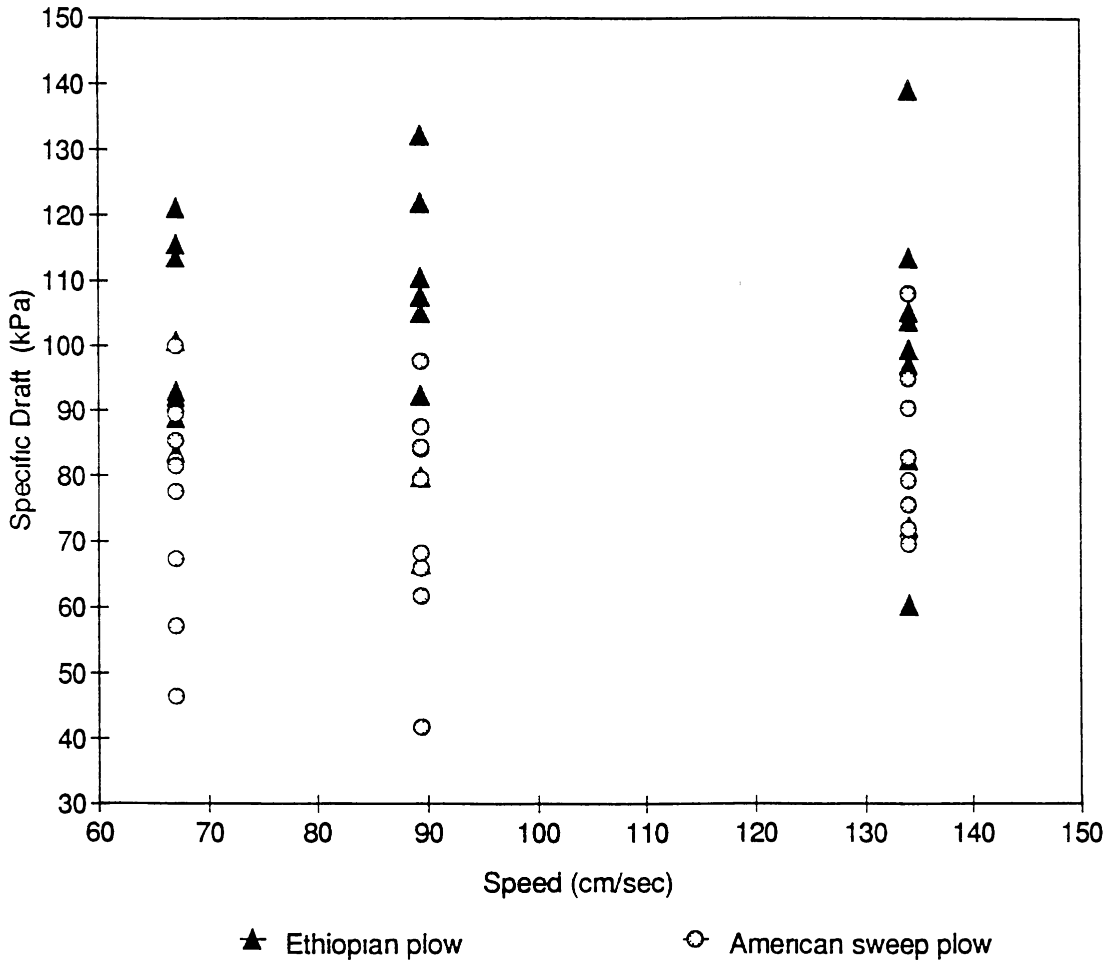

Figure 11. A scatter plot of a specific draft vs. speed for an Ethiopian plow and an American sweep plow.

The multiple regression analysis shown in Table XII and XIII indicate that the predictor variables are not significant at 5% significance level. Thus, the specific draft is not affected either by depth or speed of operations. Therefore, the data could be represented by a constant function in both kinds of plows. The model for the specific draft of both types of plows is mathematically formulated as follows:

For the Ethiopian plow

Specific draft = 99.92 kPa (14.491 psi)

For the American sweep plow

Specific draft = 77.8 kPa (11.283 psi)

Table XII

REGRESSION ANALYSIS OF SPECIFIC DRAFT FOR AN ETHIOPIAN TRADITIONAL PLOW

VARIABLE	REGRESSION COEFF.	STD. ERROR	T	P(2 TAIL)
CONSTANT	32.971	9.842	3.35	0.003
DEPTH	-1.065	0.601	-1.77	0.090
SPEED	-6.234	3.723	-1.675	0.108
DEPTH * SPEED	0.355	0.234	1.517	0.143

