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A FIELD MACHINERY SELECTION MODEL FOR WHEAT PRODUCERS IN THE ANDES PRE-CORDILLERA OF SOUTH CENTRAL CHILE

By

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ABSTRACT

A FIELD MACHINERY SELECTION MODEL FOR WHEAT PRODUCERS IN THE ANDES PRE-CORDILLERA OF SOUTH CENTRAL CHILE

By

Edmundo J. Hetz

Chile's most important crop is wheat, which with other small grain cereals account for 80% of the area planted with annual crops. However, the area seeded yearly with wheat has been experiencing a steady decline. It has gone down from 780,000 hectares in 1966 to 546,000 hectares in 1980. Wheat output has fallen to less than 40% of domestic usage versus 75% a decade ago.

Wheat production costs in Chile are heavily influenced by the cost of owning and operating agricultural machinery. It has been estimated that the agricultural machinery cost component can vary between 30 to 36% of the total wheat production cost. Crop rotations and tillage intensity have important effects upon machinery system requirements and, consequently, production costs.

This research project focused upon the development of a computer model to aid the selection of machinery systems for wheat producers in Chile, evaluating the effects of crop rotations and tillage systems upon machinery requirements and machinery related production costs. A systems analysis approach was used as the analytical and problem solving technique. Field work was carried out in Chile in order to collect agro-meteorological, agronomic, economic and agricultural engineering data to develop the computer model. Model validation was conducted with data collected through field surveys carried out at the farm level.

The most important conclusions derived from the survey of wheat

producers and the computer simulation analysis were as follows:

The large majority of farmers (85%) owned one (60%) or two (25%) two-wheel drive tractors. A very good correlation (r = 0.95) was found between the yearly seeded area and the total power available on the farm. The individual tractor power range was found to vary from 37.3 to 73.1 PTO-kW, with an average power per unit cultivated area of 0.55 kW/ha.

Computer predictions of days suitable for fieldwork at the 0.70 probability were matched very closely by the results from the farmer's survey. For 10 of the 12 biweekly periods the 0.70 design probability values were found to be within 10% of the farmers' estimates, with a correlation coefficient r = 0.91.

Ownership cost was consistently the largest of the system cost components, with values ranging from 41 to 36% (75 to 45% for the harvester) of the total system cost. Labor and timeliness costs had the lowest relative importance among the cost components. As the number of crops in the rotation increased to include oats and lentils, machinery requirements decreased along with the costs per hectare. Diesel fuel requirements per hectare were affected by both the tillage level and the crop rotation. The effect of the first factor can be more important than the effect of the crop rotation, generating savings of up to 27.0 L/ha in a 110 hectare farm.

Approved Merle L. Esmay
Major Professor

Approved Donald M. Edwards
Department Chairman

Dedicated to:

Jean-Hendrik Hetz van Kapel, and

Caterina Shelby Hetz van Kapel

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1. INTRODUCTION

1.1. Agricultural Overview of Chile

Chile is located on the southern Pacific coast of South America. It is a narrow, ribbonlike country, averaging 175 km. in width, and extending 4200 km. in length from 17° 30' S to 55° 59' S. The total area of continental Chile is approximately 756,000 square kilometres (CORFO, 1965).

Northern Chile is one of the driest places in the world and has one of the few weather stations at which no rain has ever been recorded. Southern Chile is one of the rainiest parts of South America, where glaciers descend from snow-covered mountains to a deeply fiorded coast. Between these two extremes is middle Chile, the center of population concentration, intellectual, social and economic activity. Middle Chile contains the Central Valley, a narrow fertile depression between the Andes Mountains on the east and the Coastal Mountain Range and the sea on the west.

The Central Valley has a mediterranean climate with rainfall increasing gradually from the northern transitional desert region in Coquimbo to the southern boundary of the region at Puerto Montt (See Figure 1.1.). The climate and the fertility of the Valley's soil provide ideal conditions for intensive vegetable farming, orchards and vineyards, cereal crops, legumes, sugar beet, sunflower, soybeans, rice, maize, rapeseed, potatoes, and livestock.

With the advantage of a harvest season when Europe and North America enter the winter months, the Central Valley offers Chile a

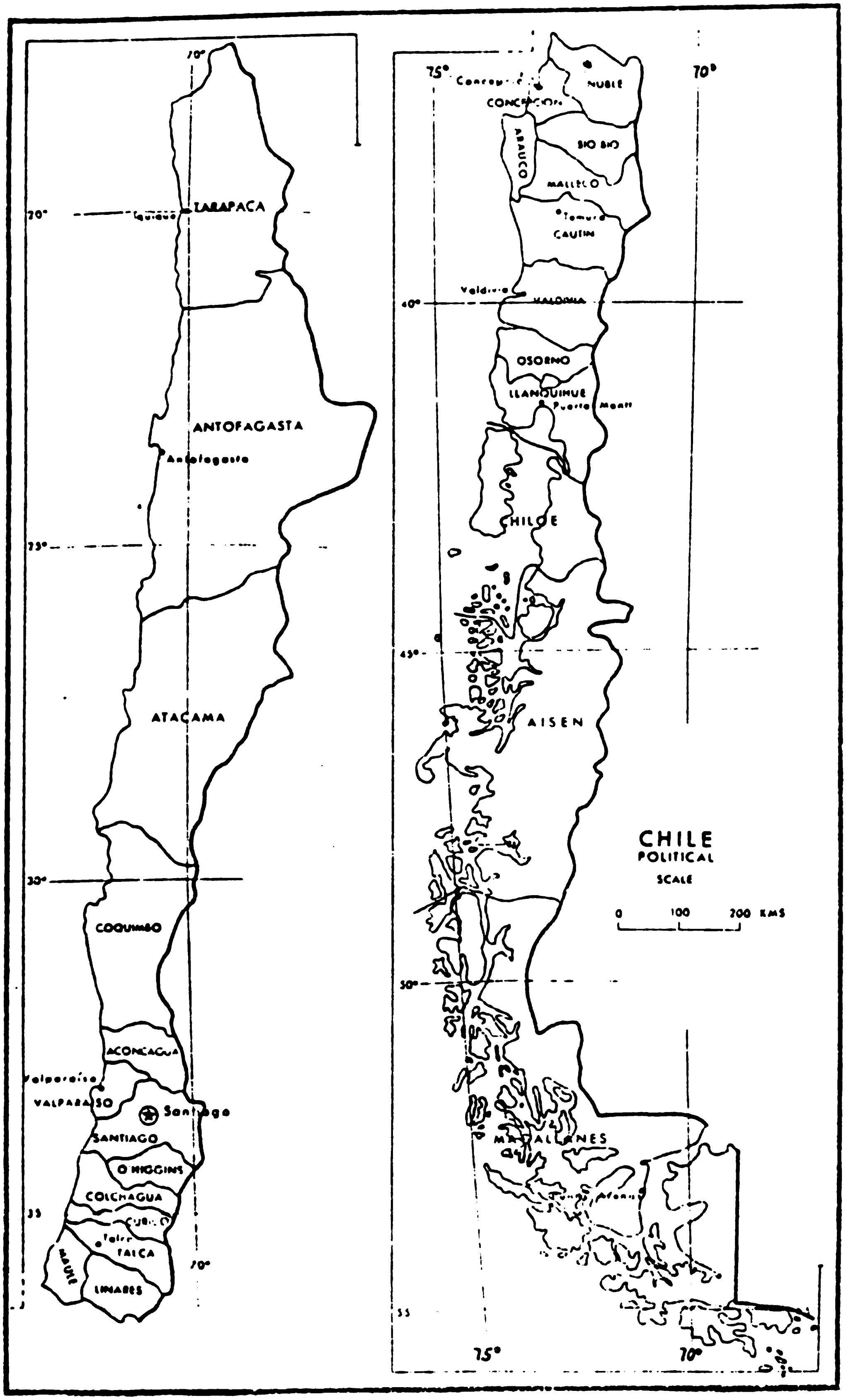

Figure 1.1. Map of Chile.

potential source of foreign exchange through the export of high-quality fruits, vegetables, seeds, wines, dairy products, and other specialty crops.

1.2. Problem Statement

Chile has 11 million hectares of arable land, 19 million hectares of grasslands, and 23 million hectares of woodlands. There are also 22 million hectares with no agricultural or forestal aptitude. They add up to 75 million hectares which corresponds to the geographic area of continental Chile (CORFO, 1965).

If only the five million hectares without limitations, Soil Class I, were considered and the coefficients developed by Revelle (1976)* are applied, Chile would be able to feed about 100 million persons. Furthermore, if only the 1.3 million irrigated hectares, whose quality is among the best in the world, were considered, Chile could feed about 25 million inhabitants. However, with a population of only 11 million people it has been importing, since 1939, an ever increasing amount of food that in 1980 reached a value close to 1,000 million dollars (USDA, 1981; FAO, 1981).

Chile's most important crop is wheat, which with other small grain cereals account for 80% of the area planted with annual crops. However, the area seeded yearly with wheat has been experiencing a steady decline. It has gone down from 780,000 hectares in 1966, to 546,000

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*These coefficients estimate that 24 human beings can be fed adequately from one hectare of high quality farmland worked at a level of agricultural technology comparable to that practiced in the Midwest of the USA.

hectares in 1980, a decrease of 30%. At the same time, wheat consumption in the country has gone up from 155 kilogram per person per year in 1965, to 205 kilograms per person per year in 1980. According to Fouchs (1981), wheat output has fallen to less than 40% of domestic usage versus 75% a decade ago. This situation has forced the country to import large amounts of wheat. In 1980, it was necessary to import 955,000 tonnes of wheat and in 1981 wheat imports reached 1.2 million tonnes (FAO, 1981; Fouchs, 1981; USDA, 1981).

Only a mosaic of reasons could explain completely this paradigm of a declining area seeded with wheat and the importation of nearly half the demand for the product. Important reasons why farmers are not seeding as much wheat as during the 1960's are the stead rise in production costs, the relatively low price of wheat in the international market, and a changing economy.

The main reasons for the high cost of wheat production in Chile are the high cost of agricultural machinery, fuel, and fertilizers. Agricultural equipment in Chile is very costly, both to purchase and to operate, due to high costs in the manufacturing countries (up by 100% between the Spring of 1977 and the Fall of 1980, according to Mayfield et al. [1981]), transportation costs, import tariffs, and the wide profit margin of machinery importers and distributors. Also, according to the Chilean Ministry of Foreign Relations (1980), more than 65% of the fuel used in Chile is imported and its price to the farmer is almost double that paid by a farmer in the USA. Although labor is, comparatively, cheap in Chile in the case of wheat production it does not help a great deal because small grain cereals are highly mechanized crops.

Several authors, Singh (1978), McIsaac and Lovering (1977), van Kampen (1973), Moore (1980), have pointed out that field machinery costs are a major component of the total farm budget, with a value in the range of 20 to 25% for the USA and Canada, in general. In the case of Saskatchewan farms, Brown (1981), estimated that machinery and implement operating expenses and depreciation charges can account for as much as 45% of the total farm operating expenses and depreciation charges.

Chilean wheat producers also have a high machinery component in their production cost. According to Franco (1981), the agricultural machinery cost component can vary between 30 and 36% of the total wheat production cost, depending upon the cultural practices and machinery field efficiency.

Moreover, the great majority of farmers in Chile still use conventional tillage systems which demand many passes over the field. Research comparing tillage systems which differ in tillage intensity has been carried out in the wheat growing area by the University of Concepcion. The reduced tillage systems have been proven successful to farmers with adequate farming and management skills.

Under these circumstances, a farmer who wants to stay in the farming business has to be a very good manager. Unfortunately, he does not have at his disposal the tools that would help him make sound decisions concerning machinery management and other related activities. Furthermore, the 'Ingeniero Agronomos' with whom he could consult are not adequately prepared to deal with these problems.

The University of Concepcion, at Chillan, is strengthening the Agricultural Engineering Department which offers undergraduate instruction and master of science programs to train students to deal with these and other shortcomings affecting the Chilean farmers at the present time.

Agricultural mechanization in Chile has progressed to the point where the application of the principles of scientific management is a necessity. With only 18% of the population living in the rural areas, the Chilean farmer has become increasingly dependent on his machinery set to carry out his work on schedule. This is especially true for the cereal producers because these crops are almost completely mechanized.

The selection of a machinery complement is a complex problem involving many economic, biological, physical, and social factors, such as weather uncertainties, timeliness, sequential and parallel operations, soil type and conditions, type of crops and rotations, management practices, and labor and fuel supply. Machinery selection decisions are among the most important that producers must make in today's agriculture. The importance of these decisions stems from the relatively high proportion of total costs attributable to or related to machinery and the infrequency and irrevocability of such decisions. The importance of machinery sizing decisions and general machinery management cannot be overstated. Mayfield et al. (1981), have determined that the total cost of owning and operating the typical farm tractor increased approximately 100% from the Spring of 1977 to the Fall of 1980.

During the past decade the systems analysis approach has been successfully applied to agricultural machinery management and to other agricultural problems. Several authors, Brown (1981); Burrows and Siemens (1974); Danok et al. (1980); Doster et al. (1980); Edwards and Boehlje (1980); Hughes and Holtman (1976); Hunt (1977); Krutz et al. (1980); Loewer (1980); Muhtar (1982); Osborn and Barrick (1970); Wolak (1981); Pfeiffer and Peterson (1980); Von Bargen (1980), have proposed a variety of methods to select crop production systems and the associated machinery complement for agricultural enterprises. Computer models have proven to be a very useful analysis tool for the selection and scheduling of agricultural machinery, prediction of available time for field operations, and for the economic analysis of the machinery investment.

A computer model which would address the machinery selection and management needs of the Chilean wheat producers, would be a most useful educational tool that could be used in the new Agricultural Engineering Department of the University of Concepcion, at Chillan.

1.3. Objectives

The global objective of this project was to develop a computer model to determine least cost machinery systems for the wheat producers located in the Andes Pre-Cordillera area of the province of Nuble, in Chile. The model was designed for use as an educational tool for the students of the Agricultural Engineering Department of the University of Concepcion and to assist farmers in their machinery purchase and management decisions.

The specific objectives of the project were:

1.3.1. To use climatological records to estimate the expected number of days suitable for fieldwork in the eastern part of the province of Nuble, at selected probability levels.

1.3.2. To develop a computer model to aid the selection of field machinery systems for the wheat producers in this region.

1.3.3 To compare production systems differing in tillage intensity level and crop rotations including wheat, oats, lentils, and subterranean clover, with respect to machinery requirements and total costs including machinery, labor, timeliness, and fuel costs.

2. LITERATURE REVIEW

2.1. Mechanization and Wheat Production in Chile

2.1.1. Agricultural Mechanization Development

In the Latin American panorama, Chile is one of the countries that has mechanized its agriculture to a high level. Most of Chile's modern agricultural machinery has been imported. The importation of tractors was initiated around 1930, but not until the 1950's did the number of tractors in use in the country reach a significant value, as shown in Table 2.1.

TABLE 2.1. Agricultural Tractors in Chile.

Year	Working Tractors
1930	660
1936	1,560
1940	2,750
1944	3,880
1948	5,400
1955	14,180
1963	16,500
1970	20,000*
1975	23,000*
1980	20,000*

Sources: CORFO (1969); *Estimates by Ibanez et al. (1979)

The 1975 peak was reached with the importation of about 8,000 tractors, Belaruz MTZ-50 and Universal 650-M, from the USSR and Rumania respectively by the Allende Government. After 1975 these tractors were left without spare parts and at the present time few of them are still working.

Before the establishment of the Plan Chillan to develop agriculture in south-central Chile in 1954, with the assistance of the USA's Point IV Program, no research or extension work on the use of agricultural machinery had been carried out.

Research on agricultural mechanization has been meager. Prior to 1963 not more than 10 significant experiments related to agricultural machinery had been performed (Ulloa, 1969).

Like most South American countries, except Argentina and Brazil, Chile depends on importations for tractors and other agricultural equipment. Importers have seldom considered the needs of the Chilean farmers, and the main criteria to decide on what to import have been profits and the initiative of dealers and distributors. The result has been inadequate equipment and proliferation of makes and models (CORFO, 1969).

Importation of agricultural machinery has represented about 5% of the total value of imported goods. Until 1966, the USA and the UK were the source of 76% of all the imported agricultural machinery (CORFO, 1969). However, at the present time Argentina and Brazil have replaced the UK becoming important sources of agricultural machinery for Chile.

The national production of agricultural machinery has been small, representing between 5 to 7% of all machinery purchases (UN, 1968). Equipment manufactured in small quantities in Chile includes plows, harrows, tool bars, sprayers, ditchers, lime applicators, fertilizer broadcasters, dryers, maize shellers, sunflower headers, hammer mills, wagons, animal drawn equipment and hand tools. Only electric motors are made in significant quantities in Chile.

Until 1975 the Andean Group of Free Trade represented an attractive market for Chilean manufacturers of agricultural machinery. However, in 1975 Chile ceased to be a member of the Group, consequently the market was lost to the national manufacturers.

Chile is still far below the mechanization level of more developed countries. In 1963 there were 16,500 tractors, 274,450 horses, 291,930 oxen to work 2,317,800 hectares (UN, 1968 and CORFO, 1969). If all the work was to be done exclusively with tractors, each tractor working 25 hectares, which is the average for nine Western European countries, and working only the full capacity of Chile's five million hectares of Class I soil, a total of 200,000 tractors would be required.

A more realistic approach was presented by Stenstrom (1959), in his Report to the Government of Chile. He indicated that one tractor per 100 hectares under cultivation is an adequate ratio for developing countries when the tractor is used mainly for the heavy farm work. Increasing the mechanization level to include the rest of the farm work, one tractor per each 50 cultivated hectares would then be adequate. According to this last ratio and considering only the cultivated area in Chile a total of 66,000 tractors would be needed at the present time.

Furthermore, if we consider the thesis developed by Giles (1967), that 0.5 HP of effective capacity per cultivated hectare is a minimum power requirement for developing countries and considering the 3.3 million hectares under cultivation, 33,000 tractors with a 50 HP effective capacity,* would be required in Chile at the present time. This quantity of

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*Effective horsepower capacity is defined as the measured, rated drawbar horsepower, not engine horsepower or advertising claims by the manufacturers.

tractors is much larger than the latest estimation by Ibanez et al. (1979), of 20,000 as working in Chile in 1980. The number of working tractors in 1980 is smaller than the number in 1975 because: 1) they have not been replaced by small farm operators who are the beneficiaries of the land reform program due to a large increase in the price of tractors; and 2) the lack of subsidized credit.

All the numbers presented previously show the need to increase the power available for agricultural production in Chile. Although it is recognized that mechanization alone is not the answer to the problem of adequate food supply it is equally true, however, that without the power and the proper tools to perform the production operations in a satisfactory and timely way, much of the potential benefits of improved crop varieties, increased use of fertilizers, increased water availability, and improved cultural practices cannot be achieved. Under dryland farming conditions with low and/or very seasonal rainfall, timeliness of operation and particularly of seeding is very important. Only with power equipment can this timeliness be achieved over the large areas concerned (Kitching, 1968).

2.1.2 Wheat Production and Characteristics of the Andes Pre-Cordillera

The VIII Region, located in south-central Chile, comprises the provinces of Nuble, Bio-Bio, Concepcion and Arauco (See Figure 1.1.). The Andes Pre-Cordillera area of the provinces of Nuble and Bio-Bio covers about 640,000 hectares, of which no less than 300,000 hectares have agricultural aptitude, being classified as Soil Classes II, IV and VI (INIA, 1980).

The soils typical of this area have developed from recent volcanic ashes (Dystrandept) and they have been classified as Santa Barbara Serie. They are deep soils, with a loam to silt loam texture, brown to dark gray in color, and have a rolling hills topography with an 8 to 12% representative slope. These soils are very permeable, with a very high organic matter content, very low bulk density and high total porosity. They have good to excellent internal and external drainage characteristics. Phosphorus fixation capacity is high due to the presence of oxides of iron and aluminum, and their infiltration coefficient and basic infiltration velocity are also high (Bernier, 1966; Mellado, 1981).

The Andes Pre-Cordillera area of the province of Nuble has a temperate mediterranean climate, rainy, with one to three dry months. Frost-free season longer than 4.5 months. Temperatures for the coldest month go from -2.5° to -10° C. Maximum average temperature for the warmest month is 21° C. The average annual rainfall and average winter rainfall are 1305 and 760 mm., respectively (Pena, 1978).

The agricultural production alternatives for this vast area include cereals (wheat, oats, barley, rye), lentils, rapeseed, natural and artificial pastures. All these crops have to be grown under dryland conditions. By far the most important crops are winter wheat and oats, with an average of 35,000 and 10,000 hectares seeded yearly, respectively (INIA, 1980).

As stated earlier, wheat has always been Chile's most important crop. However, since 1940 the country's wheat production has not been enough to satisfy the demand. The central and southern parts of Chile have good wheat growing conditions, but the average yield for the country, at 1500 kg/ha., can be considered very low when compared with the average of 3650 kg/ha. obtained during four years in more than 50 demonstration centers, located in the Andes Pre-Cordillera of the province of Nuble

(INIA, 1980).

The main reasons for the low average wheat yields in Chile seem to be: inadequate varieties and poor seed quality, insufficient fertilization, untimely tillage, seeding and harvesting, insufficient use of grain drills, inadequate weed control and crop rotations (INIA, 1976).

Furthermore, wheat production in the Andes Pre-Cordillera of Nuble is also negatively affected by diseases, especially by foot rot (Gaemannomyces graminis, Fusarium sp) and by rusts (Puccinia sp). The best ways to reduce the effects of these diseases are to use resistant varieties, adequate crop rotations, early seeding and timely spraying (INIA, 1980).

Kitching (1968), indicated that since wheat is the staple food in the developed countries, the cultural practices and machines best suited to producing high yields at low cost under varying soil and climate conditions are well known. In theory, it would only remain to apply these methods and machines to production in the less developed areas. Moreover, since wheat and rice are the world's basic food crops, together making up approximately 41% of the total human food consumption, it is important that priority be given to means of increasing the production of these crops.

2.2. Systems Analysis in Agricultural Engineering

2.2.1. The Systems Approach

Modern systems for producing and processing food, fiber, and forest products are complex syntheses of modern science and technology. Complexity and size have, in recent years, lead to the application of systems analysis to agricultural problems.

A system has been defined, by several authors (Manetsch and Park, 1977; Naylor, 1971; Gordon, 1978), as a collection of objects, called components, which interact synergistically to perform a given function or functions. The components are differentiated into: 1) exogenous or environmental variables; 2) endogenous or controllable input variables; 3) input parameters; and 4) output variables.

Smerage (1979) indicated that a system resides in an environment that stimulates it by external, independently generated forces. It responds in some manner, over time, to those forces and the system may, in addition, respond to a nonequilibrium, internal condition or state.

Dent and Anderson (1971) emphasized that the systems view is a holistic one, which implies that an isolated study of parts of the system will not be adequate to understand the complete system. This is because the separate parts are linked in an interacting manner. A system implies a complex of factors that are interrelated, it implies interaction between these factors and it implies that a conceptual boundary may be erected around the complex as a limit to its organization autonomy.

Churchman (1979) and Rountree (1977) pointed out that the system analysis approach is a method of problem solving which attempts to study the whole, its parts and their interrelationships. Systems analysis is concerned with the analysis of system behavior and the compositional basis for behavior. A system is analyzed to predict its responses to specific stimuli and its general behavioral properties. The medium for this analysis is a model that is obtained, first, by a separate analysis of system composition.

The essence of the systems concept is to describe a situation with many interacting elements where, to be understood, any individual element in the system must be viewed in the context of the whole. This

fact has important implications for model construction since all relevant elements must be represented in the model (Dent and Anderson, 1971).

2.2.2. Farming Systems, Models and Simulation

Farming systems are characterized by the fact that man is attempting to control biological systems in an uncertain environment to achieve some goal which is predominantly economic in nature. For this reason, they are frequently referred to as bio-economic systems. The degree of control exerted over the system can vary considerably from extensive pastoral farming, which is essentially a harvesting operation, to an intensive system (such as poultry farming) where management control can be almost complete. In most farming systems, however, management control is not complete and the biological goals of the plant and/or animal subsystems often conflict with those of management (Wright, 1971).

Dent and Anderson (1971) indicated that the environment of farming systems is probably best considered in two distinct parts, reflecting the fact that weather and prices constitute the two major sources of uncertainty for management. The climate influences plant and animal production and may provide essential system inputs, such as water. The socio-economic environment provides system inputs in the form of goods and services and determines the economic outcome of the system's operation. Socio-economic conditions also influence the farmer, who is a component of both the farming system and a wider socio-economic system. Farmer's goals are often poorly defined and much analytical work has been based on the simplifying assumption that they are profit maximizers, whereas a more realistic assumption would be that they are risk averters.

Wright (1971) stated that the complexity of farming systems and the uncertainty associated with the decision making process are features which indicate that a systems approach to research could be particularly useful. There seems to be a growing recognition of the need for such an approach to the study of farming systems, both in systems analysis and in systems design.

Dent and Blackie (1979) indicated that systems research relies to a considerable extent on the use of models because it is often impossible or impractical to study the real system. If the research is concerned with the design of new systems, then by implication the corresponding real systems do not yet exist and models must be used. Even when the real system exists, experimentation may not be feasible due to factors of time, cost, disturbance, etc.

Gordon (1978) stated that a model is a system which is an abstraction of a real world system; therefore, a model is not only a substitute for a system, it is also a simplification of the system. He defines a model as the body of information about a system gathered for the purpose of studying the system. Since the purpose of the study will determine the nature of the information that is gathered, there is no unique model of a system. Different models of the same system will be produced by different analysts interested in different aspects of the system or by the same analyst as his understanding of the system changes.

Smerage (1979) stated that a model has two parts: 1) the conceptual model, and 2) the mathematical model. The conceptual model expresses the perceptions of its author about the components of the real system and their structural arrangement to form that system. It is usually expressed by a schematic with supporting narrative. The behavioral properties of each component are described by relations between its relevant attributes (parameters). System structure dictates the interactions between components; it is described by another set of equations expressing constraints between the attributes of individual components. The mathematical model describes the properties of its behavior as a single entity. It consists of a set of equations for certain attributes of the components and the environmental stimuli. It is formulated, by alternative approaches and in alternative formats, from the component and structural descriptions of the corresponding conceptual model. The precise nature of an 'adequate' model will be dictated by the purpose of the investigation and the kind of problems to be solved.

