SIMULATION OF TIMELINESS AND TRACTABILITY CONDITIONS FOR CORN PRODUCTION SYSTEMS

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ABSTRACT

SIMULATION OF TIMELINESS AND TRACTABILITY
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by

Mehmet Yener Tulu

The necessary models for the components of a corn production system were developed to investigate timeliness losses incurred in corn production. Special attention was focused on tractability conditions of the fields. Simulations were made with 16 years of weather data for nine different machine capacity combinations on a hypothetical 200 acre farm in Southeast Michigan.

The model for tractability is deterministic and was developed using only weather and soil property data. Work, no-work conditions are obtained as model output for each day as a tractability state. Verification of the model was made utilizing weather data and work, no-work records from three Northern Indiana farms. Tractability model output proved to be in quite good agreement with the farmers' records of work, no-work conditions. Total work days were in error by one day for spring and a maximum of three days for fall operations.

The yield values (Bushel per acre) were generated stochastically. Generation was made for five consecutive planting periods between April 16 and June 11. The yield value of each planting period was assumed to be distributed normally and correlated to the previous period's yield value. Statistics for the stochastic generation were estimated from Michigan corn yield data.

Two different planting strategies were considered: 1) finishing the ploughing and harrowing for 200 acres and then planting, 2) finishing ploughing and harrowing for the first field (each field is 40 acres) and planting it, and continuing in the same manner for the remaining four fields.

Planting date timeliness losses due to tillage capacity were dominant to those caused by harvesting capacity for planting strategy 1. Timeliness losses for planting strategy 1 due to tillage capacities were 19.76, 13.77, and 8.54 Bu/A for 3-bottom plough and 10 ft disc harrow (55 HP tractor), 4-bottom plough and 13 ft disc harrow (75 HP tractor), and 6-bottom plough and 18 ft disc harrow (110 HP tractor), respectively. Planting strategy 2 caused lower timeliness losses due to tillage capacity than planting strategy 1. The losses were 12.06, 6.94, and 5.03 Bu/A for planting strategy 2 at the same conditions. Harvest losses were close to each other (lower for planting capacity 2) for each planting strategy and varied from 4.59 to 5.50

percent of yield before harvest losses for different tillage and harvesting capacity combinations. Generally, decreasing drying costs and increasing harvest losses were observed with decreasing harvest capacities.

A stochastic model of work, no-work days was developed. Probability densities were assumed for the number of work, no-work days in successive 15-day periods of the year. The parameters of the densities were estimated employing simulation results obtained utilizing the deterministic tractability model. The stochastic simulation was satisfactory for the period April 15 - November 25.

The following conclusions were derived from the results of this study:

1. The tractability model is adequate for corn production simulation and its use should be extendable to other crops and other locations.

2. The yield model is sufficient to represent the real yield values.

3. Planting date timeliness losses dominate those associated with harvest losses.

4. Stochastic generation of work, no-work days appear feasible but needs further development to cover the entire year.

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SIMULATION OF TIMELINESS AND TRACTABILITY CONDITIONS FOR CORN PRODUCTION SYSTEMS

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Corn is raised extensively in Michigan as well as in other Mid-western states of the U. S. Its main usage is as an animal feed. Meat consumption in the U. S., per capita or as a whole, is the largest in the world, and the demand for high quality meat and dairy products is increasing steadily. A high level of agricultural mechanization and advanced production techniques allow this country to be a leading producer of agricultural goods in the world, with less than two percent of its population engaged in agriculture.

Food is produced in mainly two categories: carbohydrates and proteins. The efficient American agriculture produces more carbohydrates than the population needs, resulting in surplus grains. Because the consumption of proteins, in the form of dairy products and meat, in the U. S. is so high it is necessary to import animal proteins. Even if the surplus grains of the U. S. were converted into animal protein by conventional methods, the demand for proteins would not be met (Borgstrom, 1965).

Corn is rich in carbohydrates, but poor in proteins. However, the low cost of feed nutrients compared to other crops, the possibility of nearly complete mechanization of harvesting and feeding, and the reduced cost of protein resulting from feeding low-cost urea as a supplement, make corn the most favourable animal feed throughout the country. Technological advances have increased corn yield at a more rapid rate than that of any other feed crop, making high yields relatively easy to attain, of course, not without a limit (Hildebrand, et al., 1971). Thus, corn has played an important role in the closing of the protein gap, at least partially.

The efficiency and profitability of raising field crops are closely related to the geographical situation of the fields and the prevailing meteorological conditions; corn is no exception. In fact, in places like Michigan, where year to year variability of climatic conditions is so great, corn crop development in the field is extremely susceptible to weather inputs.

Every farmer is in the position of optimizing the utilization of his resources. Extension specialists recommend some operational dates to the farmers, which are the results of research done by Agricultural Experiment Stations, as well as other suggestions on hybrids, field preparation, fertilizer application, storage, etc. The dates suggested for planting tend to be earlier than they were years ago (to obtain higher yields). To minimize harvest losses, it is recommended that harvesting begin when kernel moisture content reaches 30 - 35%, w.b. (wet basis). Both, the earlier planting dates, (mid-April to the beginning of May) and minimum loss harvesting dates (late September to mid-November) are unfavourable time periods for these operations meteorologically. As a result of high rates of precipitation in these two periods, working conditions in the field are very restricted for agricultural operations. The farmer's situation is a well known dilemma: either give up the increased income from timely operations or burden himself economically with extra machine capacity.

The general behaviour of the agricultural production system is more probabilistic and intricate than the somewhat deterministic industrial processes. The Agricultural Engineers Yearbook (1972) defines the probabilistic behaviour of agricultural processes as "timeliness": "Ability to perform an activity at such a time that quality and quantity of a product are optimized". The phrase " ... at such a time ..." is where the stochasticity arises. Stochastic processes are defined as the family of random variables, $X(t)$, $t \geq 0$, which are often used to describe the behaviour of phenomena over intervals of time (Brockwell, 1971). Time dependent meteorological variables govern the agricultural operations, by causing changes in the environment.

The main objective of this study was to simulate corn producing farm operations, and develop necessary models to investigate the timeliness effect of weather inputs on production with specific attention given to the modeling of work and no-work days.

1.1 Need for Simulation

Model building is the backbone of simulation work. Models have been constructed for the prototypes of large and costly engineering designs, such as dams, airplanes and navigational vessels. With the introduction of hybrid and digital computers the methods of model building and similitude engineering became an inevitable tool of many diversified areas. Today, it is possible to see studies in economics, education, social and political sciences using models and simulation.

There is criticism of the extensive use of modeling and simulation, even from its contributors. In terms of Operations Research, Saaty (1972) states that "Operations Research is the subject in which we never know the real problem we should be talking about nor whether our solution of it has any relevance to reality. Nevertheless, we do such research because people have problems and, as scientists, we believe that any model is better than none, it is all right to give bad answers to problems if worse answers would otherwise be given". Although at times this criticism may be true, the use of simulation and modeling techniques to study problems in farm management should be of value.

The use of simulation techniques in agriculture has been stimulated by the advancement of computer usage and system science in other industries. Since the early sixties, computers and simulation techniques have been used to analyze farm operations. The American Journal of Agricultural Economics is a good guide to this earlier period. Most of the material deals with mathematical programming methods (linear, nonlinear, quadratic, etc.), and later with the stochastic behaviour of agricultural operations. Zusman and Amiad (1965) see simulation as a tool for farm planning under conditions of weather uncertainty. A survey done by Link and Splinter (1968) reviews simulation techniques and applications to agricultural problems. This survey shows that with the continuing efforts of agricultural engineers, simulation may have considerable impact on agricultural research. The late sixties produced considerable research using computer simulation techniques on agricultural production systems. These are in areas as widely diversified as are agricultural operations. Machinery selection (Scott, 1970), insect control (Brewer, 1970), sprinkler irrigation (Stegman and Shah, 1971), environmental features of corn (Jones, et al., 1970), and harvest operations under stochastic conditions (Sorensen and Gilheany, 1970) have been studied.

Holtman, et al., (1970) state that: "The number of significantly different circumstances under which the system must function satisfactorily and the number of alternative courses of action open to the decision-maker definitely suggest the need for automating the data transformation task. Production system simulation models are not substitutes for actual measurement. Rather their purpose is to transform previous observations into new forms of information which are of value to the decision-maker".

1.2 Factors Involved in the System

For the simulation of a corn production system there is a necessity to obtain information from other disciplines in agriculture, as well as from other sciences. This is almost imperative, since any kind of production system is a synthesis of physical and economic interactions of the system's components.

The land on which corn production takes place has a definite influence on the process. Besides the economic factors such as value, rent, and taxes, the size of the land base is important in determining the size of the operation itself. Partitioning by service roads and other influences on field shape are also important for machinery movement patterns, especially if the size of a field is small.

Geographical closeness to markets determine transportation needs.

Distance from the machiner storage area and distances from field to field (if the farmer has scattered portions of land) should be considered since these factors influence fuel consumption and labour costs, and contribute to machine depreciation.

The soil moisture status of a field is a function of meteorological inputs and soil type. Soil is constituted mainly of three elements: clay, loam and sand. Different proportions of these components produce different moisture holding capacities in the soil. The working conditions of machines on the ground and the available water for the plant depend upon the moisture holding capacity of the soil.

Of the weather variables, temperature and precipitation are the most significant. Temperature is often considered to determine the growing period for any kind of plant. Since the temperature is a direct function of radiation, which is caused by sunlight, the maturity level of the plant is a function of daily temperatures. In Chapter 3 this aspect of maturity is discussed in terms of "growing degree days". Evaporation is also a result of daily heat gains caused by sunlight. The tractability of soil is dependent on it. While it is not a common practice to irrigate corn in Michigan, irrigation needs due to evapotranspiration should also be mentioned.

Precipitation is an important source of water to the corn plant. As it influences soil moisture the precipitation affects the tractability condition of the field.

Important crop parameters are, variety, the time required for maturity, and yield. As a result of research on corn, there are growing numbers of properties revealed, which can be included into a system model. However, required time for maturity and yield values are considered essential.

In addition to the capacity specifications of individual machines, man-machine, and machine-crop relations have significance. Labour, fuel needs, machine breakdowns, repair times, maintenance, harvest losses, list prices of machines and taxation should also be considered. Fertilizer, seed, hauling and drying costs of the harvested crop, and the market value of corn have a definite effect. As we progress the parameters will be defined and assumptions about them will be made.

The computations in this study were performed at the facilities of Michigan State University, East Lansing, Michigan using a FORTRAN IV language. The list of variables, routine names, their functions and flow charts of some of them are given in Appendices A, B, and C.

CHAPTER II

TRACTABILITY CONDITIONS

The tractability state of a given field is a direct consequence of weather inputs and soil properties. However, the mechanical features of the work which takes place on the ground is also important. Equipment to be used differ in design and in construction material according to their desired function, which effects their performance on the soil.

The earlier work on soil mechanics has been associated with the needs of earthwork construction and foundations for large structures. With the increasing number of off-the-road vehicles and traction devices in military, construction, agriculture, and mining operations, soil dynamics has gained importance.

The urgent need to be able to predict performance, particularly for military mobility, has led to the development of simplified performance equations with limited but accepted accuracy. Most of these equations have been empirically developed.

The National Tillage Machinery Laboratory, Auburn, Alabama, The Army Mobility Research Center, Vicksburg, Mississippi, and The Land Locomotion Laboratory, Warren, Michigan are research centers, which conduct experiments in soil dynamics.

The term soil tractability, or as it is sometimes called, "soil trafficability" (Knight and Freitag, 1962), was developed in connection with off-the-road vehicles. Tractability may be defined as the ease with which a terrain may be traversed. In the broadest sense, it includes the influence of all features such as vegetation, slopes and barriers such as chasms or rivers. In tractability, the primary interest is in the movement of the vehicle over the soil with little regard for the soil conditions produced by the movement. In agricultural operations, however the effect of the vehicle on the soil may be more important than the maximum tractive capability that can be developed. A traction device that develops the desired pull at high efficiency may not be useful for agricultural purposes if, in the process, the device compacts the soil or ruts it so severely that excessive erosion, mechanical impedence, lack of moisture, or poor aeration drastically curtail the subsequent growth of plants.

The terms that are used in tractability are often misleading. For instance, the term "go", "no-go" and "work", "no-work" imply only that a soil can or cannot be traversed. When tractability is further characterized by adverb modifiers such as, easily, or with difficulty, time and cost considerations are also implied.

Soils have been classified for construction and tractability purposes. Waterways Experiment Station (1953), U. S. Department of Interior, Bureau of Reclamation (1960), and the U. S. Army Corps of Engineers (Waterways Experiment Station, 1961) have unified these classifications to some extent. The classifications are based on physical properties that are determined by standardized methods and that indicate certain behavioral characteristics. These properties are graduation of particle size, consistency, porosity or void ratio, specific gravity, moisture content, bulk density, penetration resistance, unconfined compressive strength, and soluble salts. USDA's textural soil classification, which is shown in Figure 1, is based on the particle size of the mineral constituents of a soil, and is used widely by researchers.

Knight and Meyer (1961) used a soil classification system to estimate the probability of a vehicle being able to successfully cross a specific soil. The estimation is based on comprehensive empirical relations that establish the probability that different soil strengths will adequately support the passage of different vehicles. The vehicles were characterized by the vehicle cone index, which

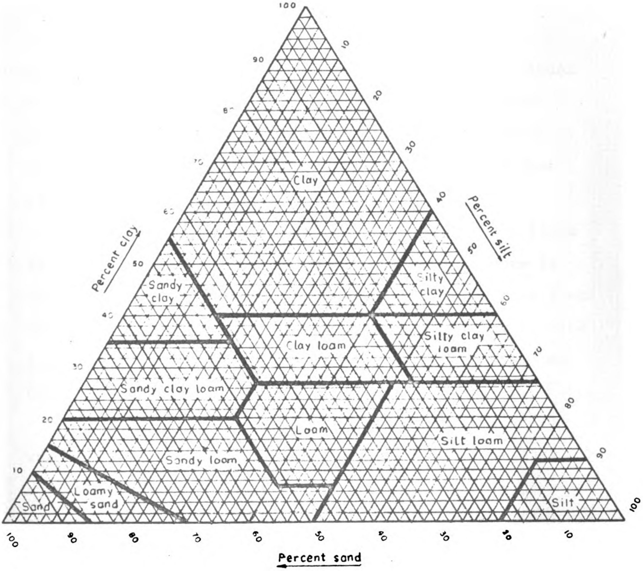

Figure 1.--Soil Triangle of the Basic Soil Textural Classes (Soil Dynamics in Tillage and Traction, 1967).

was the minimum rating cone index required by the vehicle in order to complete 50 passes over the soil. Soil was also characterized by a rating cone index that was measured with a cone penetrometer. The rating cone index of any soil could be determined by direct measurement. Thus a means was available to predict "go" or "no-go" conditions for any vehicle whose vehicle cone index was known.

Since the condition of soil can vary from a fluid to a rigid mass, Knight and Meyer's (1961) procedure is applicable only when soil parameter measurements have just been made. The condition of a soil at any instant in time depends on its moisture content, soil type, and previous history.

A procedure similar to Knight and Meyer's (1961) was developed by the Waterways Experiment Station (1948) by using specially developed cone parameters to determine the soil conditions. Their relative success can be attributed to the limited soil conditions of loose sand and wet saturated clay with which they experimented. The Waterways Experiment Station's (1962) publication is a compilation of research done by the U. S. Army on tractability. Link (1962), and Link and Bockhop, (1964) used a probabilistic model employing a first order Markov chain, to determine the working days on a "typical" Iowa corn farm. The Markov chain parameters were estimated

from the work, no-work data of the Ames Agronomy Farm, Ames, Iowa. Morey, et al., (1969) labeled the days from September 1 through December 31 as "go" or "no-go" days by using the daily work data provided by the Department of Agricultural Statistics, Purdue University, Lafayette, Indiana.

Frisby (1970), to predict the good working days for fall and spring tillage in Missouri also used a first order Markov chain. Standard weather data were used. He reported that the Markov chain procedure would be better with more years of weather data.

2.1 Soil Moisture Model

Shaw's (1963) soil moisture budget was programmed for the computer by Dr. J. B. Holtman of the Agricultural Engineering Department, Michigan State University. Although the model was designed for a soil moisture budget for the top 5 feet of soil under corn, only the top 6 inches were important for tractability conditions (see Section 2.2).

Shaw's (1963) model estimates evaporation in determining soil moisture. It was assumed that the actual evaporation rate is .1 inch/day from the top 6 inches as long as any available moisture exists in the top 6 inch layer. While the model gave quite good overall results, it was noted that because of the assumption made about evaporation, the estimation of the moisture of the top 6 inch layer could be inadequate, which would be crucial to the accuracy of the state of field. Baier and Robertson (1966) gave a set of evaporation coefficients for the top 6 inches of soil, dividing them into the top 1.2, the next 1.8 and the next 3.0 inch layers. Using Baier and Robertson's (1966) coefficients (represented by k_i, $i = 1, 2, 3$) evaporation, E_i, was described as:

$$E_i = k_i \text{ PE AM}_i, \text{ for every } i = 1, 2, 3$$

where:

i = layer number corresponding to the 1.2, 1.8, and 3.0 inch layers

E_i = evaporation from i^{th} layer for the day (inches of water)

k_1 = .55

k_2 = .40

k_3 = .05

PE = .36 open pan evaporation for the day (inches of water)

AM_i = fractional available moisture in i^{th} layer

$$= \frac{\text{actual available moisture of } i^{th} \text{ layer (inches of water)}}{\text{maximum available moisture of } i^{th} \text{ layer (inches of water)}}$$

---

*Maximum available moisture is defined to be field capacity minus wilting point water content.

Precipitation (after runoff) was assumed to first saturate the top layer, then the second and finally the third. Any reminaing precipitation was assumed to be infiltrated instantaneously. Runoff was computed by the method of Shaw (1963).

2.2 Modeling of Surface Condtions

Rutledge and McHardy (1968) developed a work, no-work criterion based on the soil moisture distribution in the top 6 inches of soil. They divided the top 6 inches of soil into the top 1.2, the next 1.8, and the next 3.0 inch layers. A work day was assumed to exist if:

$$AM_i < C_i, \text{ for every } i = 1, 2, 3$$

where:

i = layer number corresponding to the 1.2, 1.8, and 3.0 inch thick layers, respectively

AM_i = fractional available moisture of i^{th} layer

$$= \frac{\text{actual available moisture of } i^{th} \text{ layer (inches of water)}}{\text{maximum available moisture of } i^{th} \text{ layer (inches of water)}}$$

Suggested values of C_i, $i = 1,2,3$ were:

$C_1 = .95$

$C_2 = .95$

$C_3 = .95 - .995$ (depending on the soil type and drainage characteristics).

Initially it was assumed that C_3 might take on one of four different values depending upon soil characteristics. These were labeld by the integers 1, 2, 3 and 4. Criterion number 1 (C_3 = 1.0) was assumed to be representative of light (sandy) soils. Critera numbers 2 (C_3 = .985) and 3 (C_3 = .97) represent heavy (clay-loam) soils, the first one on well drained and the second one on poorly drained fields. Finally, criterion number 4 (C_3 = .99 was assigned to well drained medium textured (fine to very fine sandy loam) soils. This model was assumed to characterize tractability conditions during that period of the year in which the soil was thawed.

The time period of importance for corn production may extend from soil thawing in the spring past the date of soil freezing in the winter. In some years corn harvesting may be delayed into January or February. Thus, soil freezing and thawing dates were required. Finally, spring soil temperatures were also required to determine the earliest possible corn planting date (soil temperature greater than 50^{o}F).

Fridley and Holtman (1972), developed a model which determines soil freezing and soil thawing dates, and also calculates soil temperature in the spring. To determine soil freezing and soil thawing dates a heat unit system was used.

Beginning March 1 soil heat unit accumulation is made according to the formula:

$$\text{Daily Soil Heat Units} = \begin{cases} \dfrac{T_{max} + T_{min}}{2} - 32 & \text{no snow on the ground} \\[2ex] \dfrac{(T_{max} + T_{min})/\ 2 - 32}{6} & \text{snow on the ground} \end{cases}$$

where:

T_{max} = maximum temperature for the day (^{o}F)

T_{min} = minimum temperature for the day (^{o}F)

These daily soil heat units are accumulated. If on a certain day the soil heat unit accumulation from March 1 was less than zero, the heat unit accumulation was set to zero. When the heat unit accumulation exceeded 25 the soil was assumed to be thawed.

Upon the occurrence of soil thawing, actual available soil moistures for each layer are equated to the maximum available soil moistures. Work, no-work conditions are then determined as described above by checking the fractional available soil moisture contents of the top three layers.

To determine the earliest planting date, soil temperature was computed via exponential averaging of the previous air temperatures beginning with the date of soil thawing (Fridley and Holtman, 1972). This was accomplished by using the DELDT subroutine of the FORDYN simulation language (Llewellyn, 1965). The input to DELDT (first order delay, magnitude of delay equal to one) routine was:

$$\text{Input to DELDT} = \begin{cases} \dfrac{T_{max} + T_{min}}{2} & \text{no snow on the ground} \\[2ex] \dfrac{(T_{max} + T_{min})/2 - 32}{6} + 32 & \text{snow on the ground} \end{cases}$$

The output of DELDT is then soil temperature.

October 1 is the date, from which daily soil heat unit accumulation begins in determining the soil freezing date. In the fall, in contrast to spring, if the soil heat unit accumulation since October 1 was greater than zero on a certain day it was defined to be zero. When the soil heat unit accumulation became less than -110, the soil was assumed to be frozen.

It should be noted that the days from the soil freezing date to March 1 were labeled as work days and from March 1 to the soil thawing date were labeled as no-work days. This was done so that unharvested corn could be harvested after soil freezing. The days on which the soil is frozen are work days only for the harvesting operation of course.