R-SQUARED = 0.082

VARIABLE	REGRESSION COEFF.	STD. ERROR	T	P(2 TAIL)
CONSTANT	14.491	0.525	27.612	0.000

Table XIII

REGRESSION ANALYSIS OF SPECIFIC DRAFT
FOR AN AMERICAN SWEEP PLOW

VARIABLE	REGRESSION COEFF.	STD. ERROR	T	P(2 TAIL)
CONSTANT	5.043	11.994	0.421	0.678
DEPTH	0.233	0.549	0.424	0.675
SPEED	3.982	6.125	0.650	0.522
DEPTH * SPEED	-0.158	0.284	-0.556	0.583

R-SQUARE = 0.063

VARIABLE	REGRESSION COEFF.	STD. ERROR	T	P(2 TAIL)
CONSTANT	11.283	0.429	26.308	0.000

A statistical analysis was performed to investigate the significance of observed differences between the specific draft of an Ethiopian plow and an American sweep plow. The following hypothesis was formulated.

Ho : $\mu 1 - \mu 2 = 0$
H1 : $\mu 1 - \mu 2 \neq 0$

where,

$\mu 1$ - is the mean of the specific draft of an Ethiopian plow

$\mu 2$ - is the mean of the specific draft of an American sweep plow

A t-test was used to verify the differences of these two means. The calculated t-value was 4.73 and the tabulated t-value was 3.707 at 0.001 ordinary significant level (OSL). This indicates that there is a significant difference between the means of specific draft of an Ethiopian plow and an American sweep plow.

TABLE XIV

COMPARISON OF SPECIFIC DRAFT REQUIREMENT OF ETHIOPIAN TRADITIONAL PLOW AND AMERICAN SWEEP PLOW

PLOW TYPE	REP	AVERAGE X-AREA		AVERAGE DRAFT		AVERAGE SPEC.DRAFT		GRAND SPEC.DRAFT	
		sq.in	sq.m	lb	kN	psi	kPa	psi	kPa
	1	14.81	0.0096	229.64	1.022	15.44	106.43	-	-
ETH	2	13.48	0.0087	190.28	0.846	14.14	97.50	-	-
	3	19.06	0.0123	257.79	1.147	13.90	95.81	14.4	99.92
	1	22.86	0.0147	290.88	1.290	12.64	87.14	-	-
AME	2	24.54	0.0158	231.22	1.030	9.500	65.50	-	-
	3	19.76	0.0144	231.88	1.030	11.71	80.74	11.28	77.8

Where,

AME - AMERICAN SWEEP PLOW

ETH - ETHIOPIAN PLOW

REP - REPLICATION

CHAPTER V

CONCLUSION

Draft measurement in the field requires an accurate mechanical system which enables one to maintain uniform speed and depth throughout the test. The effect of speed on draft for the American sweep plow tested was insignificant up to a depth of 12.7 cm (5 in). However, as the depth of tillage increased beyond 12.7 cm (5 in), the draft of the American sweep plow seemed to be affected by speed variation.

The Ethiopian traditional plow was very sensitive to speed variation. Draft increased in proportion to an increase in depth of tillage and speed of operation. As far as turning of the furrow slice is concerned, the American sweep plow performed better than the Ethiopian plow. The average draft for the American sweep plow was greater than the average draft for the Ethiopian plow. However, The specific draft requirement of the American sweep plow was considerably lower than the Ethiopian traditional plow. This may be due to the increase in volume of the soil disturbed per unit increase of draft.

Generally, the analysis reveals that the use of the American sweep plow in place of the Ethiopian traditional plow is technically feasible and may even offer some advantages in terms of tillage quality and soil tilth. However, use of the bottom must be accomplished in such a way that it is compatible with animal power.

The draft model for both plow types may be used to predict draft requirement based on speed, depth, and bulk density information gathered for a silty loam type of soil. For a best estimate, the depth of tillage should be in a range of 7.62 to 12.7 cm (3 to 5 in).

Recommendation

Test data is limited to one soil type (port silty loam). Additional research is necessary for different soil types and environments. The results would be more meaningful if performance in Ethiopian soils was measured. If the soil type found in Stillwater (Oklahoma) is different from the soil type found in Ethiopia, the models may not accurately predict the draft requirements of each plow.