According to Gordon (1978) and Naylor (1971) models can be used in a number of ways, but a basic distinction can be drawn between descriptive and normative applications. When used for descriptive purposes, the model acts as a framework for the identification of system components and relationships and the determination of satisfactory functional forms of these relationships. The descriptive use of models is mainly a tool of systems analysis where the objective is to gain a better understanding of the system. Models are used in a normative fashion in an attempt to solve problems; the problem may be the derivation of decision rules that will assist a decision-maker in making an optimal decision. A normative model thus requires some objective function to evaluate different decision rules.

Descriptive models are not primarily concerned with solving problems, so they do not usually include an objective function. Simulation, however, uses descriptive models to study decision-making problems. The model merely describes the behavior of the system under a given set of assumptions; yet, by experimenting with the model, approximate solutions to problems can be obtained (Dent and Blackie, 1979).

The term 'simulation' like "system" is sometimes a source of some confusion. In its widest sense, to simulate means to duplicate the essence of a system without actually attaining reality itself. Naylor (1971) presents a useful applied definition of simulation, as 'a technique that involves setting up a model of a real situation (system), and then performing experiments on the model'. That is, simulation is essentially a two-phase operation involving modeling and experimentation. The real system is replaced by an analogous, but abstract, system in order to overcome problems of physical experimentation.

It is not the concept of simulation that is new, but rather the use of computers to run mathematical analogues of real systems, and the emphasis on whole or total systems. In this sense, the development of electronic computers has been a necessary prerequisite to the development of simulation as a systems research technique (Manetsch and Park, 1977).

A general methodology for simulation is illustrated in Figure 2.1. The main feature is the feedback to any previous step, which is characteristic of the almost cyclic nature of many simulation studies.

The diversity of fields in agricultural research means that the development of simulation models is always likely to be a major task for an individual. Wright (1971) pointed out that the most practical solution is the adoption of an interdisciplinary approach utilizing the specialist knowledge of researchers in the relevant fields. Although the lack of data seems to be a major limitation to the development of satisfactory models, the mere attempt to develop models can play a useful role in terms of highlighting the sort of information that is lacking.

In most experimental work there is a problem of relating the results to the real system because the experimental environment is not the same as that in which the results are to be applied. This problem

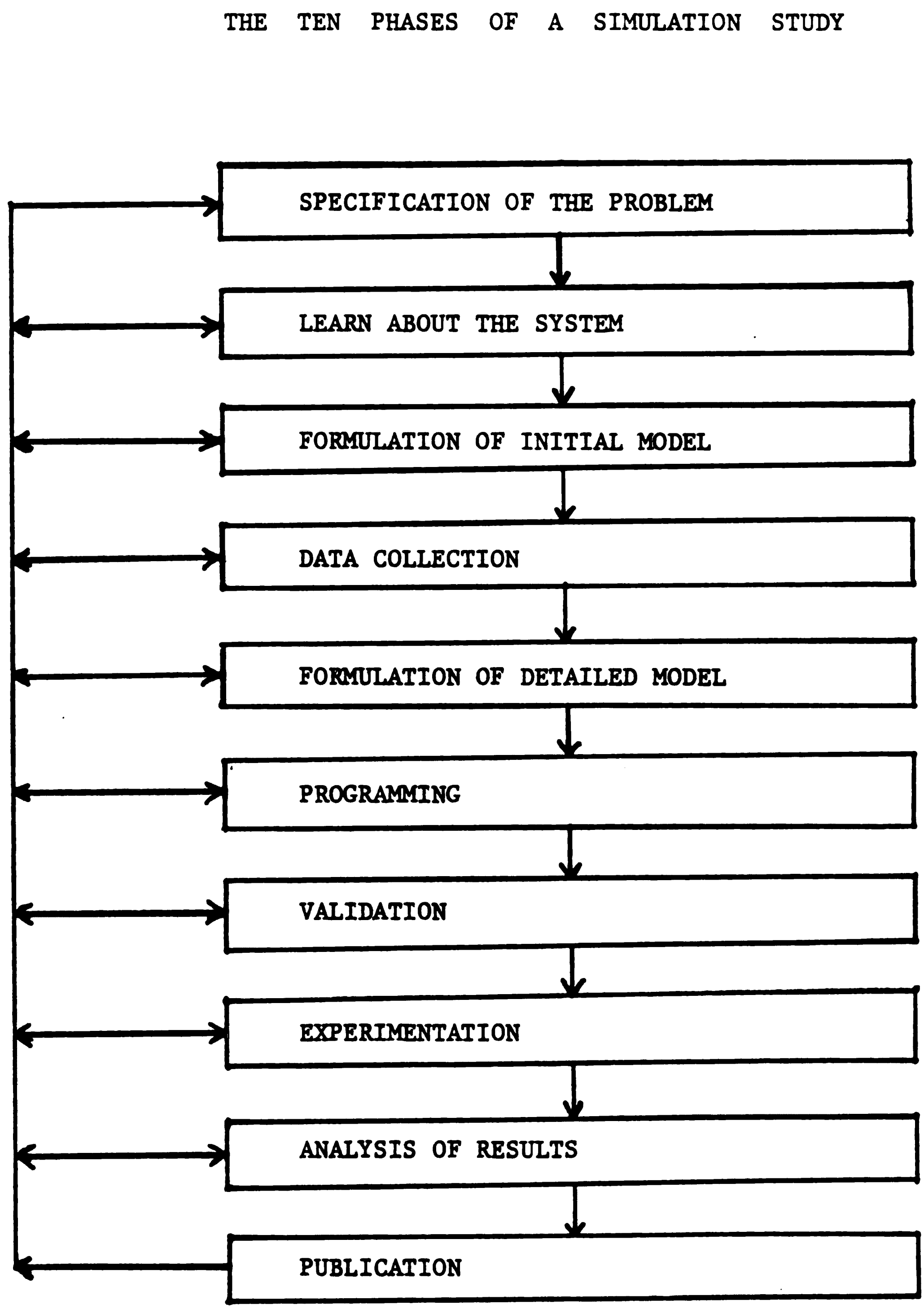

Figure 2.1. Diagramatic representation of the methodology for simulation. (Adapted from Wright, 1971).

of interference is particularly true of simulation models in that the results are obtained from a mathematical rather than a physical model. The process of evaluating the model in relation to reality is referred to as the verification or validation stage of simulation.

Dent and Blackie (1979) and Wright (1971) have stated that 'verification' and 'validation' are often used synonymously in relation to simulation models, although each term does have a distinct application. Literally, to verify means 'to establish the truth or correctness of' so that verification of a model is concerned with establishing whether the model is a true or correct representation of reality. On the other hand, validation is not so much concerned with the correctness of a model, but rather whether it is effective or suitable for a specific purpose. Thus a model is 'validated' in relation to the purpose for which it was constructed, whereas a model is 'verified' in relation to absolute truth.

Although validation implies some sort of comparison between model and reality, there may be little quantitative information about the real system that can be used as a basis for comparison. Therefore, a considerable degree of subjective judgement may be necessary. The crucial test in validation of system models should be whether the model leads to better decisions that can be obtained by using other techniques (Dent and Blackie, 1979).

2.2.3. Application of Systems Analysis to Agricultural Engineering Problems

As early as 1934, attempts were made to develop systematic procedures to select farm equipment (Carter, 1934). In a more general view of agricultural problems, Pinches (1956) suggested the need for agricultural engineering research with explicit application of 'agricultural systems engineering' to agriculture. He concluded that agricultural systems engineers should seek to bring the farm's resources of soil and water, machinery, structures, livestock, and labor into a condition of better operational balance. Such an integrated approach would challenge the technological validity and biological necessity of every operation. It would evaluate critically the type, scale, timing, sequence, nature, and purpose of every element of the process.

Sammet (1959) stated that a useful alternative to experimental comparison of entire systems is the representation and comparison of alternative systems through synthesis or model building. He described a planned approach to systems studies at two levels. Systems analysis, comprising the study, definition and description of processes, and the establishment of optimum relationships; and systems design and development, including research and development oriented to methods' improvement and the execution of plans of action based on results of systems analysis.

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

The same year, however, Stewart (1965), observed that the application of systems analysis (operations research) to agriculture had lagged behind the advances made in other areas. He noted that American agriculture has become a highly complex undertaking where man, machines, money, biology and environment interact to produce food and fiber at a profit. His question was: is agriculture too complex to profit from the successes of systems analysis in industrial and military enterprises?

Esmay (1974) described an applicable systems analysis approach and proposed a plan for development of a standardized approach for all engineers involved in feasibility studies and the development of recommendations for selective agricultural meachanization.

Friedley and Holtman (1974), used systems analysis to predict the socio-economic implications of mechanization. They concluded that a careful systems analysis approach could maximize benefits and minimize adverse effects.

Link and Splinter (1970) and Loewer et al. (1980) in their survey of simulation techniques and applications to agricultural problems concluded that the fears expressed by Stewart (1965) could be put aside. Simulation had become one of the most powerful research tools in agricultural engineering and other fields of agriculture.

2.3. Agricultural Machinery Productivity

Singh (1978) stated that the design of field machinery systems involves calculation of machine productivities, estimation of days suitable for field work, selection of an appropriate performance criterion and development of an adequate procedure for optimizing performance criteria subject to specified constraints.

Hunt (1977) and Bowers (1975b) indicated that the major factors influencing the productivity (performance) of agricultural machines are size (width), operating speed, field efficiency and energy requirements.

According to White (1978) operating width, under most circumstances, is a design factor, and cannot be readily changed once the machine has been purchased, but for a few exceptions. Operating speed for most machines can, at least theoretically, be varied over a wide range. Practical limitations, however, such as operator ability, tractor power and speed ranges, topography, crop and soil conditions, and machine performance characteristics, tend to set both lower and upper limits.

Available sizes of various machines can be obtained from the literature published by the several agricultural equipment manufacturers, such as the Whole Goods Price List, or the Implement & Tractor Red Books. Typical ranges in operating speed and field efficiency for most types of machines are presented in the Agricultural Engineers Yearbook (1982) and in most of the agricultural machinery text books and extension bulletins.

Field efficiency is undoubtedly the most elusive factor in estimating farm machinery productivity. It is a measure of the relative productivity of a machine under field conditions. White (1978) defines field efficiency as the ratio of the theoretical productivity of a machine to its actual productivity. It accounts for failure to utilize the full operating width of the machine and for time losses due to turning, idle travel, material handling, cleaning clogged equipment and field repair and maintenance. Hunt (1977) analyzed the various factors affecting the field efficiency of a machine.

Field machinery energy requirements consist of functional requirements and rolling resistance requirements (Kepner et al., 1980). Functional requirements are those that relate directly to the processing of soils, seeds, chemicals or crops. Rolling resistance power requirements arise from the necessity for moving heavy machinery over soft field surfaces. Functional requirements depend upon soil and crop conditions which are highly variable. According to Singh et al. (1979) tillage draft varies with soil type, soil moisture, root development, organic matter content and depth of penetration. Forward speed also significantly affects plow draft.

Draft of tillage implements is normally reported per unit of effective width or per row. Hunt (1977) presents functional and rolling resistance requirements combined for most tillage and ground driven machines. Ranges of draft or energy requirements for most field machines are listed in the Agricultural Engineers Yearbook (1982) and elsewhere (Hunt, 1977; Bowers, 1975b; White, 1977, 1978).

Agricultural machinery productivity has been thoroughly studied by many researchers. Recently, Renoll (1981) developed a mathematical expression to predict row-crop machine performance rate, which uses 14 specific input coefficients including items relating to the actual machine and its use, field size, shape, physical condition, and machine management. Predicted values were compared with actual capacity and found to be at least 95 percent accurate.

2.4. Estimation of Days Suitable for Field Work

The farmer is the world's most interested weather observer. He scans the skies upon arising in the morning and he speculates on the next day's weather as he goes to bed. He listens avidly to radio and television weather broadcasts and he can recall years later the unusual weather associated with a particular planting or harvesting season. Weather is the variable in farming over which he has no control. It is a variable of such importance that it can either bankrupt or enrich him.

For efficient machinery management, a farmer needs information on the number of days suitable for field work available in order to properly balance between the high timeliness costs of a small machinery complement and the inflated costs of overinvestment in machinery (Elliot et al., 1977).

Hunt (1980) pointed out that only the most unusual weather interferes with mechanical operation of field machines. Torrential rains, freezing temperatures, high winds, and blowing snow can, in a few instances, impede crop gathering mechanisms and conveyors, interfere with lubrication and hydraulic control, and cause a loss of traction and steering control. But generally, most tractors and implements are capable of operating over a wide range of weather conditions. Instead, it is the effects of weather on soils and crops that control field machine operations.

It is the farm operator's task to recognize and, if possible, predict these effects. He must make and continuously review a decision as to whether today's and tomorrow's field conditions are such that machines can operate. The farmer being only an amateur weatherman will usually resort to a trial field operation of his machine to test whether the soil and the crop are ready for field work (Hunt, 1980).

Van Kampen (1971) stated that the moisture state of the soil or crop is usually the most important factor affecting machine operations. Soil moisture constrains machine operations in relation with tillage and trafficability. Responsible management should limit traffic to the same moisture content as that for tillage. Working the soil at field capacity or above, whether from tillage tools or rolling wheels, causes a puddled condition which may reduce soil productivity for years afterwards. Crop moisture contents must be limited to well-known percentages for safe, dry storage and the limits often dictate the moisture content at which field machines operate. High moisture harvest and storage is one way to beat the weather in that field operations are constrained only by the trafficability of the soil.

Tulu (1973) indicated that the integration of soil and crop conditions with past, present, and anticipated weather can lead to that single most important measure of weather to a farmer--the likelihood that a working day has arrived. The actual arrival cannot be related to a specific calendar date but depends on both past and present weather. Seasonal accumulations of temperature, precipitation and evapotranspiration affect the initial state of both crops and soils on any particular day. Should seasonal weather indicate the arrival of a working day, bad weather for that day or hour can still cancel the arrival event.

Given that the season indicates a working day, an experienced farmer designates a day as a working day only after considering many factors and exercising many agronomic skills. He considers yesterday's weather, today's conditions and tomorrow's forecast. He must recognize the arrival maturity of crops and the losses of quality and quantity from untimely field operations. He monitors the growth of weeds, insects, diseases, and judges the potential for damage from soil manipulations at a non-optimum moisture content. And then he declares a working or non-working day (Hunt, 1980).

There is an abundance of literature concerning days suitable for field work. Two categories of workday data have been reported: 1) observed data for a location and year, and 2) generated data using weather and soil parameters.

2.4.1. Observed Field Work Data

The papers in this category are few. Link (1968) reported on days suitable for field work developed from the observations kept in the personal diary of the manager of the Agronomy Farm, at Ames, Iowa. The record presents working conditions in the fields of that farm from 1932 to 1962, except for 1940 and 1941.

Morey et al. (1971) reported daily work data which was collected by the department of agricultural statistics at Purdue University, in central Indiana from 1952 to 1968.

Fulton et al. (1976) reported observed number of suitable days in Iowa at four different probability levels for field operations throughout the crop season based on records of the Iowa Crop and Livestock Reporting Service. The data for each week were ranked and the minimum number of suitable days was determined under each probability level to permit estimates to be made according to an acceptable risk.

2.4.2. Generated Field Work Data

Hunt (1980) concluded that until working day forecasts are perfected, simulation models of weather will be used by researchers to estimate field machine performance. These models generally assume a moisture content of soils and crops at some initial date. Mathematical statements of the change in moisture resulting from weather factors are derived and applied to a moisture accounting procedure. Various weather conditions are entered for each day as a passing of the season is simulated. The number of days when the calculated state of the crop or soil is favorable for machine operations are counted as days suitable for field work. The varying answers from repeated simulations leads to probabilistic statements of the number of working days. Most simulations are site and soil specific.

In one of the earliest publications, Shaw (1965) estimated the moisture content in the top 15 cm of the soil considering precipitation and evaporation. A working day was defined as one in which the soil was not frozen and the available soil moisture in the top 15 cm of the profile was less than 19 mm. He compared the number of predicted days suitable for field operations to the record of suitable days from the Agronomy Farm, Ames, Iowa (Link, 1968). The correlations between the observed and predicted number of days during March, April and May ranged from 0.87 to 0.93.

2.4.2.1. Precipitation-frequency analysis. Models for hay making and other crop harvesting operations have tended to depend only on rainfall. Von Bargen (1966) presented the 'Open Haying Day' criteria defined as: ". . . less than 0.1 inches (2.5 mm) of rainfall on that day, less than one inch (25 mm) of rainfall the previous day, and greater than 70% sunshine on that day."

Probability theory has been used extensively to analyze precipitation patterns and to predict sequences of wet or dry days.

Weiss (1964) used a Markov Chain Probability Model to fit sequences of wet or dry days to records of various length and for several climatically different areas of the USA and Canada. A Markov Chain is defined as a type of time-ordered probability process which goes from one state to another according to probabilistic transition rules that are determined by the current state only (Jones et al., 1972).

A convenient nomograph was presented by Weiss (1964) relating probability, length of sequence, and cumulative probability distribution, for dry or wet sequences. The author concluded that the Markov Chain model might be used to indicate the rainfall or drought probability regime of a station and from the results from many stations to specify it over a wide area.

Colville and Myers (1965) and Feyerherm et al. (1966) and Dale (1968) studied the weather of Nebraska, Michigan and Indiana, respectively.

They developed probabilities of wet or dry days from past weather records. Initial probability, used when no information exists on the previous day, and transition probability, computed whether the previous day is known to be wet or dry, were calculated considering four amounts of precipitation to define a wet or dry day. The probabilities were grouped for each seven-day period (climatological week) of a year. Dry and wet values are given for initial probabilities. Sequences of dry/dry, wet/dry, dry/wet, wet/wet probabilities are presented for transition probabilities. Procedures for determining the probability that a particular day or group of days will be dry or wet are explained along with a method for checking computations.

MacHardy (1966b) and Wiser (1966) applied the Monte Carlo method to the study of probability urn models of the precipitation process and the sizing of farm machines for weather dependent operations. The Monte Carlo method is a simulation technique which uses a series of random numbers to create statistical distribution functions. This method is used to study stochastic models of physical or mathematical processes and is based on the fact that the probability distribution of the random variable is known. Three different urn models were tested: the Bernoulli model, the Polya model, and the Markov model. Results showed that the Bernoulli model was the simplest but the least precise in determining expected values of precipitation and applies only to independent events. The Markov and the Polya models were not suitable when weather persistance extended over several periods. If this is not the case, the Markov model was superior in obtaining expected values of precipitation.

Jeffers and Staley (1968) developed a method of calculating probabilities of runs of days suitable for haying operations using meteorological records, for areas with marine climate on the west coast of continents between latitudes 40 and 60 degrees north and south. The probabilities were used to modify the theoretical time available for forage machine operations.

Coon and Leistritz (1974) studied the rainfall effects on annual capacities of hay harvesting machines in North Dakota. Four weekly rainfall classes and three different drying situations were considered for the central part of each of four farming areas. Total annual capacity for different machines were calculated to help farmers select a hay harvesting machinery complement.

Amir et al. (1977) developed a procedure for determining and verifying probabilities of a single dry or wet day, consecutive dry or wet days and conditional probabilities. The procedure was applied to Guelph and Ottawa, in Canada, showing significantly good correlations between the observed and the calculated probabilities.

Hayhoe (1980) worked on two practical problems related to suitable days that had been pointed out by Fulton et al. (1976). The two problems are: 1) the number of days available on a weekly basis cannot, in general, be added directly for multiweek estimates, and 2) the mathematical probability distribution of the number of suitable days during each week is not generally known. He developed techniques to generate workday probability distributions for periods for which the distribution is specified for subperiods. They could be used to generate probability distributions for arbitrary periods from tables providing workday probabilities for fixed periods, such as on a weekly basis. His assumptions required statistical independence between the number of workdays in each of the subperiods and whether the differences between observed and predicted values could reasonably be attributed to random variation.

2.4.2.2. Soil moisture content budgeting. Baier and Robertson (1966) presented a new technique for the estimation of daily soil moisture on a zone-by-zone basis from standard meteorological data. The method is more versatile than previous meteorological budgets and makes use of basic concepts, such as taking potential evapotranspiration (PE) as a possible maximum of actual evapotranspiration (AE) and subdividing the total available soil moisture into several zones of different capacities. Adjustments for runoff, drainage, different types of soil-drying curves and the effect of different atmospheric demand rates on the AE/PE ratio were also incorporated.

Rutledge and MacHardy (1968) divided the soil into six moisture zones and used the soil moisture budget developed by Baier and Robertson (1966) to estimate the soil moisture content in each zone from climatological records. They also calculated values of soil shear strength required for tillage in Alberta soils, and concluded that required shear strength would be developed at soil moisture contents at or below field capacity. They obtained a good correlation with observed days suitable for tillage when 95% of available water capacity was used as the maximum soil moisture content in the top three zones.

Link (1968) used a moisture budgeting technique to estimate daily soil moisture contents. He proposed the plastic limit as the maximum value for the soil to be trafficable, and indicated that field conditions suitable for tillage operations could be defined by a maximum soil moisture content below the plastic limit and some minimum soil moisture content.

Frisby (1970) used an equation for the drying rate of soil above field capacity and a soil moisture budgeting technique to predict the number of good days available for primary tillage in the spring and fall for a soil in central Missouri. He classified a day as suitable for tillage if the soil moisture content was equal to or less than field capacity and if precipitation was less than 2.5 mm.

Selirio and Brown (1972) estimated spring workdays from climatological records in Ontario, Canada. Based on two years of soil moisture measurements and observation of work conditions, they concluded that tillage was possible when the soil moisture content was about 90% of field capacity to a depth of 12 cm regardless of soil moisture content in the lower zones. A day was assumed to be suitable for field work if the top 12 cm of the soil were at or below 90% of field capacity, daily snowfall was less than 2.5 cm and maximum air temperature was above 0° C.

Morey et al. (1971) used a soil moisture budget and the tractability criteria based on the results of Rutledge and MacHardy (1968) to estimate the number of days suitable for harvesting corn in Indiana. A suitable day was defined as one having less than 2.5 mm of precipitation and moisture content less than 95% of available water capacity in the top 15 cm of the soil profile.

Jones et al. (1972) developed an environmental model by using past records of daily rainfall, maximum and minimum air temperature, and evaporation at State College, Mississippi. The model predicts daily soil moisture values for various depths depending upon the weather, soil properties, and the initial boundary conditions of the soil.

Baier (1973) estimated field workdays in Canada using the Versatile Soil Moisture Budget developed in 1966. A country wide analysis of field workdays is suggested, subject to verification of the assumptions made in the study. The statistics provide useful information for scheduling farming operations, planning farm machinery size, and for research and services by agricultural engineers.

Tulu (1973) and Tulu et al. (1974) extended the work of Holtman et al. (1973) to frozen soil. This model considers the combined effects of precipitation, evaporation and soil moisture to define a workday. He assumed a day was suitable for corn harvesting if the soil was frozen, or if thawed, the available water capacity in the upper 7.5 cm of soil profile was below 95%. For spring tillage and planting operations, a workday was assumed if the available water capacity in the upper 7.5 cm of the soil profile was below 95% and in the second 7.5 cm of the soil profile was below 98%. The total number of workdays as determined by the model agreed well with the observed days, but a day by day comparison showed that more than 10% of the days were missing. The authors believed this was due to the fact that the model did not give partial workdays, which were reported in the farm record as full workdays.

Hassan and Broughton (1975) attempted to clarify points which had been subjected to inaccuracy and confusion in tractability research because of insufficient care with terminology. They also included some field measurements from which workday criteria for tillage and planting were deduced. They concluded that the limiting soil moisture condition can be specified on either percentage of field capacity or percentage of available water capacity, as long as the basis of the limiting condition is clearly stated. They also concluded that the limiting conditions of soil suitability for tillage and planting may be more directly related to soil plasticity, stickiness, slipperiness, and susceptibility to compaction than to absolute soil moisture content.

Elliot et al. (1977) developed a soil water balance model to predict favorable tillage days for a farmer during the spring months in Illinois. The model was to be somewhat general in nature and not site specific. It contained a drainage component to evaluate various drainage characteristics imposed on each soil. Percent of available soil moisture in the top 15 cm of the soil was used as a tillage criterion: 80% for fine sandy loam and 90% for silt loam soils. They tested the model against field workdays data from the Illinois Cooperative Crop Reporting Service and local daily field observations of workdays and found it to be sufficiently good to predict available days for tillage on a monthly basis.

Dyer and Baier (1979) developed and tested a new technique to estimate field workdays in the fall, for several locations in Canada. The model is based on soil tractability and uses soil moisture budgeting principles, simplified so that crop type differences were ignored and only the near surface soil was considered. The basic assumption made is that in the fall, tractability is more dependent on the drainage rate of excess water (above field capacity) through the top layers of soil than on evaporation, although both factors must be considered. The method agreed well with day-to-day field work observations by farmers and showed promise as a means of making general fall workday probability estimates.

Hunt (1980), in a review of the weather data used in field machinery operations, stated that the best agreement with historical soil moisture data is obtained with models that include daily precipitation, previous day's precipitation, maximum soil moisture content in the top 15 cm, maximum snowfall, maximum depth of snow on the ground, and existence or non-existence of frozen soil.

2.5. Field Machinery Selection Criteria

2.5.1. Physical Performance

A field machinery selection system based on physical performance answers the question: will the machinery complement do the job on time?

The complement is selected on the basis of work capacity (match the land), power requirements (match power to implements), and time constraints. The objective is, implicitly, to minimize timeliness costs, i.e. crop losses due to untimely field operations. However, it may sometimes require the use of very large machinery.