2.3 Verification of the Tractability Model

Work, no-work data were recorded on three farms under the supervision of Samuel D. Parsons (1972) of Purdue University, Lafayette, Indiana. The farms are located in Northern Indiana. Work, no-work conditions were recorded for the following periods:

Farm 1: April 17, 1970 - June 12, 1970
October 1, 1970 - November 24, 1970

Farm 2: April 16, 1970 - May 23, 1970
September 23, 1970 - October 16, 1970

Farm 3: April 16, 1970 - June 6, 1970
September 22, 1970 - November 25, 1970

The fall operations recorded for each farm were corn harvesting only. Daily rainfall at these farms was recorded for the period September 1, 1969 - February 28, 1971. U. S. Weather bureau data which included open pan evaporation values were obtained from appropriate stations in Northern Indiana. The soil type distributions for each farm were recorded by Parsons (1972). The use of Figure 1 with these soil type distributions yielded the soil types for each farm as can be seen in Table 1. The moisture holding capacities of each soil type were taken from the U. S. Soil Service Soil Survey Series (1961) for Indiana.

Simulations were first made using subroutine SURFIS, which was designed to determine tractability as described in Section 2.2 (See Appendices B and C), with the aforementioned data. The missing values of evaporation data were estimated with the computer routine prepared by Dr. J. B. Holtman of the Agricultural Engineering Department, Michigan State University. The values of moisture holding capacities listed in Table 1 were used. The results were compared with the work, no-work records of the farmers. The records of the farmers and the results obtained by simulation are given in Table 2.

Table 1.--Soil Types of Three Northern Indiana Farms.

Farm 1		Farm 2		Farm 3	
Soil Type	Moisture Holding Capacity (inch/ft)	Soil Type	Moisture Holding Capacity (inch/ft)	Soil Type	Moisture Holding Capacity (inch/ft)
Silt Loam	2.1	Silt Loam	2.1	Silt	2.1
Loam	2.0	Silty Clay Loam	2.4	Silty Clay	2.3
Silty Clay Loam	2.4			Sandy Clay	2.04

The farmer's records for Farm 3 indicated that he did not have work days on 110170, 110970, 111270, 111470, 111570, and on 111670. Upon examining the precipitation records it was decided that the days were misrecorded or the fields were not ready for harvesting (perhaps due to high moisture content of kernels). Therefore, these days were assumed to be work days and are so indicated by asterisks in Table 2.

The model describes spring thaw very well. Model output values and actual values (as recorded by the farmer) of the first work day of the spring were, respectively:

1) April 17 and April 17 for Farm 1, 2) April 18 and April 16 for Farm 2, and 3) April 17 and April 16 for Farm 3. These results were obtained using tractability criterion 2.

One possible index of the measure of the model's accuracy is the number of days on which the model's result and the farm record match. This may be misleading as "partial" work days were not considered. Results for the spring period were (model criterion 2):

Farm 1: 6 out of 57 missed

Farm 2: 5 out of 38 missed

Farm 3: 9 out of 55 missed

Another index of model accuracy is the total number of work days in the period as computed with the model in comparison with the farm records. As indicated in Table 2 the maximum deviation was one day. Recorded and calculated (from the simulation) values of work, no-work days were judged to be in good agreement for the spring period.

The fall period results yielded less agreement when tractability criterion 2 was used. After October 31 the agreement was definitely unsatisfactory. However, simulations made with tractability criterion number 1 gave satisfactory results for the fall harvesting period. This was attributed to machine characteristics. In spring tillage operations, there is a slippage problem. In the fall, the combine works on a field covered with stalks and remnants of plants, and does not pull equipment behind it. The results for criteria numbers 1 and 2 were as follows:

	CRITERION NUMBER 1	CRITERION NUMBER 2
Farm 1:	5 out of 55 missed	25 out of 55 missed
Farm 2:	3 out of 24 missed	6 out of 24 missed
Farm 3:	6 out of 64 missed	23 out of 64 missed

Table 2 shows the daily and total work, no-work results. It was concluded that choices of criterion number 2 for spring tillage and criterion number 1 for fall harvesting would be appropriate.

Table 2.--Verification Results of Tractability Model.

Date	Prec. (in)	Evap. (in)	W,NW# (Model)	W,NW# (Record)	Date	Prec. (in)	Evap. (in)	W,NW# (model)	W,NW# (Record)
				Farm 1: Spring, Model Criterion 2					
41770	.0	.12	1	1	50970	.0	.34	1	1
41870	.0	.24	1	1	51070	.0	.26	1	1
41970	.0	.0¢	1	1	51170	.95	.15	0	0
42070	3.20	.0	0	0	51270	.0	.11	0	0
42170	.20	.16	0	0	51370	.30	.0	0	0
42270	.0	.15	0	0	51470	.50	.15	0	0
42370	.42	.24	0	0	51570	.12	.07	0	0
42470	1.50	.16	0	0	51670	.13	.20	0	0
42570	.47	.25	0	0	51770	.0	.14	0	0
42670	.0	.13	0	0	51870	.0	.21	0	0
42770	.36	.16	0	0	51970	.0	.23	0	1
42870	.10	.15	0	0	52070	.0	.24	1	1
42970	.0	.12	0	0	52170	.0	.25	1	1
43070	.40	.22	0	0	52270	.0	.30	1	1
50170	.12	.22	0	0	52370	.16	.25	1	1
50270	.0	.25	0	0	52470	2.25	.24	0	0
50370	.0	.12	0	0	52570	1.12	.19	0	0
50470	.0	.17	1	1	52670	.0	.23	0	0
50570	.0	.15	1	1	52770	.0	.31	1	0
50670	.0	.16	1	1	52870	.0	.21	1	0
50770	.0	.18	1	1	52970	.0	.0	1	0
50870	.0	.20	1	1	53070	.0	.22	1	1

#W=Work, NW=No-Work (1 and 0 respectively).

¢Zero indicates that the evaporation value was missing in the Weather Bureau record.

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
53170	.0	.16	1	1	60670	.0	.09	0	0
60170	.51	.08	0	0	60770	.0	.22	0	1
60270	.04	.10	0	0	60870	.0	.27	0	1
60370	.05	.11	0	0	60970	.0	.21	1	1
60470	.0	.09	0	0	61070	.0	.25	1	1
60570	.12	.14	0	0	61170	.0	.19	1	1
					61270	.10	.25	1	1

Total days = 57 Total Work Days (Model) = 23

Total Work Days (Record) = 23

Farm 2: Spring, Model Criterion 2

41670	.0	.18	0	1	50270	.0	.25	0	0
41770	.0	.12	0	1	50370	.0	.12	0	0
41870	.0	.24	1	1	50470	.0	.17	1	0
41970	1.25	.0	0	0	50570	.0	.15	1	0
42070	1.00	.0	0	0	50670	.0	.16	1	1
42170	.30	.16	0	0	50770	.0	.18	1	1
42270	.0	.15	0	0	50870	.0	.20	1	1
42370	.25	.24	0	0	50970	.0	.34	1	1
42470	.30	.16	0	0	51070	.0	.26	1	1
42570	.0	.25	0	0	51170	1.25	.15	1	1
42670	.0	.13	0	0	51270	.50	.11	0	0
42770	.0	.16	1	0	51370	.25	.0	0	0
42870	.30	.15	0	0	51470	.25	.15	0	0
42970	.40	.12	0	0	51570	.25	.07	0	0
43070	.0	.22	0	0	51670	.10	.20	0	0
50170	.20	.22	0	0	51770	.10	.14	0	0

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
51870	.0	.21	0	0	52170	.0	.25	1	1
51970	.0	.23	0	0	52270	.0	.30	1	1
52070	.0	.24	1	1	52370	.0	.29	1	1

Total days = 38
Total Work Days (Model) = 14
Total Work Days (Record) = 13

Farm 3: Spring, Model Criterion 2

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
41670	.0	.18	0	1	50570	.0	.15	1	1
41770	.0	.12	1	1	50670	.0	.16	1	1
41870	.0	.24	1	1	50770	.0	.18	1	1
41970	3.10	.0	0	0	50870	.0	.20	0	0
42070	.40	.0	0	0	50970	.0	.34	1	1
42170	.0	.16	0	0	51070	.0	.26	1	1
42270	.0	.15	0	0	51170	.75	.15	0	1
42370	.24	.24	0	0	51270	.75	.11	0	0
42470	1.25	.16	0	0	51370	1.25	.0	0	0
42570	.0	.25	0	0	51470	.25	.15	0	0
42670	.0	.13	0	0	51570	.0	.07	0	0
42770	.40	.16	0	0	51670	.0	.20	0	0
42870	.44	.15	0	0	51770	.0	.14	0	0
42970	.30	.12	0	0	51870	.0	.21	1	0
43070	.0	.22	0	0	51970	.0	.23	1	1
50170	.0	.26	0	0	52070	.0	.26	1	1
50270	.0	.25	1	0	52170	.0	.25	1	1
50370	.0	.12	1	1	52270	.0	.30	1	1
50470	.0	.17	1	1	52370	.0	.29	1	1

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
52470	2.50	.24	0	0	60170	.40	.08	0	0
52570	.0	.19	0	0	60270	.0	.10	1	1
52670	.0	.23	0	0	60370	.60	.11	0	0
52770	.0	.31	1	0	60470	.0	.09	0	1
52870	.0	.21	1	0	60570	.0	.14	0	1
52970	.0	.0	1	1	60670	.0	.09	0	1
53070	.0	.22	1	1	60770	.0	.22	1	1
53170	.0	.16	1	1	60870	.0	.27	1	1
					60970	.0	.21	1	1

Total days = 55 Total Work Days (Model) = 26

Total Work Days (Record) = 27

Farm 1: Fall, Model Criterion 1

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
100170	.0	.17	1	0	101370	.10	.07	0	0
100270	.0	.12	1	1	101470	.10	.03	0	0
100370	.0	.26	1	1	101570	.0	.07	1	0
100470	.0	.23	1	1	101670	.0	.09	1	1
100570	.0	.15	1	1	101770	.0	.08	1	1
100670	.0	.19	1	1	101870	.0	.10	1	1
100770	.0	.18	1	1	101970	.0	.07	1	1
100870	.98	.18	0	0	102070	.27	.07	0	0
100970	.33	.11	0	0	102170	.05	.0	0	0
101070	.0	.18	1	1	102270	.0	.0	1	1
101170	.0	.13	1	1	102370	.0	.06	1	1
101270	.28	.04	0	0	102470	.0	.08	1	1

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
102570	.0	.07	1	1	110970	.22	.0	0	0
102670	.0	.05	1	1	111070	.05	.0	0	0
102770	.0	.07	1	1	111170	.0	.0	0	0
102870	.52	.05	0	0	111270	.0	.0	1	0
102970	.14	.03	0	0	111370	.0	.0	1	1
103070	.0	.07	1	1	111470	.20	.0	0	0
103170	.0	.15	1	1	111570	.0	.0	0	0
110170	.0	.0	1	1	111670	.0	.0	1	1
110270	.56	.0	0	0	111770	.0	.0	1	1
110370	.06	.0	0	0	111870	.0	.0	1	1
110470	.0	.0	1	0	111970	.0	.0	1	1
110570	.0	.0	1	1	112070	.50	.0	0	0
110670	.0	.0	1	1	112170	.0	.0	0	1
110770	.0	.0	1	1	112270	.0	.0	1	1
110870	.0	.0	1	1	112370	.0	.0	1	1
					112470	.0	.0	1	1

Total days = 55 Total Work Days (Model) = 37

Total Work Days (Record) = 34

Farm 2: Fall, Model Criterion 1

92370	.0	.0	1	1	92870	.0	.13	1	1
92470	.0	.17	1	1	92970	.0	.13	1	1
92570	.0	.15	1	1	93070	.0	.15	1	1
92670	2.50	.28	0	0	100170	.0	.17	1	1
92770	.0	.06	0	0	100270	.0	.12	1	1

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
100370	.0	.26	1	1	101070	.0	.0	1	0
100470	.0	.23	1	1	101170	.0	.13	1	0
100570	.0	.15	1	1	101270	.15	.04	0	1
100670	.0	.19	1	1	101370	1.00	.07	0	0
100770	.0	.18	1	1	101470	.0	.03	0	0
100870	.50	.18	0	0	101570	.0	.07	1	1
100970	.50	.11	0	0	101670	.0	.09	1	1

Total days = 24 Total Work Days (Model) = 17

Total Work Days (Record) = 16

Farm 3: Fall, Model Criterion 1

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
92270	2.00	.34	0	0	100470	.0	.23	1	1
92370	.25	.0	0	1	100570	.0	.15	1	1
92470	.0	.17	1	1	100670	.0	.19	1	1
92570	.0	.15	1	1	100770	.0	.18	1	1
92670	1.75	.28	0	0	100870	.50	.18	0	0
92770	.0	.06	1	0	100970	.77	.11	0	0
92870	.0	.13	1	0	101070	.0	.0	1	1
92970	.0	.13	1	1	101170	.0	.13	1	1
93070	.0	.15	1	1	101270	.25	.04	0	0
100170	.0	.17	1	1	101370	1.00	.07	0	0
100270	.0	.12	1	1	101470	.0	.03	0	0
100370	.0	.26	1	1	101570	.0	.07	1	1

Table 2.--Continued.

Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)	Date	Prec. (in)	Evap. (in)	W,NW (Model)	W,NW (Record)
101670	.0	.09	1	1	110670	.0	.0	1	1
101770	.0	.08	1	1	110770	.0	.0	1	1
101870	.0	.10	1	1	110870	.0	.0	1	1
101970	.0	.07	1	1	110970	.0	.0	1	1*
102070	.75	.07	0	0	111070	.50	.0	0	0
102170	.25	.0	0	0	111170	.0	.0	0	1
102270	.0	.0	1	1	111270	.0	.0	1	1*
102370	.0	.06	1	1	111370	.0	.0	1	1
102470	.0	.08	1	1	111470	.0	.0	1	1*
102570	.0	.07	1	1	111570	.0	.0	1	1*
102670	.0	.05	1	1	111670	.0	.0	1	1*
102770	.0	.07	1	1	111770	.50	.0	0	0
102870	.70	.05	0	0	111870	.0	.0	0	0
102970	.0	.03	0	1	111970	.0	.0	1	0
103070	.0	.07	1	1	112070	.75	.0	0	0
103170	.0	.15	1	1	112170	.0	.0	0	0
110170	.0	.0	1	1*	112270	.0	.0	1	0
110270	.50	.0	0	0	112370	.0	.0	1	1
110370	.50	.0	0	0	112470	.0	.0	1	1
110470	.0	.0	1	1	112570	.0	.0	1	1
110570	.0	.0	1	1					

*Assumed to be work days

Total days = 65   Total Work Days (Model) = 45

Total Work Days (Record) =43

CHAPTER III

THE CORN PLANT

The characteristics of the corn plant were put into four main categories. There was a need to measure the development of the plant. The most important variable, yield had to be determined. The effect of the time between the physiological death of the plant and harvesting time on the moisture content of kernels was significant because of its effect on drying costs. Finally, we needed to know the losses that occur in the field before and during harvest. It was our belief that these characteristics are sufficient to comprehend the behaviour of the corn plant in the context of this study.

3.1 Plant Development

The concept of considering a plant as a heat storage unit via physiological conversion of heat into carbohydrates and other plant components led to the idea of heat units or as sometimes called "growing degree days (GDD)" (Van Den Brink, *et al.*, 1971). The term, heat units, does not denote BTU's or kilocalories. It is the accumulation from planting date of daily average temperatures above some base temperature. This base is usually taken as 50°F. Those days with average temperature less than 50°F. are ignored.

Newman and Blair (1969) recommended the measure of degree days to predict 30 percent kernel moisture at maturity time, given the planting date of corn. Taking 50°F as the base temperature a sum of daily average degrees above 50°F of 2600-2800 is required in Central Indiana for full season hybrids. To adjust for extreme conditions Newman and Blair (1969) proposed the following computations:

if $T_{max} \geq 90^{o}F$ and $T_{av} \geq 75^{o}F$:

$$\text{Daily GDD} = T_{av} - 50 - (T_{max} - 90), \text{ and}$$

if T_{av} does not exceed 65°F but is above 50°F ($50^{o}F \geq T_{av} \geq 65^{o}F$):

$$\text{Daily GDD} = T_{av} - 50 + (T_{max} - 65),$$

otherwise:

$$\text{Daily GDD} = T_{av} - 50,$$

with:

$$T_{av} = \frac{T_{max} + T_{min}}{2} \text{ (daily average temperature } ^{o}F)$$

where:

T_{max} = daily maximum temperature, °F

T_{min} = daily minimum temperature, °F.

Brown (1969) recommended a new method for use in Ontario, Canada. It treats day time temperature distinctly from that at night:

$$\text{Daily GDD} = (\text{Day} + \text{Night})/2$$

where:

$$\text{Day} = 1.85\ (T_{max} - 50) - .026\ (T_{max} - 50)^2$$

$$\text{Night} = T_{min} - 40.$$

Van Den Brink, et al., (1971) published growing degree days for Michigan. They used a formula without any correction factor, i.e.:

$$\text{Daily GDD} = \frac{T_{max} + T_{min}}{2} - T_{base}$$

where:

T_{base} = base temperature (^{O}F).

They found the GDD at four different base temperatures for different stations in Michigan. Marvin, et al., (1971) made studies of the application of the GDD concept to classifying corn hybrids with respect to maturity using six Ohio locations with three hybrids and four planting dates. Brown's (1969) method gave the least variation in the Ohio studies.

To determine heat unit requirements and corresponding varieties the corn planting dates of Hildebrand, et al., (1964) were assumed to be the characteristic dates for Michigan. These dates lie between April 16 and June 11. For each day of this period heat units were accumulated over the period from planting date to an assumed maturity date using:

$$\text{Daily GDD} = \frac{T_{max} + T_{min}}{2} - 50$$

The assumed maturity date was October 15. Sixteen years of Detroit City Airport temperature data were used. The second lowest heat unit accumulation for the October 15 maturity date was assumed to be an appropriate heat unit requirement for corn in Southeast Michigan. As shown in Figure 2 the planting period was divided into four subperiods and by linear approximation heat unit values were found for each subperiod. Varieties were selected according to the schedule described in Table 3. Yield frost penalties were determined by the method outlined in Section 3.2.3.

Table 3.--Varieties and Heat Unit Requirements.

Planting Period	Required Heat Units	Variety Number
416 - 430	2592	1
501 - 514	2537	2
515 - 528	2418	3
529 - 611	2254	4

3.2 Yields

Most Agricultural Experiment Stations keep records of corn yield as well as other crops. Due to differences of weather, soil, regional practices and plant variety these

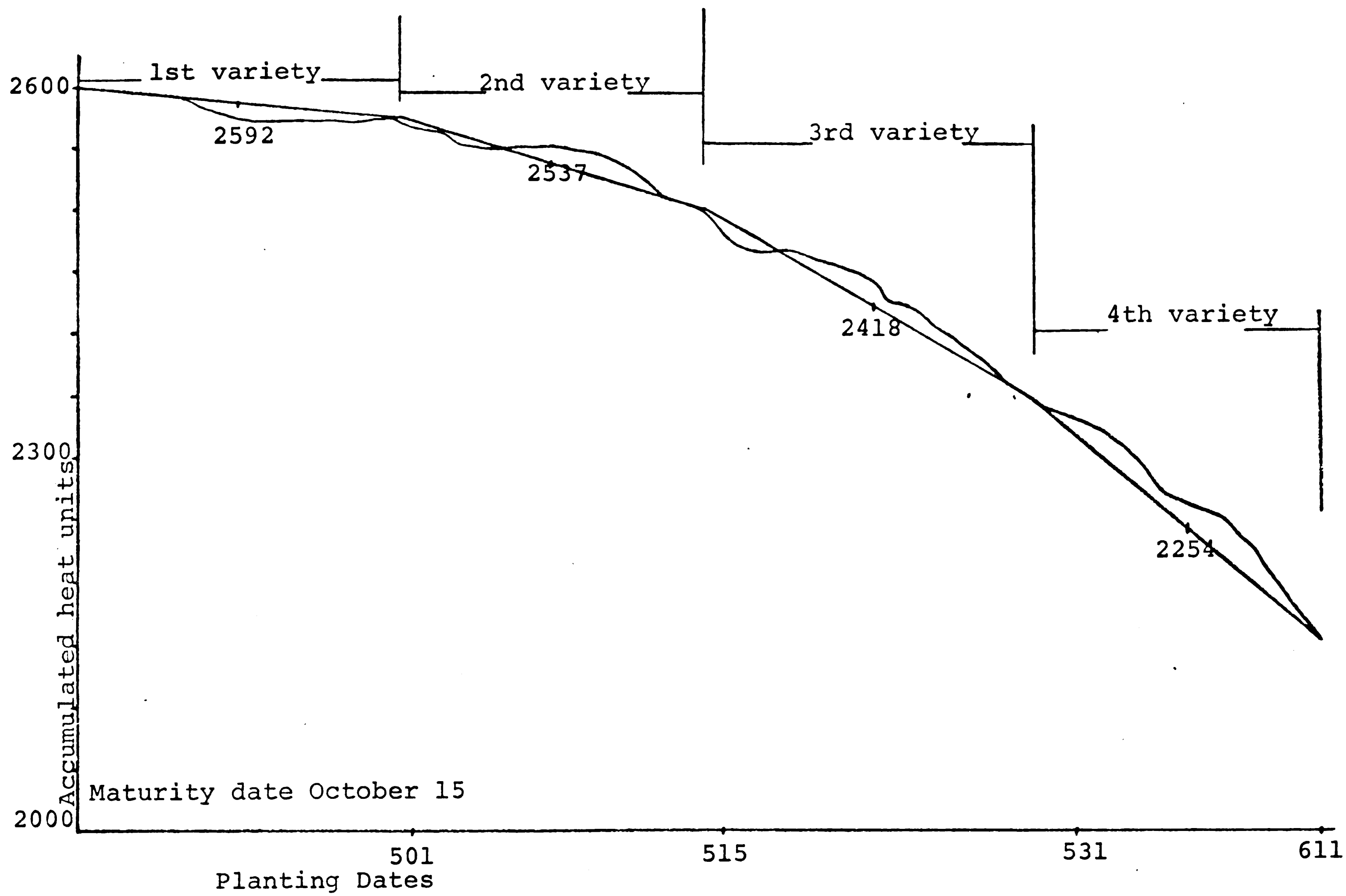

Figure 2.--Variety Selection and Planting Date.

records show considerable variability. Data from the Ohio Agronomy Guide (1972) show the increase in corn yields in recent years over earlier periods which could be attributed to agrotechnological improvements.

