This is to certify that the

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A COMPUTER MODEL FOR FEED HARVESTING MACHINERY SELECTION ON A DAIRY FARM

By

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ABSTRACT

A COMPUTER MODEL FOR FEED HARVESTING MACHINERY SELECTION ON DAIRY FARMS

By

Jesus Antonio Sisco

At Michigan State University, a Dairy Research Group has been formed to study the feed-dairy production system, which stated the need for a computer model for the selection of feed harvesting machinery on dairy farms.

A methodology was set up to build the model. Surveys were conducted to identify the different feed production methods; to get information on feed disappearance, cropland distribution and size of dairy farms in Michigan; and to determine the number, size and type of field machinery specifically used in forage, hay and grain harvesting.

Feed requirement, feed losses and available time were used to calculate the required system capacity. Effective field capacity and effective material capacity were computed by using alogorithms developed for each machine component of the feed harvesting system. Selection of size and number of machines was made when machine effective material capacity was greater or equal to the required system capacity.

Jesus Antonio Sisco

Comparison of model output to data from four selected surveys showed a reasonable model behavior in the selection of farm machinery for a feed harvesting system, as well as its ability to handle actual data.

The model output reacts to changes of relevant parameters such as transport unit travel distance and speed, crop yield, available time, and the harvesting rate.

The feed harvesting machinery selection model could be added as a complement to existing farm machinery selection models; to studies evaluating feed quality and quantity losses due to harvesting and handling; to the management of feed harvesting machines in relationship with the rest of the farm; and to studies on the effect of decreased field drying time on a total dairy farm operation.

Approved______________________
Major Professor

Approved______________________
Department Chairman

To

my beloved children:

Miguel, Vladimir, Lina and Kathleen

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a	acre
a/h	acre per hour
bu	bushel
bu/a	bushel per acre
ft	foot
ft^3	cubic foot
ft/s^2	foot per square second
gal	gallon
gal/a	gallon per acre
gal/h	gallon per hour
gal/ton	gallon per ton
h	hour
ha	hectare
ha/h	hectare per hour
hp	horsepower
hp/ft	horsepower per foot
hp · h/gal	horsepower-hour per gallon
hp · h/lb	horsepower-hour per pound
hp · h/ton	horsepower-hour per ton
hp/lb	horsepower per pound
kg	kilogram
kg/ha	kilogram per hectare

kg/m^3	kilogram per cubic meter
kg/s	kilogram per second
km	kilometer
km/h	kilometer per hour
kN	kilonewton
kW	kilowatt
kW/h	kilowatt per hour
kW · h/kg	kilowatt-hour per kilogram
kW · h/L	kilowatt-hour per liter
kW · h/t	kilowatt-hour per ton
kW/kg	kilowatt per kilogram
kW/m	kilowatt per meter
kW/row	kilowatt per row
L	liter
m	meter
m^2	square meter
m^3	cubic meter
$m \cdot s^{-2}$	meter per square second
mi	mile
mi/h	mile per hour
$/ha	dollars per hectare
$/t	dollars per ton
$/yr	dollars per year
t	metric ton
t/h	metric ton per hour
t/ha	metric ton per hectare
t/yr	metric ton per year

CHAPTER 1

INTRODUCTION

1.1. Justification for a Computer Model.

On a feed producing dairy farm, the selection of a machinery complement is a complex problem involving many economic, biological and social factors, such as weather uncertainities, timeliness, sequential and parallel operations, soil type and conditions and management practices, not to mention the farmer's preferences for certain machines or agronomic practices.

At Michigan State University, a Dairy Research Group has been formed to study the feed-dairy production systems, which stated the need for a computer model for the selection of feed harvesting machinery that could be added to existing computer models, such as the ones developed by Singh (1978) and Wolak (1980).

During the past years, several authors have proposed a great variety of methods or procedures to select the feed production system and the related farm machinery complement for agricultural enterprises, including dairy farms. Those methods range from simple hand calculation methods to sophisticated analytical and simulation methods.

Computer models have proved to be a very useful tool in the selection and scheduling of farm machinery, the prediction of available time for field machinery operations and the economic analysis of farm machinery investments.

This study attempts to develop a general computer model to cope with the different feed requirements, field machinery uses and agronomic practices commonly found in the State of Michigan. The present version of the computer model does not include scheduling of machinery use. Rather it is considered that selection of feed-harvesting machinery is comprehensively treated so as to be used as the basis for further work.

1.2. Assumptions to Build Model.

The development of the computer model was initiated under the following assumptions:

a) Available time for field operations can be reasonably predicted from probabilistic procedures based on actual weather information.

b) Feed requirements and feed losses are previously determined and used as input to the model.

c) Feed production in dairy farms is considered as a problem of processing and transporting material from the field to the storage or feeding areas in the time available for such operations.

d) The wide variety of feed production methods are summarized in five large methods, e.g. silage, haylage, hay, green feeding and grain.

e) Silage and grain harvest are considered once over operations, while haylage, hay and green feeding are harvested more than once during the production season.

f) Feed production is treated as a material handling system and, consequently, suitable to application of system analysis methods.

g) The machinery set selected is the result of the working days availability for the years under study, with work days being generated from weather data for a specified period of years.

1.3. Objectives.

The objectives of this study include the following:

a) To develop a computer model for feed-harvesting systems commonly used on dairy farms in Michigan. Such a model will enable comparison between systems with respect to machinery requirements and costs of use.

b) To select the optimal machinery complement for the feed-harvesting systems on dairy farms in Michigan.

1.4. Methodology.

In order to accomplish the stated objectives, the study was conducted according to the following steps:

a) Review of literature

b) Formulation of an initial model

   a. Diagram of feed production methods

   b. Numerical modeling

   c. Small computer program

c) Data collection

   a. Feed harvesting systems data

   b. Machinery data

   c. Preparation of input data

d) Formulation of detailed model

   a. Establish mathematical relationships

   b. Diagram of the model

   c. Detail model components

e) Programming

   a. Flow chart of feed production methods

   b. Translation to FORTRAN

   c. Debugging programs

f) Validation of model

   a. Machinery survey in dairy farms

   b. Comparison of model results to survey data

   c. Tests of sensitivity

g) Analysis of results

h) Publication

CHAPTER 2

LITERATURE REVIEW

2.1. Applications of System Analysis to Agriculture.

Pinches (1956) suggested the need for agricultural engineering research with explicit application of management engineering to farm operations; one step forward of hand calculation procedures. Integration of processes, machines, structures and form of products, as they are found in agriculture, constitute a system and as such suitable to application of management engineering.

Sammet (1959) stated the use of model building as an alternative to experimental comparison. Definitions and schematizations of system engineering given in this paper facilitated the conceptualization of the model here presented. A planned approach to systems studies at two levels of activity is described. System analysis, comprising the study, definition and description of processes, and the establishment of optimum relationships; and system design and development, including research and development oriented to methods improvement and the execution of plans of action based on results of systems analysis.

Rockwell (1965) stated the importance of using simulation methods for solution of operational system problems in almost every field of the economic and social activities. An analogy was established between industrial and agricultural production systems to encourage the application of system analysis to agricultural production.

Von Bargen (1965, 1966) developed procedures to apply system analysis to alfalfa hay harvesting.

Link (1965) stated that decisions about what machines to use are related to the crop-production methods in such a way that both have to be considered together. For this purpose, Link proposed the use of techniques of activity network analysis for analyzing crop production systems and machinery selection.

Chen and Wensink (1978) illustrated the application of resource planning and management networks (RPM) in agricultural systems analysis, as a means of solving mathematical programs.

Linear programming models have been presented to build models for forage production systems as a whole and for each of their component sub-systems. Kjelgaard and Quade (1975) developed a model for forage transport and handling, and Tseng and Mears (1975) modeled a system for forage production. Analysis of results from both papers proved to be valuable in determining the harvesting and handling practices in a forage production system.

Peart et al., (1963) applied mathematical programming to the optimization of materials-handling systems. Losses in alfalfa dry matter during harvest were determined by Dale et al., (1978) during the development of a harvesting simulation model. Also, to show the effect of handling, harvesting and drying on hay yield, quality, digestability and dry matter, Dobie et al., (1963) established an experimental procedure using four harvesting treatments. Hay raked and baled at low moisture content had a lower loss in yield than hay raked and baled too dry. The effect of harvest starting date, harvesting rate and weather on the value of forage for dairy cows are shown by Millier and Rehkugler (1970) through an analysis of simulated harvesting systems.

Parke et al., (1978) studied forage conservation methods applying modeling and simulation techniques to determine forage quality and quantity losses.

2.2. Farm Machinery Selection.

Hunt (1977) derived formulas to determine annual costs, power requirements and machine size in relation to a timeliness factor, and applied the obtained values to the selection of farm machinery.

Recent works of Burrow and Siemens (1974), Hughes and Holtman (1974), Von Bargen and Cunney (1974) approached the problem of farm machinery selection using several techniques from system analysis theory. Wolak and Holtman (1976) designed a computer program to analyze dairy farm design and determine energy requirements in southern Michigan dairy farms. Singh et al., (1978a) developed a computer program for multi-crop farms to determine operations schedule, field machinery requirements and costs. Singh (1978) previously designed a system modeling Michigan cash crop production systems.

Wolak (1980) developed a comprehensive computer model for selection and scheduling of farm machinery as a basis for investigation of cropping systems in Michigan's Saginaw Valley.

Bowers (1975) stressed that selection of optimum machinery sets depends on accurate input data for available working time, schedule of field operations, draft requirements and machine capacity.

Fridley and Holtman (1974) pointed out, by using system analysis, the importance of predicting the socio-economic implications of mechanization, such as the effect of this technology on labor lay-off and farm income. Evaluation of potential solutions to that problem, according to the authors, is a previous step to determine which solutions are not realizable and practical.

The interaction between machines as components of a system is treated by Hunt (1977) and Kepner et al., (1978). Overall system capacity and reliability is affected by individual capacity and reliability of machines components of that system. Hunt also stated the complexity of a machinery system when sequential or parallel operations are performed, as is the case in many harvesting operations. Hunt recommends the use of cycle diagrams to determine system performance in parallel operations.

2.3. Determination of Available Working Days.

Determination of available working days is another problem with a great variety of answers. Several authors have presented different concepts about what to consider a "dry day" available for working a feed production system. Von Bargen (1966) presented the "open haying day" criteria, developed at Missouri, defined as: "...less than 0.1 in precipitation on the date; less than 1.0 in precipitation on the previous date, and more than 70 percent of the possible sunshine on the date."

Wiser (1966) explained the application of the Monte Carlo method to a study of the parameters of frequency distributions of amount of precipitation. In this case, a wet or dry day was defined according to whether or not at least 0.01 inch of precipitation occurred. Three different urn models were tested, the Bernoulli model, the Polya model and the Markov model. Results showed that the Bernoulli model was the simplest but the least precise in determining expected values of precipitation and applies only to independent events. The Markov model was not suitable when weather persistence extended over several periods. If this is not the case, the Markov model was superior in getting expected values of precipitation. The fit for the dry days was particularly good as compared to observed data.

Tulu (1973) and Tulu et al., (1974) applied the concept of tractability developed by Rutledge and McHardy (1968) to design a model to determine available working days from available weather data. This model considers the combined effect of precipitation, evaporation and soil moisture to define a work day. The total number of work days as determined by the model agreed well with the observed work days, but a day by day comparison showed that more than 10 percent of the days are missed. The authors believe that this was due to the fact that the model does not give partial work days, while they are reported in the farm record as full work days.

Tseng and Mears (1975) used the precipitation criteria described by Von Bargen and the tractability criteria of Rutledge and McHardy to estimate a "good day". The good day was considered as: "...less than 2.5 mm (0.1 in) of precipitation on the date and soil moisture content of no more than 95 percent of field capacity." Precipitation data was obtained from climatological data and the soil moisture content was computed according to the procedure developed by Thornwaite.

Fulton et al., (unknown) based on reports about crop and field conditions from the Iowa Crop and Livestock

Reporting Service, developed a model to determine the days suitable for field work at Iowa. A procedure is applied to calculate available work days whether the calendar period of time is within a climatic week, two adjacent climatic weeks or a greater operational period. Four probability levels were chosen (0.24, 0.50, 0.76 and 0.80), the data for each week were ranked, and the minimum number of suitable days was determined under each probability level to permit estimates to be made according to an acceptable risk.

An environmental model was developed by Jones et al., (1972) by using past records of daily rainfall, maximum and minimum temperature, and evaporation for State College, Mississippi. The model yields daily values of rainfall, temperature, evaporation and variations of soil moisture content with depth.

Feyerhem et al., (1966) developed probabilities of sequences of wet and dry days in Michigan from past weather records. Two types of probabilities were given: initial probability, used when no information exists on the previous day, and transition probability, computed whether the previous day is known to be wet or dry. For more flexibility in calculations of periods of wet or dry days for the different field operations, probabilities were computed that depend on the amount of precipitation that is considered to define a wet or dry day, that is 0.01, 0.10, 0.20 and 0.50 inch of precipitation.

Probabilities are grouped for each seven-day period of a year. For initial probability, dry and wet values are given. For transition probability sequences of dry/dry, wet/dry, dry/wet and wet/wet probabilities are also given. Procedures for determining the probability that a particular day or group of days will be dry or wet are clearly explained along with a method for checking computations.

Russell (1979) stated that work days for field operations is determined by the interaction of factors such as weather, soil and crop conditions, machinery being used, and the kind of operation being performed. Work day was considered as: "...one in which work takes place and there is no need to precisely identify the underlying relationships." Detailed farm records are used to calculate working days and to derive distributions for particular climatic situations. However, when such farm records are not available, it is suggested to use simulation in determination of working days. Working day criteria as established by Russell are:

> "...for operations disturbing the soil, ground not frozen, when less than 0.1 inch of precipitation fall in the day in question and when soil moisture is below specified levels. For operations not disturbing the soil, less than 0.5 in of precipitation on the previous day and there is less than 0.05 in of precipitation on the day in question. In addition, corn silage harvesting may take place if the ground is frozen."

2.4. Handling and Harvesting of Hay and Forage.

Bowers and Rider (1974) reported study of hay handling and harvesting systems in Oklahoma farms in relation to conventional hay baling system. Results showed that new hay harvesting systems, such as stacking and round-baling, maintained quality and permitted harvesting and storing increased tonnages when system capacity matched need.

A simulation model of forage transport and handling was developed by Kjelgaard and Quade (1975). This model contained variables for machine types, harvesting rates and transport distances. Outputs of the model were the calculated daily capacity (ton), mechanical energy (kcal/ton) and labor requirements (min/ton) for forage transport and handling.

Renoll et al., (1974) showed that handling hay from windrow to storage using the stack system reduced labor needs and that hourly capacity was equal or greater than the conventional bale system.

Rider and Barr (1976) described the hay and forage harvesting operations and set guidelines for evaluating harvesting systems and for the selection of related machinery. Hay stacking and field cubing data from this work were incorporated to the model here presented.

Evaluations of hay and forage harvesting methods were made by Friesen (1978) and Hilmerson and Heir (1978). Parson et al., (1978) presented alternatives for storage and feeding of big-package hay, and Renoll et al., (1978) studied machine systems for handling and feeding round bales.

2.5. Some Characteristics of Dairy Farms in Michigan.

Hoglund (1976) and Hoglund and McBride (1970) studied Michigan's dairy industry. Results showed a change in dairy farming such as reduction of number of farms, but an increase in specialization and in the use of mechanization. Farms were divided in five categories according to the gross value of sales per farm. The number of cows averaged 82 in class I, 42 in class II, 27 in class III, 17 in class IV and 11 in class V. The overall average per farm was 35.8 cows. Partial results of this study are shown in Table 2.1.

Hoglund and Shapley (1973) reported on a study completed in 1971 to determine the impact of the physical and economic environment on farm organization and the changes that have occurred on dairy farms in Michigan. Results shown in Table 2.2 indicate that more than 80% of the dairymen interviewed used a hay conditioner or windrower; more than 84% used balers; a third used bale throwers. Forage choppers and blowers were used for more than 60% of the dairymen, except the Upper Peninsula (50.1% and 42.2% respectively). More than 59% of the farmers used pull-type or self-propelled combines.

Table 2.1. Percentage Distribution and Some Characteristics of Dairy Farms, Cows, Milk Sales and the Labor Force By Economic Class, 1964 Census of Agriculture.

Item	Economic Class					
	I	II	III		IV	V
Gross Value of Sales/Farm	$40,000 and over	$20,000 -39,999	$10,000 -19,999	Sub-total	$5,000 -9,999	$2,500 -4,999
Percent of farms	3	17	34	54	28	18
Percent of cows	9	28	36	73	19	8
Percent of gross sales	12	32	36	80	15	5
Average per farm						
All products sold	$54,667	$26,589	$14,301		$7,374	$3,738
Milk sold						
Gross value	$38,673	$18,863	$10,378		$5,303	$2,613
Pounds/farm	928,000	455,000	253,000		130,000	62,000
Pounds/cow	11,390	10,940	9,170		7,640	5,640
Cows per farm	82	42	27		17	11
Man equivalents	3.4	2.2	1.6		1.3	1.0
Percent of labor hired	52	27	13		6	3
Off farm income (a)						
Percent of household	60	65	67		78	78
Value/household	$ 4,849	$ 3,287	$ 2,847		$ 3,473	$3,505
Estimated 1969 gross Income equivalent (b)	$56,000 and over	$28,000 -55,999	$14,000 -27,999		$ 7,000 -13,999	$3,500 -6,999

(a) Income and earnings from off-farm employment and other sources for all members of a household. This often included the operator or one or more members of the family or a combination of operator and other family members.

(b) Based on 40% higher milk price. Equivalent gross value of sales per farm to those in 1964 on basis of present cost-price relationship.

SOURCE: Hoglund and McBride, 1970.

Table 2.2. Percent of dairy farmers reporting use of specialized equipment for milking, manure handling, forage harvesting and handling and combining, six areas of Michigan, fluid milk farms, 1971.

Equipment Used	Area of State					
	Western	South Central	Detroit Metro	Thumb	Northern	Upper Peninsula
			------percent reporting------			
Milking and manure handling						
Milk conveyor	23.4	15.6	7.6	13.3	9.8	15.5
Permanent pipe line	2.5	4.3	5.6	6.6	7.3	13.3
Milking parlor	18.2	35.1	14.6	22.2	15.6	8.7
Gutter cleaner	61.1	41.5	34.1	31.9	33.9	83.9
Liquid manure system	2.7	3.9	6.6	1.3	1.4	1.3
Forage harvesting and handling						
Crimper, crusher, windrower	86.5	94.5	86.6	93.7	79.3	88.5
Baler	93.1	92.0	91.2	84.1	96.8	95.2
Bale thrower	37.2	34.5	21.5	32.0	13.5	35.8
Forage chopper	66.4	79.5	79.9	80.3	61.6	50.1
Forage blower	63.8	69.4	75.3	68.4	61.6	42.2
Silo unloader	45.6	47.2	36.0	57.4	22.8	27.4
Mechanical bunk	21.1	28.1	23.0	41.9	18.6	10.7
Combine						
Pull type	52.0	31.9	38.8	18.9	55.2	46.6
Self propelled	7.9	35.8	38.9	46.2	14.4	29.1

SOURCE: Hoglund and Shapley, 1973.

The same report pointed out that the total cropland operated ranged from 84.1 ha (208 acres) to 110.5 ha (273 acres). The most common feed crops were alfalfa and mixtures (30 to 72% of the total area); corn grain (21 to 27% of the total area, except northern and Upper Peninsula) and corn silage (5 to 12%). Less than 10% of the dairymen practiced green chopping and hauling forage daily for summer feeding. Acres of cropland along with some other information is given in Table 2.3.

Table 2.3. Average number of milk cows, acres of cropland operated and acres of various crops produced per farm, and feed crops grown per cow, six areas of Michigan, fluid milk farms, 1971.

	Area of State					
	Western	South Central	Detroit Metro	Thumb	Northern	Upper Peninsula
Milk cows per farm	41.0	44.6	43.0	41.8	33.4	33.8
Acres per farm						
Total cropland operated	208	253	217	273	222	230
Acres crops produced						
Corn grain	55.7	64.1	59.0	59.8	21.0	2.7
Corn silage	24.5	30.8	27.6	30.4	20.1	11.6
Alfalfa and mixtures	(92.6)	(81.0)	(65.8)	(83.0)	(146.1)	(105.2)
Hay and silage	71.8	60.1	47.5	63.6	124.9	117.6
Green chop	5.3	5.0	8.8	5.7	2.7	5.6
Pasture	15.5	15.9	9.5	13.7	18.5	42.0
Sudan, soybean-sudan	1.4	2.3	3.1	1.4	-	-
Oats and barley	14.3	19.1	23.3	34.5	24.8	43.2
Wheat	6.2	13.8	14.2	19.2	3.8	1.2
Other cash crops	2.8	17.1	13.5	28.5	-	2.1
Diverted and idle	10.5	24.8	10.5	16.2	6.2	4.0
Acres per cow						
Corn grain	1.33	1.44	1.37	1.43	.63	.08
Oats and barley	.33	.43	.54	.82	.74	1.30
Total grain	1.66	1.87	1.91	2.25	1.37	1.38
Corn silage	.60	.69	.64	.73	.60	.31
Alfalfa and silage	1.75	1.12	1.10	1.52	3.75	3.51
Green chop	.13	.11	.20	.14	.08	.16
Pasture	.41	.41	.29	.36	.56	1.24
Total forage	2.89	2.33	2.23	2.75	4.99	5.22

SOURCE: Hoglund and Shapley, 1973.

CHAPTER 3

DEVELOPMENT OF THE MODEL

3.1. Survey of Feed Production Methods.

A survey to determine the methods of feed production commonly used was the first step to develop this model. The types of machines used in each one of the production methods were established and, at the same time, a clearcut classification of the machinery facilitates comparisons.

A summary of such feed production methods is presented in Table 3.1, based on the work of Tseng and Mears (1975).

3.2. Flow Chart Representation of the Feed Production System.

Based on the same work of Tseng and Mears (1975), a flow chart is presented in Figure 3.1, to describe the overall structure of the feed production system. The flow chart presented by Tseng and Mears for the forage production system is completed by the inclusion of other forage production methods such as cubing from green chopped, partially field cured and complete field cured materials, haylage from partially field cured and chopped material, stack building from complete field cured and chopped material, and round baling from complete field cured material.

Table 3.1. Methods of Feed Production

1. Pasturing

2. Green Chopping

    2.1 Green feeding
    2.2 Silage
    2.3 Dehydration
        2.3.1 Market
        2.3.2 Storage
        2.3.3 Pelleting
            2.3.3.1 Market
            2.3.3.2 Storage
        2.3.4 Cubing

3. Mowing and conditioning long loose wet forage

    3.1 Partially field curing
        3.1.1 Transfer to mow/drying
        3.1.2 Chopping
            3.1.2.1 Transfer to mow/drying
            3.1.2.2 Transfer to dryer/feeder
            3.1.2.3 Silage
            3.1.2.4 Haylage
        3.1.3 Conventional Baling
            3.1.3.1 Wagon drying
                3.1.3.1.1 Storage
                3.1.3.1.2 Market
            3.1.3.2 Transfer to mow/drying
                3.1.3.2.1 Storage
                3.1.3.2.2 Market
        3.1.4 Cubing
    3.2 Complete field curing
        3.2.1 Conventional Baling
            3.2.1.1 Storage
            3.2.1.2 Market
        3.2.2 Round Baling
        3.2.3 Transfer to long loose forage storage
        3.2.4 Stacks on the field
        3.2.5 Chopping
            3.2.5.1 Storage
            3.2.5.2 Wafering
                3.2.5.2.1 Storage
                3.2.5.2.2 Market
            3.2.5.3 Stacks
        3.2.6 Field Wafering
            3.2.6.1 Storage
            3.2.6.2 Market

Table 3.1. (cont'd.).