Hughes and Holtman (1974) developed a computer program for selecting and sizing machinery complements based upon calendar date constraints on field operations. The model selects a machinery complement, including power units, which is capable of performing the required field operations at a rate sufficient to achieve successful crops. Field operations were organized into subsets or groups of operations that must be performed either simultaneously or sequentially during a specific time period. Timeliness costs were not considered explicitly. Rather, a calendar period constraint was assumed for each subset of operations. It was assumed that all field operations used the same fixed percentage of rated tractor drawbar power at all times and subset time was divided among operations according to the energy requirements of the operations. The effective horsepower required for the system was the maximum required for any one subset. It was possible to reduce this maximum power by manually modifying the distribution of work among subsets and re-running the program.

Bowers (1975a) used a similar procedure for machinery selection in a 50,000 hectare farming operation in Yugoslavia. A tractor size was assumed and implements were matched to the tractor. A timeliness constraint was included by requiring that operations be completed before yields started reducing at an accelerated rate. Calendar date constraints were adjusted manually to obtain the least-cost feasible allocation of field work over time.

Singh and Holtman (1979) developed a heuristic agricultural machinery selection algorithm based upon field work specifications, calendar date constraints, machinery capacity, and field work conditions. Timeliness was viewed as a constraint rather than a penalty. Field operations must be completed within specific calendar periods. Thus, machine productivity is matched to available time in such a way that all operations are completed by the specified date with a design probability level.

2.5.2. Economic Performance

The selection criterion used in machinery complement design is, most often, an economic one, i.e. least-cost or maximum profit (Burrows and Siemens, 1974; Eidsvig and Olson, 1969; Stapleton and Hinz, 1974; McIsaac and Lovering, 1974, 1976, 1977; Miller, 1980; Zoz, 1974).

Under this criterion the costs considered are machinery, labor and timeliness costs.

Machinery costs are divided into fixed costs and variable costs. Fixed costs are independent of machine use, while variable costs increase proportionally with use. The cost of interest on machinery investment, taxes, housing, and insurance are dependent on calendar year time and are independent of use. The costs of fuel, lubrication, service and maintenance are associated with use. Depreciation and repair costs seem to be a function of both use and time. However, most often depreciation is included in the fixed category and repair cost in the variable cost category (Hunt, 1977).

Procedures for estimating machinery costs are available in the Agricultural Engineers Yearbook (1982), Hunt (1977), Bowers (1975b), and in most agricultural machinery textbooks and extension bulletins.

Batterham (1974) outlined an economic model of farm machinery investment and financing. The traditional method of analyzing farm machinery investment using partial budgeting based on cost-curve theory was rejected on the grounds that the effects of the passage of time were not included in the analysis. Capital budgeting methods based on investment theory were used to analyze a buy or custom hire decision for a combine. The results of the capital budgeting analysis indicated that the opposite decision should be taken to that indicated in the partial budgeting analysis, using the same data.

The calculation of machinery costs under inflation has been discussed by Rotz et al. (1981), Bartholomew (1981), and Schoney and Finner (1981). It was shown that, at current inflation rates, most tractors and combines are likely to retain a very substantial portion of their original price. It was also suggested that the traditional approach to machinery costing needs to be modified to provide a consistent analysis.

Labor costs, for a farm operator, are the opportunity cost of operator time used for operating machinery. When hired labor is used, the cost may be on a hourly or annual basis. On a hourly basis, total labor cost is directly proportional to machine operating time and inversely proportional to machine productivity. When labor is hired on an annual basis, total labor cost, is independent of machine operating time and productivity (White et al., 1977).

Burrows and Siemens (1974) calculated labor cost assuming that each man was hired at an annual salary, full time, only to operate machinery. Moore et al. (1980) assumed hired labor on a hourly basis. Mayfield et al. (1980), on the other hand, did not include labor cost in their model because they felt machinery owners have a good knowledge of their labor cost and it can be easily added to the other costs.

Timeliness is defined in the Agricultural Engineers Yearbook (1982) as the ability of a machine to perform an activity at such a time that quality and quantity of a crop are maximized. Timeliness costs arise from reduced yields due to improper tillage and planting operations; losses associated with improper timing of machine operations to biological needs of the plants; and any reduction in product quality that may be attributed to untimely machine operations. Some operations may have near zero timeliness costs. Others, particularly seeding of many crops and harvest of highly perishable products, may have very high timeliness costs.

The relationship between crop value and the operation date varies with the operation, crop, location, and even from one year to another. Hunt (1977), Bowers (1975b) and the Agricultural Engineers Yearbook (1982) present estimates of timeliness loss factor (fractional reduction in yield or value of the crop per acre-day of delay) for some specific crops and operations. A linear reduction in yield of the crop after an optimum date is assumed.

Since reliable data for timeliness costs for all operations and for all crops is not readily available for all locations, some researchers (Hughes and Holtman, 1974; Bowers, 1975a) have considered timeliness a system design constraint.

Doster et al. (1980), Edwards and Boehlje (1980a) and Von Bargen (1980) have modeled timeliness constraints in different parts of the USA. They concluded that timeliness data are available for general use in machine sizing, but these data must be modified for application to specific situations. They also demonstrated the sensitivity of machinery size to varying timeliness factors.

Parsons et al. (1981) in a study of machinery down time costs usi

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using the Purdue Crop Budget Model B-94 (Krutz et al., 1980) concluded that the principle of oversizing equipment as insurance against time loss from machinery breakdowns was demonstrated by showing a dramatic reduction in down time costs with oversized planting equipment. The use of two smaller planters vs. one larger unit was shown to be quite profitable on a 404-hectare farm where field time available is critical, but was of little benefit on a 200-hectare farm.

Edwards and Boehlje (1980b) suggested risk-returns criteria for selecting farm machinery. Their basic idea was to maximize profits within certain acceptable risk levels. They considered timeliness costs stochastically dependent on the number of suitable days for field work during critical periods of each year. The risk-return decision criteria included expected cost, standard deviation frontiers; stochastic dominance; least-cost, least-variance; and upper confidence limit criteria. They concluded that the least-cost, least variance criterion is relatively simple to use and produces results consistent with those of the other criteria tested.

2.6. Field Machinery Complement Selection Procedures

The reference literature contains much data on the costs of operating field machinery, i.e. Mayfield (1980), Moore et al. (1980), Campbell (1978). A smaller number of publications have considered the problem of capacity or size selection of field machinery. The essential methodology for matching the size of soil engaging implements to tractor power and for calculating productivity is presented in ASAE Engineering Practice EP 391 and ASAE Data: ASAE D230.3 (Agricultural Engineers Yearbook, 1982).

Hunt (1963, 1967) presented procedures for selecting optimum machine sizes on an economic basis. Annual cost equations for each implement were written in terms of effective width of implements and for tractors in terms of maximum PTO power. The model is based upon a linear price-width relationship incorporated into a calculus based minimization function. Similar approaches were used later by Chancellor (1968), Hunt (1972) and Hughes et al. (1973) to determine the economic power level for tractors.

Link and Bockhop (1964) approached machinery selection from a scheduling viewpoint, where the requirements of the farm and the constraints of environmental conditions are imposed upon the system. Later on, Link (1965, 1967) using the techniques of activity network developed a method to select a complete set of farm machinery with a mathematical approach.

Frisby and Bockhop (1968) used Link's model to determine the area yielding maximum income for a given machinery complement and to decide when the complement should be abandoned as the area is increased.

The systems analysis approach to farm machinery selection has been specifically used by Osborn and Barrick (1970). They developed a computer model to select the power and equipment combinations that would minimize annual power and machinery costs. The initial basis for the computer model was the most limiting operation which was determined by the greatest power capacity requirement. The model began the selection with the smallest tractor and largest implement of a type which would satisfy the most limiting operation. Implement size was decreased and tractor size increased until an adequate match was obtained, subject to doing all work in the time allocated. They concluded that the procedure had several advantages, although it had to be modified if workday probabilities and timeliness cost were to be included.

MacHardy (1966a) used a combination of Lagrange's method and linear programming to determine minimum cost machinery combinations. The procedure determines implement productivities and tractor power such that the annual fixed machinery cost is a minimum. MacHardy (1966b) described a procedure for selecting machinery size and timeliness costs. Cumulative distribution curves for consecutive workdays and a Monte Carlo approach were used. Russell and MacHardy (1970) used MacHardy's (1966b) method to investigate grain harvesting in western Canada. A computer simulation of a thousand years of wheat harvesting allowed them to conclude that the combine should be sized so that the area to be harvested could be completed in 10 to 14 working days; over a number of years there is a higher total cost per hectare for buying a combine too large than buying one too small; in any one year there is a much greater probability of obtaining a penalty of zero with a large combine than with a small combine.

Von Bargen and Hines (1973) developed a computer program to predict the economic performance of a complement of farm machines. Only machines available in the market were considered and real prices instead of a general price-width or size relationship were used. The model could be used to analyze machinery needs for a specific farm; to teach farm machinery management; and for enterprise planning with linear programming models.

Considering that tillage has always been one of the larger power consuming operations on a farm, the selection of tillage systems was analyzed by Parsons (1968), Zoz (1974), and Krenz and Micheel (1974). Implement width, traveling speed, and combining operations to limit the number of trips across the field were considered the most important fac

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factors to increase productivity of field operations.

McIsaac and Lovering (1974, 1976, 1977) described algorithms designed to calculate least-cost implement sizes for tillage, seeding and harvesting of cereals in Canada. The combine selection model estimates combining cost as a function of crop area, crop yield, combine ownership and operating costs; it also estimates natural crop losses as a function of time and combine loss as a function of combine throughput and rated capacity. It was concluded that it is not always 'least-cost' to operate a combine at its rated capacity; there are circumstances where it is advantageous to operate a combine at a rate higher than its rated capacity and incur in higher combining losses and lower natural losses; the least-cost combine size is specific to each crop production situation.

The least-cost implement size models for tillage and seeding of cereals, (McIsaac and Lovering, 1976 and 1977), considered fixed and variable costs for each implement and tractor, labor costs, and the value of crop losses due to late seeding. The models assumed a constant work-day probability throughout the entire seeding period and a linear relationship between price and size of machines. The least-cost implement size complements are specific for each area, cultural practice, soil, climate, crop and crop value. The models are helpful in machinery investment decisions and to choose least-cost cultural practices in situations where the crop yields that may be expected with each cultural practice are known.

The influence of weather risk on grain harvest machinery capacity has been addressed by Donaldson (1968) and van Kampen (1971). Their models regarded rates of combine work, weather, and diurnal grain moisture content as probabilistic, with known distributions based on empirical data. Edwards and Boehlje (1980c), Danok et al. (1980) and Whitson et al.

(1981) incorporated weather variability to the crop and machinery complement selection procedures. The mathematical programming model developed included: a) the stochastic nature of weather; b) the integer nature of machinery decisions; c) the joint selection of machinery and crop plans; and d) the selection among machinery sets rather than among individual machines.

Linear programming models have been used by several researchers, i.e. Krutz et al. (1980), Pfeiffer and Peterson (1980), Von Bargen (1980), Whitson et al. (1981), to address specific machinery management and crop production situations. Although linear programming models can be useful for evaluating machinery sizing decisions, they are more appropriate for organizing the enterprise mix to maximize returns given a current machinery complement. The models point out where bottlenecks occur in the present machinery complement and how much could be spent to alleviate them. Linear programming models are less effective for applications to search strategies and require the user to enter large amounts of data, and ability in reading and interpreting results.

Heuristic models to select farm machinery have been developed at Michigan State University (Singh, 1978; Wolak, 1981; Muhtar, 1982).

Singh (1978), developed a heuristic agricultural field machinery selection algorithm for multicrop farms, in Michigan. The model designs a machinery system based upon field work specifications, field operation calendar date constraints, machinery capacity relations, and field work conditions for a farm growing a mix of field crops using a sequence of suboptimizations on harvesting capacity, tractor power, and implement sizes. The model specifies the size and number of each component, prepares a work schedule, gives the distribution of labor needs, calculates fuel requirements, and makes a cost analysis of the selected machinery complement.

Wolak (1981) modified and applied Singh's (1978) model to the selection of field machinery under Michigan's Saginaw Valley conditions. The new model expanded the number of crop enterprises, put a limit to the labor supply, included 4-wheel drive tractors, and selects a machinery set for each year of available workday data in an effort to elicit true design probabilities.

Muhtar (1982), revised the two previous models in order to overcome important restrictions dealing with timeliness of operations, types of soil, cultivated area, used machinery, and custom hire options. The new model was successfully used to compare conventional and conservation tillage systems in the Saginaw Bay area of Michigan.

Considering the characteristics of the models surveyed and the special economic, agronomic, and environmental conditions under which wheat is grown in south central Chile, it was considered necessary to develop a specific computer algorithm that would satisfy all the system constraints and would address the needs of these farmers. The new model was developed upon the basis of the previous work by Singh (1978), Wolak (1981), and Muhtar (1982), but keeping in mind the specific characteristics of agricultural production in a developing country.

3. MODEL DEVELOPMENT

3.1. Field Work in Chile

As pointed out by Batterham et al. (1973), Harris and Bender (1973a) and by Stapleton and Barnes (1967), the development of a field machinery selection model needs data characterizing the climatological, agronomic, agricultural engineering, and economic conditions of the environment under which the model should work.

In order to collect this information, field work was undertaken in the Andes Pre-Cordillera of the province of Nuble, in November and December of 1981. During this period the author joined the extension specialists of the Technology Transfer Program for the Andes Pre-Cordillera that is being carried out by the Quilamapu Experiment Station of the Institute of Agricultural Research (I.N.I.A.).

The purpose of the Technology Transfer Program is to transfer to the farmers the knowledge acquired during five years of research in the area (INIA, 1980). In order to achieve this objective they are using, mainly, Field Days at Demonstration Centers located on farmers fields throughout the area. Other extension activities, like farmers workshops, articles in newspapers and radio talks, are also being performed.

To rationalize and speed up the data collection process, work-sheets were specifically developed at Michigan State University, in the summer term of 1981 while taking the course AEC 868: Data Collection in Developing Countries, with professor Warren H. Vincent of the Agricultural Economics Department (Appendix A).

Worksheet 1 dealt with the climatological data and soil parameters needed to estimate the expected number of days suitable for fieldwork. Worksheets 2, 3 and 4 were designed to collect the engineering, economic and agronomic information pertinent to wheat production in the study area. The information collected with worksheets 5 and 6 was used to validate model results in relation to suitable fieldwork days and the machinery systems owned by the farmers, respectively.

The main sources of information in Chile were field measurements, farmer and machinery dealers surveys, discussions with faculty, researchers and extension personnel of I.N.I.A. and the College of Agriculture of the University of Concepcion. Other sources were the daily records of the Agrometeorological Station and publications by researchers of I.N.I.A. and the University of Concepcion.

3.2. The Wheat Production System

Winter wheat is the predominant crop in the study area. It is seeded in rotations with oats, lentils, rapeseed, barley, subterranean clover or natural grass pasture. Due principally to economic reasons and risks associated with rapeseed and barley production, these two crops have almost disappeared from the area. The three most common crop rotations used now in the area and selected for this study are:

1) Oats-Lentils-Wheat-Pasture(3); (O-L-W-P-P-P)
2) Oats-Wheat-Pasture(3); (O-W-P-P-P)
3) Wheat-Pasture(3); (W-P-P-P)

Fields are left under pasture three years when subterranean clover is seeded and two years when natural grasses are allowed to grow. Livestock use the clover directly in the fields. A large number of farmers use rotations 2 and 3. However, the Extension Service is trying hard to have them adopt rotation 1 which is longer, better balanced and can fight diseases more successfully, especially radicular. It is very important that wheat follow oats or lentils in order to reduce the attack of radicular diseases, making therefore rotation 3 not recommendable (INIA, 1976; INIA, 1980; Chavarria, 1981).

A large percentage of farmers seed lentils every year. However, the area seeded by each farmer rarely exceeds 30 hectares, commonly being around 10 hectares. Lentils are a cash crop that in a good year (spring rainfall) can produce an attractive income. Unfortunately, the cultivated area does not increase substantially because of weather risks, labor bottlenecks at weed control and harvest time, and large fluctuations in prices paid to the farmers (Chavarria, 1981).

Tillage intensity is another cultural practice which varies among wheat producers. Because of rapidly increasing fuel prices in the last seven to eight years, the level of tillage intensity has been reduced and so has the loss of soil through erosion. Cross-plowing has almost disappeared, disk harrows have replaced plowing whenever possible and the number of disk passes has also decreased. The three following tillage intensity levels are clearly identified:

1) Low: two disk harrow passes and one spike-tooth harrow pass;
2) Medium: three disk harrow passes and no spike-tooth harrow pass;
3) High: four disk harrow passes and no spike-tooth harrow pass.

The specific field operations and calendar date constraints used in the present model are displayed in Tables 3.1 to 3.3, for all crops in the three rotations and at the three tillage intensity levels.

TABLE 3.1. Field operations and calendar date constraints for the low intensity tillage level.

Field Operation	Rotation 1				Rotation 2			Rotation 3	
	Oats	Lentils	Wheat	Clover	Oats	Wheat	Clover	Wheat	Clover
Plowing	$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$ (a)				$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$			$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$	
Disk 1	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	
Disk 2	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	
Harrowing	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	
Seeding	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$ (d)
N Application	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	
Spraying	$\frac{9}{13}/\frac{9}{30}$	$\frac{5}{1}/\frac{5}{10}$ (b)	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	
Cutting		$\frac{12}{10}/\frac{12}{25}$ (c)							
Harvesting	$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$	
Transport	$\frac{1}{1}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{31}$	$\frac{1}{10}/\frac{2}{15}$		$\frac{1}{10}/\frac{2}{15}$	

Sources: I.N.I.A. (1976, 1980); Chavarria, (1981); Farmers' Survey.

(a) Numbers represent starting date and ending date; $\frac{\text{month}}{\text{day}}$; date at center is the end of the optimum period.
(b) This is a lentils only pre-seeding spraying.
(c) This operation is carried out by hand or animal drawn mower.
(d) Subterranean clover is seeded simultaneously with the wheat and does not require an extra operation.

TABLE 3.2. Field operations and calendar date constraints for the medium intensity tillage level.

Field Operation	Rotation 1				Rotation 2			Rotation 3	
	Oats	Lentils	Wheat	Clover	Oats	Wheat	Clover	Wheat	Clover
Plowing	$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$(a)				$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$			$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$	
Disk 1	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	
Disk 2	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	
Disk 3	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	
Seeding	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$(d)
N Application	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	
Spraying	$\frac{9}{13}/\frac{9}{30}$	$\frac{5}{1}/\frac{5}{10}$(b)	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	
Cutting		$\frac{12}{10}/\frac{12}{25}$(c)							
Harvesting	$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$	
Transport	$\frac{1}{1}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{31}$	$\frac{1}{10}/\frac{2}{15}$		$\frac{1}{10}/\frac{2}{15}$	

Sources: I.N.I.A. (1976, 1980); Chavarria, (1981); Farmers' Survey.

(a) Numbers represent starting and ending date; $\frac{\text{month}}{\text{day}}$; date at center is the end of the optimum period.
(b) This is a lentils only pre-seeding spraying.
(c) This operation is carried out by hand or animal drawn mower.
(d) Subterranean clover is seeded simultaneously with the wheat and does not require an extra operation.

TABLE 3.3. Field operations and calendar date constraints for the high intensity tillage level.

Field Operation	Rotation 1				Rotation 2			Rotation 3	
	Oats	Lentils	Wheat	Clover	Oats	Wheat	Clover	Wheat	Clover
Plowing	$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$(a)				$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$			$\frac{12}{1}/\frac{12}{31}/\frac{1}{10}$	
Disk 1	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	$\frac{2}{1}/\frac{3}{2}$		$\frac{2}{1}/\frac{3}{2}$	
Disk 2	$\frac{3}{3}/\frac{3}{31}$	$\frac{3}{3}/\frac{3}{31}$	$\frac{3}{3}/\frac{3}{31}$		$\frac{3}{3}/\frac{3}{31}$	$\frac{3}{3}/\frac{3}{31}$		$\frac{3}{3}/\frac{3}{31}$	
Disk 3	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	$\frac{4}{1}/\frac{4}{30}$		$\frac{4}{1}/\frac{4}{30}$	
Disk 4	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	$\frac{5}{12}/\frac{6}{15}$		$\frac{5}{12}/\frac{6}{15}$	
Seeding	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$	$\frac{5}{15}/\frac{5}{31}/\frac{6}{15}$	$\frac{5}{15}/\frac{6}{15}$(d)
N Application	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	$\frac{9}{1}/\frac{9}{12}$		$\frac{9}{1}/\frac{9}{12}$	
Spraying	$\frac{9}{13}/\frac{9}{30}$	$\frac{5}{1}/\frac{5}{10}$(b)	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	$\frac{9}{13}/\frac{9}{30}$		$\frac{9}{13}/\frac{9}{30}$	
Cutting		$\frac{12}{10}/\frac{12}{25}$(c)							
Harvesting	$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{20}/\frac{1}{31}$	$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$		$\frac{1}{10}/\frac{1}{31}/\frac{2}{15}$	
Transport	$\frac{1}{1}/\frac{1}{31}$	$\frac{12}{20}/\frac{1}{10}$	$\frac{1}{10}/\frac{2}{15}$		$\frac{1}{1}/\frac{1}{31}$	$\frac{1}{10}/\frac{2}{15}$		$\frac{1}{10}/\frac{2}{15}$	

Sources: I.N.I.A. (1976, 1980); Chavarria, (1981); Farmers' Survey.

(a) Numbers represent starting date and ending date; $\frac{\text{month}}{\text{day}}$; date at center is the end of the optimum period.
(b) This is a lentils only pre-seeding spraying.
(c) This operation is carried out by hand or animal drawn mower.
(d) Subterranean clover is seeded simultaneously with the wheat and does not require an extra operation.

3.3. The Weather Model

Appropriate agricultural machinery management, including selection and scheduling, depends to a high degree upon the ability to predict available working time in the field during any part of the crop season. Numerous studies have been carried out to meet the widely recognized requirement for this type of information and it is readily available for the major agricultural regions of the USA, Canada and Europe, i.e. ASAE (1982), Baier (1973), van Kampen (1971). However, in Chile, as in most of South America, this kind of information is sorely lacking. Moreover, records of days suitable for fieldwork, like the ones reported by Link (1968), Morey et al. (1971), and Fulton et al. (1976) have not been kept in Chile. It was, therefore, necessary to develop a weather model which would estimate the time available for the different field operations used in wheat production in the study area. An approach similar to the one presented by Rosenberg et al. (1981), was followed to estimate the time available for field work.

The biggest weather-related problem for these farmers is the very uneven precipitation distribution pattern in the area, which has a large amount of rain falling at seeding time, (May - June), as shown in Figure 3.1.

The weather model proceeds in two major steps. First, it generates sequences of work-no work days using 17 years of daily weather records kept at the Agrometeorological Station of the University of Concepcion, at Chillan. A no work day represents a day when conditions are such that efficient field machinery operations can not occur. Separate series of work-no work days are generated for each of three field operations categories.

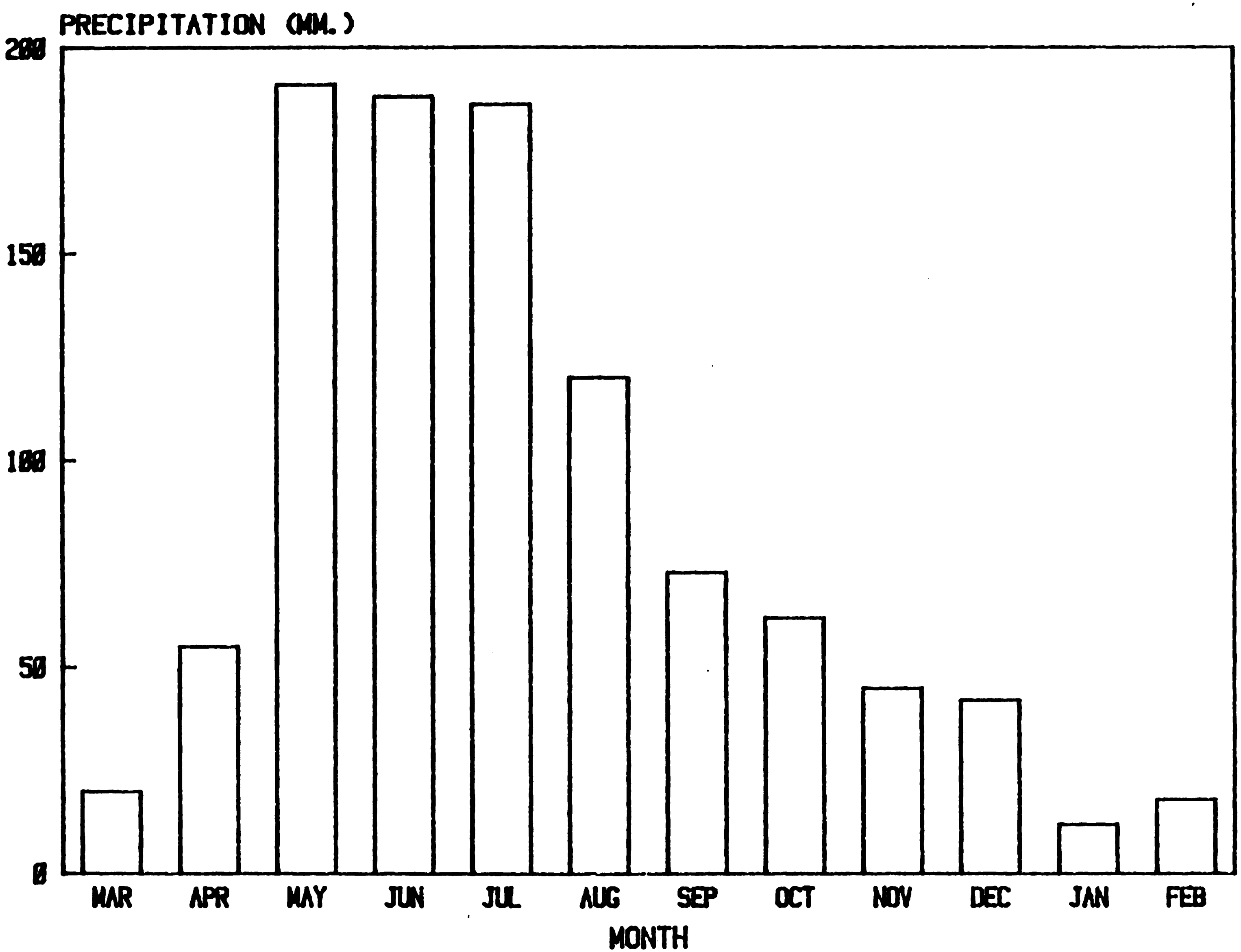


Figure 3.1. Average (17-years) Monthly Distribution of Rainfall at Chillan, Chile.