Denmead and Shaw (1959, 1960), Fulton (1970), and Hanks, et al., (1969) have all done some research to relate the effect of climatological factors to corn yield via soil moisture stress (Moisture Stress Days or Index), evapotranspiration, etc. Runge (1968), and Bonnevalli, et al., (1970) considered the effect of weather variables on corn yield. The effects of chemical fertilizers, plant population, row width, and seeding depth on the development of the corn plant have been studied (e.g. Nunez and Kamprath, 1969).

The most important soil parameter in influence on corn yield variability from season to season in Michigan is the soil moisture (Hildebrand, et al., 1964). One of the earlier studies of soil moisture, a classic, was conducted by Thornwaite (1948). This work was the basis for many later researchers. Thornwaite, et al., (1965) published a more general water balance method, which dealt with water loss to the air from the continents' surface. Holmes and Robertson's (1959) soil moisture budget was intended to account for soil moisture stress changes in the drying cycle, which was not handled before. Baier and Robertson (1966) developed a new technique for the estimation of daily soil moisture on a zone by zone basis from standard meteorological data and called it the "versatile soil moisture budget". Pierce (1966) presented a practical method of estimating water use by crops and determining the amount of moisture remaining in the soil at any particular moment. This model was tested under corn, meadow, and wheat. Monthly evapotranspiration, runoff, and soil moisture storage were predicted numerically and agreement with the actual data was found to be fairly good by Letteau (1969). For actual evapotranspiration, Eagleman's (1971) statistically derived method was reported to be satisfactory when used for estimating moisture changes in the soil. Availability of soil water to plants, as affected by soil moisture and climate was investigated by Denmead and Shaw (1962). Dale and Shaw (1965) and Dale (1968) reported a method of considering the interaction of potential evapotranspiration, soil moisture and non-moisture stress days for corn in Iowa.

In the earlier stages of this study the main concern was to develop a yield model with climatic variables as input and produces corn yields as output. To accomplish this, the works of Shaw (1963) and Dale and Shaw (1965) were to be used for soil moisture and moisture stress day index determinations. This model failed to reflect one important feature of corn yield behaviour. Contrary to the known general trend of decreasing yields with later planting dates (see section 3.2.1), the model produced increasing yields.

This result is understandable as Dale and Shaw's (1965) study did not consider variations in date of planting.

3.2.1 Date of Planting (DOP)

Corn crop yields are susceptible to the planting date. Generally, it is accepted that earlier planting dates produce higher average yields (Dale, 1968). Most of the research results from the Mid-West corn area conclude that planting dates later than May 10, result in approximately one bushel per acre per day reduction in yield for each day (Hildebrand, et al., 1964). This means that the corn producer has a limited time for planting. The May 10 limit is often exceeded, however, because of practical constraints of work time and equipment capacity.

Jones (1967) states that, the earlier planted corn is less likely to lodge or break over, since the height of it is less than the later planted ones. Earlier planted corn of the same variety will have a lower moisture content than the later planted corn at harvest time. Hicks and Peterson (1971) published results of DOP studies for Minnesota. Yields, days required for emergence, and ear moisture content for three different maturity groups were reported. One of the other publications of the Minnesota Agricultural Experiment Station is (Hicks, et al., 1970) more detailed and gives the results of DOP studies for different nitrogen application rates, populations, and hybrid maturity combinations.

Hildebrand, et al., (1964) stated that early planted corn usually yields more because it has passed the critical stage of growth and roots are developed by late July and early August when a dry period of some duration occurs in Michigan.

Helm, et al., (1968) in their experiment with high amylose corn stated that the later planted corn has a lower yield, whole kernel nitrogen, and kernel hardness. Pendleton and Egli (1969) found in their research that the later planting dates resulted in lower yields and decreasing stalk resistance. Genter and Jones (1970) reported the same kind of results for Northern Virginia. They found approximately one half day delay of silking, for each day's delay in planting.

Almost all yield - DOP recordings from the Mid-West area show the general pattern exhibited in Figure 3.

3.2.2 Modeling of Yields

The complexity of interactions of different phenoma which contribute to the yield of corn prevented the development of a deterministic yield model (Section 3.2.1). Stochastic generation of yield values was sought to represent the year to year variations in yields.

It was hypothesized that the yield values in subperiods of the planting period would have a normal

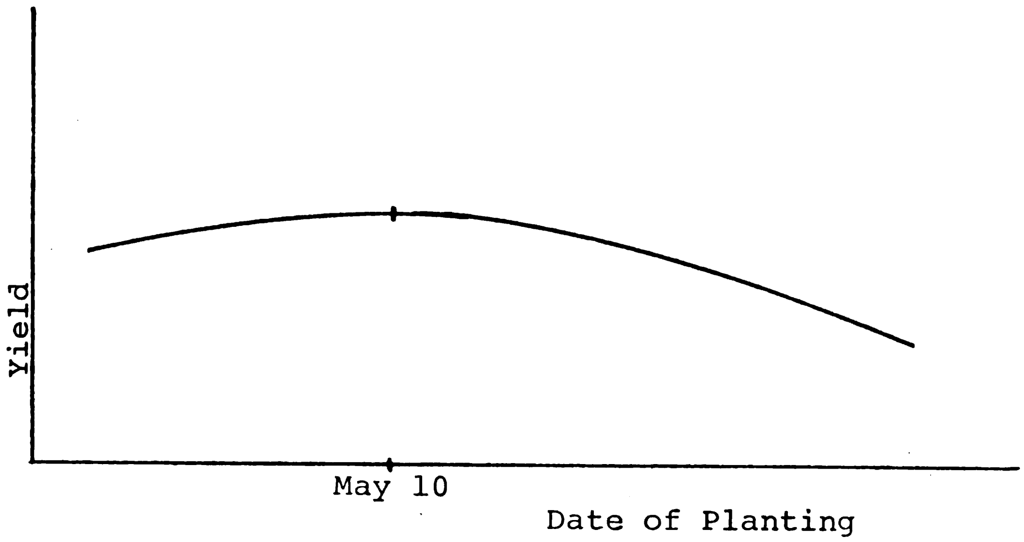

Figure 3.--The Effect of Date of Planting on Corn Yield.

distribution over the years, i.e., the probability density function of yield is:

$$f_{y_i}(y_i) = N(\mu_i, \sigma_i), \text{ for every } i = 1, \ldots, n$$

where:

i = subperiod number

y_i = yield values for planting subperiod i (Bu/A)

μ_i = mean of yields for subperiod i (Bu/A)

σ_i = standard deviation of yields for subperiod i (Bu/A).

The first subperiod's yield value was generated:

$$y_i = \sigma_1 X + \mu_1$$

where:

$X = N(0, 1)$ random variable.

For the remaining ($i = 2, \ldots, n$) subperiods the yield values were generated as:

$$y_i = \mu_i + \rho_{i-1} (\sigma_i / \sigma_{i-1}) (y_{i-1} - \mu_{i-1}) + \sqrt{1 - \rho_{i-1}^2}\ \sigma_i X$$

where:

ρ_{i-1} = correlation coefficient of yield values for subperiods $i-1$ and i.

The autocorrelated model (Bartlett, 1955) was used to capture the high degree of correlation of yields in successive periods of the same year.

The ten year data of Hildebrand, et al., (1964) were utilized to estimate the model parameters. Unfortunately, varieties were not specified. The planting season was divided into the planting periods of April 16 - April 30, May 1 - May 11, May 12 - May 20, May 21 - May 31, and June 1 - June 11. For the stochastic modeling of corn yeild these five (n = 5) subperiods were assumed to be sufficient to reflect the effect of DOP on yield. It was also accepted that these data would represent Southeast Michigan corn yields better than any other available data. Table 4 lists the estimated values of μ, σ, and ρ for the subperiods.

Table 4.--Parameters of Yield Model.

Planting Subperiods	μ (Bu/A)	σ (Bu/A)	ρ
April 16-April 30	105.7	17.77	.939
May 1-May 11	109.5	18.61	.943
May 12-May 20	99.6	22.97	.981
May 21-May 31	91.1	23.03	.948
June 1-June 11	80.50	23.62	

The simulation of the normal variate X, with $\mu_x = 0$ $\sigma_x = 1$. employed the Central Limit Theorem (Cramer, 1946). If RN_1, RN_2, ..., RN_N are N independent, identically distributed random variables each having expected value,

$E\ (RN_i) = \mu$, and variance, $V\ (RN_i) = \sigma^2$, by the Central Limit Theorem:

$$\lim_{N\to\infty} P\ [a < \frac{\sum_{i=1}^{N} RN_i - N\mu}{\sqrt{N}\ \sigma} < b] = \frac{1}{\sqrt{2\pi}} \int_a^b e^{-\frac{1}{2} z^2} dz$$

where:

$$E\ (\sum_{i=1}^{N} RN_i) = N\mu$$

$$V\ (\sum_{i=1}^{N} RN_i) = N\sigma^2$$

and

$$z = \frac{\sum_{i=1}^{N} RN_i - N\mu}{\sqrt{N}\ \sigma} = \text{a } N\ (0,1) \text{ random variable}$$

The simulation of the normal variate X by computer employed the sum of K uniformly distributed (0,1) continuous random variates RN_1, RN_2, ..., RN_K. The application of the Central Limit Theorem and the use of the expected value and standard deviation of the uniform random variable yield:

$$\mu = \frac{1}{2}$$

$$\sigma = \frac{1}{\sqrt{12}}$$

and

$$z = \frac{\sum_{i=1}^{K} RN_i - K/12}{\sqrt{K}/\sqrt{12}}$$

Any normal random variable can be transformed to the N (0,1) random variable, z, by:

$$z = \frac{X - \mu_x}{\sigma_x}$$

By equating these last two equations for z we find:

$$\frac{X - \mu_x}{\sigma_x} = \frac{\sum_{i=1}^{K} RN_i - K/2}{\sqrt{K/12}}$$

or

$$X = \sigma_x \left(\frac{12}{K}\right)^{\frac{1}{2}} \left(\sum_{i=1}^{K} RN_i - \frac{K}{12}\right) + \mu_x$$

It can be seen from the Central Limit Theorem that for asymptotic convergence to normality K should be taken as large as possible. However, the value of K selected must be justified by the computer time spent in generating K uniform random variates for each normal variate in relation to the resulting accuracy. In simulation studies it has been suggested that K can be as small as 10 (Hillier and Lieberman, 1968; Naylor, _et al._, 1968; and Abramowitz and Stegun, 1964). There is a computational advantage if K is chosen as 12. If 12 is used,

$$X = \sigma_x \left(\sum_{i=1}^{12} RN_i - 6\right) + \mu_x.$$

K = 12 truncates the distribution at the $\pm$ 6σ limits. Thus, it is not extremely reliable for the tail sections of the distribution.

The YIELD routine was designed with K = 12. Its flow chart is in appendix C.

3.2.3 Frost Penalty

The loss in yields due to an early freeze in the fall was calculated by the following formula (Newman, 1968):

$$YR = \begin{cases} .02\ (RGDD - AGDD)^2/10^4 & \text{if } RGDD - AGDD < 450 \\ .4 & \text{if } RGDD - AGDD \geq 450 \end{cases}$$

where:

RGDD = Required GDD (Base 50°F) from planting to physiological maturity for the variety planted

AGDD = Accumulated GDD (Base 50°F) from planting to freezing date

YR = Fraction of yield lost due to the deficit of heat units accumulated before a fall freeze.

3.3 Harvest Losses

Harvest losses in yield can be considered in two categories, preharvest and harvester (corn combine) losses. Both of these losses depend upon the amount of stalk lodging which differs according to the corn variety and DOP.

Holtman, et al., (1970) gave some computational formulae for computing lodging. Fridley, et al., state that lodging is a function of time, weather, plant population per acre and corn hybrids:

$$L = KC_h P^n\ (D - 199)^{1.7}$$

where:

L = percent stalk lodging

K = 2.5×10^{-4} (constant of proportionality)

P = plant population per acre (thousands of plants)

D = number of days from March 1

$n = 1.5$

C_h = hybrid constant.

Hybrid constants (C_h) were given for four different hybrid categories as, .7, 1.0, 1.3, and 1.6 respectively.

Parsons, et al., (1971) gave formulas for different kinds of losses. These were:

$$L_p = .07L$$

$$L_c = .14\ (\min\ [\max\ (M,\ .22),\ .35] - .22)$$

$$L_s = .55M^2 - .23M + .038$$

where:

L_p = preharvest loss, decimal fraction of yield at maturity

L_c = cylinder loss, decimal fraction of gathered yield

L_s = separation loss, decimal fraction of gathered yield

L = stalk lodging, decimal

M = grain moisture, decimal wet basis.

Holtman, et al., (1970) suggested a formula for gathering losses:

$$L_g = .01 + C_r\ (.01 + .17L)$$

where:

L_g = gathering loss, decimal fraction of available corn for harvesting

C_r = row spacing coefficient

L = stalk lodging, decimal fraction.

In this work values of plant population of 18000 and row spacing coefficient of 1.1 were used. $C_r = 1.1$ corresponds to 30 inch row spacing and 2.5 mile/hour ground speed of combine.

3.4 Natural Field Drying

Between the date of physiological death, i.e., the maturity date of the corn plant, and harvest time natural drying of the kernel occurs. Reduction of kernel moisture reduces the drying cost for corn.

Schmidt and Hallaner's (1966) field drying model was used. This model's quality was indicated by correlation coefficients of .72 to .92 for the various stages as shown below. Their final least square estimates were:

$$R = \begin{cases} -2.00 + .047T & 75\% \geq MC_i \geq 50\% \\ -0.54 + .021T & 50\% \geq MC_i \geq 30\% \\ -0.08 + .119D & 30\% \geq MC_i \geq 25\% \\ -0.432 + .146D & 25\% \geq MC_i \geq 20\% \end{cases}$$

or:

$R = 0.$, whichever is larger.

Then:

$$MC_{i+1} = MC_i + R$$

where:

MC_i = moisture content, percent wet basis on day i

R = daily percent wet basis reduction in MC

T = dry bulb temperature (^{o}F)

D = wet bulb temperature (^{o}F)

The output of this model was the basis for drying cost calculations.

CHAPTER IV

FIELD OPERATIONS

Daily capacity for field operations was calculated by:

$$\text{Effective Field Capcity (Acre/Day)} = \frac{S.\ W.\ E}{8.25}\ H$$

where:

S = speed of the machine (miles/hour)

W = effective width of equipment (ft)

E = efficiency (decimal)

H = number of work hours worked per day.

The effective field capacity values were reduced by five percent to account for machine breakdowns.

The following equations were used for horsepower requirements of different operations (Bowers, 1968):

$$HP_p = NB\ \frac{WB}{12}\ V_p\ \frac{850}{375}$$

$$HP_h = WH\ V_h\ \frac{280}{375}$$

$$HP_{pl} = NR\ \frac{RW}{12}\ V_{pl}\ \frac{110}{375}$$

where:

HP_p = horsepower requirement for ploughing (HP)

HP_h = horsepower requirement for harrowing (HP)

HP_{pl} = horsepower requirement for planting (HP)

NB = number of bottoms of plough

WB = width of plough bottoms (inches)

V_p = ploughing speed (mile/hour)

WH = width of harrow (ft)

V_h = harrowing speed (mile/hour)

NR = planter width (number of rows)

RW = row width of planter (inches)

V_{pl} = planting speed (mile/hour)

Horsepower requirements of harvesting were calculated by the formulae of Parsons, et al., (1971).

The values of field efficiencies and speeds used in the model for different operations are given in Table 5.

Table 5.--Field Efficiencies and Speeds.

Operation	Efficiency	Speed (mile/hour)
Ploughing	.825	4.5
Harrowing	.825	4.5
Planting	.725	4.5
Harvesting	.750	2.5

CHAPTER V

TIMELINESS SIMULATION

Determination of machinery requirements has been a problem of agricultural production systems for a long time. The owner of the machine wants to make maximum possible profit. The timeliness of a certain agricultural machinery operation is, therefore, a very important factor in machinery selection. If the machinery cannot perform the necessary operation during the climatologically optimum period, then timeliness cost occurs.

The "timeliness function" as defined by Link and Barnes, (1959) is shown in Figure 4. This same representation was also used by Sowell (1967).

5.1 Simulated Conditions

A corn production simulation was made for 16 years of weather data from the period 1953 through 1968. The weather data included maximum and minimum daily temperatures (^{0}F), wet bulb temperature (^{0}F), daily precipitation (inches), daily open pan evaporation (inches), and a snow indicator (one or more inches on the ground, snow, otherwise no-snow).

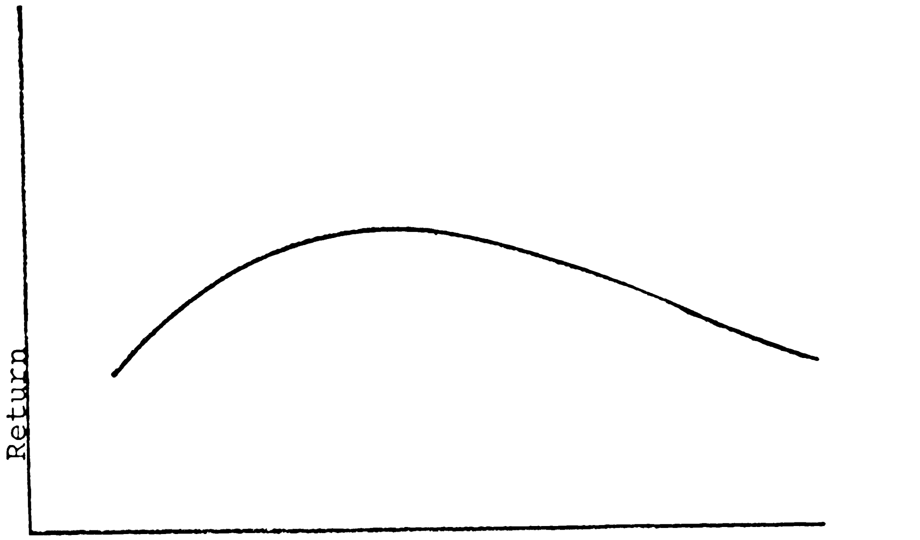

Figure 4.--Timeliness Function.

Open pan evaporation data were from U. S. Weather Bureau's Dearborn-Detroit weather station; and data from U. S. Weather Bureau's Detroit City Airport weather station were used for the other values.

A hypothetical corn producing farm of 200 acres was the basis of our study. These 200 acres were assumed to consist of five equally sized fields. Distances from the machinery storage area, and distances from field to field were neglected. The farm was operated by one worker and whenever extra labour was needed (for transport), family labour was assumed to be available. One tractor, one combine and necessary tillage and planting equipment were assumed. A work day was assumed to be ten hours. Sundays and holidays were considered to be work days if working conditions were technically appropriate.

Field operations were divided into two parts: spring operations (tillage and planting) and the fall harvest operation. The operations in spring were considered in the following order: 1) ploughing, 2) harrowing, and 3) planting. There was no fall tillage. This sequencing of events was assumed to be adequate to reveal the timeliness effects on corn production. However, the model can depict a different sequencing of operations with slight modifications.

Two kinds of planting strategies were considered: 1) finishing the ploughing and harrowing for 200 acres and then planting (planting strategy 1), 2) finishing ploughing and harrowing for the first field (each field is 40 acres) and planting it, then continuing in the same manner for the remaining four fields (planting strategy 2). The first strategy represents the extreme case and is not preferred by farmers most of the time. In the second strategy, the 40 acre portions were thought to be typical for sectionwise completion of spring operations. Upon completion of each operation a one hour deduction from the available working hours was made to account for the time required to get ready for the next operation.

To compute drying costs 0.005 dollar per point above 15.5 percent moisture (wet basis) per bushel was charged for drying of the harvested crop (Maddex and White, 1972).

5.2 Simulation Procedure

Nine different machine capacity combinations were considered using the models described in previous chapters. A simplified flow chart of the simulation model can be seen in Appendix C for 16 years for planting strategy 1. The machine capacity combinations were three tillage capacities with three different harvesting capacities for each tillage capacity. Variation in planting capacity was not considered. Table 6 shows the assumed capacities and related values for these machine capacity combinations. The machine capacities are indicated by T#H# (Tillage system number and Harvesting system number). Related horsepower values for tractors were taken to be approximately 1.33 times the required horsepower values for each operation. The horsepower requirement for harvesting (H1, H2, and H3) changes from 35 HP to 83 HP because it is affected by variability in yield (Parsons, et al., 1971). Although 1-row and 2-row combines are not now manufactured they were used to reveal the effect of a lower capacity system on harvest losses (this could also be considered as a reduction of work hours per day or increased acreage).

Each of the machine capacity combinations shown in Table 6 was simulated three times over the 16 year period for both planting strategies. Yield values were stochastically generated for each planting period as described in Chapter 3. However, the discontinuities in yield vs. planting date implied by this procedure gave irregular results. Yields for all planting dates prior to May 6 were assumed to be the generated value for the second planting period (May 1 - May 11). Linear interpolation between adjacent yield values was used to determine yield values for planting dates after May 6. (The yield value for a given planting period was assumed to be the actual yield value for a planting date which was the mid-date of the planting period). This procedure on the average gives no yield penalty for planting dates prior to May 6 and a one Bu/day penalty for each day after May 6.

Field harvest dates and harvest moisture contents were assumed to be those values on the day when one half of the field was harvested. Field planting dates, however, were set to that date when the planting of the field was completed.

5.3 Results

Results obtained from the computer simulation model for both planting strategies are listed in Table 7. Standard deviations of values are given in parenthesis.

5.3.1 Yields Before Harvest Losses

Table 4 shows that the climatologically best yield, 109.5 Bu/A with standard deviation 18.61 Bu/A, occurs if the planting date of corn is between May 1 and May 11. Yields before harvest losses were calculated over all observations of tillage capacities (T1, T2, and T3) in both planting strategies. Each mean and standard deviation of yield before harvest losses for individual tillage capacities shown in Table 7 is based on 144 observations. In Figure 5 it can be seen that the timeliness loss in bushels per acre decreases with increasing tillage capacity in both planting strategies. The timeliness losses for three ploughing capacities are: 19.76, 13.77, and 8.54 Bu/A for

TABLE 6.--Machine Capacity Combinations and Related Values.

