This is to certify that the

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CONVENTIONAL AND ALCOHOL FUEL
CONSUMPTION MODEL FOR CROP PRODUCTION
MACHINERY SYSTEMS

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# CONVENTIONAL AND ALCOHOL FUEL CONSUMPTION MODEL
# FOR CROP PRODUCTION MACHINERY SYSTEMS

BY

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ABSTRACT

CONVENTIONAL AND ALCOHOL FUEL CONSUMPTION MODEL
FOR CROP PRODUCTION MACHINERY SYSTEMS

BY

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A computer program was developed which models machine performance to calculate the energy requirements for 50 field operations from soil preparation to transportation. The model was developed with standard relationships of the American Society of Agricultural Engineers.

Validation of the program was made by comparing the results with field data collected on Michigan farms. Further validation was made by comparing results of modeled farms to data of a Michigan Energy Audit Study which collected fuel consumption averages from 52 Michigan farms. Modeled data was within 6 percent of actual data of farms studied.

Results from the computer program for fuel consumption by machine, by operation group, and by enterprise are presented for three farm sizes. Farms are actual Michigan farms which produce corn, oats, wheat, hay, soybeans, navy beans, and sugar beets.

Carlos Fontana

The use of alcohol (ethanol) as an alternative fuel was investigated. Alcohol is better utilized in gasoline engines where engine conversions to run on straight alcohol are possible. With today's energy scenario only tractors with high annual use can be economically operated on a dual-fuel system. For the three farms studied, 34, 29, and 35 percent of the total fuel use could be replaced by alcohol. This would require 1.4, 1.4, and 1.7 percent of the total farming area to be planted in corn for alcohol production to supply the supplementary fuel needs for 79, 200, and 550 hectare farms, respectively.

Four conversion methods were modeled including two methods for spark-ignition engines and two methods of dual-fueling diesel engines. For diesel and gasoline prices of $0.40 per liter, break-even prices for alcohol of $0.30, $0.31, $0.16, and $0.20 per liter were obtained for the first, second, third, and fourth conversion methods, respectively.

Approved ______________________
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To Elena, for her help and encouraging words

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TABLE OF CONTENTS


| | Page |
|---|---|
| LIST OF TABLES | vii |
| LIST OF FIGURES | x |
| LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE | xi |
| Chapter | |
| 1 INTRODUCTION | 1 |
| 2 OBJECTIVES | 6 |
| 3 LITERATURE REVIEW | 7 |
| 3.1 Energy consumption for field operations | 7 |
| 3.2 Machinery models | 21 |
| 3.2.1 Machinery selection models | 21 |
| 3.2.2 Economic models | 22 |
| 3.2.3 Energy models | 25 |
| 3.3 Alcohol utilization | 26 |
| 3.3.1 Alcohol use in spark-ignition engines | 26 |
| 3.3.1.1 Alcohol use in blends with gasoline | 27 |
| 3.3.1.2 Straight alcohol use in gasoline engines | 28 |
| 3.3.2 Alcohol use in diesel engines | 31 |
| 3.3.2.1 Alcohol use through dual-fueling | 31 |
| 3.3.2.2 Straight alcohol use in diesel engines | 33 |

Chapter Page

4 MODEL FORMULATION . . . . . . . . . . . . . . . . . . . . . . 34

4.1 Feasibility study . . . . . . . . . . . . . . . . . . 34

4.1.1 Needs analysis . . . . . . . . . . . . . . . 34

4.1.2 System identification . . . . . . . . . . 35

4.1.2.1 Model inputs . . . . . . . . . . 36

4.1.2.2 Model outputs . . . . . . . . . . 37

4.1.3 Problem formulation . . . . . . . . . . . 37

4.2 Model description . . . . . . . . . . . . . . . . . . 38

4.2.1 Energy subroutine . . . . . . . . . . . . 38

4.2.1.1 Draft requirements for tillage operations . . . . . . . . . . . 38

4.2.1.2 Draft requirements for seeding operations . . . . . . . . . . . 43

4.2.1.3 Draft requirements for cultivation operations . . . . 44

4.2.1.4 Draft requirements for fertilizer and chemical application . . . . . . . . . . . 44

4.2.1.5 Power requirements for harvesting operations . . . . . 45

4.2.1.6 Energy requirements for transportation . . . . . . . . . 48

4.2.1.7 Load determination . . . . . . 49

4.2.2 Fuel consumption subroutine . . . . . . 50

4.2.3 Alcohol subroutine . . . . . . . . . . . . 57

4.2.4 Cost subroutine . . . . . . . . . . . . . 58

Chapter | Page


5 DATA COLLECTION AND VALIDATION . . . . . . . . . . . . . . . 60

5.1 Validation by operation . . . . . . . . . . . . . 60

5.1.1 Data collection . . . . . . . . . . . . 60

5.1.2 Validation . . . . . . . . . . . . . . . . 71

5.2 Whole farm validation . . . . . . . . . . . . . . 74

5.2.1 Energy Audit Study data . . . . . . . . 74

5.2.2 Validation . . . . . . . . . . . . . . . . 79

5.2.2.1 Small-size farm . . . . . . . . . 79

5.2.2.2 Medium-size farm . . . . . . . . 81

5.2.2.3 Large-size farm . . . . . . . . . 83

6 ETHANOL AS TRACTOR FUEL . . . . . . . . . . . . . . . . . . 87

6.1 Conversion methods . . . . . . . . . . . . . . . 87

6.2 Ethanol use on typical farms . . . . . . . . . 88

6.2.1 Small-size farm . . . . . . . . . . . . 88

6.2.2 Medium-size farm . . . . . . . . . . . . 90

6.2.3 Large-size farm . . . . . . . . . . . . 93

6.3 Tractor use and ethanol feasibility . . . . . . 95

6.3.1 Gasoline tractor with minor modifications . . . . . . . . . . . . . . . 96

6.3.2 Gasoline tractor with increased compression . . . . . . . . . . . . . . . 96

6.3.3 Dual-fueling with spray-injection . . . 97

6.3.4 Dual-fueling with carburated ethanol . . 98

7 SUMMARY . . . . . . . . . . . . . . . . . . . . . . . . 103

8 CONCLUSIONS . . . . . . . . . . . . . . . . . . . . . . 105

LIST OF REFERENCES . . . . . . . . . . . . . . . . . . . . . 106

GENERAL REFERENCES . . . . . . . . . . . . . . . . . . . . . 113

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1 | Fuel consumption for tillage operations for 8 states in liters of diesel fuel per hectare . . . . . . . . . . . . . . | 8 |
| 2 | Fuel consumption for seeding operations for 10 states in liters of diesel fuel per hectare . . . . . . . . . . . | 9 |
| 3 | Fuel consumption for cultivating operations for 7 states in liters of diesel fuel per hectare . . . . . . . . . . . | 10 |
| 4 | Fuel consumption for spraying and fertilizing operations for 8 states in liters of diesel fuel per hectare . . . . . | 11 |
| 5 | Fuel consumption for harvesting operations for 6 states in liters of diesel fuel per hectare . . . . . . . . . . . | 12 |
| 6 | Fuel consumption for transportation operations for 4 states in liters of diesel fuel per hectare (4.8km from the farm) . . . . . . . . . . . . . . . . . . . . . . . . | 14 |
| 7 | Approximate energy requirements for corn production per hectare (Madex and Bakker-Arkema, 1978) . . . . . . . . . . | 18 |
| 8 | Energy requirements for New York state agriculture (Gunkel et al., 1974) . . . . . . . . . . . . . . . . . . . | 18 |
| 9 | Fuel consumption for field operations for 4 cropping systems in the state of Michigan (Christenson, 1977) . . . | 19 |
| 10 | Fuel requirements for corn production systems in liters of diesel fuel per hectare (Collins et al., 1978) . . . . . | 20 |
| 11 | Specific fuel consumption for 13 diesel tractors (Nebraska Tractor Test data) . . . . . . . . . . . . . . . | 52 |
| 12 | Specific fuel consumption for 13 gasoline tractors (Nebraska Tractor Test data) . . . . . . . . . . . . . . . | 54 |
| 13 | Values for the parameters used in the fuel consumption model . . . . . . . . . . . . . . . . . . . . . . . . . . . | 55 |
| 14 | Machinery size and performance for farm number one in the fall season of 1980 . . . . . . . . . . . . . . . . . . . . | 61 |

Table | Page


15 Machinery performance and fuel consumption for farm number one in the fall season of 1980 . . . . . . . . . . . 62

16 Machinery size and performance for farm number two in the fall season of 1980 . . . . . . . . . . . . . . . . . . . 68

17 Machinery performance and fuel consumption for farm number two in the fall season of 1980 . . . . . . . . . . . 69

18 Fuel consumption for field operations on farm number one . 72

19 Fuel consumption for field operations on farm number two . 73

20 Crops grown on the small-size farm in 1979 . . . . . . . . . 75

21 Power units used on the small-size farm in 1979 . . . . . . 76

22 Crops grown on the medium-size farm in 1979 . . . . . . . . . 76

23 Power units used on the medium-size farm in 1979 . . . . . 77

24 Crops grown on the large-size farm in 1979 . . . . . . . . . 77

25 Power units used on the large-size farm in 1979 . . . . . . 78

26 Tractor usage level and fuel consumption for the small-size farm . . . . . . . . . . . . . . . . . . . . . . . . 79

27 Fuel consumption by operation group for a small-size farm . 80

28 Fuel consumption by enterprise for the small-size farm . . 81

29 Machine usage level and fuel consumption for the medium-size farm . . . . . . . . . . . . . . . . . . . . . . . . 82

30 Fuel consumption by operation group for the medium-size farm . . . . . . . . . . . . . . . . . . . . . . . . . . 82

31 Fuel consumption by enterprise for the medium-size farm . . 83

32 Machine usage level and fuel consumption for the large-size farm . . . . . . . . . . . . . . . . . . . . . . . . . . 84

33 Fuel consumption by operation group for the large-size farm . . . . . . . . . . . . . . . . . . . . . . . . . . 85

34 Fuel consumption by enterprise for the large-size farm . . 86

35 Parameters used for 4 conversion methods . . . . . . . . . 88

| Table | | Page |
|---|---|---|
| 36 | Fuel consumption for tractor number 1 using 2 different conversion methods on a small-size farm . . . . . . . . . . | 89 |
| 37 | Break-even prices for alcohol fuel for 2 conversion methods on a small-size farm . . . . . . . . . . . . . . . . . . | 90 |
| 38 | Fuel consumption for tractor number 2 using 2 conversion methods on a medium-size farm . . . . . . . . . . . . . . . | 91 |
| 39 | Break-even prices for alcohol fuel for tractor number 2 on a medium-size farm . . . . . . . . . . . . . . . . . . . . | 92 |
| 40 | Diesel and alcohol fuel use when spray injection was used for 5 different tractors . . . . . . . . . . . . . . . . . | 94 |
| 41 | Diesel and alcohol fuel use when the carburated dual-fuel system was used for 5 different tractors . . . . . . . . . | 94 |
| 42 | Break-even prices for alcohol fuel for 5 tractors and 2 dual-fuel methods for a large-size farm . . . . . . . . . . | 95 |
| 43 | Ethanol break-even prices for gasoline tractor with minor modifications . . . . . . . . . . . . . . . . . . . . . . . | 96 |
| 44 | Ethanol break-even prices for gasoline tractor with increased compression . . . . . . . . . . . . . . . . . . . . . | 97 |
| 45 | Ethanol break-even prices when dual-fueling with spray injection is used . . . . . . . . . . . . . . . . . . . . . . | 99 |
| 46 | Ethanol break-even prices when dual-fueling with carburated ethanol is used . . . . . . . . . . . . . . . . . . . . | 99 |
| 47 | Ethanol break-even prices for 2 recovery periods and 4 conversion methods (conventional fuel prices of $0.40 per liter) . . . . . . . . . . . . . . . . . . . . . . . . . . | 100 |
| 48 | Diesel prices required to allow ethanol to be economically feasible with a production cost of $0.46 per liter . . . . | 101 |

## LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1 | Model flowchart | 39 |
| 2 | Specific fuel consumption as a function of engine load | 53 |
| 3 | Tractor usage levels and ethanol break-even prices for gasoline and diesel prices of $0.40 per liter | 102 |

## LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

| | |
|---|---|
| A | discount rate |
| ACAF | annual fuel cost |
| ACC | annual conversion cost |
| AKPL | average fuel consumption |
| ALOG | natural logarithm |
| ALUSE | alcohol use |
| AREA | area |
| BC | bite length |
| FEPA | break-even price of alcohol |
| $CA_n$ | draft parameter |
| CAP | capacity |
| CAREA | area covered |
| $CC_n$ | draft parameter |
| CFC | conventional fuel cost |
| CFP | conventional fuel cost |
| CFUSE | conventional fuel use |
| CLP | LP gas consumption |
| cm | centimeter |
| $C_n$ | draft parameter |
| CO | carbone monoxide |
| CONCOS | conversion cost |
| CRF | capital recovery factor |
| DCON | diesel fuel consumption |
| DRAFT | implement draft |
| EFC | effective field capacity |

| | |
|---|---|
| EFF | machine field efficiency |
| ENNE | power requirement |
| EXP | exponential |
| FCHA | fuel consumption per hectare |
| FCP | alcohol fuel consumption parameter |
| FD | field distance |
| FLPH | fuel consumption per hour |
| FR | feed rate |
| GCON | gasoline fuel consumption |
| h | hour |
| ha | hectare |
| ICN | soil surface condition |
| ICOTY | conversion type |
| ID | identification variable for grain drills |
| IDEN | crop density |
| IFACT | load ranges |
| IST | soil type |
| LOAD | engine load |
| m | operation number |
| n | operation number |
| NB | number of bottoms |
| NK | number of knives |
| NN | recovery period |
| NOP | operation number |
| $NO_x$ | nitrates |
| NROWS | number of rows |
| PAR | alcohol fuel consumption parameter |

| | |
|---|---|
| PAVA | power available |
| PREQ | power required |
| PTO | power take off |
| r | revolution |
| SI | spark ignition |
| SLIP | wheel slip |
| SPEED | field speed |
| TD | working depth |
| TE | tractive efficiency |
| TCOSTA | alcohol fuel costs |
| TCOSTD | conventional fuel costs |
| TDRAFT | total implement draft |
| TTOTA | total alcohol fuel use |
| UDRAFT | unit draft |
| USE | machine use |
| YIELD | crop yield |
| W | implement weight |
| WIDTH | implement width |
| WM | machine weight |

# CHAPTER 1

# INTRODUCTION

In spite of public awareness of limited petroleum availability, conservation of energy is not being practiced by the majority of farmers (Ozkan, et al. 1979). In the last 25 years, the population increase has forced most nations to continue to search and to improve technology. Much of the new technology is much more energy dependent. For example, in an agricultural production system, more energy is now utilized to replace labor through use of chemicals, and large electrical and field machines than was used 25 years ago.

The world petroleum price has increased in an unexpected rate in the last 8 years. With the increased price, uncertainties about the availability of fossil fuels is a major concern not only for the producers but also for the consumers. Agriculture is known as one of the few industries that produces more energy than it uses. Despite this fact, improvements can be obtained through using more energy efficient methods of crop production. Farmers, by adopting new machinery systems such as conservation and no-tillage systems can not solve the energy problem, but they may be better prepared for future shortages.

The events of the last 8 years suggest that availability and cost of energy will play an increasingly important role in crop production. The competition with other sectors of society and diminishing petroleum reserves will produce higher fuel costs in the future. Agriculture consumes only 3 percent of the U.S. total energy consumption, but modern agriculture is highly dependent on fuels and petroleum based products of pesticides and fertilizers.

In 1973 we experienced an energy crisis which increased interest in the energy demand of crops. The total energy input of a particular practice not only includes the fossil fuel used directly, but also the energy used in manufacturing, marketing and repairing equipment as well as the manual labor required to perform the operations. The amount of energy used indirectly in the production process, may be difficult to lower. More efficient machines and tractors can be designed, and more important, the total use of energy for field operations for cropping systems can be reduced considerably.

Primary tillage has always been one of the larger power consuming operations on a farm (Zoz, 1974). Over the years the moldboard plow has been the most accepted primary tillage tool; only recently has it been challenged by various systems offering reduced tillage.

Tractors are prime movers for agriculture and are used in most farming operations. Although the major portion of fuel and oil used on the farm is consumed by the farm tractor, consideration should also be given to other machines, such as combines, trucks and self-propelled machines.

From the U.S. government reports, in 1973, an average of 157 liters of refined petroleum fuel (gasoline, diesel, and liquefied petroleum gas) per hectare was used for all crops in the United States. Fuel use varied from 28 liters per hectare for pasture and hay to over 468 liters per hectare for Irish potatoes and fruit. In 1974 the top three crops in the U.S. in terms of hectares grown were: corn for grain, soybeans, and wheat. These accounted for over half of all fuel used in crop production (Gunkel et al., 1974).

Better management decisions can be made if better data for field operations, crops, cropping systems, and machines are available for the farmers and decision makers. According to Hunt (1968) one third of crop production costs can be attributed to machinery costs. This makes the selection of a compliment of machines and machine replacement decisions, the major decisions facing machinery managers. Mayfield et al., (1980), report the costs per hour for a 121 Kw tractor. Fuel and lubrication had a cost of $3.20 per hour in the spring season of 1977 and this accounted for 30 percent of the total tractor cost. In the fall season of 1980 the fuel and lubrication costs accounted for 37 percent of the total tractor costs, with a cost of $7.93 per hour. This shows not only the importance of the fuel and lubrication costs in total tractor costs, but also the rising cost of petroleum fuels.

Present fuel consumption figures do not easily permit calculations and comparisons with speed and load conditions under which most tractors operate (Persson, 1969). Tractor engines operate predominantly under part load and varying speed conditions. The determination of tractor field performance such as wheel slip, tractive efficiency, fuel economy, and fuel costs require detailed models for accurate prediction.

Fuel requirements for a specific operation can, and do, vary widely from one state to another, from one section of the state to another, from one farm to another, and even within the same farm. This is due to a number of factors, such as the following:

1. Weather
2. Variations in the soil type
3. Topography
4. Soil condition (drainage)
5. Size of field
6. Depth of tillage
7. Machine type (physical characteristics)

8. Operating speed

9. Match between power unit and implement

10. Soil surface condition

11. Operator working habits and management ability

All the above factors make the recommendation of the amount of fuel for field operations very difficult to be presented in a short range. White (1974) reported that it takes 8.5 to 35.0 liters of diesel fuel to plow one hectare of land in the state of Michigan. A study where all the above factors are included requires a systems approach.

The intensive search for energy independence has led many in the United States to consider using alcohol, and vegetable oils as an extender or replacement for gasoline and diesel fuels. These alternative fuels are produced from renewable resources. Alcohol, particularly ethanol and methanol, have long been considered as potential fuels for internal combustion engines. Recently they have received more attention because of rapidly increasing costs and serious future depletions of non-renewable petroleum resources in the United States.