Generally, the effectiveness of the American sweep plow is unquestionable. However, the plow point requires some modification in shank design so that it fits and holds the wooden handle by simple friction in absence of bolt and nuts, screw and screw drivers, and wrenches.

From an Ethiopian farmer's point of view, simplicity, ease of operation, and low cost are the leading arguments, and cannot be overlooked. If a new type of plow is to be introduced, it must be simple and at a comparable price to the Ethiopian traditional plow. Therefore, these conditions would be resolved by introducing a prototype of new plows to blacksmiths so that they could modify and fabricate it from local materials which might make it cheaper and easier to introduce to farmers. Development of an extension system in agricultural mechanization would help considerably in promoting new technologies to farmers.

Suggested Further Studies

The following suggestions are made concerning planning future studies.

1. Tests should be carried out in Ethiopia for different soil types. Results should be compared to the results obtained in this study.
2. A depth control device should be designed to control tillage depth throughout the operation.
3. A device should be designed to measure the amount of soil loosened and cross sectional areas affected.
4. The use of faster machines (computer) and sampling frequencies may result in a more accurate output.
5. Plow tests should be done by farmers to assess the ease of using American plow points, and adopting them to individual needs.

BIBLIOGRAPHY

ASAE DATA: ASAE 230.4. (1980). Agricultural Machinery Management Data. ASAE Standards.

Ashby, W. 1931. A method of comparing plow bottom shapes. Agricultural Engineering. 411-412.

Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., and Clark, F.E. 1985. Methods of soil Analysis. American society of Agronomy. Agronomy No. 9. Part 1, 7th printing, (1-770).

Carter, L.M. 1981. Instrumentation for measuring average draft. Transactions of the ASAE. 24: 23-25,30.

Clark, S.J., Oni, K.C., and Johnson, W.H. 1981. Effect of sweep design parameters on draft. Presented at winter meeting of the ASAE, Chicago, Illinois, 1981. ASAE Paper No 81-1531.

Devadattam, S.D.K., and Maurya, N.L. 1978. Draftability of Haryana bullocks. Indian Journal of Dairy Science. 31: 120-127.

Ellen, H. 1984. Tillage effects and specific energy requirements of rotary tillage. Soil and Tillage Research. 4: 471-484.

Erickson, L.R., Larsen, W.E., and Rust, S.J. 1982. Four wheel drive tractor axle and drawbar horse power: Field evaluation and analysis. ASAE Paper No. 82-1057.

Freeland, R.S., Tompkins, F.D., and Wilhelm, L.R. 1987. Keeping test errors within acceptable limits. Agricultural Engineering. 13-15.

Gill, W.R., and McCreery, W.F. 1960. Relation of size of cut to tillage tool efficiency. Agricultural Engineering. 372-374, 381.

Gill, W.R., and Vaanden, B.G.E. 1967. Soil Dynamics in Tillage and Traction. Agricultural Research Service. USDA. Agriculture Hand Book No. 316.

Godwin, R.J. 1982. Force measurement on tillage implement. presented at the 9th conference of the International Soil Tillage Research Organization. Socialist Federal Republic of Yugoslavia, OSIJEK. 627-632.

Goe, M.R. 1986. Animal traction in smallholder farms of Ethiopian highlands. Ph.D. Dissertation, Cornell Univ. USA.

Harrison, H.P., and Reed, W.B. 1962. An analysis of draft, depth, and speed of tillage equipment. Canadian Agricultural Engineering. 20-23.

Harrison, H.P., and Reed, W.B. 1961. The design and application of draft transducers using strain gauges. Canadian Agricultural Engineering. Vol (3), No. 1.

Huffnagel, H.P. 1961. Agriculture in Ethiopia. FAO, Rome,

Inns, F.M. 1979. Animal power in agricultural systems with special reference to Tanzania. Presented to the sixth Scientific conference, Tanzania society of animal production. 2-10.

Kocher, M.F., and Summer, J.D. 1987. Design of drawbar transducers for measuring dynamic forces. Transactions of the ASAE. 70-74.

Kyle, J.T. 1961. Farm machinery testing by public agencies. Presented at annual meeting of the ASAE. Washington, D.C. ASAE Paper No. 62-128.

Mckyes,E., and Desir, F.L. 1984. Prediction and field measurements of tillage tool drat forces and efficiency in cohesive soils. Soil and tillage research. 4: 459-470.