Machine Capacity Combination	Plough Bottom Number (16")	HP Required for Ploughing	Width of Disc Harrow (ft)	HP Required for Harrowing	Planter Row Number (30" Spacing)	HP Required for Planting	Rated Tractor HP	Combine Row Number
T1H1	3	40.80	10	33.57	6	19.80	55	1
T2H1	4	54.40	13	43.52	6	19.80	75	1
T3H1	6	81.60	18	60.25	6	19.80	110	1
T1H2	3	40.80	10	33.57	6	19.80	55	2
T2H2	4	54.40	13	43.52	6	19.80	75	2
T3H2	6	81.60	18	60.25	6	19.80	110	2
T1H3	3	40.80	10	33.57	6	19.80	55	3
T2H3	4	54.40	13	43.52	6	19.80	75	3
T3H3	6	81.60	18	60.25	6	19.80	110	3

Table 7.--Outputs of the Model.

Tillage Capacity	Yield Before* Harvest Losses (Bu/A)	Harvest Capacity	Harvest Losses (Percent of Yield Before Harvest Losses)	Yield Before# Harvest Losses (Bu/A)	Drying Cost ($/Bu)
		Planting Strategy 1			
T1	89.74	H1	5.50	90.91	.031
	(23.35)		(1.69)	(23.16)	(.0083)
		H2	4.76	89.10	.043
			(1.51)	(23.26)	(.0119)
		H3	4.75	89.21	.051
			(1.41)	(23.67)	(.0151)
T2	96.73	H1	5.35	98.43	.030
	(25.50)		(1.93)	(24.87)	(.0093)
		H2	4.70	93.12	.041
			(1.60)	(27.17)	(.0136)
		H3	4.68	98.63	.048
			(1.43)	(24.40)	(.0156)
T3	100.96	H1	5.28	104.19	.029
	(22.45)		(1.66)	(23.44)	(.0104)
		H2	4.59	96.42	.039
			(1.01)	(21.51)	(.0150)
		H3	4.61	102.29	.045
			(1.38)	(22.38)	(.0166)

*Based on 144 observations

#Based on 48 observations

Table 7.--Continued.

Tillage Capacity	Yield Before* Harvest Losses (Bu/A)	Harvest Capacity	Harvest Losses (Percent of Yield Before Harvest Losses)	Yield Before# Harvest Losses (Bu/A)	Drying Cost ($/Bu)
		Planting Strategy 2			
T1	97.43	H1	5.24	97.43	.032
	(21.44)		(1.59)	(21.02)	(.0106)
		H2	4.75	96.98	.045
			(1.39)	(21.34)	(.0157)
		H3	4.77	97.20	.051
			(1.28)	(21.83)	(.0143)
T3	101.56	H1	5.20	103.56	.030
	(22.55)		(1.83)	(21.54)	(.0103)
		H2	4.64	97.77	.044
			(1.38)	(24.50)	(.0152)
		H3	4.69	103.35	.051
			(1.25)	(21.45)	(.0154)
T3	104.47	H1	5.15	108.22	.030
	(20.45)		(1.55)	(21.09)	(.0104)
		H2	4.63	100.52	.043
			(1.03)	(19.92)	(.0175)
		H3	4.74	105.57	.050
			(1.38)	(20.33)	(.0167)

Tl, T2, and T3 respectively for planting strategy 1. Planting strategy 2 gave lower losses: 12.06, 6.94, and 5.03 Bu/A for Tl, T2, and T3 are recorded respectively. It may be expected that the curves in Figure 5 approach the 109.5 bushel per acre value if the ploughing, harrowing and planting capacities are increased. However, it will never exceed the climatologically best yield (109.5 Bu/A).

Variations in yields are lower for planting strategy 2 than for planting strategy 1. In both planting strategies the highest tillage capacity, T3, gives the lowest variation in yield (Table 7). In Figure 6 timeliness losses in bushels per acre are depicted for the total Acre/Day ploughing-harrowing-planting capacity of each system (Tl, T2, and T3) for both planting strategies.

Table 8 lists the "average" planting, maturity and harvesting dates for all combinations and planting strategies for the years between 1953 and 1968. The "average" was computed as the arithmetic mean of the dates for the five fields. The "extreme" (latest over the five fields) dates are given in Table 9.

5.3.2 Harvest Losses and Drying Costs

Decreasing harvest losses and increasing drying costs occur as the harvest capacity increases for planting strategy 1 (Table 7) except machine capacity combination T3H3. In this case high harvest moisture contents produce high cylinder and separation losses (See Section 3.3). This behaviour of harvest losses is dominant in planting strategy 2. The harvest losses which occur with H3 in all the tillage capacities are higher than caused by H2. A comparison of planting strategies 1 and 2 reveals that the harvest losses with H1 for planting strategy 1 is higher than for planting strategy 2. The losses associated with H2 are very close to each other for the two different planting strategies. This behaviour is again attributed to the moisture content of the harvested grain. Figures 7 and 8 show the harvesting losses for the two different planting strategies.

The highest harvest losses occur with H1H1 for both planting strategies, while the lowest drying costs per bushel are recorded for T3H1 for planting strategy 1 and, for T2H1 and T3H1 for planting strategy 2. If the mature crop stays on the field in the late fall (after October) rather than in the early fall, the natural field drying rate is not as high because of cooler temperatures. The decrease in drying costs is limited by the temperature inputs for the time duration the mature crop is in the field. The reason that the machine capacity combination T1H1 does not have the lowest drying cost is due to this limit in both planting strategies. The T3H1, T2H1 and T3H1 capacity combinations produce a long stay on the field in the early fall for the mature crop for planting strategy 1, and planting strategy 2

Table 8.--"Average" Planting, Maturity and Harvesting Dates at Different Machine Capacity Combinations for Each of the Sixteen Years

Tillage Capacity		Harvest Capacity		
T1		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
		Planting Strategy 1		
60253	90753	93053	91853	91453
51254	92954	120754	102254	101554
50955	90255	92555	91355	91055
53056	93056	102556	101856	100456
60657	100757	120157	102057	101557
51958	101858	111858	102558	102458
52359	90859	101759	91459	91059
61160	101160	112560	102560	102160
60161	91361	101861	92461	92261
52162	100562	112262	102262	101662
52963	91863	100763	100163	92563
53064	91764	101464	100564	100164
53165	93065	111065	101465	100965
52466	91366	100666	92266	91966
53567	100467	121367	101667	101367
52868	91268	100468	92168	91768
T2		H1	H2	H3
52753	91653	100253	92153	91953
50954	92854	120154	101854	101554
50555	90155	92855	91155	90755
52656	101456	111556	102556	102156

Table 8.--Continued

Tillage Capacity		Harvest Capacity		
T2		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
60257	92757	102057	100557	100257
51458	101758	111358	102558	102358
50759	90359	100559	91459	91059
60760	100760	111260	101760	101260
52761	91661	101061	92961	92761
51762	92062	102662	100762	93062
52463	92563	101663	100563	100163
52664	92564	101764	100664	100364
52165	101065	112065	102065	101465
50866	91366	100566	92466	92066
52167	100367	121367	101867	101367
51168	91368	101168	92768	92168
T3		H1	H2	H3
52253	91153	100653	92453	92053
50454	92854	120954	102254	101554
50155	82955	92455	91055	90655
52256	101256	111456	102156	101656
53057	92857	101957	100657	100557
51058	101758	111258	102858	102358
43059	90259	100459	91459	90559
52760	93060	101860	100560	100360
52261	91961	101761	100261	92661
51362	91662	110262	100662	92962
51863	92163	101363	100263	92863

Table 8.--Continued

Tillage Capacity		Harvest Capacity		
T3		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
52264	92064	101864	100764	100564
51665	92765	102565	100965	100665
50666	91366	100666	92466	92066
51767	100167	121367	101467	101267
50468	91268	101168	92568	92068
		Planting Strategy 2		
T1		H1	H2	H3
52053	91053	93053	91753	91353
50554	92454	110754	101354	100954
50255	83055	92355	90955	90555
51456	101256	102856	101856	101556
52957	100857	101957	101057	101157
51258	101758	111858	102658	102058
50559	90359	100459	91459	91259
52860	100760	102060	101160	100960
52461	91561	100561	92761	92561
51562	92762	102662	100662	93062
51863	92463	101263	100163	92363
52364	92164	101564	100664	100264
52165	101265	112065	101965	101565
51066	91366	100566	92466	92066

Table 8.--Continued.

Tillage Capacity		Harvest Capacity		
T1		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
51367	100767	121367	101867	101367
51268	91268	100968	92568	91968
T2		H1	H2	H3
51753	91053	93053	91853	91453
50154	92854	120454	102254	101554
42855	82955	102255	90855	90355
51256	101156	102556	101756	101456
52257	100357	101957	100857	100657
50958	101658	112258	102758	102258
42959	90259	100459	91459	91059
52360	100160	101860	100460	100260
52261	91661	101061	92761	92361
51362	91962	102662	100462	92662
51263	92363	101363	100263	92863
52164	91964	101564	100464	92864
51665	93065	102365	100965	100565
50766	91366	100666	92466	92066
51067	100967	121367	101867	101467
50568	91368	101168	92568	92068

Table 8.--Continued.

Tillage Capacity		Harvest Capacity		
T3		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
51253	91053	93053	91853	91453
42854	92754	111754	101754	101054
42455	82855	92155	90855	90355
50456	101456	112356	102256	102056
51957	100457	101957	101357	100757
50758	101758	112258	102758	102258
42659	90259	100459	91459	91059
51860	92960	102060	100360	100160
51761	92061	101461	93061	93061
50962	91562	102562	100562	93062
50463	92263	101363	100663	92863
51864	91564	101364	93064	92564
51265	100265	102365	100965	100565
50666	91366	100666	92466	92066
50567	100967	123167	101867	101467
42968	91468	101068	92568	92068

Table 9.--"Extreme" (Latest) Planting, Maturity and Harvesting Dates at Different Machine Capacity Combinations for Each of the Sixteen Years

Tillage Capacity		Harvest Capacity		
T1		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
		Planting Strategy 1		
60453	91053	100853	92753	92053
51454	92954	20255	110854	102354
51155	90355	102255	91755	91555
60156	100256	110756	101656	101056
60857	100957	21657	103157	102157
52158	102158	122058	110558	102058
52759	90859	110359	92159	91559
61160	110760	123060	111460	111360
60461	91661	110261	100561	92961
52362	100762	12663	102962	102362
53163	91763	102463	100563	93063
60164	91864	103164	101264	100664
60465	100765	112265	102665	101665
52566	91566	102166	93066	92466
52767	100567	22668	103067	102167
60268	90968	103068	92568	92368
T2		H1	H2	H3
52953	91853	101753	100253	92753
51054	92854	20255	100854	102354

Table 9.--Continued.

Tillage Capacity		Harvest Capacity		
T1		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
50755	90255	102055	91955	91355
52856	101556	12457	110356	102656
60457	100157	111157	101357	100757
51658	102358	121758	110558	110158
50959	90459	110359	92159	91559
60960	100960	122560	102560	101860
52961	92161	110261	100861	100361
51962	93062	112762	101862	101262
52663	92663	110263	101263	100663
52864	92764	110264	101464	100864
52865	102965	22166	110165	103165
51066	91366	102266	100166	92566
52367	100367	22768	103067	102167
52368	91468	110268	100468	92668
T3		H1	H2	H3
52453	91153	102153	100253	92653
50654	92854	20255	110854	102354
50355	83055	101555	91855	91255
92456	101356	11857	102656	102156
53157	102357	110757	103057	102957
51258	101758	122158	110658	103158
50559	90259	110359	92159	91559
52960	100660	111460	101360	100960
52461	92061	110961	101061	100461

Table 9.--Continued.

Tillage Capacity		Harvest Capacity		
T3		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
51562	92462	112762	101862	101262
52263	92463	102863	100963	100363
52464	92264	110264	101464	100864
51865	93065	111565	101965	101465
50766	91366	102266	100166	92566
51967	100367	22767	103067	102167
50668	91268	110268	100468	92668
Planting Strategy 2				
T1		H1	H2	H3
60953	91953	101553	92653	92253
51554	92854	12555	102554	101854
51255	90355	101455	91755	91155
60256	101556	111456	102756	102256
60957	102257	110757	102957	102857
52358	102258	121958	110458	102958
52859	90859	110359	92159	91559
61160	110760	112360	111460	111360
60561	92261	110261	100661	100161
52462	100862	112762	101862	101262
60163	93063	102763	100863	100263
60264	92764	110164	101364	100764
60565	102965	22166	110165	103165

Table 9.--Continued.

Tillage Capacity		Harvest Capacity		
T1		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
52566	91566	102266	100166	92566
52867	100867	22768	103067	102267
60368	91468	110168	100168	92568
T2		H1	H2	H3
60153	91653	101653	92753	92053
51154	92854	20255	110854	102354
50855	90255	101155	91655	90955
52956	101556	111356	102656	102156
60557	101657	110757	102257	102157
51758	102158	122058	110558	103058
51059	90459	110359	92159	91559
61960	101060	111460	101360	101260
53061	92161	110261	100561	93061
52062	100362	112762	101862	101262
52763	92663	102863	100963	100363
52964	92364	101564	101164	100564
52965	101165	111265	101865	101365
51066	91366	102266	100166	92566
52467	102367	22768	103067	102567
52468	91468	110268	100468	92668
T3		H1	H2	H3
52653	91653	101753	92853	92153
50754	92854	13055	102654	102054

Table 9.--Continued.

Tillage Capacity		Harvest Capacity		
T3		H1	H2	H3
Planting Date	Maturity Date	Harvesting Date	Harvesting Date	Harvesting Date
50455	83155	101155	91655	90955
52556	101556	12257	103056	102456
60157	102257	110757	102957	102857
51358	102158	122158	110658	103158
50659	90359	110359	92159	91559
60660	100560	112060	101260	100760
52661	92361	102261	100861	100261
51662	91762	112762	101862	101262
52363	92663	102863	100963	100363
52564	92364	102864	100964	100364
51965	101565	111265	101965	101765
50766	91366	102266	100166	92566
52067	101767	22768	103067	102267
50768	91468	110268	100468	92668

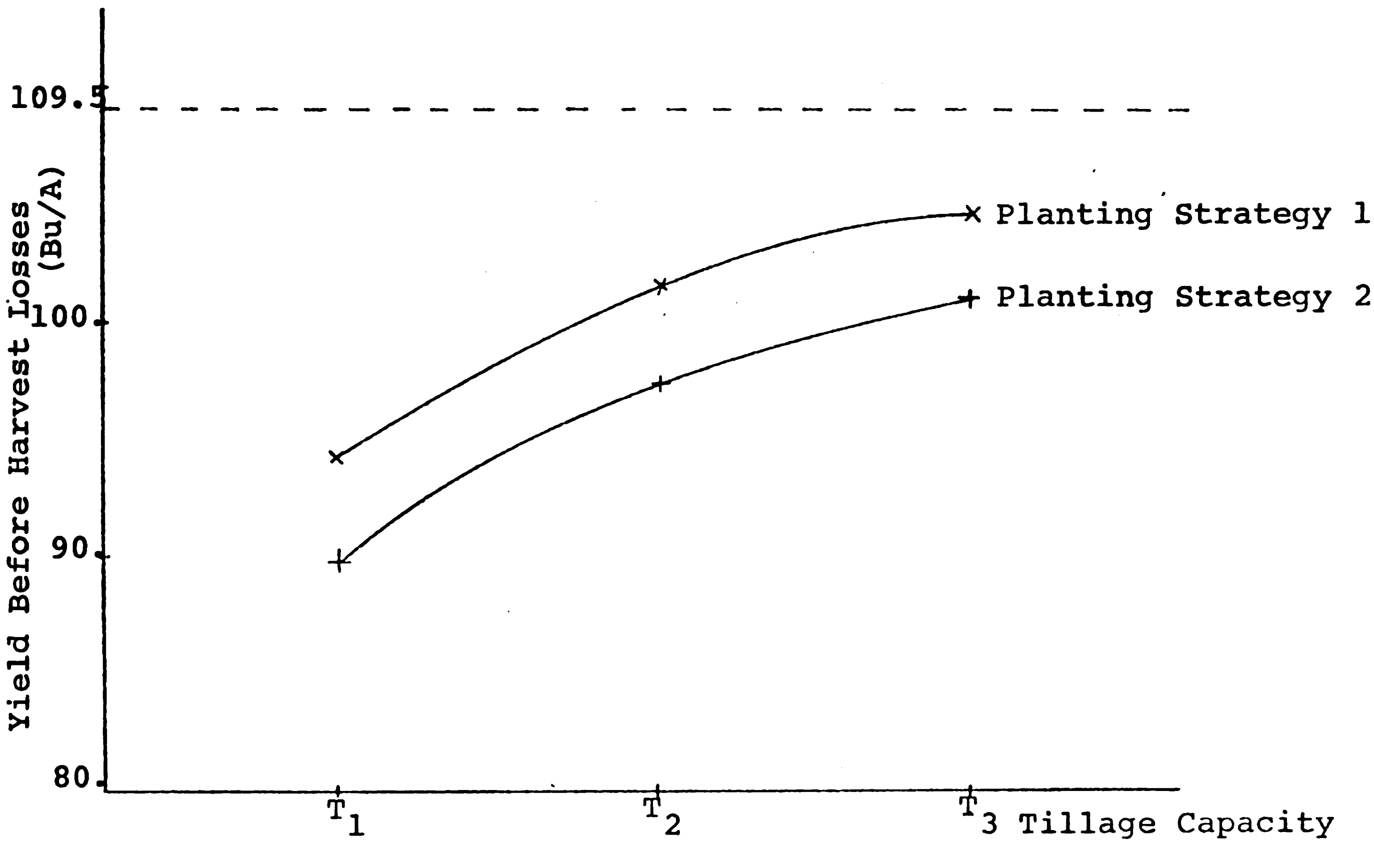

Figure 5.--Yield Before Harvest Losses at Different Tillage Capacities.

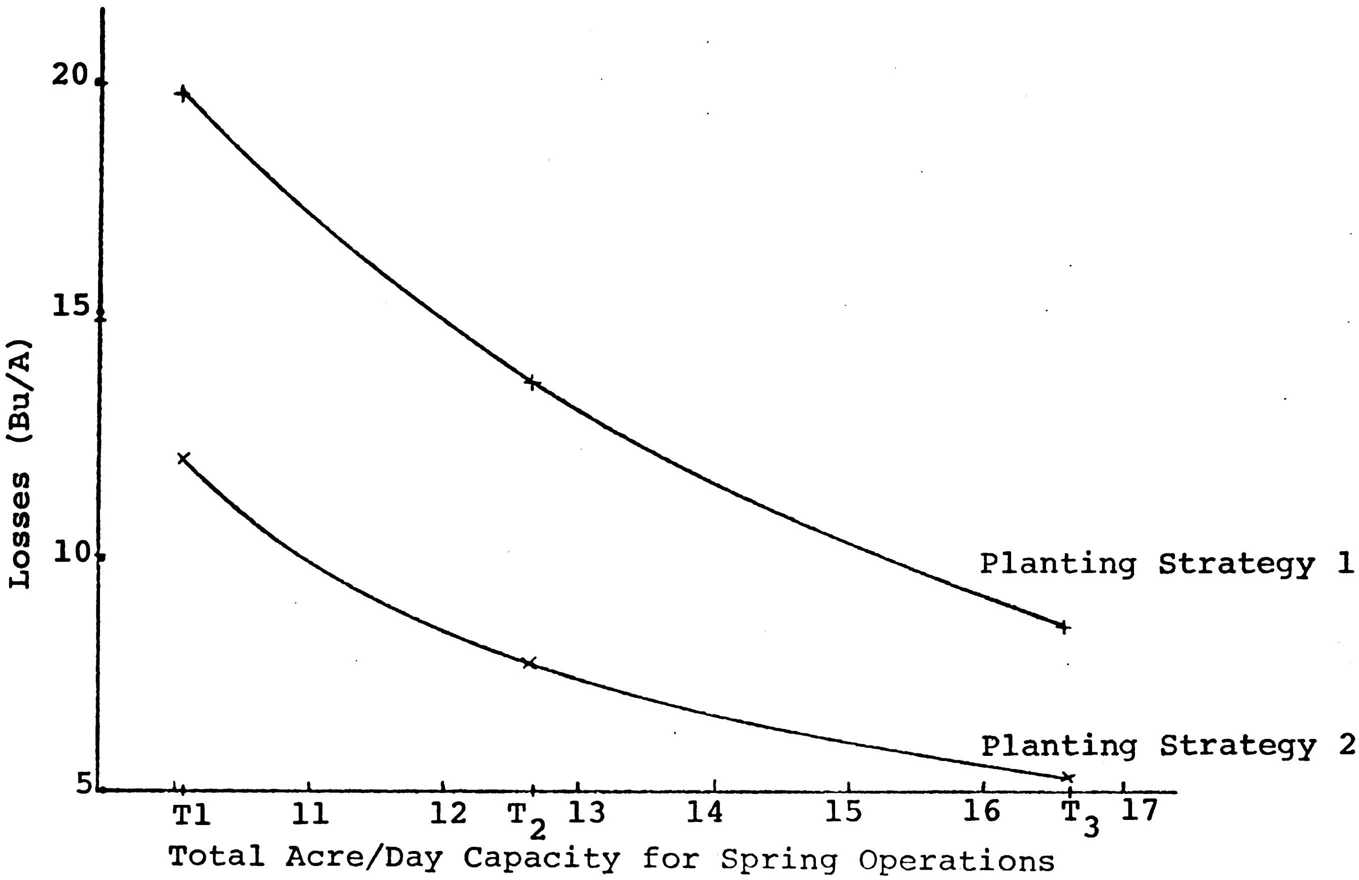

Figure 6.--Timeliness Losses Due to Tillage Capacity.

respectively, therefore, the lowest drying costs are recorded for these combinations (Figures 9 and 10).

As tillage and harvest capacities are varied there is always a tradeoff between harvest losses and drying costs. The tradeoff could be found, but we cannot make a definite statement about the farmer's utility of harvest losses against drying costs.