Four basic methods are available for using alcohol in spark-ignition and diesel engines. These include the following:

1. Use of alcohol in gasoline engines after minor modifications such as a carburetor change or replacement to provide a correct air/fuel ratio for alcohol.

2. Use of alcohol in gasoline engines after a major modification of rebuilding the engine with increased compression as well as carburetor changes.

3. Use of alcohol in diesel engines, when alcohol is sprayed into the intake air by pressurized air from the turbocharger.

4. Use of alcohol in diesel engines where alcohol is aspirated into the intake air through a carburetor system.

The idea of using alcohol as a motor fuel is as old as the automobile itself. Methanol is today used in racing cars because of its special characteristics such as higher octane rating, allowing higher compression ratios which deliver more power out of the engine. Correon in 1928 wrote "it may not be long before the world will have to grow its motor fuel rather than depend on oil wells." Alcohol is viewed by some as the most promising substitute as a motor fuel. Alcohol burns very well when engines are designed for alcohol fuel. Research and road tests have shown that alcohol does not have to be pure to be used in spark-ignition engines. These engines work well on alcohol containing up to 15 percent water.

Diesel engines burn fuels by compression heating the air-fuel mixture to the ignition temperature. Because of this, a wide variety of burn very well on unmodified diesel engines due to uncontrolled ignition. Alcohol can, however, be used as a supplement in diesel engines through dual-fueling.

In the future, engines may be redesigned for alcohol use. Since most farm tractors are diesel fuelled, a long period of time will be required for alcohol engines to replace diesel engines. The dual-fuel systems may be a good way of displacing part of the diesel fuel, in field operations. Substitution rates of 30 to 45 percent can be obtained by using the dual-fuel systems.

# CHAPTER 2

# OBJECTIVES

The overall objective of this work was to study the fuel consumption on typical farms to determine the feasibility of using alcohol as an alternative fuel. To obtain this overall objective, the following specific objectives were set:

1. To write a computer program to model the fuel consumption for tractors, combines, trucks, and self-propelled machines performing different operations on Michigan farms.
2. To validate the fuel consumption model by comparing modeled fuel requirements for different machinery sets and crop rotations to actual farm fuel requirements.
3. To determine the portion of the machinery fuel requirement which can be met with alcohol fuel based upon the available methods of using alcohol fuel and the efficiencies of these methods.
4. To determine a break-even price for producing alcohol in order to allow tractor conversion and utilization of alcohol to be economically feasible.

# CHAPTER 3

# LITERATURE REVIEW

## 3.1 Energy consumption for field operations.

In the last 10 years several researchers have studied fuel use for specific field operations. comparisons between some of the results are made in Tables 1 through 6. Fuel consumption in liters of diesel fuel per hectare are summarized for field operations from soil preparation to transportation. Most of the information was obtained from Extension Bulletins as referenced on the tables.

Several researchers studied tractor performance under field condition in order to determine the energy requirements for realistic situations. Ricketts (1961) instrumented a tractor for field tests and measured the amount of power required for farm operations. With the test results and information obtained by cooperating farmers, he determined the optimum combinatin of power and engine speed for farm operations. This was a relevant contribution because some farm operations require part load, part throttle conditions, likewise there are others which require near full load and full governed speeds.

Gunkel et al. (1974) made an engineering analysis of farm operations. The information on the engineering aspect of fuel use is composed of two parts. The first section outlines the fuel needs of various agriculture operations for tillage, chemical application, planting, cultivation and harvesting. The second section adds the appropriate operations to determine the fuel needs for each of the various crops grown in the state of New York. The following were

Table 1. Fuel consumption for tillage operations for 8 states in liters of diesel fuel per hectare.

| State / Operation | Illinois | Iowa | Kansas | Michigan | Missouri | New York | Ohio | Wisconsin |
|---|---|---|---|---|---|---|---|---|
| Moldboard plow | 20.38 | 17.77 | 18.90 | 17.02 | 15.62 | 27.50 | 17.02 | 17.77 |
| Chisel plow | 14.77 | 11.22 | 10.20 | 10.47 | 10.47 | 16.27 | 10.47 | 9.82 |
| Heavy tandem disk | | 8.88 | 8.10 | 7.20 | | 7.20 | 7.20 | 13.09 |
| Standard tandem disk | | 5.61 | | 5.89 | 4.58 | | 5.89 | 6.55 |
| Spring tooth harrow | | 6.54 | | 3.93 | 2.99 | 6.55 | 3.93 | 4.68 |
| Field cultivator | | 7.48 | | 6.54 | 3.93 | 10.19 | 6.54 | 6.54 |
| Rotary tiller | | 14.96 | | | | 16.27 | | |
| Spike tooth harrow | | | | 2.62 | 1.68 | | 2.62 | 2.62 |
| Field conditioner | | | 5.40 | | | | | |
| Rod weeder | | | 4.50 | | | 4.96 | | |
| One way disk | | | 5.80 | | | | | |
| Subsoiler | | | | | | 20.39 | | |

Sources: References 25, 29, 37, 38, 39, 42, 43

Table 2. Fuel consumption for seeding operations for 10 states in liters of diesel fuel per hectare.

| Operation / State | Florida | Illinois | Iowa | Kansas | Michigan | Missouri | New York | Ohio | Wisconsin | Wyoming |
|---|---|---|---|---|---|---|---|---|---|---|
| Row crop planter | 2.99 | | 4.21[a]<br>5.61[b] | 4.70 | 4.58[a]<br>5.89[b] | | 8.79 | 4.58[a]<br>5.89[b] | 3.92[a]<br>5.23[b] | 5.50 |
| Grain drill | 3.37 | | 3.28 | 3.80 | 3.28 | 2.99 | 3.93 | 3.28 | 3.27 | 3.25 |
| Potato Planter | | | | | 8.84 | | 14.59 | 8.84 | 9.82 | |
| Vegetable planter | | | | | 8.84 | | 4.30 | 8.84 | | |
| Transplanter | | | | | 11.78 | | 43.11 | 11.78 | 11.78 | |
| No till planter | | | 4.68 | | | 1.50 | | | | |
| Harrow planter | | | 8.42 | | | | | | | |
| Rotary strip till-planter | | | 9.82 | | | | | | | |
| Broadcast seeder | | | 1.40 | | | | | | | |
| Disk Planter | | 12.91 | | | | | | | | |
| Small grain seed | | 12.40 | | | | | | | | |
| Hill planting | | | | | | | 9.91 | | | |

a. Seeding only
b. Seeding, fertilizer, herbicide

Sources: References 25, 29, 37, 38, 39, 41, 42, 43, 48

Table 3. Fuel consumption for cultivating operations for 7 states in liters of diesel fuel per hectare.

| State<br>Operation | Iowa | Kansas | Michigan | Missouri | New York | Ohio | Wisconsin |
|---|---|---|---|---|---|---|---|
| Row crop, 1st cultivator | | 4.00 | 3.93 | 3.18 | 3.52 | 3.93 | 3.93 |
| Row crop, 2nd cultivator | | | 3.28 | | | 3.28 | 3.28 |
| Vegetable crop cultivator | | | 5.23 | | | 5.23 | 5.23 |
| Rotary hoe | 1.87 | | 1.64 | 1.68 | | 1.64 | 1.96 |
| Sweet cultivator | 4.21 | | | | | | |
| Rolling cultivator | 3.74 | | | | | | |
| Cultivator with disk tillers | 4.21 | | | | | | |
| Powered rotary cultivator | 6.55 | | | | | | |
| Hill forming (pre-planting) | | | | | 7.29 | | |
| Hill potatoes | | | | | 8.98 | | |
| Hill reshaping | | | | | 4.21 | | |

Sources: References 25, 29, 37, 38, 39, 43

Table 4. Fuel consumption for spraying and fertilizing operations for 8 states in liters of diesel fuel per hectare.

| State / Operation | Florida | Iowa | Kansas | Michigan | Missouri | New York | Ohio | Wisconsin |
|---|---|---|---|---|---|---|---|---|
| Row crop sprayer | | 0.93 | 2.90 | 0.98 | 0.93 | 2.71 | 0.98 | 1.31 |
| Orchard sprayer | 20.06* | | | 4.91 | | | 4.91 | 6.55 |
| Fertilizer spreader | | 1.40 | 2.20 | 1.31 | | 2.71 | 1.31 | 1.96 |
| Anhydrous ammonia applicator | | 5.61 | 6.00 | 10.47 | | | 10.47 | 11.12 |
| Chisel-fertilizer application | | | | | | 20.20 | | |

* citrus

Sources: References 25, 29, 37, 38, 39, 41, 43

Table 5. Fuel consumption for harvesting operations for 6 states in liters of diesel fuel per hectare.

| State / Operation | Florida | Iowa | Michigan | Missouri | Ohio | Wisconsin |
|---|---|---|---|---|---|---|
| Cutterbar mower | 4.02 | 3.27 | 3.92 | 2.15 | 3.92 | 3.27 |
| Mower conditioner - PTO | | 5.61 | 6.54 | | 6.54 | 6.54 |
| Mower conditioner - self propelled | | 4.68 | 9.16 | | 9.16 | 6.54 |
| Hay rake | 1.96 | 2.34 | 1.97 | 1.31 | 1.97 | 1.87 |
| Hay baler | | 4.21 | 9.16 | 6.55 | 9.16 | 9.40 |
| Straw baler | | | 7.20 | | 7.20 | 7.20 |
| Forage harvester, flail, green chop | | 11.96 | 22.26 | 6.55 | 22.26 | 22.91 |
| Forage harvester, flail, dray hay or straw | | | 11.13 | | 11.13 | |
| Forage harvester, cylinder flywheel, haylage | | 33.67 | 22.26 | 20.57 | 22.26 | 16.37 |
| Forage harvester, dray hay or straw | | | 9.82 | 3.27 | 9.82 | 9.82 |
| Combine row crop, 1 m row | | 17.77 | 20.95 | | 20.95 | 10.64 |
| Combine row crop, 76 cm row | | | 23.57 | | 23.57 | 21.51 |
| Combine harvester, small grains | 14.47 | | 9.82 | 6.17 | 9.82 | 9.82 |
| Combine harvester, peas and soybeans | | 10.29 | 10.80 | | 10.80 | 11.22 |
| Corn harvesting, 1 m row | | 14.96 | 11.78 | 10.66 | 11.78 | 12.44 |

Table 5 (cont'd)

| State<br>Operation | Florida | Iowa | Michigan | Missouri | Ohio | Wisconsin |
|---|---|---|---|---|---|---|
| Corn harvesting, 76 cm row | | | 13.75 | | 13.75 | 13.75 |
| Corn picker, 1 m row | 13.47 | 10.75 | 8.51 | | 8.51 | 8.51 |
| Corn picker, 76 cm | | | 9.16 | | 9.16 | 9.16 |
| Corn picker-sheller and picker grinder, 1 m row | | | 9.82 | | 9.82 | 9.82 |
| Corn picker-sheller and picker grinder, 76 cm row | | | 11.78 | | 11.78 | 11.78 |
| Potato harvester | | | 14.34 | | 14.34 | 15.71 |
| Sugar beet harvester | | | 13.75 | | 13.75 | |
| Vegetable harvester | | | 15.71 | | 15.71 | |
| Tree fruit harvester (shaken) | | | 26.18 | | 26.18 | |
| Vine topper (beets and potatoes) | | | 13.74 | | 13.74 | |
| Stalk shredder | | 4.68 | 5.89 | | 5.89 | |
| Bean puller and windrower | | | 3.93 | | 3.93 | |
| Rotary mower | | | | 6.17 | | |

Sources: References 37, 38, 39, 41, 43

Table 6. Fuel consumption for transportation operations for 4 states in liters of diesel fuel per hectare (4.8 Km from the farm).

| State<br>Operation | Iowa | Michigan | Ohio | Wisconsin |
|---|---|---|---|---|
| Corn silage, haylage, potatoes sugar beets, cherries | | 27.82 | 27.82 | 32.73 |
| Small grain, shelled corn, vegetable crops, apples | | 5.56 | 5.56 | 10.29 |
| Baled hay, straw | | 3.60 | 3.60 | 10.29 |
| Green forage | 6.55 | | | |
| Corn silage | 34.14 | | | |
| Grain corn | 5.38 | | | |
| Soybeans | 1.92 | | | |
| Haylage | 6.55 | | | |
| Transport grains | 2.72 | | | |

Sources: References 37, 38, 39, 43

followed to determine the fuel consumption per operation:

1. The range of draft requirements and speed from the ASAE yearbook were selected.
2. The power-take off requirements for each operation as outlined in the ASAE yearbook (1974) were calculated.
3. A tractor size most closely meeting this need was selected from Nebraska Tractor Test data.
4. The fuel efficiency was used to calculate the fuel requirements.
5. A 10 percent increase in fuel use was given to account for mismatching of tractor and implement.

Three values for fuel requirments were given; a low value for muck soils and some sand soils, an average value for clay loam soils, and a high value for heavy clay soils.

The tractive efficiency is a very important variable when determining the power that can be delivered by a tractor under field conditions. Burt et al., (1979) found that the net traction, input and output power are functions of dynamic load and travel reduction. They showed that tractive efficiency can be improved under field conditions by selecting the appropriate dynamic load for a particular soil condition.

Sulek and Lane (1968) pointed out that in most cases the Nebraska PTO full economy data are used incorrectly. Statistical analyses were done by using the Nebraska PTO varying power and fuel consumption test to evaluate the fuel economy of tractor models. A poor correlation was found.

Fuel consumption comparisons between different sizes, models and brands of tractors are frequently made in connection with the purchase of tractors (Persson, 1969). Because engines operate predominantly under part load and varying speed conditions.

Persson developed an empirical relationship between fuel consumption and power. The fuel consumption for crawler, 2 wheel drive, and 4 wheel drive tractors was given as a function of the net heat value of fuel, engine speed, engine displacement, engine power as measured at the PTO shaft, and engine constants determined from Nebraska PTO test data. The same equation was used by Macnab (1976) to determine the fuel consumption of tractors under field conditions.

Better information to assist farmers, fuel suppliers, and others concerned with agricultural production is needed in estimating fuel requirements, both for specific farming opeations and for the overall operation of the total farm enterprise (White, 1974). White presented the fuel requirements for farm tractors when working at approximately 75 percent load. Tractors are normally designed so that this is the best load in terms of fuel efficiency, safety, and reduced engine wear. Farmers sometimes need the job done in a certain period of time, so they have large machines. Mismatching is difficult to avoid and tractors work underloaded or overloaded during many operations.

Fuel consumption for field operations, from soil preparation to transportation, to produce corn for silage in the state of Michigan is presented by White (1974) as 76.9 liters of diesel fuel per hectare. Christenson (1977) stated that 78.3 liters of diesel fuel per hectare were required to do the same operations outlined by White. Madex and Bakker-Arkema (1978) presented fuel requirements to produce and dry corn for grain in the state of Michigan. According to them, it takes 57.26 liters of diesel fuel per hectare to perform the field operations (drying is not included). The approximate energy requirements for corn production per hectare are presented in Table 7. The requirements for New York state major crops are presented by Gunkel et al. (1974) in Table 8.

Christenson (1977) presented the fuel requirements (for the state of Michigan) for 4 cropping systems. The fuel consumption for these field operations is listed in Table 9.

Several researchers have studied the energy requirements for specific soil types and for specific implements. Collins et al., (1978) studied the energy requirements for tillage systems on Costal Plain soils. Speeds for minimizing draft have been determined where draft is related to the cone index. Collins presented field machinery data for corn production on two soil types (loamy sand and silty loam). Table 10 shows the fuel requirements for corn production systems. Based on the results a regression analysis was made to determine the unit draft. The relationship between unit draft and speed for a soil type was found. The results showed that the least energy requirements (l/ha) for a no-tillage planter was obtained with the speed of 12.63 Km/h, while a disk tiller with seeding attachment was 9.81 Km/h.

Table 7. Approximate energy requirements for corn production per hectare (Madex and Bakker-Arkema, 1978)

| Operations | Diesel fuel (l/ha) |
|---|---|
| 1. Moldboard plow | 17.0 |
| 2. Disk | 5.9 |
| 3. Harrow | 2.6 |
| 4. Plant | 5.9 |
| 5. Spray | 1.0 |
| 6. Anhydrous ammonia application | 10.5 |
| 7. Combine | 11.8 |
| 8. Transport | 2.6 |
| TOTAL | 57.3 |

Table 8. Energy requirements for New York state agriculture (Gunkel et al., 1974).

| Enterprise | Diesel fuel equivalent (l/ha) |
|---|---|
| 1. Corn | 63.5 |
| 2. Soybeans* | 49.8 |
| 3. Wheat | 52.4 |
| 4. Corn silage | 102.7 |
| 5. Dry beans | 103.5 |
| 6. Hay bale | 66.2 |
| 7. Hay silage | 77.3 |
| 8. Oats | 64.1 |
| 9. Rye | 26.2 |
| 10. Barley | 64.1 |

* = no cultivation

Table 9. Fuel consumption for field operations for 4 cropping systems in the state of Michigan (Christenson, 1977).

| Operations / Systems | Fuel consumption in liters of diesel fuel per hectare | | | |
|---|---|---|---|---|
| | Alfalfa-Hay | Corn silage | Corn+Soybens | Navy-beans, wheat & Sugar beets |
| Land preparation | 22.91 | 22.91 | 47.79 | 77.91 |
| Planting | 3.27 | 5.89 | 5.89 | 20.95 |
| Cultivation | | | 7.20 | 14.40 |
| Fertilizer application | 6.55 | 11.78 | 11.78 | 13.09 |
| Fertilizer hauling | 7.39 | 2.24 | 2.71 | 5.99 |
| Herbicide application | 2.99 | 1.03 | 1.96 | 3.93 |
| Insecticide application | 3.93 | | | |
| Pulling windrowing navy beans | | | | 7.86 |
| Cut windrowing alfalfa | 146.65 | | | |
| Baling alfalfa | 146.65 | | | |
| Chopping | | 23.57 | | |
| Combining | | | 27.50 | 31.42 |
| Hauling | 40.03 | 13.09 | 14.96a | 50.50[1] |
| Hauling | | | 4.97b | 1.22[2] |
| Hauling | | | | 2.93[3] |
| Topping sugar beets | | | | 13.75 |
| Harvesting sugar beets | | | | 13.75 |
| Totals Rotation | 380.37 | 80.53 | 124.76 | 257.76 |
| Year | 70.06 | 80.53 | 62.38 | 64.44 |

a = corn b = soybeans 1 = sugar beets 2 = navy beans 3 = wheat

Table 10. Fuel requirements for corn production systems in liters of diesel fuel per ha (Collins et al., 1978).

| Soil types and tillage systems | Loamy sand | | | Silty loam | | |
|---|---|---|---|---|---|---|
| Operations | Moldboard plow | Chisel plow | No till | Moldboard plow | Chisel plow | No till |
| 1. Moldboard plow | 20.48 | | | 23.90 | | |
| 2. Chisel plow | | 13.65 | | | 20.48 | |
| 3. Disk | 6.82 | 6.15 | | 8.19 | 10.24 | |
| 4. Disk | | | | 6.82 | 6.82 | |
| 5. Spring tooth | 4.09 | 4.09 | | 4.77 | 4.77 | |
| 6. Pulvimuch | | | | 6.15 | 6.15 | |
| 7. Plant | 6.82 | 6.82 | 6.82 | 12.97 | 12.97 | 12.97 |
| 8. Spray | | | | 2.73 | 2.73 | 4.09 |
| Totals | 38.21 | 30.71 | 6.82 | 65.53 | 64.16 | 17.06 |

Smith and Fornstrom (1978) studied the energy requirements of selected dryland wheat cropping systems. No till represented a potential method of saving energy. The energy requirements on various implements provide a basis for selection of implements and cropping rotations. On farm, fuel consumption data were gathered by several researchers in several states. Kramer et al., (1978) present the results of studies done on Kansas-Nebraska farms. Myers, et al., (1979) present the preliminary studies of fuel consumption on Michigan farms.