3.2.7 Cubing
3.2.7.1 Storage
3.2.7.2 Market
4. Stover
4.1 Silage
4.1.1 Storage
4.2 Stacks
4.3 Round baling
5. Grain production
5.1 Low-moisture grain
5.1.1 Combining
5.1.2 Ear corn snapper
5.1.3 Pick-up harvesting
5.2 High-moisture grain
5.2.1 Combining
5.2.2 Ear corn snapper

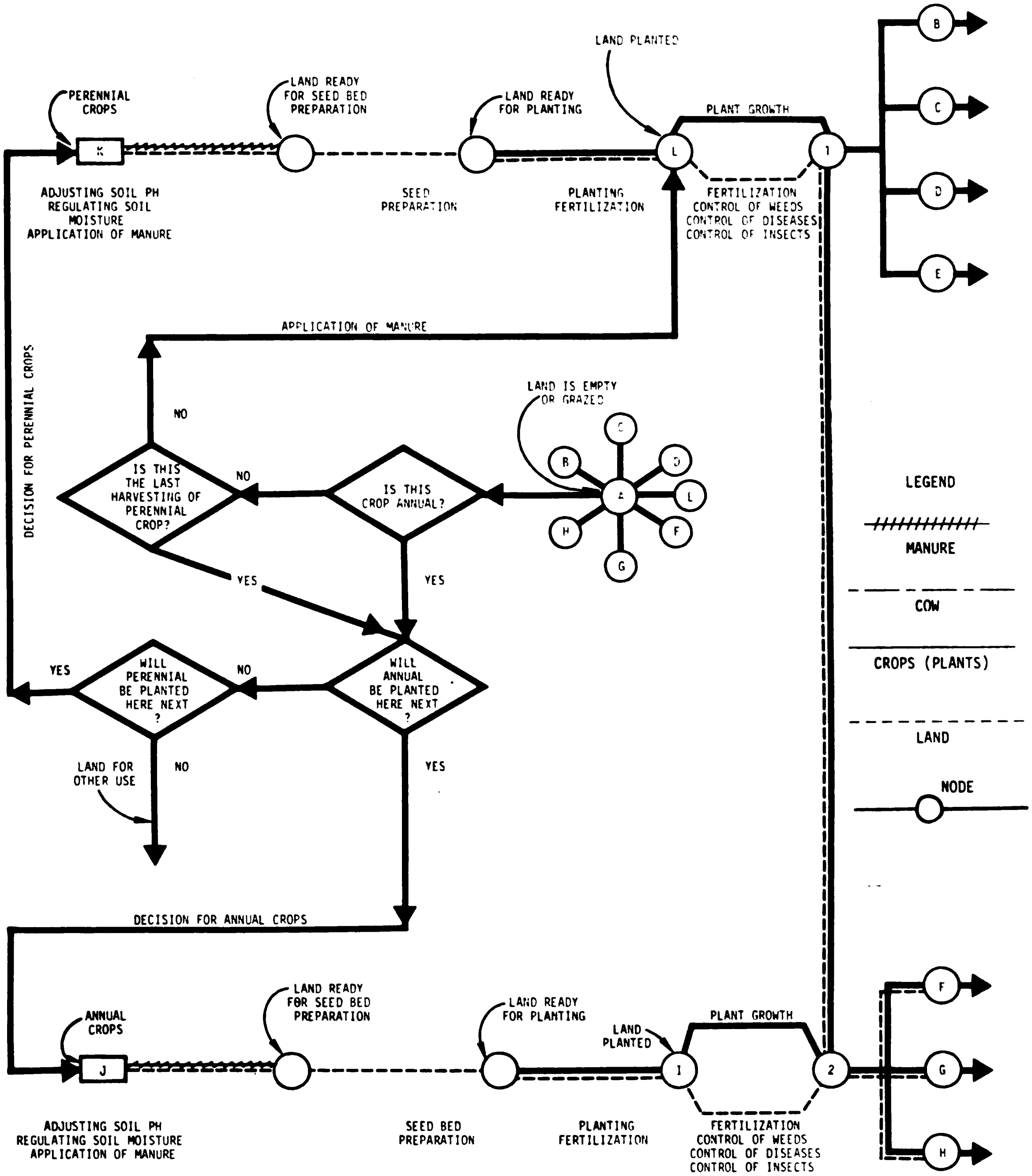
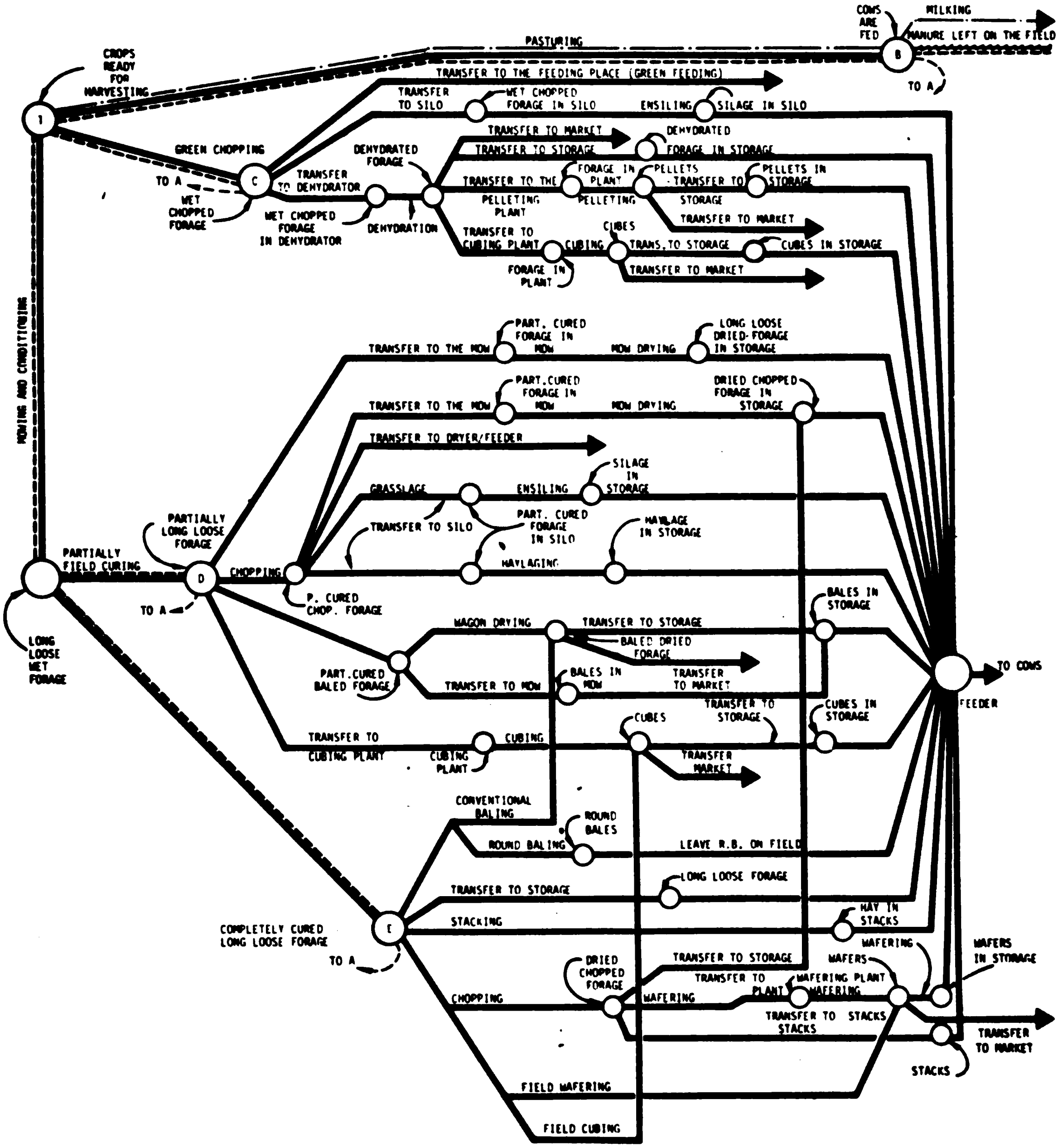


Fig. 3.1 Flow chart for feed production system. Adapted from Tseng and Mears, 1975.



CROPS READY FOR HARVESTING
PASTURING
COWS ARE FED
MILKING
MANURE LEFT ON THE FIELD
TO A
TRANSFER TO THE FEEDING PLACE (GREEN FEEDING)
TRANSFER TO SILO
WET CHOPPED FORAGE IN SILO
ENSILING
SILAGE IN SILO
GREEN CHOPPING
TRANSFER TO MARKET
TRANSFER TO STORAGE
DEHYDRATED FORAGE IN STORAGE
DEHYDRATED FORAGE
TRANSFER TO DEHYDRATOR
WET CHOPPED FORAGE
WET CHOPPED FORAGE IN DEHYDRATOR
DEHYDRATION
TRANSFER TO THE PELLETING PLANT
FORAGE IN PLANT
PELLETING
PELLETS
TRANSFER TO STORAGE
PELLETS IN STORAGE
TRANSFER TO CUBING PLANT
CUBING
CUBES
TRANS. TO STORAGE
CUBES IN STORAGE
MOWING AND CONDITIONING
PART. CURED FORAGE IN MOW
TRANSFER TO THE MOW
MOW DRYING
LONG LOOSE DRIED FORAGE IN STORAGE
DRIED CHOPPED FORAGE IN STORAGE
TRANSFER TO DRYER/FEEDER
SILAGE IN STORAGE
GRASSLAGE
ENSILING
PART. CURED FORAGE IN SILO
HAYLAGE IN STORAGE
HAYLAGING
PARTIALLY LONG LOOSE FORAGE
PARTIALLY FIELD CURING
CHOPPING
P. CURED CHOP. FORAGE
LONG LOOSE WET FORAGE
BALES IN STORAGE
WAGON DRYING
BALED DRIED FORAGE
PART. CURED BALED FORAGE
TRANSFER TO MOW
BALES IN MOW
TRANSFER TO MARKET
TO COWS
FEEDER
TRANSFER TO CUBING PLANT
CUBING PLANT
CUBES IN STORAGE
CONVENTIONAL BALING
ROUND BALES
ROUND BALING
LEAVE R.B. ON FIELD
LONG LOOSE FORAGE
HAY IN STACKS
STACKING
COMPLETELY CURED LONG LOOSE FORAGE
WAFERING
WAFERS IN STORAGE
WAFERS
DRIED CHOPPED FORAGE
WAFERING PLANT
TRANSFER TO PLANT
TRANSFER TO STACKS
STACKS
FIELD WAFERING
FIELD CUBING

Fig. 3.1 (cont'd.).

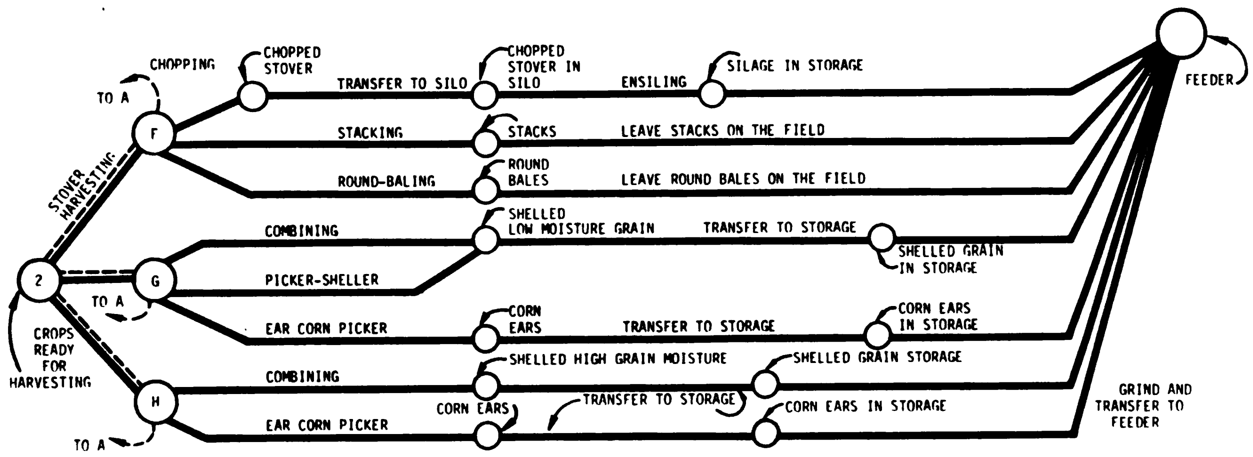

CHOPPING
TO A
CHOPPED STOVER
TRANSFER TO SILO
CHOPPED STOVER IN SILO
ENSILING
SILAGE IN STORAGE
FEEDER
STACKING
STACKS
LEAVE STACKS ON THE FIELD
STOVER HARVESTING
ROUND-BALING
ROUND BALES
LEAVE ROUND BALES ON THE FIELD
COMBINING
SHELLED LOW MOISTURE GRAIN
TRANSFER TO STORAGE
SHELLED GRAIN IN STORAGE
PICKER-SHELLER
TO A
EAR CORN PICKER
CORN EARS
TRANSFER TO STORAGE
CORN EARS IN STORAGE
CROPS READY FOR HARVESTING
COMBINING
SHELLED HIGH GRAIN MOISTURE
SHELLED GRAIN STORAGE
CORN EARS
TRANSFER TO STORAGE
CORN EARS IN STORAGE
GRIND AND TRANSFER TO FEEDER
EAR CORN PICKER
TO A

Fig. 3.1 (cont'd.)

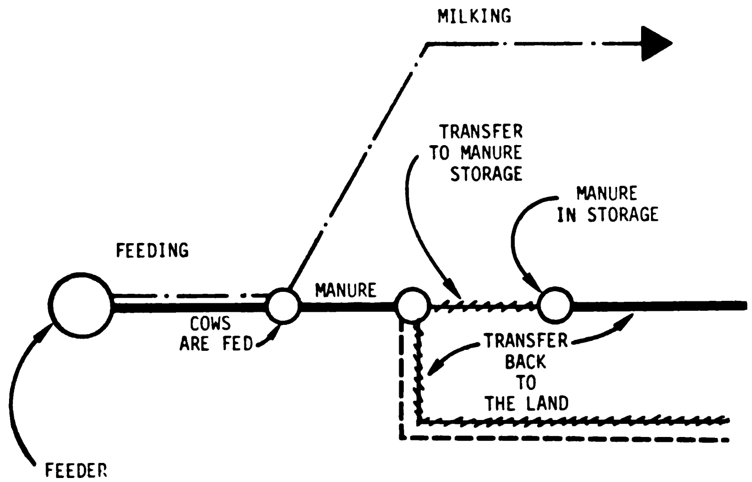

MILKING
TRANSFER
TO MANURE
STORAGE
MANURE
IN STORAGE
FEEDING
MANURE
COWS
ARE FED
TRANSFER
BACK
TO
THE LAND
FEEDER

Fig. 3.1 (cont'd.).

Also, particular consideration is given to the use of stover as a source of animal feeding. In many dairy farms, it is not a current practice to use grain crop residues to produce stover silage and stover in stacks or round bales.

Grain production is included describing three main production methods: Harvesting low-moisture grain, high-moisture grain and ear corn.

The description of this flow chart is the same given by Tseng and Mears. Links represent activities or operations, the nodes describe the state of material flow, land flow, crop flow, animal flow and the manure flow. Each one of these is shown by different kind of lines. At the right-hand side of the flow chart, the methods of making feed can be identified following the land and crop paths.

The use of the land is defined by the sequential decision diamonds at the left-hand side of the flow chart. At nodes B, C, D, E, F, G and H the crop is either pastured by the animal or harvested and the land is ready to continue in production with the same crop or a new crop.

3.3. Flow Chart for the Selection of Machinery Complement.

The selection of machinery complement is the result of considerations of many factors.

The first step is to consider the size of the agricultural firm (in our case, the size of the dairy farm) since this is going to directly determine the size of the machinery complement. The first two blocks, in Figure 3.2, state this problem. The decision is basically an economic one and it is the result, in the best of the cases, of a feasibility study or, as in most cases, a personal decision. Either case is out the scope of this study, and will therefore be assumed as previously determined.

The second step considers technical aspects related to the environment, that is, the local weather conditions and types of soils, as stated in the next 2 blocks of the flow chart.

These four blocks of information are used to determine if the dairy, or any other kind of farm activity, can be established following the sequential decision diamonds and, if the answer is positive, to arrive at the types of crops to be used.

In order to select the crop production sub-system, it is necessary to generate more information and this is indicated by the blocks corresponding to feed requirements and feeding method, crop management decisions and land allocation.

Data on available time, machinery and labor requirements, energy requirements and cost analysis is required for the selection of the machinery complement. This information will be determined in the model by calling subroutines or furnished as parameters or given values.

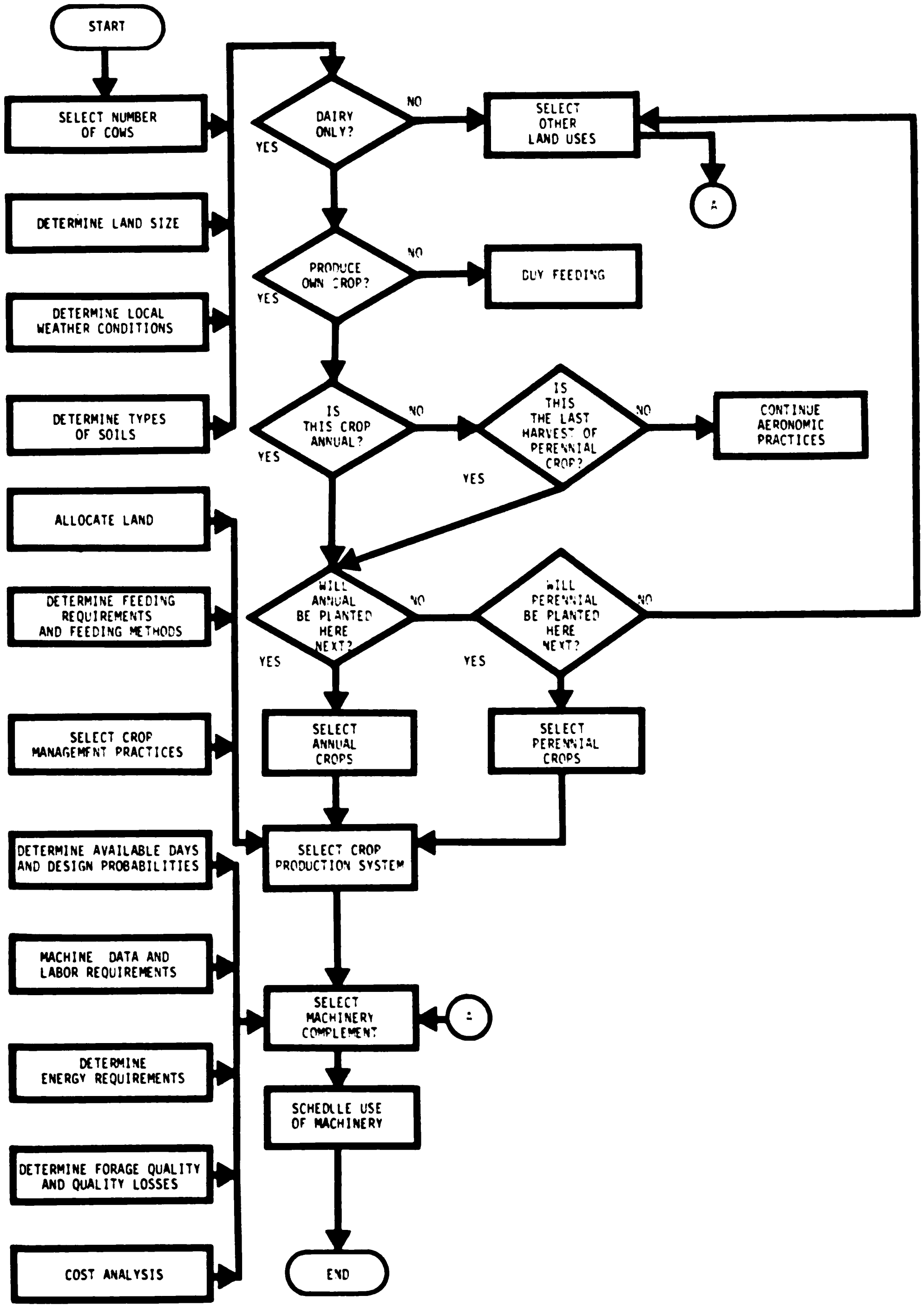


Fig. 3.2 Machinery complement selection flow chart.

3.4. Types of Input Data and Parameters.

Input data and parameters used in this model belong to one of the following groups:

a) Constants and logical statements controlling methods of feed production, use of multivalue parameters (arrays) and selection of machines and storage methods.

b) Machinery data such as field efficiency, speed, rate of material feeding, sizes, types, field capacity, tractive efficiency and rolling resistance coefficients.

c) Data related to farm management decisions: type of crops, crop yields, feed requirements, feed losses, number of cuts, farm size, feeding methods and type of transport units.

d) Data on available time: harvesting dates, hours or work per day and weather data and probabilities.

3.4.1. Machinery Capacity Parameters.

3.4.1.1 System capacity.

The first step is to determine the system capacity of each one of the feed production methods, since feed harvesting is considered as a problem of material handling in the available time. The general formula to calculate system capacity is:

$$SC = (FR + FL) / AH \qquad (3.1)$$

where:

SC = system capacity, t/h

FR = feed requirement, t

FL = feed losses, t

AH = available time, h.

Available time (AH) is calculated by:

$$AH = WD * HPD \tag{3.2}$$

where:

WD = working days

HPD = working hours per day.

Therefore, in order to select the set of machinery for the feed production method, the set must have a capacity greater or equal to the system capacity. This condition is maintained through every and each machinery calculation, to help assure a flow of material at the rate specified by the system capacity.

3.4.1.2. Effective Field Capacity.

It is the actual rate of performance of land or crop processed in a given time, based upon total field time.

This parameter can be calculated from field speed, machine working width and the field efficiency or by using values of material capacity and crop yield:

$$EFC = W * S * EFF / 10 \tag{3.3}$$

where:

EFC = effective field capacity, ha/h

S = working speed, km/h

W = working width, m

EFF = field efficiency, decimal

or:

EFC = EMC/CY (once over harvest) (3.4)

EFC = EMC/(CY * FRY) (more than one cut) (3.5)

where:

EMC = effective material capacity, t/h

CY = crop yield, t/ha

FRY = fraction of yield in each cut, decimal

3.4.1.3. Forage Harvester Capacity.

For this machine the total system capacity is:

SCH = EFF * FHC * HANUM (3.6)

where:

SCH = total forage harvester capacity, t/h

EFF = forage harvester efficiency, decimal (0.65)

FHC = forage harvester capacity, t/h

HANUM = number of forage harvesters.

3.4.1.4. Transport Unit Capacity.

The transport unit capacity was calculated using the formula:

TRACAP = 60. * TUC * TANUM/CYT (3.7)

where:

TRACAP = total transport unit capacity, t/h

TUC = size of transport unit, t

TANUM = number of transport units

CYT = cycle time, min.