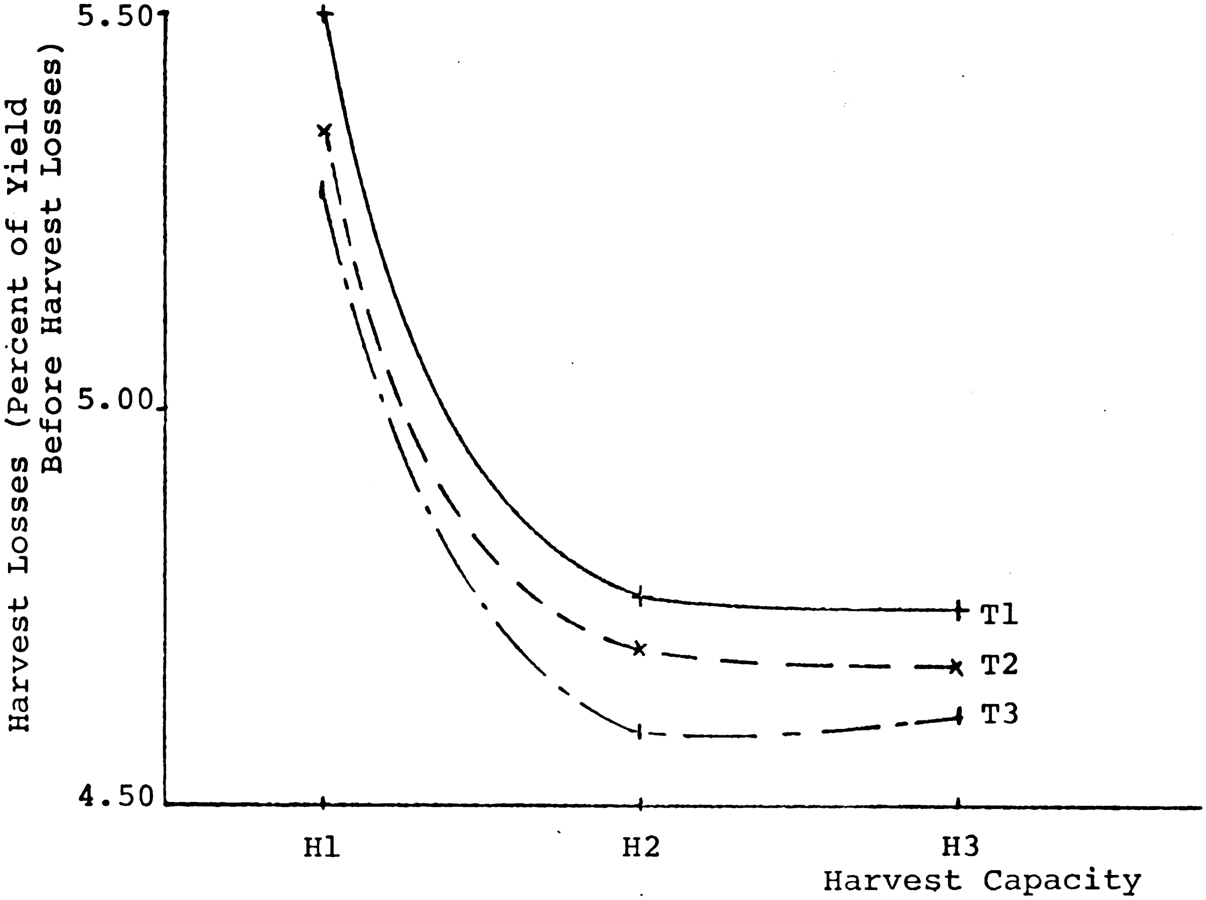

Figure 7.--Timeliness Losses Due to Harvest Capacity at Different Tillage Capacities (Planting Strategy 1).

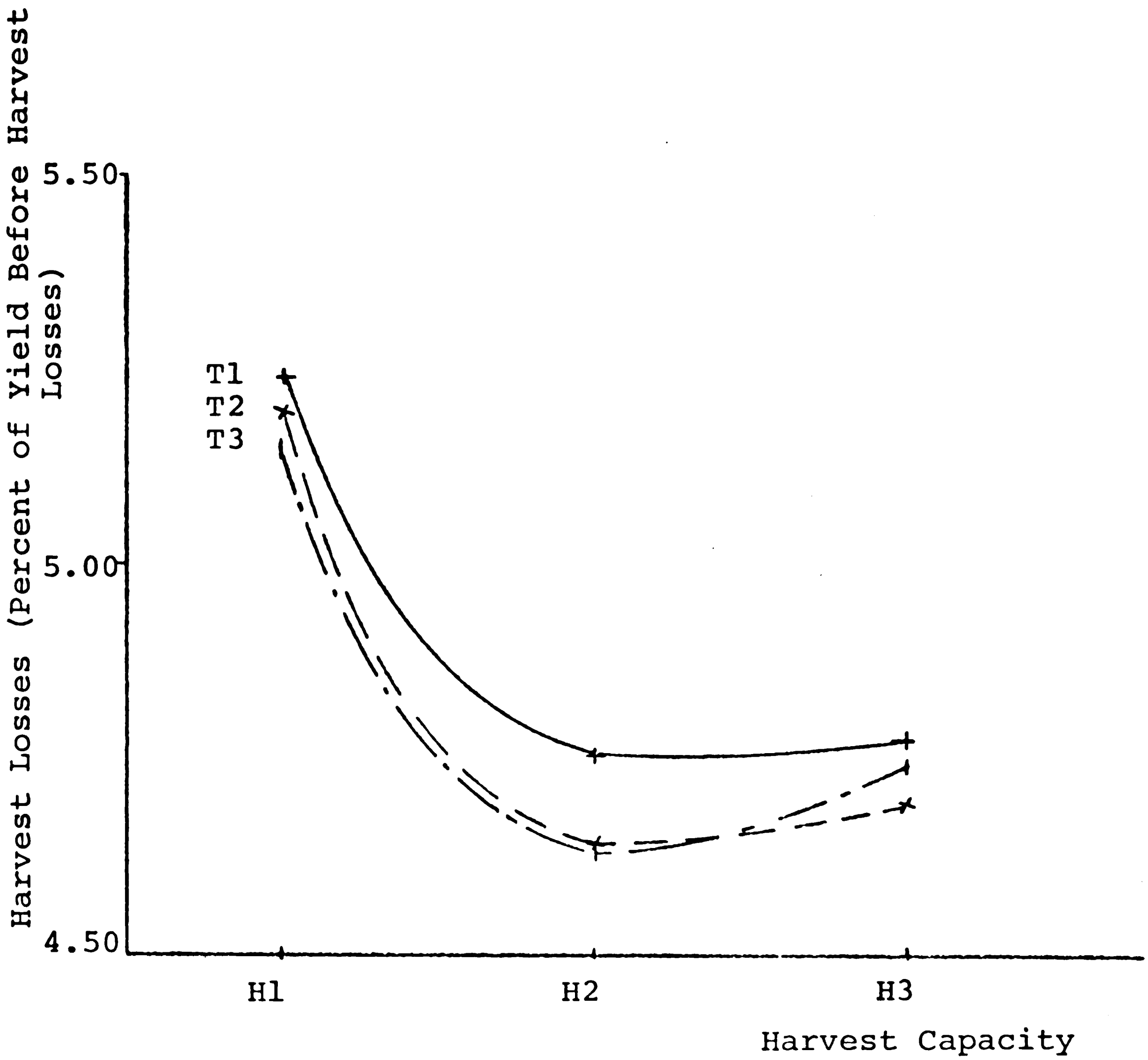

Figure 8.--Timeliness Losses Due to Harvest Capacity at Different Tillage Capacities (Planting Strategy 2).

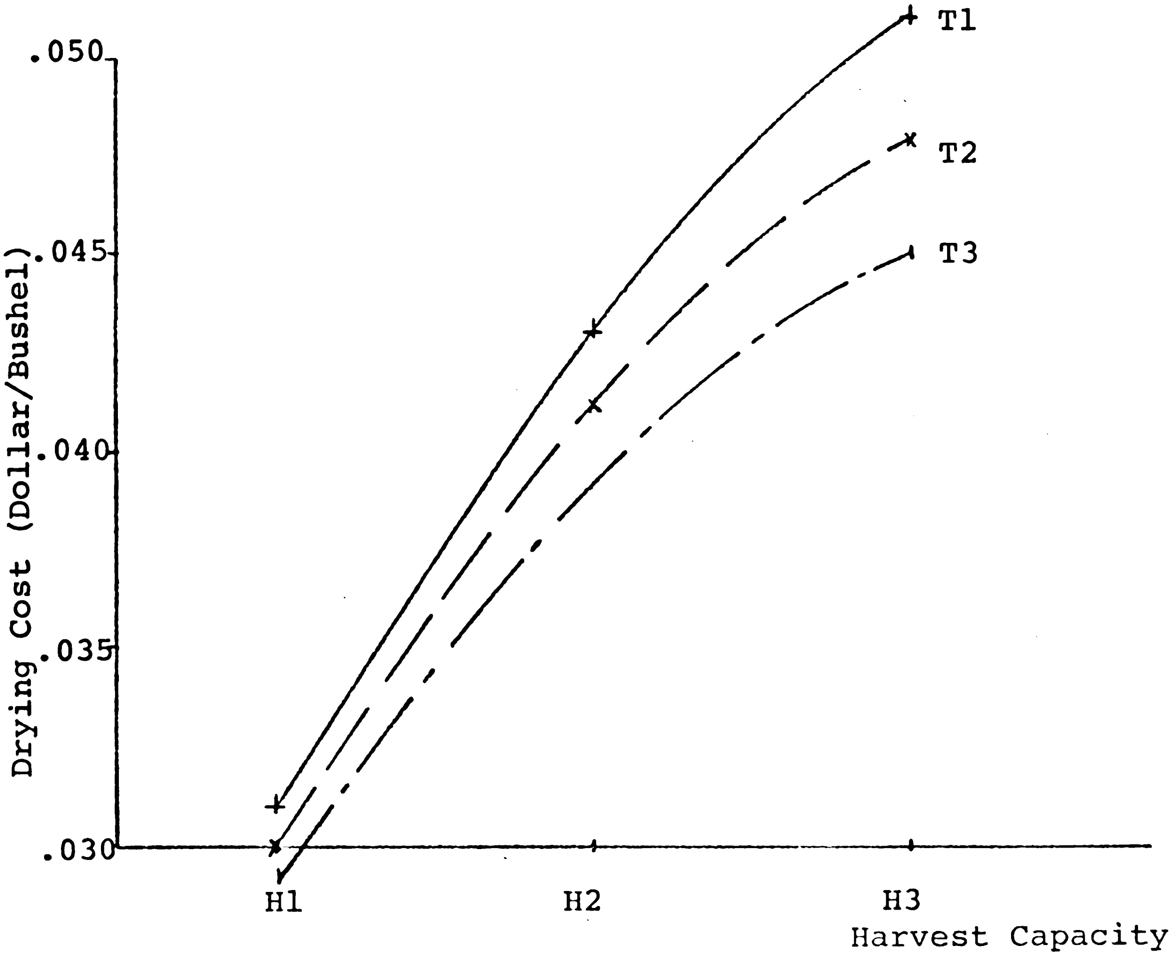

Figure 9.--Drying Costs at Different Machine Capacity Combinations (Planting Strategy 1).

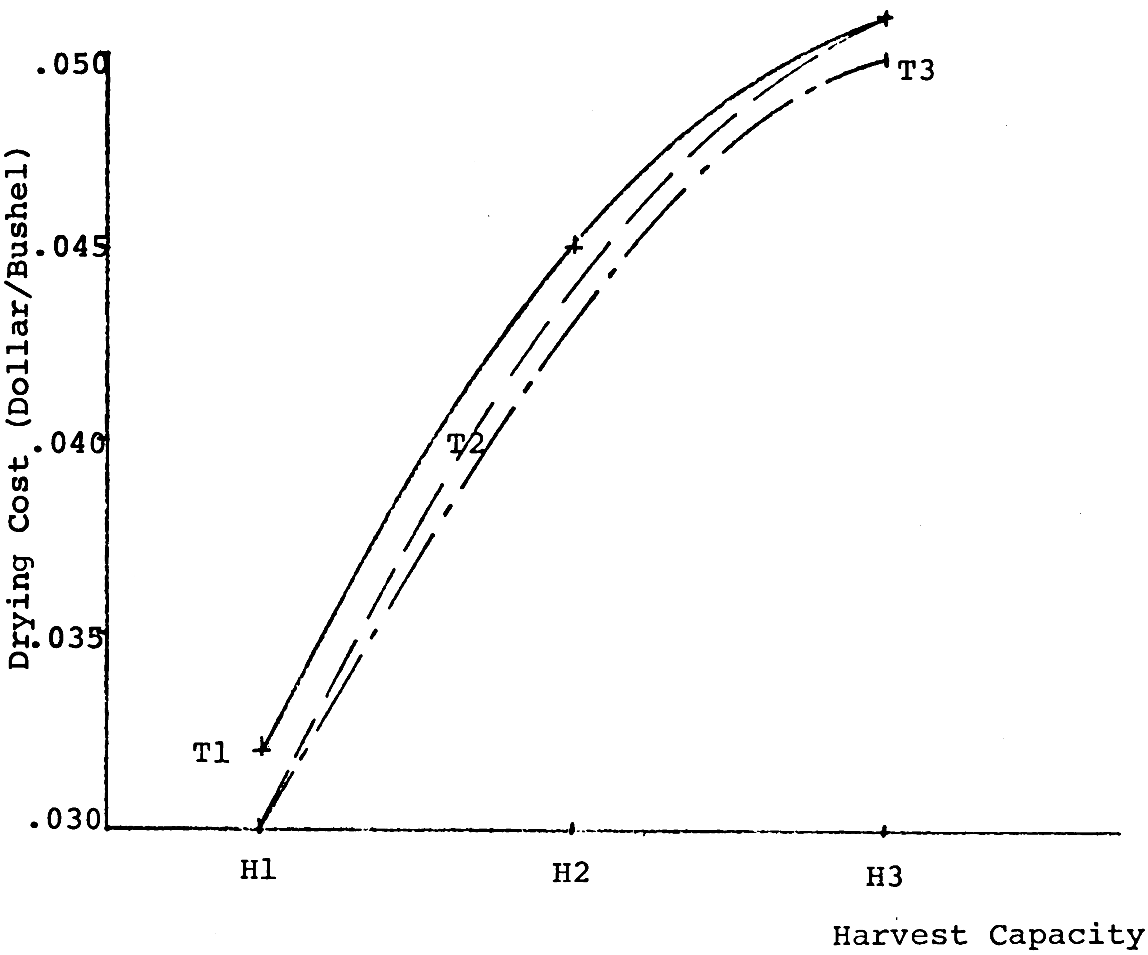

Figure 10.--Drying Costs at Different Machine Capacity Combinations (Planting Strategy 2).

CHAPTER VI

STOCHASTIC GENERATION OF WORK NO-WORK DAYS

The procedure for labeling the days as work or no-work day, which was described in Chapter 3 requires the use of weather data throughout the simulation period. Machine storage of the weather inputs and the required soil moisture budget is costly for computer calculations. The purpose of the stochastic generation of work, no-work days was to reduce the time spent on data evaluation either manually or by computer. If the stochastic generation of work, no-work days could be proven feasible, work, no-work conditions could be characterized very concisely for different localities via the values of their stochastic parameters.

The World Meteorological Organization recommends (Selirio and Brown, 1972) the use of at least 30 years of data for good estimation of weather related probabilities. Feyerharm, et al., (1966) published wet and dry day probabilities in Michigan by using weather records starting from 1886 for some locations. This climatological model gives the initial and transition probabilities for a year determined by a Markov chain probability model. Strommen, *et al.*, (1966) prepared a bulletin for farmers' use in Michigan based on Feyerharm's (1966) work.

6.1 Procedure

The following scheme was proposed for the stochastic generation of work, no-work days:

1. Generate Stochastically:
   a. The number of days from March 1 to soil thawing,
   b. The number of days from March 1 to the first occurence of soil temperature exceeding 50°F,
   c. The number of days from December 1 to soil freezing.
2. Generate and distribute the work days between soil thawing and soil freezing.

Properties of the values in 1. were found utilizing the tractability model and 16 years of weather data (Dearborn-Detroit). These values were generated assuming that they were normally distributed. The means and standard deviations of the numbers of days for the 16 years of weather data are shown in Table 10.

For the generation of work days between the dates of soil thawing and soil freezing 15-day periods were used. This was done to capture the known persistency in work, no-work sequences (Holtman, 1973). Panol (1972) reported that for his weather simulation based on the utilization of the "rain, no-rain state" on the previous day (first order

Table 10.--Estimated Means and Standard Deviations for the Number of Days in Critical Periods (16 Years of Data).

	Mean	Standard Deviation
March 1 to Thawing	13.60	9.36
March 1 to the First Occurence of Soil Temperature Greater than 50°F	31.93	9.52
December 1 to freezing	46.50	18.17

Markov assumption) some inadequacies in capturing the persistency of rain, no-rain sequences existed. Starting from March 1, which is the beginning of the simulated meteorological year, the year was divided into 15-day periods. The use of the tractability model for tractability criterion 2 (December 26 to August 27), and tractability criterion 1 (August 28 to December 25) yielded the values given in Table 11 for 16 years of data (Dearborn-Detroit).

The first attempt was to assume a normal distribution for work days in the 24 15-day periods as was done for the generation of yield values in Chapter 4.

Table 11.--Means, Standard Deviations, and Correlation Coefficients of Work Days in 24 15-Day Periods.

Starting Date of Period	Mean	Standard Deviation	Correlation Coefficient
301	0.0	0.0	0.0
316	0.0	0.0	0.0
331	1.19	1.91	0.040
415	3.75	3.26	-0.015
430	7.00	4.21	0.285
515	9.75	3.84	-0.466
530	10.81	2.23	-0.081
614	10.13	3.18	0.623
629	11.86	2.36	0.068
714	11.69	2.24	0.236
729	10.25	2.30	0.093
813	11.06	3.04	0.223
828	12.06	2.14	0.390
912	11.56	2.19	0.150
927	11.31	3.28	0.354
1012	12.18	2.07	0.198
1027	10.75	2.23	0.065
1111	7.43	3.08	0.131
1126	2.50	3.39	-0.203
1211	1.63	4.06	0.860
1226	2.81	6.05	0.899
110	3.94	6.10	0.658
125	7.88	7.46	0.833
209	10.13	6.59	

The results in terms of means, standard deviations, and correlation coefficients after 1000 repetitions were satisfactory. However, due to the large magnitude of the standard deviations, the number of work days in individual 15-day periods often fell outside the interval (0, 15). Therefore, the assumption of normality was abandoned.

The Beta was then considered since it is bounded on the positive real line (0, 1). Naylor, et al., (1968) state that the beta distribution is the distribution of the ratio of two gamma variables with identical values of α and parameters k_1 and k_2 respectively. α and k can be seen in the following:

$$f(x) = \begin{cases} \dfrac{\alpha^k x^{k-1} e^{-\alpha x}}{(k-1)!}, & \alpha>0,\ k>0,\ x\geq 0 \\ 0 & x<0 \end{cases} \quad \text{(Gamma Distribution).}$$

The beta variable is then given by:

$$x = \frac{x_1}{x_1 + x_2}, \quad 0<x<1$$

where:

x = beta variable

x_1 = gamma variable with parameter k_1

x_2 = gamma variable with parameter k_2

(This can be proven by convolution (Feller, 1971)).

Equating means and standard deviations of work days in the 15-day periods to the beta mean and standard deviation resulted in k_1 and k_2 values which were non-integers. Since there is a great deal of difficulty associated with generating gamma random variables with non-integer parameters, further work in this direction was terminated.

6.1.1 A Stochastic Work, No-Work Days Model

We made the assumption that the number of working days in successive 15-day periods were independent random variables. Results of a test of this assumption are given in 6.2.1. The probability distribution of number of work days was assumed to be characterized by the following density for each period:

$$f_{NWD_i}(NWD_i) = \begin{cases} a_{i/5} & 0 < NWD_i \leq 5 \\ b_{i/5} & 5 < NWD_i \leq 10 \\ c_{i/5} & 10 < NWD_i \leq 15 \end{cases}$$

where:

$i = 1, \ldots, 24$ period numbers

NWD_i = number of work days in period i

$c_i = 1 - a_i - b_i$

With the aid of the definitions of mean and variance for a continuous random variable the following relationships must hold if we require the mean and standard deviation of the stochastically generated number of days to be equal to the data of Table 10:

$$\mu_i = \int_0^5 \frac{a_i}{5} x dx + \int_5^{10} \frac{b_i}{5} x dx + \int_{10}^{15} \frac{1-(a_i+b_i)}{5} x dx$$

$$\sigma_i^2 = \int_0^5 \frac{a_i}{5} (x-\mu_i)^2 dx + \int_5^{10} \frac{b_i}{5} (x-\mu_i)^2 dx + \int_{10}^{15} \frac{[1-(a_i+b_i)]}{5} (x-\mu_i)^2 dx$$

where: $i = 1, \ldots, 24$ period numbers

μ_i = mean number of work days in period i

σ_i^2 = variance of work days in period i

Solving simultaneously the a_i's and b_i's can then be computed by:

$$a_i = \frac{275 - 15\mu_i - 3\mu_i^2 + 3\sigma_i^2}{3(50 + 20\mu_i)}$$

$$b_i = \frac{25 - 2\mu_i - 20a_i}{10}$$

The computer generation of the random variables was made using the inverse transformation technique (Naylor, et al., 1968), i.e., the cumulative distribution function is:

$$F_{NWD_i}(NWD_i) = \begin{cases} 0 & NWD_i \leq 0 \\ \dfrac{a_i\ NWD_i}{5} & 0 < NWD_i \leq 5 \\ \dfrac{b_i\ NWD_i}{5} - b_i + a_i & 5 < NWD_i \leq 10 \\ 3(a_i+b_i) - 2 + \dfrac{(1-a_i-b_i)}{5}\ NWD_i & 10 < NWD_i \leq 15 \\ 1 & NWD_i > 15 \end{cases}$$

and NWD_i can be computed by:

$$NWD_i = \begin{cases} 5R/a_i & R \leq a_i \\ (R + b_i - a_i)5/b_i & a_i < R \leq a_i + b_i \\ (R - 3(a_i+b_i) + 2)5/(1-a_i-b_i) & \text{otherwise} \end{cases}$$

where:

R is (0,1) uniform random variate.