In the second step, the year is divided into periods of specified lengths. The sequences of work-no work days are grouped and summed for each period and year in order to establish estimates of the expected number of workdays at selected probability levels. Figure 3.2 shows the general flow diagram of the weather model.

3.3.1. Soil Moisture Content Budget

The computer model uses a soil moisture content budget approach in order to determine work-no work days (Baier, 1973; Elliot, 1977; Rosenberg et al., 1981). Relationships based on precipitation, pan evaporation, time of year, and hours of sunshine are used to compute the daily soil moisture content in the upper 150 mm of the soil, since the use of agricultural equipment is determined by the moisture level in that layer (Shaw, 1965; Rutledge and McHardy, 1968; Nath and Johnson, 1980).

The soils typical of this area have developed from recent deposits of volcanic ashes (Dystrandept) and they have been classified into the Santa Barbara series. The soils are a deep well drained loam (49% sand, 31% silt, 20% clay), brown to dark gray in color, and have a rolling topography with an eight to 12% slope. Bulk density is 0.65 g/cc and the total porosity is 75%. They are highly permeable with a basic infiltration rate of 5.0 cm/hr, have a total organic matter content of 16%, and a high plastic limit (Bernier, 1966; Mellado, 1981; Pena, 1978).

At this point certain terms will be defined (Schwab et al., 1966) and assigned values. Saturation is defined as the maximum amount of water held temporarily by the soil matrix. Thus, once saturation is

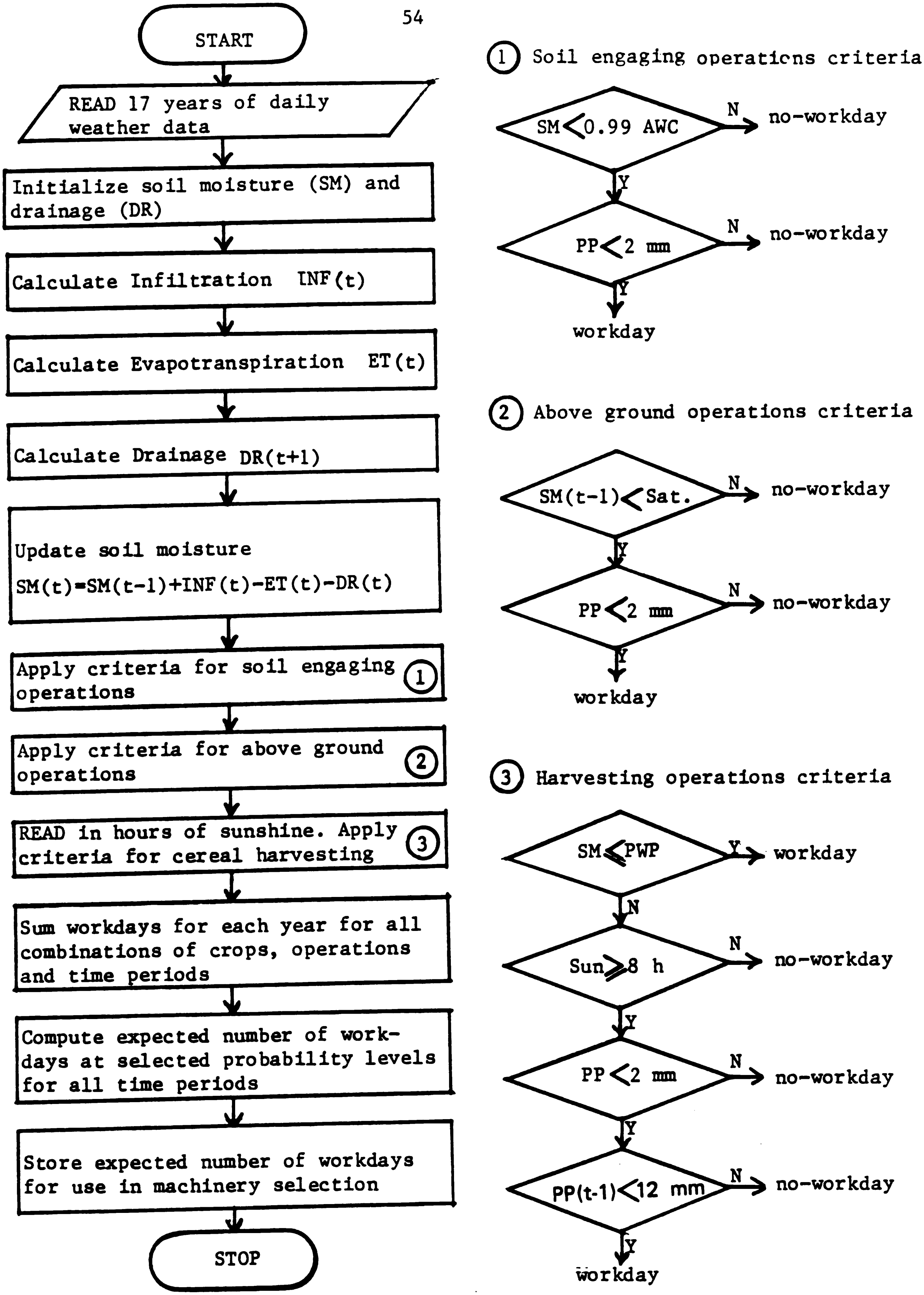


Figure 3.2. General Flow Diagram for the Weather Model.

reached water no longer enters the soil but instead is lost by surface runoff or ponded on the soil surface. Saturation for this soil, determined by Bernier (1966), is 113 mm/150 mm layer.

Field Capacity is defined as the amount of water left in the soil after subsurface drainage or the emptying of macropores has been completed. This remaining water is, in part, the stored water available for plant use. Field Capacity for this soil is 54 mm/150 mm layer (Bernier, 1966). Permanent Wilting Point (PWP) is defined as the moisture content of the soil at which a plant will wilt and no longer regain turgor. Permanent Wilting Point for this soil is 19.5 mm/150 mm layer (Bernier, 1966).

Evapotranspiration is defined as the total water lost from the soil due to the combination of evaporation from the soil surface and transpiration from the growing plant. Available Water Capacity (AWC) is defined as the amount of water a soil holds between Field Capacity and Permanent Wilting Point (Hassan and Broughton, 1975).

Soil moisture for day t, SM(t), is calculated by the following equation:

$$SM(t) = SM(t-1) + Infiltration(t) - Evapotranspiration(t) - Drainage(t) \qquad (3.1)$$

An initial soil moisture content is needed, however. Soil moisture is initialized at Permanent Wilting Point at the start of each computational year (March 1), since the weather records show that January and February are consistently hot and dry.

Infiltration is set at 0.90 of precipitation (PP), based on results obtained by Mellado (1981), and to cease once saturation is reached.

Evapotranspiration is computed daily using the evaporation values recorded from a USA Weather Service class A pan. Pan evaporation is considered to be greater than evaporation from a free water surface, hence a pan coefficient of 0.7 is used (Schwab et al., 1966). Crops do not generate the same evapotranspiration as from a free water surface depending upon crop development. Crop coefficients used were 0.36 for bare soil (Tulu, 1974), 0.50 for emergence to 20% cover, 0.90 for 20% cover to maturity, and 0.5 for maturity to plowing (Pair et al., 1976). One additional coefficient is used as a zone coefficient since we are only dealing with the upper 150 mm of the soil profile. During the peak growing season only 60% of the moisture used is taken from the upper zone since deep roots draw water from the lower soil horizons (Baier and Robertson, 1966). Thus for the peak growing season, a zone coefficient of 0.60 is used, else the zone coefficient equals 1.0.

Soil moisture lost then through evapotranspiration is calculated as pan evaporation times pan coefficient times crop coefficient times zone coefficient. Evapotranspiration is assumed to be zero when the soil moisture content reaches Permanent Wilting Point.

Whenever the soil moisture content is greater than Field Capacity a drainage quantity is calculated for use in the following day's moisture budget. It is known that complete drainage of a saturated soil down to Field Capacity occurs in 48 hours (Schwab, et al., 1966). Therefore the maximum drainage per day cannot exceed 29 mm of water. Drainage is assumed and defined as not occurring below a moisture content of Field Capacity.

3.3.2. Suitable Day Criteria

Once the soil moisture content is computed a set of criteria is employed to determine if a day is a suitable workday. Three types of suitable days exist according to the field operation, namely: 1) soil engaging (tillage, seeding); 2) above ground (fertilizer broadcasting, spraying); and 3) cereal harvesting.

A day suitable for soil engaging operations must meet the following two criteria:

a) soil moisture content less than 99% of Available Water Capacity. Although these soils classify as loam their high plastic limit extends the trafficability period to high moisture contents (Rutledge and McHardy, 1968; Rosenberg et al., 1981). In the opinion of the farmers surveyed they would wait two days after heavy rains to start working their soils again.

b) less than 2 mm precipitation (Frisby, 1970).

Suitable days for above ground operations require less than 2 mm precipitation on the day in question as well as unsaturated soil on the previous day (Hunt, 1980; Frisby, 1970).

Days suitable for cereal harvesting differ from the other two types of field operations in that the amount of daily sunshine is also considered as a criterion. It should also be noted here that only the period from December 20 to February 15 is considered as appropriate for cereal harvesting in the study area.

A day suitable for cereal harvesting has to meet all the following criteria (Wolak, 1981; Von Bargen, 1966; van Kampen, 1971):

a) eight or more hours of sunshine, unless the soil moisture content is at PWP;

b) less than 2 mm precipitation;

c) less than 12 mm precipitation on the previous days.

3.3.3. Expected Number of Fieldwork Days at Selected Probability Levels

The design of field machinery systems often requires a probability level higher than the mean. It is, therefore, necessary to estimate the expected number of suitable fieldwork days at different probability levels (Fulton et al., 1976).

After all the daily weather data has been transformed into a series of work-no work days for the 17 years on record, estimates of the minimum number of suitable days at the 0.50, 0.60, 0.70, 0.80, and 0.90 probability level were derived using empirical cumulative probability distributions (Rosenberg et al., 1981).

The empirical cumulative distribution approach was selected because:

a) Determining the best theoretical probability distribution is beyond the scope and time constraints of this project; in using the cumulative probability distribution the theoretical probability distribution does not need to be assumed.

b) Histograms of expected number of fieldwork days suggests that different periods have different theoretical distributions; the cumulative probability distribution captures different theoretical probability distributions.

c) General experience suggests that for small samples, observations generated using the empirical cumulative probability distribution are often more reliable than those generated using an estimated probability distribution function. In part, this occurs because estimates of the parameters of probability distributions take away degrees of freedom.

The empirical cumulative distribution was constructed from sequences of work-no work days in a four step process, as follows:

1) the number of workdays for each time period and year are summed to form observations of the number of fieldwork days in each time period;

2) workday frequencies are ordered from smallest to largest and assigned a probability using the rule that the Kth ordered observation is a measure of the K/(N+1) fractile (Anderson et al., 1977);

3) the probability assigned to a given number of suitable workdays is smoothed by averaging the probabilities associated with tied values;

4) the number of suitable days at the 0.50, 0.60, 0.70, 0.80, and 0.90 probability level is now obtained by linear interpolation. The 0.70 probability level, for example, represents the minimum number of suitable days that can be expected to occur seven out of 10 years.

3.4. Wheat Production Machinery Selection Model

In the initial stages of model development the hierarchical structure of systems and subsystems was defined. Figure 3.3 shows the initial model diagram with a crop production system and a machinery system. Within the machinery system two smaller subsystems are identified as: a) tillage and seeding subsystem; and b) harvesting subsystem. All the components and their relationship are also shown in Figure 3.3.

From this initial system diagram model development progressed into an input-output view of the machinery selection model. Figure 3.4 shows the inputs to be used, system parameters, and expected outputs for the model. All systems parameters and desired outputs were develoepd from the data collection process carried out in Chile.

Three main criteria were established in order to further develop the model and arrive at a machinery system selection strategy:

a) only machine types and size available to the farmers in the study

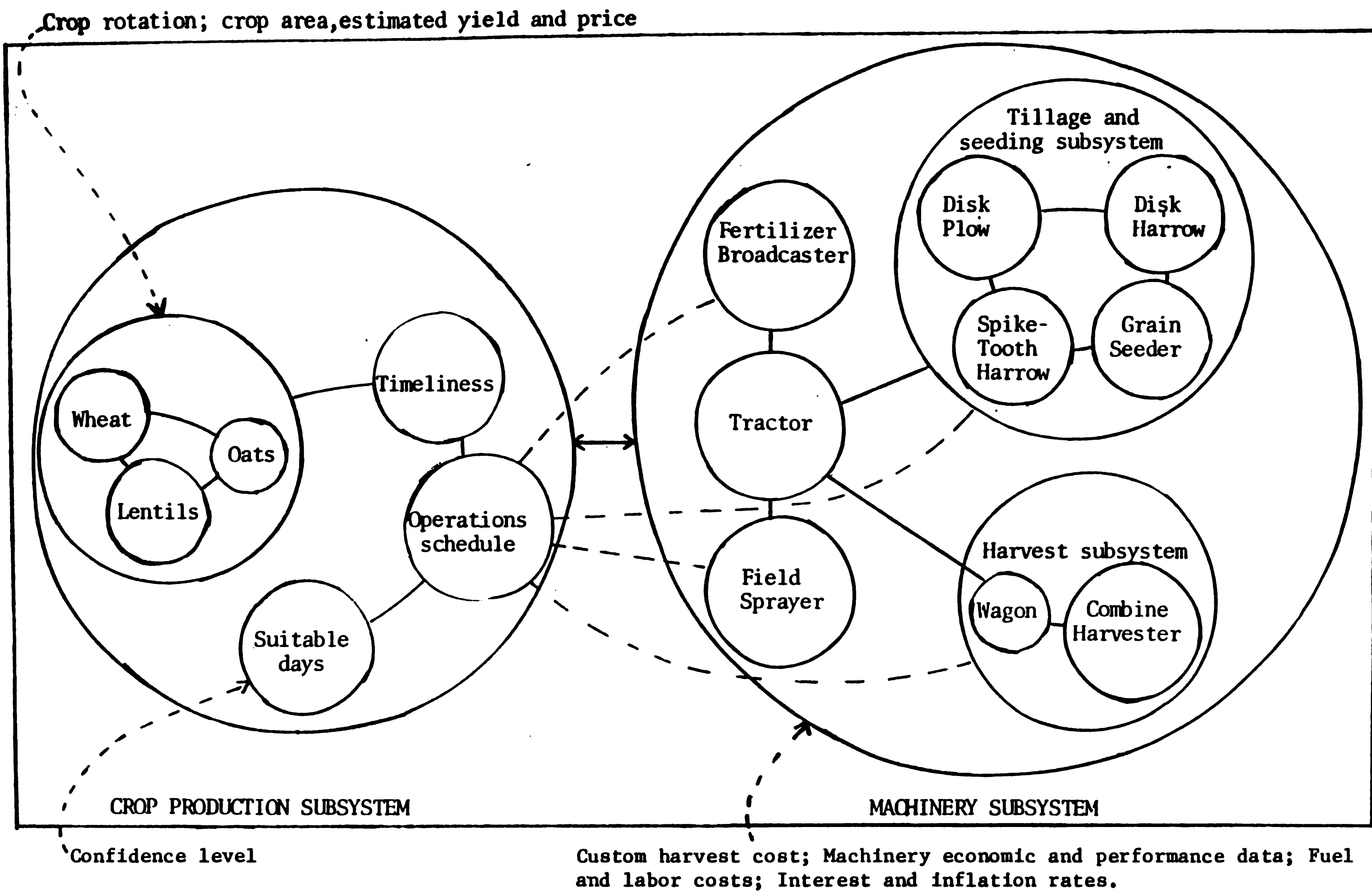
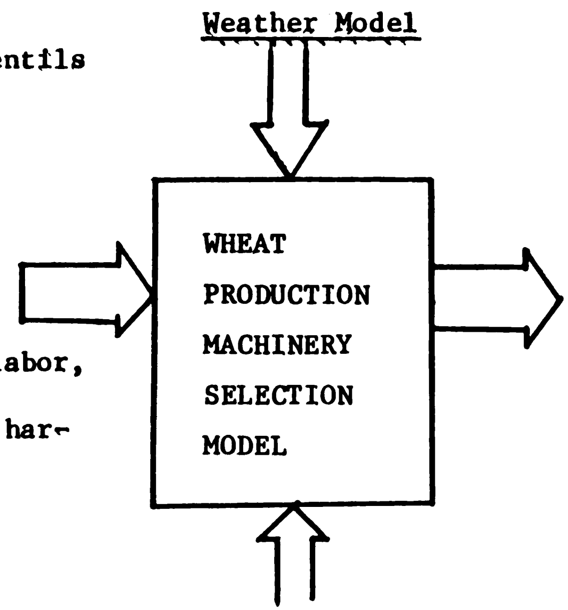


Figure 3.3. Wheat Production Machinery Selection System - Initial Model Diagram.

INPUTS

1. Rotation used
2. Area seeded with oats, wheat, lentils
3. Workday confidence level
4. Disk harrow passes
5. Diesel fuel cost
6. Labor cost
7. Bank interest rate
8. Expected yield
9. Expected price for crop
10. Farmer's rate of return
11. Inflation for machinery, fuel, labor, and crop
12. Work hours per day for plowing, harvesting and other operations
13. Risk factor for custom harvest



OUTPUTS

1. Least cost machinery system, including number and size of tractors, plow, disk harrow, spike-tooth harrow, seeder, fertilizer broadcaster, sprayer, combine harvester and wagon
2. Minimum size machinery system
3. Second and third least cost machinery systems
4. Total 10 year cost and annual equivalent cost for all systems
5. Cost of fuel,labor, timeliness, repair & maintenance, and ownership
6. Machinery system cost per hectare
7. Fuel consumption per year
8. Custom harvest cost
9. Tractor hours used per year
10. Annual equivalent gross income

SYSTEM PARAMETERS

Machinery Performance Data: speeds, efficiencies, draft and power units, available sizes.

Machinery Economic Data: prices, payment schedule, salvage value, repairs and maintenance coefficients, fuel and labor factors, planning horizon.

Operations schedule.

Figure 3.4. Input-Output View for the Wheat Production Machinery Selection Model.

area would be considered;

b) there would be time constraints for all operations, according to agronomic data, within which operations must be finished. That is, in a first step a minimum size machinery system capable of doing all the work in the time allocated would be selected.

c) from this minimum size machinery system a size incrementation process would be used to search for a least cost system by determining the trade-offs among timeliness costs, ownership costs and the other components of the total system cost, which is used as the basis for selection.

Figure 3.5 presents a simplified flow diagram of the machinery selection model, showing the general approach to the problem. Figure 3.6, on the other hand, presents a more detailed view of the structure of the model showing, in particular, the system size incrementation process.

The machinery system selected includes the following components; two-wheel drive tractor(s), disk plow, off-set disk harrow, spike-tooth harrow, grain seeder, centrifugal fertilizer broadcaster, boom-type field sprayer, self-propelled combine harvester and transport wagon.

Results from the farmers' survey, presented in Table 3.4, indicate that selection of up to two tractors would address the problem of 85% of the mechanized wheat producers in the study area.

Survey results also indicated that farmers owning two tractors would use a (larger) tractor for tillage (plowing, disking, harrowing) and another (smaller) for seeding, fertilizing and spraying. Owning two tractors only becomes very important for large producers at seeding time when disking or harrowing and seeding are to be carried out during the same period, according to the field operations calendar presented

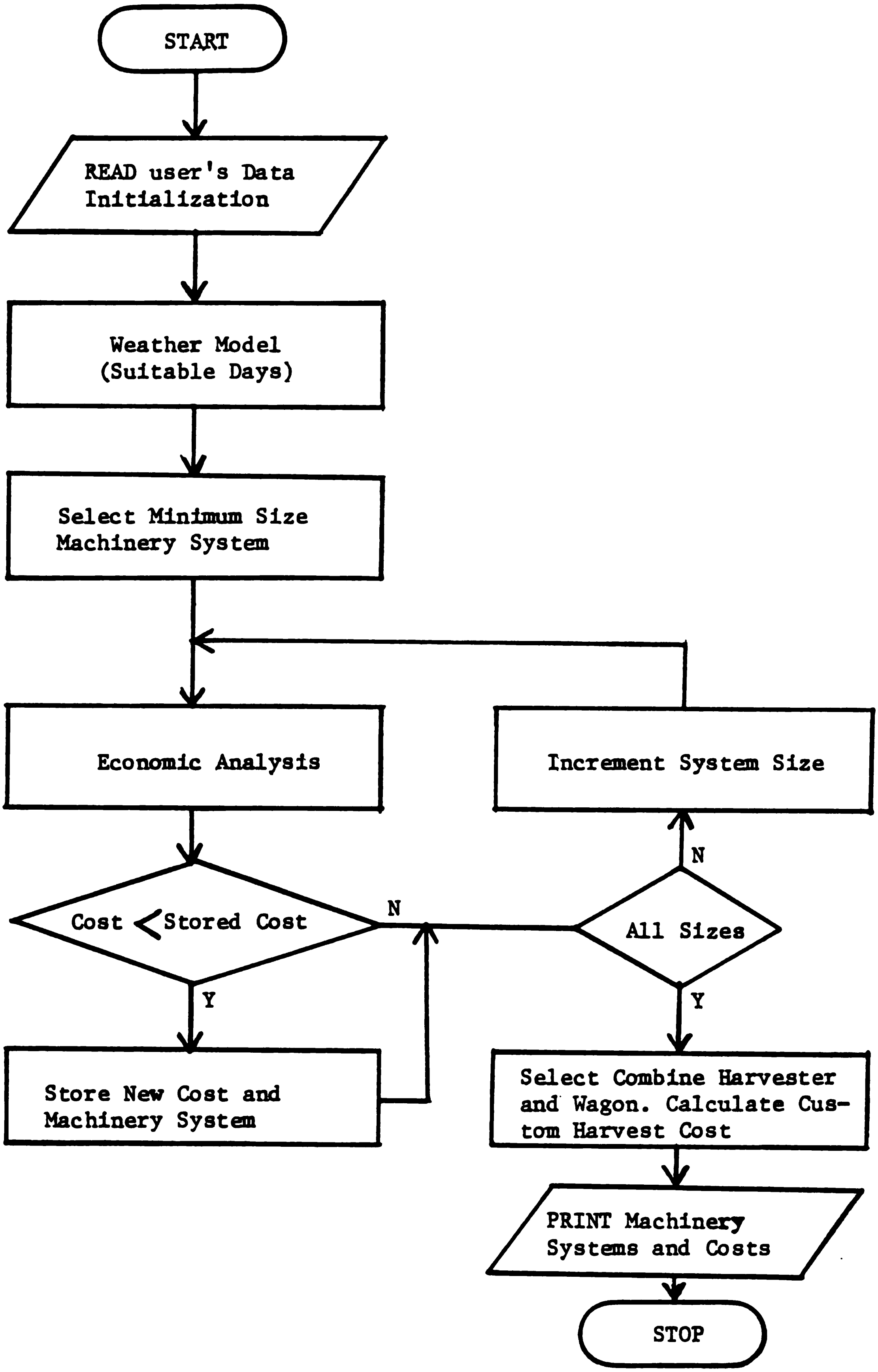


Figure 3.5. Simplified Flow Diagram for the Wheat Production Machinery Selection Model.

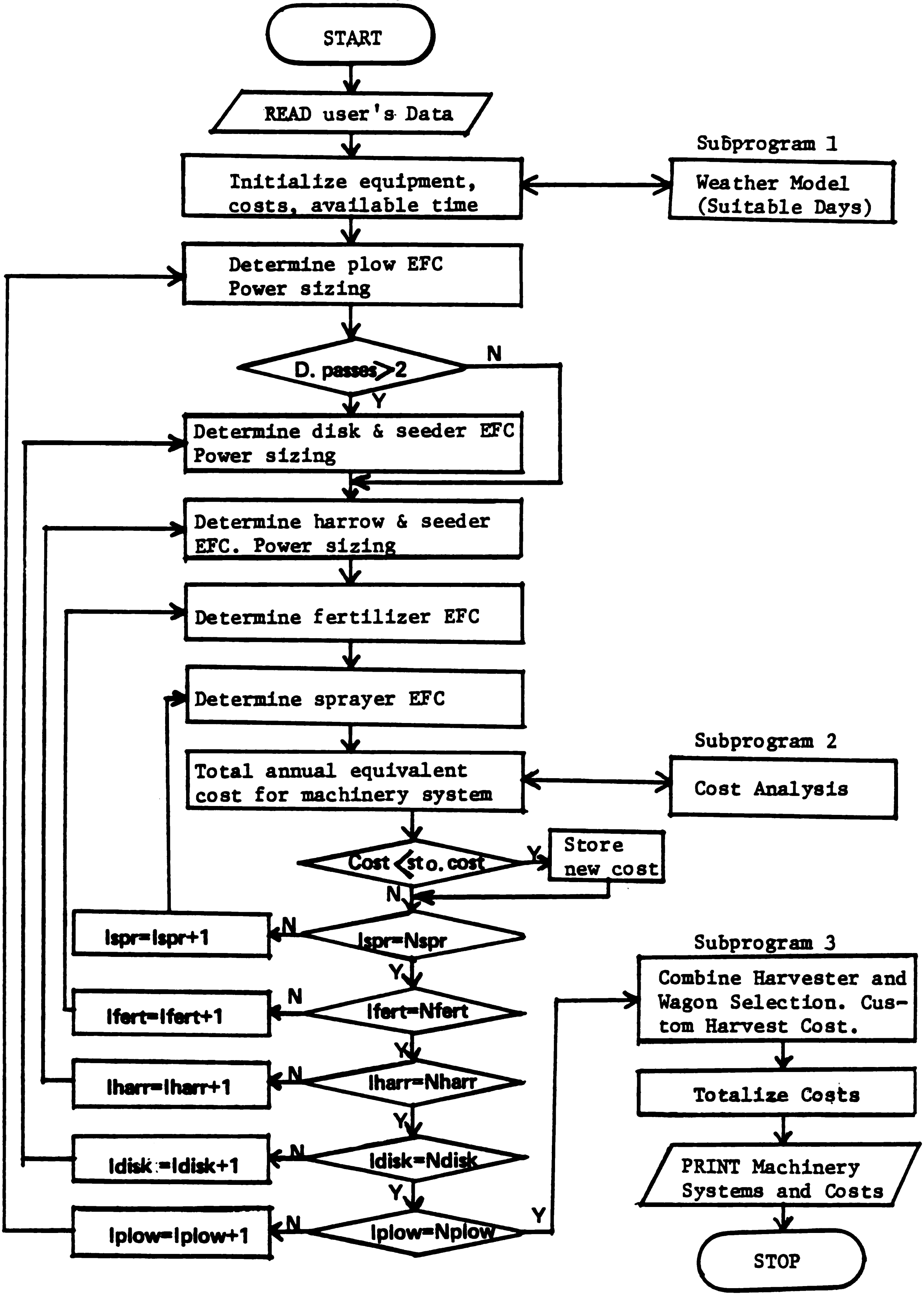


Figure 3.6. Flow Diagram for the Wheat Production Machinery Selection Model.

earlier in Tables 3.1 to 3.3.