McKyes, E. 1978. The calculation of draft forces and soil failure boundaries of narrow cutting blades. Transactions of the ASAE. 20-24.

Mukherjee, D.P., Dutta, S. and Bhattacharya, P. 1961. Studies on draught capacity of Hariana bullocks. Indian Journal of Veterinary Science. 31: 39-50.

Nicholas, M.L., Reed, I.F., and Reaves, C.A. 1958. Soil reaction: To plow share design. Agricultural Engineering. 336-339.

Payne, P.C.J. 1954. The relationship between the mechanical properties of soil and the performance of simple cultivation implements. Reading Univ. Ph.D. Thesis.

Plasse, R., Raghavan, G.S.V., and McKeys, E. 1985. Simulation of narrow blade performance in different soils. Transactions of the ASAE. 28(4): 1007-1012.

Randolph, J.W., and Reed, I.F. 1938. Tests of tillage tools. Agricultural Engineering. 29-33.

Reaves, C.A., and Robert, L.S. 1971. Soil measurements related to the performance of soil-machine system. Earthmoving industry conference of SAE, Chicago, Illinois, 1971 Paper No 710512.

Reaves, C.A., and Schafer, R.L. 1975. Force versus width of cut for moldboard bottoms. Transactions of the ASAE. 852-854,858.

Rowe, R.J., and Barnes, K.K. 1961. Influence of speed elements of draft of a tillage tool. Transactions of the ASAE. 55-57.

Smith, A.J. 1981. Draught animal research, A neglected subject". World Animal Review. 43-48.

Stafford, J.V. 1979. The performance of a rigid tine in relation to soil properties and speed. Journal of Agricultural Engineering Research. 24: 41-56.

Summers, J.D., Khalilian, A., and Batchelder, D.G. 1986. Draft relationships for primary tillage in Oklahoma soils. Transactions of the ASAE. 21(1): 37-39.

Summers, J.D., Kocher, M.F., and Solie, J.B. 1985. Frequency analysis of tillage tool forces. Proceedings of International conference on soil dynamics. Aubum, Alabama. Vol. 2.

Upadhyaya, S.K., Kemble, L.J., Collins, N.E., and Camargo,Jr. F.A. 1985. Accuracy of mounted implement draft prediction using strain gages mounted directly on three-point linkage system. Transactions of the ASAE. 40-46,50.

Upadhyaya, S.K., Williams, T.H., Kemble, L.J., and Collins, N.E. 1984. Energy requirements for chiseling in coastal plain soils. Transactions of the ASAE. 1643-1649.

Upadhyay, R.C., Madan, M.L., and Rao, M.V.N. 1987. Draught animal power research in India Review. World Review of animal production. 23(1): 65-70.

Walker, H.B. 1930. The Engineer and tillage research. Agricultural Engineering. 281-285.

Wildman, W.E., Reaves, C.A., and Gill, W.R. 1978. Effect of slip plow design on draft forces and soil loosening. Transactions of the ASAE. 422-426.

Young, S.C., Johnson, C.E., and Shafer, R.L. 1984. Real time quantification of soil physical condition. ASAE Paper No. 84-1037.