6.2 Results

In Table 12 the computed values of a and b are shown. To have a valid probability distribution function the following relationships must hold:

$$0 \leq a_i \leq 1$$

$$0 \leq b_i \leq 1$$

$$0 \leq 1 - a_i - b_i \leq 1$$

Excluding the trivial periods beginning March 1 and March 16, it was concluded that the 15-day periods outside of the time interval April 15 to November 25 could not be described by the assumed probability distribution function. Although negative a values do occur during the period April 15 to November 25, they are small in magnitude. Smoothing of the a values (See Figure 11) would eliminate all of the difficulties. Thus it was concluded that the stochastic model was adequate for the time period April 15 to November 25. The histogram for the period beginning January 25 (See Figure 12) illustrates the difficulty for the periods where the assumed probability distribution fits poorly. The histograms for these periods have peaks at zero and fifteen. A Markov chain model might be appropriate to describe this situation as the number of working days in successive periods are not independent for these periods (Section 6.2.1).

6.2.1 Test of Independence of Work Days in 15-Day Periods

To test the independence of numbers of work days for successive in 15-day periods a version of Spearman's Rho test, the Hotelling-Pabst test (Conover, 1971) was used for the periods between April 15 and November 25 as well as the

Table 12.--Parameters of Stochastic Tractability Model

Starting Date of Period	a	b	"Smoothed" Values of a
301	1.833	-1.167	-
316	1.833	-1.167	-
331	1.459	- .656	-
415	.826	.097	.826
430	.368	.364	.368
515	.129	.291	.129
530	-.054	.446	.0
614	.036	.403	.036
629	.015	.094	.015
714	-.009	.181	.0
729	-.060	.570	.0
813	.041	.205	.041
828	.013	.067	.013
912	-.022	.231	.0
927	.083	.072	.083
1012	.015	.032	.015
1027	-.055	.461	.0
1111	.154	.705	.154
1126	1.187	-.375	-
1211	1.566	-.958	-
1226	1.598	-1.258	-
110	1.314	-.915	-
125	1.035	-1.145	-
209	.703	-.930	-

other periods. The test statistic for the Hotelling-Pabst test is given by:

$$T = \sum_{j=1}^{16} [R(NWD_i) - R(NWD_{i+1})]^2, \quad i = 1,...,13$$

where:

i = corresponds to the periods between April 15 and November 25

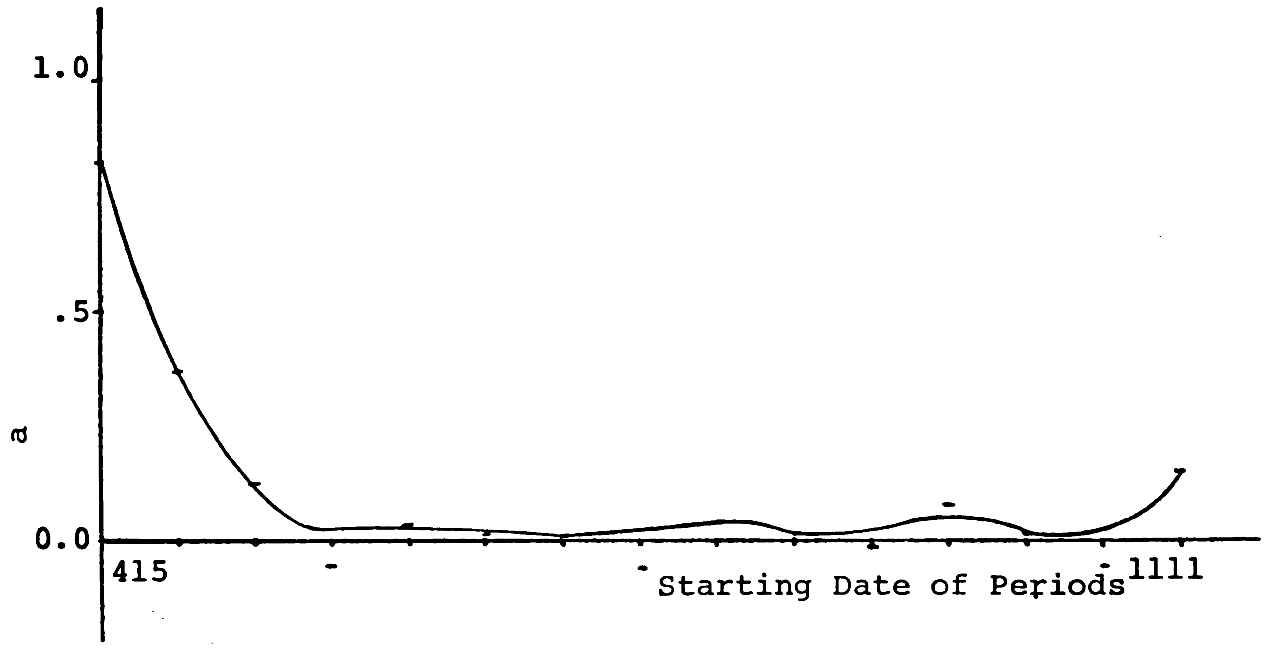

Figure 11.--Smoothing Tractability Parameters.

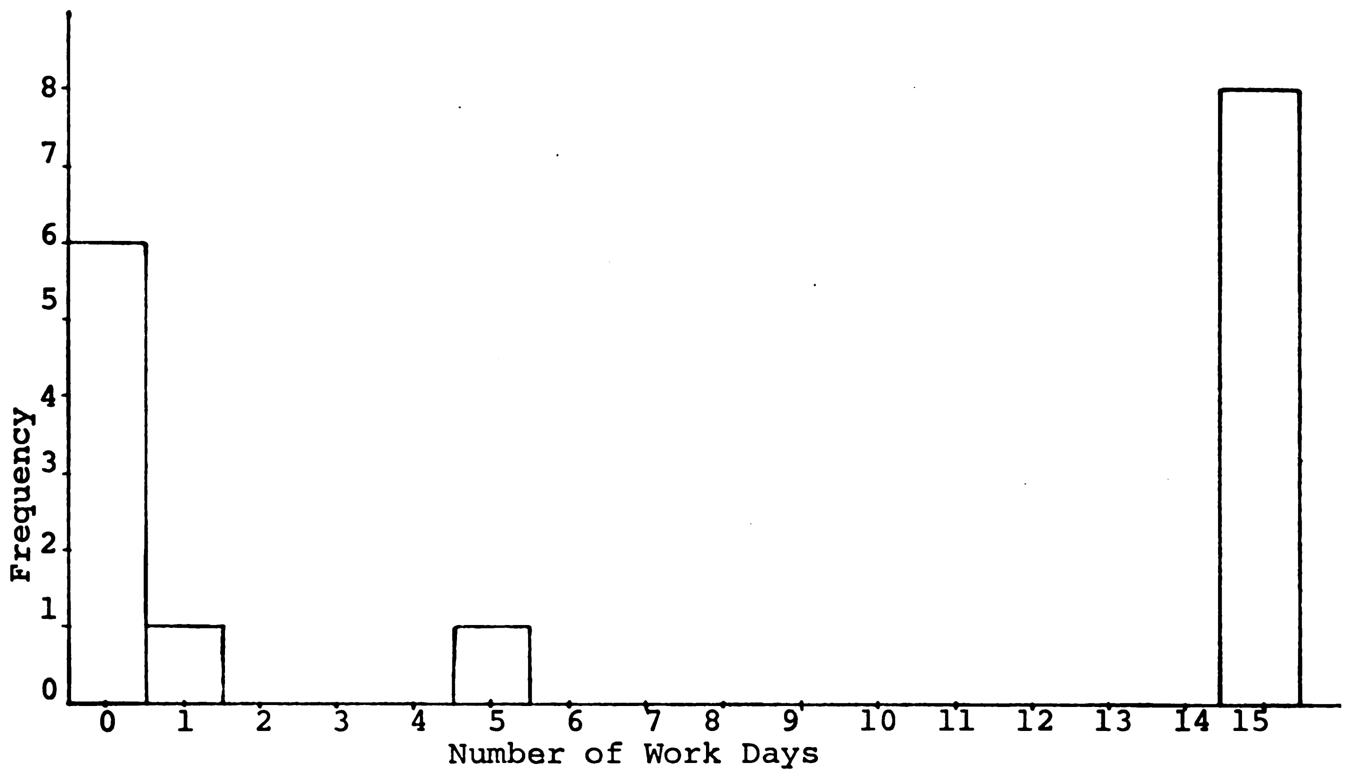

Figure 12.--Histogram of Work Days for the Period January 25-February 8.

$R(NWD_i)$ = rank of the number of days in period i.

j = 1,..., 16 year index (between 1953-1968).

The hypothesis was:

H_o : number of working days in two consecutive 15-day periods are mutually independent

H_1 : H_o is not true,

H_o is rejected if $\alpha/2$ quantile of T< observation of T.

Table 13 gives the results of this test. It was concluded that H_o should not be rejected for the period April 15 - November 15.

The test was also applied to the remaining periods and H_o was rejected in every case (the test is not applicable for the periods beginning March 1 and March 16).

Table 13.--Hotelling-Pabst Test Statistic.

Starting Date of Periods	$T = \sum_{j=1}^{16} [R(X_i) - R(Y_i)]^2$	α	Decision
415,430	668	.05	Do not reject H_o
430,515	526.50	.05	Do not reject H_o
515,530	957	.05	Do not reject H_o
530,614	588	.05	Do not reject H_o
614,629	265	.05	Reject H_o
629,714	604	.05	Do not reject H_o
714,729	477.25	.05	Do not reject H_o
729,813	588	.05	Do not reject H_o

Table 13.--Continued.

Starting Date of Periods	$T = \sum_{j=1}^{16} [R(X_i) - R(Y_i)]^2$	α	Decision
813,828	483.50	.05	Do not reject H_o
828,912	341.50	.05	Do not reject H_o
912,927	656	.05	Do not reject H_o
927,1012	397.50	.05	Do not reject H_o
1012,1027	476	.05	Do not reject H_o
1027,1111	975	.05	Do not reject H_o

.025 quantile of T = 340

.01 quantile of T = 250

CHAPTER VII

SUMMARY AND CONCLUSIONS

The necessary models for the components of a corn production system were developed to investigate timeliness losses incurred in corn production. Special attention was focused on tractability conditions of the fields. Simulations were made with 16 years of weather data for nine different machine capacity combinations on a hypothetical 200 acre farm in Southeast Michigan.

The model for tractability is deterministic and was developed using only weather and soil property data. Work, no-work conditions are obtained as model output for each day as a tractability state. Verification of the model was made utilizing weather data and work, no-work records from three Northern Indiana farms. Tractability model output proved to be in quite good agreement with the farmers' records of work, no-work conditions. Total work days were in error by one day for spring and a maximum of three days for fall operations.

The yield values (Bushel per acre) were generated stochastically. Generation was made for five consecutive planting periods between April 16 and June 11. The yield value of each planting period was assumed to be distributed normally and correlated to the previous period's yield value. Statistics for the stochastic generation were estimated from Michigan corn yield data.

Two different planting strategies were considered: 1) finishing the ploughing and harrowing for 200 acres and then planting, 2) finishing ploughing and harrowing for the first field (each field is 40 acres) and planting it, and continuing in the same manner for the remaining four fields.

Planting date timeliness losses due to tillage capacity were dominant to those caused by harvesting capacity for planting strategy 1. Timeliness losses for planting strategy 1 due to tillage capacities were 19.76, 13.77, and 8.54 Bu/A for 3-bottom plough and 10 ft disc harrow (55 HP tractor), 4-bottom plough and 13 ft disc harrow (75 HP tractor), and 6-bottom plough and 18 ft disc harrow (110 HP tractor), respectively. Planting strategy 2 caused lower timeliness losses due to tillage capacity than planting strategy 1. The losses were 12.06, 6.94, and 5.03 Bu/A for planting strategy 2 at the same conditions. Harvest losses were close to each other (lower for planting strategy 2) for each planting strategy and varied from 4.59 to 5.50 percent of yield before harvest losses for different tillage and harvesting capacity combinations. Generally

decreasing drying costs and increasing harvest losses were observed with decreasing harvest capacities.

A stochastic model of work, no-work days was developed. Probability densities were assumed for the number of work, no-work days in successive 15-day periods of the year. The parameters of the densities were estimated employing simulation results obtained utilizing the deterministic tractability model. The stochastic simulation was satisfactory for the period April 15 - November 25.

The following conclusions were derived from the results of this study:

1. The tractability model is adequate for corn production simulation and its use should be extendable to other crops and other locations.

2. The yield model is sufficient to represent the real yield values.

3. Planting date timeliness losses dominate those associated with harvest losses.

4. Stochastic generation of work, no-work days appears feasible but needs further development to cover the entire year.

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APPENDICES

APPENDIX A

VARIABLE STORAGE ALLOCATION FOR CORN

PRODUCTION SYSTEMS ANALYSIS

VARIABLE STORAGE ALLOCATION
FOR
CORN PRODUCTION SYSTEM ANALYSIS
(VERSION TULU)

THE FOLLOWING IS AN ALLOCATION OF STORAGE FOR THE VARIABLES IN THE SYSTEM MODEL

X = F (X, E, I) . WHERE,

I = TIME, DAY
X = SYSTEM STATE VECTOR AT ANY TIME I
E = SYSTEM INPUT VECTOR OVER TIME INTERVAL
F = VECTOR TRANSFORMATION FUNCTIONAL PRODUCING NEW VALUES OF X AT ANY TIME I + 1

ANY VARIABLE OF THE SYSTEM STATE VECTOR IS DESIGNATED X(J) AND ANY VARIABLE OF THE SYSTEM INPUT VECTOR IS DESIGNATED E(K).

TIME VARIABLE

IDATE A 6 DIGIT INTEGER NUMBER (MONTH DAY YEAR, IE. 100867 IS FOR OCTOBER 8, 1967), WHICH IS THE FIRST THING COMPUTED FOR EACH DAY'S RUN.

VARIABLE LOCATION IN SYSTEM STATE VECTOR

STATE VARIABLE, X(J)		DESCRIPTION
FROM J=	TO J=	
11	20	MAXIMUM AVAILABLE MOISTURE FOR EACH SOIL LAYER STARTING WITH THE SURFACE LAYER AND GOING DOWN, INCHES OF WATER.
21	30	ACTUAL SOIL MOISTURE/INCH OF SOIL STARTING WITH THE SURFACE LAYER, INCHES OF WATER
31		DESIGNATES TRACTABILITY CRITERION TO BE USED.

FROM J=	TO J=	
32		TRACTABILITY STATE. 0 IMPLIES NOT TRACTABLE. AND 1 IMPLIES TRACTABLE.
33		NUMBER OF SECTIONS IN FARM.
36		IN YIELD ROUTINE IF X(36)=0 ALL YIELD VALUES ARE GENERATED. IF X(36)=1 PROPER YIELD VALUES ARE PICKED. WHICH WERE GENERATED WHEN X(36)=0. FOR THE PLANTING PERIODS.
38		SUM OF TRACTABLE DAYS.
40		NUMBER OF DAYS SINCE MARCH 1. MARCH 1 BEING DAY NUMBER 1.
41	50	PRECIPITATION RECORD TO DAY AND PRECEEDING 9 DAYS. X(41) IS PRECIPITATION TODAY. X(42) IS YESTERDAY. X(50) IS 9 DAYS AGO.
51		HEAT UNITS ACCUMULATED FOR SOIL FREEZING AND THAWING.
52		SOIL STATE. 0 IMPLIES SOIL IS FROZEN. 1 IMPLIES SOIL IS THAWED. 2 LOCATES THE STARTING DATE OF SOIL FREEZING.
53		SOIL TEMPERATURE INDICATOR. 0 IMPLIES SOIL TEMPERATURE IS LESS THAN 50 F DEGREES. 1 IMPLIES GREATER THAN OR EQUAL TO 50 F DEGREES. 2 LOCATES THE DATE IN WHICH SOIL TEMPERATURE IS RAISED ABOVE 50 F DEGREES.
54		SOIL TEMPERATURE. IN FAHRENHEIT DEGREES.
55		IT IS USED IN ROUTINE SURFIS CORRESPONDING TO THE INITIAL VALUE OF VARIABLE STINT.
56		IN PLOUGHING. HARROWING. PLANTING. AND HARVESTING INDICATES. IF -1 DAY'S WORK DONE SECTION NOT FINISHED. IF 0 DAY'S WORK DONE SECTION FINISHED. IF 1 DAY'S WORK DONE SECTION FINISHED. BUT THERE IS AN EXTRA CAPACITY TO BE USED FOR THE NEXT SECTION ON THE SAME DAY. IF 2 NONE OF THE ABOVE.

FROM J=	TO J=	
57		IT KEEPS TRACK OF THE SECTION BEING HARVESTED.
101		DESIGNATES THE SECTION TO BE WORKED ON.
102		REMAINING NON-WORKED PART OF CURRENT SE+TION. ACRES.
103		EXCESS WORKING CAPACITY AFTER FINISHING THE CUR- RENT SECTION. TO BE USED ON ANOTHER SECTION ON THE SAME DAY. ACRES.
104		TOTAL HORSEPOWER-HOURS FOR COMBINING.
105		NUMBER OF WORKING HOURS PER DAY PER WORKER.
106		COST OF GASOLINE. DOLLAR/GALLON.
107		COST OF DIESEL FUEL. DOLLAR/GALLON.
108		COST OF LPG. DOLLAR/GALLON.
110		LAST TWO DIGITS OF IDATE (YEAR).
111		STARTING YEAR OF SIMULATION (LAST TWO DIGITS)
112		DIFFERENCE OF CURRENT AND STARTING YEAR.
113		ANNUAL USE OF TRACTORS FOR PLOUGHING (IN HOURS).
114		TOTAL PLOUGHING LABOR (DOLLARS).
115		TOTAL FUEL AND LUBRICANT COSTS FOR PLOUGHING
116		TOTAL REPAIR COSTS FOR PLOUGHING.
117		TOTAL VARIABLE COSTS FOR PLOUGHING.
118		TOTAL HORSEPOWER-HOURS FOR HARROWING.
119		ANNUAL USE OF TRACTORS FOR HARROWING (IN HOURS).
120		TOTAL HARROWING LABOR (DOLLARS).

FROM J=	TO J=	
121		TOTAL HARROWING FUEL AND LUBRICANT COSTS (DOLLARS)
122		TOTAL REPAIR COSTS FOR HARROWING (DOLLARS).
123		TOTAL VARIABLE COVTS FOR HARROWING (DOLLARS).
124		TOTAL HORSEPOWER-HOURS FOR PLANTING.
125		ANNUAL USE OF TRACTORS FOR PLANTING (IN HOURS).
126		TOTAL PLANTING LABOR (DOLLARS).
127		TOTAL PLANTING FUEL AND LUBRICANT COSTS (DOLLARS).
128		TOTAL REPAIR COSTS FOR PLANTING (DOLLAR).
129		TOTAL VARIABLE COSTS FOR PLANTING (DOLLARS).
130		SEED COST PER ACRE (DOLLARS).
131		TOTAL SEED COSTS (DOLLARS).
201	300	AREA OF SECTIONS , ACRES.
301	400	DATE OF PLANTING.
701	800	DATE OF PHYSIOLOGICAL DEATH (MAXIMUM DRY WEIGHT OR FIRST KILLING FROST).
1001	1100	GROWING DEGREE DAYS (BASE 50F) ACCUMULATED SINCE EMERGENCE.
1101	1110	LABOR COST FOR EACH TRACTOR FOR PLOUGHING.
1111	1120	FUEL AND LUBRICANT COSTS FOR EACH TRACTOR FOR PLOUGHING (DOLLAR/HOUR).
1121	1130	INITIAL (LIST PRICE) COST OF TRACTORS. DOLLAR.
1131	1140	TOTAL FUEL AND LUBRICANT COSTS FOR PLOUGHING FOR EACH TRACTOR (DOLLARS).
1141	1150	TOTAL ACCUMULATED REPAIR COSTS (TAR) FOR TRACTORS

FROM J=	TO J=	
		FOR PLOUGHING (DOLLARS).
1151	1160	HOURLY REPAIR COSTV FOR EACH TRACTOR FOR PLOUGHING
1161	1170	INITIAL (LIST PRICE) COST OF PLOUGHS.
1181		TOTAL DEPRECIATION FOR PLOUGHS(DOLLARS).
1182		OTHER FIXED COSTS FOR PLOUGHS (DOLLARV).
1183		TOTAL DEPRECIATION FOR HARROWS (DOLLARS).
1184		OTHER FIXED COSTS FOR HARROWS (DOLLARS).
1185		TOTAL DEPRECIATION FOR PLANTERS (DOLLARS).
1186		OTHER FIXED COSTS FOR PLANTERS (DOLLARS).
1187		TOTAL FIXED COSTS FOR SPRING OPERATIONS.
1188		TOTAL VARIABLE COSTS FOR SPRING OPERATIONS.
1189		TOTAL EXPENSES FOR SPRING OPERATIONS.
1190		COST PER ACRE FOR VPRING.
1191		LABOR HOURS FOR SPRING.
1192		SPRING OPERATIONS COST PER HOUR.
1193		TOTAL SALVAGE VALUE OF COMBINES (DOLLARS).
1194		TOTAL SALVAGE VALUE OF TRACTORS (DOLLARS).
1195		TOTAL SALVAGE VALUE OF PLOUGHS (DOLLARS).
1196		TOTAL SALVAGE VALUE OF HARROWS (DOLLARS).
1197		TOTAL SALVAGE VALUE OF PLANTERS (DOLLARS).
1198		MARKET VALUE OF CORN (DOLLAR/BUSHEL).