60 = dimensionality constant

3.4.1.5. Cycle Time.

Cycle time is a very important factor in the calculation of the transport unit capacity, since it reflects the effect of the distance between the field and the storage or feeding area, the time of loading and unloading the transport unit, the blower support time and, when wagons are used, the time of hitching the wagon to the forage harvester and to the shuttle tractor:

$$CYT = ALT + TT + BST + UT + HWFHST + HWTST \qquad (3.8)$$

where:

CYT = cycle time, min.

ALT = loading time, min.

BST = blower support time, min.

TT = travel time, min.

UT = unloading time, min.

HWFHST = hitching wagon to forage harvester time, min.

HWTST = hitching wagon to the tractor time, min.

Elements of cycle time were calculated by using:

$$ALT = 60. * TUC / (EFF * FHC) \qquad (3.9)$$

$$TT = 60. * AD/AS \qquad (3.10)$$

UT = 60. * TUC/BLCAP (for vertical silos) (3.11)

UT = FT (for green feeding) (3.12)

UT = UTH (for horizontal silos) (3.13)

where:

AD = average travel distance, km

AS = average transport speed, km/h

BLCAP = blower capacity, t/h

FT = feeding time, min.

UTH = time unloading transport unit in horizontal silo, min.

60 = dimensionality constant.

Blower support time and the time for hitching wagon to the forage harvester and to the tractor are measured or estimated values.

3.4.1.6. Blower Capacity.

In order to avoid bottlenecks at the blower, the capacity of this machine must relate to the rate of material harvested and transported to the blower. A formula was devised that gives the blower capacity as a function of the efficiency, capacity and number of forage harvesters:

BLCAP = EFF * FHC * HANUM (3.14)

A provision is taken for the case when only one forage harvester is required to insure that the blower capacity is at least twice the forage harvester capacity. In addition, 10 percent of reserved capacity is added to the calculated blower capacity. These precautions are used to reduce the risk of bottlenecks at the blower.

3.4.1.7. Baler Capacity.

Again, the total baler capacity is expressed as a function of the field efficiency, the baler capacity and the number of balers:

$$BALTPH = EFF * BALCAP * BALRN \tag{3.15}$$

where:

BALTPH = total baler capacity, t/h

EFF = baler field efficiency, decimal

BALCAP = baler capacity, t/h

BALRN = number of balers

3.4.1.8. Continuous width implement.

For this type of implement, effective field capacity is calculated first and then the equation is solved by width:

$$W = EFC * 10. /(EFF * S) \tag{3.16}$$

where:

W = total width required, m

EFC = effective field capacity, ha/h

EFF = field efficiency, decimal

S = working speed, km/h

The next step is to calculate the number of implements of commercial size that satisfy the total width, that is,

$$W = SIZE * NUMBER \tag{3.17}$$

This procedure applies to mowers, conditioners, mower-conditioner, windrowers and rakes.

3.4.1.9. Non-continuous Width Implements.

This is the case of implements designed to work in rows, such as pickers, picker-shellers, combines and forage harvesters. The general formula is:

$$W = ANR * RWWD * NUMBER \qquad (3.18)$$

where:

W = total width required, m

ANR = number of rows

RWWD = row width, m

NUMBER = number of implements

Effective field capacity is previously calculated in the usual way.

3.4.2. Power Requirements

Values of power requirement for each implement were calculated following procedures and formulas from the A.S.A.E. Yearbook (1980), standards EP 391 and D230.3.

3.4.2.1. Rolling Resistance.

Defined as the opposition offerred by the soil and crop residues to the wheels of moving implements.

$$RRF = WT * CR * ACC/1000 \qquad (3.19)$$

where:

RRF = rolling resistance force, kN

WT = weight of implement, kg

CR = coefficient of rolling resistance, decimal

ACC = acceleration of gravity, ($9.8\ m \cdot s^{-2}$)

3.4.2.2. Rolling Resistance Coefficient.

This value was calculated applying the formula:

$$CR = (1.2/Cn + 0.04) \qquad (3.20)$$

where:

CR = rolling resistant coefficient

Cn = dimensionless ratio equal to the product of the cone index for the soil, the unloaded tire section width, and the unloaded overall tire diameter divided by the dynamic wheel load normal to the soil surface.

Values of Cn and CR, under specified conditions, are given in Table 3.2.

Table 3.2 Values of ratio Cn and rolling resistance coefficient CR.

Type of Soil	Cn	CR
Hard soils	50	0.064
Firm soils	30	0.080
Tilled soils	20	0.100
Soft, sandy soils	15	0.160

3.4.2.3. Drawbar Power and Power Take-off Equivalent.

Values of drawbar power are obtained from the rolling resistance force (RRF) and the implement working speed (S).

$$DBKW = RRF * S /3.6 \qquad (3.21)$$

where:

DBKW = kilowatts, kW

RRF = kilonewtons, kN

S = km/h

3.6 = dimensionality constant

This value is converted into value of equivalent power at the power take-off in the following way:

$$PTOKWE = DBKW/(TR * TE) \qquad (3.22)$$

where:

PTOKWE = power take-off equivalent, kW.

TE = tractive efficiency, decimal (0.72)

TR = transmission coefficient, decimal (0.96).

3.4.2.4. Power-takeoff Power.

It is the power required by the implement from the power take-off shaft of the tractor or engine:

$$PTOKW = UNP * W \qquad (3.23)$$

where:

PTOKW = power-takeoff power, kW

UNP = unit power requirement, kW/m

W = machine width, m

3.4.2.5. Total implement power requirement.

The addition of implement power components is the total implement power requirement:

$$TIKW = PTOKWE + TPOKW \qquad (3.24)$$

where:

TIKW = total implement power requirement, kW

3.4.2.6. Tractor Power.

It is the implement total power requirement plus an estimated reserve of 20 percent to overcome any changes in normal conditions of operation and any optional tractor attachments:

$$TPTOKW = TIKW/0.8 \qquad (3.25)$$

where:

TPTOKW = tractor power at PTO, kW.

CHAPTER 4

DESCRIPTION OF THE MODEL

4.1. Feed Harvesting Machinery Selection Model.

The model consists of a main program and sixteen subroutines. It calculates the effective material capacity (EMC) of every machine and its comparison to the system capacity (SYSCAP), which is determined from the feed requirements, feed losses and the available time.

When the effective material capacity of the machine under consideration is greater or equal to the system capacity, that machine is selected, in both number and size. This is achieved by an iteration of the calculation of machinery size and number and the associated effective material capacity, with a continuous comparison to the system capacity. Both effective material capacity and system capacity are expressed in ton per hour.

In order to minimize the investment in machinery, first the model tries to satisfy the system capacity by increasing the machinery size up to the maximum size available in the market. If this is not possible, then the number of machines is increased by one unit at a time, progressively from the smallest to the largest size.

The next step is a screening of these machines that have common use when corn silage and haylage are produced on the same farm. As an example, the same forage harvester can be used in both with just a change of heads. A similar situation is found with the use of tractors. The model calculates the number and power of the tractors required by every pull or mounted type machinery selected, and then reduces the number of tractors to the strictly necessary by means of conventional agreements according to the feed production method and the type of transport unit to be used. Formulas used in calculation of tractor number are given in Table 4.1.

4.2. Feed Harvesting Machinery Selection Program.

The main program of the model controls the operation of subroutines by means of indexes (integer constants), logical statements and by direct calls to the proper subroutines. The flow chart for this program is presented in Figure 4.1.

The data required by the program consist of specifications of farm size, management practices, field machinery data and available time. Data input to the main program are summarized in Table 4.2.

Parameters defining the number of cuts, the method of feed production, initial and final dates of harvesting season and number of working hours per day along with data

Table 4.1. Formulas for calculation of tractor number.

Feed Production Method	Type of Harvesting Machinery: Self-propelled		Pull or Mounted	
	Type of Transport Unit: Wagon	Truck	Wagon	Truck
Silage and haylage	TN = SHUTR + BLTRAC	TN = BLTRAC	TN = TRACF + SHUTR + BLTRAC	TN = TRACF + BLTRAC
Hay	TN = SHUTR	TN = TRACMW	TN = TRACB + SHUTR	TN = TRACB
Green feeding	DNA	DNA	TN = TRACF + SHUTR	TN = TRACF
Grain	TN = SHUTR + BLTRAC	TN = BLTRAC	TN = TPS + SHUTR + BLTRAC	TN = TPS + BLTRAC

TN = number of tractors
SHUTR = transport unit tractors
BLTRAC = silo tractors
TRACF = forage harvester tractors
TRACMW = mow-conditioner and windrower tractors
TRACB = baler tractors
TPS = picker or picker-sheller tractors
DNA = does not apply.

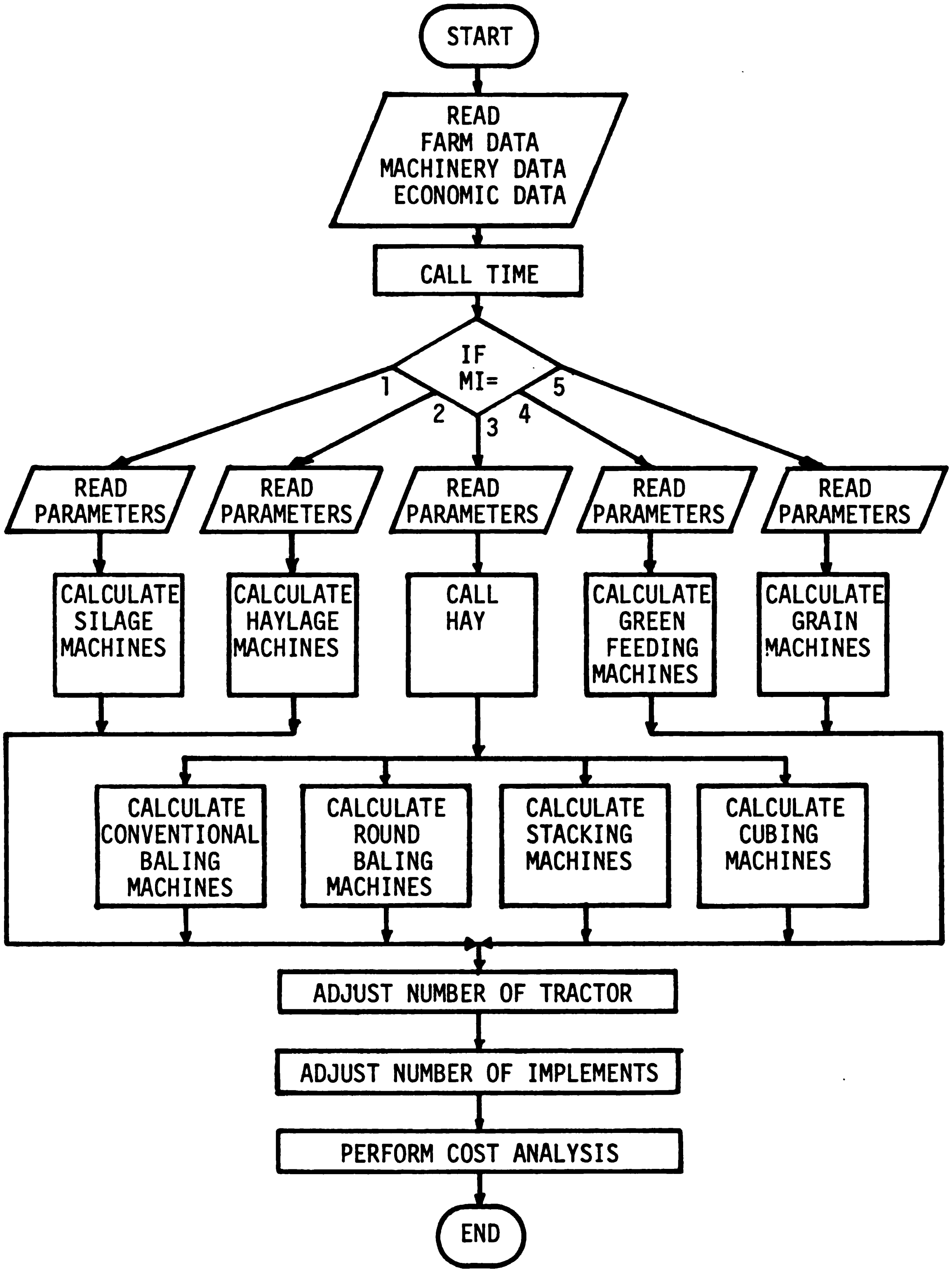


Fig. 4.1 Flow chart for program FHMS.

Table 4.2. Input parameters for main program.

Farm size
total surface and distribution by crops, SURF, HECT ha
number of dairy animals
feed requirements, FR, t/yr
feed losses, FL, t/yr
Management practices
type of storage facility, ISW
type of crop, K, KA
number of cuts, NC, JA, J
feed production method, MI
crop yield, CY, t/ha
use of mower logical, MOWER, M
type of transport unit, BI, BMTI, logical WAGON
use of conventional baling logicals, CONBAL, A
hay partial field curing logicals, PAEFC, B
hay mow drying logicals, MOWDRY, C
use of mower-conditioner logical, MC
production of shelled grain logical, SHC
rowcrop spacing, I
use of self-propelled combines, logical SPCO
transportation travel distance, AD, km
Field machinery data
machine size, m, t/h, kW
machine weight, kg, t
power requirement unit, kW/m, kW-h/t, kW/row
specific fuel consumption, L/kW-h
row width RWWD, m
number of rows, ANR
effective material capacity, EMC, t/h
effective field capacity, EFC, ha/h
field efficiency, EFF, decimal
working speed, S, SP, km/h
Available time
harvesting season initial and final dates
number of working hours per day, HPD, h
daily precipitation data

on daily precipitation for an extended period of years are furnished before calling the subroutine TIME. This subroutines calculates the available working days and transfers this information to the following subroutines.

The subroutines for the different methods of feed production are successively called and in that way the number and size of machines are calculated by an algorithm specifically designed for every machine.

The next section of the program makes the final selection of the machinery set by reducing the number of tractors, calculated for every pull or mounted type implement, and the machines which have common use in silage, haylage and green feeding, if these feed production methods are simultaneously utilized in the farm.

The program output is arranged in machinery sets or systems. Every set is identified with the system name, the system capacity, number of working days and working hours per day. Other information printed is the number, size and type of machine components of the selected system. If desired, extra information is available regarding excess forage harvester capacity and transportation capacity, both in percentage.

4.3. Available Work Time.

Subroutine TIME calculates the available time for each operation in forage, hay and grain production, based on weather probabilities and management decisions, according to the algorithm presented in Figure 4.2.

Input data for subroutine TIME consist of indication of feed production method (MIA), the number of working hours per day (HPD), the initial and final date of the harvesting season (MDI, MDF), daily precipitation for an extended period of time (PR), the number of years in this period (NP, ANY, NY), the criteria defining a dry day, as a function of amount of precipitation, (A1, A2 upper and lower limits respectively), the number of cuts (NC), the total number of days in the cutting period of specified years of daily precipitation (TD) and, finally, the total number of days in the cutting period when the crop is only harvested once (DG) and when the crop is harvested more than once (TDP).

According to the type of feed production method, the subroutine proceeds to the calculation of dry days, so that for green feeding, silage and grain production, considered as once over crop harvesting methods, the number of dry days in the cutting period is calculated by calling subroutine COUNT, then with this value and the number of days in the cutting period, the probability of occurence of dry days in that period is calculated, so:

$$TDG = DG * ANY \qquad (4.1)$$

$$PDD = DD/TDG \qquad (4.2)$$

where:

PDD = probability of occurence of dry days, decimal

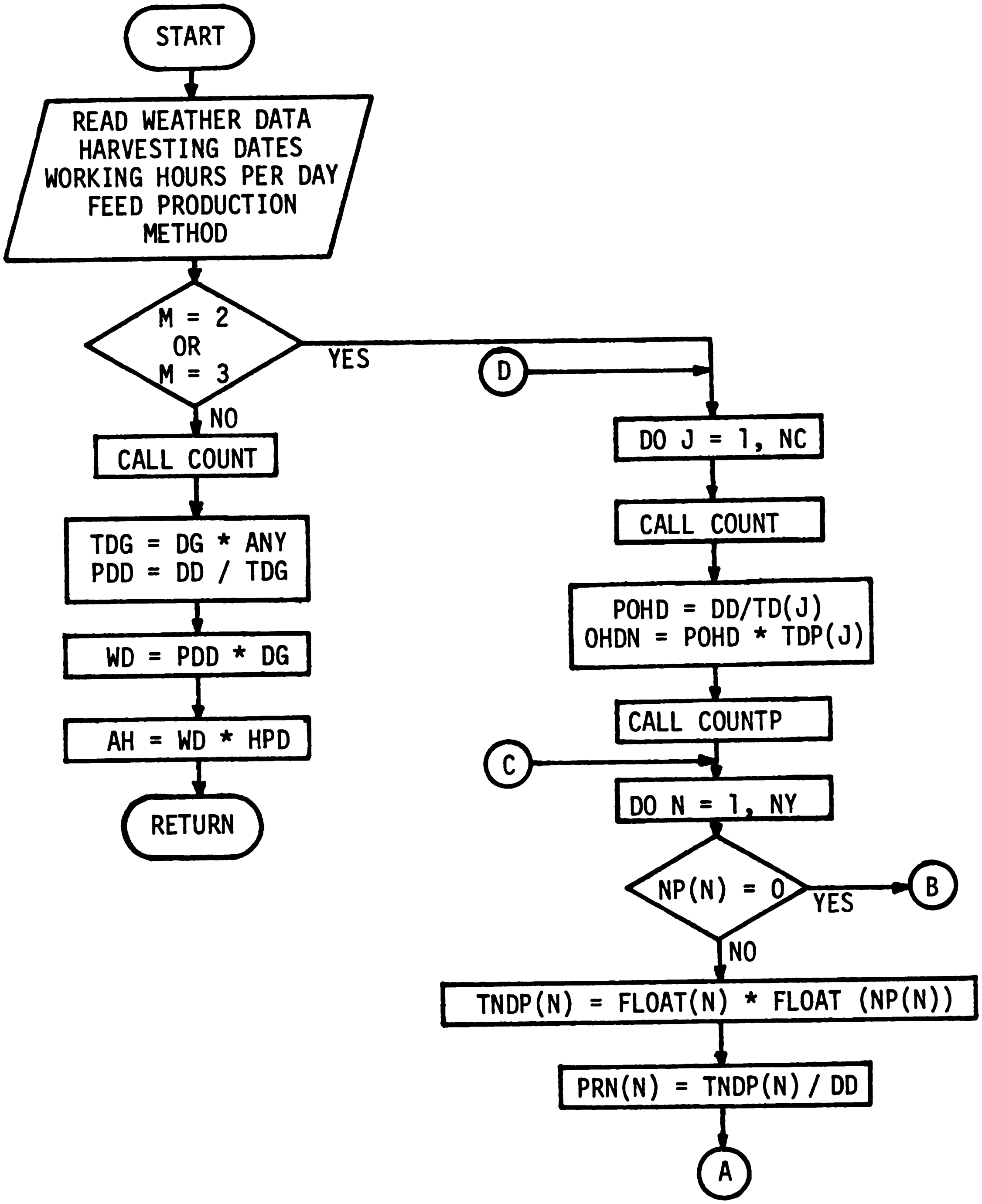


Fig. 4.2 Flow chart for subroutine TIME.

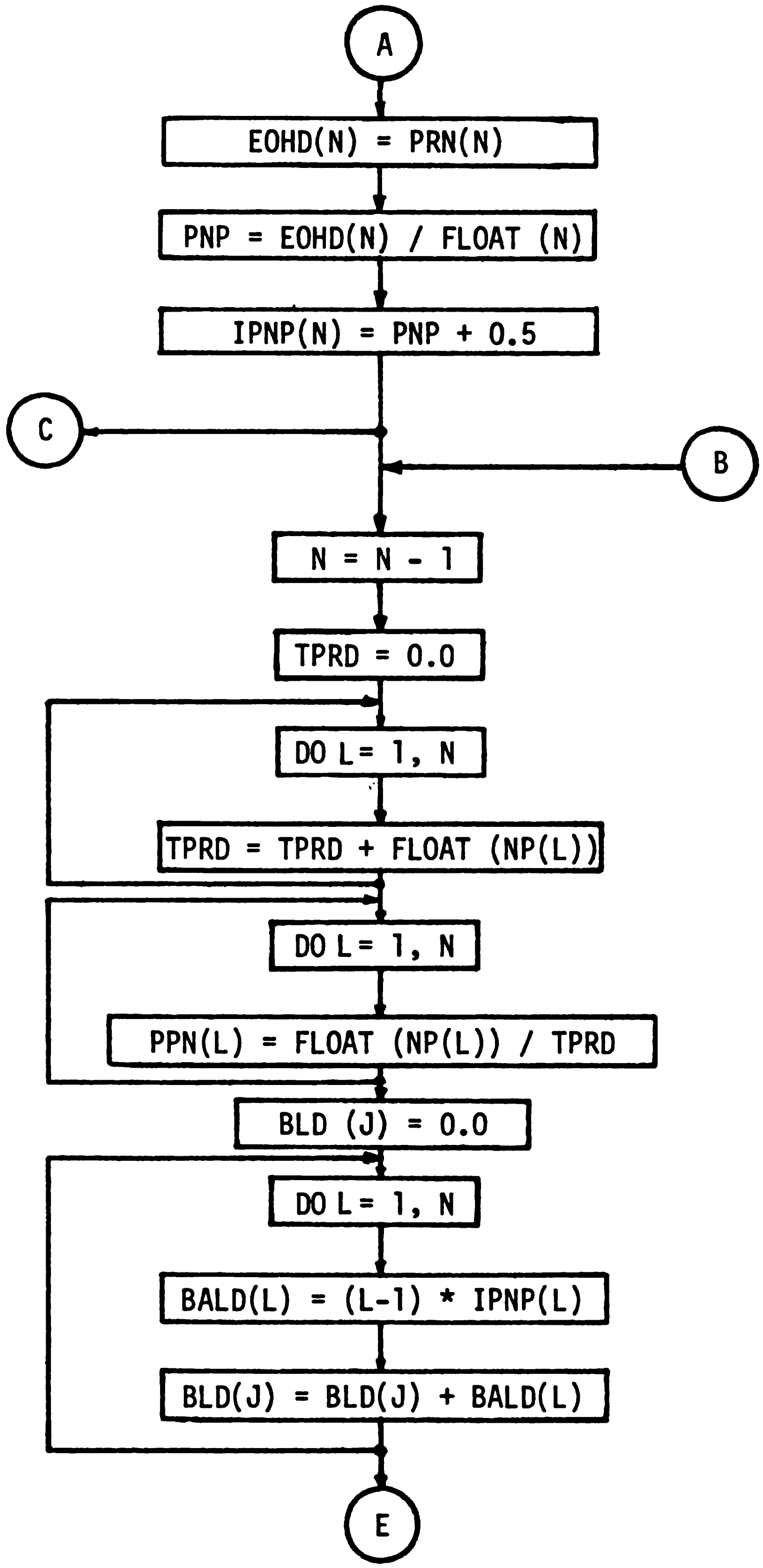

A
EOHD(N) = PRN(N)
PNP = EOHD(N) / FLOAT (N)
IPNP(N) = PNP + 0.5
C
B
N = N - 1
TPRD = 0.0
DO L= 1, N
TPRD = TPRD + FLOAT (NP(L))
DO L= 1, N
PPN(L) = FLOAT (NP(L)) / TPRD
BLD (J) = 0.0
DO L= 1, N
BALD(L) = (L-1) * IPNP(L)
BLD(J) = BLD(J) + BALD(L)
E

Fig. 4.2 (cont'd.).