APPENDIX A

COMPUTER PROGRAM USED FOR DATA COLLECTION

```
************************************************************
*                                                          *
*  A BASIC PROGRAM USED TO COLLECT THE DATA IN THE FIELD   *
*                                                          *
*                                                          *
************************************************************

10  REM THIS IS A LOAD CELL PROGRAM
20  LOCATE 4,20
40  DIM FORCE(1000), SF(1000), AVF(1000)
50  OPEN "COM1:9600,N,8,2,CS,DS" FOR RANDOM AS #1
60  IF LOC(1)<>0 THEN X$ = INPUT$(LOC(1),1)
70  CN=17
80  CLS
90  GOSUB 600
100 LOCATE 2,15
110 INPUT " THE VALUE OF N"; N
120 LOCATE 4,15
130 INPUT "FILE NAME"; FILE$
140 OPEN FILE$ FOR OUTPUT AS #2
150 CLS
160 LOCATE 2,15
170 PRINT "PRESS 'B' TO BEGIN SAMPLING
180 Q$ = INKEY$: IF Q$= "  " THEN 170
210 IF Q$ = 'B' OR Q$ = 'b' THEN 230 ELSE 200
230 LOCATE 4,20: PRINT ".........COLLECTING......."
240 FOR I = 1 TO N
260 GOSUB 600
270 FORCE (I) = Z
280 NEXT I
290 INPUT " END "; AAA$
300 FOR II = 1 TO N
310 PRINT #2, II, FORCE (II)
320 NEXT II
330 REM CALCULATE THE MINIMUM AND THE MAXIMUM
340 MIN = 5000
350 FOR K = 1 TO N
360 IF FORCE (K) < MIN THEN MIN = FORCE (K)
370 NEXT K
390 PRINT #2, "THE MINIMUM IS=" USING "#####.##"; MIN
400 MAX = -5000
410 FOR L = 1 TO N
420 IF FORCE (L) > MAX THEN MAX = FORCE (L)
430 NEXT L
450 PRINT #2, "THE MAXIMUM IS=" USING "#####.##"; MAX
460 REM CALCULATE THE AVERAGE FORCE
470 SF (0) = 0
480 FOR J = 1 TO N
490 SF(J) = SF(J-1) + FORCE (J)
```

```
500 NEXT J
510 AVF = SF(N)/N
530 PRINT #2, "THE AVERAGE IS="; USING "#####.##"; AVF
540 PRINT "DO YOU WISH TO TAKE ANOTHER MEASUREMENT?"
550 Q$ = INKEY$: IF Q$ = "  " THEN 550
560 IF Q$ = "Y" OR "y" THEN 170
570 IF Q$ = "N" OR "n" THEN 580 ELSE 550
580 CLOSE #1
590 END
600 PRINT #1, CHR$(CN-1);
610 GOSUB 740
620 PRINT #1, CHR$(161);
630 GOSUB 740
640 HB = CH
650 IF (HB AND 128) <> 0 THEN 620
660 PRINT #1, CHR$(145);
670 GOSUB 740
680 LB = CH
690 HM = HB AND 15
700 Z = LB + 256 * HM
710 IF (HB AND 16) = 0 THEN Z = -Z
720 RETURN
730 REM
740 IF LOC(1) = 0 THEN 740
750 X$ = INPUT$(LOC(1),1)
760 CH = ASC(X$)
770 RETURN
780 END
```

APPENDIX B

LOADCELL CALIBRATION DATA AND GRAPH

TABLE XV

CALIBRATION DATA

WEIGHT (LB)	READINGS (DIGITS)
0	-246.72
4.5	-211.71
29.2	-11.46
55.5	204.05
75.5	365.47
103.5	575.09
206.5	1422.13
308.5	2173.85
414.5	3029.17
501.5	3805.61

The regression equation for the above data is:

WEIGHT = 30.931 + 0.125 * READINGS

R-square value is: 99.99

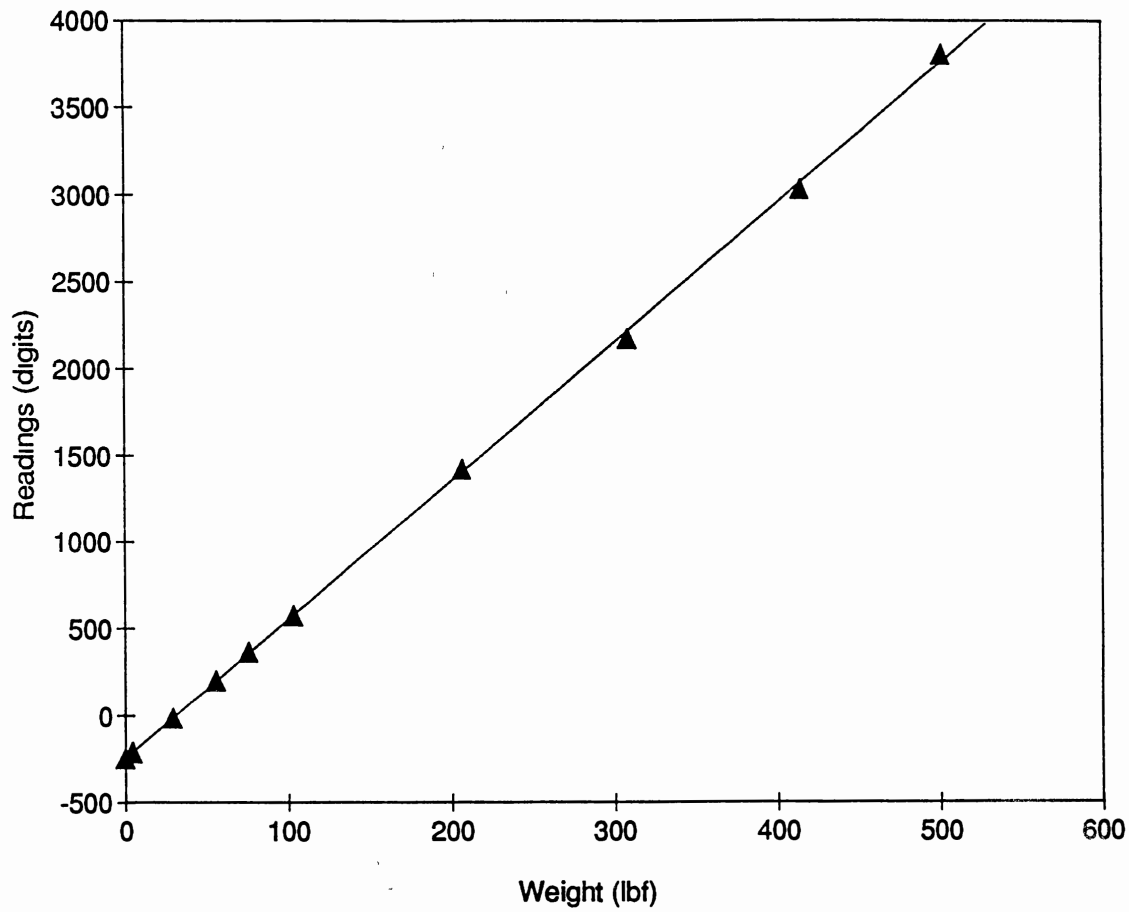

Figure 12. Calibration graph for the load cell.

APPENDIX C

DRAFT AND SPECIFIC DRAFT TABLES

TABLE XVI

DRAFT MEASUREMENT DATA

REP	PLOW-TYPE	SPEED (mph)	ACT.DEPTH (inch)	DRAFT (lb)
1.00	ETH	1.50	4.35	266.17
1.00	ETH	1.50	4.39	248.59
1.00	ETH	1.50	4.10	242.49
1.00	ETH	2.00	3.55	160.41
1.00	ETH	2.00	4.11	329.80
1.00	ETH	2.00	4.00	255.18
1.00	ETH	3.00	3.56	198.02
1.00	ETH	3.00	4.50	305.97
1.00	ETH	3.00	3.90	303.64
2.00	ETH	1.50	4.53	287.24
2.00	ETH	1.50	3.97	220.44
2.00	ETH	1.50	4.16	204.38
2.00	ETH	2.00	3.85	212.37
2.00	ETH	2.00	4.35	275.83
2.00	ETH	2.00	4.45	281.89
2.00	ETH	3.00	3.00	145.30
2.00	ETH	3.00	4.18	225.05
2.00	ETH	3.00	3.50	214.14
3.00	ETH	1.50	4.00	204.83
3.00	ETH	1.50	4.43	261.31
3.00	ETH	1.50	4.25	225.17
3.00	ETH	2.00	4.02	261.05
3.00	ETH	2.00	4.86	281.87
3.00	ETH	2.00	4.04	263.00
3.00	ETH	3.00	3.50	192.66
3.00	ETH	3.00	3.82	296.13
3.00	ETH	3.00	4.52	306.88
1.00	AMER	1.50	3.84	217.15
1.00	AMER	1.50	4.93	326.76
1.00	AMER	1.50	5.20	410.54
1.00	AMER	2.00	3.90	255.59
1.00	AMER	2.00	4.29	317.31
1.00	AMER	2.00	3.98	311.00
1.00	AMER	3.00	3.40	217.67
1.00	AMER	3.00	4.79	402.87
1.00	AMER	3.00	4.47	327.46

TABLE XVI (CONTINUED)