FROM J=	TO J=	
		PLANTING•MPH•
1211	1220	NUMBER OF PLOUGH BOTTOMS FOR EACH PLOUGH•
1221	1230	BOTTOM WIDTHS (INCHES)•
1231	1240	FIELD EFFICIENCIES FOR PLOUGHING• HARROWING HAS THE SAME EFFICIENCY VALUES•
1241	1250	WIDTH OF HARROWS• FEET (DISC HARROWS)•
1251	1260	NUMBER OF ROWS OF PLANTERS•
1261	1270	FIELD EFFICIENCIES FOR PLANTING•
1271	1280	HORSEPOWER REQUIREMENTS FOR EACH TRACTOR PLOUGH COMBINATION•
1281	1290	HORSEPOWER-HOURS FOR EACH PLOUGH TRACTOR COMBINATION•
1291	1300	ACCUMULATIVE USE OF TRACTORS FOR PLOUGHING (HOURS)
1301	1400	THIS ARRAY RECORDS THE SECTION NUMBERS WHICH ARE ALREADY PLOUGHED• HARROWED• PLANTED AND HARVESTED•
1401	1410	COMBINE SPEEDS• MPH•(CONSTANT SPEED POLICY)•
1411	1420	TOTAL HORSEPOWER REQUIREMENTS FOR EACH COMBINE•
1421	1430	GROUND DRIVE HORSEPOWER FOR COMBINES•
1431	1440	HEADER HORSEPOWER FOR COMBINES•
1441	1450	CYLINDER-SEPARATOR HORSEPOWER FOR COMBINES•
1451	1460	GRAIN TANK UNLOAD HORSEPOWER FOR COMBINES•
1461	1470	HORSEPOWER-HOURS FOR EACH COMBINE FOR HARVESTING•
1501	1600	TRACTOR TO BE USED (AND ACCOMPANYING EQUIPMENT• IF PLOUGHS• HARROWS• PLANTERS)• INTEGER FROM 1 TO 10•

FROM J=	TO J=	
1601	1610	TOTAL ACCUMULATED REPAIR COSTS FOR TRACTORS (TAR) FOR PLANTING (DOLLARS).
1611	1620	INITIAL (LIST PRICE) COSTS OF PLANTERS (DOLLARS).
1621	1630	HOURLY REPAIR COSTS FOR PLANTING (DOLLARS).
1701	1800	CURRENT GRAIN MOISTURE CONTENT (EQUAL TO HARVEST MOISTURE CONTENT AFTER HARVEST). DECIMAL FRACTION. WET BASIS.
1801	1900	VARIETY PLANTED. INTEGER FROM 1 TO 25.
1901	2000	SEED COSTS OF SECTIONS.
2001	2100	MAXIMUM AVERAGE YIELD (FOR THE BEST PLANTING PERI OD (BUSHEL/ACRE).
2101	2200	LODGING. DECIMAL FRACTION.
2201	2300	DATE OF HARVEST OF SECTIONS.
2301	2310	LABOR EXPENSE FOR EACH TRACTOR FOR HARROWING.
2311	2320	COST OF FUEL AND LUBRICANTS FOR EACH TRACTOR FOR HARROWING.
2321	2330	TOTAL ACCUMULATED REPAIR COSTS (TAR) FOR HARROWING
2331	2340	INITIAL (LIST PRICE) COST OF HARROWS (DOLLARS).
2341	2350	HOURLY REPAIR COSTS FOR HARROWING.
2351	2360	HORSEPOWER REQUIRED FOR PLANTING BY EACH TRACTO-.
2361	2370	HORSEPOWER-HOURS BY EACH TRACTOR FOR PLANTING.
2371	2380	ACCUMULATIVE USE OF TRACTORS FOR PLANTING (HOURS).
2381	2390	LABOR EXPENSE FOR EACH TRACTOR FOR PLANTING.
2391	2400	COST OF FUEL AND LUBRICANTS FOR EACH TRACTOR FOR PLANTING (DOLLARS).

FROM J=	TO J=	
2501	2600	PREHARVEST LOSSES FOR SECTIONS (FRACTION OF LODGING).
2601	2700	GATHERING LOSSES FOR SECTIONS. EQUIV. BU./ACRE.
2701	2800	CYLINDER LOSSES FOR SECTIONS. EQUIV. BU./ACRE.
2801	2900	SEPARATION LOSSES FOR SECTIONS. EQUIV. BU./ACRE.
2901	3000	ACTUAL MACHINE YIELD (GRAIN TO HARVESTER BIN). EQUIV. BU./ACRE.
3001	3010	HORSEPOWER REQUIRED FOR EACH TRACTOR FOR HARROWING.
3011	3020	HORSEPOWER-HOURS FOR EACH TRACTOR FOR HARROWINGC
3021	3030	ACCUMULATIVE USE OF TRACTORS FOR HARROWING (HOURS)
3031	3040	SALVAGE VALUE OF PLANTERS IN DOLLARS.
3101	3200	YIELD HAVING REMOVED VARIETY. MOISTURE STRESS EARLY MATURITY LOSS. EQUIV. BU./ACRE.
3201		PART OF SECTION PLOUGHED. HARROWED. PLANTED OR HARVESTED AT THE END OF THE DAY. REMAINDER OF WHICH HAS NOT BEEN WORKED.
3501	3600	DRYING EXPENSE FOR EACH SECTION (DOLLARS).
3801	3825	DECIMAL FRACTION OF AVERAGE MAXIMUM YIELD (X(2001) TO X(2100)) POSSIBLE WITH VARIETY.
3826	3850	GROWING DEGREE DAYS (BASE 50F) REQUIRED FROM PLANTING TO PHYSIOLOGICAL MATURITY (MAXIMUM DRY WEIGHT) FOR VARIETY.
3901	4000	COMBINE TO BE USED. INTEGER FROM 1 TO 10.
4001	4010	NUMBER OF ROWS OF COMBINES.
4011	4020	COMBINE ROW SPACING (SAME AS PLANTER). INCHES

FROM J=	TO J=	
4041	4050	ACCUMULATIVE ANNUAL USE OF COMBINES IN HOURS.
4061	4070	RATED COMBINE ENGINE HORSEPOWERS.
4071	4080	FIELD EFFICIENCIES OF INDIVIDUAL COMBINES.
4081	4090	INITIAL (LIST PRICE) COST OF COMBINES (DOLLARS).
4091	4100	TOTAL ACCUMULATED REPAIR COSTS (TAR) FOR COMBINES.
4141	4150	YEARLY REAPIR COST FOR EACH COMBINE.
4151	4160	HOURLY REPAIR COSTS FOR COMBINES.
4171	4180	SALVAGE VALUE OF COMBINES IN DOLLARS.
4181	4190	AMOUNT LEFT TO BE DEPRECIATED (REMAINIG FARM VA-LUE-REV-) FOR TRACTORS.
4191	4200	AMOUNT LEFT TO BE DEPRECIATED (REMAINING FARM VA-LUE -REV-) FOR COMBINES.
4201	4210	YEARLY DEPRECIATION OF TRACTORS.
4211	4220	OTHER FIXED COSTS FOR TRACTORS.
4221	4230	TOTAL FIXED COSTS FOR EACH TRACTOR.
4231	4240	AMOUNT LEFT TO BE DEPRECIATED FOR PLOUGHS.
4241	4250	YEARLY DEPRECIATION OF PLOUGHS.
4251	4260	OTHER FIXED COSTS FOR PLOUGHS.
4261	4270	AMOUNT LEFT TO BE DEPRECIATED FOR HARROWS.
4271	4280	YEARLY DEPRECIATION OF HARROWS.
4281	4290	OTHER FIXED COSTS FOR HARROWS.
4291	4300	AMOUNT LEFT TO BE DEPRECIATED FOR PLANTERS.
4301	4310	YEARLY DEPRECIATION OF PLANTERS.

FROM J=	TO J=	
4311	4320	OTHER FIXED COSTS OF PLANTERS.
4321	4330	SALVAGE VALUE OF TRACTORS IN DOLLARS.
4331	4340	SALVAGE VALUE OF PLOUGHS IN DOLLARS.
4341	4350	SALVAGE VALUE OF HARROWS IN DOLLARS.
4361	4370	YEARLY DEPRECIATION OF COMBINES.
4401	4410	FUEL AND LUBRICANT COSTS PER HOUR OF COMBINING.
4411	4420	TOTAL FUEL AND LUBRICANT COSTS FOR EACH COMBINEC
4431	4440	TOTAL EXPENSES OF EACH COMBINE (FIXED + VARIABLE).
4441	4450	OTHER FIXED COSTS FOR EACH COMBINE.
4451	4460	TOTAL FIXED COSTS FOR EACH COMBINE.
4471	4480	LABOR COST FOR EACH COMBINE.
4701		TOTAL FUEL AND LUBRICANT COST FOR COMBINING.
4702		TOTAL REPAIR COSTS FOR COMBINIG.
4703		TOTAL DEPRECIATION FOR COMBINING.
4704		TOTAL OTHER FIXED COSTS FOR COMBINING.
4705		NUMBER OF TRACTORS (MAXIMUM 10).
4707		TOTAL VARIABLE COSTS FOR COMBINING.
4708		TOTAL FIXED COSTS FOR COMBINING.
4709		TOTAL MACHINE EXPENSES FOR COMBINING.
4710		HARVESTING COST PER ACRE.
4711		HARVESTING COST PER HOUR OF MACHINE UVE.
4713		TOTAL LABOR EXPENSES FOR A GIVEN PRODUCTION YEAR.

FROM J=	TO J=	
4714		TOTAL LABOR EXPENSES FOR HARVESTING.
4715		TOTAL CORN DRYING EXPENSE.
4716		DRYING COST PER BUSHEL.
4717		DRYING COST PER ACRE.
4718		HARVESTING COST PER BUSHEL OF CORN.
4724		TOTAL EXPENSES FOR A GIVEN PRODUCTION YEAR INCLUDING 5 CENTS/BUSHEL FOR HAULING.
4725		COST PER ACRE FOR A GIVEN PRODUCTION YEAR.
4727		COST PER BUSHEL FOR A GIVEN PRODUCTION YEAR.
4728		TOTAL DEPRECIATION EXPENSE FOR TRACTORS.
4730		INCOME PER ACRE.
4731		INCOME PER BUSHEL.
4739		INCOME WITHOUT TAX REDUCTION.
4971		MAXIMUM OPERATOR PAY HOURS.
4975		TOTAL OF OTHER FIXED COSTS FOR TRACTORS.
4981		TOTAL ACRES IN FARM.
4982		HOURS OF ANNUAL USE OF ALL COMBINES.
4986		TOTAL BUSHELS OF CORN HARVESTED.
4992		NUMBER OF COMBINES (MAXIMUM 10).
4995		DRYING CHARGE FOR EACH PERCENT OVER 15.5 PERCENT IN CENTS.
6001	7000	MAXIMUM AVAILABLE SOIL MOISTURE FOR EACH LAYER IN EACH SECTION. EG. X(6001) IS THE FIRST LAYER OF THE FIRST SECTION AND X(6105) IS THE SECOND

FROM J=	TO J=	
		LAYER OF FIFTH SECTION, ETC.
7001	8000	ACTUAL SOIL MOISTURE FOR EACH LAYER OF ALL SECTIONS ARRANGED THE SAME AS THE X(6000)'S.

VARIABLE LOCATION IN SYSTEM INPUT VECTOR OVER TIME

INPUT VARIABLE, E(K) FOR K=	DESCRIPTION
1	MAXIMUM DAILY TEMPERATURE, F
2	MINIMUM DAILY TEMPERATURE, F
3	WET BULB TEMPERATURE, F
4	DAILY PRECIPITATION, INCHES
5	DAILY OPEN PAN EVAPORATION, INCHES
6	SNOW, NO-SNOW CONDITION. 0-NO SNOW, 1-SNOW ON THE GROUND.

APPENDIX B

SUBROUTINE NAMES AND THEIR FUNCTIONS

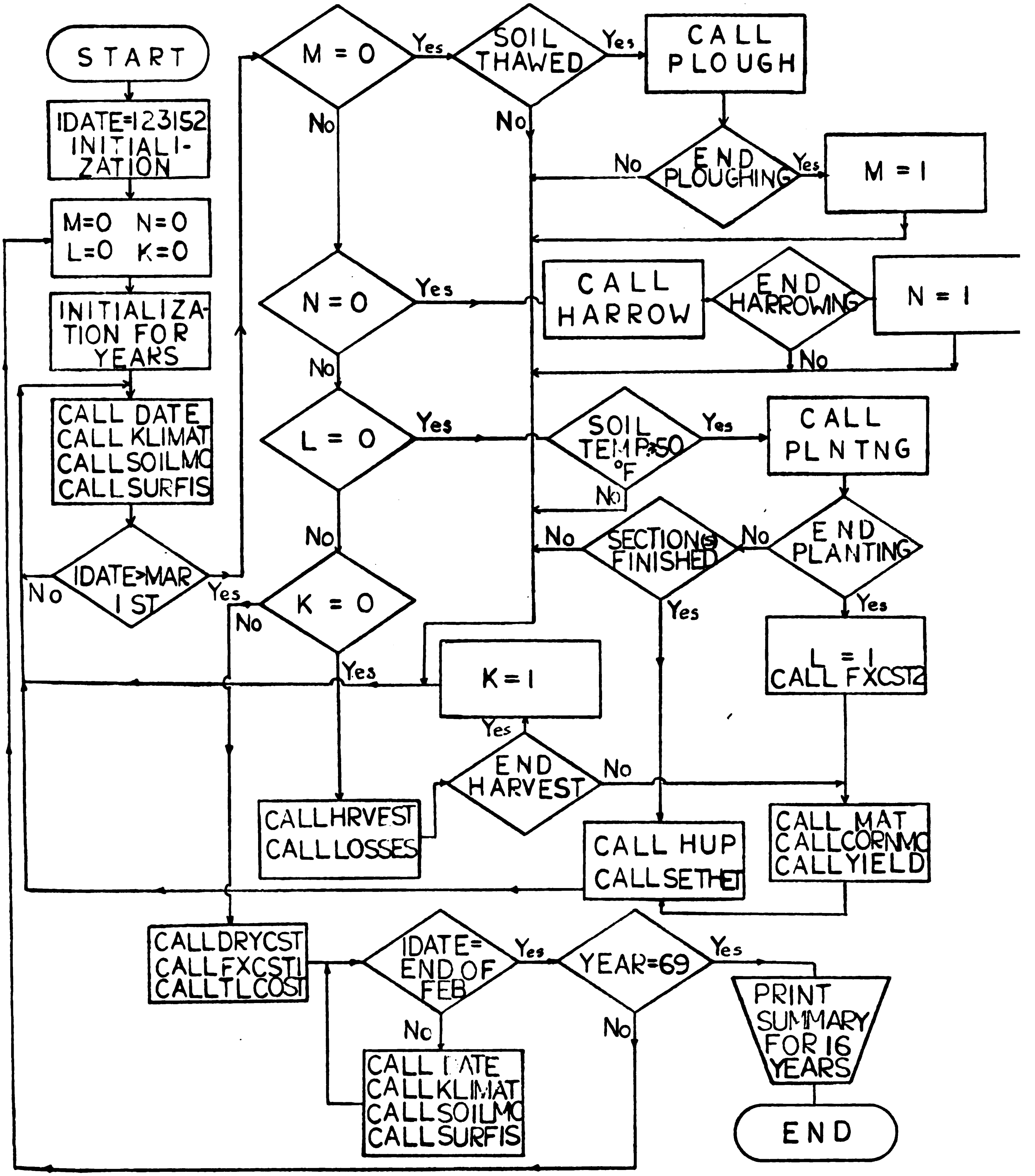
NAME OF SUBROUTINE	FUNCTION
DATE	Generates calendar dates
KLIMAT	Reads weather data
NOPAN	Estimates missing evaporation values
SOILMC	Updates soil moisture budget
SURFIS	Finds surface conditions (Tractability)
PLOUGH	Performs ploughing
PLCOST	Calculates variable cost for ploughing
HARROW	Performs harrowing (Disc)
HRWCST	Calculates variable costs for harrowing
PLNTNG	Performs planting
PLNCST	Calculates variable costs for planting
SETHET	Sets heat units requirements and variety number
FXCST2	Calculates fixed costs for spring field operations
HUP	Accumulates heat units starting from planting dates
MAT	Determines maturity of fields (sections)
CORNMC	Determines kernel moisture (wet basis) of corn at harvest time
YIELD	Generates yield values (Bu/A) stochastically
HRVEST	Performs harvesting

NAME OF SUBROUTINE	FUNCTION
HRCOST	Calculates variable costs for harvesting
LOSSFS	Calculates pre-harvest and harvest losses
FXCST1	Calculates fixed costs for fall operations
DRYCST	Calculates drying costs
TLCOST	Calculates overall costs for production year.