TABLE 3.4 Distribution of the Number of Tractors Among the Farmers Surveyed*

Number of Tractors	Farmers %
1	60
2	25
3	10
4 or more	5

*Source: Farmers' Survey.

The selection of two tractors is, therefore, approached in such a way that, when the seeded area demands it, a second tractor is sized to power the grain seeder, fertilizer broadcaster, field sprayer and transport wagon.

The essential methodology used in this model for matching the size of soil engaging implements to tractor power and for calculating their productivity has been developed from the Agricultural Engineers Yearbook (ASAE, 1982).

Productivity data are required to establish the power needed of the tractor and the work capacity of machines:

$$PTOkW = D * S * W / LF * TE * CONV * C1 \qquad (3.2)$$

$$EFC = S * W*Eff / C2 \qquad (3.3)$$

Where:

PTOkW = tractor power takeoff power (kW)

D = implement draft (kN/m)

S = implement speed (km/h)

W = implement width (m)

LF = tractor load factor (decimal)

TE = tractive efficiency (decimal)

CONV = tractor PTO to axle power ratio (decimal)

C1 = dimensionality constant (C1=3.6)

EFC = effective field capacity (ha/h)

Eff = field efficiency (decimal)

C2 = dimensionality constant (C2=10)

Table 3.5 presents four factors developed from data collected in Chile that can be used to solve Equations 3.2 and 3.3. Table 3.5 also presents the sizes of machines available in the Chilean market as well as the logical increment units to use in the model.

The load factor (LF) is the tractor design loading rate. It reduces tractor wear (Bowers, 1978) while providing extra power for difficult field conditions briefly encountered. LF has been assigned a value of 0.77 in this model, based partly on values reported by White (1977) and the elevation being greater than 500 metres above mean sea level, for the location of these farms. The PTO to axle power conversion factor (CONV) has been given a value of 0.96 (ASAE, 1982).

Tractor power is determined by the size of the plow or the disk harrow, unless two tractors are selected, whereas the power of the second tractor is determined by the size of the seeder.

The selection of the combine harvester was originally approached in a different way. Because this operation can be customized, it seemed appropriate to develop an independent model. The model calculates the cost of eleven harvesting alternatives. The first alternative is to customize all the area, the next five alternatives represent the use of the five sizes of combines available in the market (12 to 16-foot), plus custom cost if necessary; the last five alternatives represent the use

TABLE 3.5. Agricultural Engineering Data Collected in Chile.*

Machine number and identification	Draft (kN/m)	Tractive Effic. (decimal)	Work Speed (km/h)	Field Effic. (decimal)	Limits to Available sizes Minimum-Maximum	Work Unit Increment
1 Tractor	----	----	---	----	25 - 75 PTOkW	0.75 kW (1 HP)
2 Disk plow	10.7	0.60	6.5	0.80	2 - 6 disks	0.24 metre (1 disk)
3 Off-set disk harrow	5.0(stub.)	0.55	6.5	0.85	12(6) - 28 disks(14)	0.23 metre (1 disk)
	4.5(pass 1)	0.48	6.5	0.85	12(6) - 28 disks(14)	0.23 metre (1 disk)
	4.5(2,3,4)	0.53	7.0	0.85	12(6) - 28 disks(14)	0.23 metre (1 disk)
4 Spike-tooth harrow	0.8	0.53	7.5	0.80	2.5 - 6 metres	0.50 metre
5 Grain seeder	1.8	0.53	7.0	0.65	10 - 18 rows	0.1778 m (1 row)
6 Field sprayer	0.4	0.55	6.0	0.60	12 - 16 nozzles	1.00 metre
	0.4	0.55	5.5	0.60	18 - 24 nozzles	1.00 metre
7 Fertilizer broadcaster	0.6	0.55	5.5	0.60	10 - 16 metres	1.00 metre
8 Self-propelled harvester	----	----	4.5	0.65	12 - 14 feet	0.3048 m (1 foot)
	----	----	4.5	0.70	15 - 16 feet	0.3048 m (1 foot)
9 Transport wagon	----	----	9.0	----	2 - 8 tonnes	0.50 tonne

*Sources: Agricultural Engineering Department-University of Concepcion-Chillan-Chile; Farmers' Survey; Interviews to Agricultural Machinery Dealers-Chillan-Chile; A.S.A.E., (1982); White, (1977); Hunt, (1977); Kepner et al. (1978).

of two harvesters: one 16-foot combine and a second one changing in size from 12 to 16 feet.

While experimenting with this model, three facts became clear: a) a risk factor needed to be introduced in the custom cost calculation to have a fair comparison with alternatives contemplating ownership; 2) unless unrealistic changes in prices were made, most of the time the least cost combine was the minimum size harvester. This is due to the large increase in purchase price as combine size is increased; c) because this model could handle very large areas, over 800 hectares, it is not fully compatible with the rest of the wheat production machinery selection model.

It became necessary then to develop a new combine harvester selection algorithm, which would be compatible with the larger model. Considering the farmers' survey results showing that only 10% of them have two combines and considering that custom harvest is a common practice in the area a new approach was devised, in such a way that calculations proceed, first to establish the cost of customizing all the area and, second to select a combine harvester and establish its cost. In this way the user can specify the risk he associates with the custom harvest, therefore, increasing the cost, and can compare this cost with the one related to ownership of a harvester.

Custom cost is calculated using the following equations:

$$\text{CUSTPR} = 192 * \text{PRICECR} \qquad (3.4)$$

$$\text{CUSTCO} = \text{AREAT} * \text{CUSTPR} * \text{RISK} * \sum_{j=1}^{n} \left[\frac{1+\text{INMA}}{1+\text{IF}}\right]^{j} \qquad (3.5)$$

Where:

CUSTPR = custom price ($/ha)

192 = cost in kilograms per hectare (actual charge is 3.0 metric quintals per 15,625 m^2)

PRICECR = crop price ($/kg)

CUSTCO = custom cost ($/years analyzed)

AREAT = area being custom harvested (ha)

RISK = risk factor associated with custom harvest (dimensionless)

INMA = annual inflation rate for machinery (%)

IF = farmer's rate of return (%)

n = number of years analyzed

Combine harvester capacity is determined by matching required effective field capacity to the capacity of harvesters available in the Chilean market. Engine power, on the other hand, is calculated from the results of the farm machinery dealers survey (Appendix B).

A transport wagon is also considered with the combine selection algorithm, in such a way that 12 and 13-foot combines are assigned a four tonne wagon and 14, 15 and 16-foot machines are assigned a five tonne wagon. This approach is based on survey results and machine tank and work capacities. A better approach to the wagon selection would require a more complex model using distance, yields, cycle time, speed, and other data not available at the present time. It is felt that the gains in accuracy would not fully justify the degree of complexity required of the model.

3.5 Costs Analysis

The cost analysis method used by most Agricultural Engineers is called the fixed/variable cost method. The primary advantage is its simplicity. However, the cash flow method of cost analysis is better suited than the fixed/variable cost method to model inflation's affect on costs since all costs are modeled as they occur.

In this model the cash flow method of cost analysis is used, following the basic methodology presented by Rotz et al. (1981), who demonstrated that their model is most useful for comparing machines or systems of machines available to farmers. Changes in the methodology include the addition of timeliness costs, elimination of tax benefits, modification of repair, maintenance and shelter calculations, and the inclusion of two interest rates and four different inflation rates for machinery, fuel, labor and crop prices. Figure 3.7 presents the flow diagram of the cost analysis algorithm.

A linear relationship between size and purchase price of machines is assumed in this model (Hunt, 1967, 1977; McIsaac and Lovering, 1974, 1976, 1977; Singh, 1978). Purchase price is predicted by regression equations developed from data obtained through the farm machinery dealers survey, in Chile. The results from the survey and the regression equations are presented in Appendix B.

Other economic data used to compute owning and operating costs of agricultural machinery are presented in Table 3.6.

3.5.1. Cash Flow Method

Smith and Oliver (1974), took an annuity approach to model the cost of machine ownership. They broke the initial cost of the machine down to a series of equal annual costs. A similar approach has been used to determine the annual equivalent cost of owning and operating agricultural machinery (Rotz et al., 1981). The annual equivalent cost is determined by multiplying the initial capital cost by a capital

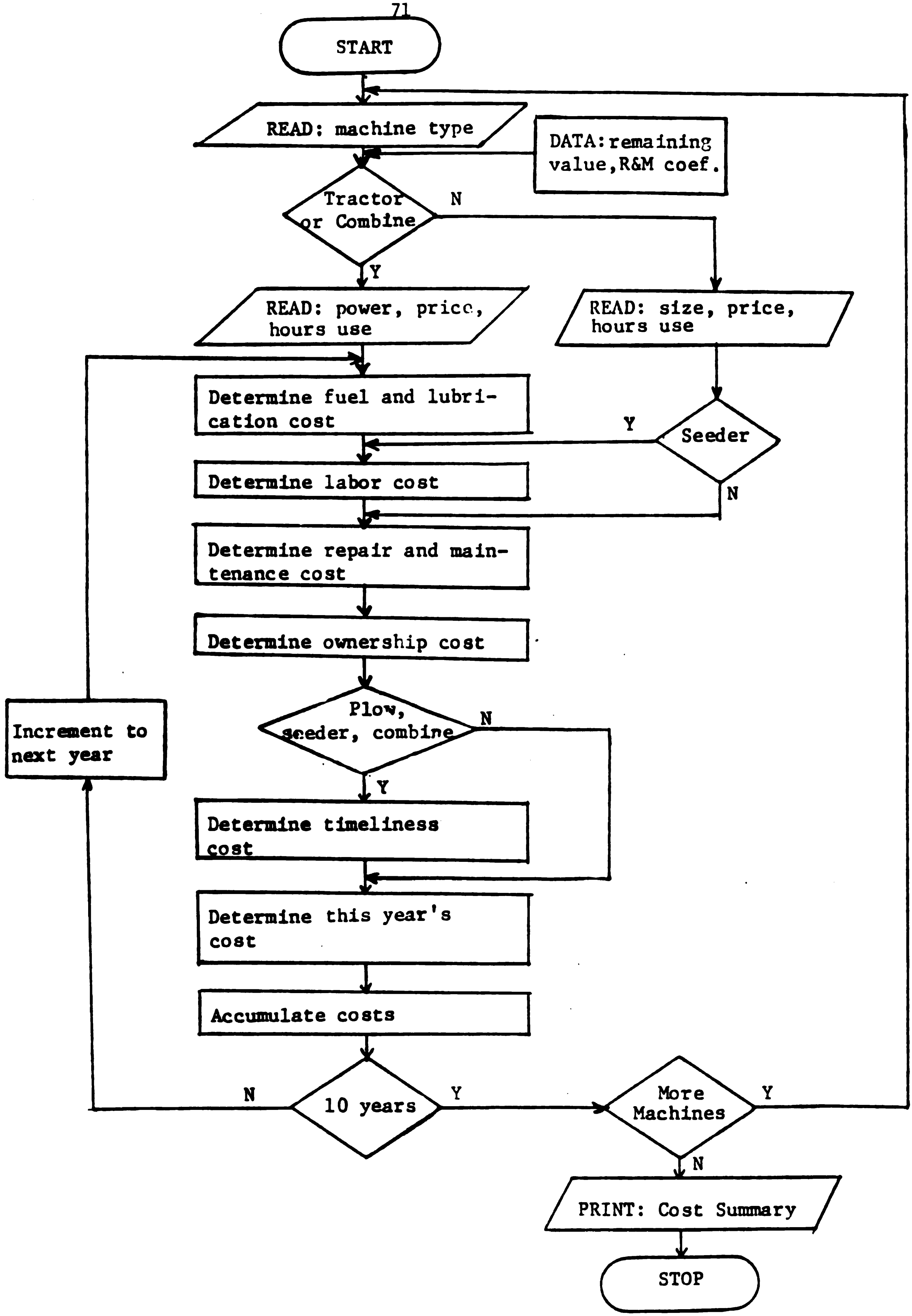


Figure 3.7. Flow Diagram for the Economic Analysis of the Machinery System.

TABLE 3.6. Economic Information. Owning and Operating Agricultural Machinery Costs.*

Machine Identification	Machine life		Annual Use.	Annual Depreciation.	Remaining Value.	Repairs, maintenance and shelter (% of purchase price)	
	Years	Hours	Hours	%	% PP	Year	Hour
Tractor	12	12,000	1,000	8.33	10	12	0.00012
Disk plow	15	4,500	300	6.67	10	8	0.00027
Off-set disk harrow	12	4,800	400	8.33	10	9	0.00023
Spike-tooth harrow	15	1,500	100	6.67	10	4	0.00040
Grain seeder	12	3,000	250	8.33	10	9	0.00036
Field sprayer	12	1,800	150	8.33	10	8	0.00053
Fertilizer broadcaster	12	1,800	150	8.33	10	7	0.00047
Self-propelled combine harvester	15	6,000	400	6.67	10	8	0.00020
Transport wagon	15	5,250	350	6.67	10	7	0.00020

*Sources: Departments of Agricultural Engineering and Agricultural Economics-University of Concepcion-Chillan-Chile. Ibanez and Rojas (1979).

recovery factor.*

In present value analysis, all future costs are discounted to present value for a net present value cost of owning and operating the equipment. In the cash flow analysis method, the actual down payment, annual loan payments and the remaining value replace depreciation and interest for the cost of ownership. Current costs are inflated to future cost before they are discounted to present value. In this way we can compare costs which occur in different time periods.

The major agricultural machinery costs used in this model include the following: a) capital investment or ownership; b) repair, maintenance and shelter; c) fuel and lubrication; d) labor; and 3) timeliness costs.

3.5.2. Ownership Cost

The cost of machine ownership is determined as the sum of the down payment plus all principal and interest payments for the purchase of the machine minus the remaining value at the end of its life. The down payment occurs in the present and, therefore, is in present value terms. Annual payments are in the future and normally represent a uniform series of costs which can be converted to present value by multiplying a single payment cost by the uniform-series-present-worth factor, which is the reciprocal of the capital recovery factor. The machinery remaining value is a single sum which must be inflated to future value and discounted to present value.

A relationship for determining the ownership cost is presented

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*The capital recovery factor is an annuity factor which is a function of the interest rate and the number of years. When multiplied by an amount of capital, the capital is reduced to equivalent annual costs over the given number of years with compound interest considered.

in Equation 3.6.

$$O.C. = DP + AP \left[\frac{(1+IF)^m - 1}{(IF(1+IF)^m}\right] - RV \left[\frac{1+INMA}{1+IF}\right]^n \qquad (3.6)$$

Where:

O.C. = ownership cost ($/years analyzed);

DP = down payment (20%);

AP = principal and interest loan payment;

$$AP = (0.8*PP)* \left[\frac{IB(1+IB)^m}{(1+IB)^m-1}\right] \qquad (3.7)$$

Where:

PP = purchase price ($);

IB = bank interest (%);

m = loan term in years (5);

IF = farmer's rate of return (%);

INMA = annual inflation rate for machinery (%);

n = number of years analyzed;

RV = remaining value (0.1*PP).

Data collected in Chile permits the use of Equation 3.6 with the following assumptions: down payment at 20% of purchase price; loan term at five years; planning horizon or years analyzed equal 10; remaining value equal to 10% of purchase price.

3.5.3. Fuel and Lubrication Costs

They are calculated as the product of the fuel price, fuel consumption factor for the tractor or combine harvester operation, engine power rating and hours of annual use. To include lubrication cost, the fuel cost is increased by 15%. The cost is a current cost which must be inflated to future cost and discounted to present value.

A relationship for determining fuel and lubrication costs is presented in Equation 3.8.

$$F\&L\ C. = 1.15*PRFUEL*POWER*FCF*HRUSE* \sum_{j=1}^{n} \left[\frac{1+INFU}{1+IF}\right]^{j} \qquad (3.8)$$

Where:

F&L C. = fuel and lubrication costs ($/years analyzed);

PRFUEL = fuel price ($/L);

POWER = engine power of tractor or combine harvester (kW);

HRUSE = annual use (h);

FCF = fuel consumption factor (L/kW-h).

Three different fuel consumption factors are used in the model (ASAE, 1982; Kepner et al., 1978): a) 0.26 L/kW-h for plowing and disking; b) 0.17 L/kW-h for harrowing, seeding, fertilizer broadcasting, and spraying; c) 0.22 L/kW-h for harvesting.

3.5.4. Repairs and Maintenance Costs

Equation 3.9 presents a relationship for determining repairs and maintenance costs. This relationship has been developed from the procedure presented by Ibanez and Rojas (1979) and implemented for conditions in Chile using the data presented in Table 3.6.

$$R\&M\ C. = PP*COEFRM*HRUSE \sum_{j=1}^{n} \left[\frac{1+INMA}{1+IF}\right]^{j} \qquad (3.9)$$

Where:

R&M C. = repairs, maintenance and shelter costs ($/years analyzed);

COEFRM = repair and maintenance coefficient (Table 3.6).

3.5.5 Labor Costs

Another major cost in this model is that of labor which, again, is modeled as a series of inflating costs. Another inflation rate can be used to allow independent manipulation of inflation rates. The labor requirement is increased by 10% in order to account for setting up and delivery of machines to the field.

Equation 3.10 presents the relationship used to determine labor costs:

$$L.C. = 1.10*WAGE*HRUSE* \sum_{j=1}^{n} \left[\frac{1+INLA}{1+IF}\right]^{j} \qquad (3.10)$$

Where:

L.C. = labor costs ($/years analyzed);

WAGE = wage rate ($/h);

INLA = annual inflation rate of labor cost (%).

3.5.6. Timeliness Costs

Timeliness costs arise from reduced yields due to improper tillage and planting operations; losses associated with improper timing of machine operations to biological needs of the plants; and any reduction in product quality that may be attributed to untimely machine operations. Some operations may have near zero timeliness costs. Others, particularly seeding and harvesting of highly perishable products may have very high timeliness losses.

In this model, three operations, for which there is reliable data, are assumed to incur in timeliness losses, i.e. plowing, seeding and harvesting. Timeliness loss factors, K, for plowing and harvesting have been developed using the procedure presented by Hunt (1977), from data obtained in field experiments carried out by I.N.I.A. researchers in the study area (INIA, 1976, 1980). The K factor for wheat harvesting has been found to be fairly similar for different areas, and it has been adapted from data presented by Hunt (1977) and Bowers (1975b).

Equation 3.11 presents a general relationship for determining timeliness costs:

$$T.C. = \sum_{j=1}^{N\ days} AREA*K*J*YIELD*PRICE* \sum_{j=1}^{n} \left[\frac{1+INCR}{1+IF}\right]^{j} \qquad (3.11)$$

Where:

T.C. = Timeliness costs ($/years analyzed);

Ndays = days taken to finish penalized area;

AREA = area being penalized in a particular day (ha);

J = day in which the calculation is being made;

K = timeliness loss factor (1/day). K=0.0009 for plowing; K=0.002 for seeding; K=0.004 for harvesting;

YIELD = crop yield (kg/ha);

PRICE = crop price ($/kg);

INCR = annual inflation rate of crop (%).

The timeliness cost calculation is approached in such a way that when the minimum size machinery system is selected using all the available time, presented in Table 3.1 to 3.3, the total system cost includes a fair amount of timeliness cost. However, when the system size incrementation process begins, timeliness costs decrease, and although ownership costs may increase the total system cost might be smaller. These trade-offs among the five components of the total cost are the basis of the search for a least cost machinery system.

3.5.7 Machinery System Cost

The total present value cost of a machinery system is calculated by adding all costs in the 10 year period, as shown in Equation 3.12:

$$P.V.C. = O.C. + R\&M\ C. + F\&L\ C. + L.C. + T.C. \qquad (3.12)$$

Where:

P.V.C. = present value cost (\$/10 years).

Since a total present value cost is usually more foreign to engineers than an annual cost, an annual equivalent cost can be calculated by multiplying the present value cost by the capital recovery factor, as shown in Equation 3.13:

$$AEC = PVC * \frac{IF(1+IF)^n}{(1+IF)^n - 1} \qquad (3.13)$$

Where:

AEC = annual equivalent cost (\$/yr).

This takes the present value total cost and distributes it into equivalent annual costs. Either the total present value cost or the annual equivalent cost can be used as a basis for comparing machinery systems.

4. DESCRIPTION OF THE MODEL

Two computer models are described in this Chapter. Program WEATHR estimates the expected number of days suitable for fieldwork available in eastern Nuble province. Program TRIGO selects field machinery systems for wheat producers in this area, using selected output from program WEATHR (Appendix C).

4.1. Program WEATHR

This program consists of a main program and eleven subroutines. A flowchart for the main program has been presented in Figure 3.2. The first five subroutines transform 17 years of daily weather data, from March 1, 1965 to February 28, 1982, into 1's or 0's, that represent workdays and no-workdays, respectively. The other six subroutines manipulate the data mathematically and statistically in order to establish the expected number of days suitable for fieldwork, at selected probability levels, for all field operations, crops, rotations, and time periods.

4.1.1. Subroutine INFILT

This subroutine calculates the portion of precipitation which infiltrates into the soil. Infiltration occurs at the rate of 90% of precipitation regardless of rainfall intensity (Mellado, 1981). Since soil water content cannot exceed saturation, maximum infiltration equals saturation minus soil water content for the previous day. Figure 4.1

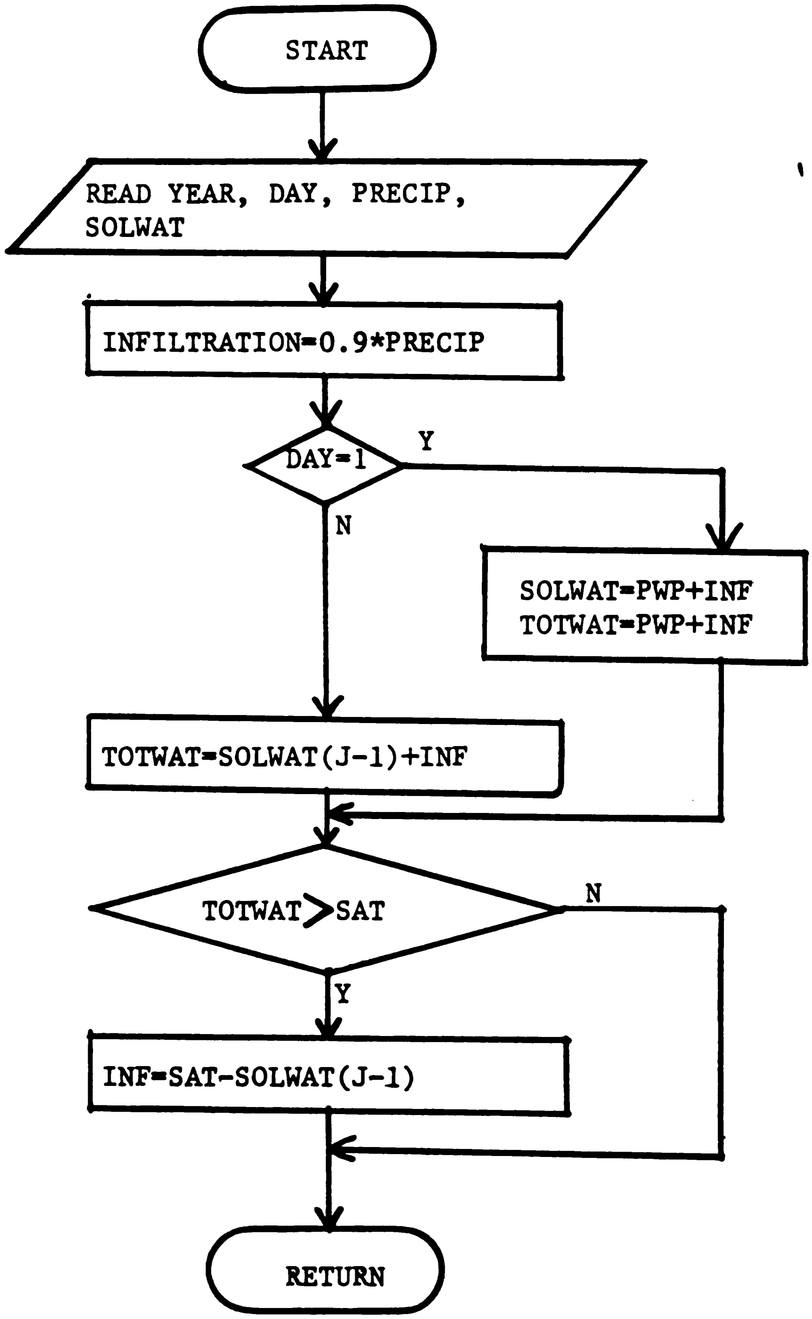

Figure 4.1. Flowchart for subroutine INFILT.

depicts the flowchart for subroutine INFILT.