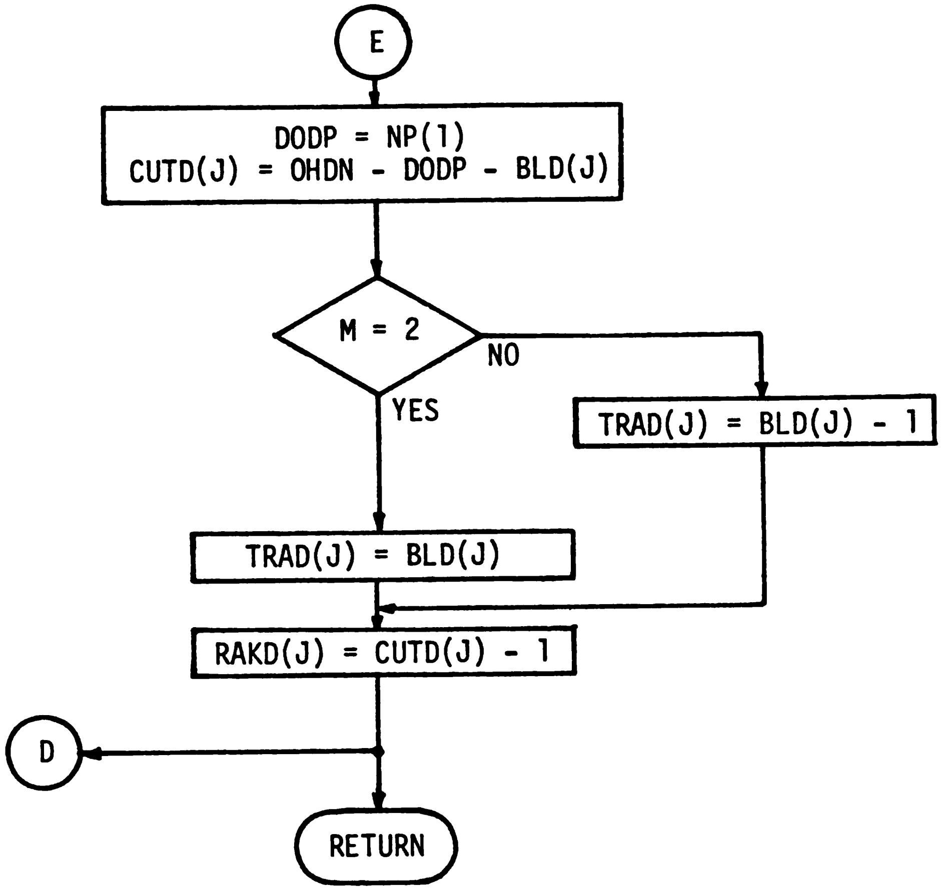

E
DODP = NP(1)
CUTD(J) = OHDN - DODP - BLD(J)
M = 2
NO
YES
TRAD(J) = BLD(J) - 1
TRAD(J) = BLD(J)
RAKD(J) = CUTD(J) - 1
D
RETURN

Fig. 4.2 (cont'd.).

DD = total number of dry days in cutting periods

TDG = total number of days in period of years of observed precipitation

DG = number of days in cutting period

ANY = number of years in period when observed precipitation occurs

Then, the number of working days and the available time in hours are determined by:

$$WD = PDD * DG \tag{4.3}$$

$$AH = WD * HPD \tag{4.4}$$

where:

WD = working days

AH = available time, h

HPD = working hours per day

If the crop is going to be harvested more than once, as it is the case of haylage and hay production, the procedure to determine available time is more elaborate. The criteria of "open haying day" presented by Von Bargen (1966) is used to determine the time available for each operation at every cut. Therefore, the first step is to calculate the number of dry days in each cutting period. This is achieved by calling subroutine COUNT and running it as many times as the number of cuts (NC) that has been chosen. The probability of occurence of open haying days at each cut is then calculated by:

$$POHD = DD/TD(J) \tag{4.5}$$

and the number of open haying days is:

$$OHDN = POHD * TDP(J) \quad (4.6)$$

where:

POHD = probability of occurence of open haying days, decimal

DD = dry days in cutting periods in observed number of years

J = index for number of cuts

TD = number of days in cutting periods in observed number of years

OHDN = number of open haying days

TDP = number of days in the cutting period

The number of periods (NP) of N consecutive open haying is calculated by calling subroutine COUNTP and running it as many times as the number of cuts (NC). Then the probability of occurrence of a period of N consecutive open haying days is computed by dividing the number of such periods by the total number of periods occurring during the observed number of years. So,

$$PPN = NP(L)/TPRD \quad (4.7)$$

where:

PPN = probability of occurrence of a period of N consecutive days, decimal

NP = number of periods of N consecutive number of open haying days

TPRD = total number of periods in observed number of years.

The periods of N consecutive days are considered as mutually exclusive events. Therefore, an open haying day occurs in only one period. The expected number of open haying days for a cutting period can be computed by previously calculating the probability of a given open haying day occurring in a period of N consecutive open haying days and multiplying this value by the number of open haying days in the given cutting period. Thus,

$$TNDP(N) = N * NP(N) \quad (4.8)$$

$$PRN(N) = TNDP(N)/DD \quad (4.9)$$

and

$$EOHD(N) = PRN(N) * OHDN \quad (4.10)$$

where:

TNDP = total number of days in a period of N consecutive open haying days

N = number of days in the period

NP = number of periods

PEN = probability of occurrence of an openning haying day in a period of N consecutive open haying days.

DD = total number of dry days in a cutting period

EOHD = expected number of open haying days

OHDN = number of open haying days.

Finally, a prediction for the number of days for every operation, in haylage or hay production, can be made by using the formulas given below.

For baling operation, assumption is made that at least two consecutive dry days are necessary to perform such an operation. Thus:

$$BALD(L) = (L-1) * NP(L) \tag{4.11}$$

eliminates the periods with only one open haying day, and

$$BLD(J) = BLD(J) + BALD(L) \tag{4.12}$$

calculates the total number of days for baling.

New terms in the formulas are:

BALD = baling days in every period of N consecutive open haying days

BLD = total number of baling days

For computation of number of cutting days:

$$CUTD(J) = OHDN - DODP - BLD(J) \tag{4.13}$$

new terms:

CUTD = number of cutting days

DODP = total days in one-day periods

Days required for transportation in hay production:

$$TRAD(J) = BLD(J) \tag{4.14}$$

but for haylage:

$$TRAD(J) = BLD(J) \tag{4.15}$$

new term:

TRAD = number of days for transportation

The number of days for raking is calculated by using:

$$RAKD(J) = CUTD(J) - 1 \qquad (4.16)$$

new term:

RAKD = number of days for raking

The output of this subroutine is arranged to yield the results for haylage and hay production separately from green feeding, silage and grain.

For hay and haylage, values of the calculated parameters are presented in tables, one for every cut. At the bottom of the table, the information on the number of days available for each operation is summarized.

For green feeding, silage and grain, the calculated parameters are only summarized.

4.4. Counting Dry Days.

Subroutine COUNT finds the number of dry days in every cutting period and has been specially prepared to read daily precipitation data in such periods, according to the new format of daily climatological data designed by the Weather Service of the Michigan Department of Agriculture (1980).

The input data are the daily precipitation for an extended period of time, the initial and final dates of the harvesting period and the upper and lower limits of precipitation that, according to the criteria applied, define a dry day for field machinery operations.

The subroutine counts the number of dry days just in the range set by the initial and final date of the harvesting period, by comparing the amount of precipitation in those days to the selected dry day criteria. A flow chart for this subroutine is given in Figure 4.3.

4.5. Counting Open Haying Day Periods.

Subroutine COUNTP calculates the number of periods of N consecutive open haying days in every cutting period. Data input to this subroutine are the same as for subroutine COUNT and the number of years of weather data.

The subroutine counts the number of periods of N consecutive open haying days applying the same procedure used in subroutine COUNT, but since the periods of N consecutive open haying days are considered mutually exclusive events, care is exerted to avoid the counting of a given day in more than one period. The flow chart for this subroutine is presented in Figure 4.4.

4.6. Green Feeding (Chopping) of Forage.

The subroutine GF selects the size and number of machines used in the production of green feeding forage. A flow chart for this subroutine is in Figure 4.5.

Data input for this subroutine are the available time, transferred from subroutine TIME, and the feed requirement and feed losses, transferred from the main program.

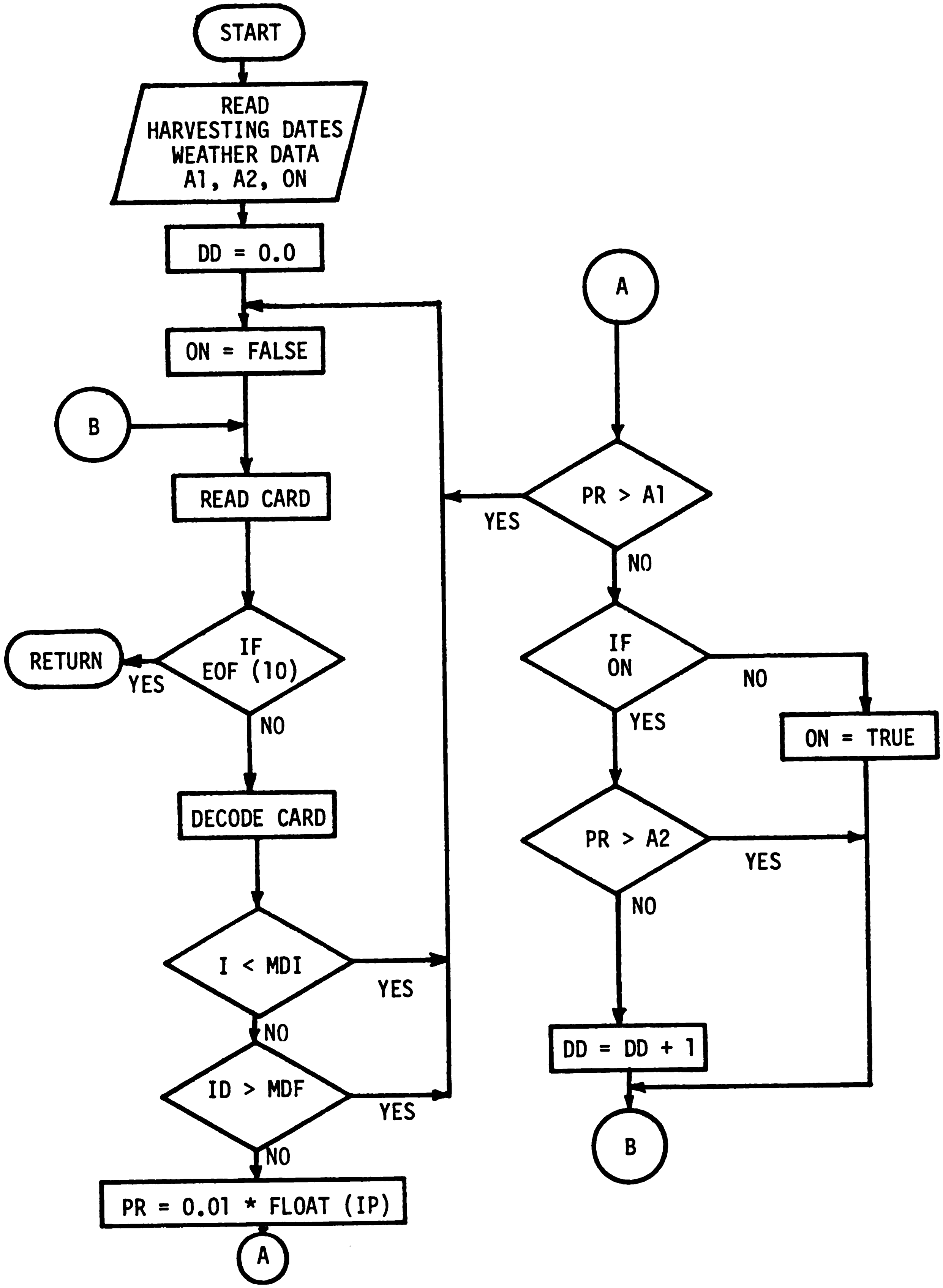


Fig. 4.3 Flow chart for subroutine COUNT.

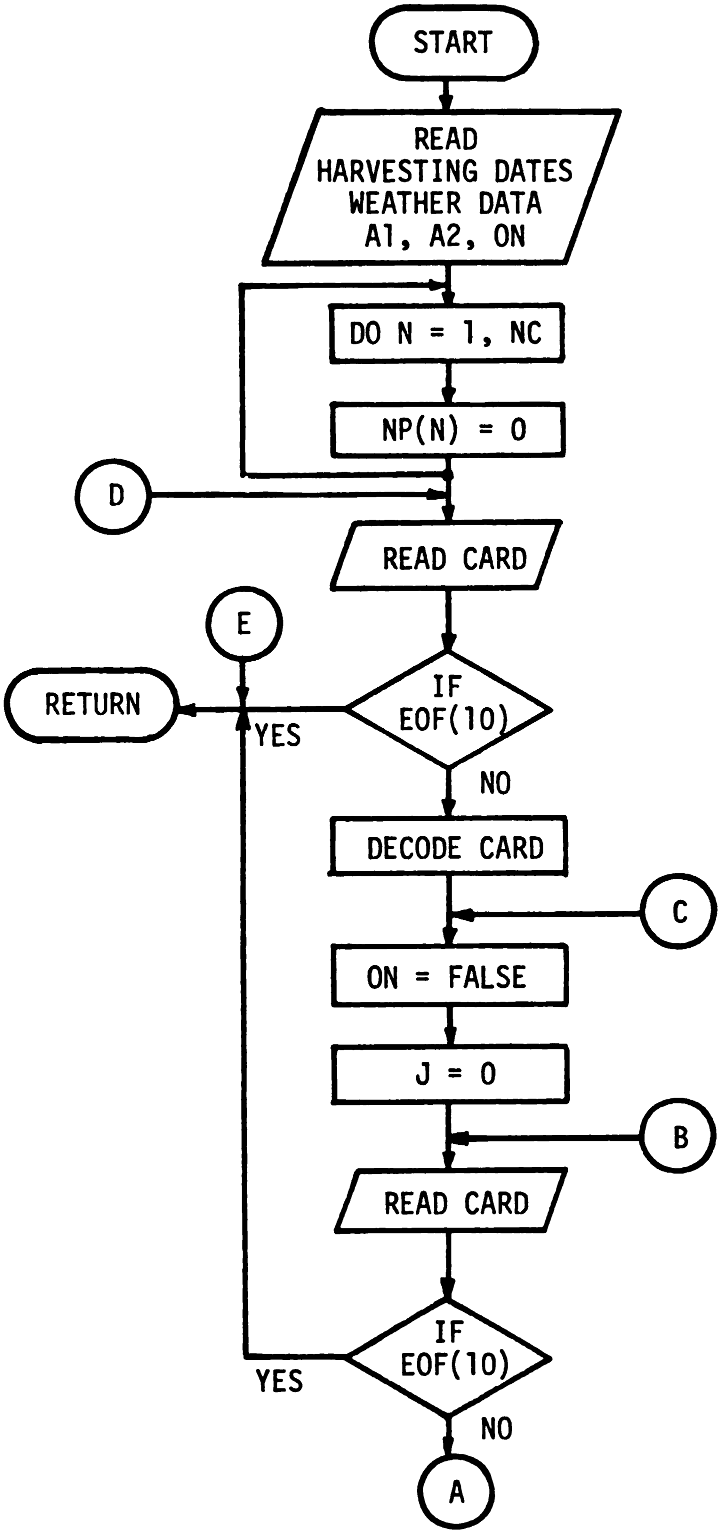


Fig. 4.4 Flow chart for subroutine COUNTP.

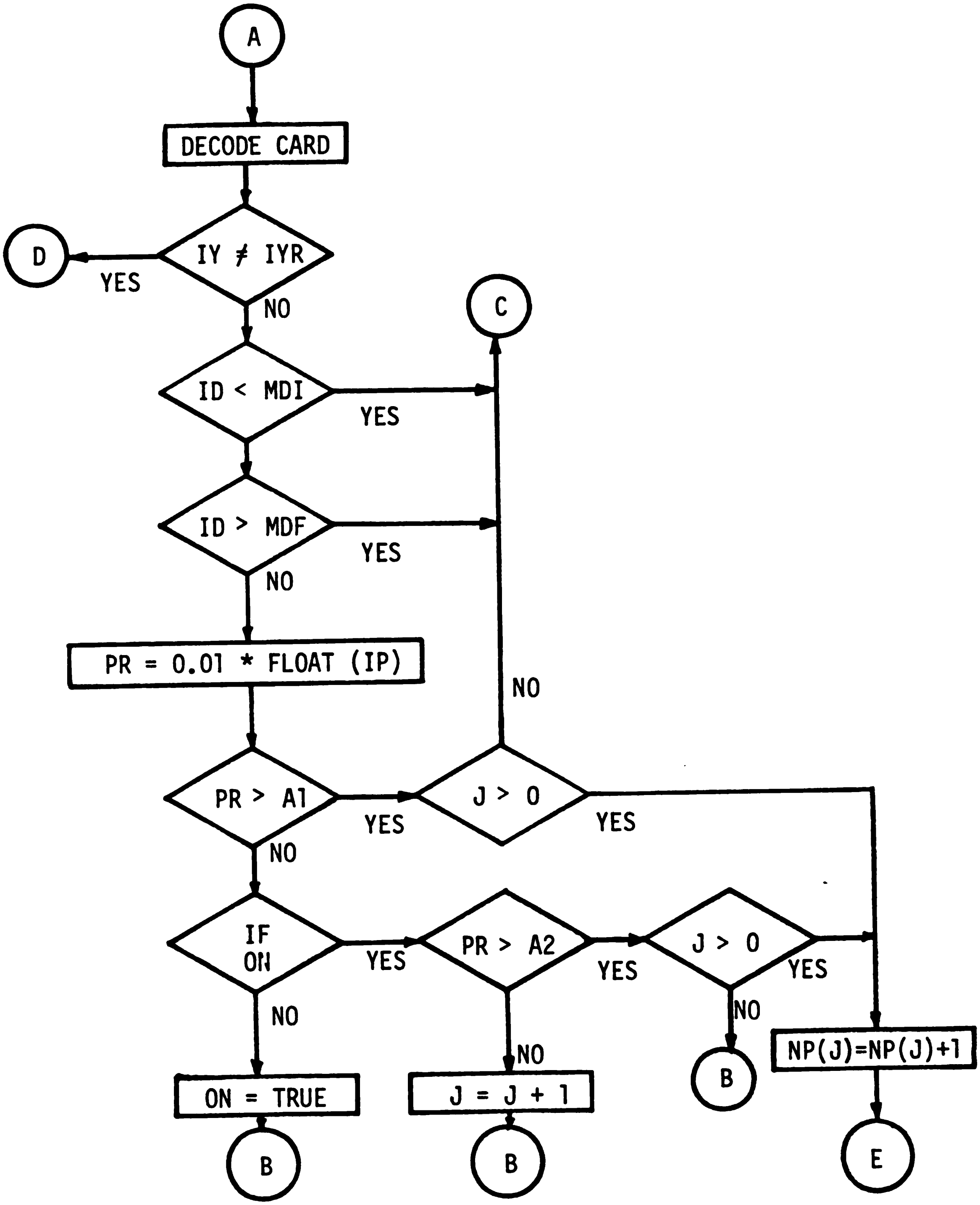

A
DECODE CARD
IY ≠ IYR
D
YES
NO
C
ID < MDI
YES
ID > MDF
YES
NO
PR = 0.01 * FLOAT (IP)
NO
PR > A1
YES
J > 0
YES
NO
IF ON
YES
PR > A2
YES
J > 0
YES
NO
NO
NO
ON = TRUE
J = J + 1
B
NP(J)=NP(J)+1
B
B
E

Fig. 4.4 (cont'd.).

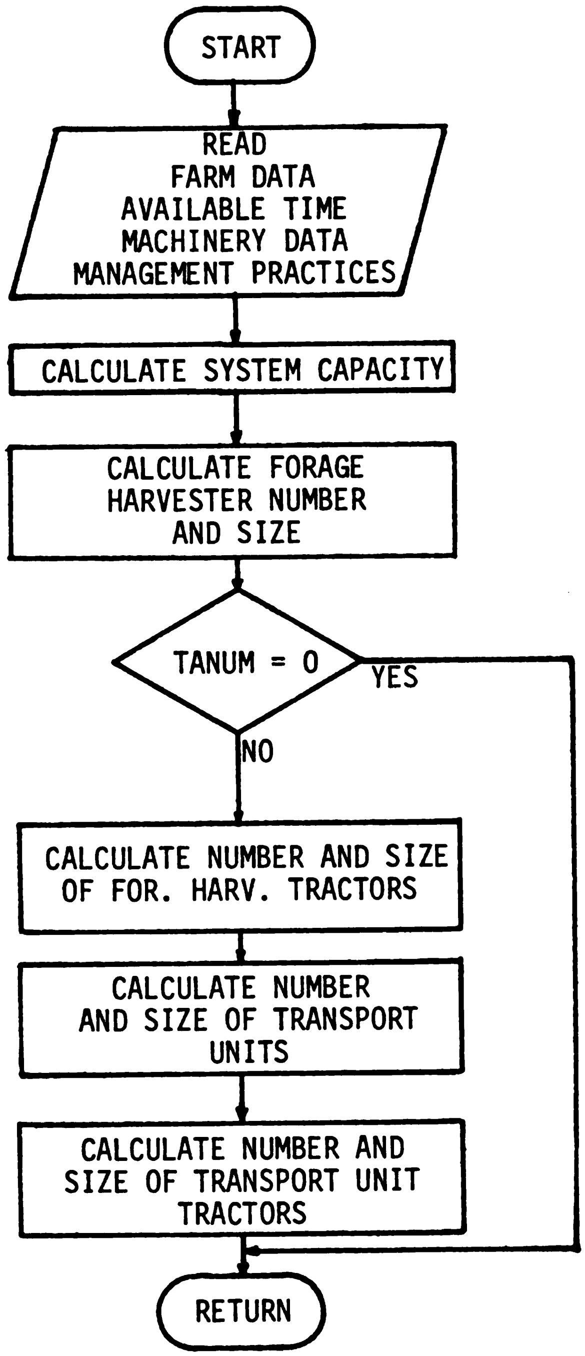


Fig. 4.5 Simplified flow chart for subroutine GF.

The system capacity is computed and its value transferred to the subroutine FORHAR. Formulas used in this computation are:

$$FL = PCL(MI) * FR(MI) \tag{4.17}$$

$$SC = FR(MI) + FL \tag{4.18}$$

where:

FL = feed losses, t

PCL = fraction of feed losses, decimal

FR = feed requirement, t

SC = system capacity, t.

Values of FL, PCL and FR are kept in arrays controlled by the index which defines the method of feed production. To GF corresponds the index MI = 4.

The subroutine GF calls subroutine FORHAR for the calculation of the number and size of transport units, when wagons are used, the power required for pulling the wagon along with the number, and power in kW, of the tractors required for the wagons are also computed.