3.2 Machinery models.

Review was done for machinery selection models, economic models, and energy models.

3.2.1 Machinery selection models.

Kjelgaard and Quade (1975) presented a system model of forage transport and handling. The diversity of machine alternatives and inter-dependence of machine functions within forage systems make it difficult to select and schedule the system mechanical elements. The model contains variables for machine types, harvesting rates, and transport distances. The outputs of the system are: daily capacity for transport and handling machines, mechanical energy, and labor requirements.

Hughes and Holtman (1976) developed a machinery selection model based on time constraints. The model selects machines and power units which have the capacity to perform the required field operations at a rate which ensures the target dates for successful crops are met. The computer model was composed of four major segments: system power requirement determination, tractor selection, field machine selection, and cost analysis.

Singh et al., (1979) developed an algorithm for machinery selection for multicrop farms. The algorithm designs a machinery system based upon field work specifications, field operations date constraints, machine capacity relations and field work conditions. The algorithm specifies the size and number of each component, prepares a detailed week-by-week work schedule, gives distribution of labor needs, calculates fuel requirements for each operation, and makes a detailed cost analysis for the selected machinery set. Singh et al., (1979) studied the field machinery requirements as influenced by crop rotations and tillage practices. They used a previously designed algorithm to determine the machinery requirements and costs for 29 cash crop production systems of Southern Michigan.

3.3.2 Economic models.

Miller (1980) determined the minimum machinery cost compliment for various situations. A model was developed to determine the number and sizes of tractors. The equipment capacity and the days available for work were included in the model in such a way that the best equipment size could be determined.

Edwards and Boehlje (1980) studied the risk-return criteria for selecting farm machinery. Risk preferences were introduced into machinery selection by estimating the mean and standard deviation for total costs, including timeliness costs, associated with various machinery sets. A machinery selection model was developed. Ten machinery sets were chosen, representing the best combination of machines and power units. Several risk-return criteria were tested using the cost distribution data generated by the simulation model. The criteria were: expected cost; standard deviation frontiers; stochastic dominance;

least-cost, least variance, and upper confidence limit criteria. These criteria were compared in terms of applicability, results and practicability of use. For small farms (80 - 160 ha) most of the criteria were consistent by selecting the same machinery set for least-cost, except for the expected mean, standard deviation that chose several machinery sets. For large farms (320 - 360 ha) only the least-cost, least variance; and upper confidence limit (0.9) criteria were consistent and chose only one machinery set. The least-cost, least variance criterion is relatively simple to use and produced results consistent with those of the other criteria tested.

Mayfield et al., (1980) developed a model to estimate farm machinery operating costs. The model used a depreciation schedule based on replacement list prices rather than initial list prices. The model has been used since early 1977 to estimate farm machinery operating costs in the state of Alabama. The Alabama Cooperative Extension Service issued, in October of 1980, a Bulletin where farm machinery operating costs are listed in dollars per hour. The cost per hour for different usage levels are also listed.

Computerized machinery cost analysis programs were also developed by Moore et al., (1980). The computer program developed estimates a single machine's cost, an operation's cost with two machines, or a total job cost using up to 5 power units and 5 pulled units plus labor. Both computer programs give the costs per hour for several usage levels.

Chancellor and Cervinka (1975) presented a costing procedure for combines. Costs related to the speed of combine operation, and costs proportional to years of ownership were presented. Basic input information were developed such as combine grain losses, timeliness coefficient for harvest, and combine parameters such as size, speed, etc. Conclusions about combine management, crop research, and combine development were presented. Cervinka and Chancellor (1975) also presented the costs for rice production in California. Economic and physical aspects of major increases in intensity of farm machinery use were examined.

Peterson and Milligan (1976) presented an economic-life analysis for machinery replacement decisions. A method for determining fixed and operating costs was presented. A computer model was developed which computed and tabulated costs for all likely combinations of machinery acquisition and retirement ages. An example for a potato harvester was presented.

Kolarik et al., (1979) presented a performance analysis of farm machinery. The computer program is described as: Farm Machinery Availability and Cost Simulation (FMACS) model, which is a two level (system-subsystem) simulation model. The simulation model considers usage requirements, multiple working conditions, operating aspects, subsystem failure and detection, service, maintenance, repair and costs associated with operation, service, maintenance, repair and timeliness. The model was designed for specific operating conditions and with the idea of helping designers and manufacturers to balance out system and subsystem designs.

Krutz et al., (1980) described the equipment analysis with farm management models. Two linear programming farm management models were described: Purdue Model B-93 (Purdue Crop Budget, 1976) and the International Harvester Pro-Ag Program (Pro-Ag Model, 1977). The model allows the user to evaluate alternative sets and sizes of machinery.

3.2.3 Energy models.

An empirical relationship was developed by Persson (1969) to determine the fuel consumption in Kg per hour. This relationship was used by Macnab (1976) as part of a computer model. Tractor performance and fuel consumption could be obtained by using as input the tractor characteristics and working conditions. Three relationships are presented in the ASAE Yearbook (1978). These relationships use the engine load to determine the diesel, gasoline, and Liquified Petroleum gas consumption in a l/Kw-h basis. These are the relationships used in this study to determine the engine fuel consumption as a function of load (a correction factor was included).

Many researchers have developed sophisticated fuel meters to determine the fuel consumption for field operations. The power required to pull a determined implement has also been a major concern for years, but relatively little data are available to check the validity of these relationships. The relationships are general and few parameters are included. When data are obtained and compared with results calculated by these relationships, differences are sometimes too high to be acceptable.

Pimentel et al., (1973) delineated the energy inputs to corn production as: labor, machinery manufacturing, fuel, nitrogen, phosphorus, potassium, seed, irrigation (if required), insecticides, herbicides, grain drying, electricity, and transportation.

Clark and Johnson (1975) presented an energy budget for grain sorghum tillage systems. A procedure for developing energy budgets for tillage systems is illustrated. Draft, fuel, and energy requirements for field operations used in tillage systems are also presented.

Ozkan and Frisby (1979) presented the development and application of a linear programming model to maximize the overall energy efficiency of a multi-crop, example farm. A computer model gave the fuel and energy consumption for field operations, and fuel and energy consumption for selected crops.

A method for determining the total energy input for agricultural practices was developed by Bridges and Smith (1979). The energy required for a particular practice included the fossil fuel used, energy used in manufacturing, marketing, and repairing equipment as well as the manual labor required to perform the operation. The approach and an example were presented. The model used was developed by Loewer et al., (1977).

### 3.3 Alcohol utilization.

The utilization of alcohol in mixture with gasoline or even pure alcohol is not a new adventure. Alcohol has been used as motor fuel, in the form of blends since the first automobiles were made. Alcohol has also been used in racing because of its special characteristics.

Strong (1911) and several other researchers looked for new ways of replacing fossil fuels. Alcohol obtained from plants containing sugar and starch proved to be a good fuel and was economically feasible in case of a shortage of petroleum.

This review presents some of the research done with gasoline and diesel engines using alcohol as a blend or in its straight form.

#### 3.3.1 Alcohol use in spark-ignition engines.

The first report on the use of alcohol was published in 1907 by the U.S. Department of Agriculture, entitled "Use of Alcohol and Gasoline in

Farm Engines." In 1926, in Britain, Ross and Ormandy published a paper on the use of alcohol fuel in internal combustion engines. The following includes a review of the use of alcohol in spark ignition engines, in blends with gasoline or in its straight form.

3.3.1.1 Alcohol use in blends with gasoline.

Zimmerman (1924) conducted tests with alcohol gasoline blends. Correon (1928) used commercial alcohol (190 proof) mixed either with gasoline or kerosene as fuel for gas engines. He concluded that most farm gas engines could operate with gasoline, kerosene or mixtures of gasoline and alcohol without structural changes. Gray in 1933 and in 1934 used alcohol with gasoline blends and obtained more power by increasing the compression. This was explained as making better use of the higher octane rating of alcohol. Similar results were obtained by Miller (1933). In 1936, Bridgeman published a paper on the "Utilization of Ethanol and Gasoline Blends." In 1938, the U. S. Department of Agriculture published a booklet on "Motor Fuel from Farm Products." Since the second world war few studies were done and most of them were related to the use of alcohol in blends with gasoline.

In the 70's work was done by Ingamels et al., (1975), Chui et al., (1979), Sheller (1977), Owens (1977), Baker (1977), Pishinger et al., (1979), and Stephenson (1980). Conclusions which can be drawn are that both methanol and ethanol can be used as an octane booster. For unmodified engines, as the alcohol concentration is increased, driveability decreases and corrosion problems occur. Sheller presented four reasons for blending alcohol with unleaded gasoline: increased octane number, positive volume charge of mixing, reduced fuel consumption, and few pollutants in the exhaust. Test results showed an advantage (lower fuel consumption) for ethanol due to its higher Kcal content, when compared to methanol.

3.3.1.2 Straight alcohol use in gasoline engines.

Ingamells (1975) showed in his tests that methanol could be used effectively in special vehicles designed to handle its corrosion, water absorption, and vaporization characteristics.

Chui (1977) using two engines (1.4 L and 2.3 L) performed tests with neat ethanol. Improvements in power were due primarily to differences in equivalence ratio and fuel octane rating. To get a comparable equivalence ratio the metering jets in the carburetor were enlarged. Cold start was not possible when the temperature was below 5°C. Adding gasoline to the fuel bowl extended cold start capability downward to 0°C. He stated that higher compression engines, carburetor adjustments, spark timing and cold starting should be given attention when redesigning engines to use neat ethanol. The redesigned engine had a higher thermal efficiency and increased power. The use of ethanol fuel decreased $NO_X$ and increased fuel exhaust emissions. CO emissions were similar. The most significant differences in the unburned fuel emissions were the presence of unburned ethanol and substantial amounts of aldehydes.

Owens (1977) reported that using methanol in spark ignition engines at low temperatures increased the rate of wear of the piston rings and cylinder bore, when conventional lubricant was used.

Baker (1977) reported the potential advantages of methanol relative to gasoline, were most evident when it was used in the neat form. Some of the advantages are: increased power through increased compression, reduced specific fuel consumption, and extended lean misfire limit, reduced $NO_X$ and increased fuel octane quality.

McCormack (1977) performed tests on a four-cylinder, 2.3 L spark ignition engine. Five configurations of intake manifold, and fuel injection systems were examined. Gains were seen in fuel economy for all of the methanol fueled systems ranging between 6 and 30 percent in the urban cycle and between 10 and 30 percent on the highway. Johnson (1977) performed tests using straight methanol in a single cylinder spark ignition engine. Methanol and methanol + 5 percent water exhibited efficiency increases of 2 - 3 percent for the range of test conditions. For constant manifold heat conditions (sustantially lower mixture temperature) methanol and methanol + 5 percent water produced 5 - 7 percent more power than gasoline.

Hunt (1979) said "We have shown that you don't have to use pure alcohol in spark ignition engines. These engines work nicely on alcohol containing 16 percent water." Hunt ran a modified spark ignition engine on 167 proof alcohol (83.5 percent ethanol and 16.5 percent water), and concluded that ethanol/water solutions worked fine in spark ignition engines.

Pishinger (1977) wrote that the use of straight alcohol for vehicle use in Brazil goes back to 1923. Ethanol fueled cars used 12.68 liters of fuel per 100 Km compared to 10.37 liters per 100 Km for gasoline (a 22.3 percent increase). Stephenson (1980) performed tests in an air-cooled, four-cycle, single-cylinder, spark-ignition engine, using 100 percent ethanol of 200, 190, and 180 proofs. The higher octane rating of ethanol was an advantage at the increased compression and it was consistent for 100 percent ethanol.

Swarr (1981) used ethanol and distilled water solutions of 100, 95, 90, 85, 80, 75, and 70 percent ethanol in a Ford 2000, three cylinder gasoline tractor. The modifications included the replacement of a gasoline carburetor with a carburetor designed for use with ethanol. Ignition timing was advanced, and the spark plugs and fuel pump were replaced. He measured power output, thermal efficiency and fuel efficiency and compared performance with ethanol to that with gasoline. As the water content in the fuel increased, more fuel was necessary to provide a given torque level. The fuel efficiency for 90 percent ethanol was a little less than for 100 percent ethanol. He concluded that the best ethanol fuel as far as engine performance as well as economical value contains 10 percent water. Increases in fuel consumption of 32 percent were obtained when using an 8:1 compression in the engine.

A high compression (12:1) with fuel injection engine can be called the true alcohol engine. This efficient engine was tested in September of 1941 at the National Experiment Station at Bellevue, France as the Brandt System. Some characteristics of this engine are the following:

a) Higher thermal efficiencies when compared to conventional SI engines.

b) Smaller engines are required to deliver the same amount of power.

c) Higher fuel consumption due to lower caloric value of alcohol can be compensated by higher engine output (Kw-h/l) due to the higher octane rating of alcohol. This allows higher compression which will give higher thermal efficiencies for the true alcohol engine.

### 3.3.2 Alcohol use in diesel engines.

Most of the research done was using alcohol through dual-fueling, where minor engine modifications are required. When the dual-fueling method is used, up to 45 percent of the diesel fuel can be replaced by alcohol.

#### 3.3.2.1 Alcohol use through dual-fueling.

Holmer (1977) selected the dual-fuel diesel engine as the best compromise and studied it when using methanol dual-fueled with diesel. Holmer used a turbocharged diesel engine, with a displacement of 10 L and compression ratio of 15 to 1. A separate alcohol fuel system was used. He concluded that diesel engines can easily be converted to a dual-fuel engine and attain good performance and low emissions of smoke, HC, and noise.

Panchapakesan (1977) used a alcohol-diesel engine, where alcohol was the main fuel, aiming to achieve the maximum use of alcohol with the best possible thermal efficiency and output. The results showed that it was possible to derive as much as 70-80 percent of the total energy requirements of the engine from alcohol for most of the load range. Extensive work on the use of alcohol as a principal fuel in diesel engines by dual-fuel operation has been investigated also by Harvermann and others at the Indian Institute of Science. Some advantages of alcohol/diesel engines are:

a. The engine permits the use of alcohol (renewable fuel) as the main fuel.

b. The engine using alchol can achieve substantially higher peak power outputs.

c. The engine using alcohol can attain better thermal efficiency.

Scott (1977) investigated the extent to which methanol could replace normal diesel fuel in truck type engines. The substitution rate was limited by both quench and knock. The maximum substitution was 80 percent and it was only reached at 36.7 r/s, by inlet mixture heating to 30°C and 2 percent amyl nitrate as fuel additive. The main problem was igntion delay. This was also a problem for Panchasepakesan in his research. A turbocharged engine would have more suitable characteristics teristics for operation on methanol.

Pishinger (1979) developed an ignition spray concept for dual-fueling a diesel engine with methanol, and some conclusions on his work are listed below:

a. The engine presented less visible smoke.

b. The engine emissions of gaseous pollutants was reduced.

c. A large portion of oil can be substituted by methanol.

d. The engine presented better thermal efficiency.

e. The engine thermal and mechanical stresses were reduced.

f. The engine compression ratio can be varied over a wide range (14.5:1 to 19.5:1).

Berg and Holmer (1979) used two separate systems in a turbocharged engine to investigate the use of ethanol and methanol. Several alcohol proofs were tested. The conclusions were similar as the above. The dual-fuel system broadens the use of the engine permitting the utilization of a broad range of light liquid fuel.

Cruz et al., (1980) found that carburated alcohol can supply 50 percent of the fuel energy for diesel engines operated in a dual-fuel mode. The direct injection proved to be a better way to use alcohol than with a precombustion chamber. Cruz (1979) also found that 47 percent of the total energy requirements could be supplied by carburated methanol. Similar problems like rate of substitution which was limited by knock were encountered Cruz (1981).

3.3.2.2 Straight alcohol use in diesel engines.

Little work has been done in the area of alcohol use in diesel engines in its straight form. Alcohol powered tractors are being tested in Brazil. Heavy weight trucks were recently put into the market in Brazil. The tractors and trucks are running on straight alcohol produced from sugar cane. The "alcotractors" are being tested under different field working conditions in several agricultural states of Brazil. The tractor engines were redesigned to operate with a spark-ignition system and decreased compression.

# CHAPTER 4

# MODEL FORMULATION

Model formulation is divided into two major phases: Feasibility study and model description.

## 4.1 Feasibility study.

This phase of the model formulation is divided into three subphases: needs analysis, system identification, and problem formulation.

### 4.1.1 Needs analysis.

According to the ASAE Yearbook (1978) the draft requirements vary considerably from one soil type to another. For example, for each square centimeter of sandy soil plowed, 2.5 Newtons of draft are required while 9.0 Newtons are required to plow clay soils, using the same speed of 6.0 Km/h. White (1974) reported that it takes 8.5 to 34.0 liters of diesel fuel to plow one hectare of land in the state of Michigan. Other factors such as those discussed in chapter 1.0 make it difficult to calculate the exact amount of fuel required for a specific operation under specific conditions. A close determination of the amount of fuel to be used can be done if data related to the soil type, soil conditions, working depth, machine speed, and other variables are considered.

Some of the needs are listed below:

a. Better knowledge concerning the energy needs for specific field operations, crops, tillage and cropping systems.

b. Systems analysis by using a computer program where equations listed in the ASAE Yearbook (1978) would be used to determine the energy requirements for field operations.

c. Check results from the computer program with results collected from the farm.

d. A computer program that calculates the energy and fuel requirements for most of the operations performed on Michigan farms.

e. A computer program that requires only relevant information as input data, easy to be obtained and produces valid results.

f. A computer program that analyzes the influence of alcohol (as motor fuel) used in several ways in gasoline and diesel engines, and in several cropping systems.