REP	PLOW-TYPE	SPEED (mph)	ACT.DEPTH (inch)	DRAFT (lb)
2.00	AMER	1.50	3.97	186.32
2.00	AMER	1.50	4.91	338.84
2.00	AMER	1.50	4.72	262.74
2.00	AMER	2.00	4.20	303.46
2.00	AMER	2.00	4.73	336.54
2.00	AMER	2.00	5.00	381.63
2.00	AMER	3.00	3.66	249.20
2.00	AMER	3.00	4.41	273.98
2.00	AMER	3.00	4.25	245.74
3.00	AMER	1.50	3.75	263.10
3.00	AMER	1.50	3.59	224.60
3.00	AMER	1.50	3.68	256.74
3.00	AMER	2.00	3.36	270.48
3.00	AMER	2.00	3.29	268.26
3.00	AMER	2.00	4.00	317.90
3.00	AMER	3.00	3.71	250.25
3.00	AMER	3.00	3.87	266.77
3.00	AMER	3.00	3.56	249.62

TABLE XVII

DATA FOR A CROSS-SECTION OF A FURROW

REP	PLOW-TYPE	SPEED (mph)	VERTICAL (inch)	TOP WIDTH (inch)	BOT.WIDTH (inch)
1.00	ETH	1.50	3.57	6.25	2.07
1.00	ETH	1.50	4.29	6.04	2.00
1.00	ETH	1.50	4.00	6.11	1.71
1.00	ETH	2.00	3.36	5.50	1.07
1.00	ETH	2.00	4.57	6.11	1.82
1.00	ETH	2.00	3.86	7.36	1.86
1.00	ETH	3.00	2.50	3.71	1.32
1.00	ETH	3.00	4.03	6.82	1.50
1.00	ETH	3.00	4.21	5.78	1.60
2.00	ETH	1.50	4.46	5.85	2.61
2.00	ETH	1.50	3.61	7.03	1.93
2.00	ETH	1.50	3.89	6.82	1.46
2.00	ETH	2.00	3.50	5.39	1.11
2.00	ETH	2.00	3.89	5.93	1.86
2.00	ETH	2.00	3.82	5.89	2.21
2.00	ETH	3.00	2.54	3.64	1.04
2.00	ETH	3.00	2.57	4.21	1.78
2.00	ETH	3.00	3.75	6.14	1.61
3.00	ETH	1.50	4.00	5.64	1.96
3.00	ETH	1.50	4.03	6.07	1.64
3.00	ETH	1.50	4.53	5.93	1.96
3.00	ETH	2.00	4.32	6.71	1.61
3.00	ETH	2.00	5.21	8.25	1.93
3.00	ETH	2.00	4.50	8.07	2.25
3.00	ETH	3.00	3.71	7.21	2.03
3.00	ETH	3.00	4.03	5.86	2.00
3.00	ETH	3.00	4.89	6.96	2.14
1.00	AMER	1.50	3.39	7.43	2.53
1.00	AMER	1.50	4.60	9.00	2.78
1.00	AMER	1.50	5.21	8.75	2.57
1.00	AMER	2.00	4.21	7.35	2.67
1.00	AMER	2.00	4.17	8.35	2.32
1.00	AMER	2.00	4.86	8.57	2.36
1.00	AMER	3.00	3.67	7.57	2.64
1.00	AMER	3.00	4.39	8.07	2.42
1.00	AMER	3.00	3.75	8.64	2.35
2.00	AMER	1.50	3.86	6.71	3.36
2.00	AMER	1.50	4.64	9.21	2.50
2.00	AMER	1.50	4.32	7.07	4.11

TABLE XVII (CONTINUED)

REP	PLOW-TYPE	SPEED (mph)	VERTICAL (inch)	TOP WIDTH (inch)	BOT.WIDTH (inch)
2.00	AMER	2.00	4.63	8.25	2.75
2.00	AMER	2.00	4.57	7.28	3.93
2.00	AMER	2.00	4.96	8.96	3.53
2.00	AMER	3.00	4.28	8.79	2.14
2.00	AMER	3.00	4.21	7.53	3.39
2.00	AMER	3.00	3.42	7.39	3.46
2.00	AMER	1.50	3.64	7.21	3.57
2.00	AMER	1.50	3.96	6.75	3.11
2.00	AMER	1,50	3.89	7.04	3.57
2.00	AMER	2.00	3.53	6.82	3.25
2.00	AMER	2.00	3.25	6.78	3.39
2.00	AMER	2.00	3.82	7.68	3.50
2.00	AMER	3.00	3.43	7.14	4.07
2.00	AMER	3.00	4.46	7.21	2.75
2.00	AMER	3.00	3.75	7.28	3.89