It may happen that the number of transport units is not calculated because the capacity of the transportation subsystem is exceeded. When this occurs the calculation stops and the word "COMMENTS" is printed to point out this situation.

4.7. Forage Harvest Machines.

Subroutine FORHAR, as stated above, calculates the number and size of machines utilized in harvesting forage for green chop, silage and haylage.

According to the flow chart of this subroutine, presented in Figure 4.6, the effective material capacity required for the harvesting system (RTPH) is first calculated in ton per hour unit, as explained in Section 3.4.2.1. Next, the total forage harvester capacity (SCH) is computed using the formula of Section 3.4.2.3, and both values are compared.

If SCH is greater or equal to RTPH, the number and size of forage harvesters is obtained and the subroutine TRAPUN is called to perform the calculations related to the transport units. If this condition is not achieved, then the capacity of the forage harvester (FHC) is increased up to the set limit of 60 ton per hour (rated capacity). If this limit is exceeded, then the number of forage harvester (HANUM) is increased by one at a time and again the forage harvester capacity is increased until the combination size and number of forage harvesters yields a total capacity that satisfies the condition:

SHC . GE . RTPH

There is also another limit to the number of forage harvesters (HANUM = 10). If this limit is exceeded then the calculation stops and the word "COMMENTS" is printed. This means that the available time for harvesting is scarce, or that the system requirement is too large, or a combination of these two factors.

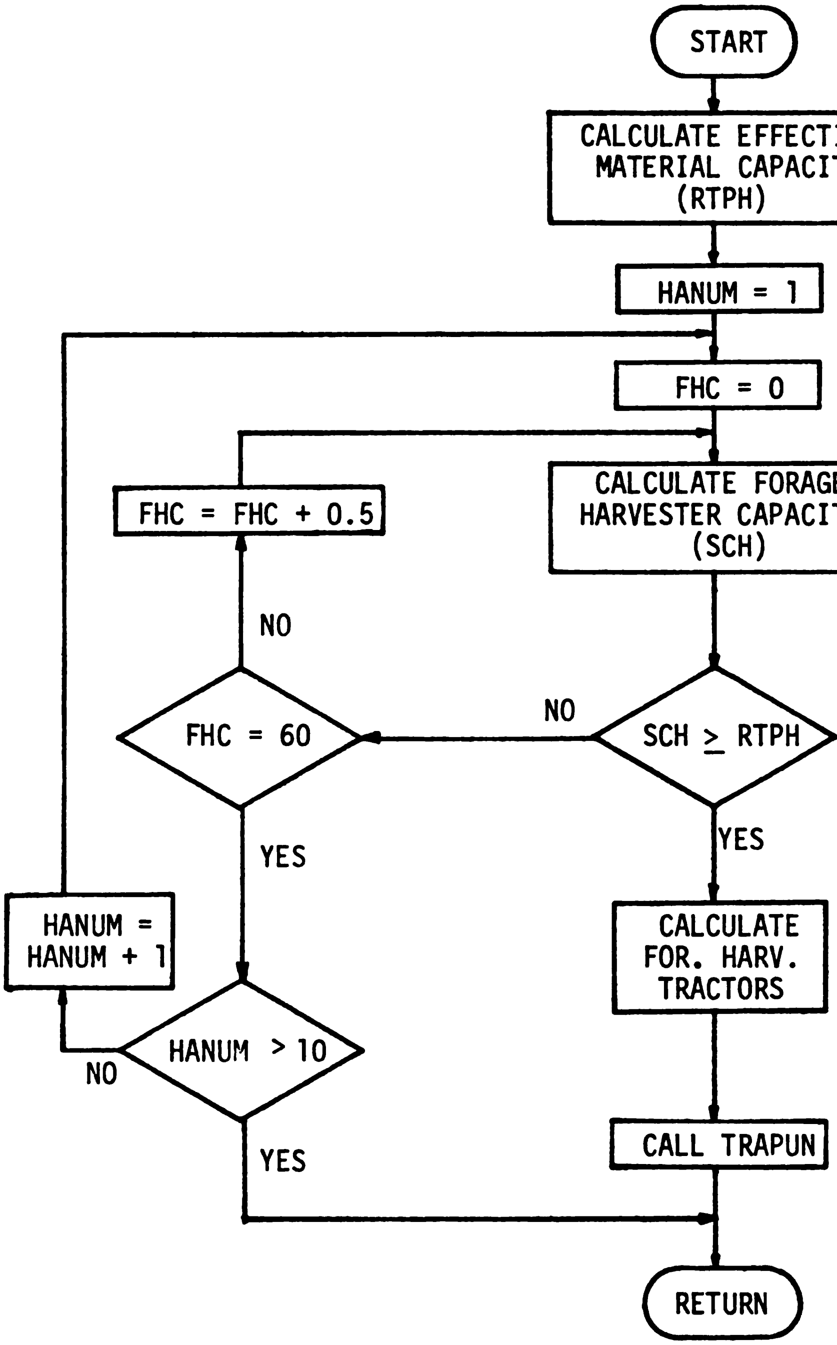


Fig. 4.6 Flow chart for subroutine FORHAR.

Provisions are taken to care for the calculation of the harvesting sub-system capacity when the crop is harvested once or more than once. Also, the number and power of tractors is not computed when self-propelled forage harvesters are used. Power requirement is determined for both self-propelled and tractor driven forage harvesters.

4.8. Transportation Units.

Subroutine TRAPUN calculates the number and size of transport units and their power requirement in accordance to the size and number of forage harvesters, combines, picker or picker-shellers. A flow chart for this subroutine is given in Figure 4.7.

A logical parameter (WAGON) is used to separate calculation of wagons from trucks, as the selected means of transportation for forage and grain. The first step is the calculation of cycle time following the procedure described in Section 3.4.2.5. Three options are considered: 1) the transported material is going to be directly fed to the animals, 2) placed in a horizontal silo or 3) in a vertical silo. In the first option, the unloading time (UT) is made equal to the feeding time (FT) and in the second to the time of unloading the transport unit, (UTH). In the third option the unloading time is calculated by dividing the transport unit capacity (TUC) by the blower capacity (BLCAP).

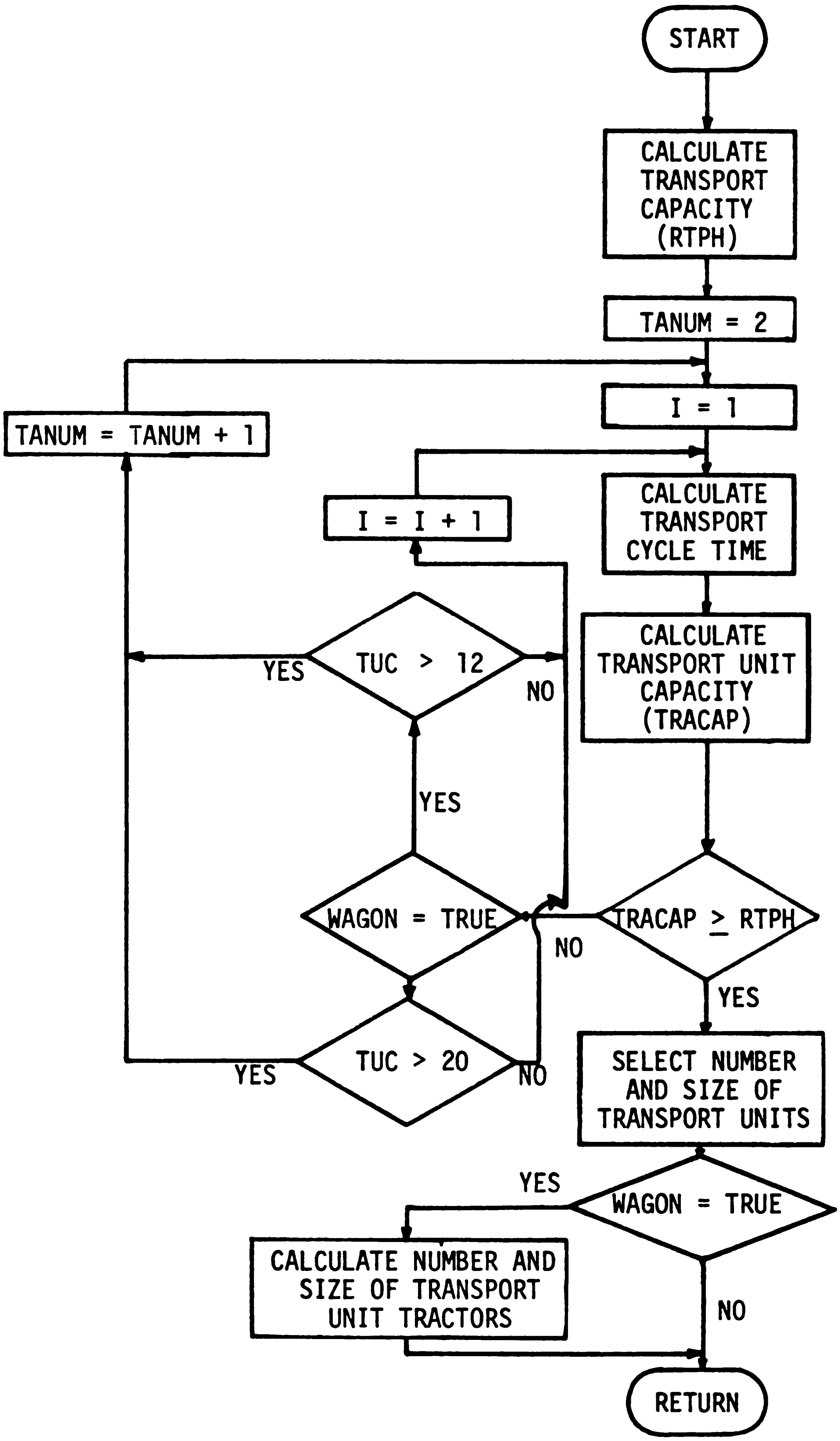


Fig. 4.7 Flow chart for subroutine TRAPUN.

The required transport capacity (RTPH) is computed in ton per hour unit according to the feed production method. The value for silage and green feeding transportation is based on the number and capacity of forage harvesters. For haylage it is based in the amount of material obtained from each cut and the available time for harvesting and, finally, for grain it is based on the required capacity of the grain harvesting subsystem.

The transport unit capacity, the number of transport units and the cycle time are used to determine the total capacity of the transportation subsystem. This value is compared to the required transportation capacity and by following a procedure quite similar to the one described in FORHAR, the number and size of transport units are selected. Top limits for wagon and truck capacities are 12 ton and 20 ton respectively.

If wagons are used, the number and power of tractors required for pulling them is determined by using the procedure explained in section 3.4.3.

4.9. Harvesting Silage or Haylage.

Subroutine SILHYL computes the number and size of machines used in silage and haylage. It also calculates the capacity of the blowers in ton per hour unit, when they are used for filling vertical silos, the power of the tractor required by the blower and the power requirement of the implements as well as the number of tractors used for pulling them.

As illustrated in Figure 4.8, after reading all of the input data, the subroutine divides the calculations in two branches, one corresponding to silage and the other to haylage, by using the control index MI (MI = 1 for silage and MI = 2 for haylage).

When silage is the option, then the required capacity of the system is obtained first and it is transferred to FORHAR which proceeds to select the machines used in harvesting, as it was explained in section 4.7.

Subroutine TRAPUN, called by FORHAR, performs the calculation of machines utilized in transportation of chopped material to the silos, as described by section 4.8. If the time allowed for transportation is limited or the amount of material to be transported is too large as to exceed the transportation capacity of the system, the calculation stops and the word "COMMENTS" is printed to indicate this situation.

A different procedure is applied to determine the required system capacity for haylage. Since harvesting is done in several cuts, the rate of harvesting in ton per hour unit is calculated for each cut and the maximum of these figures is selected as the required system capacity for haylage. This is possible by repeating the computation of the tonnage as many times as the number of cuts (NC)

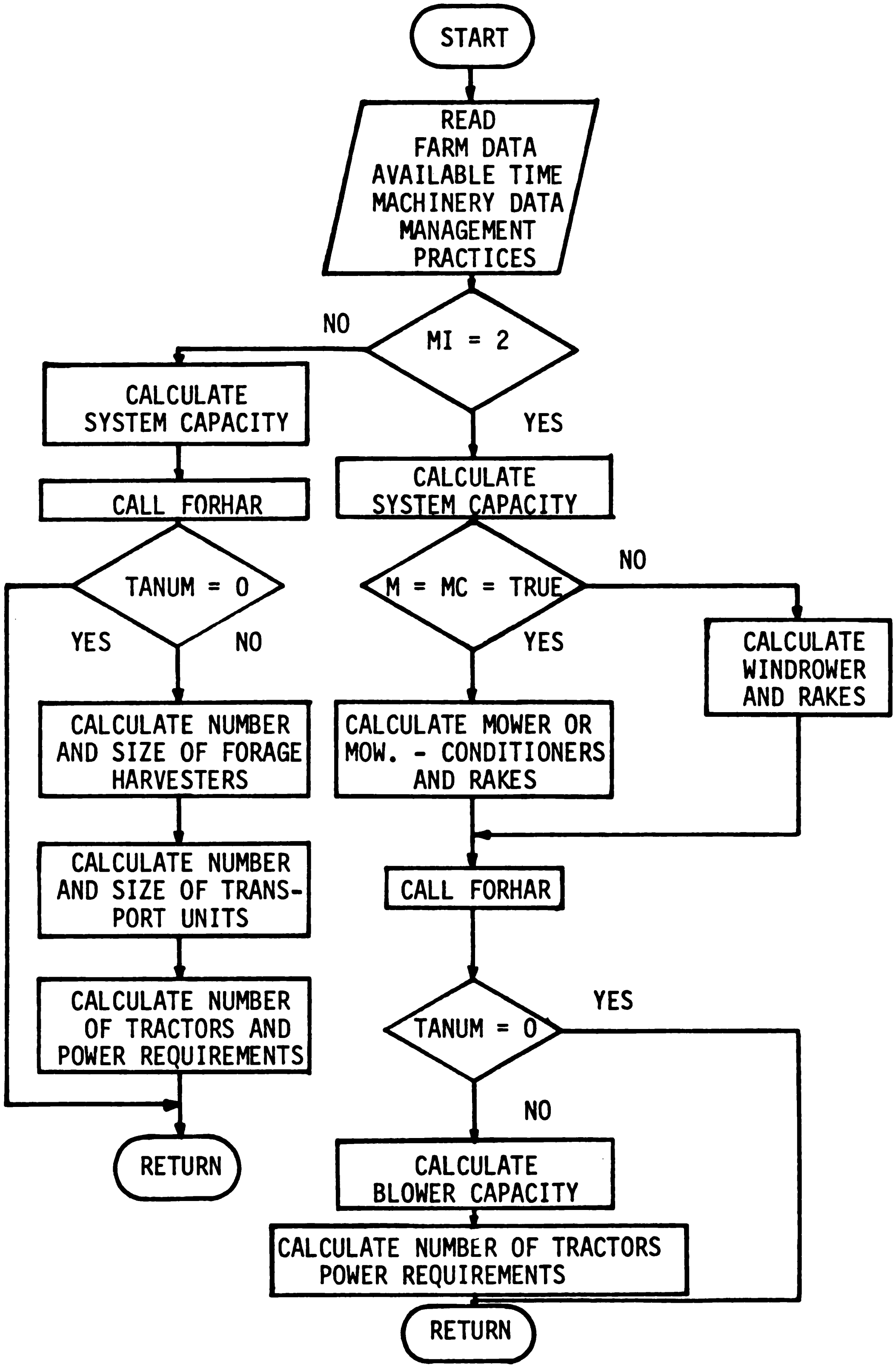


Fig. 4.8 Flow chart for subroutine SILHYL.

and calling subroutine RBC, which will be described later, to calculate the rate of cut in ton per hour.

A management decision has to be made in advance, whether a mower and conditioner or a mower-conditioner or a windrower is going to be used in order to select the proper implement.

Selection of harvesting and transportation machines is the same as with silage but with the addition of calculations for blower capacity, in ton per hour unit, and the power of the tractor required to operate the blower. The number of these units is also computed.

4.10. Hay (Dry) Harvest.

Subroutine HAY calculates the tonnage per cut based on feed requirements, feed losses and the fraction of yield obtained in each cut.

The total amount of cut material is first obtained by:

$$FL = PCL * FR(MI) \quad (4.19)$$

$$SYSCAP = FR(MI) + FL \quad (4.20)$$

where:

FL = total feed losses, t

PCL = fraction of feed losses, decimal

FR = feed requirements, t

MI = index for feed production method

SYSCAP = total cut material, t

The tonnage per cut is calculated by:

$$TONCUT(J) = FRY(J) * SYSCAP \qquad (4.21)$$

where:

TONCUT = tonnage produced at cut J, t

FRY = fraction of crop yield at cut J, decimal

Values of TONCUT are transferred to the subroutines dealing with calculations of machines used in hay production. A flow chart for subroutine HAY is presented in Figure 4.9.

4.11. Conventional Baling.

Subroutine BALING selects the type of balers, bale movers and wagon dryers used in conventional baling. It also finds the size and number of round baler and round-bale movers, and the number of tractors and power requirement for each of those machines.

As shown in Figure 4.10, subroutine BALING takes into account two methods of baling, small rectangular bales and large round bales; two agronomic practices, partial and complete hay field curing; connected with partial field hay curing, two hay drying methods, mowdrying and wagon-drying; two storage practices, bales stacked on open-level ground and bales stacked in barn with bale elevator; and eight transportation alternatives for conventional baling and three for round baling.

Conventional baling, partial field during and

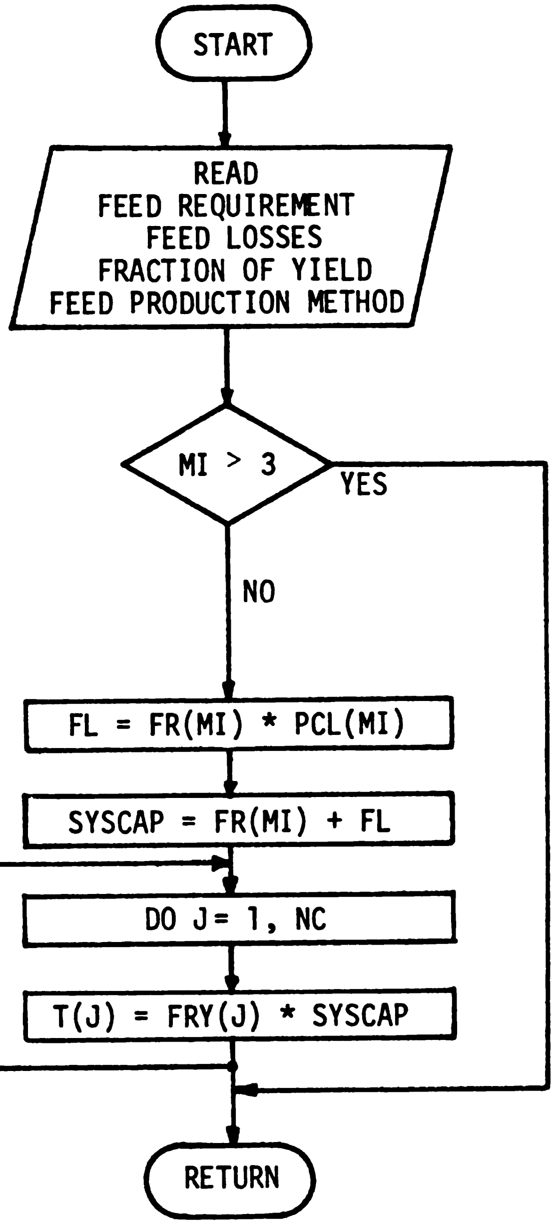


Fig. 4.9 Flow chart for subroutine HAY.

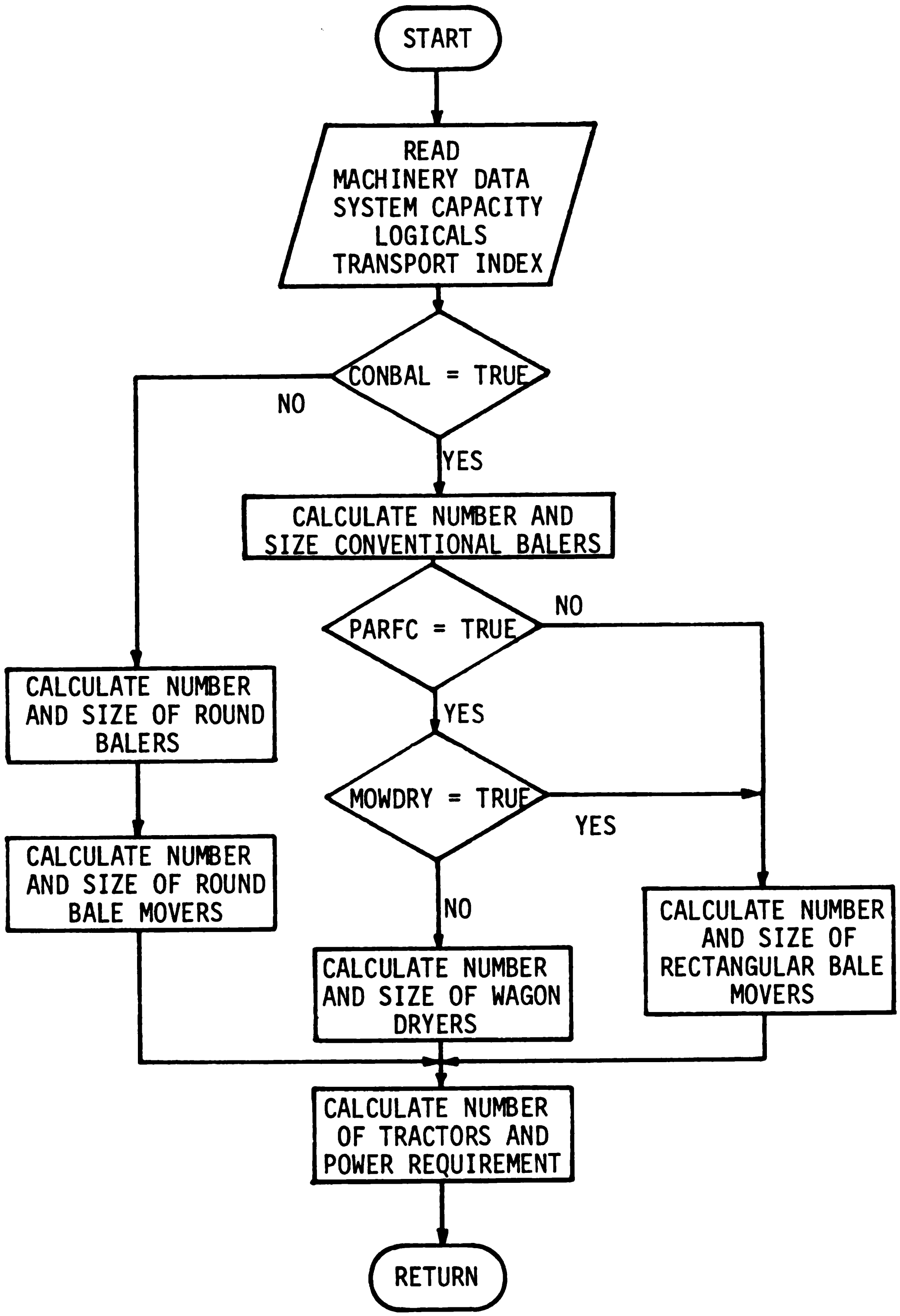


Fig. 4.10 Simplified flow chart for subroutine BALING.

mowdrying are handled by the logical statements CONBAL, PARFC and MOWDRY respectively.