4.1.2 System identification.

The farm is the system under study. Machinery is a subsystem made up of tractors, combines, trucks, and self-propelled machines which are the major components of the system. Implements are considered components of the system as well. Linkages are present between components of the system. A tractor pulling a plow is an operation in which the two components are linked by energy requirement (plow) and energy availability (tractor). The linkages are represented by mathematical relationships giving the amount of energy or amount of power required to perform an operation. When self-propelled machines, such as combines, trucks, and windrowers, etc. are used, mathematical relationships are used to determine the amount of power and thus fuel requirement for that specific component. The major inputs for our system are the machinery set specifications such as size of machines and power units, soil type, and operating conditions. The major outputs of the system are the energy and fuel requirements, machine load, and fuel costs for specific farm operations. System parameters are used to make the system more general and most of them are stored in a subroutine block data and used whenever necessary. The weather is the most important environmental (exogenous) input for agricultural systems. In this program no constraints are put on time available to finish a certain operation. We assume the farmer knows which operations he is going to perform and the machinery sets are large enough to complete the operations by a certain date. Weather is not considered in this program. More attention to the input, parameters, and outputs will be given in chapter 5.0. The following is a brief description of the input and outputs of the model.

4.1.2.1 Model inputs.

Lines of input data can be supplied interactively or by cards. The following are the input data.

a. General input data. This includes prices of fuels, number of machines, discount rate and number of years to depreciate the machine conversion costs, and total farm area.

b. Input for each machine. This includes fuel types, decision to convert an engine to alcohol, conversion type, number of operations to be performed, power and weight of machine, and operation to be performed by a machine.

c. Input data for each field operation. These inputs are supplied by a group of operations. The operation groups are the following: seeding, cultivating, fertilizer and chemical application, harvesting, and transportation operations.

The following are the inputs to be supplied for each operation: implement size, depth of work, implement weight, number of rows, machine speed, soil type and conditions, area to be covered, crop density and feed rate, and for transportation (crop yield, transport distance, fuel consumption in Kilometers per liter, and truck and wagon capacity).

#### 4.1.2.2 Model outputs.

When conventional fuels are used the following outputs are obtained. Output for each field operation includes: Wheel slip and tractive efficiency, total implement draft, power required, engine load, fuel consumption per hour, effective field capacity, number of hours to complete the job, machine accumulated use, fuel consumption per hectare, total fuel use, total fuel cost, and fuel cost per hectare.

When alcohol fuel is used in the system the same outputs as the above are given plus the following: amount of alcohol used, fossil fuel savings, cost of alcohol fuel per hectare, and breakeven price for alcohol.

### 4.1.3 Problem formulation.

After analyzing the needs and identifying the system, the problem is formulated in order to find a feasible solution. Based on the information generated during system identification, we develop what the system must do in order to satisfy the determined needs. The problem formulation will be: to determine the machine performance under field conditions (i.e., determine the wheel slip, tractive efficiency, energy requirements to pull implements or power requirements for self-propelled machines, machine loads, fuel consumption and costs of fuel, explore the use of alcohol as alternative fuel, determine break-even prices for alcohol fuels, etc.), such that the identified outputs are provided, the results are correct, and the results can be validated.

## 4.2 Model description.

The computer program is made up of five subroutines which perform the calculations according to the flowchart shown in Figure 1. The first subroutine calculates the energy needs and machine loads for field operations. The second calculates fuel consumption, effective field capacity, and machine use. The third calculates alcohol utilization when either one of four conversion methods is used. The fourth calculates the conventional and alernative fuel costs. The fifth subroutine contains information such as machine field efficiency, draft parameters, tractor conversion costs, alcohol fuel consumption parameters, and alpha numeric code for machine and operation names.

### 4.2.1 Energy subroutine.

This subroutine computes the energy needs for field operations from soil preparation to transportation. The field operations are divided into six groups: tillage, seeding, cultivating, fertilizing and spraying, harvesting, and transportation.

#### 4.2.1.1 Draft requirements for tillage operations.

Sixteen field operations are modeled in this group. Draft is defined as the force required in the horizontal direction of travel to pull an implement. The following equations calculate only functional draft (soil and crop resistance).

Draft requirements for moldboard plows are modeled as the product of unit draft and cross-sectional area of cut. The draft per unit cross-section of furrow slice is for bottoms equipped with high speed moldboards, coulters, and landsides. The implement draft is modeled using the following equations:

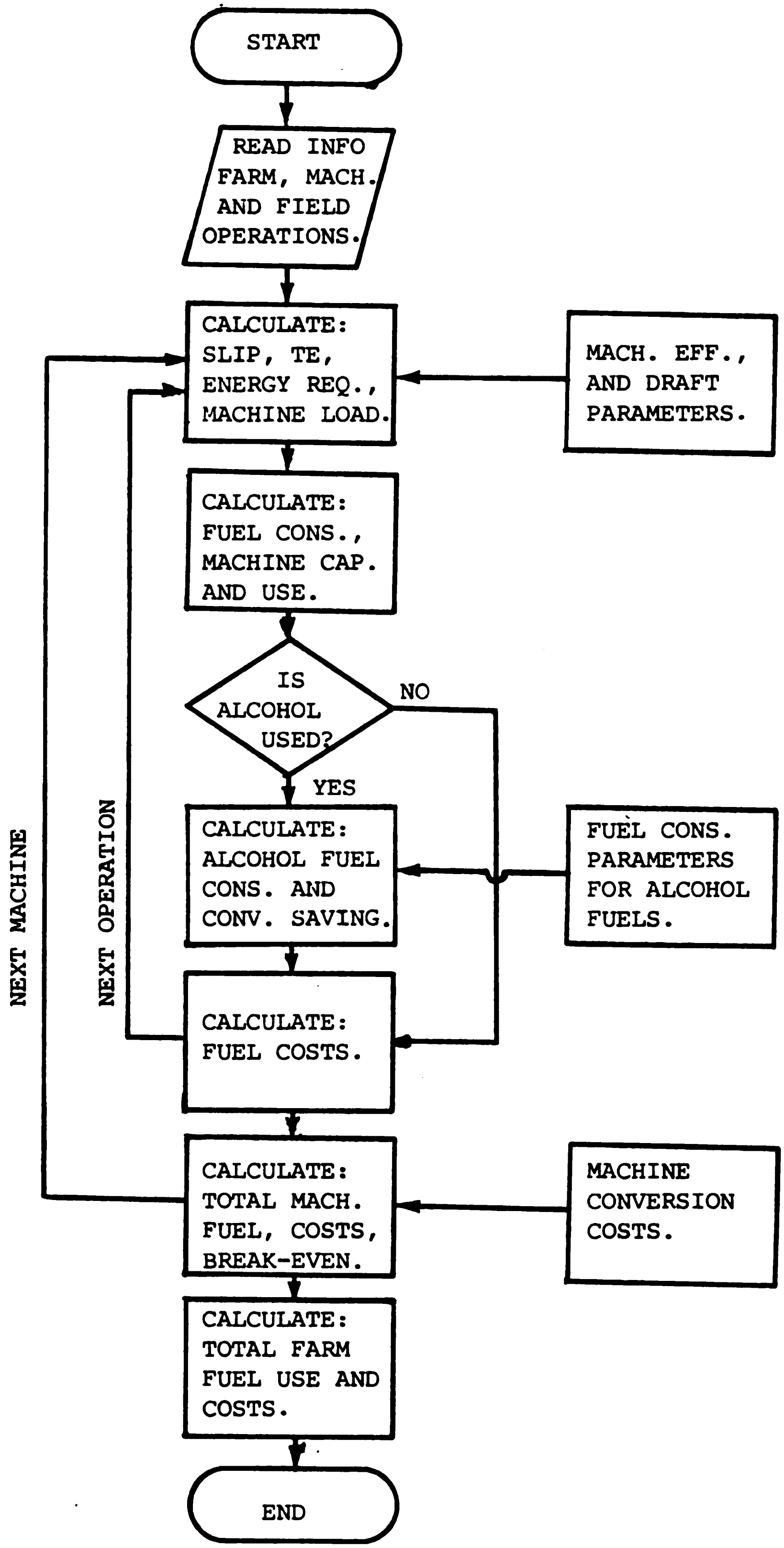


Figure 1. Model flowchart

DRAFT = CAREA * UDRAFT (1)

Where DRAFT is the implement draft in Newtons, CAREA is the area covered in $cm^2$, and UDRAFT is the unit draft in Newtons/$cm^2$. CAREA is calculated by multiplying the implement width by the working depth, both in cm. The unit draft (UDRAFT) is given by the following equation:

UDRAFT = C1(IST) + CC1(IST) *SPEED ** 2 (2)

Where C1 and CC1 are constants and their values depend on the soil type. A list of all the constants used in this model are presented in Table 13. Values for several soil types are stored in the block data subroutine. IST is the input variable for soil type which can assume values from 1 to 7. SPEED is the machine speed in Km/h. Soil moisture and apparent specific gravity parameters are not included in this model.

Disk plows were modeled similar to moldboard plows. The draft per unit cross-section of furrow slice for a 66 cm diameter disk with a tilt angle of 0.38 rad and a horizontal angle of 0.75 rad is modeled by two equations similar to Equations (1) and (2). Constants C2 and CC2 are stored for two different soil types and IST can assume values of 1 or 2.

Draft requirements for listers were modeled as the product of number of bottoms and working depth to the second power. The draft per 36 cm bottom at 6.76 Km/h is modeled by the following equation:

DRAFT = C3*NB*TD**2 (3)

Where NB is the number of bottoms, TD is the working depth in cm, and C3 is a constant for silty clay loam soils.

Draft requirements for disks harrows are modeled as a function of implement mass. The implement draft at any speed, and typical working depth is modeled by the following equation:

DRAFT = C4(IST)*W (4)

Where C4 is a constant which can assume three values to calculate the draft for clay, silt loam, and sandy soils. IST is the input variable for soil type, assuming values of 1, 2, and 3. W is the implement mass in Kg.

The draft requirements for chisel plows are modeled as a function of the number of tools and field speed. Equations derived from data presented by Frisby and Summers, 1979 were prefered over the ASAE yearbook equations. The draft requirements for chisel plows and field cultivators according to the ASAE yearbook equations were too high to be used for Michigan soil conditions. The following equation was used to calculate the draft for loam, sand, and clay soils when tools are spaced at 31 cm.

DRAFT = NB*(C5(IST)+CC5(IST)*SPEED) (5)

Where DRAFT is the implement draft in Newtons at 30.7 cm depth, NB is the number of tools, C5 and CC5 are constants for three soil types (loam, sand, and clay), IST and SPEED are the same as defined above.

The draft requirements for field cultivators are modeled similar to chisel plows. Data from Frisby and Summers, 1979 were used to derive Equation (6). Equation (6) calculates the draft requirements for field cultivators when working at 20.5 cm depth and the tools are spaced by 16 cm.

DRAFT = NB*(CFC1(IST)+CFC2(IST)*SPEED) (6)

Where CFC1 and CFC2 are draft parameters derived from experimental data.

The draft requirements for rotary tillers are modeled as the product of unit draft and cross-sectional area of cut. The effective draft per unit cross-section of furrow slice, 45 cm diameter rotor, 10 cm depth, 6.7-11.7 r/s is modeled for dry silt loam soils as follows:

DRAFT = CAREA*UDRAFT (7)

UDRAFT = C6(IST)/BL**0.46 (8)

Where DRAFT is the draft in Newtons, CAREA is the area covered in $cm^2$, and BL is the bite length in cm.

The draft requirements for one way disks with seeder attachments are modeled as the product of unit draft and implement width. The draft for a tillage depth of 7.5 cm, including rolling resistence for three soil types is modeled by the following equations:

DRAFT = 1000.0*UDRAFT*WIDTH (9)

Where

UDRAFT = C7(IST)+CC7(IST)**SPEED (10)

WIDTH is the machine width in m, UDRAFT is the unit draft in Kilonewtons/m, C7 and CC7 are constants for clay, clay loam, and loam soils, other variables were already defined above.

The draft requirements for subsoilers are modeled similar to chisel plows and field cultivators. The total draft as a function of the number of shanks and working depth is given by the following equation:

DRAFT = NB*(C8(IST)*TD) (11)

Where NB is the number of shanks, TD is the working depth in cm, C8 is the constant for soil types, and IST is the input variable for soil types (from clay to sandy loams). The draft requirements for minor tillage tools as a function of implement width is modeled according to the following equation:

$$DRAFT = CA(IST)*WIDTH \quad (12)$$

Where CA10, CA11, CA12, CA13, and CA14 are the constants for land plane, spike tooth harrow, spring tooth harrow, rod weeder, and roller and packer, respectively. The equation for the stalk shredder is the same only the constant is C16. WIDTH is the machine width in m.

4.2.1.2 Draft requirements for seeding operations.

Four seeding operations are included in the program, including row crop planters and grain drills. The draft requirements for row crop planters (seeding only) as a function of the number of rows for good seedbed, including the rolling resistence is given by the following equation:

$$DRAFT = C17(IST)*NROWS \quad (13)$$

Where NROWS is the number of rows. Three values are stored (high, medium, and low) for C17, depending on the value of IST (1, 2, and 3).

The draft requirements for row crop planters (seeding, fertilizer, and herbicide) as a function of the number of rows is given by Equation (13) where C18 is the constant used.

The draft requirements for grain drills as a function of the number of furrow openers (number of rows), including rolling resistence is given by Equation (13). C19 contains the constant values for regular furrow and CC19 contains values for deep furrow. An input variable (ID) is used to specify which method is used.

The draft requirements for no-till planters are modeled by a similar equation as Equation (13) where the constant is C20.

4.2.1.3 Draft requirements for cultivation operations.

Three cultivation operations are included in the program.

The draft requirements for row and lister cultivators as a function of working depth and implement width for all typical speeds is given by:

DRAFT = C(IST)*TD*WIDTH (14)

Where C21 is the constant for row cultivators and C22 for a lister cultivator. TD is the working depth in cm, WIDTH is the machine width in m, and the constants C can assume high, medium, and low values for clay, silty, and sandy soils, respectively.

The draft requirements for rotary hoes as a function of implement width and speed is given by:

DRAFT = C23+CC23*SPEED*WIDTH (15)

Where DRAFT, SPEED, and WIDTH were defined above, and C23 and CC23 are constants (draft parameters).

4.2.1.4 Draft requirements for fertilizer and chemical application.

Equations for anhydrous ammonia applicators, fertilizer distributors, and pesticide sprayers were used. The draft requirements for anhydrous ammonia applicators as a function of the number of knives is given by:

DRAFT = C24*NK (16)

Where DRAFT is the draft is Newtons, NK is the number of knives, and C24 is a constant.

The power requirements for fertilizer distributors and pesticide sprayers include both the rolling resistence of the implement plus hydraulic power. The hydraulic power usually is very low, so only the rolling resistence of the implement was considered. The draft as a function of implement weight and soil surface conditions is given by the following equation:

DRAFT = 9.8*W*(1.2/C25(IST)+0.04) (17)

Where W is the implement mass in Kg, C25 is a constant assuming different values for soil surface conditions.

4.2.1.5 Power requirements for harvesting operations.

Equations to calculate power requirement for combines, self-propelled machines, and tractors performing harvesting operations of soybeans, small grain, corn, cotton, potatoes, sugar beets, forage, and hay are listed as follows:

The power requirements for harvesting soybeans and small grain is modeled as a function of feed rate by the following equation:

ENNE = C26+CC26*FR (18)

Where ENNE is the power required in Kw, FR is the feed rate in Kg/s of typical material (wet basis), and C26 and CC26 are constants.

The power requirements for corn haresting is modeled similar to soybeans and small grain harvesting. The result of Equation (18) is multiplied by 1.1 to obtain an estimated power requirement for corn harvesting.

The power requirement for harvesting windrowed small grains is modeled similar to soybeans and small grain harvesting. Equation (18) is used and the result is multiplied by 0.9.

The power requirement for cotton pickers, cotton strippers, and beet toppers are modeled as a function of the number of rows and given by:

$$ENNE = C(IDEN)*NROWS \qquad (19)$$

Where C27 is a constant for a cotton picker, C28 is a constant for a cotton stripper, and C29 is a constant for a beet topper. IDEN is an input variable for crop density and can assume values of 1, 2, and 3. The constant C has three values stored; high, medium, and small to model corresponding crop densities.

Beet harvestors and potato diggers are pulled by tractors and the PTO power requirement is given by the following equation:

$$ENNE = C(IDEN)*NROWS \qquad (20)$$

The variable C in Equation (20) can be C32 for a beet harvestor and C33 for a potato digger. The draft requirement to pull the harvesting machine is given by:

$$DRAFT = CC(IDEN)*NROWS \qquad (21)$$

Where DRAFT is the implement draft in Newtons, CC can be CC32 for a beet harvestor and C33 for a potato digger.

The power requirments for a cutterbar mower (for alfalfa) is given by:

ENNE = C34*WIDTH (22)

Where ENNE is the power requirement in Kw, C34 is a constant, and WIDTH is the machine width in meters.

The power requirements for a cutterbar mower-conditioner (for alfalfa) as a function of crop density and implement width is given by:

ENNE = C35(IDEN)*WIDTH (23)

Where IDEN is the crop density and C35 is a constant.

The power requirements for a flail mower conditioner (for alfalfa) as a function of feed rate is given by:

ENNE = C36+CC36*FR (24)

Where FR is the feed rate of typical material, in Kg/s, wet basis. The power requirements for conditioner only (for alfalfa) are modeled similar to the cutterbar mower. The constant is C37.

The power requirements for a 2.44 m side delivery rake as a function of machine speed is given by:

ENNE = C38+CC38*SPEED (25)

Where C38 and CC38 are constants and SPEED is the machine speed in Km/h.

The power requirements for rectangular and round balers used to bale normal hay or straw is given by:

ENNE = C*FR (26)

Where C is C39 for a rectangular baler and C40 for a round baler, and FR is the feed rate in Kg/s.

The power requirement for a flail type forage harvester, for green forages is given by Equation (24). Equation (24) multiplied by a factor of 2.0 gives the power requirements for a flail type forage harvester, for other forages.

The power requirement for a shear bar type forage harvester, for corn is given by:

$$ENNE = C43+CC43*FR \tag{27}$$

Where the variables are the same as the ones defined above. Equation (27) multiplied by a factor of 1.33 gives the power requirements for a shear bar type forage harvester, for green forage. Equation (27) multiplied by a factor of 2.0 gives the power requirements for a shear bar type forage harvester, for low moisture forage and hay.

The draft requirements for pulling, windrowing, and pulling-windrowing beans as a function of the number of rows is given by:

$$DRAFT = C*NROWS \tag{28}$$

Where C is C46 for a bean puller, C47 for a bean windrower, and C48 for a bean puller-windrower.