4.1.2. Subroutine EVAP

This subroutine calculates the evapotranspiration (ET) from the upper 150 mm of the soil on any given day. ET is calculated as Pan Evaporation*Pan Coefficient*Crop Coefficient*Zone Coefficient. The use of these coefficients was discussed in Section 3.3.1. and their values were selected after considering the opinions of researchers in Chile and the values proposed by Schwab et al. (1966), Tulu (1974), Pair et al. (1976), and Baier and Robertson (1966). A flowchart for subroutine EVAP is presented in Figure 4.2.

4.1.3. Subroutine RUNOUT

This subroutine calculates the amount of water drained from the soil given the amount of rainfall infiltrated into the soil and the soil moisture content. Drainage occurs only if the soil water content from the previous day plus the infiltration for the day minus the drainage for the day exceed field capacity (54 mm of water/150 mm of soil). Full drainage from saturation (113 mm of water/150 mm of soil) to field capacity occurs in 48 hours. Thus, the maximum drainage per day equals 29 mm of water. It is assumed that the water infiltrated today will drain tomorrow. Therefore, drainage calculated in this subroutine is for day J+1. Figure 4.3 presents a flowchart for subroutine RUNOUT.

The drainage value, along with the values for infiltration and evapotranspiration are sent back to the main program, which updates daily the soil water content according to Equation 3.1.

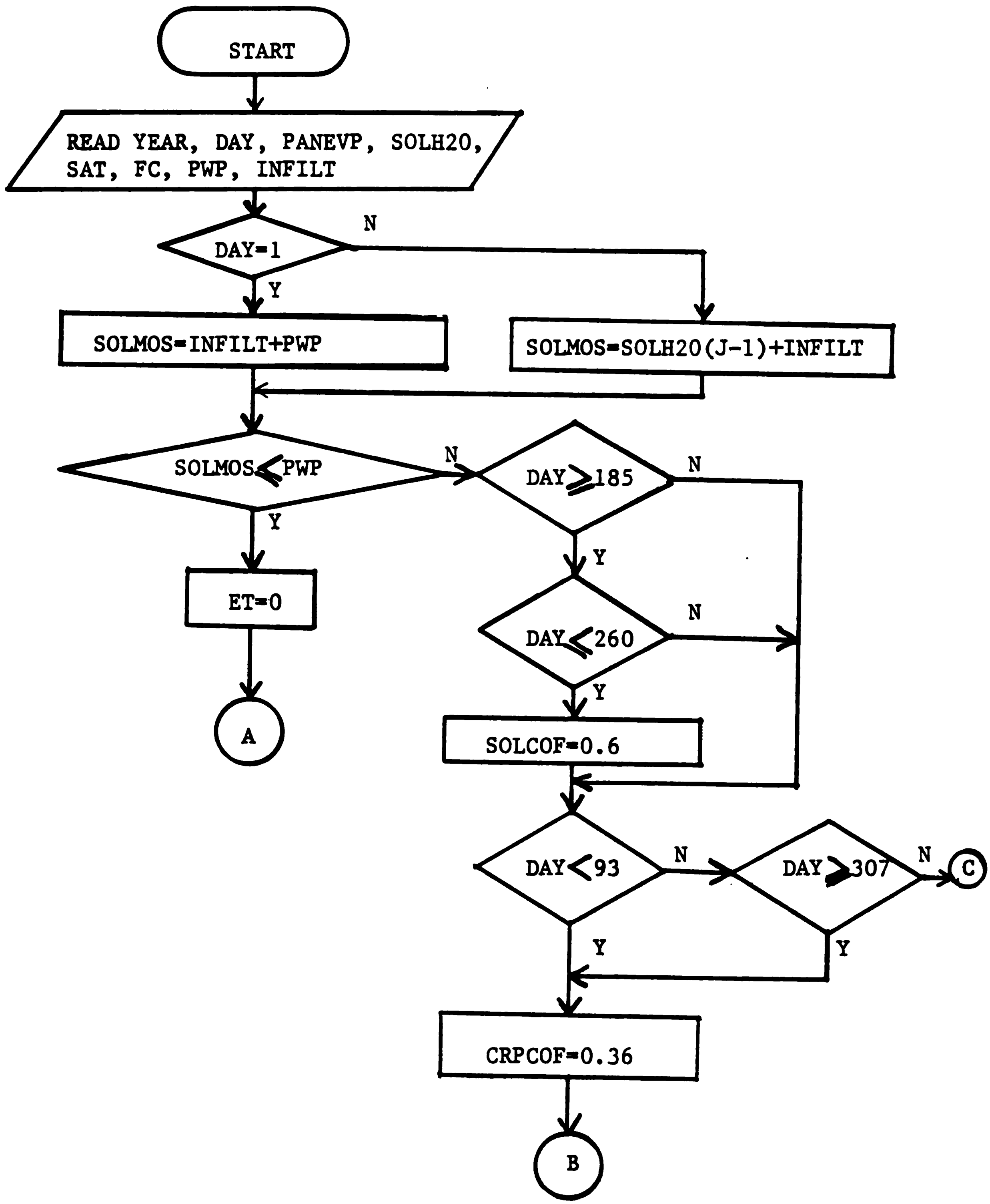

Figure 4.2. Flowchart for subroutine EVAP.

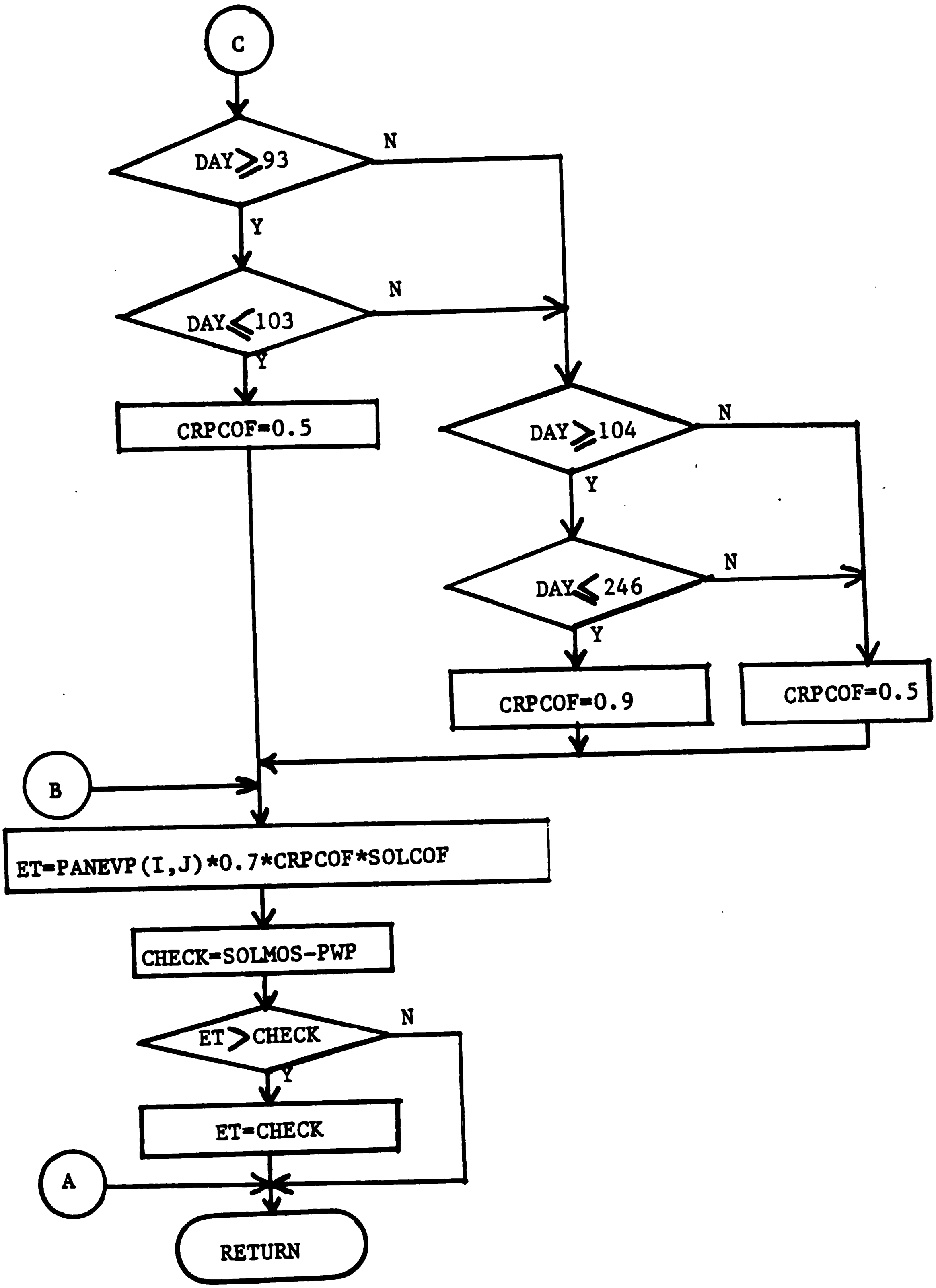

Figure 4.2. (Cont'd.).

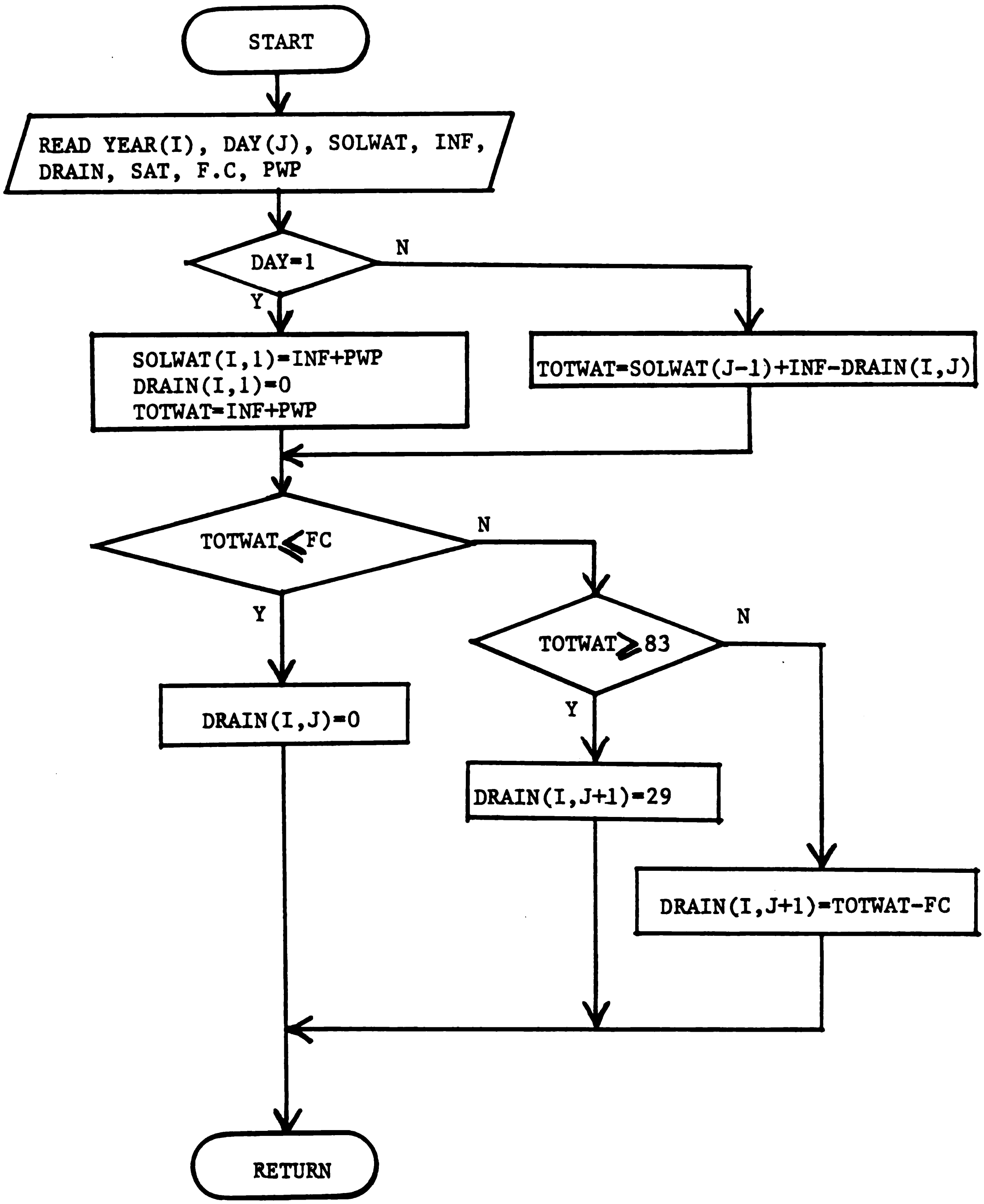

Figure 4.3. Flowchart for subroutine RUNOUT.

4.1.4. Subroutine GODAYS

At this point the program is ready to apply the suitable day criteria developed in Section 3.3.2. Subroutine GODAYS does this work for soil engaging operations (i.e. tillage, seeding) and for above ground operations (i.e. fertilizer broadcasting, spraying).

A one (1), for workday, is assigned to any day in which all conditions that make up the criteria are met. For soil engaging operations (called BELOW in the program), soil water content must be less than 0.99 of available water content and precipitation for the day must be less than 2 mm. For above ground operations (called ABOVE in the program), soil water content for the day and the previous day must be less than saturation and precipitation for the day must be less than 2 mm.

When these criteria are not met the day is assigned a zero (0), for no-workday. All these data are then used in the summation and probability calculation subroutines. Figure 4.4 presents a flowchart for subroutine GODAYS.

4.1.5. Subroutine HVDAYS

Subroutine HVDAYS carries out a function similar to the one performed by subroutine GODAYS, except that now the suitable day criteria for cereal harvesting are applied. These criteria include the amount of daily sunshine and consequently these values are read in for the harvesting period between December 20 and February 15.

Figure 4.5 presents a flowchart for subroutine HVDAYS, based on the criteria developed in Section 3.3.2.

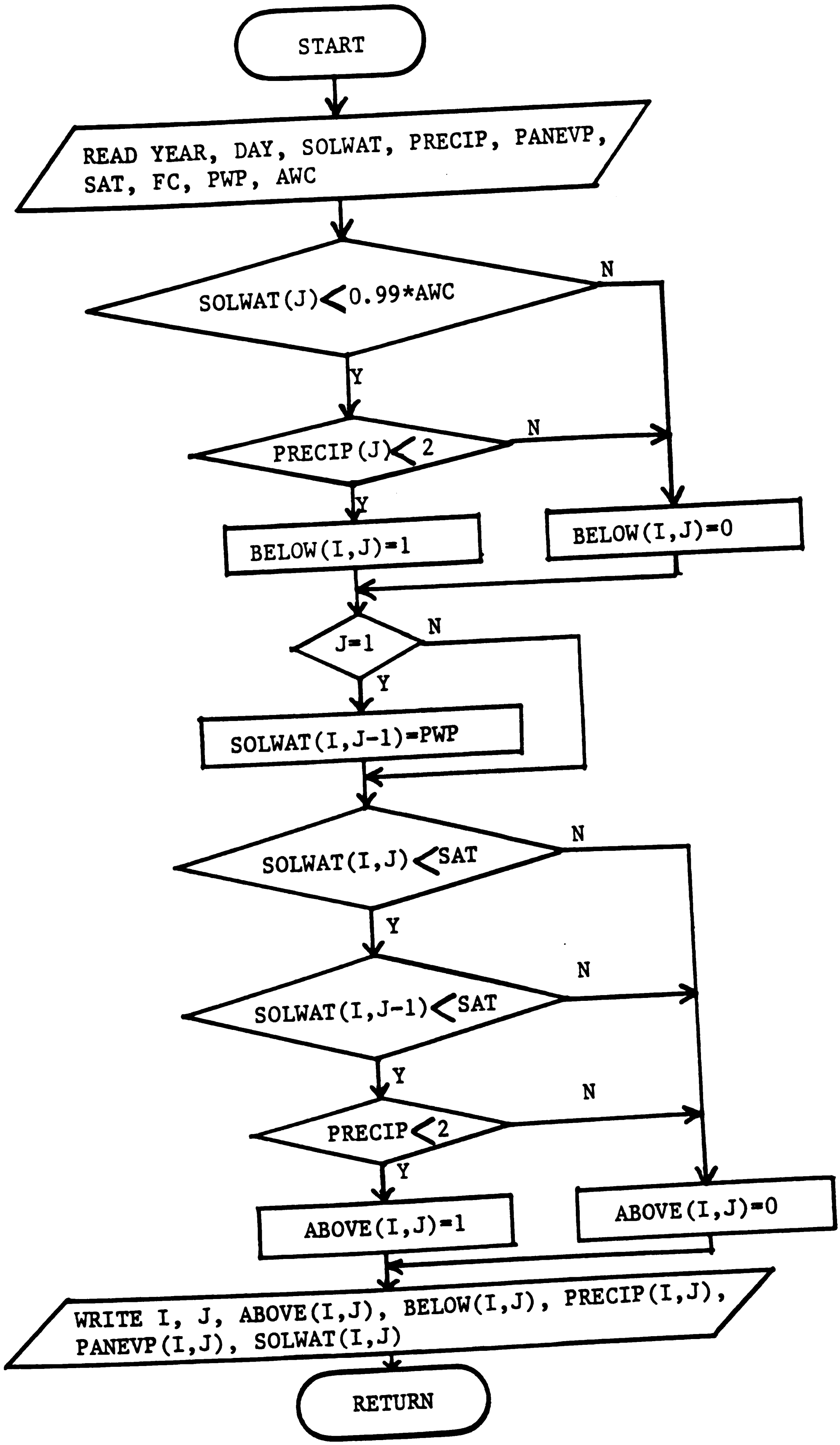

Figure 4.4. Flowchart for subroutine GODAYS.

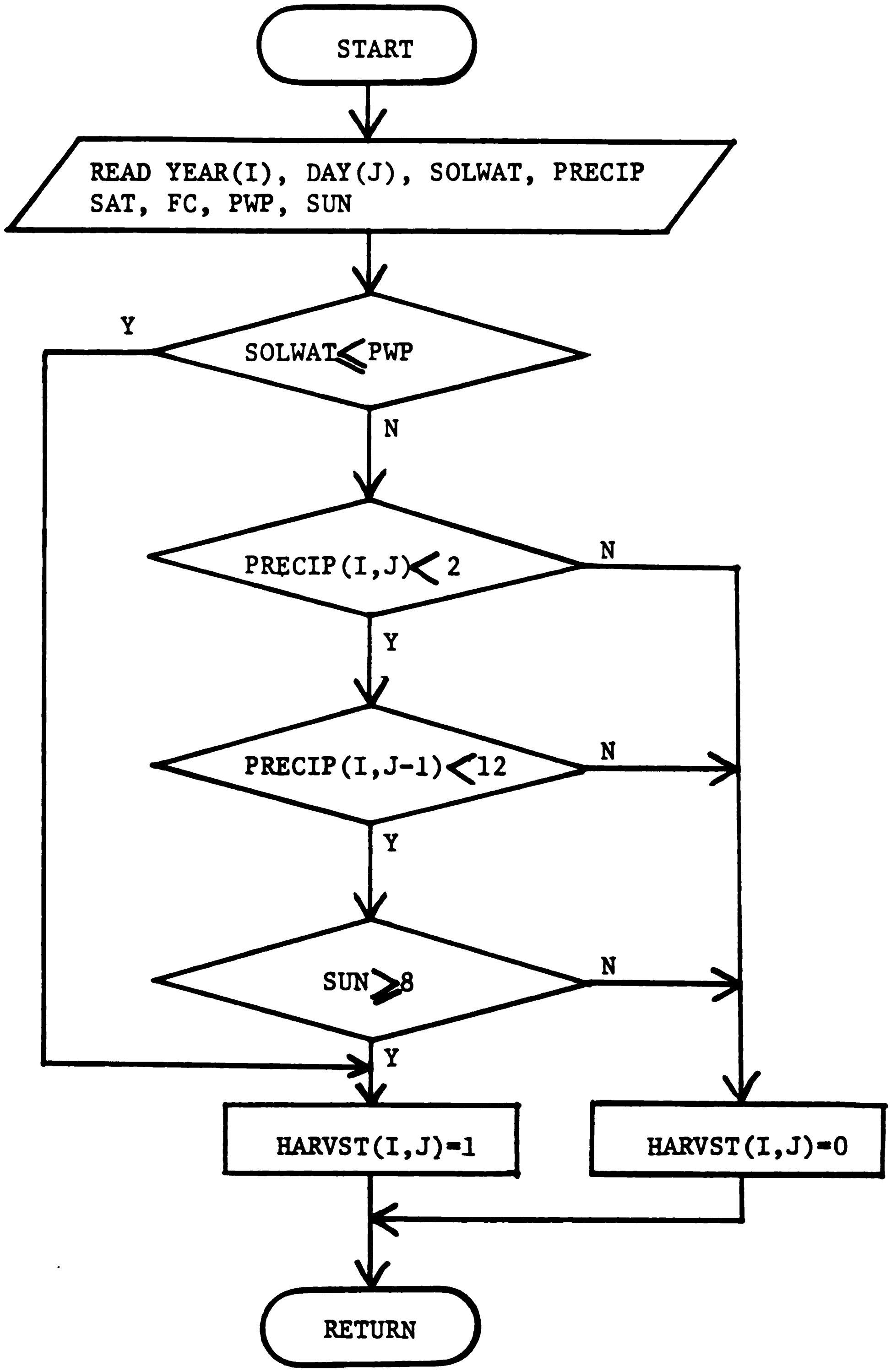

Figure 4.5. Flowchart for subroutine HVDAYS.

4.1.6 Subroutine SUM

This subroutine sums up the number of days suitable for soil engaging and above ground operations for all crops, rotations, and time periods. Two types of workday data are used as follows: a) IADAYS (17,365) are workdays for above ground operations; and b) IBDAYS (17,365) are workdays for soil engaging operations. March 1, 1965 has been assigned Julian date number 1. Therefore, all calendar dates for the different cultural practices previously presented in Tables 3.1 to 3.3 have been transformed into their respective Julian dates.

Other nomenclature used in this subroutine include the following: c) EWKDY(I,J)=suitable days for soil engaging operation I in year J; d) EPWKDY(I,J)=time available in the optimum period plus the penalty period for soil engaging operation I in year J; e) AWKDY(I,J)=time available for above ground operations.

Soil engaging operations start on day ESTART(I). The optimum finishing date for soil engaging operations is EENDR(I). The following code designates each operation: 1 = plowing; 2 = first disk pass; 3 = second disk pass; 4 = third disk pass; 5 = fourth disk pass or harrow and seeding.

Above ground operations start and end on days ASTART(I) and AEND(I). No penalty period exists for these operations and the following code is used: 1 = Nitrogen application; 2 = spraying; 3 = transport oats; 4 = transport wheat; 5 = cutting lentils; 6 = transport lentils.

A flowchart for subroutine SUM is presented in Figure 4.6.

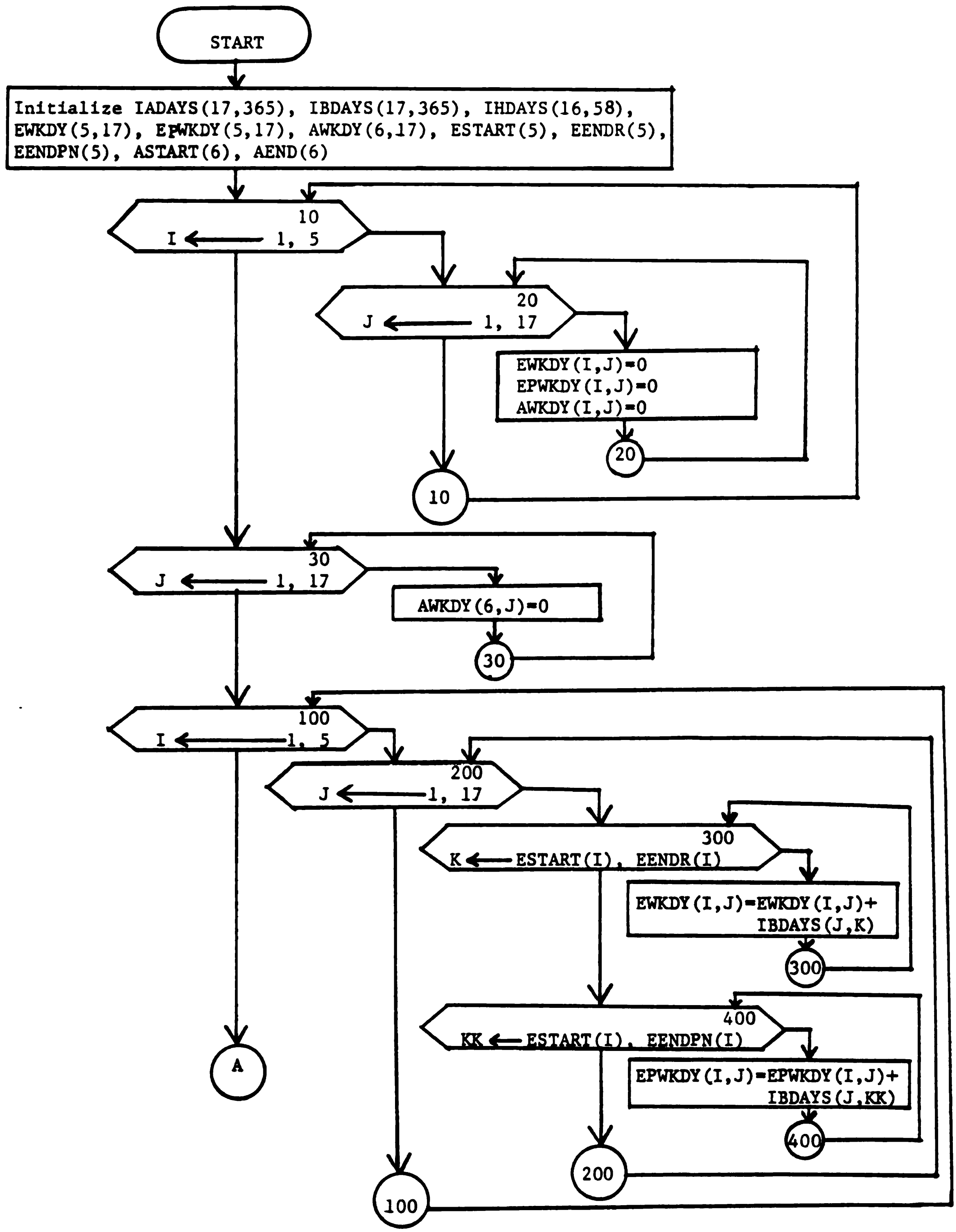

Figure 4.6. Flowchart for subroutine SUM.