Machines used for transporting bales range from simple flat wagons to automatic self-propelled bale wagons and trucks. The use of one of these machines is controlled by assigning digits from one to eight to the indexes BI and BMTI in a pre-established sequence.

After determining the available time for baling and the required baling capacity, a decision is made with respect to the use of rectangular or round balers. In either case, the number and size of balers are calculated following the general procedure explained in previous sections.

For the selection of the bale movers, the cycle time is individually calculated, since each one has characteristics which cannot be treated in a general way. The number and size of bale movers for rectangular balers and round balers are separately calculated.

There is a section of this subroutine exclusively devoted to the calculation of number and capacity of wagon dryers, based on the baler effective capacity and the rate of drying of the equipment used for that purpose.

The number of tractors and the power used by each of the machines selected in this subroutine are computed following the procedure established in the A.S.A.E. Yearbook (1980).

4.12. Conventional Baling System.

Size and number of machines complement to the conventional baling method are selected by subroutine HAYB1.

A flow chart for this subroutine in Figure 4.11 indicates that after obtaining the required baling capacity, a decision has to be made between the use of mower and conditioners and mower-conditioner. Once the decision is made, the alternative machines are selected in number and size.

Next steps are the computation of the size and number of single rakes and the number and power of tractors utilized in this subsystem, along with the power requirement of each implement selected.

By calling subroutine BALING, the calculation of balers and bale movers completes the selection of machines for the conventional baling method.

Subroutines SILHYL and STACK partially utilize to subroutine HAYB1. Controls are set to limit the extension of this usage and consequently to stop the subroutine operation. For SILHYL, MI = 2 and for STACK, BIC = 0.0 accomplish that prupose.

4.13. Rate of Cut for Implements.

Subroutine RBC was designed to calculate the maximum rate of cut in ton per hour. This subroutine is called at any moment that this value is required, which happens very frequently in subroutines BALING, HAYB1, HAYB2, STACK, CUBE, FORHAR and TRAPUN.

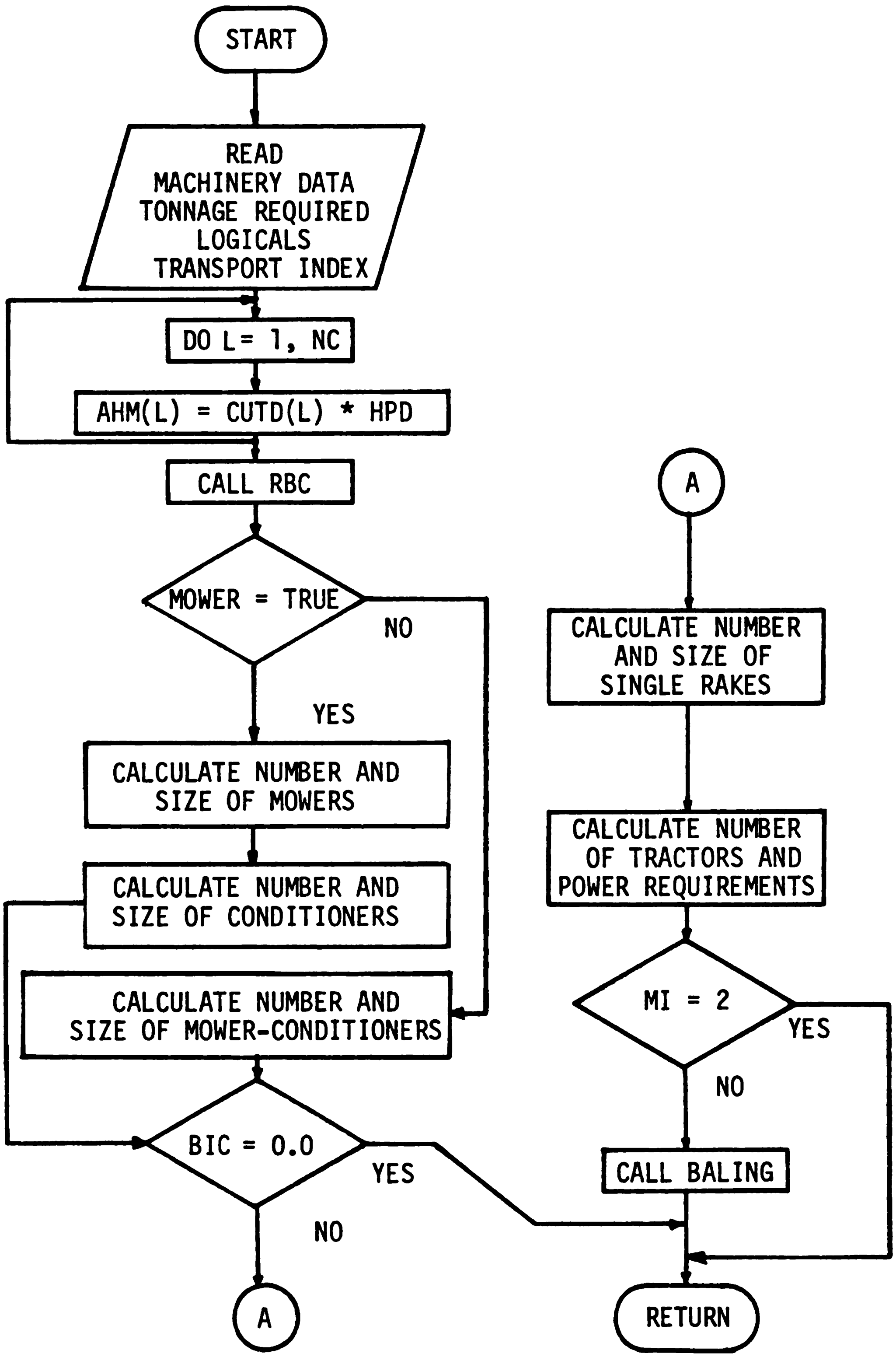


Fig. 4.11 Flow chart for subroutine HAYB1.

A flow chart for subroutine RBC is given in Figure 4.12.

4.14. Round Baler Systems.

Subroutine HAYB2 was prepared to select the machines used in large round baling method, as shown in Figure 4.13.

Windrowers and tandem rakes are calculated in size and numbers by this subroutine, as well as the power required to operate the tractors.

Round bales and round-bale movers are selected by subroutine BALING in the way explained in section 4.11.

Indexes are assigned to control the usage of subroutine HAYB2 for other subroutines. So, MI = 2 for SILHYL and BIC = 0.0 for STACK and CUBE stops the operation of HAYB2.

4.15. Stack Systems.

Size and number of stackers, stack movers and their power requirements are computed and selected by subroutine STACK.

Information concerning machine capacity, size, weight, working speed, and tractive efficiency is furnished to this subroutine along with data related to the type of crop, crop yield and fraction of crop yield in each cut.

In this case, the parameter set for the selection of stacker is its effective field capacity (EFC), which is compared to the effective field capacity required by the stacking system (EFCS).

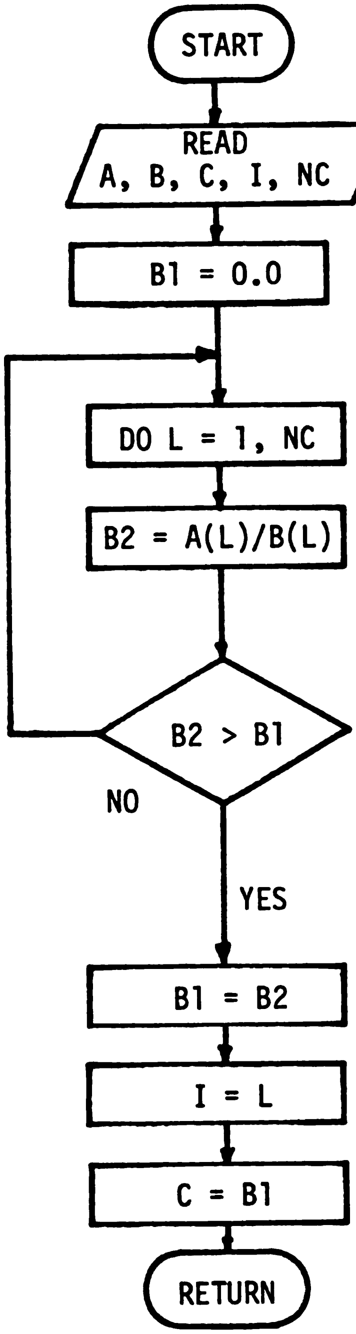


Fig. 4.12 Flow chart for subroutine RBC.

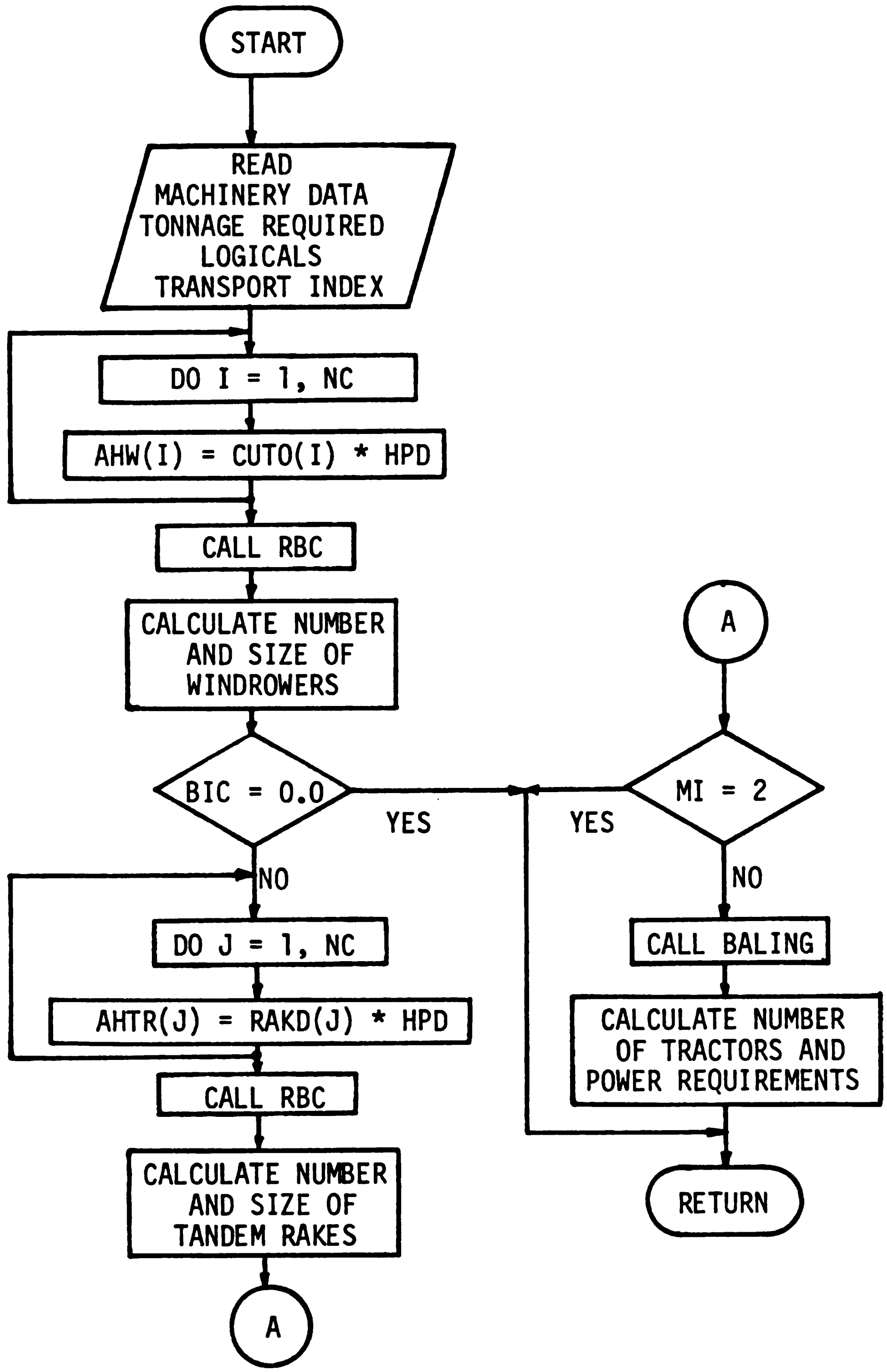


Fig. 4.13 Flow chart for subroutine HAYB2.

Values of stacker field capacity in hectare per hour are kept in one to one correspondence to the stacker size in ton, so that the stacker size is indirectly selected at the moment that the effective field capacity of the stacker under consideration be greater or equal to the effective field capacity required by the system.

In order to keep a reasonable size-capacity relationship, mower-conditioners are selected when the calculated stacker size does not exceed 0.907 t (1 ton), but when the stacker size is larger than that figure, then windrowers are selected because their large capacity are a better match to medium and big stacker size. The index I = 1 is set to control the alternative of using HAYB1 for calculation of mower-conditioners and HAYB2 for calculation of windrowers.

A section of this subroutine selects the number and size of stack movers used only in farms. No highway-type stack mover is considered. The size of stack mover is obtained by a procedure similar to the one used to determine the stacker size, that is, the correspondence one to one between the stack mover capacity in ton per hour and the stack mover size in ton.

The last section calculates the number of tractors and the power required by the stack wagon and stack mover.

A flow chart of subroutine STACK is presented in Figure 4.14.

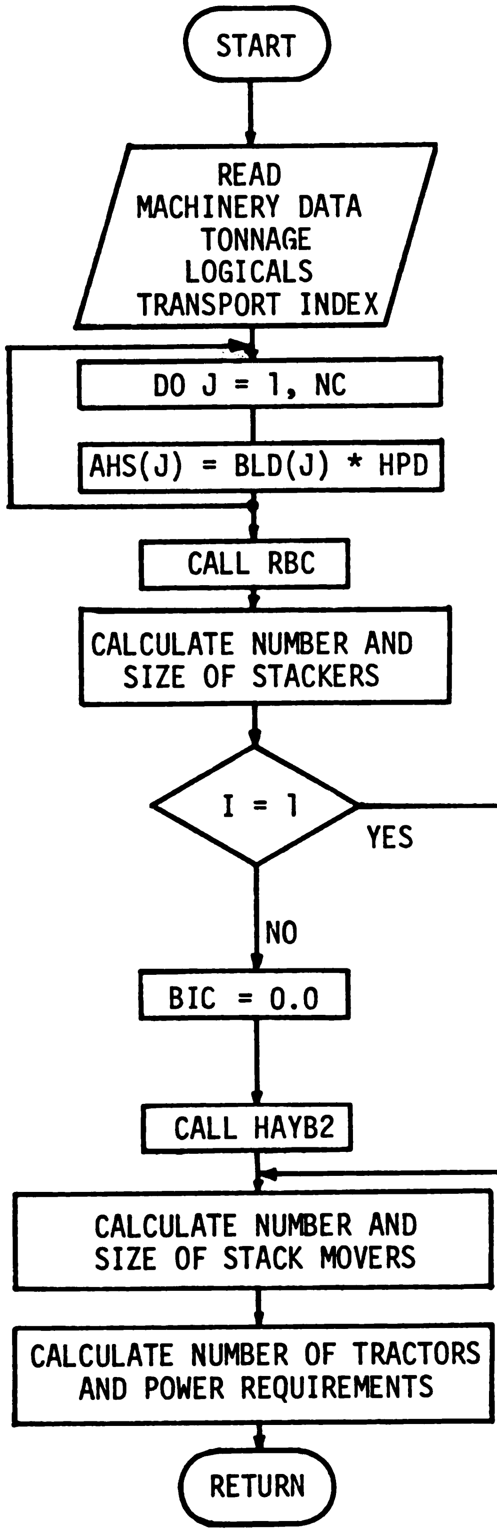


Fig. 4.14 Flow chart for subroutine STACK.

4.16. Cuber Systems.

Subroutine CUBE selects the size and number of machines used in hay-cubing systems.

As it is shown in Figure 4.15, subroutine HAYB2 is called to select the number and size of windrowers. The selection of this machine is done because its capacity matches the requirement of a high volume operation such as cubing.

As usual the required cubing capacity is calculated from the available time and the maximum rate of cut as determined by subroutine RBC.

Comparison between the calculated field capacity (EF) and the cuber field capacity (EFC) allows the selection of field cuber number and size.

A high-dump wagon is selected by matching its number and capacity to the number and size of field cuber respectively.

The cycle time for cube hauling by trucks is computed by adding the travel time, the loading time and the unloading time. The time for dumping a load is a variable in the calculation of the loading time.

The required truck capacity is calculated by using:

$$TRC = 60. * TC * TRN/CYT \quad (4.22)$$

where:

TRC = total truck transportation capacity, t/h

TC = truck size, t

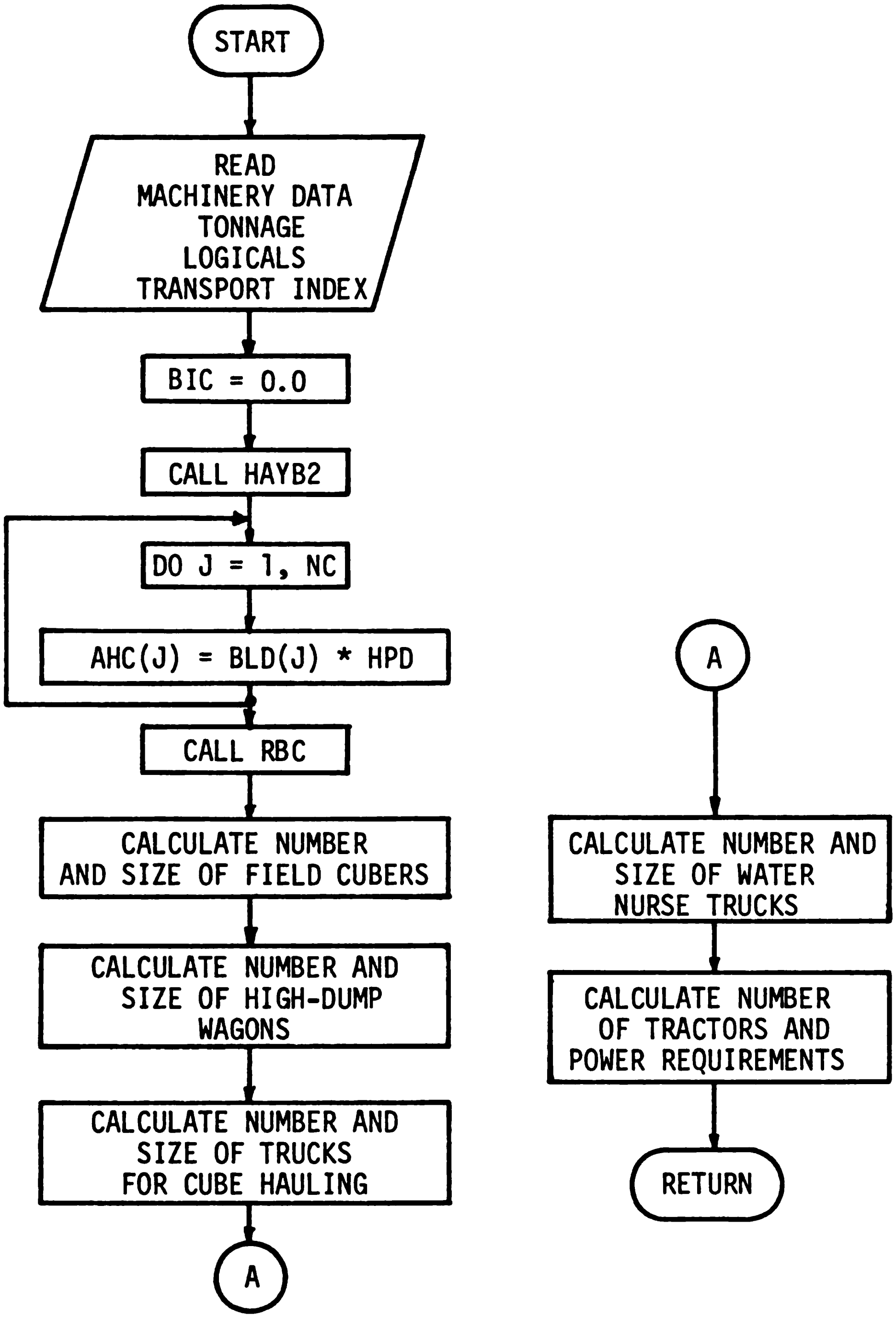


Fig. 4.15 Simplified flow chart for subroutine CUBE.

TRN = number of trucks

CYT = cycle time, min.

60. = dimensionality constant

Successive comparison of this value to the required cubing capacity (RPH) yields the size and number of trucks at the moment that

TRC . GE . RPH

Water nurse trucks are required to carry the water used in field cubing operations. The number and size of trucks used for this purpose are calculated from the requirement of water per ton of hay and the total tonnage of hay per day. So,

$$FCMC = EF * CY * FRY(J) \qquad (4.23)$$

$$THPD = FCME * HPD \qquad (4.24)$$

$$TRCP = 85.851 * THPD/1000 \qquad (4.25)$$

where:

FCMC = field cuber material capacity, t/h

EF = total field cuber capacity, ha/h

CY = crop yield, t/ha

FRY = fraction of crop yield in cut J, decimal

THPD = tonnage of hay per day, t

HPD = working hours per day, h

1000 = dimensionality constant

85.851 = kg of water per ton of hay

TRCP = truck size, t

4.17. Grain Harvest.

Subroutine GRAIN calculates the number and size of machines used in the production of low moisture and high moisture grain.

Once the required grain production capacity is calculated, the flow chart in Figure 4.16 indicates that a management decision is required, that is, if the grain is going to be shelled or not. This decision is excuted by the logical statement SHC (shelled corn). Immediately after, another decision is called for: use of self-propelled combine or picker-sheller, if shelled grain is going to be produced. The logical statement that directs the control of this decision is SPCO (self-propelled combine).

According to the alternative selected, either self-propelled combines or picker-shellers are selected in number, capacity, number of rows and row width. If the decision is the production of corn ears, then the same parameters are computed for the picker.

Subroutine TRAPUN is called to take care of the selection of transport units required by the grain systems. Either wagons or trucks may be selected by using the logical statement WAGON.