4.2.1.6 Energy requirements for transportation.

The program calculates the amount of fuel used in transportation for short distances (from field to farm storage or from farm storage to field, and from farm storage to market or field to market). Two transportation operations are allowed. Transportation with trucks or with wagons pulled by farm tractors.

The fuel used to transport a determined amount of product using a truck is determined as follows:

TFU = 2.0*FD*(AREA*YIELD/CAP)/AKPL (29)

Where TFU is the total fuel used in liters, FD is the field distance in Km, AREA is the area in hectares, YIELD is the crop yield per hectare in Kg, CAP is the truck capacity in Kg, AKPL is the average fuel consumption of the truck in Km/l, and 2.0 is a constant to model a round trip over a given distance.

Equation (17) is used to calculate the draft requirements to pull wagons.

4.2.1.7 Load determination.

Equations (1) through (29) calculate the draft requirements or power required to pull an implement or machine when performing field operations. The rolling resistence of the implement was included whenever necessary. The equations do not include the rolling resistence of a tractor when pulling an implement. The energy required to overcome the rolling resistence can be considerable, especially in soft, plowed soils. In order to calculate the tractor total load, the wheel slip and tractive efficiency were modeled by including a coefficient of rolling resistence.

A loss of power occurs between the power arriving and power leaving the tractor powered wheels. A loss of power due to slippage also is inevitable. In order to quantify these losses, the wheel slip and tractive efficiency were calculated. The wheel slip was used to calculate the tractive efficiency and the latter was used to calculate the total power required to pull an implement under field conditions. When equations are used to calculate power requirements in Kw, the tractor or machine rolling resistence is calculated, transformed into Kw, and the ratio of PTO power required to maximum PTO power available was determined. When equations calculated the draft requirements the following calculations were made:

```
SLIP  = 1.0/(0.3*C25(ICN)*ALOG(0.75-((TDRAFT/9.8)/WM+(1.2/C25(ICN)
         +0.04))))                                                  (30)
TE    = (1.0-SLIP)*(1.0-(1.2/C25(ICN)+0.04)/(0.75*(1.0-EXP(-0.3*C25
         (ICN)*SLIP))))                                             (31)
PREQ  = 0.0002778*DRAFT*SPEED/(0.96*TE)                             (32)
RATIO = PREQ/PAVA                                                   (33)
LOAD  = 100.0*RATIO                                                 (34)
```

Where SLIP is the wheel slip in percentage, TDRAFT is the total draft in Newtons, WM is the machine dynamic weight in kg, TE is the tractive efficiency in percentage, PREQ is the PTO power required in Kw, PAVA is the maximum PTO power available in Kw, SPEED is the machine speed in Km/h, RATIO is the PTO power required divided by maximum PTO power available, TLOAD is the machine load in percentage, and C25 (ICN) is the constant for different soil surface conditions.

### 4.2.2 Fuel consumption subroutine.

The value for RATIO calculated in the energy subroutine is used to calculate the specific fuel consumption in l/Kw-h. Values for field efficiencies which are stored in the subroutine block data are used to calculate the machine effective field capacity in ha/h. The fuel consumption in liters per hectare was then calculated.

The diesel, gasoline, and liquified petroleum gas consumption are calculated with the following equations:

DCON = 2.64*RATIO +3.91-0.2*(738.0*RATIO+173.0)**0.5 (35)

GCON = 2.74*RATIO+3.15-0.2*(697.0*RATIO)**0.5 (36)

CLP = 2.69*RATIO+3.14-0.2*(646.0*RATIO)**0.5 (37)

Where DCON, GCON, and CLP are the diesel, gasoline, and liquified petroleum gas consumption in l/Kw-h and RATIO as defined above is the PTO power required divided by maximum PTO power available.

Equations (35) and (36) were checked against the Nebraska Tractor Test data and were found to overestimate the specific fuel consumption for most tractor models. The specific fuel consumption for 13 diesel tractors was obtained from Nebraska Tractor Test data and are listed in Table 11. The specific fuel consumptions (l/Kw-h) at 50, 75, and 100 percent load were compared with the results from Equation (35). As 75 percent is the best load for engines to operate a 13 percent decrease in the specific fuel consumption of Equation (35) was given and the new Equation (35) is listed as follows:

DCON = 2.3*RATIO+3.4-0.174*(738*RATIO+173)**0.5 (35)

The specific fuel consumption for 13 gasoline tractors was also obtained from Nebraska Tractor Test data as listed in Table 12. The same procedure as described for diesel tractors was used. A correction factor of 0.92 was used for Equation (36). The new Equation (36) is given as follows:

GCON = 2.521*RATIO+2.898-0.184*(697*RATIO)**0.5 (36)

Figure 2 presents the curves for three engine types described by Equations (35), (36), and (37). The specific fuel consumption for diesel and gasoline engines using a correction factor is also plotted in Figure 2. Equation (37) was not changed because not enough information about new LP gas tractors was available in the Nebraska Tractor Test data.

Table 11. Specific fuel consumption for 13 diesel tractors (Nebraska Tractor Test data)

| Tractor number | Specific fuel consumption (1/Kw-h) | | |
|---|---|---|---|
| | 50% load | 75% load | 100% load |
| 1 | 0.491 | 0.414 | 0.387 |
| 2 | 0.522 | 0.445 | 0.417 |
| 3 | 0.500 | 0.424 | 0.406 |
| 4 | 0.504 | 0.432 | 0.407 |
| 5 | 0.522 | 0.453 | 0.426 |
| 6 | 0.497 | 0.426 | 0.417 |
| 7 | 0.503 | 0.417 | 0.375 |
| 8 | 0.533 | 0.447 | 0.421 |
| 9 | 0.492 | 0.417 | 0.381 |
| 10 | 0.507 | 0.439 | 0.442 |
| 11 | 0.540 | 0.456 | 0.424 |
| 12 | 0.507 | 0.425 | 0.393 |
| 13 | 0.551 | 0.447 | 0.407 |
| Average | 0.513 | 0.434 | 0.408 |
| Stand. dev. | 0.019 | 0.014 | 0.019 |
| Equation (35) | 0.574 | 0.499 | 0.513 |
| Difference (%) | 10.627 | 13.026 | 20.468 |

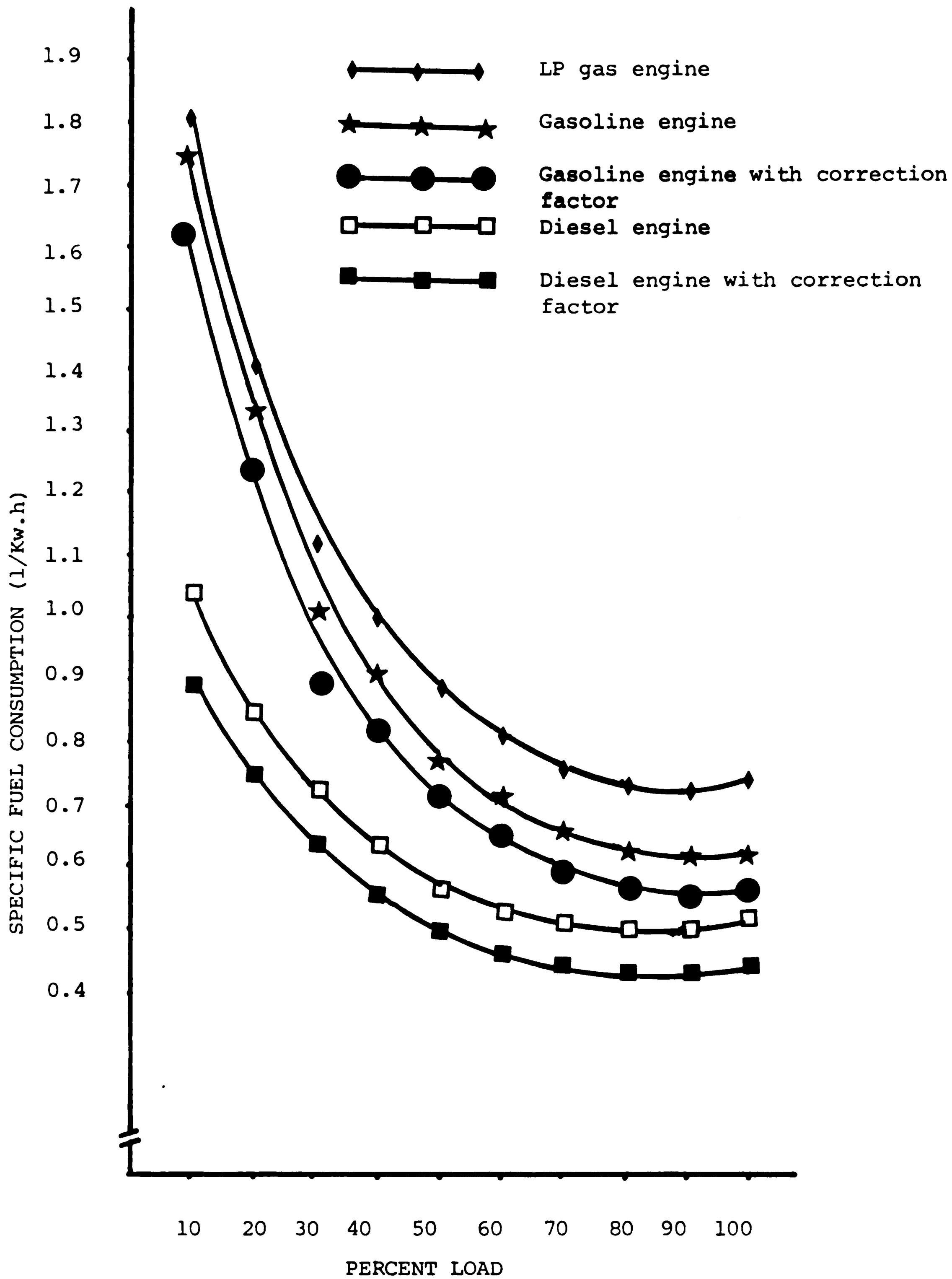


Figure 2. Specific fuel consumption as a function of engine load.

Table 12. Specific fuel consumption for 13 gasoline tractors (Nebraska Tractor Test data).

| Tractor number | Specific fuel consumption (l/Kw-h) | | |
|---|---|---|---|
| | 50% load | 75% load | 100% load |
| 1 | 0.720 | 0.579 | 0.546 |
| 2 | 0.731 | 0.592 | 0.562 |
| 3 | 0.623 | 0.532 | 0.520 |
| 4 | 0.675 | 0.566 | 0.518 |
| 5 | 0.603 | 0.512 | 0.491 |
| 6 | 0.808 | 0.669 | 0.567 |
| 7 | 0.686 | 0.577 | 0.540 |
| 8 | 0.630 | 0.550 | 0.541 |
| 9 | 0.646 | 0.535 | 0.523 |
| 10 | 0.757 | 0.651 | 0.648 |
| 11 | 0.741 | 0.651 | 0.569 |
| 12 | 0.769 | 0.632 | 0.567 |
| 13 | 0.604 | 0.538 | 0.510 |
| Average | 0.692 | 0.538 | 0.546 |
| Stand. dev. | 0.068 | 0.050 | 0.039 |
| Equation (36) | 0.786 | 0.632 | 0.609 |
| Difference (%) | 11.959 | 7.753 | 10.492 |

The specific fuel consumption is then multiplied by the power required to obtain the fuel consumption in liters of fuel per hour.

$$FLPH = ESPFC*PREQ \quad (38)$$

Where FLPH is the fuel consumption in liters per hour, ESPFC is the specific fuel consumption in l/Kw-h, and PREQ is the PTO power required in Kw.

The effective field capacity is given by the following equation:

Table 13. Values for the parameters used in the fuel consumption model.

| Parameters | Values | | | | | | |
|---|---|---|---|---|---|---|---|
| C1 | 7.000 | 6.000 | 4.800 | 3.000 | 3.800 | 2.800 | 2.000 |
| C11 | 0.049 | 0.053 | 0.024 | 0.020 | 0.032 | 0.013 | 0.013 |
| C2 | 5.200 | 2.400 | | | | | |
| CC2 | 0.039 | 0.045 | | | | | |
| C3 | 21.500 | | | | | | |
| C4 | 14.700 | 11.700 | 7.800 | | | | |
| C5 | 500.000 | 500.000 | 500.000 | | | | |
| CC5 | 206.000 | 86.000 | 194.000 | | | | |
| CFC1 | 300.000 | 300.000 | 300.000 | | | | |
| CFC2 | 50.000 | 70.000 | 35.000 | | | | |
| C6 | 43.900 | 0.140 | | | | | |
| C7 | 2.000 | 1.700 | 1.600 | | | | |
| CC7 | 0.170 | 0.130 | 0.130 | | | | |
| C8 | 280.000 | 228.000 | 190.000 | 175.000 | 155.000 | 120.000 | |
| CA10 | 11600.000 | 8000.000 | 4400.000 | | | | |
| CA11 | 730.000 | 585.000 | 440.000 | | | | |
| CA12 | 2190.000 | 11825.000 | 1460.000 | | | | |
| CA13 | 1830.000 | 1355.000 | 880.000 | | | | |
| CA14 | 880.000 | 660.000 | 440.000 | | | | |
| C16 | 2926.000 | | | | | | |
| C17 | 800.000 | 625.000 | 450.000 | | | | |
| C18 | 2000.000 | 1550.000 | 1100.000 | | | | |
| C19 | 450.000 | 290.000 | 130.000 | | | | |
| CC19 | 670.000 | 502.000 | 335.000 | | | | |
| C20 | 2800.000 | 2400.000 | 2000.000 | | | | |
| C21 | 230.000 | 173.000 | 115.000 | | | | |
| C22 | 2200.000 | 1465.000 | 730.000 | | | | |
| C23 | 440.000 | | | | | | |
| CC23 | 21.700 | | | | | | |
| C24 | 1800.000 | | | | | | |
| C25 | 50.000 | 30.000 | 20.000 | 15.000 | | | |
| C26 | 7.500 | | | | | | |
| CC26 | 7.500 | | | | | | |
| C27 | 11.000 | 9.300 | 7.500 | | | | |
| C28 | 2.200 | 1.900 | 1.500 | | | | |
| C29 | 5.200 | 4.450 | 3.700 | | | | |
| C32 | 3.000 | 2.300 | 1.500 | | | | |
| CC32 | 4000.000 | 3000.000 | 2000.000 | | | | |
| C33 | 1.500 | 1.100 | 1.750 | | | | |
| CC33 | 3500.000 | 2900.000 | 2200.000 | | | | |
| C34 | 1.200 | | | | | | |
| C35 | 4.900 | 4.300 | 3.700 | | | | |

Table 13. (cont'd)

| Parameters | Values | | | | |
|---|---|---|---|---|---|
| C36 | 8.200 | | | | |
| CC36 | 2.130 | | | | |
| C37 | 2.450 | | | | |
| C38 | -0.186 | | | | |
| CC38 | 0.052 | | | | |
| C39 | 2.950 | | | | |
| C40 | 2.950 | | | | |
| C43 | 1.500 | | | | |
| CC43 | 3.300 | | | | |
| C46 | 1668.000 | | | | |
| C47 | 448.000 | | | | |
| C48 | 1668.000 | | | | |
| FCP | 1.440[1] | 1.280[2] | | | |
| PAR | 0.720 | 0.740 | 0.840 | 0.760 | 0.940[3] |
| | 0.860 | 0.920 | 0.890 | 0.860 | 0.800[4] |

1 and 2 = Parameters for 180 proof alcohol.
3 = Parameters for 100 proof alcohol.
4 = Parameters for 160 proof alcohol.

EFC = WIDTH*SPEED*EFF(NOP)/10.0 (39)

Where EFC is the effective field capacity in ha/h, WIDTH is the machine width in m, SPEED is the machine speed in Km/h, EFF is the field efficiency for field operations, and NOP is the operation number.

Machine use is calculated by dividing the area (AREA) by the effective field capacity (EFC).

USE = AREA/EFC (40)

The fuel consumption in liters per hectare (FCHA) is then given by:

FCHA = FLPH/EFC (41)

If any of the engines are converted to run on alcohol fuel then the alcohol subroutine is called, otherwise the variables are used to calculate the costs in the cost subroutine.

### 4.2.3 Alcohol subroutine.

This subroutine allows alcohol to be used in either one of the following tractor conversion methods:

1. Use of alcohol in gasoline engines after minor carburetor modifications.
2. Use of alcohol in gasoline engines after major modifications for increased compression.
3. Use of alcohol through dual-fueling of diesel engines where alcohol is sprayed into the intake air by pressurized air from the turbocharger.
4. Use of alcohol through dual-fueling of diesel engines where alcohol is aspirated into the intake air through a carburetor system.

The alcohol consumption for the first and second conversion methods is calculated by the following equation:

ALUSE = CFUSE*FCP (42)

Where ALUSE is the alcohol use in liters, CFUSE is the conventional fuel use in liters, and FCP is the alcohol fuel consumption parameter. Different parameters for ethanol are stored in the subroutine block data.

The third and fourth conversion methods are modeled by the following equation:

ALUSE = CFUSE*PAR(IFACT) (43)

Where IFACT is the values assigned for different load ranges. Five load ranges are used for each conversion methods and for each alcohol type. PAR is the alcohol fuel consumption parameter.

4.2.4 Cost subroutine.

The cost subroutine calculates the conventional and alternative fuel costs. The following relationship is used:

CFC = CFUSE*CFP/AREA (44)

Where CFC is the conventional fuel cost in dollars per hectare and CFP is the cost of fuel in dollars per liter. A similar equation is used for alcohol fuel costs.

In order to calculate the alcohol break-even price the following were taken into consideration: Annual cost due to machine conversion, conventional fuel cost, and alcohol fuel consumption. The calculations were made on an annual basis. A capital recovery factor was calculated in order to determine the annual conversion cost. The following equations were used to calculate the annual machine fuel cost and alcohol break-even price.

CRF = A*(1.0+A)**NN/((1.0+A)**NN-1.0) (45)

Where CRF is the capital recovery factor. A is the discount rate in decimal. NN is the number of years for recovery of investment.

The annual conversion cost was calculated by the following equation:

ACC = CONCOS(ICOTY)*CRF (46)

Where ACC is the annual cost to be recovered, and CONCOS is the conversion cost depending on the conversion type ICOTY. The conversion cost includes the cost for parts and cost for labor when converting engines to alcohol.

Annual fuel cost for an alcohol fueled engine was determined by:

$$ACAF = TCOSTD+TCOSTA+ACC \quad (47)$$

Where ACAF is the annual fuel cost. TCOSTD and TCOSTA are the cost of conventional fuel (in the case of dual fuel engines) and alcohol fuel costs.

A break-even price for alcohol fuel was then obtained by using Equation (48).

$$BEPA = (TCOSTF-TCOSTD-ACC)/TTOTA \quad (48)$$

Where BEPA is the break-even price for alcohol fuel in dollars per liter, TCOSTF is the annual cost for conventional fuel, and TTOTA is the total alcohol use in liters.