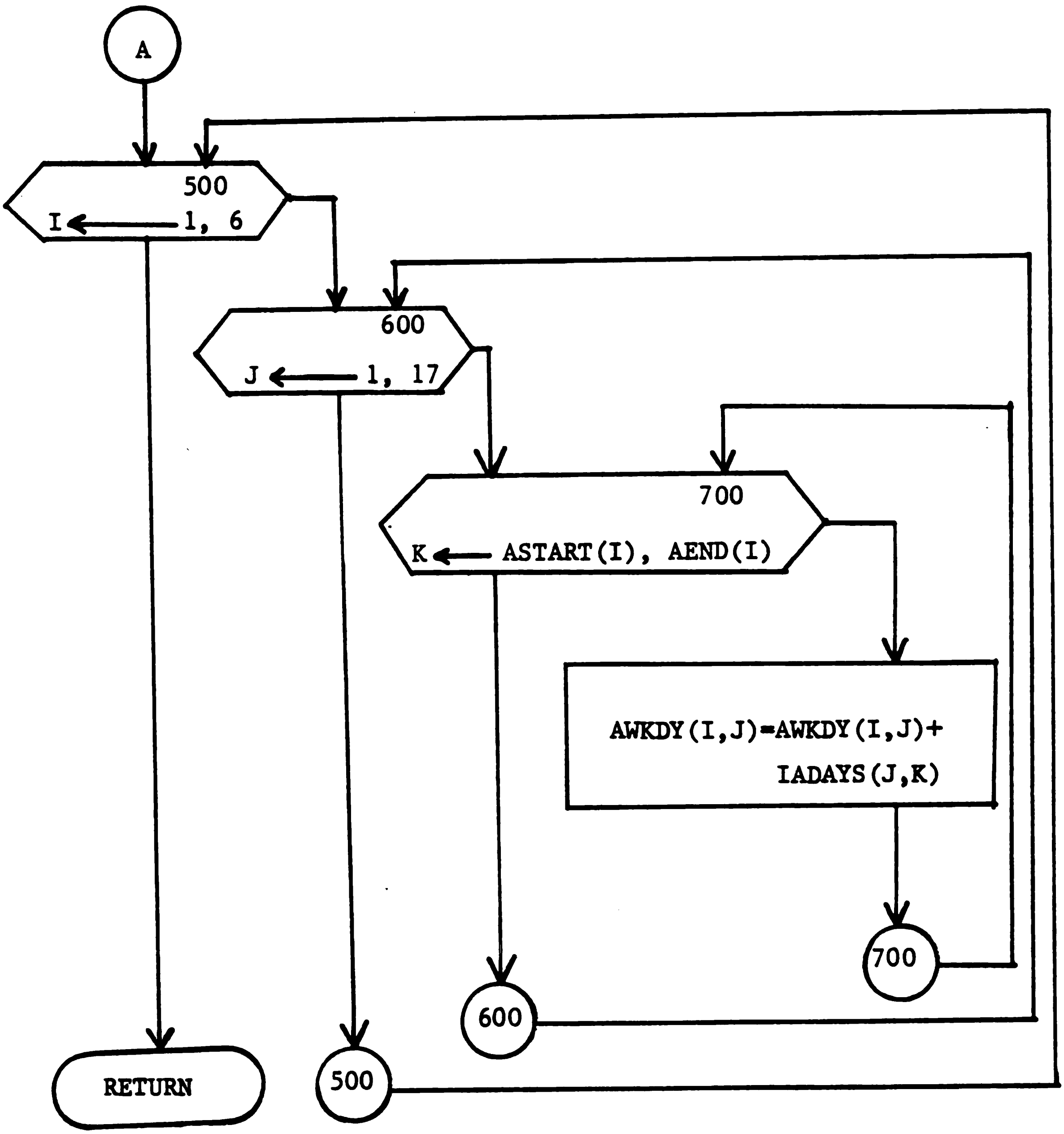

Figure 4.6. (Cont'd.).

4.1.7 Subroutine HARVEST

Subroutine HARVEST does for harvesting operations what SUM does for soil engaging and above ground operations. This subroutine uses the data for workdays and no-workdays stored in IHDAYS(16,58) to sum the number of suitable harvesting days for each crop. As in subroutine SUM the workdays of each year for each crop harvesting period are placed into a variable and this variable is returned to the main program where expected number of workdays at selected probability levels are worked out.

Beginning and ending dates for each harvesting operation are stored in START(I) and HEND(I). The dates for ending with penalty are stored in HENDP(I). The following code is used: 1 = harvest oats; 2 = harvest wheat; 3 = harvest lentils.

Other variables in this subroutine include HWKDY(I,J), which is the number of days suitable for harvesting operations that occur in each of the years on record, I being the crop and J the year; HPWKDY(I,J) which is the number of suitable days for harvesting operations that occur in the optimum period plus the number in the penalty period.

A flowchart for subroutine HARVEST is presented in Figure 4.7.

4.1.8. Subroutine WEEKS

This subroutine sums up the number of suitable workdays for 52 climatological weeks, starting on March 1 of each year, for soil engaging and above ground operations. Suitable harvesting days are summed for an eight week period between December 20 and February 13.

The following new nomenclature is used in this subroutine:

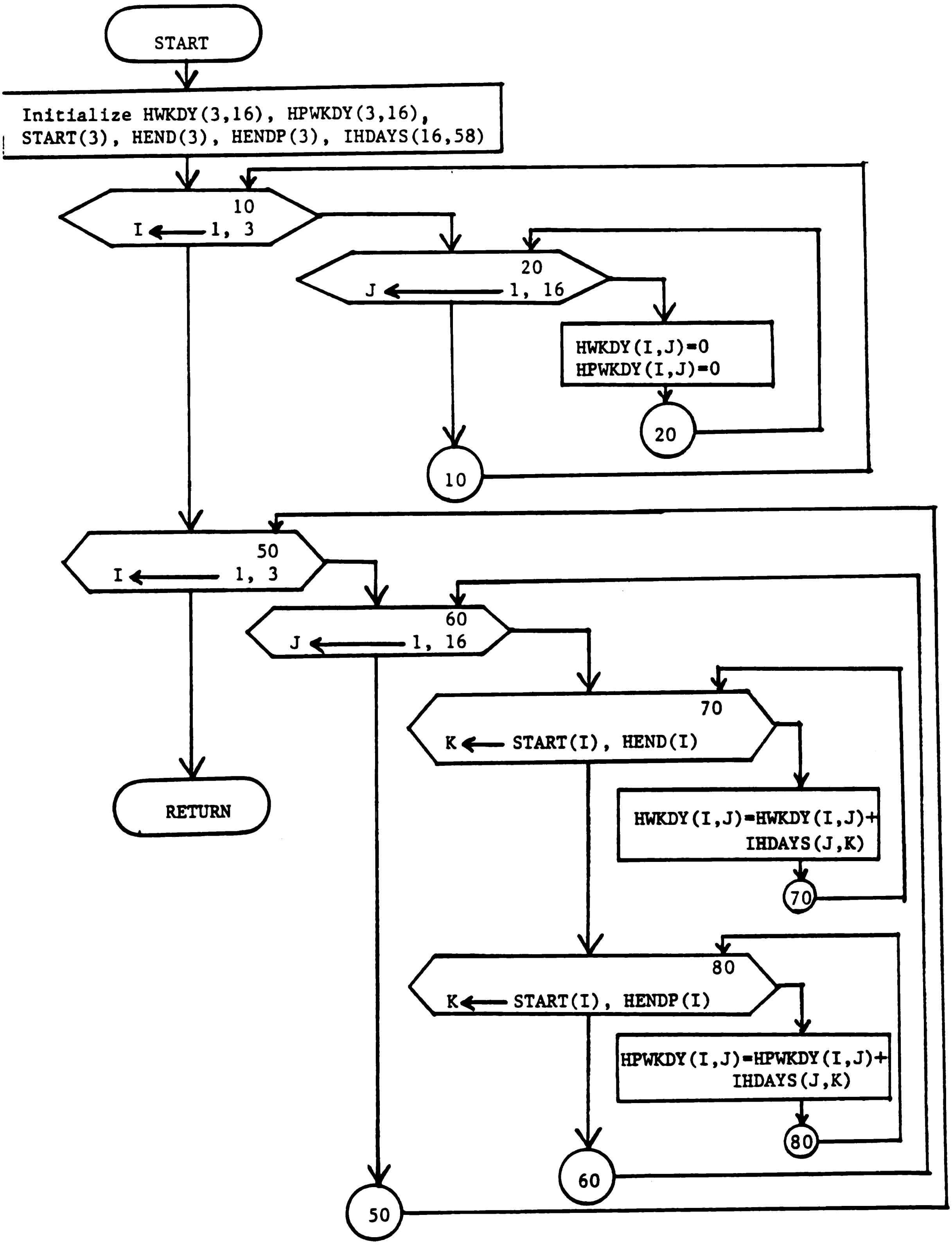

Figure 4.7. Flowchart for subroutine HARVEST.

EWEEK(I,J) is the number of suitable days for soil engaging operations in week (I), year (J); AWEEK(I,J) is the number of days suitable for above ground operations in week (I), year (J); HWEEK(I,J) is the number of days suitable for cereal harvesting operations in week (I), year (J).

A flowchart for subroutine WEEKS is presented in Figure 4.8.

4.1.9. Subroutine SORT

This subroutine sorts the number of suitable workdays for each of the operations, crops, rotations and time periods. The year with the maximum number of suitable days is given top rank, and the year with the minimum number of suitable days is given the lowest rank.

A flowchart for subroutine SORT is presented in Figure 4.9.

4.1.10. Subroutine SMOOTH

This subroutine takes the ordered years from subroutine SORT, assigns each a probability value, smooths the data and then sends the data to a linear interpolation subroutine. PROB(I) contains the (K/N+1) cumulative probability value for each year. K is the rank of a given year assigned by subroutine SORT.

Figure 4.10 represents a flowchart for subroutine SMOOTH.

4.1.11. Subroutine INTERP

Subroutine INTERP locates a specific value of suitable workdays for a given probability level. In this subroutine, X is the probability level input and Y is the number of suitable workdays found by linear

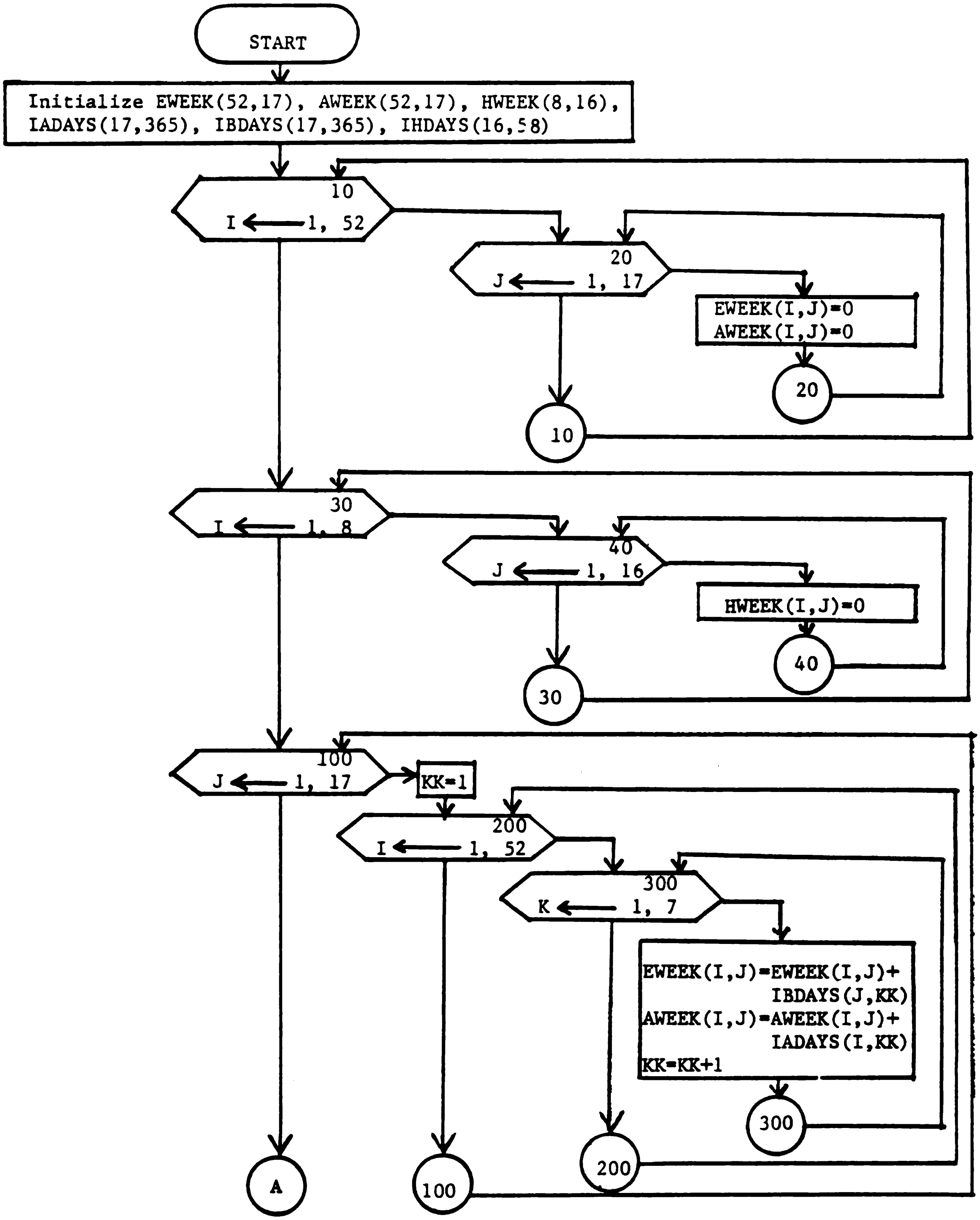

Figure 4.8. Flowchart for subroutine WEEKS.

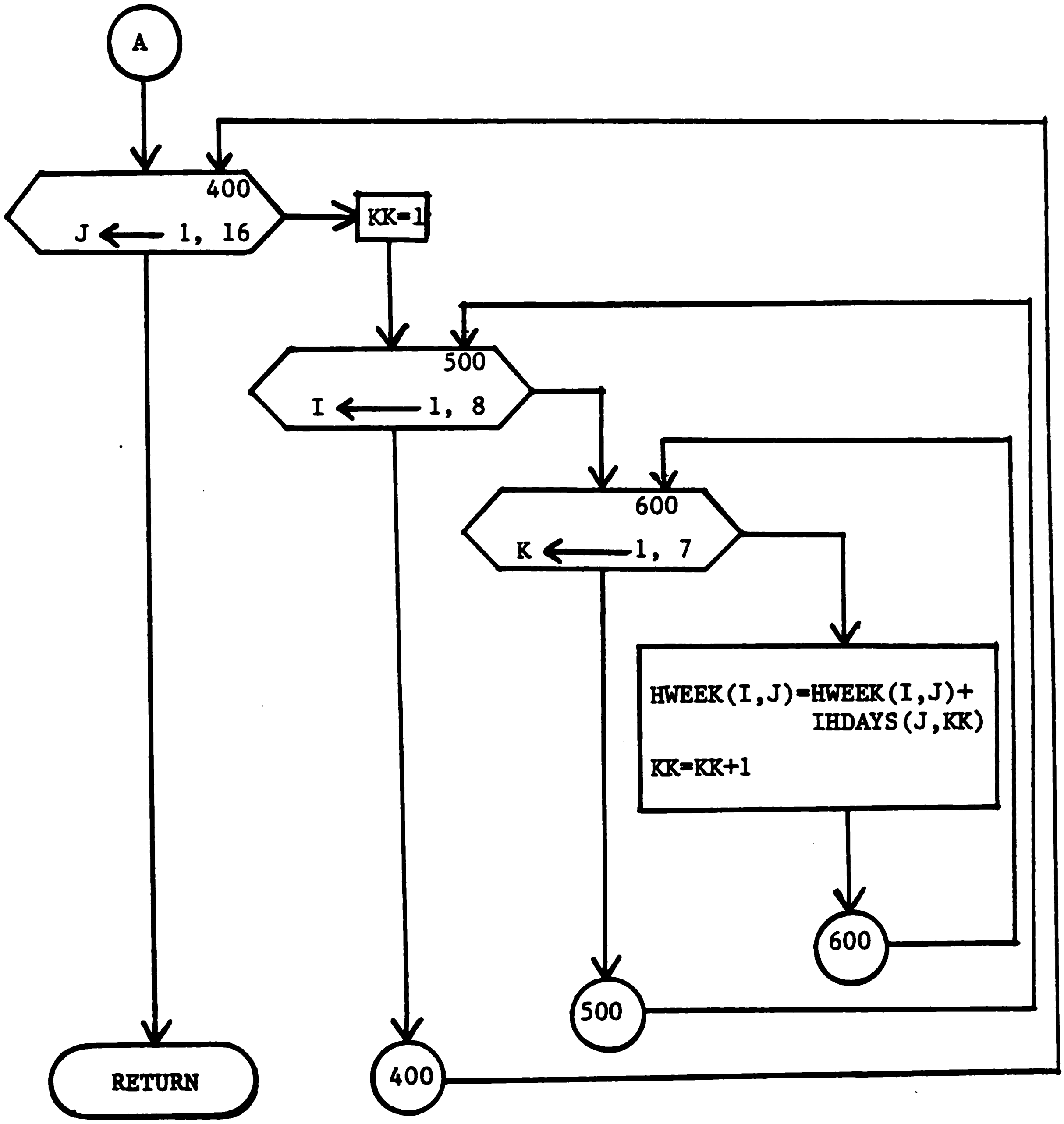

Figure 4.8. (Cont'd.).

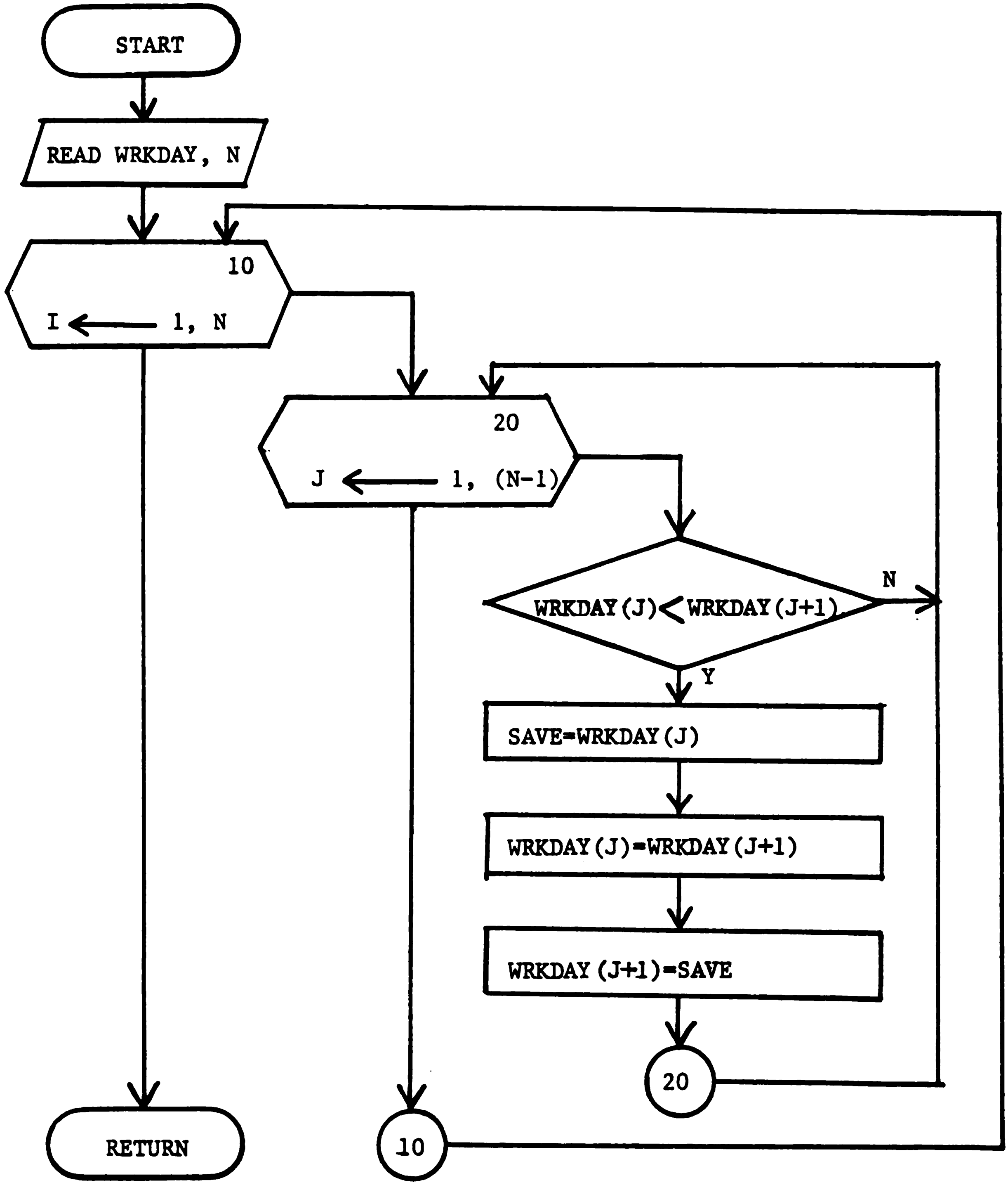

Figure 4.9. Flowchart for subroutine SORT.

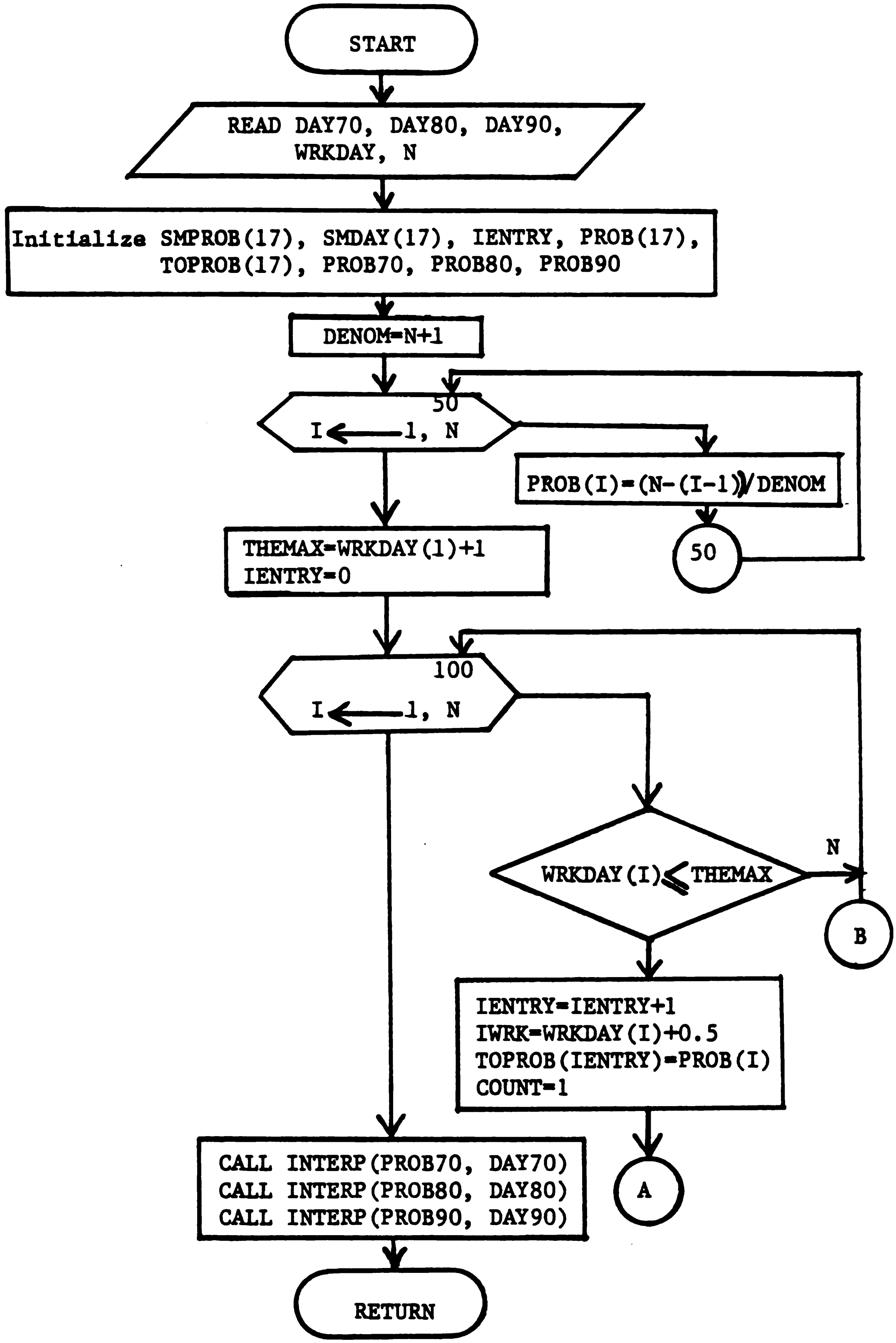

Figure 4.10. Flowchart for subroutine SMOOTH.