The size of the blower in ton per hour and the power of the tractor to operate the blower to fill the silo are determined according to total capacity of the harvesting

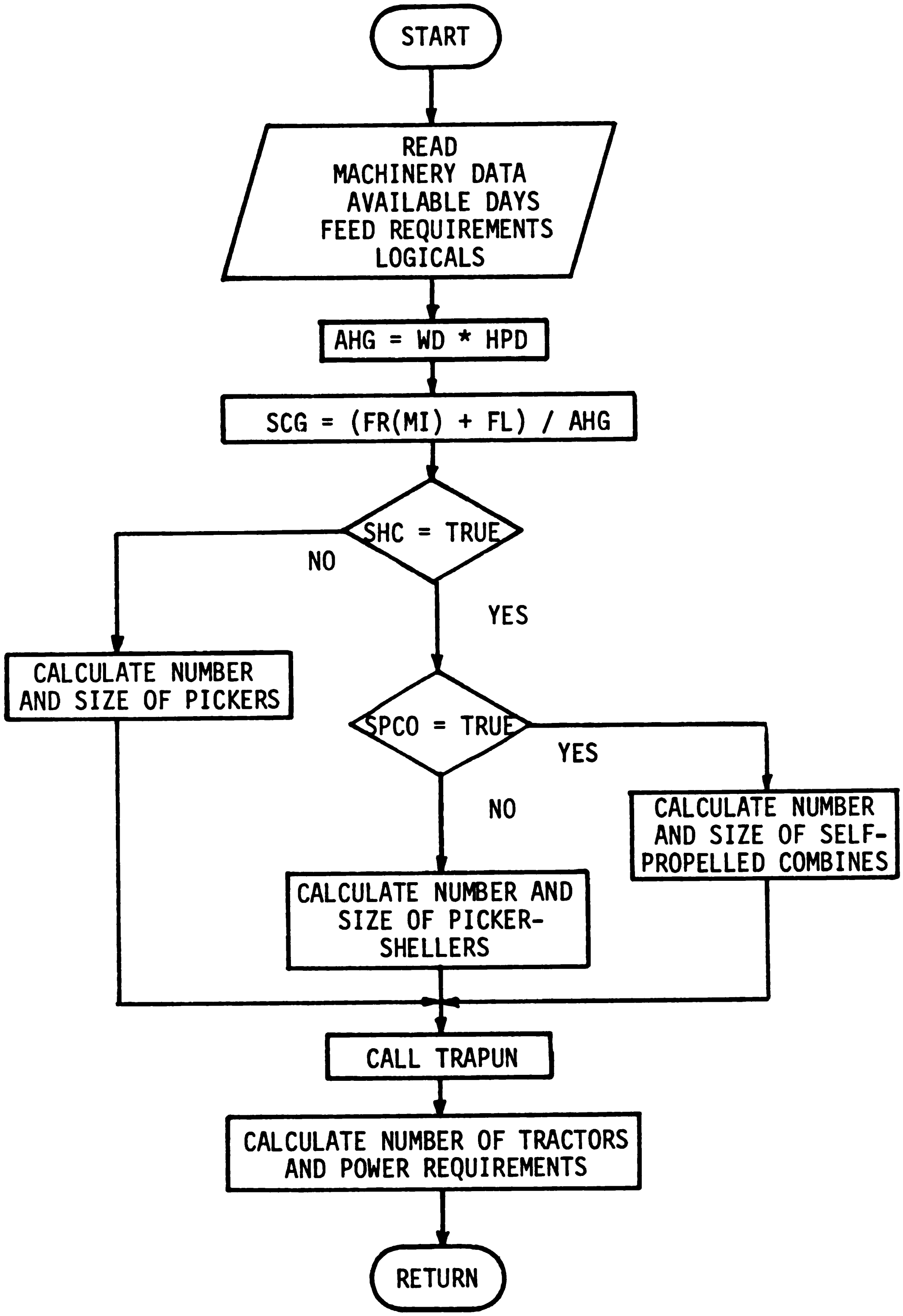


Fig. 4.16 Flow chart for subroutine GRAIN.

machines and the type of material (low or high moisture grain, ground or complete material).

In order to cope with any peak condition, the capacity of the blower is increased by 10%. At the same time, to guarantee enough power in the tractor used for the blower, a provision is taken so that the tractor power is never less than that required by the silo height.

The last section of the subroutine calculates the power requirements and the tractors used with pull type implements.

CHAPTER 5

VALIDATION OF MODEL, ANALYSIS AND RESULTS

5.1. Model Validation.

One important step in modeling is to verify that the model is an acceptable representation of the actual system under study, which is referred to as model validation.

Traditionally, model validation is conceived as a two-stage process. First, the verification of the program and its components subdivisions (subroutines) to make sure that each one worked the way it was intended to do and second, the comparison of program results with actual data.

5.1.1. Verification of Program and Subroutines.

The verification procedure consisted of detection and diagnosis of errors in sintaxis and program logic, successive runs and testing of subroutines, examination of the output produced and correction of the anomalies detected.

This procedure was followed with each one of the subroutines before their final assembling and in order to accomplish that, the initial version of subroutines were designed to simulate the actual work of the final version by using input data obtained from the literature reviewed and actual farm data. The method proved to be very useful in understanding the behavior of each component of the feed harvesting system model. This facilitated its construction since better and more logical relationships could be established among the model components.

Subroutines GF (green feeding) and SILHYL (silage and haylage) were tested by varying three parameters simultaneously: tonnage cut per year, values ranged from 116 to 2320 tons per year, number of working days from one to eighteen and number of working hours per day, from one to eight.

An output sample for subroutine GF is presented in Table 5.1, corresponding to 464 tons per year and 5 working hours per day. There it can be observed how the number and capacity of forage harvesters and wagons are affected by the available time. Also, the excess of harvesting capacity and transportation capacity, given in percentages, were used as a check for calculation of those parameters.

Excess of harvesting capacity ranged from 0.02% to 25.5%. It is convenient to point out that the upper range limit appeared only once in the complete test, and that the most common values ranged from 0.8% to 5.9%.

Excess of transportation capacity ranged from 0.03% to 11.2%. No concentration of values at any particular range was observed.

Table 5.1. Output sample, test of subroutine GF.

Working Days	Number Forage Harvesters	Forage Harvester Capacity(t/h)	Excess Harvesting Capacity (%)	Number Transport Units	Transport Unit Capacity(t)	Excess Transport Capacity(%)
1	3	48.0	.86	7	12.0	2.04
2	2	36.0	.86	5	10.0	6.02
3	1	48.0	.86	3	8.0	2.38
4	1	36.0	.86	3	6.0	2.38
5	1	29.0	1.56	3	5.0	4.08
6	1	24.0	.86	2	12.0	1.18
7	1	20.5	.51	2	10.0	.57
8	1	18.0	.86	2	10.0	3.68
9	1	16.0	.86	2	8.0	1.18
10	1	14.5	1.56	2	7.0	.31
11	1	13.0	.16	2	7.0	2.95
12	1	12.0	.86	2	6.0	1.18
13	1	11.0	.16	2	6.0	3.25
14	1	10.5	2.96	2	6.0	4.32
15	1	10.0	5.06	2	5.0	1.18
16	1	9.0	.86	2	5.0	3.68
17	1	8.5	1.21	2	5.0	4.97
18	1	8.0	.86	2	4.0	1.18

tonnage cut per year = 464 t
working hours per day = 5 h
transport unit average travel distance = 3 km
transport unit average speed = 10 km/h

Table 5.2. Output sample, test of subroutine SILHYL (Horizontal silo).

Working Days	Number Forage Harvesters	Forage Harvester Capacity(t/h)	Excess Harvesting Capacity(%)	Number Transport Units	Transport Unit Capacity(t)	Excess Transport Capacity(%)
1	2	59.5	.02	6	10.0	2.80
2	1	59.5	.02	3	10.0	2.80
3	1	40.0	.86	3	7.0	4.82
4	1	30.0	.86	3	5.0	2.38
5	1	24.0	.86	2	12.0	1.18
6	1	20.0	.86	2	10.0	1.18
7	1	17.0	.02	2	10.0	4.97
8	1	15.0	.86	2	8.0	2.72
9	1	13.5	2.12	2	7.0	2.05
10	1	12.0	.86	2	6.0	1.18
11	1	11.0	1.70	2	6.0	3.25
12	1	10.0	.86	2	5.0	1.18
13	1	9.5	3.80	2	5.0	2.41
14	1	8.5	.02	2	5.0	4.97
15	1	8.0	.86	2	4.0	1.18
16	1	7.5	.86	2	4.0	2.72
17	1	7.0	.02	2	4.0	4.32
18	1	7.0	5.90	2	4.0	4.32

tonnage cut per year = 464 t
working hours per day = 6 h
transport unit average travel distance = 3 km
transport unit average speed = 10 km/h

Table 5.3. Output Sample, Test of Subroutine SILHYL (vertical silo).

Working Days	Number Forage Harvesters	Forage Harvester Capacity (t/h)	Excess Harvesting Capacity (%)	Number Transport Unit	Transport Unit Capacity (t)	Excess Transport Capacity (%)	Blower Capacity (kW)	Blower Tractor Power (kW)
1	1	51.0	.02	6	10.0	10.47	72.93	90.65
2	1	51.0	.02	3	10.0	10.47	72.93	90.65
3	1	34.0	.02	3	6.0	5.24	48.62	60.43
4	1	25.5	.02	3	5.0	10.47	36.46	45.32
5	1	20.5	.51	2	10.0	.57	29.31	36.43
6	1	17.0	.02	2	10.0	4.97	24.31	30.21
7	1	15.0	2.96	2	8.0	2.72	21.45	26.66
8	1	13.0	1.98	2	7.0	2.95	18.59	23.10
9	1	11.5	1.49	2	6.0	2.20	16.44	20.44
10	1	10.5	2.96	2	6.0	4.32	15.01	18.66
11	1	9.5	2.47	2	5.0	2.41	13.58	16.88
12	1	8.5	.02	2	5.0	4.97	12.15	15.10
13.	1	8.0	1.98	2	4.0	1.18	11.44	14.22
14.	1	7.5	2.96	2	4.0	2.72	10.72	13.33
15	1	7.0	2.96	2	4.0	4.32	10.01	12.44
16	1	6.5	1.98	2	4.0	5.97	9.29	11.55
17	1	6.0	.02	2	3.0	1.18	8.58	10.66
18	1	6.0	5.90	2	3.0	1.18	8.58	10.66

Tonnage cut per year = 464 t
Working hours per day = 7 h
Transport unit average travel distance = 3 km
Transport unit average speed = 10 km/h

Lines for one and two working days in Tables 5.1 and 5.2 reflect one of the characteristics of this model, that is, the purpose to cope with the cutting requirements using the least number of forage harvesters by increasing the machine capacity if available time allows it.

Output samples for subroutine SILHYL are given in Tables 5.2 (horizontal silo) and 5.3 (vertical silo), corresponding to six and seven working hours per day respectively, and the same tonnage, 464 tons per year, for both. For vertical silos there is extra information on blower capacity and the tractor power for blowing operation.

Observations of values for blower capacity and for tractor power conducted to the establishment of provisions, as cited somewhere before, to avoid bottlenecks at the blower and make sure that tractor power matches the power required in relation to silo height.

Observations of components of cycle time for transport units, particularly the loading time and its effect on forage harvester efficiency led to the setting of the transport unit number at a minimum of two. This provision guarantees the forage harvester work with an efficiency close to the maximum that can be achieved with this machine by reducing the time waiting for the transport units. This is shown in Tables 5.1, 5.2 and 5.3, where the number of transport units remains equal to two even though the available time becomes greater. The model response is to reduce the individual capacity of the transport units to keep pace with the required transportation capacity.

Subroutine Baling was tested using six methods of transportation for conventional baling and two for round baling. These included two baling procedures: conventional and round baling, two agronomic practices: partial and complete hay field curing, and mow-drying or wagon drying when partial hay field curing was used. Results given in Table 5.4 correspond to a system capacity of 280 tons per year, to an available time of 66 effective working hours for baling and four cuts per season.

Observations on these results led to adjust the maximum capacity of the conventional baler to 10 tons per hour, and for the round baler to 14 tons per hour, to keep calculations of this parameter inside the limits of actual machine capacity as reported by manufacturers and the literature reviewed. Also, calculation of wagon dryers number and size were isolated from the other transportation units, since this proved to be more appropriate due to the characteristics of wagon-drying operations are quite different of those of other bale transport units.

When using conventional a baler with a trailing wagon, it was necessary to separate calculation of trailing wagon taking into consideration if the baler was furnished with bale ejector or bale chute. So, the capacity of trailing

Table 5.4. Test of subroutine BALING.

Machine	Number	Capacity	Units
round baler	1	3.0	t/h
round multi-bale mover	1	5.0	bales
round one-bale mover	2	1.0	bales
conventional baler	1	2.5	t/h
trailing wagon	1	12.0	t
flat wagon w/bale loader	2	2.0	t
self-propelled bale handler	1	12.0	t
automatic bale wagon, pull type	1	6.0	t
automatic bale wagon, SP	1	6.0	t
trucks w/bale loader	1	12.0	t
wagon dryers	2	1.0	t

tonnage cut per year = 280 t
number of cuts = 4
available baling time = 66 h
transport average distance = 3 km
transport average speed = 10 km/h

wagon equipped with bale ejector was considered reduced by 10 percent due to the bale ejector random stacking pattern. Similar consideration was applied to the loading time when the transport cycle time for this unit was computed.

For conventional baling (HAYB1) two options were tested, the use of a mower and conditioner or mower-conditioner. The transport unit selected was a flat wagon with bale loader. For a hay production of 702 tons per year, four cuts per season and an available time for baling of 66 effective working hours, the results are presented in Table 5.5.

Under the same conditions as above, subroutines HAYB2, STACK and CUBE were tested and the output presented in Table 5.6 corresponds, in the same order, to round baling, stacking and cubing as the hay production methods.

Analysis of results of these tests determined the need for correction of a formula used for calculation of field capacity taking into account the fraction of yield obtained in each cut. Thus, the corrected formula is:

$$EFC = RTPH / [CY (K) * FRY (J)] \qquad (5.1)$$

where:

EFC = effective field capacity, ha/h

RTPH = required material capacity, t/h

CY = crop yield, t/ha

Table 5.5. Test of subroutine HAYB1.

Machine	Number	Size	Units
Using mower			
conventional baler	1	7.00	t/h
mower	1	2.44	m
single rake	1	2.74	m
flat wagon w/bale loader	2	7.00	t
Not using mower			
conventional baler	1	7.00	t/h
mower-conditioner	1	3.66	m
single rake	1	2.74	m
flat wagon w/bale loader	2	7.00	t

tonnage cut per year = 702 t
available baling time = 66 h
number of cuts = 4
transport unit average travel distance = 3 km
transport unit average speed = 10 km/h

Table 5.6. Test of subroutines HAYB2, STACK and CUBE.

Machine	Number	Size	Units
Round baling			
windrower	1	2.13	m
tandem rake	1	3.66	m
round baler	1	7.00	t/h
flat wagon w/bale loader	2	7.00	t
Stacking			
stacker	1	0.90	t
mower-conditioner	1	3.66	m
stack mover	1	2.72	t
Cubing			
windrower	1	2.13	m
field cuber	1	1.62	ha/h
high-dump wagon	1	4.26	t
cube hauling truck	1	2.0	t
water nursing truck	1	2.2	t

tonnage cut per year = 702 t
available baling time = 66 h
number of cuts = 4
transport unit average travel distance = 3 km
transport unit average speed = 10 km/h

FRY = fraction of yield in cut J

K = crop index

Also, the calculation of rolling resistance force (RRF) in trailing machines was corrected by adding the weight of material carried to the machine weight, wherever this situation was found. In general, the corrected formula is:

$$RRF = (WCM + WM) * CR(IS) * ACC / 1000. \quad (5.2)$$

where:

RRF = rolling resistance force, KN

WCM = weight of carried material, kg

WM = machine weight, kg

CR = rolling resistance coefficient

IS = rolling resistance coefficient index

ACC = acceleration of gravity, $m \cdot s^{-2}$

1000 = dimensionality constant.

Grain production subroutine (GRAIN) was tested using management practices such as production of shelled corn or ear corn, use of a combine or picker sheller when the option was shelled corn, and two transportation units wagons and trucks. Results given in Table 5.7 correspond to the production of shelled corn, harvesting with picker-sheller and wagons as transport units. Grain production is 330 tons per year (12990 bu/yr) and the available time for harvesting is 66 effective working hours.

Table 5.7. Test of subroutine GRAIN.

Machine	Number	Size	Units
picker-sheller	2	3.17	t/h
row width		1.02	m
number of rows	2		
power requirement		32.38	kW
picker-sheller tractors	2	40.47	kW
wagons	3	3.0	t
wagon tractors	3	11.75	kW (1)
blower	1	6.97	t/h
blower tractor	1	44.05	kW

tonnage harvested per year = 330 t
available harvesting time = 66 h
transport average distance = 3 km
transport average speed = 10 km/h
silo height = 18 m

(1) power used to pull the wagon

5.1.2. Dairy Farm Survey

A dairy farm survey was conducted to obtain the production records of 40 dairy farms selected at random among those participating at Telfarm, a computarized accounting project offerred by the Cooperative Extension Service at Michigan State University.

The objective of this survey was to get information about the size of the farms expressed in number of dairy cows and the feed disappearance, and the surface cropland distribution. Ten farms were selected from each one of the following groups: less than 50 dairy cows, 50 to 75 dairy cows, 76 to 100 dairy cows and more than 100 dairy cows.

A brief analysis of the survey data showed that the different methods of feed production were reported by the farmers in the following percentages: silage 87.5%, hay and haylage 100.0%, grain 100.0% and pasture 50.0%. Other cash crop production was reported by 75.0% of the farmers.

The average number of dairy cows and surface of cropland produced in each group are given in Table 5.8. All of the dairy farms reported rented land to produce at least one crop used to feed animals. The total tillable land is presented as owned, rented and a combined total for both. Hay and haylage production is given as a whole figure under the designation of hay equivalent.

Table 5.8. Average Number of Dairy Cows and Surface of Cropland Produced.

	Farm Size by Number of Cows							
	Less than 50		50 - 75		76 - 100		More than 100	
	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented
Number of dairy cows	43.5		66.7		88.2		144.7	
Hectares per farm								
Total tillable land	59.9	28.2	92.1	48.4	102.0	45.5	165.3	100.8
Combined total	88.1		140.5		147.5		266.1	
Surface cropland produced								
corn silage	8.3	4.3	17.1	3.4	11.1	1.9	33.9	13.7
corn grain	17.2	15.4	29.4	27.6	33.4	25.4	55.8	45.3
hay equivalent	21.7	3.2	30.8	7.8	39.9	9.4	40.6	27.5
pasture	2.7	0.0	3.1	0.0	3.9	0.7	7.4	8.6
oatlage	0.0	0.0	0.0	0.0	1.6	0.0	0.7	0.0
wheat	5.1	1.5	5.5	3.9	2.9	1.1	6.2	2.9
oats	2.9	0.3	3.7	0.8	7.0	1.8	3.8	0.0
other cash crops	0.6	2.2	1.6	4.2	0.5	4.3	9.7	2.8
diverted and idle	1.4	1.3	0.9	0.7	1.7	0.9	7.2	0.0

The average surface of cropland per cow devoted to feed production is presented in Table 5.9. There it can be observed that the combined total for forage and hay is 0.76 ha/cow for the group of 76-100 cows and about 0.9 ha/cow for the other groups. The average for all groups is 0.88 ha/cow. The combined total for grain is 0.7 ha/cow for the groups of 76-100 cows and more than 400 cows, 0.82 ha/cow for the group of less than 50 cows and 0.92 ha/cow for the group of 50-75 cows. The average for all groups is 0.81 ha/cow.

Feed disappearance was calculated based on farmer's estimates of feed production, sales, purchases, and beginning and ending inventories, as reported to Telfarm:

$$FD = BI + PR + PUR - EI - SAL \qquad (5.3)$$

where:

FD = feed disappearance, t

BI = beginning inventory, t

PR = production, t

PUR = feed purchase, t

EI = ending inventory, t

SAL = sales, t

Reported information and calculated feed disappearance for each one of the farm groups are given in Tables 5.10, 5.11, 5.12 and 5.13. The survey form is presented in Appendix C.

Table 5.9. Average Surface of Cropland per Cow, ha/cow.

	Farm Size by Number of Cows							
	Less than 50		50 - 75		76 - 100		More than 100	
	Owned	Rented	Owned	Rented	Owned	Rented	Owned	Rented
Corn silage	0.19	0.09	0.26	0.05	0.13	0.02	0.24	0.09
Hay equivalent	0.49	0.07	0.46	0.12	0.45	0.11	0.28	0.19
Pasture	0.06	0.00	0.05	0.00	0.04	0.007	0.05	0.06
Total forage and hay	0.74	0.16	0.77	0.17	0.62	0.14	0.57	0.34
Combined total	0.90		0.94		0.76		0.91	
Corn grain	0.39	0.35	0.44	0.41	0.38	0.29	0.39	0.31
Oats	0.07	0.01	0.06	0.01	0.08	0.02	0.03	0.00
Total grain	0.46	0.36	0.50	0.42	0.46	0.31	0.42	0.31
Combined total	0.82		0.92		0.77		0.73	

Table 5.10. Average feed disappearance in farms with less than 50 cows, t.

	Beginning Inventory	Production	Sales	Ending Inventory	Feed Purchased	Feed Disappearance
corn silage	329.6	369.9	0.0	290.3	0.0	409.2
hay equivalent	110.9	214.9	45.0	302.1	41.6	107.5
pasture	0.0	11.7	0.0	0.0	0.0	11.7
oatlage	0.0	0.0	0.0	0.0	0.0	0.0
corn grain	85.4	173.9	41.3	147.1	7.6	78.5
oats	5.9	15.4	0.4	8.4	3.4	15.9

Table 5.11. Average feed disappearance in farms with 50 - 75 cows, t.

	Beginning Inventory	Production	Sales	Ending Inventory	Feed Purchased	Feed Disappearance
corn silage	602.6	707.9	0.0	613.4	0.0	697.1
hay equivalent	170.0	416.7	0.0	260.0	0.7	327.4
pasture	0.0	9.4	0.0	0.0	0.0	9.4
oatlage	0.0	0.0	0.0	0.0	0.0	0.0
corn grain	166.4	351.0	58.2	216.1	5.7	248.8
oats	10.1	11.9	1.6	6.0	1.2	15.6

Table 5.12. Average feed disappearance in farms with 76 - 100 cows, t.

	Beginning Inventory	Production	Sales	Ending Inventory	Feed Purchased	Feed Disappearance
corn silage	463.8	431.5	0.0	331.0	0.0	564.3
hay equivalent	270.2	533.9	4.2	488.9	10.8	321.8
pasture	0.0	28.5	0.0	0.0	0.0	28.5
oatlage	8.4	24.3	0.0	14.9	0.0	17.8
corn grain	234.9	372.8	53.2	298.5	11.4	267.4
oats	12.2	20.4	0.5	14.3	0.5	18.3

Table 5.13. Average feed disappearance in farms with more than 100 cows, t.

	Beginning Inventory	Production	Sales	Ending Inventory	Feed Purchased	Feed Disappearance
corn silage	1226.7	1765.6	0.0	1458.2	77.1	1611.2
hay equivalent	365.0	724.4	0.0	418.7	0.0	670.7
pasture	0.0	36.3	0.0	0.0	0.0	36.3
oatlage	0.0	5.4	0.0	0.0	0.0	5.4
corn grain	303.6	648.5	95.0	530.5	2.5	329.1
oats	0.8	10.9	0.0	5.3	0.8	7.2

5.1.3. Field Machinery Survey.

In order to get information on farm machinery specifically used in feed production, a survey was conducted among the same farms selected in the dairy farm survey, but only sixteen farmers answered it.

Percent of dairy farmers reporting use of specialized equipment for feed production is given in Table 5.14. It is observed that the use of forage choppers, forage wagons and rakes was reported by all of the farmers. Mower-conditioners by 81.2% against 18.2% for mowers. Conventional baling was used in a proportion of 2 to 1 with respect to round baling. Self propelled combines were used by 81.0% of the farmers in comparison to 43.7% for corn pickers and 12.5% for corn picker-shellers. Three of them reported the use of combine and picker simultaneously.

None reported the use of hay stacker, stack mover or hay conditioners. The use of blowers and bale elevators was indicated by 93.7% and 68.7% of the farmers respectively. Wagons were the most common machine used for material transportation. The survey form is given in Appendix D.