# CHAPTER 5

# DATA COLLECTION AND VALIDATION

## 5.1 Validation by operation.

Two types of data were collected. Field data and data from a Michigan Energy Audit Study.

### 5.1.1 Data collection.

It was decided that one way of validating the model was through a comparison between the model results and field data collected for field operations on Michigan farms. Michigan farms were evaluated in the fall season of 1980.

The first farm chosen to collect data (farm one) was a cash crop farm located in Ithaca, Michigan. Five crops were grown on a total of 340 hectares. Data were collected for six field operations including: Pulling and windrowing navy beans, combining navy beans, combining corn, combining soybeans, moldboard plowing, and chisel plowing. The machine sizes, performance and fuel consumption data are listed in Tables 14 and 15.

Table 14. Machinery size and performance for farm number one in the fall season of 1980.

| Operation name | Machine type and model | Gear used | RPM | Implement size (m) | Working depth (cm) | Soil type, condition |
|---|---|---|---|---|---|---|
| 1. Pulling-windrowing | Tractor, Ford 7000, dsl, 1974, 62 Kw | 6 | 1900 | 2.84 (4 rows) | 8 | sandy, field capacity |
| 2. Combining navy beans | Combine, Gleaner F, gas, 1975, 75 Kw | 2 | 2400 | 5.68 (8 rows) | - | sandy, field capacity |
| 3. Combining corn | Combine, Gleaner F, gas, 1975, 75 Kw | 2 | 2400 | 2.84 (4 rows) | - | sandy, residues little wet surface |
| 4. Combining soybean | Combine, Gleaner F, gas, 1975, 75 Kw | 2 | 2400 | 3.56 (5 rows) | - | clay, residues little wet surface |
| 5. Moldboard plowing | Tractor, Versatile 855 diesel, 175 Kw | 2/2 | 2100 | 3.67 (8 bottoms) | 22 | sandy loam, field capacity |
| 6. Chisel plowing | Tractor, Versatile 855 diesel, 175 Kw | 2/1 | 2050 | 4.57 (15 shanks) | 24 | sandy loam, frosty and very hard surface |

dsl = diesel
gas = gasoline

Table 15. Machinery performance and fuel consumption for farm number one in the fall season of 1980.

| Operation name @ | Feed rate (Kg/s) | Field efficiency (%) | Speed (Km/h) | EFC (ha/h) | Fuel consumption (l/h) | Fuel consumption (l/ha) |
|---|---|---|---|---|---|---|
| 1. Pulling-windrowing navy beans | - | 80* | 9.92 | 2.25 | 6.62 | 3.83 |
| 2. Combining navy beans | 2.63 | 80* | 4.06 | 1.81 | 19.60 | 10.83 |
| 3. Combining corn | 4.87 | 68+ | 4.15 | 0.80 | 21.38 | 26.73 |
| 4. Combining soybeans | 3.11 | 74+ | 4.45 | 1.17 | 16.37 | 13.99 |
| 5. Moldboard plowing | - | 80* | 8.00 | 2.35 | 43.12 | 18.31 |
| 6. Chisel plowing | - | 80* | 6.80 | 2.49 | 39.07 | 15.69 |

* = From ASAE yearbook
+ = Determined from field operations
@ = The machines used for these operations are listed in Table 14.

The following information was obtained from the farmer or through field tests: operations performed; machine type, model, year, hours of use; power, number of gears, gear used, engine RPM, and cylinder RPM (for some harvesting operations); implement size and working depth; soil type and conditions; machine speed; combine feed rate; engine fuel consumption; and machine field efficiency (for some harvesting operations).

For the first operation, pulling and windrowing of navy beans, data was collected from a two hectare plot. The operation was performed with a 1974 Ford 7000 diesel tractor, pulling a 4-row puller and windrower, working at approximately an 8 cm depth. The soil was a sandy type, and the moisture was close to field capacity. The tractor worked in sixth gear at approximately 1900 RPM. The crop rows were spaced by 71 cm. A 32.44 m rope was used to take the speed samples for all operations, and the time was obtained from a stop watch. Fourteen speed samples were taken and the average speed was 9.92 Km/h with a standard deviation of 0.53 Km/h. The tractor worked for 48 minutes to pull and windrow two hectares of navy beans. The tractor fuel tank was filled completely before starting the operation. To refill the tank 6.9 liters of diesel fuel were required.

Combining navy beans was performed in the same two hectare plot where the pulling and windrowing operation was done. This operation was performed with a 1975 Gleaner F combine, gasoline-fueled with approximately 75 Kw of power. The combine worked in second gear at approximately 2400 engine RPM. Each pass the combine harvested 8 rows or a 5.68 m width.

Nineteen feed rate samples were taken throughout the two hectare plot. The samples were taken along one meter of row. The plants were pulled by hand and taken to the Agricultural Engineering Department to be weighed on a precise scale. The average number of plants per meter in a row was 15.73 with a standard deviation of 1.97 plants. The average sample weight was 0.297 Kg with a standard deviation of 0.0427 Kg. The feed rate was then calculated obtaining a value of 2.63 Kg/s.

Fourteen speed samples were taken and the average speed was 4.06 Km/h with a standard deviation of 0.21 Km/h. The combine worked for 55 minutes to finish the two hectare plot. The combine fuel tank was filled in the field before starting harvest and the total fuel used was 17.8 liters of gasoline.

The next operation was combining of corn. The operation was performed with the same Gleaner F combine, using a 4-row header. The rows were spaced by 71.12 cm. The combine was monitored for 178 minutes. The soil was a sandy type and the surface was a little wet. The combine worked in second gear at approximately 2400 engine RPM and at 400 cylinder RPM. The corn was harvested at 28 percent moisture content.

Fourteen feed rate samples were taken throughout the field where the combine later harvested the corn. A distance of 3.05 m was used to take samples along the rows. The corn ears were picked by hand and weighed in the field. The average number of plants per 3.05 m was 13.9 with a standard deviation of 1.7 plants. The number of ears was 13.4 with a standard deviation of 1.77 ears per 3.05 m. The average sample weight was 3.22 kg with a standard deviation of 0.23 Kg. The feed rate was then calculated obtaining a value of 4.87 Kg/s. The corn yield was approximately 9140 Kg per hectare.

Ten speed samples were taken. The average speed was 4.15 Km/h with a standard deviation of 0.24 Km/h. From the total time (178 minutes), 120 minutes was working time, 4 minutes was travel time, 25 minutes was unloading time, and 29 minutes was idle time. The field efficiency for the combine was calculated as 68 percent.

The combine fuel tank was filled when the combine left the farm center and refilled after 178 minutes. The fuel consumption was 42.8 liters of gasoline.

The next operation was combining of soybeans. This operation was performed with the same Gleaner F combine, using a header that could harvest 5 rows, spaced by 71.12 cm. The combine was monitored for 301 minutes. The soil was a clay type and the surface was a little wet. The combine worked in second gear at approximately 2400 RPM. The crop was harvested at 16 percent moisture content and the yield was approximately 1850 Kg/ha.

Nineteen feed rate samples were taken throughout the field. A distance of one meter was used along the row. Plants were cut at approximately the same height as the combine was harvesting, and were weighed on a precise scale. The average number of plants per meter was 16.21 with a standrad deviation of 4.55 plants. The average sample weight was 0.50 Kg with a standard deviation of 0.10 Kg. The feed rate was calculated obtaining a value of 3.11 Kg/s.

Nine speed samples were taken and the average speed was 4.45 Km/h with a standard deviation of 0.24 Km/h.

From the total time (301 minutes), 222 minutes was working time, 10 minutes was travel time, 22 minutes was unloading time, and 47 minutes was idle time. The combine field efficiency was 74 percent.

The combine fuel tank was filled when the combine left the farm center and refilled after 301 minutes. The fuel consumption was 60.6 liters of gasoline.

The next operation performed was moldboard plowing. The operation was performed with a 4 wheel drive, Versatile 855 tractor and an 8-bottom moldboard plow, 3.89 m wide, working at approximately a 22 cm depth. The soil was a sandy loam type. The operation was performed after disking the corn stalks. The soil was at a good moisture content for plowing.

Six speed samples were taken with the tractor working in 2nd/2nd gear at approximatley 2100 RPM. The average speed was 8.00 Km/h with a standard deviation of 0.30 Km/h. The speed according to the chart inside the tractor cab was 8.8 Km/h. Part of the difference may be attributed to the tractor wheel slip which was not measured but observed to be in the optimum range (10 - 15 percent). The actual cutting width for the moldboard plow was very close to the theoretical width. This was observed by taking several samples.

The tractor worked for 80 minutes. The useful time was 70 minutes. The 10 minutes difference was idle time, when stops were made to unplug the bottoms of the moldboard plow. The tractor spent 52.0 liters of diesel fuel for the plowing test.

The last operation performed was chisel plowing. The same Versatile 855 tractor was used to perform this operation. The chisel plow had 15 shanks spaced at 30.48 cm. The working depth was approximately 24 cm, which was controlled by the depth control lever. Only in certain occasions when the tractor slip was too high, the depth control was touched to decrease the working depth. The soil was a sandy type, with some residues from a previous sugar beet crop. The operation was performed in the morning while the surface was frosty, making it difficult to brake the soil crust.

Six speed samples were taken with the tractor working in 2nd/1st gear at approximately 2050 RPM. The average speed was 6.8 Km/h with a standard deviation of 0.4 Km/h. The chart of speeds inside the tractor cab indicated 7.5 Km/h. The difference was mainly attributed to the high wheel slip which increased as the frosty surface melted.

During the 97 minutes of work, no stops were made. Only 8 turns were made and the engine was kept at a high speed. During the chisel plowing test the tractor spent 57.0 liters of diesel fuel.

Data were collected for disking, chisel plowing, and moldboard plowing operations on a second farm (farm number two). Three tractors were used. Machinery size, performance, and fuel consumption data for this farm are listed in Tables 16 and 17.

The first operation performed was disking of soybean stalks. The tractor used was a 1967 John Deere 4020, Diesel, with 68 Kw of power and 2485 hours of use. The disk had 48 blades, total width of 4 m, and 1200 Kg of mass. The tractor worked in two gears and in two different engine speeds. The first test was done with the tractor working in lower gear (5th) and higher RPM (2200). For the second test a higher gear (6th) was used at a lower RPM (1750). The soil was clay type with some surface residues.

For the first test eight speed samples were taken. The average speed was 9.32 Km/h with a standard deviation of 0.30 Km/h. Eight speed samples were also taken for the second test. The average speed was 10.17 Km/h with a standard deviation of 0.20 Km/h.

Table 16. Machinery size and performance for farm number two in the fall season of 1980.

| Operation name | Machine type and model | Gear used | RPM | Implement size (m) | Working depth (cm) | Soil type, condition |
|---|---|---|---|---|---|---|
| 1. Disking (after soybean harvesting) | Tractor, John Deere 4020,diesel,1967,68Kw | 5 | 2200 | 4.00 | - | clay, residues field capacity |
| 2. Disking (after soybean harvesting) | Tractor, John Deere 4020,diesel,1967,68Kw | 6 | 1750 | 4.00 | - | clay, residues field capacity |
| 3. Chisel plowing (after disking) | Tractor, John Deere 4020,diesel,1967,68Kw | 5 | 2050 | 2.44 | 30 | clay, residues field capacity |
| 4. Chisel plowing (after disking) | Tractor, Case 830 48 kw | 4 | 2050 | 2.44 | 30 | clay, residues field capacity |
| 5. Chisel plowing (after disking) | Tractor, Ford 7700, 1980, 62 Kw | 5 | 2100 | 2.44 | 25 | clay, residues little wet |
| 6. Chisel plowing (after disking) | Tractor, Ford 7700, 1980, 62 Kw | 4 | 2100 | 2.44 | 30 | clay, residues little wet |
| 7. Moldboard plowing | Tractor, Ford 7700, 1980, 62 Kw | 4 | 2100 | 2.44 | 22 | clay, residues little wet |

Table 17. Machinery performance and fuel consumption for farm number two in the fall season of 1980.

| Operation name | Field efficiency (%) | Speed (Km/h) | EFC (ha/h) | Fuel consumption (l/h) | (l/ha) |
|---|---|---|---|---|---|
| 1. Disking (after soybean harvesting) | 80 | 9.32 | 2.98 | 11.38 | 3.82 |
| 2. Disking, second test | 80 | 10.17 | 3.25 | 11.86 | 3.65 |
| 3. Chisel plowing (after disking) | 80 | 8.54 | 1.67 | 15.55 | 9.31 |
| 4. Chisel plowing (after disking) | 80 | 5.96 | 1.17 | 10.61 | 9.07 |
| 5. Chisel plowing (after disking) | 80 | 8.39 | 1.64 | 16.27 | 9.92 |
| 6. Chisel plowing (after disking) | 80 | 6.82 | 1.33 | 16.35 | 12.29 |
| 7. Moldboard plowing | 80 | 6.35 | 0.90 | 15.68 | 17.42 |

* = The tractor used for these operations are listed in Table 16.

The tractor worked for 24 minutes in the first test and spent 4.55 liters of diesel fuel. In the second test, the same amount of work was done in 22 minutes with 4.35 liters of diesel fuel.

The second operation performed was chisel plowing. Three tractors were tested in this operation. A John Deere 4020, a Case 830, and a Ford 7700. The chisel plow contained 7 shanks, with a 2.44 m width. The operation was performed after disking. The same area was covered with the John Deere 4020 and Case 830 tractors. The working depth was approximately 30 cm.

The following were the tractor speeds for the three tractors tested: the average speed was 8.54 Km/h for the John Deere 4020, 5.96 Km/h for the Case 830, 8.39 Km/h for the Ford 7700 in high gear, and 6.82 Km/h for the Ford 7700 in low gear. The standard deviation for the above tests were the following: 0.15, 0.09, 0.10, and 0.09 Km/h.

The John Deere 4020 worked for 27 minutes and used 7.00 liters of diesel fuel. The Case 830 worked for 37 minutes and did the same amount of work as the John Deere 4020 with 6.55 liters of diesel fuel. The Ford 7700 worked for 32 minutes in high gear and used 8.67 liters of diesel fuel. When working in low gear the Ford 7700 worked for 39 minutes and spent 10.62 liters of diesel fuel.

The last operation was moldboard plowing. The operation was performed with a Ford 7700 tractor working in 4th gear at approximately 2100 RPM. The moldboard plow was 1.78 m wide and worked at approximately a 22 cm depth in a clay soil. The average speed was 6.35 Km/h. The tractor worked for 48 minutes and spent 12.6 liters of diesel fuel.

5.1.2 Validation.

The data collected on farm number one and farm number two were used as input for the computer program. Table 18 presents the results of the computer program for farm number one. The fuel consumption in liters of diesel fuel per hectare from the field observation, average fuel consumption on Michigan farms, and average fuel consumption for other states are also listed in Table 18. The results from the computer program are close enough to the actual data to show that the model is reasonably accurate for modeling fuel requirements. A difference of less than 20 percent was obtained for most of the operations.

Where the results of the computer model are not close to the results from field observations, they are generally close to the Michigan average. The highest difference was obtained for pulling and windrowing navy beans. This can be attributed to the high parameter used for the implement draft equation. The equation does not take into consideration the soil type. Part of the difference could be attributed to error in the field observation measurement since only one test was done.

The fuel consumption for corn harvesting was higher than the average for Michigan farms. More energy was required to harvest corn, since the corn was grown using irrigation giving an approximate yield of 9140 Kg per hectare.

Table 19 presents the results of the computer program for farm number two. The fuel consumption in liters of diesel fuel per hectare from field observations, average fuel consumption on Michigan farms, and average fuel consumption for other states are also listed in Table 19. The results from the computer program for farm number two are also close to those from field observations. The disking operation was done on soybean ground which contained a high level of residue on the surface.

Table 18. Fuel consumption for field operations on farm number one.

| Operations[1] | Fuel consumption (l/ha)[2] | | | |
|---|---|---|---|---|
| | Model | Field obs. | Michigan ave.[3] | Other states[4] |
| Pulling and windrowing navy beans | 6.02 | 3.83 | 4.86 | 3.18 |
| Harvesting navy beans | 8.15 | 7.58 | 11.50 | 9.45 |
| Harvesting corn | 19.92 | 18.71 | 14.12 | 12.81 |
| Harvesting soybean | 12.43 | 9.79 | 11.50 | 9.45 |
| Moldboard plowing | 18.98 | 18.31 | 16.93 | 17.49 |
| Chisel plowing | 14.39 | 15.69 | 12.72 | 10.19 |

1 = The machines and implements used for these operations are listed in Tables 14 and 15.
2 = The fuel consumption is in liters of diesel fuel per hectare, a factor of 0.7 was used to convert gasoline to diesel equivalent.
3 = From Michigan Energy Audit Study (average of 52 farms).
4 = States of Iowa, Nebraska, Missouri, Wisconsin, New York, Ontario, Oklahoma, and North Dakota.

Table 19. Fuel consumption for field operations on farm number two.

| Operations[1] | Fuel consumption (l/ha)[2] | | | |
|---|---|---|---|---|
| | Model | Field obs. | Michigan ave.[3] | Other states[4] |
| Disking | 4.76 | 3.82 | 8.70 | 6.08 |
| Disking | 4.57 | 3.65 | 8.70 | 6.08 |
| Chisel plowing | 11.98 | 9.31 | 12.72 | 10.19 |
| Chisel plowing | 10.10 | 9.07 | 12.72 | 10.19 |
| Chisel plowing | 13.01 | 9.92 | 12.72 | 10.09 |
| Chisel plowing | 11.86 | 12.29 | 12.72 | 10.19 |
| Moldboard plowing | 17.01 | 17.42 | 16.93 | 17.49 |

1 = The tractors and implements used for these field operations are listed in Tables 16 and 17.
2 = The fuel consumption is in liters of diesel fuel per hectare.
3 = From Michigan Energy Audit Study (average of 52 farms).
4 = States of Iowa, Nebraska, Missouri, Wisconsin, New York, Ontario, Oklahoma, and North Dakota.

The parameters used to calculate the enrgy requirements were obtained from the ASAE yearbook. The same formula was used for disking stalks, but with the parameters reduced by 70 percent as indicated by White, 1977. The model results for some chisel plowing operations were higher than the field observations. Only three formulas were available for chisel plowing, so the most appropriate one was used. Differences in the soil type could increase the draft by 20 percent.

The computer program in general produced representative results for specific situations. In the next section we present the results from three Michigan farms, where more will be concluded about the models usefulness.

## 5.2 Whole farm validation.

### 5.2.1 Michigan Energy Study Study data.

Three farms were selected from a Michigan Energy Audit Study to make the energy comparison to the computer program. The first was a small-size farm with four crops as shown in Table 20. The soil was a loamy type. Table 21 presents the machine power units used for field operations on farm number three in 1979.