TABLE XVIII

SPECIFIC DRAFT DATA FOR AMERICAN SWEEP PLOW AND ETHIOPIAN TRADITIONAL PLOW

REP	PLOW-TYPE	SPEED (mph)	X-AREA (sq.in)	AVG.DRAFT (lb)	SPEC.DRAFT (psi)
1.00	ETH	1.50	14.85	244.92	16.49
1.00	ETH	1.50	17.25	232.63	13.49
1.00	ETH	1.50	15.64	262.37	16.78
1.00	ETH	2.00	11.04	172.38	15.61
1.00	ETH	2.00	18.12	347.45	19.17
1.00	ETH	2.00	17.79	285.12	16.03
1.00	ETH	3.00	6.29	90.67	14.41
1.00	ETH	3.00	16.76	175.81	10.49
1.00	ETH	3.00	15.53	255.45	16.45
2.00	ETH	1.50	18.87	243.29	12.89
2.00	ETH	1.50	16.17	236.37	14.62
2.00	ETH	1.50	16.10	213.34	13.25
2.00	ETH	2.00	11.38	177.51	15.60
2.00	ETH	2.00	15.15	203.00	13.40
2.00	ETH	2.00	15.47	235.71	15.24
2.00	ETH	3.00	5.94	89.43	15.06
2.00	ETH	3.00	7.70	92.13	11.96
2.00	ETH	3.00	14.53	221.71	15.26
3.00	ETH	1.50	15.20	203.40	13.38
3.00	ETH	1.50	15.54	273.12	17.58
3.00	ETH	1.50	17.87	216.79	12.13
3.00	ETH	2.00	17.97	317.83	17.69
3.00	ETH	2.00	26.52	256.54	9.67
3.00	ETH	2.00	23.22	269.27	11.60
3.00	ETH	3.00	17.14	150.28	8.77
3.00	ETH	3.00	15.84	319.53	20.17
3.00	ETH	3.00	22.25	313.36	14.08
1.00	AMER	1.50	16.88	190.03	11.26
1.00	AMER	1.50	27.09	323.50	11.94
1.00	AMER	1.50	29.49	427.33	14.49
1.00	AMER	2.00	21.09	267.67	12.69
1.00	AMER	2.00	22.25	256.57	11.53
1.00	AMER	2.00	26.54	323.51	12.19
1.00	AMER	3.00	18.74	257.75	13.75
1.00	AMER	3.00	23.03	360.52	15.65
1.00	AMER	3.00	20.61	211.04	10.24

TABLE XVIII (CONTINUED)

REP	PLOW-TYPE	SPEED (mph)	X-AREA (sq.in)	AVG.DRAFT (lb)	SPEC.DRAFT (psi)
2.00	AMER	1.50	19.44	130.86	6.73
2.00	AMER	1.50	27.17	265.23	9.76
2.00	AMER	1.50	24.15	200.18	8.29
2.00	AMER	2.00	28.60	173.14	6.05
2.00	AMER	2.00	25.61	244.88	9.56
2.00	AMER	2.00	30.98	306.72	9.90
2.00	AMER	3.00	23.39	236.02	10.09
2.00	AMER	3.00	22.99	301.01	13.10
2.00	AMER	3.00	18.55	222.93	12.02
3.00	AMER	1.50	19.62	254.48	12.97
3.00	AMER	1.50	19.52	230.63	11.82
3.00	AMER	1.50	20.64	255.64	12.39
3.00	AMER	2.00	17.77	251.23	14.14
3.00	AMER	2.00	16.53	147.99	8.95
3.00	AMER	2.00	21.35	261.31	12.24
3.00	AMER	3.00	19.23	200.64	10.43
3.00	AMER	3.00	22.21	255.42	11.50
3.00	AMER	3.00	20.94	229.54	10.96

VITA

Befekadu Wolde

Candidate for the Degree of

Master of Science

Thesis: PERFORMANCE EVALUATION OF AN ETHIOPIAN TRADITIONAL PLOW COMPARED TO AN AMERICAN SWEEP PLOW

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Dessie, Ethiopia, August 29, 1960, the son of Wolde Engida and Enanu Haile.

Education: Graduated from Maichew secondary school, Maichew, Ethiopia, in June 1978; received Bachelor of Science degree in Agricultural Engineering from Alemaya College Of Agriculture, Alemaya, Ethiopia in July 1982; completed requirements for the Master of Science degree at Oklahoma State University in December, 1990.

Professional Experience: Teaching, Addis Ababa University (Awassa College of Agriculture); Head of the Department, General Agriculture Department.