5.1.4. Comparison of Four Field Machinery Surveys to Model Output.

The number of returned field machinery surveys was lower than expected, and incomplete information on machinery size and number was furnished on the surveys that were received. For these reasons, the idea of an all survey

Table 5.14. Percent of dairy farmers reporting use of specialized equipment for feed production.

Machine	%
forage chopper	100.0
forage wagon	100.0
flat wagon	75.0
truck	56.2
mower	18.7
hay conditioner	0.0
mower-conditioner	81.2
windrower	18.7
rakes	100.0
conventional baler	68.7
round baler	31.2
bale wagon	50.0
round bale mover	25.0
high-dump wagon	12.5
grain wagon	75.0
combine	81.0
corn picker	43.7
corn picker-sheller	12.5
hay stacker	0.0
stack mover	0.0
blower	93.7
bale elevator	68.7

testing was dropped and, instead of that, one survey was sampled at random from each dairy farm size group, the relevant information supplied to the feed harvesting model and its output compared to the information given by the farmer.

Results from this comparison are not to be considered as a complete validation of the model due to the reduced number of samples, but rather to show the model ability to handle actual data and the possibility of a full validation based on an acceptable sample size.

Model output and data from a farm with less than 50 cows are presented in Table 5.15. Results in this table show a good agreement with respect the number of machines reported and the one calculated by the model. With respect to the size, the values calculated by the model were below the reported sizes. This is so because the model calculates the minimum size that guarantees the completion of operation in the available time. An incompatability exists between the size unit the forage chopper was reported and that given by the model, perhaps due to the fact that the survey was not clear enough requesting this particular information. No information was reported on size of conventional baler, bale wagon and grain blower.

Data from a farm with 50-75 cows are in Table 5.16. Exception made of single rake, bale wagon and grain wagon,

Table 5.15. Field machinery survey and model output data. One farm with less than 50 cows.

Machine	Survey Data Number	Survey Data Size	Survey Data Units	Model Output Number	Model Output Size	Model Output Units
forage chopper	1	2.0	rows	1	14.0	t/h
forage wagon	2	4.0	t	2	4.0	t
forage chopper tractor	1	58.3	kW	1	41.7	kW
mower-conditioner	1	2.74	m	1	2.14	m
single rake	1	2.74	m	1	2.14	m
conventional baler	1	-		1	3.5	t/h
bale wagon	3	-		2	1.0	t
combine	1	3.0	rows	1	2.0	rows
grain wagon	2	2.0	t	2	2.0	t
grain blower	1	-		1	7.0	t/h

Tonnage produced per year:
silage = 585.0 t
hay equivalent = 327.6 t
grain = 195.6 t

Time distribution:
forage harvesting = 66 h
forage hauling = 66 h
mow-conditioning = 24 h
raking = 24 h
baling = 66 h
bale hauling = 66 h
grain harvesting = 66 h
grain hauling = 66 h
filling silos = 66 h

Table 5.16. Field machinery survey and model output data. One farm 50 - 75 cows.

Machine	Survey Data Number	Survey Data Size	Survey Data Units	Model Output Number	Model Output Size	Model Output Units
forage chopper	1	2.0	rows	1	29.5	t/h
forage wagon	2	8.0	t	2	8.0	t
forage chopper tractor	1	97.6	kW	1	85.8	kW
mower-conditioner	1	2.74	m	1	3.66	m
single rake	1	2.44	m	2	2.14	m
conventional baler	1	4.5	t/h	1	6.5	t/h
bale wagon	3	3.75	t	2	2.0	t
picker-sheller	1	2.0	rows	1	3.0	rows
grain wagons	4	3.75	t	2	3.0	t
grain blower	1	-		1	10.5	t/h

Tonnage produced per year:

- silage = 1263.6 t
- hay equivalent = 663.4 t
- grain = 295.0 t

Time distribution:

- forage harvesting = 66 h
- forage hauling = 66 h
- mow-conditioning = 24 h
- raking = 24 h
- baling = 66 h
- bale hauling = 66 h
- grain harvesting = 66 h
- grain hauling = 66 h
- filling silos = 66 h

the number of reported machines agrees with the number calculated by the model. Machine sizes were below the reported sizes with the exceptions of mower-conditioner and picker-shellers. The size of grain blower was not reported.

The information from a farm with 76-100 cows is in Table 5.17. There is a coincidence in some values of machine number on this farm and in the model output, excepted the number of mower-conditioners, single rakes, and bale wagons. Sizes of bale wagons, combines and grain wagons, were larger than reported sizes of these machines. Grain blower size given in the survey is the maximum capacity while the size given by the model is the used capacity. Similar reasoning applies to the power of the forage chopper tractor. No information was reported on sizes of forage wagon and conventional baler.

Data from a farm with more than 100 cows and the output model appear in Table 5.18. The number of mower-conditioners and single rakes calculated by the model exceeds the one given by the farmer. Bale wagon and grain wagon number are below the reported number; the number of other machines coincides with the number computed by the model. There was not information on sizes of single rakes, conventional balers, bale wagons, grain wagons and grain blowers. The available information on machine sizes

Table 5.17. Field machinery survey and model output data. One farm 76 - 100 cows.

Machine	Survey Data Number	Survey Data Size	Survey Data Units	Model Output Number	Model Output Size	Model Output Units
forage chopper	1	2.0	rows	1	12.5	t/h
forage wagons	2	-		2	4.0	t
forage chopper tractor	1	58.3	kW	1	41.7	kW
mower-conditioner	1	2.74	m	2	2.74	m
single rake	1	3.0	m	2	2.74	m
conventional baler	1	-		1	9.5	t/h
bale wagon	1	3.2	t	2	5.0	t
combine	1	3.0	rows	1	5.0	rows
grain wagon	2	5.0	t	2	6.0	t
grain blower	1	60.0	t/h	1	17.4	t/h

Tonnage produced per year:
- silage = 526.5 t
- hay equivalent = 988.7 t
- grain = 513.0 t

Time distribution:
- forage harvesting = 66 h
- forage hauling = 66 h
- mow-conditioning = 24 h
- raking = 24 h
- baling = 66 h
- bale hauling = 66 h
- grain harvesting = 66 h
- grain hauling = 66 h
- filling silos = 66 h

Table 5.18. Field machinery survey and model output data. One farm more than 100 cows.

Machine	Survey Data Number	Survey Data Size	Survey Data Units	Model Output Number	Model Output Size	Model Output Units
forage chopper	1	2.0	rows	1	34.5	t/h
forage wagon	2	10.0	t	2	10.0	t
forage chopper tractor	1	117.0	kW	1	100.0	kW
mower-conditioner	1	3.65	m	2	2.14	m
single rake	1	-		2	2.14	m
conventional baler	1	-		1	7.0	t/h
bale wagon	3	-		2	4.0	t
combine	1	6.0	rows	1	4.0	rows
grain wagon	4	-		2	5.0	t
grain blower	1	-		1	13.9	t/h

Tonnage produced per year:
- silage = 147.9 t
- hay equivalent = 748.8 t
- grain = 417.2 t

Time distribution:
- forage harvesting = 66 h
- forage hauling = 66 h
- mow-conditioning = 24 h
- raking = 24 h
- baling = 66 h
- bale hauling = 66 h
- grain harvesting = 66 h
- grain hauling = 66 h
- filling silos = 66 h

reveals that the model sizes are below the reported ones with exception of forage wagon size.

The time data used in this comparison were eleven working days and six working hours per day for a three-week harvesting season. The time distribution per operation is given, along with other relevant information, at the bottom of tables related to this section.

5.2. Final Analysis.

A final analysis was conducted in order to determine how the feed harvesting model output reacts to change in selected model parameters, and to show the importance of how precise they have to be estimated or selected. Five parameters were chosen and the results of the tests are discussed in this section.

5.2.1. Effect of Travel Speed on Transport Unit Size and Number.

Three values of speed were used in this test at a fixed average travel distance of 3.0 km on a farm with the following feed production:

	t/year
silage	1263.6
haylage	657.7
hay	663.4
grain	295.0

The time used for transportation was 66 effective hours for silage, grain and hay in small bales and cubes.

For hay in big bales 32 effective hours and for haylage 60 effective hours. Results in Table 5.19 show that for increasing speeds the number and/or size of transport units is reduced. This is particularly more evident when trucks are used in hauling big round bales and cubed hay.

5.2.2. Effect of Travel Distance on Transport Unit Size and Number.

Three average round-trip distances were used in this test at a fixed average speed of 10.0 km/h. The conditions of this test were the same as for the travel speed test, and the results are presented in Table 5.20. There it can be observed that for increasing travel distance there is also an increase in number and size of transport units. That is, a completely reverse effect to that caused by increasing speeds. Again, the effect is more clearly noticed on trucks.

The combined effect of both factors is determinant in the calculation of size and number of transport unit, therefore, particular care should be placed in the selection or estimation of both parameters.

5.2.3. Effect of Crop Yield on Machinery Size and Number.

The effect of crop yield on number and size of machines was demonstrated by using two values of alfalfa yields, 7.0 and 15.0 ton per hectare, on a farm with a required annual hay equivalent production 748.8 ton, and four cuts in the harvesting season. Results in Table 5.21 show that low yield causes an increase in number and size

Table 5.19. Effect of travel speed on transport unit size and number (1).

Machine	Av. Speed=5.0 km/h Number	Size	Av. Speed=10.0 km/h Number	Size	Av. Speed-15. km/h Number	Size	Units
forage wagon (2)	3	7.0	2	8.0	2	7.0	t
forage wagon (3)	2	7.0	2	4.0	2	3.0	t
trailing wagon (4)	2	3.0	2	2.0	2	2.0	t
round bale mover (5)	6	5.0	4	5.0	3	5.0	bales
grain wagon	2	6.0	2	3.0	2	3.0	t
cube hauling truck	1	3.0	1	2.0	1	1.0	t

(1) av. travel distance = 3.0 km

(2) transporting silage

(3) transporting haylage

(4) baler with bale ejector

(5) truck towed

Table 5.20. Effect of travel distance on transport unit size and number (1).

Machine	Av. distance=1.5km Number	Size	Av. distance=3.0km Number	Size	Av. distance=6.0km Number	Size	Units
forage wagon (2)	2	6.0	2	8.0	3	7.0	t
forage wagon (3)	2	3.0	2	4.0	2	7.0	t
trailing wagon (4)	2	1.0	2	2.0	2	3.0	t
round bale mover (5)	3	4.0	4	5.0	5	5.0	bales
grain wagon	2	2.0	2	3.0	2	6.0	t
cube hauling truck	1	1.0	1	2.0	1	3.0	t

(1) av. travel speed = 10.0 km/h

(2) transporting silage

(3) transporting haylage

(4) baler with bale ejector

(5) truck towed

Table 5.21. Effect of crop yield on machine number and size.

Machine	Crop Yield=7.0t/ha Number	Crop Yield=7.0t/ha Size	Crop Yield=15.0t/ha Number	Crop Yield=15.0t/ha Size	Units
baler	1	7.0	1	7.0	t/h
mower-conditioner	3	3.66	2	2.14	m
single rake	3	2.74	2	2.14	m
trailing wagon	2	2.0	2	2.0	t
windrower	2	3.66	1	3.66	m
tandem rake	2	4.27	1	4.27	m
hay stacker	1	.91	1	.91	t
stack mover	1	5.44	1	5.44	t
field cuber	2	1.62	1	1.62	ha/h
cube hauling truck	1	2.0	1	2.0	t
water nurse truck	1	4.7	1	5.0	t

av. travel speed = 10.0 km/h
av. travel distance = 3.0 km

Tonnage produced per year:
silage = 1471.9 t
hay equivalent = 748.8 t
grain = 417.2 t

of machinery. This is so because in order to maintain the required production with low yield, more land has to be cropped and, consequently, more machinery is needed to cover the increased surface if working speed and field efficiency of the machinery remain the same.

5.2.4. Effect of Available Time on Machinery Size and Number.

Available time is definitively one of the most important parameters affecting the number and size of a machinery system. This effect can be observed in Tables 5.1, 5.2 and 5.3. Values contained in these tables belong to the same farm with a silage production requirement of 464 ton per year, a hauling speed 10 kilometers. Values in Table 5.1 correspond to 5 effective working hours per day. It can be observed there that just increasing the number of working days from one to two days the number of forage harvesters is reduced in one and the required capacity of this machine is also reduced in 25.0%, which means a lower investment in this type of machinery.

Increasing the number of effective working hours per day has a notable effect. As an example, by just increasing one hour a day to the working time of one day, as it is showed in the first line of Tables 5.2 and 5.3, the number of forage harvesters is reduced to one machine, and the required capacity is also reduced in 12.2.%.

5.2.5. Effect of Harvesting Rate on Transport Unit and Blower Size and Number.

Harvesting rate directly affects the number and size of transport unit number and size. This effect was used in the model by relating the total harvest capacity of forage harvesters, combines, pickers and picker-shellers to the total transport capacity when the number and size of their corresponding transport unit were calculated.

Similarly, the harvesting rate affects the blower capacity. They have to be closely related or otherwise the flow of material harvested and blowed is not guaranteed and bottlenecks may occur at either one of these machines. Both situations can be observed in Table 5.3.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions.

a. Output data of this model are to be interpreted as the minimum size and number of machines that will satisfy a defined set of conditions related to the required feed production and to the available time. Miscellaneous equipment such as bale elevators, harvesting heads, manure spreader and the like, were not included in the model.

b. The available time is used as effective working days and effective working hours per day. Consequently, the ability of the farmer in using his time will also affect the final machinery selection.

c. The present version of the model can be applied to selecting the machinery used in feed harvesting operations on dairy farms.

d. Comparisons to selected dairy farm surveys indicate an acceptable model behavior in the selection of feed harvesting machinery and its ability to handle actual data.

e. The model could be added to a more comprehensive machinery selection model; to studies evaluating feed quality and quantity losses due to harvesting and handling; to models dealing with the management of forage, hay and grain harvesting machines in relationship with the rest of the farm; and to studies of the effect of decreased field drying time on a total dairy farm operation.

f. The model reacts to changes in relevant factors such as transport unit travel distance and speed, crop yield, harvesting rate and the available time for field operations.

g. The present version of the model does not locate the sequence of periods of consecutive dry days over the harvesting season.

h. As a consequence of the inability stated above, scheduling of use of the selected machinery is not performed by this model.

6.2. Recommendations for Further Research.

a. Further work is recommended to establish an algorithm to predict the location of periods of consecutive dry days and to develop the scheduling of use of feed harvesting machinery.

b. Field time studies are also recommended to determine more precise values for cycle time components of machines such as automatic bale wagons, wagon-dryers and automatic bale wagons.

c. Another area that needs further work is related to the study of parallel mechanized operations and the calculation of cycle time in forage harvesting operations.

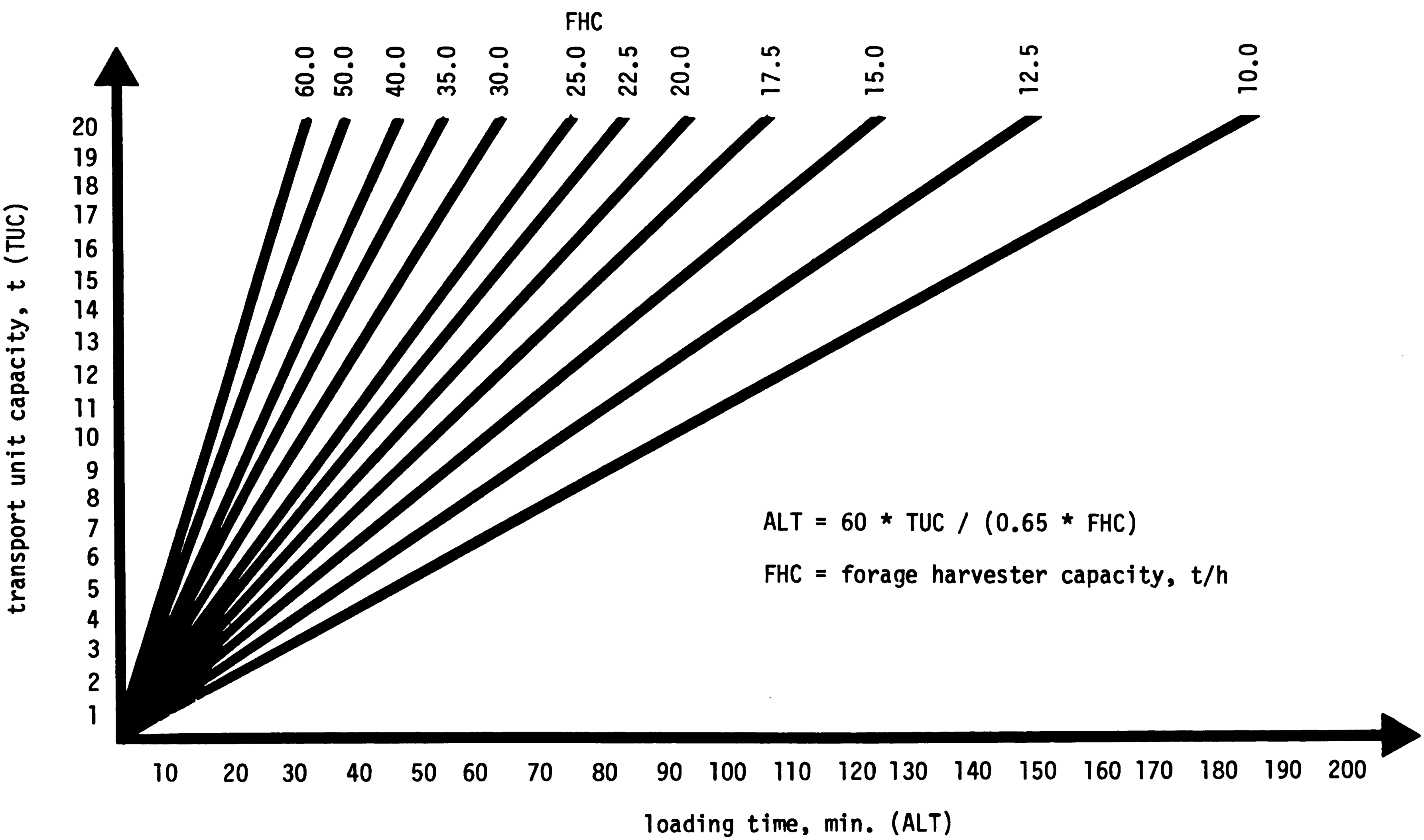
APPENDICES

APPENDIX A

NOMOGRAPH FOR DETERMINING LOADING TIME

APPENDIX A

Nomograph for Determining Loading Time

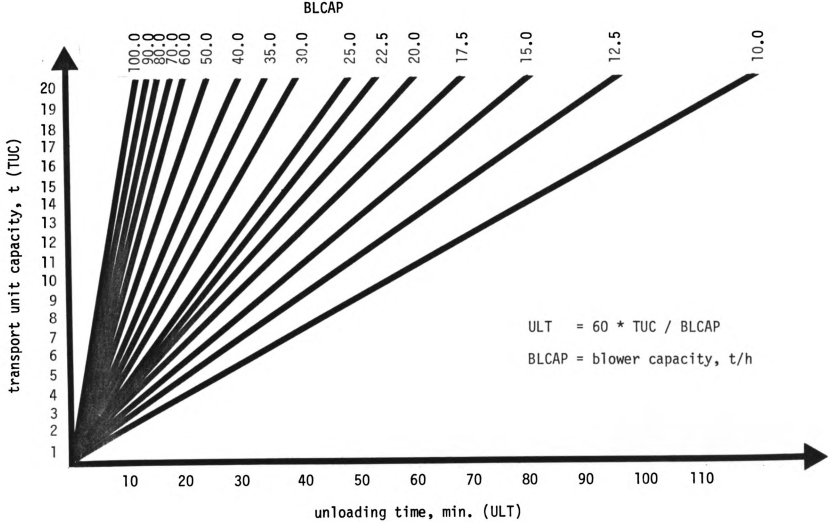


APPENDIX B

NOMOGRAPH FOR DETERMINING UNLOADING TIME

APPENDIX B

Nomograph for Determining Unloading Time



APPENDIX C

DAIRY FARM SURVEY

APPENDIX C

DAIRY FARM SURVEY

Date ____________________

1. Location

Owner's Name ____________________

County ____________________

Address ____________________

____

____

____

2. Farm Size

Crop	OWNED Area	OWNED Yield	RENTED Area	RENTED Yield	Unit
Corn Silage					
Corn, Grain					
Hay Equivalent					
Pasture					
Wheat					
Oats					

Total area ________ acres

3. Dairy Animals

Cows ____________________

Youngstock ____________________

Calves ____________________

Total ____________________

4. Feed Disappearance

	FD	BI	PR	SAL	EI	PUR
Silage						
Hay Equivalent						
Green Feeding						
Corn (Grain)						
Oats						
Pasture						

FD = Feed disappearance
BI = Beginning inventory
PR = Production
SAL = Sales
EI = Ending Inventory
PUR = Feed Pruchased

FD = BI + PR + PUR - EI - SAL

APPENDIX D

DAIRY FARM MACHINERY SURVEY

APPENDIX D

DAIRY FARM MACHINERY SURVEY

1. Capacity of Silos, Blowers and Bale Elevators

						UNITS
Horizontal Silos						ton
Vertical Silos (Forage) capacity_ _ _ _ _ _ _ height						 ton ft
Vertical Silos (grain) capacity_ _ _ _ _ _ _ height						 ton ft
Blower Capacity forage_ _ _ _ _ _ _ _ grain						 ton/hour ton/hour
Bale Elevator Capacity						bales/minute

2. Tractors

Make	Model	Size (hp)	Number

3. Field Machinery

Machine	Number	Type	Size[1] ft/row/ton	Tractor Used
Forage Chopper				
Forage Wagons				
Flat Wagons				
Trucks				
Mowers				
Hay Conditioners				
Mower-Conditioners				
Windrowers				
Rakes				
Square Balers				
Round Balers				
Bale Wagons				
Round-Bale Movers				
High-Dump Wagons				
Grain Wagons				
Hay Stackers				
Stack Movers				
Combines				
Corn Pickers				
Corn Picker-Shellers				

[1]Please place proper size unit.

APPENDIX E

CONVERSION FACTORS

APPENDIX E

CONVERSION FACTORS

From	To	Multiply By
hectare	acre	2.471
hectare per hour	acre per hour	2.471
kilogram	pound	2.204
kilogram per cubic meter	pound per cubic foot	0.063
kilogram per hectare	pound per acre	0.892
kilogram per second	pound per second	2.204
kilometer	mile	0.621
kilometer per hour	mile per hour	0.621
kilonewton	pound force	224.809
kilowatt	horsepower	1.341
kilowatt per hour	horsepower per hour	1.341
kilowatt-hour per kilogram	horsepower-hour per pound	0.608
kilowatt-hour per liter	horsepower-hour per gallon	5.076
kilowatt-hour per ton	horsepower-hour per ton	1.216
kilowatt per kilogram	horsepower per pound	0.608
kilowatt per meter	horsepower per foot	0.409
liter	gallon	0.264
liter per hectare	gallon per acre	0.107
liter per ton	gallon per ton	0.234
meter	foot	3.280
meter, cubic	cubic foot	35.315
meter, cubic	bushel	28.377
meter per square second	foot per square second	3.280
ton, metric	ton	1.102
ton per hectare	ton per acre	0.446
ton per hectare (corn)	bushel per acre (corn)	16.075
ton per hour	ton per hour	1.102

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