The next farm studied was a medium-size farm. Three crops were grown on a total of 200 hectares. The soil was a loamy type. Tables 22 and 23 present the crops, area, and machines used on the farm in 1979.

Table 20. Crops grown on the small-size farm in 1979.

| Crops | Area (ha). |
|---|---|
| Corn | 40.0 |
| Oats | 3.6 |
| Wheat | 4.4 |
| Hay | 31.0 |
| Total | 79.0 |

Table 21. Power units used on the small-size farm.

| Machine type | Power (Kw) | Fuel type |
|---|---|---|
| Tractor No. 1 | 74.74 | Diesel |
| Tractor No. 2 | 52.15 | Diesel |
| Tractor No. 3 | 45.18 | Diesel |

Table 22. Crops grown on the medium-size farm.

| Crops | Area (ha) |
|---|---|
| Corn | 59.0 |
| Oats | 31.0 |
| Wheat | 84.0 |
| Hay | 26.0 |
| Total | 200.0 |

Table 23. Power units used on the medium-size farm in 1979.

| Machine type | Power (Kw) | Fuel Effic. (Km/l) | Fuel type |
|---|---|---|---|
| Tractor No. 1 | 70.00 | | Diesel |
| Tractor No. 2 | 93.78 | | Diesel |
| Combine | 70.00 | | Gasoline |
| Truck No. 1 | | 1.30 | Gasoline |
| Truck No. 2 | | 2.00 | Gasoline |
| Truck No. 3 | | 1.50 | Gasoline |

Table 24. Crops grown on the large-size farm in 1979.

| Crops | Area (ha) |
|---|---|
| Corn | 139.0 |
| Wheat | 60.0 |
| Navy beans | 97.0 |
| Soybeans | 213.0 |
| Sugar beets | 38.0 |
| Hay | 3.0 |
| Total | 550.0 |

The final farm was a large farm of 550 hectares. The soil was loam and six crops were produced. Tables 24 and 25 present the crops, area, and machines used on the large size farm.

Table 25. Power units used on the large-size farm in 1979.

| Machine type | Power (Kw) | Fuel Effic. (Km/l) | Fuel type |
|---|---|---|---|
| Tractor No. 1 | 138.83 | | Diesel |
| Tractor No. 2 | 46.93 | | Gasoline |
| Tractor No. 3 | 74.74 | | Diesel |
| Tractor No. 4 | 93.78 | | Diesel |
| Tractor No. 5 | 112.24 | | Diesel |
| Tractor No. 6 | 130.95 | | Diesel |
| Combine | 95.00 | | Diesel |
| Truck No. 1 | | 6.38 | Gasoline |
| Truck No. 2 | | 3.20 | Gasoline |
| Truck No. 3 | | 1.35 | Diesel |
| Truck No. 4 | | 1.65 | Gasoline |
| Truck No. 5 | | 4.05 | Gasoline |
| Truck No. 6 | | 4.44 | Gasoline |
| Truck No. 7 | | 1.10 | Gasoline |

5.2.2 Validation.

The data collected for farms number three, four, and five as described in section 5.2.1 were used as input data for the computer program. The results are presented as small, medium, and large-size farms.

5.2.2.1 Small-size farm.

Table 26 presents the results from the computer program for the three tractors used on the farm. These results show that the average

Table 26. Tractor usage and fuel consumption for the small-size farm.

| Machine | Power (Kw) | Ave. load | Ave. FLPH[1] | TUSE[2] | FCHA[3] |
|---|---|---|---|---|---|
| Tractor No. 1 | 75 | 37 | 15.0 | 348 | 10.0 |
| Tractor No. 2 | 52 | 32 | 10.8 | 96 | 4.8 |
| Tractor No. 3 | 45 | 32 | 8.4 | 15 | 5.1 |

1 = Average fuel consumption (l/h)
2 = Machine annual use (h)
3 = Average fuel consumption (l/ha)

load for all the tractors was low. According to Figure 2, diesel tractors are very efficient at low load when compared to gasoline and LP gas tractors but the highest fuel efficiency for diesel tractors occurs when they are operated at 80 percent load. Tractor number one, with the highest power rating had the highest yearly use. Tractors number two and three had a low yearly use and a lower fuel consumption (l/h and l/ha). Table 27 presents the fuel consumption by operation group. The

Table 27. Fuel consumption by operation group for a small-size farm.

| Operation group | Total fuel (1) | l/ha | % of total |
|---|---|---|---|
| Tillage | 961 | 12.2 | 21 |
| Seeding | 179 | 2.3 | 4 |
| Cultivating | 91 | 1.2 | 2 |
| Spraying, fertililzer | 24 | 0.3 | 1 |
| Harvesting | 2,945 | 37.3 | 64 |
| Transporting | 369 | 4.7 | 8 |
| Total | 4,569 | 58.0 | 100 |

total fuel use for the small size farm was 4,569 liters compared to 4,282 liters reported by the farmer. The highest fuel use was for harvesting operations which included corn silage and hay harvesting. Tillage operations had a low fuel use because in this particular year no soil was prepared for alfalfa planting. The average fuel consumption for the farm was 58.0 liters of diesel fuel per hectare.

Table 28 presents the fuel consumption per enterprise for the small farm. Corn was grown for silage on this farm and the fuel consumption was 67.2 liters per hectare. Wheat and oats had a very low fuel use because few operations were reported by the farmer, and the harvesting operations were done through custom hire. Hay was the second highest energy consumer with 56.6 liters of diesel fuel per hectare.

Table 28. Fuel consumption by enterprise for the small-size farm.

| Enterprise | Total fuel (l) | l/ha |
|---|---|---|
| Corn | 2,689 | 67.2 |
| Oats | 18 | 5.9 |
| Wheat | 109 | 24.8 |
| Hay | 1,753 | 57.6 |
| Total | 4,569 | |

5.2.2.2 Medium-size farm.

Table 29 presents the results from the computer program for the power units used on the medium size farm. The smaller tractor was only used for spraying and fertilizing operations, and therefore, had a low average load and low fuel consumption (l/h and l/ha). The value for the combine represents liters of gasoline fuel used. Tractor number two had a higher usage (486 hours). This tractor was used for most of the field operations. The tractor load was higher for tillage operations and lower for other operations so the average load was still a little low. The combine presented a high load for corn harvesting, but the average load was still low. Table 30 presents the fuel consumption (diesel equivalent) by operation group. The medium size farm used 13,521 liters of diesel fuel compared to 13,484 liters reported by the farmer. An average of 67.6 liters of diesel fuel per hectare was obtained. As expected tillage required more than half of the fuel used on the farm. The second fuel consuming operation group was harvesting which used 18

Table 29. Machine usage and fuel consumption for the medium-size farm.

| Machine | Power (Kw) | Average Load | Average FLPH[1] | TUSE[2] | FCHA[3] |
|---|---|---|---|---|---|
| Tractor No. 1 | 70 | 22 | 10.8 | 160 | 3.9 |
| Tractor No. 2 | 94 | 41 | 20.9 | 485 | 8.7 |
| Combine[4] | 70 | 46 | 24.6 | 181 | 18.8 |

1 = Average fuel consumption (l/h)
2 = Machine annual use (h)
3 = Average fuel consumption (l/ha)
4 = Gasoline combine

Table 30. Fuel consumption by operation group for the medium-size farm.

| Operation group | Total fuel (l) | l/ha | % of total |
|---|---|---|---|
| Tillage | 7,518 | 37.6 | 56 |
| Seeding | 832 | 4.2 | 6 |
| Cultivating | 289 | 1.4 | 2 |
| Spraying, fertililzer | 1,903 | 9.5 | 14 |
| Harvesting | 2,474 | 12.4 | 18 |
| Transporting | 505 | 2.5 | 4 |
| Total | 13,521 | 67.6 | 100 |

Table 31. Fuel consumption by enterprise for the medium-size farm.

| Enterprise | Total fuel (l) | l/ha |
|---|---|---|
| Corn | 4,651 | 78.8 |
| Wheat | 3,342 | 107.8 |
| Soybean | 5,304 | 63.1 |
| Cover crop | 224 | 8.6 |
| Total | 13,521 | |

expected tillage required more than half of the fuel used on the farm. The second fuel consuming operation group was harvesting which used 18 percent of the fuel used on the farm. The third highest was spraying and fertilizing which used 14 percent of the fuel used on the farm. Table 31 presents the fuel consumption by enterprise. Wheat presented the highest energy use. This occurred because chisel plowing was performed twice and several spraying operations were performed on the wheat crop. Corn consumed 78.8 liters of diesel fuel per hectare, soybeans consumed 63.1 liters of diesel fuel per hectare, and the cover crop, rye, used 8.6 liters/ha of diesel fuel.

5.2.2.3 Large-size farm.

Table 32 presents the results from the computer program for the power units used on a large farm. These are the simulated results from the computer program for 1979. The tractors had a higher average load than the tractors in the small and medium size farms. Better tractor

Table 32. Machine usage and fuel consumption for the large-size farm.

| Machine | Power (Kw) | Average Load | Average FLPH[1] | TUSE[2] | FCHA[3] |
|---|---|---|---|---|---|
| Tractor No. 1 | 139 | 58 | 37.8 | 177 | 16.6 |
| Tractor No. 2 | 47 | 45 | 16.3 | 3 | 13.2 |
| Tractor No. 3 | 75 | 29 | 13.3 | 346 | 5.9 |
| Tractor No. 4 | 94 | 32 | 17.8 | 426 | 6.4 |
| Tractor No. 5 | 112 | 57 | 30.4 | 276 | 12.0 |
| Tractor No. 6 | 131 | 57 | 35.6 | 277 | 9.2 |
| Combine[4] | 95 | 32 | 18.4 | 408 | 12.0 |

1 = Average fuel consumption (l/h)
2 = Machine annual use (h)
3 = Average fuel consumption (l/ha)
4 = Gasoline combine

and implement matching was possible since 6 tractors were available. Tractor number two, a gasoline fueled tractor, was used only for one operation. Tractors number three and four were still too large for the operations assigned for them. The combine had a higher load for corn harvesting, but a lower load for wheat, navy beans, and soybean harvesting.

Table 33 presents the fuel consumption by operation group. Tillage and harvesting were the two groups with higher fuel use. Tillage operations consumed 50 percent of the fuel used on the farm. Harvesting operations consumed 20 percent of the total fuel used on the farm. The large farm consumed 37,717 liters of diesel fuel for field operations

Table 33. Fuel consumption by operation group for the large size farm.

| Operation group | Total fuel (l) | l/ha | % of total |
|---|---|---|---|
| Tillage | 19,137 | 34.8 | 50 |
| Seeding | 3,178 | 5.8 | 8 |
| Cultivating | 3,029 | 5.5 | 8 |
| Spraying, fertililzer | 2,646 | 4.8 | 7 |
| Harvesting | 7,729 | 14.0 | 20 |
| Transporting | 1,998 | 3.6 | 7 |
| Total | 37,717 | 68.5 | 100 |

from soil preparation to transportation. This value was within 4 percent the value reported by the farmer (39,166 liters of diesel fuel). The average fuel consumption was 68.5 liters of diesel fuel per hectare

Table 34 presents the fuel consumption per enterprise. Sugar beets had the highest fuel consumption (103.4 liters of diesel fuel per hectare). Navy beans and soybean consumed about the same amount of fuel per hectare. Corn and wheat had about the same amount of fuel used. Only three hectares of hay were grown on the farm. The fuel consumption per hectare for hay therefore, is not a representative result since the farmer did not report all operations performed for the hay crop.

Table 34. Fuel consumption by enterprise for the large-size farm.

| Enterprise | Total fuel (l) | l/ha |
|---|---|---|
| Corn | 8,029 | 57.8 |
| Wheat | 3,426 | 57.1 |
| Navy beans | 6,925 | 71.4 |
| Soybean | 15,283 | 71.7 |
| Hay | 126 | 41.9 |
| Sugar beets | 3,928 | 103.4 |
| Total | 37,717 | |

# CHAPTER 6

# ETHANOL AS TRACTOR FUEL

## 6.1 Conversion methods.

The use of alcohol by using the following four tractor conversion methods was investigated.

1. The use of alcohol in gasoline engines after minor modifications such as carburetor change or replacement to provide a carburetor specially designed for alcohol engines.
2. The use of alcohol in gasoline engines after major modifications of rebuilding the engine with increased compression.
3. The use of alcohol through dual-fueling diesel engines where alcohol is sprayed into the intake air by pressurized air from the turbocharger.
4. The use of alcohol through dual-fueling diesel engines where alcohol is aspirated into the intake air through a carburetor system.

Table 35 lists the parameters used for each conversion method. The fuel consumption parameters were obtained from lab tractor tests carried out in the Agricultural Engineering Department (Cruz, 1981; Swarr, 1981) of Michigan State University. As part of the ethanol research project two tractors were converted to run on ethanol. For the first and second conversion methods a Ford 2000 tractor was converted. For the third and fourth conversion methods a Ford 7700 tractor was tested with ethanol through dual-fueling. The fuel consumption parameters for the third and fourth conversion methods were functions of engine load. The parameters are listed in Table 13.

Table 35. Parameters used for 4 conversion methods.

| Parameters | Conversion Methods | | | |
|---|---|---|---|---|
| | First | Second | Third | Fourth |
| Cost ($) | 200 | 1,800 | 1,200 | 1,400 |
| Discount rate(%) | 12 | 12 | 12 | 12 |
| Recovery period (years) | 5 | 5 | 5 | 5 |
| Alcohol proof[1] | 180 | 180 | 100 | 160 |

1 = The alcohol used for all methods was ethanol.

## 6.2 Ethanol use on farms.

### 6.2.1 Small-size farm.

For the small farm described in chapter 5, section 5.2.1, the possibility of converting either one or both of the tractors was investigated. Tractor number two presented a lower usage (96 hours of use in 1979). The conversion of this tractor to alcohol as an alternative to save diesel fuel was not feasible because the annual conversion cost is higher than the fuel savings by using alcohol. Tractor number one which presented a higher annual use (348 hours) was studied for conversion. Two conversion methods were considered available (dual-fueling) for tractor number one. Both methods as described above will replace part of the diesel fuel. Table 36 shows the amount of fuel used by tractor number one when operating under the conventional or dual-fuel mode. When the third conversion method is used 22 percent of the diesel fuel can be replaced by ethanol and when the fourth conversion method is used 44

Table 36. Fuel consumption for tractor number one using 2 conversion methods in a small-size farm.

| Conversion | Diesel (1) | Dual-fuel (1) | |
|---|---|---|---|
| | | Diesel | Ethanol |
| Third | 3,565 | 2,770 | 1,322 |
| Fourth | 3,565 | 2,010 | 2,548 |

percent of the diesel fuel can be replaced by ethanol.

Table 37 shows the break-even prices for alcohol fuel when either one of the third and fourth conversion methods are used on tractor number one. The break-even prices are given for 200 proof alcohol (ethanol). The economics of using alcohol fuel in tractor number one are not promising. For the third conversion method, negative break-even prices were obtained. This means that if diesel fuel prices are less than $0.40 per liter, the amount of money saved by using alcohol is less than the amortized cost of conversion. For diesel prices greater than $0.40 per liter, alcohol should not cost more than 36 percent of the diesel cost when diesel prices are at $1.06 per liter. Better results were obtained when the fourth conversion method was used. For today's diesel fuel prices ($0.33/l) alcohol should not cost more than 19 percent of the diesel cost. For diesel prices of $.79 per liter, alcohol should not cost more than 42 percent of the diesel cost. If conversion is to be made the fourth convesion method which can save up to 34 percent of the total farm fuel use would have to be chosen. Considering a corn yield of 6276 Kg per hectare and an alcohol yield of 0.357 liters

Table 37. Break-even prices for alcohol fuel for 2 conversion methods on a small-size farm.

| Diesel price ($/l) | Break-even prices of ethanol ($/l) | |
|---|---|---|
| | Third conversion | Fourth conversion |
| 0.26 | - 0.10 | 0.01 |
| 0.33 | - 0.05 | 0.05 |
| 0.40 | - 0.01 | 0.09 |
| 0.46 | 0.03 | 0.13 |
| 0.53 | 0.07 | 0.17 |
| 0.79 | 0.22 | 0.33 |
| 1.06 | 0.38 | 0.49 |

per Kg of corn grain, 1.14 hectares of corn should be planted to supply the 2548 liters of alcohol used by tractor number one. This represents 2.9 percent of the corn area and 1.4 percent of the total farming area.

6.2.2 Medium-size farm.

The possibility of converting either one or both of the tractors used on this farm was investigated. Tractor number one presented a low usage (160 hours in 1979). The conversion of tractor number one as an alternative to save diesel fuel was not feasible because the annual conversion cost was higher than the fuel savings possible using alcohol. Tractor number two which presented a high annual use (486 hours) was studied for future conversions. Two methods were considered available (third and fourth type) for tractor number two. Table 38 shows the

Table 38. Fuel consumption for tractor number two using 2 conversion methods on a medium-size farm.

| Conversion | Diesel (1) | Dual-fuel (1) | |
|---|---|---|---|
| | | Diesel | Ethanol |
| Third | 8,970 | 6,802 | 3,582 |
| Fourth | 8,970 | 5,061 | 6,476 |

amount of fuel used by tractor number two when operating under conventional or dual-fuel mode. When the third conversion method was used a 24 percent saving in diesel fuel was obtained. When the fourth conversion method was used a 44 percent saving in diesel fuel could be obtained.

Table 39 shows the break-even prices for alcohol fuel when diesel fuel prices vary from \$0.26 per liter up to \$1.06 per liter. The break-even price for alcohol fuel considering today's diesel price (\$0.33/l) is \$0.11 per liter for the third conversion method and \$0.15 per liter for the fourth conversion method. This means that alcohol should not cost more than 33 percent of the diesel price for the third conversion method and 45 percent of the diesel price for the fourth conversion method. If diesel prices go up to \$0.79 per liter, than alcohol can cost up to 49 percent of the diesel cost for the third conversion method and up to 54 percent of the diesel cost for the fourth conversion method. If conversion is to be made, the fourth conversion method which can save up to 29 percent of the total farm fuel use for field operations should be used. Considering a corn yield of 6276 Kg of corn per hectare and an alcohol yield of 0.357 liter per Kg of corn grain, 2.87

Table 39. Break-even prices for alcohol fuel for tractor number 2 on a medium-size farm.

| Diesel price ($/l) | Break-even prices of ethanol ($/l) | |
|---|---|---|
| | Third conversion | Fourth conversion |
| 0.26 | 0.06 | 0.11 |
| 0.33 | 0.11 | 0.15 |
| 0.40 | 0.15 | 0.19 |
| 0.46 | 0.19 | 0.23 |
| 0.53 | 0.23 | 0.27 |
| 0.79 | 0.39 | 0.43 |
| 1.06 | 0.55 | 0.59 |

hectares of corn should be planted to supply the 6,476 liter of alcohol needed to run tractor number two. This represents 4.9 percent of the corn area and 1.4 percent of the total farming area.