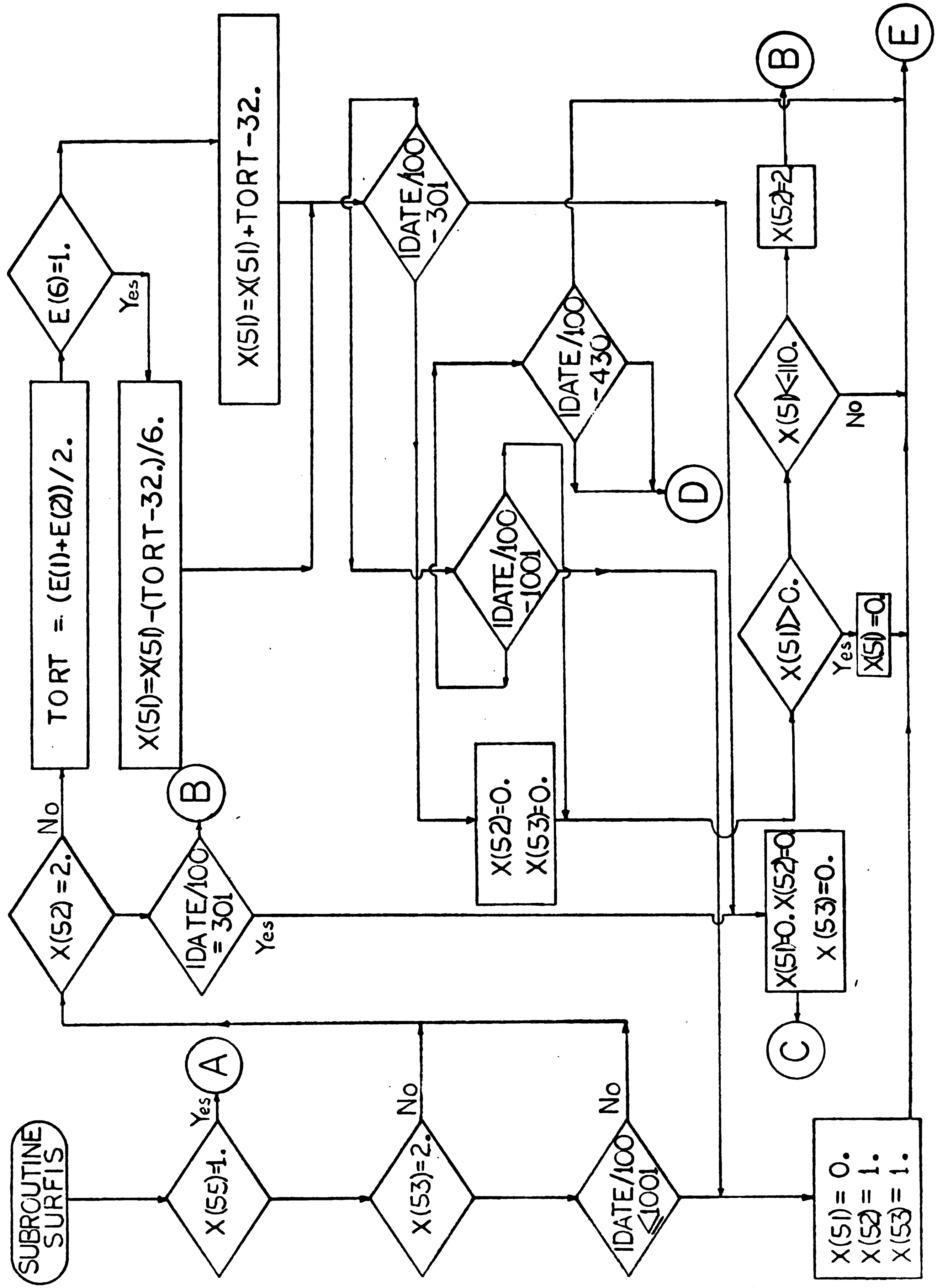
APPENDIX C

FLOW CHARTS OF SIMULATION MODEL AND

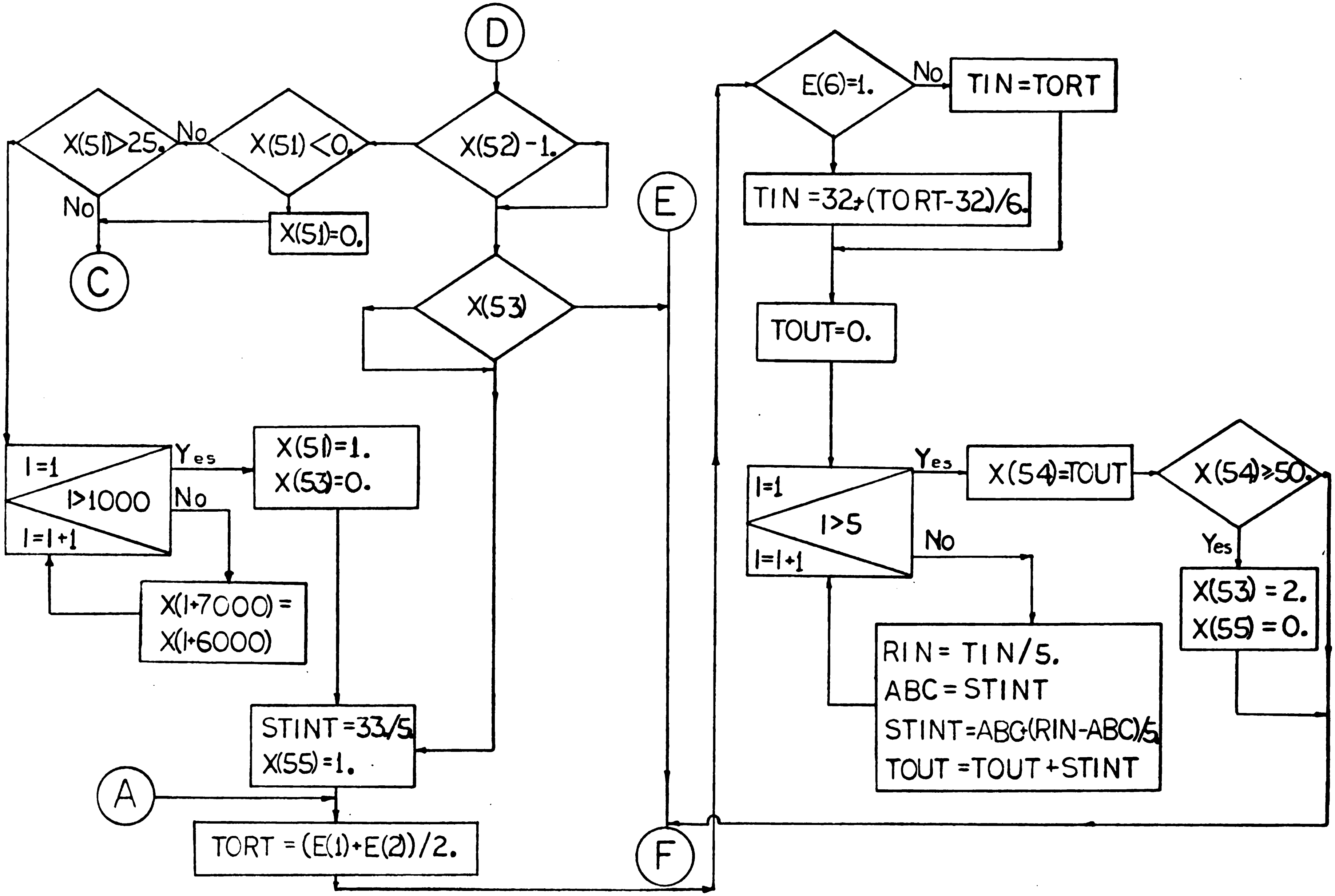
SOME OF THE SUBROUTINES



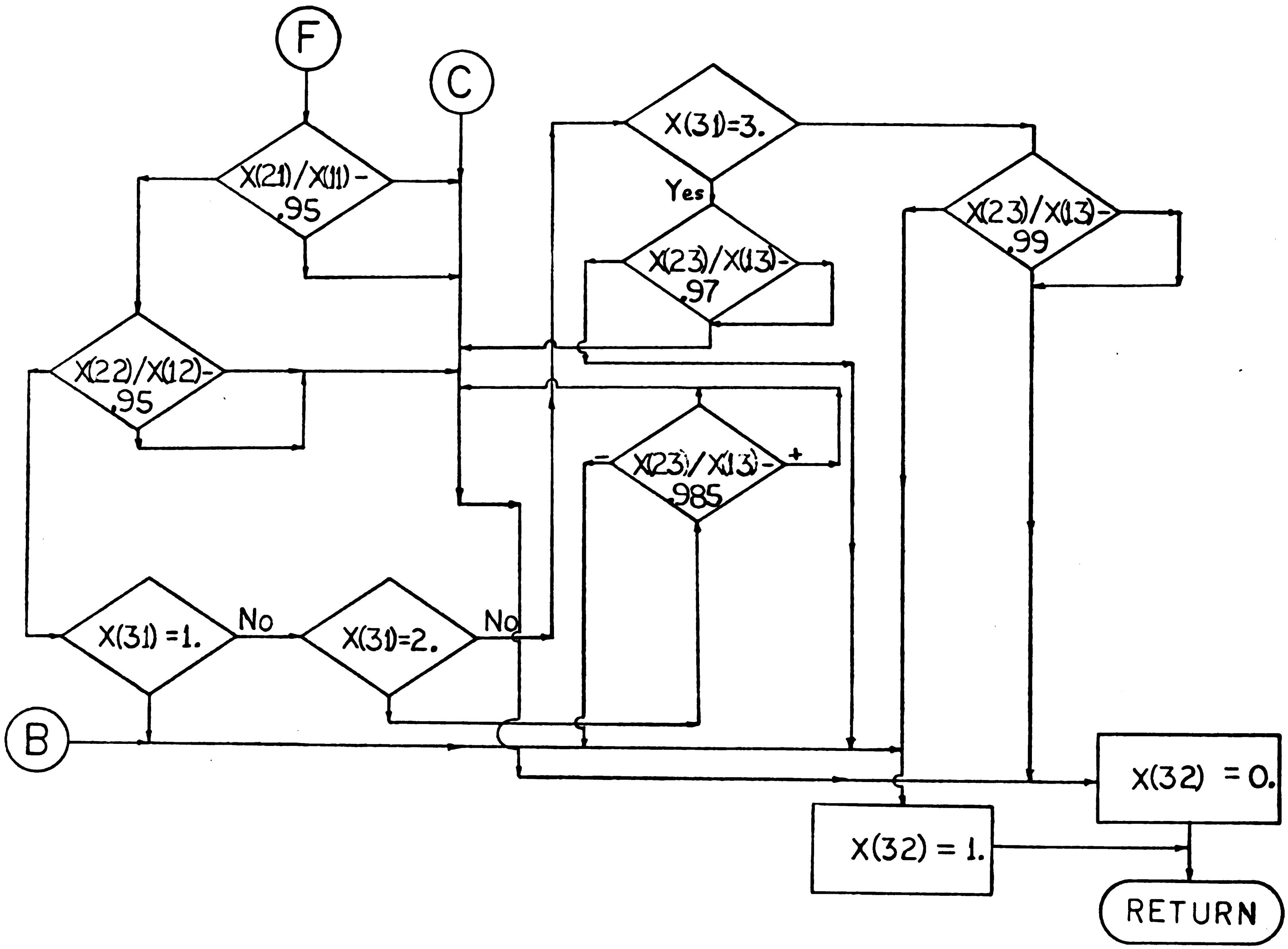
General Model



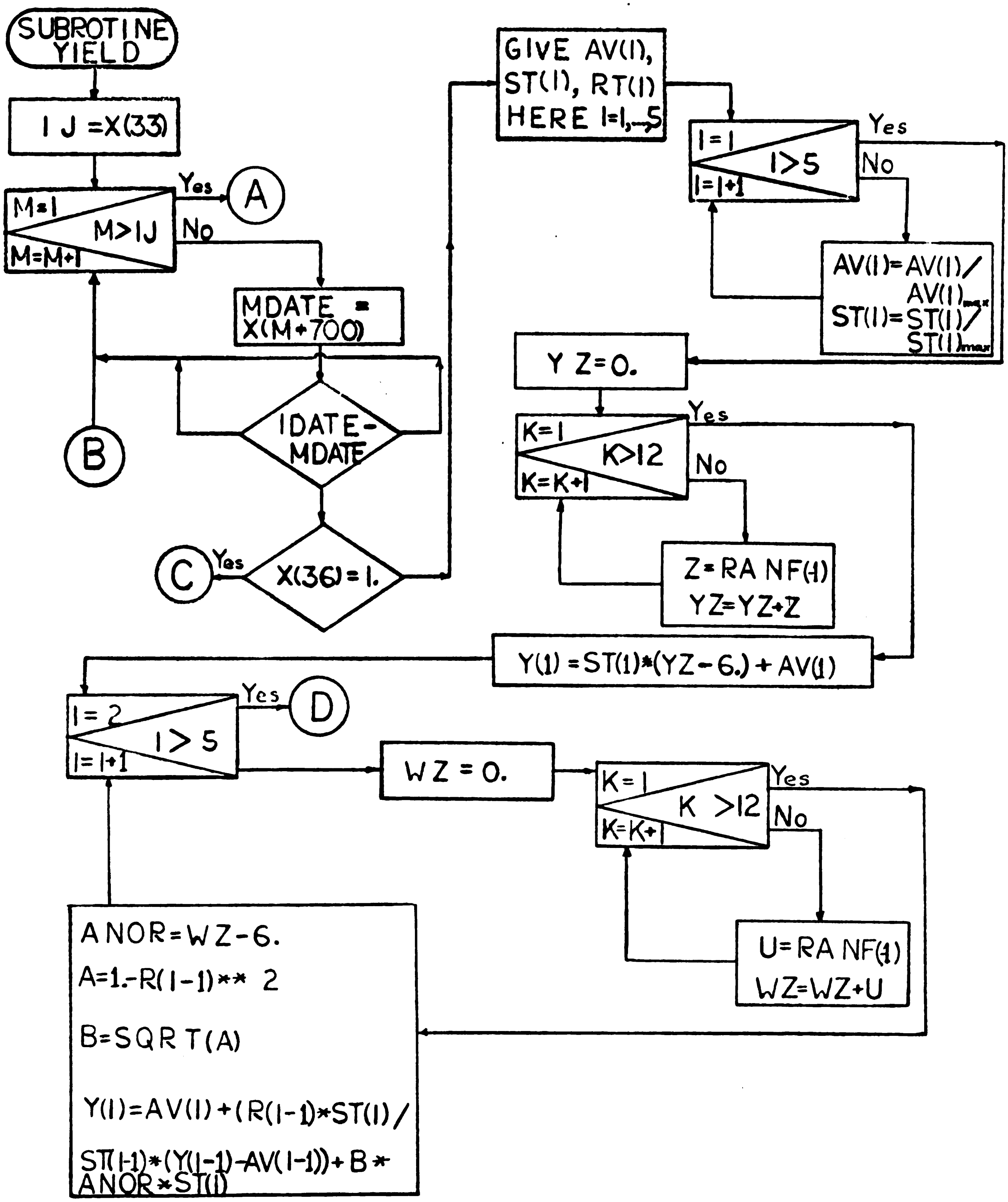
Tractability Model



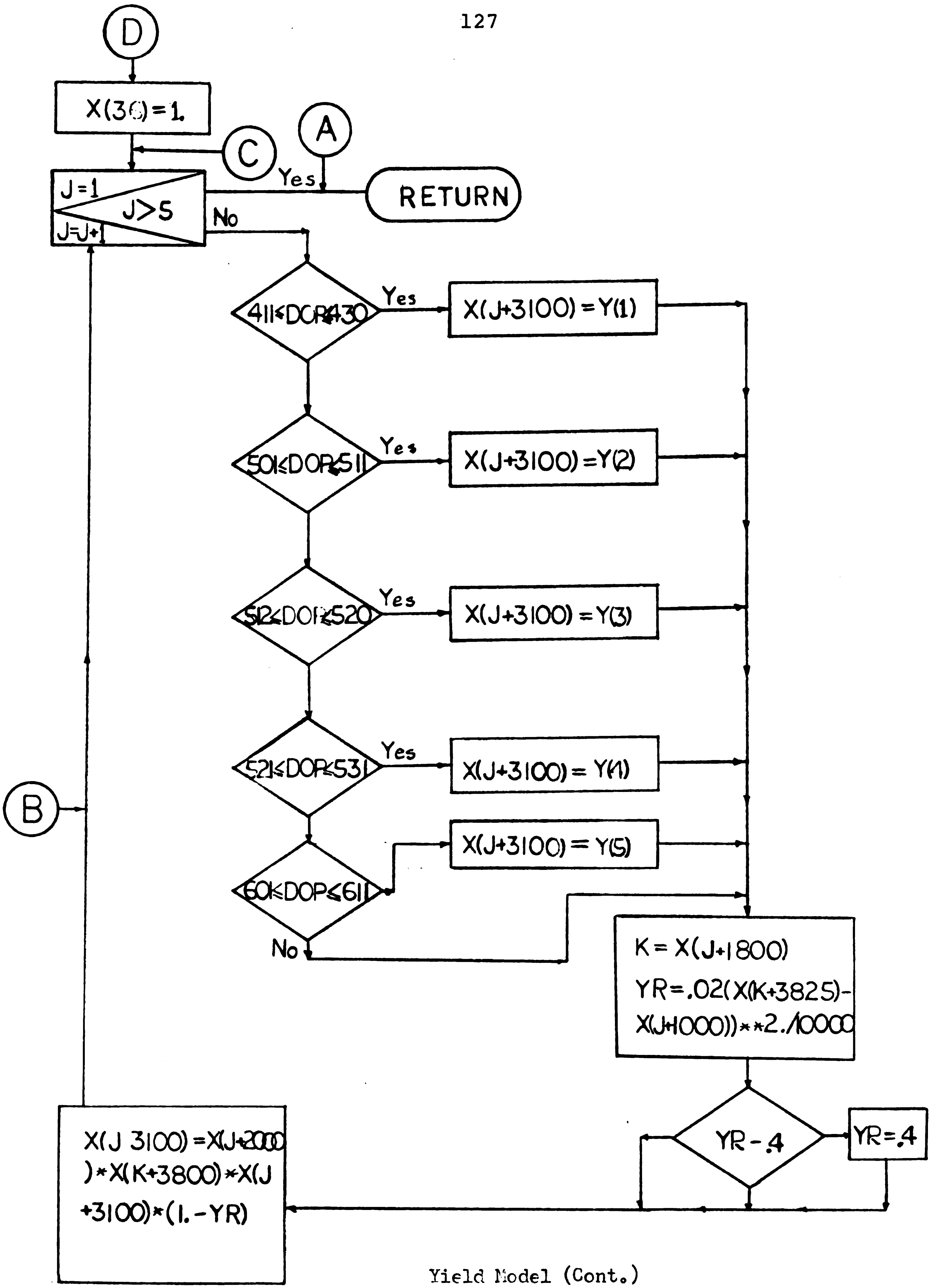
Tractability Model (Cont.)



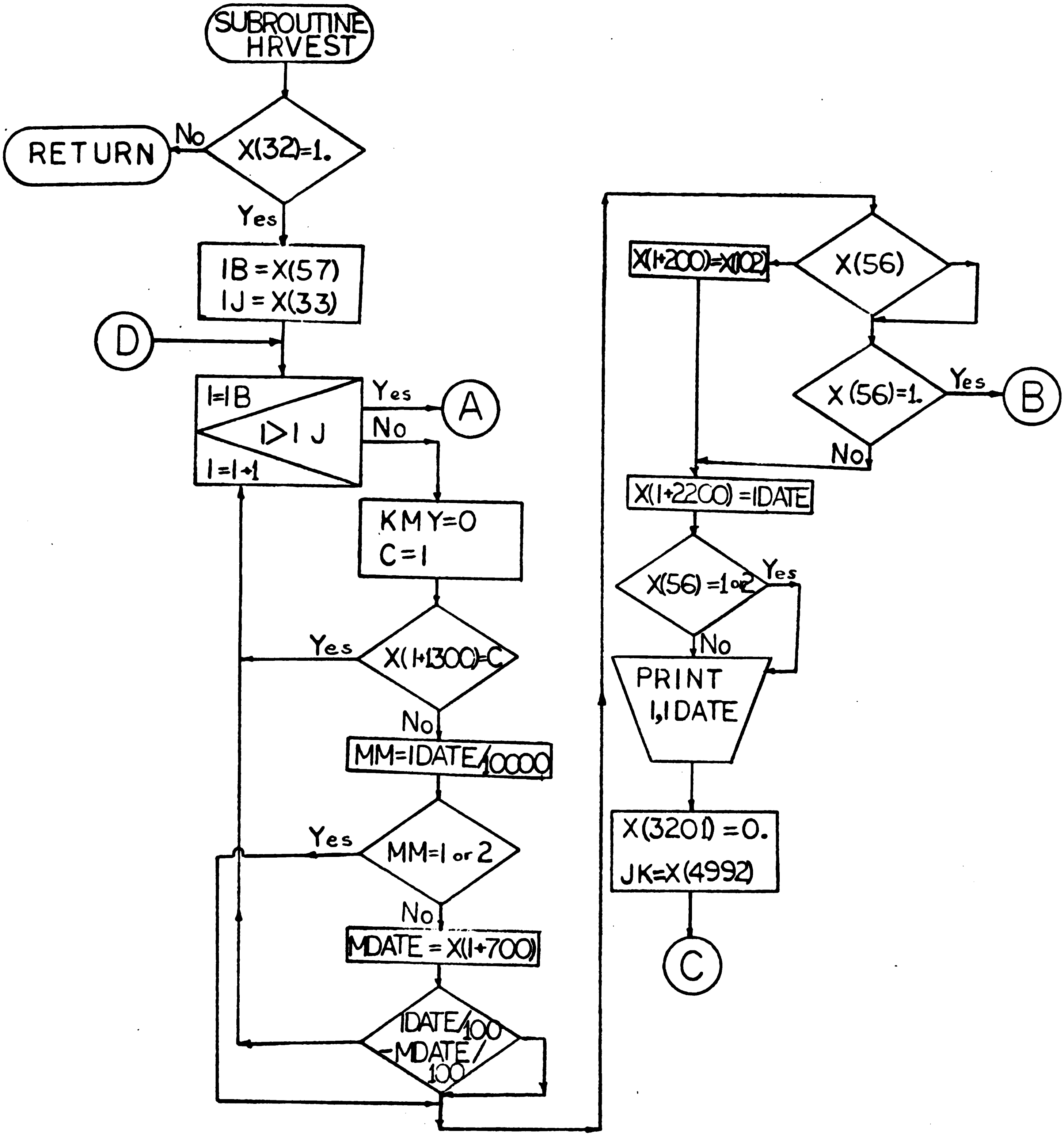
Tractability Model (Cont.)


SUBROTINE YIELD
I J =X(33)
M=1
M>IJ
M=M+1
Yes
No
A
MDATE = X(M+700)
IDATE-MDATE
B
X(36)=1.
Yes
C
GIVE AV(I), ST(I), RT(I) HERE I=1,→5
I=1
I>5
I=I+1
Yes
No
AV(I)=AV(I)/AV(I)max
ST(I)=ST(I)/ST(I)max
Y Z=0.
K=1
K>12
K=K+1
Yes
No
Z=RA NF(1)
YZ=YZ+Z
Y(1) =ST(1)*(YZ-6.)+AV(1)
I=2
I>5
I=I+1
Yes
D
WZ=0.
K=1
K >12
K=K+1
Yes
No
U=RA NF(1)
WZ=WZ+U
ANOR=WZ-6.
A=1.-R(I-1)** 2
B=SQRT(A)
Y(I)=AV(I)+(R(I-1)*ST(I)/ST(I-1)*(Y(I-1)-AV(I-1))+B*ANOR*ST(I)

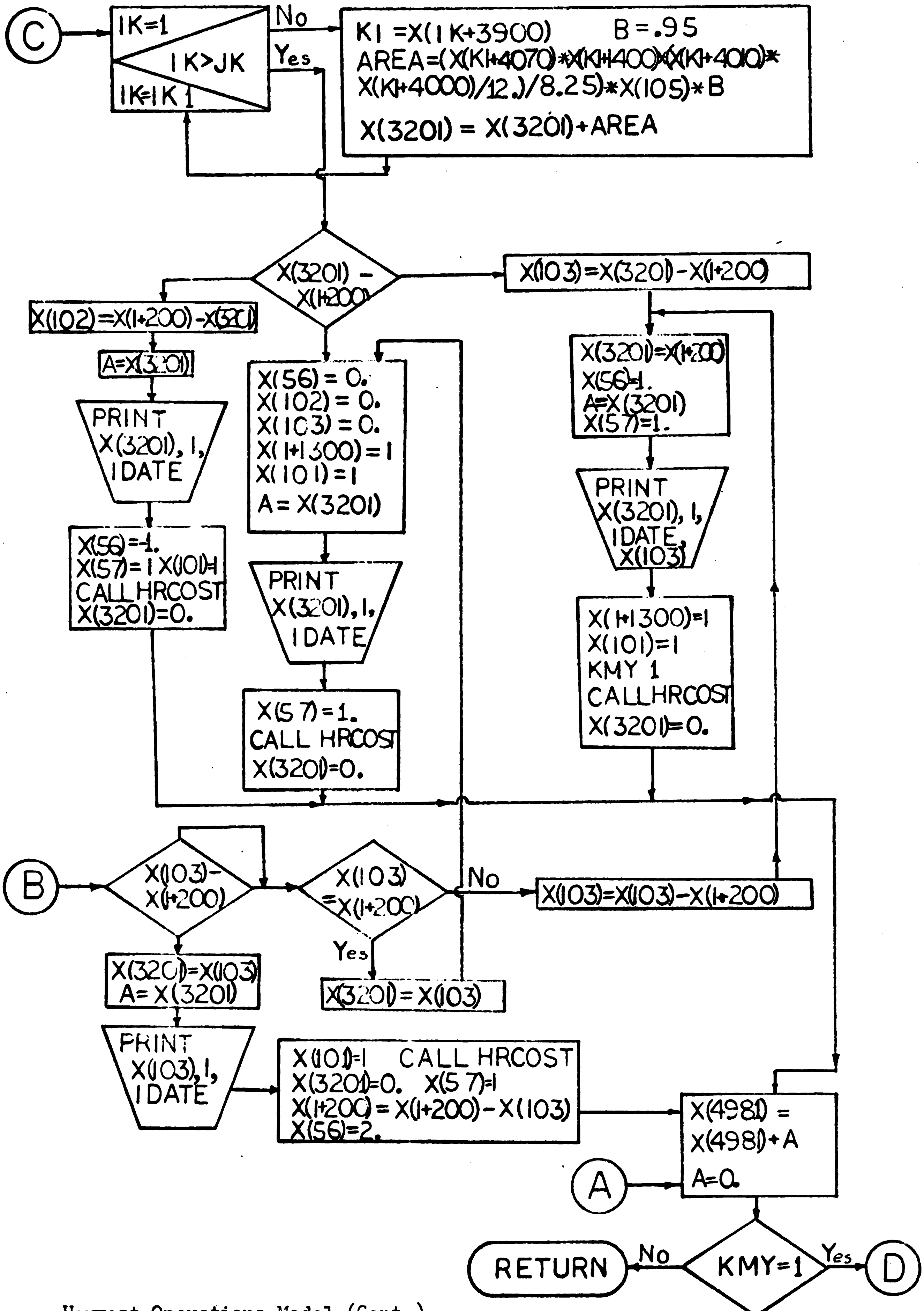
Yield Model



Yield Model (Cont.)



Harvet Operations Model



Harvest Operations Model (Cont.)