6.2.3 Large-size farm.

Five tractors were converted to alcohol by using the third and fourth conversion methods. Table 40 presents the amount of diesel and alcohol fuel used when the third conversion method was used. Table 41 presents the amount of diesel and alcohol fuel used when the fourth conversion method was used. From Table 40, the highest rate of substitution (25 percent) was obtained when tractors number one and five were converted. From Table 41, the highest rate of substitution (45 percent) was obtained when tractor number six was converted. The break-even prices for alcohol fuel are listed in Table 42. The fourth conversion method proved to be better for all the tractors converted. If tractors are to be converted to alcohol the sequence would have to be the following: The first tractor to be converted is tractor number six, then tractor number five, then tractor number one, and then tractor number four. Last would be tractor number three which presented negative break-even prices for alcohol for diesel prices up to $0.40 per liter. For today's diesel price ($0.33/l) the break-even price for alcohol fuel for tractor number six is $0.14 per liter. This means that alcohol should not cost more than 42 percent of the diesel cost. For diesel prices of $0.79 per liter alcohol should not cost more than $0.44 per liter (57 percent of the diesel cost). If all the five tractors are converted to run on dual-fuel (fourth conversion method) 35 percent of the total farm fuel used for field operations would be replaced by alcohol. This would require 9.6 hectares of corn to supply the 21,506 liters

Table 40. Diesel and alcohol fuel use when spray injection was used for 5 different tractors.

| Tractor No. | Diesel fuel (l) | Dual-fuel (l) Diesel | Dual-fuel (l) Ethanol | Savings (%) |
|---|---|---|---|---|
| 1 | 5,940 | 4,455 | 2,495 | 25 |
| 3 | 3,264 | 2,522 | 1,231 | 23 |
| 4 | 5,363 | 4,158 | 3,107 | 22 |
| 5 | 7,449 | 5,587 | 3,107 | 25 |
| 6 | 8,150 | 6,171 | 3,095 | 24 |

Table 41. Diesel and alcohol fuel use when the carburated dual-fuel system was used for 5 different tractors.

| Tractor No. | Diesel fuel (l) | Dual-fuel (l) Diesel | Dual-fuel (l) Ethanol | Savings (%) |
|---|---|---|---|---|
| 1 | 5,940 | 3,327 | 4,229 | 44 |
| 3 | 3,264 | 1,859 | 2,370 | 43 |
| 4 | 5,363 | 3,053 | 3,851 | 43 |
| 5 | 7,449 | 4,155 | 5,291 | 44 |
| 6 | 8,150 | 4,458 | 5,765 | 45 |

Table 42. Break-even prices for alcohol fuel for 5 tractors, and 2 dual-fuel methods for a large-size farm.

| Conventional fuel prices ($/l) | Conversion type | Break-even prices ($/l) for 5 tractors Tractor number 1 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 0.26 | Third | 0.02 | -0.11 | -0.01 | 0.05 | 0.06 |
| | Fourth | 0.07 | -0.01 | 0.06 | 0.09 | 0.10 |
| 0.33 | Third | 0.06 | -0.07 | 0.03 | 0.09 | 0.10 |
| | Fourth | 0.11 | 0.03 | 0.10 | 0.13 | 0.14 |
| 0.40 | Third | 0.10 | -0.03 | 0.07 | 0.13 | 0.15 |
| | Fourth | 0.16 | 0.07 | 0.14 | 0.18 | 0.19 |
| 0.46 | Third | 0.14 | 0.01 | 0.11 | 0.17 | 0.19 |
| | Fourth | 0.19 | 0.11 | 0.17 | 0.21 | 0.23 |
| 0.53 | Third | 0.18 | 0.05 | 0.15 | 0.21 | 0.23 |
| | Fourth | 0.24 | 0.15 | 0.22 | 0.26 | 0.27 |
| 0.79 | Third | 0.34 | 0.21 | 0.31 | 0.37 | 0.40 |
| | Fourth | 0.40 | 0.30 | 0.37 | 0.42 | 0.44 |
| 1.06 | Third | 0.50 | 0.37 | 0.46 | 0.53 | 0.57 |
| | Fourth | 0.56 | 0.46 | 0.53 | 0.59 | 0.61 |

of ethanol needed to run the five tractors. With the same assumptions as the ones made for the small and medium size farm, for corn and alcohol yields, 6.9 percent of the corn area and 1.7 percent of the total farming area should be planted on corn for ethanol production.

## 6.3 Tractor use and ethanol feasibility.

Computer simulation was done to find the ethanol break-even prices for four usage levels (250, 500, 750, and 1000h/yr). A 75 Kw tractor with an average load of 50 percent was used for the simulation. The four conversion methods were simulated for four usage levels and the results are presented in the following section.

### 6.3.1 Gasoline tractor with minor modifications.

Table 43 presents the break-even prices for ethanol for gasoline prices from \$0.33 to \$1.06 per liter. The break-even prices were constants for almost all usage levels. This occurred because of the low conversion costs for this conversion method. Figure 3 shows the plotted results for this and the three other conversion methods.

Table 43. Ethanol break-even prices for gasoline tractors with minor modifications.

| Gasoline prices | Usage levels(h) | | | |
|---|---|---|---|---|
| (\$/l) | 250 | 500 | 750 | 1000 |
| 0.33 | 0.25 | 0.25 | 0.25 | 0.25 |
| 0.40 | 0.30 | 0.30 | 0.31 | 0.31 |
| 0.46 | 0.35 | 0.35 | 0.35 | 0.35 |
| 0.53 | 0.40 | 0.40 | 0.41 | 0.41 |
| 0.79 | 0.60 | 0.61 | 0.61 | 0.61 |
| 1.06 | 0.81 | 0.81 | 0.82 | 0.82 |

### 6.3.2 Gasoline tractor with increased compression.

Table 44 presents the break-even prices for the second conversion method. The same usage levels and gasoline prices as in the first conversion method were used. As the usage level increased the break-even prices also increased. For gasoline prices of \$0.33 per liter the break-even price for ethanol is 79 percent of the gasoline price if the tractor is used 750 hours per year. Figure 3 shows this conversion

Table 44. Ethanol break-even prices for gasoline tractor with increased compression.

| Gasoline prices ($/l) | Break-even prices ($/l) for 4 usage levels(h) 250 | 500 | 750 | 1000 |
|---|---|---|---|---|
| 0.33 | 0.20 | 0.25 | 0.26 | 0.27 |
| 0.40 | 0.27 | 0.31 | 0.32 | 0.33 |
| 0.46 | 0.32 | 0.36 | 0.38 | 0.38 |
| 0.53 | 0.38 | 0.42 | 0.44 | 0.44 |
| 0.79 | 0.60 | 0.65 | 0.66 | 0.67 |
| 1.06 | 0.84 | 0.88 | 0.90 | 0.90 |

method being better than the first one, when the tractor is used more than 350 hours.

6.3.3 Dual-fueling with spray injection.

Table 45 presents the break-even prices for four usage levels. The break-even prices for ethanol increased as the usage level increased, for all the fuel prices. For gasoline prices of $0.33 per liter the break-even price for ethanol is $0.12 per liter (36 percent of the gasoline price), when the tractor is used 500 hours. Figure 3 shows the lower break-even prices for ethanol when compared to the first and second conversion methods.

6.3.4 Dual-fueling with carburated alcohol.

Table 46 presents the break-even prices for ethanol fuel for four usage levels. As the usage level increased the break-even prices also increased. The increases were less evident when the tractor was used 1000 h. Figure 3 shows this conversion method giving higher break-even prices for all usage levels. The change in ethanol break-even prices by changing the recovery period from 5 to 10 years is presented in Table 47. Conventional fuel prices of $0.40 per liter were used for the calculations. The changes were higher for the dual-fuel methods. The break-even prices had a higher increase for lower usage levels, except for the gasoline engine with minor modifications, where the break-even prices remained essentially the same. A 5 year recovery period is recommended because data is not availabe to show that converted engines will last 10 years, especially under high annual use.

Table 48 shows the prices that diesel fuel should be at the present time considering a ethanol production cost of $0.46 per liter. In most cases diesel prices should be at least twice the ethanol production cost. As mentioned above, all tractors used for field operations on the selected farms were diesel, so dual-fueling was the conversion recommended. Carburated ethanol presented lower diesel prices for economical use of ethanol as tractor fuel.

If a true alcohol engine is available the following could be concluded: Ethanol break-even prices equal to gasoline may be obtained. This occurs as mentioned in the literature review, because the thermal efficiency is quite high providing an alcohol fuel consumption similar to gasoline. This engine will have higher thermal efficiency and higher power outputs.

Table 45. Ethanol break-even prices when dual-fueling with spray injection is used.

| Diesel prices ($/l) | Break-even prices ($/l) for 4 usage levels(h) 250 | 500 | 750 | 1000 |
|---|---|---|---|---|
| 0.33 | -0.02 | 0.12 | 0.15 | 0.17 |
| 0.40 | 0.02 | 0.16 | 0.20 | 0.22 |
| 0.46 | 0.06 | 0.20 | 0.24 | 0.25 |
| 0.53 | 0.11 | 0.25 | 0.28 | 0.30 |
| 0.79 | 0.27 | 0.41 | 0.45 | 0.47 |
| 1.06 | 0.47 | 0.59 | 0.63 | 0.65 |

Table 46. Ethanol break-even prices when dual-fueling with carburated ethanol is used.

| Diesel fuel prices ($/l) | Break-even prices ($/l) for 4 usage levels(h) 250 | 500 | 750 | 1000 |
|---|---|---|---|---|
| 0.33 | 0.07 | 0.16 | 0.18 | 0.19 |
| 0.40 | 0.11 | 0.20 | 0.23 | 0.24 |
| 0.46 | 0.15 | 0.24 | 0.27 | 0.28 |
| 0.53 | 0.20 | 0.29 | 0.31 | 0.33 |
| 0.79 | 0.36 | 0.46 | 0.49 | 0.50 |
| 1.06 | 0.54 | 0.68 | 0.67 | 0.69 |

Table 47. Ethanol break-even prices for 2 recovery periods and 4 conversion methods (conventional fuel price of $0.40 per liter).

| Conversion methods | Ethanol break-even prices ($/l) 5 year recovery period | | | | 10 year recovery period | | | |
|---|---|---|---|---|---|---|---|---|
| | 250 | 500 | 750 | 1000 hours | 250 | 500 | 750 | 1000 hours |
| Gasoline engine with minor modifications | 0.30 | 0.30 | 0.31 | 0.31 | 0.30 | 0.30 | 0.31 | 0.31 |
| Gasoline engine with major modifications | 0.27 | 0.31 | 0.32 | 0.33 | 0.30 | 0.32 | 0.33 | 0.34 |
| Spray injection | 0.02 | 0.16 | 0.20 | 0.22 | 0.11 | 0.20 | 0.22 | 0.23 |
| Carburated ethanol | 0.11 | 0.20 | 0.23 | 0.24 | 0.16 | 0.23 | 0.24 | 0.25 |

Table 48. Diesel prices required to allow ethanol to be economically feasible with a production cost of $0.46 per liter.

| Farms | Diesel prices for Spray injection ($/l) | Diesel prices for Carburated ethanol ($/l) |
|---|---|---|
| Small farm (79 ha) | 1.18 | 1.00 |
| Medium farm (200 ha) | 0.91 | 0.86 |
| Large farm (550 ha) | | |
| Tractor No. 1 | 1.00 | 0.89 |
| Tractor No. 3 | 1.21 | 1.05 |
| Tractor No. 4 | 1.06 | 0.93 |
| Tractor No. 5 | 0.95 | 0.86 |
| Tractor No. 6 | 0.89 | 0.82 |

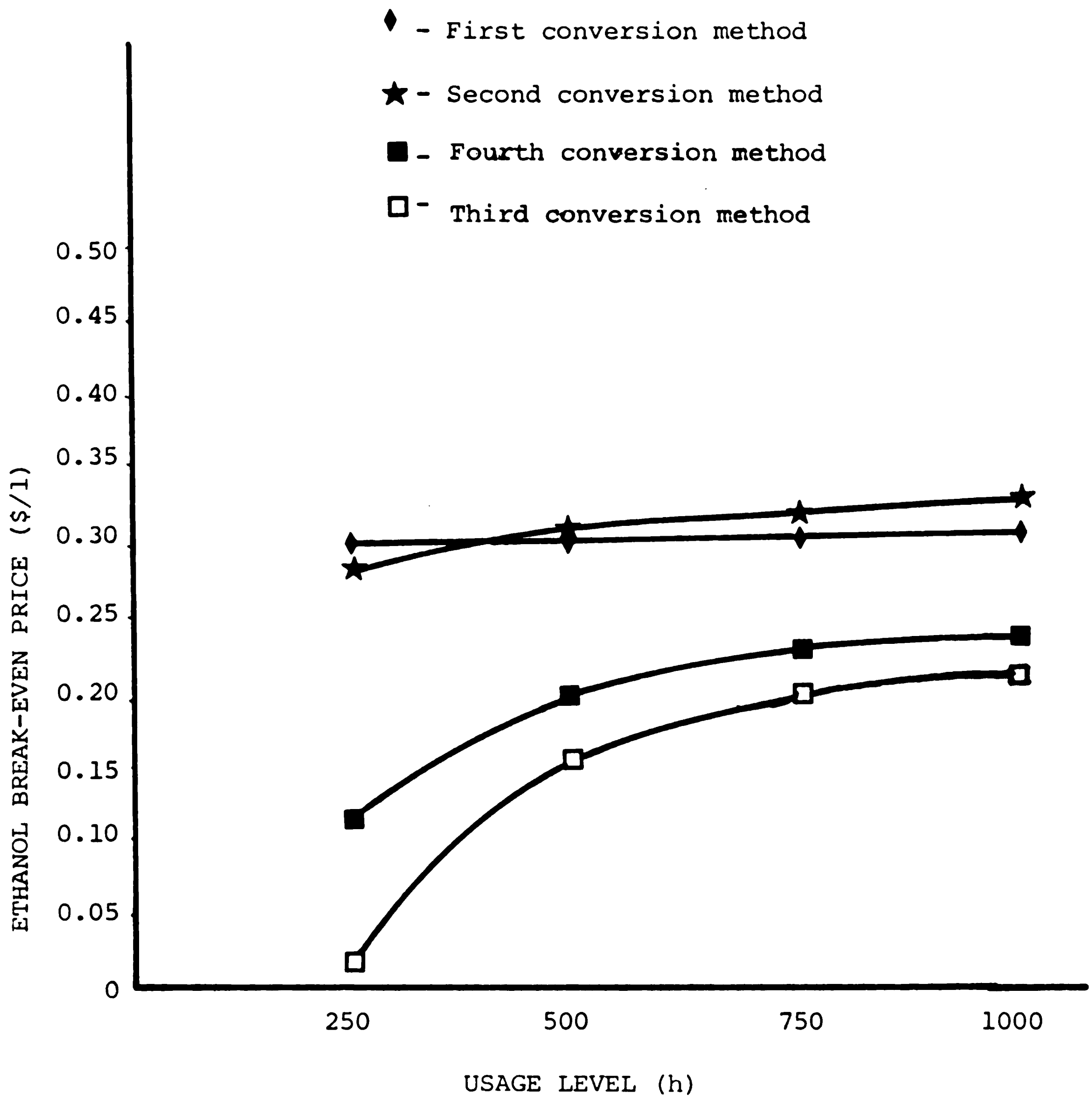


Figure 3. Tractor usage levels and ethanol break-even prices for gasoline and diesel prices of $0.40 per liter.

# CHAPTER 7

## SUMMARY

A computer program to simulate the machine performance and calculate the energy requirements for 50 field operations from soil preparation to transportation was developed. The model performs the calculations based upon input parameters including machinery sets (machine sizes, types, working depths, and field speeds), soil type and conditions, and field size. Tractor performance such as wheel slip and tractive efficiency are determined, and energy requirements for conventional fuel (diesel, gasoline, and LP gas) for field operations are calculated.

An alcohol subroutine was written where alcohol fuel consumption and conventional fuel consumption are determined for converted tractors. Four tractor conversion methods are allowed to be used in this model. An economic analysis is included in the main program to compare each of the conversions on an economic basis. Break-even prices for alcohol fuel (ethanol) were determined.

The computer model was validated by comparing the results from the computer program with field data collected on two Michigan farms in the fall season of 1980. Data from the Michigan Energy Audit Study which contained the average fuel consumption of 52 Michigan farms was also used to validate the model.

Three Michigan farms were used as case studies. Results of fuel consumption by machine, by operation group, and by enterprise were presented for a small (79 ha), medium (200 ha), and large (550 ha) farm. Large farms presented a better matching between tractors and implements. The results from the computer model for fuel consumption were within 6.2, 0.3, and 3.8 percent of the results reported by the farmer for the small, medium, and large farms, respectively.

The use of alcohol in gasoline engines after major modification of rebuilding the engine with increased compression proved to be the best way of using alcohol. Most of the farm tractors are diesel powered so this conversion method can only replace a small percentage of the conventional fuels used on the farms.

The use of alcohol in diesel engines where alcohol is fueled in a dual-fuel system by aspirating the alcohol into the intake air through a carburetor system presented substitution rates around 45 percent. This proved to be a better way of using alcohol in diesel engines when compared to spray injection.

Tractors with high annual use which used either spray injection or dual-fueling with carburated ethanol presented break-even prices closer to those when ethanol was used in gasoline engines. Because of the higher difference in heat content between diesel and ethanol than between gasoline and ethanol, the break-even prices for ethanol will always be lower when ethanol is used in diesel engines.

## CHAPTER 8

## CONCLUSIONS

1. A computer program was developed which models the fuel consumption for 50 field operations from soil preparation to transportation involving the use of tractors, trucks, combines and self-propelled machines. The program models fuel consumption with conventional and alcohol fuels.

2. The computer model produced results close to those from field observations to show that the model was valid. For the three farms studied the model results were within 6.2, 0.3, and 3.8 percent of the results reported by the farmer for the small (79 ha), medium (200 ha), and large (550 ha) farms.

3. Alcohol substitution rates of 34, 29, and 35 percent of the total fuel used on the farm were obtained for a small, medium, and large farm, respectively. Corn should be planted on 1.4, 1.4, and 1.7 percent of the total farming area if the rates of substitution are to be met for the small, medium, and large farms.

4. Larger farms would normally present more potential for economical use of alcohol, because of the high annual use of tractors.

5. If alcohol is to be used in a gasoline engine at the present time, the cost per liter should not be more than \$0.25, considering gasoline prices at \$0.33 per liter.

6. If alcohol is to be used in a diesel engine at the present time, the cost per liter should not be more than \$0.12 - \$0.16, considering diesel prices at \$0.33 per liter and annual use of 500 hours per year.

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