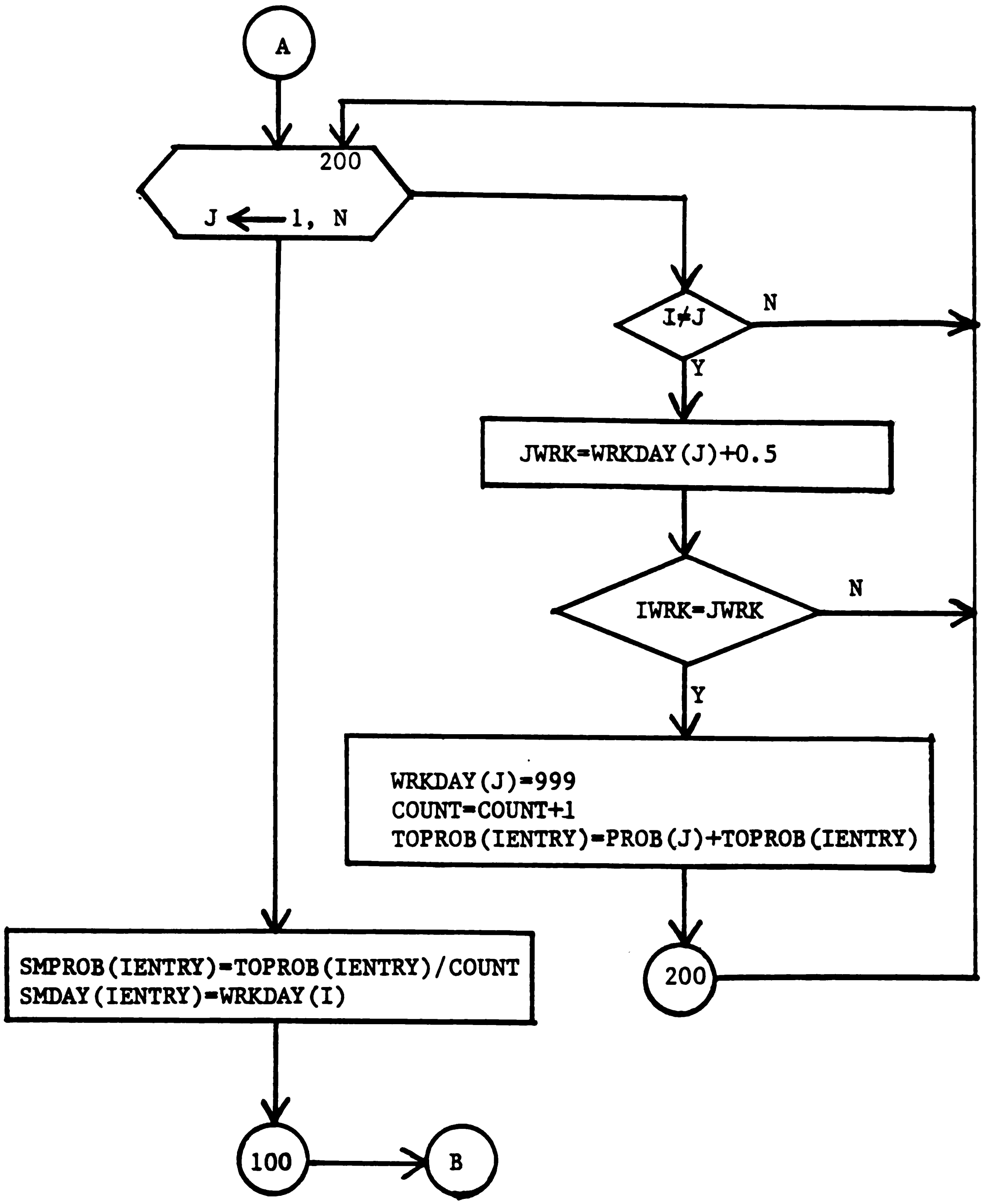

Figure 4.10. (Cont'd.).

interpolation.

Subroutine INTERP is connected to subroutine SMOOTH by a common block. A flowchart for subroutine INTERP is depicted in Figure 4.11.

4.2. Program TRIGO

Program TRIGO consists of a main program and 12 subroutines. The program has been designed for interactive use and, consequently, on each run it provides directions to the user on how to enter all the required information, which has been shown on the left side of Figure 3.4.

The main program of the model controls the operation of the subroutines by means of indexes, flags, logical expressions and by direct calls to the proper subroutines. A flowchart for program TRIGO is presented in Figure 4.12.

Initially, the main program calculates the areas over which the different field operations are to be performed, according with the nature of the crops, rotation and tillage intensity level being used. The main program also handles the correlation equations, presented in Appendix B, which predict the purchase price for all sizes of machines available from the local farm machinery dealers, in Chile.

The main program controls the operational flow during the machinery system size incrementation process. During this process the main program uses a specific algorithm to compare, sort and store the three machinery systems with the lowest total present value cost.

All the subroutines, except COST, have been provided with data specifying the effective capacity of all sizes of machines, according with equation 3.2 and the data presented in Table 3.5. Also, relevant

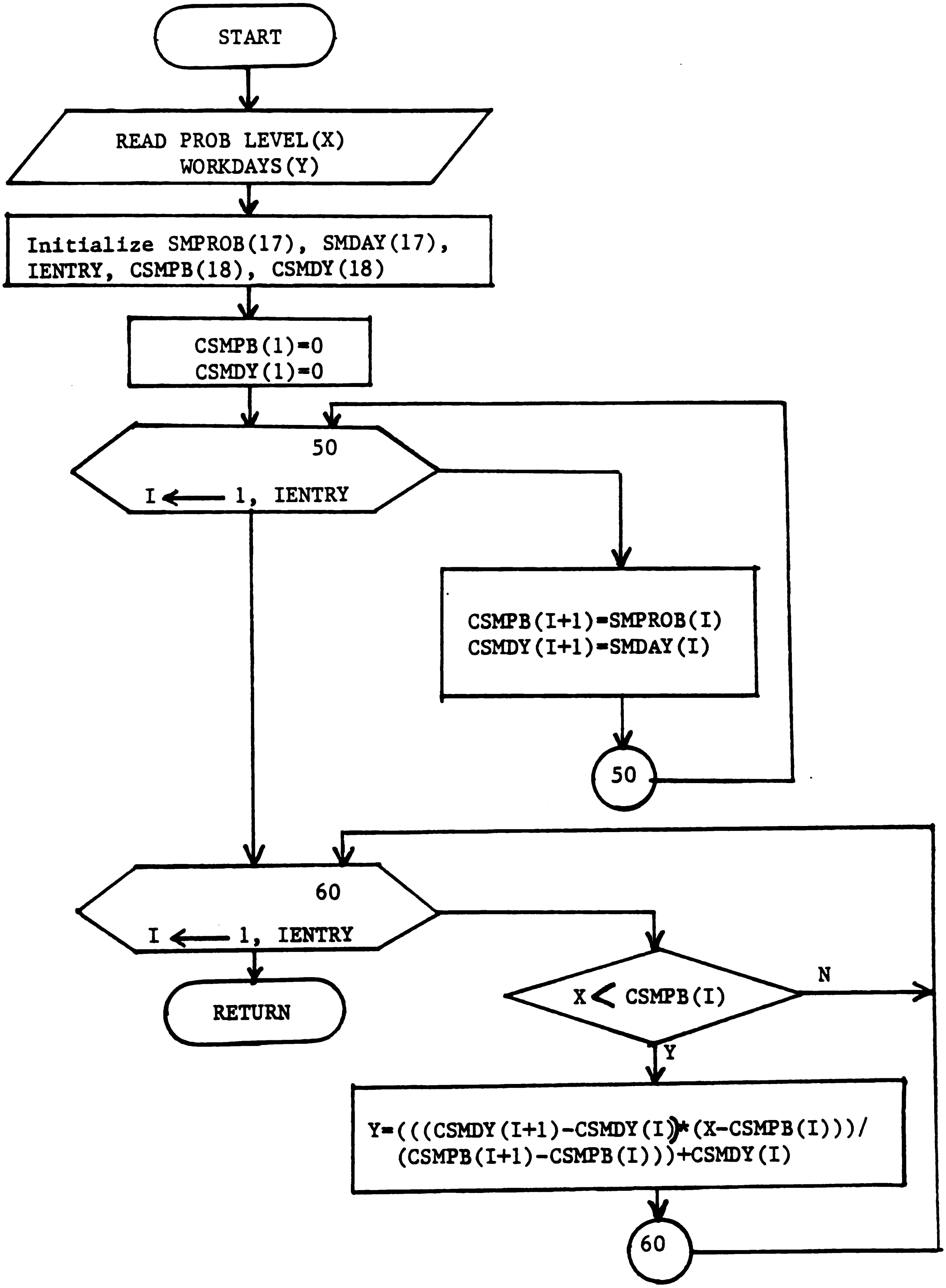

Figure 4.11. Flowchart for subroutine INTERP.

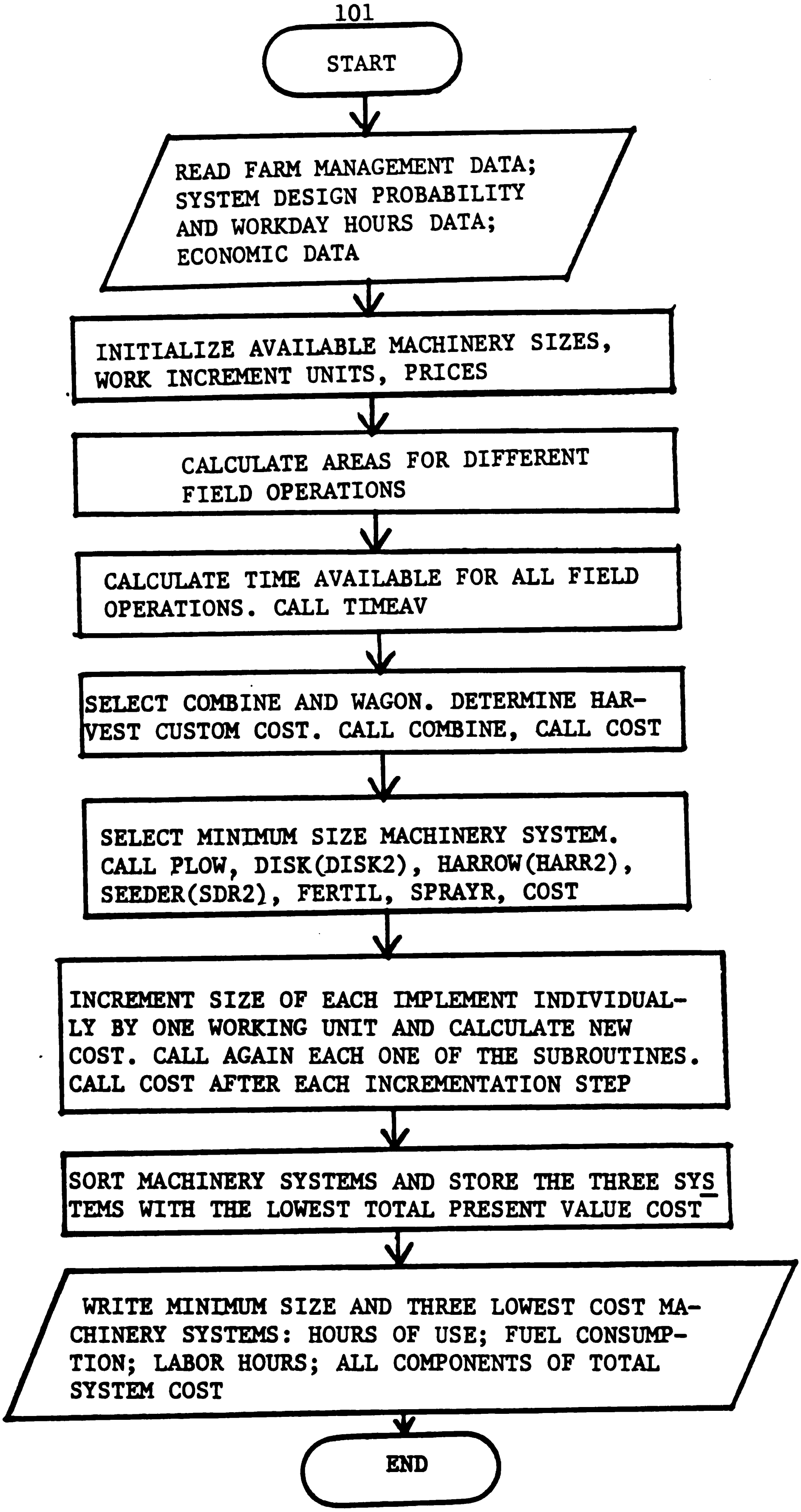

Figure 4.12. Flowchart for program TRIGO.

subroutines (PLOW, DISK, DISK2, SDR2, COMBINE) have been provided with data establishing the PTO power equivalent needed by each size of the different machines. These power requirement data were obtained using equation 3.3 and the data presented in Table 3.5.

Resulting effective field capacities and power requirements were discussed with farmers and extension personnel working for the Technology Transfer Program and modified according to their suggestions during the data collection process in Chile. Effective field capacities and power requirements of different machines used in the model are presented in Appendix D.

4.2.1. Subroutine TIMEAV

This subroutine handles selected output from program WEATHR, which will be used in program TRIGO. The time available, in days, for each field operation at 0.70, 0.80, and 0.90 probability level is stored in this subroutine. These available days are transformed into hours using variables WKHRS1 and WKHRS2, which are sent to each of the machinery selection subroutines.

A flowchart for subroutine TIMEAV is depicted in Figure 4.13.

4.2.2. Subroutine COMBINE

Subroutine COMBINE selects a self-propelled combine harvester and a transport wagon according to the algorithm presented in Figure 4.14. This subroutine also calculates the cost to the farmer if he chooses to hire a custom operator to harvest his crops.

The area used to size the combine harvester is that area which

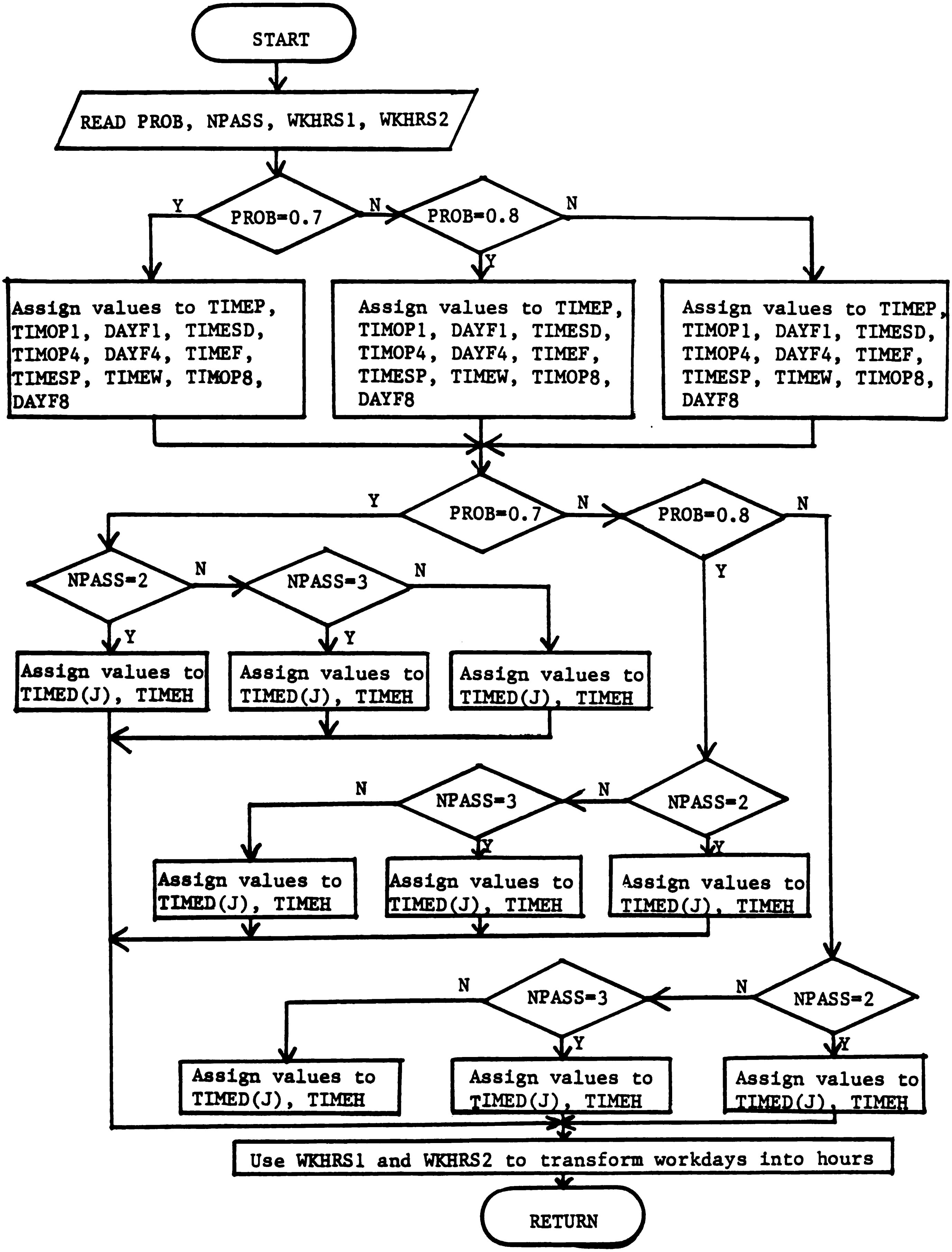

Figure 4.13. Flowchart for subroutine TIMEAV.

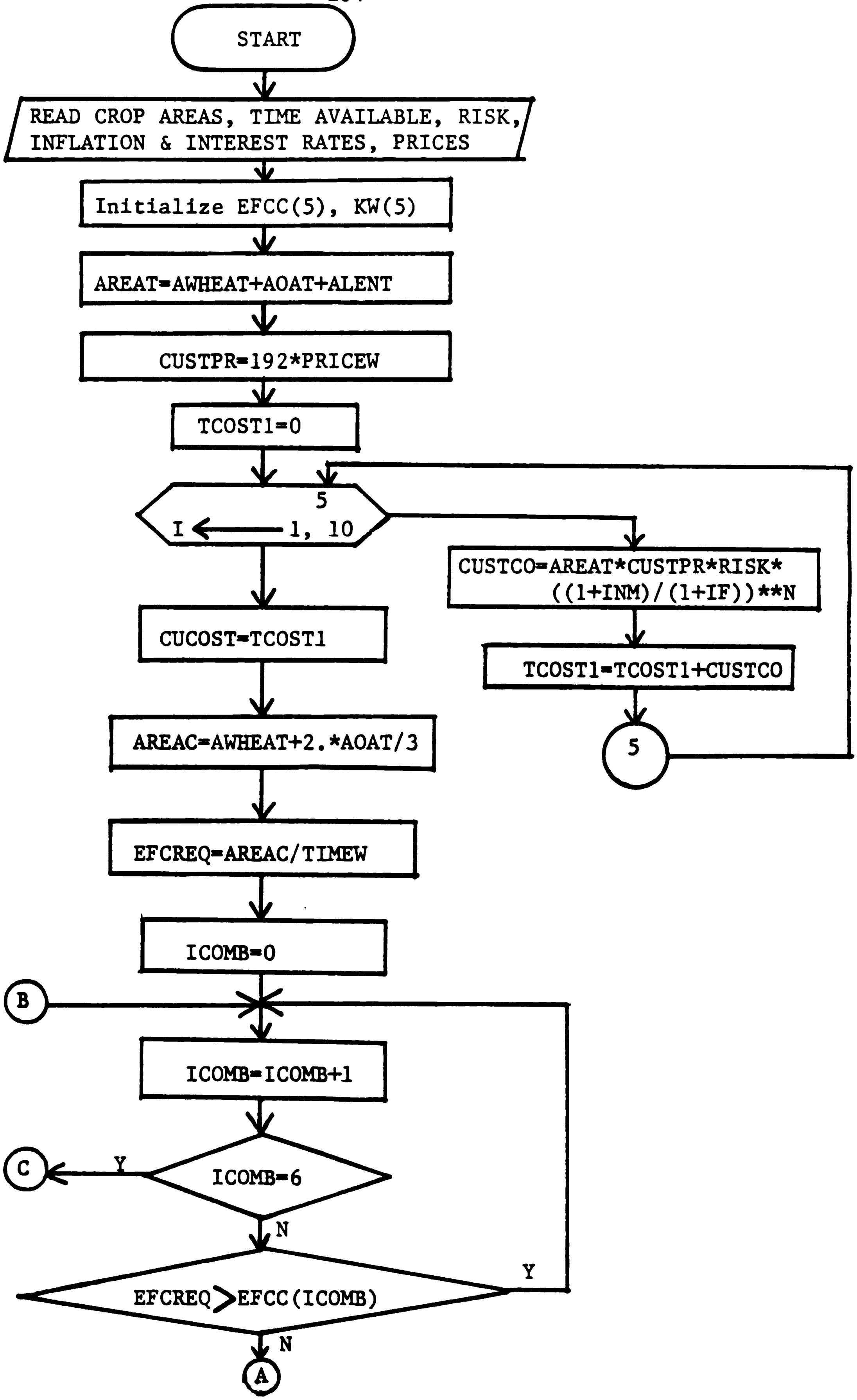

Figure 4.14. Flowchart for subroutine COMBINE.

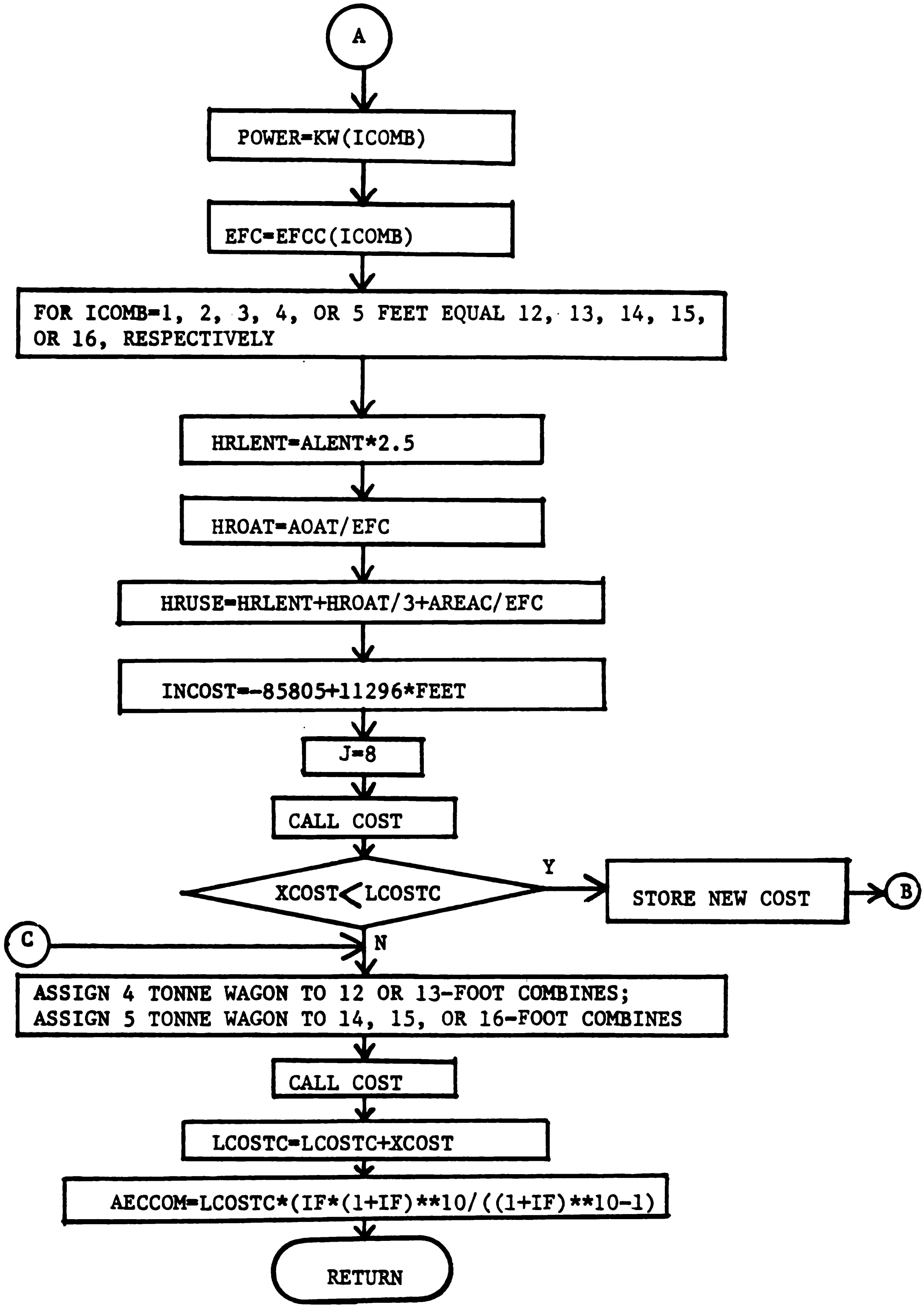

Figure 4.14. (Cont'd.).

must be harvested between January 10 and February 15. This area in accordance with the field operations calendar, includes all the area with wheat and two thirds of the area with oats. The logic behind this approach is that this is the most intensive work period, therefore, any harvester capable of handling this area in the time available would be able to harvest without any delays the rest of the area with oats and the small area seeded with lentils, which does not exceed 15% of the total cultivated area.

This calculated required effective field capacity is compared with the effective field capacity of each of the harvesters from the smallest to the largest size, until the capacity of one of the machines is equal or greater, in which case this harvester is chosen as the minimum size combine. Subroutine COST is called to determine the harvesting cost using this machine size.

In the next step, the subroutine tries the combine one size unit larger, determines the cost and compares it with the previous machine's cost. If the cost is smaller the size incrementation process continues, otherwise the program selects the smaller lower cost harvester.

The hours of use for the combine harvester are calculated from the total harvested area of wheat and oats and the effective field capacity of the selected machine. Two and a half hours per hectare are used to determine the hours needed to harvest the lentils (Ibanez and Rojas, 1979), because this crop has been previously cut and the combine is fed by workers with forks during the harvesting operation.

4.2.3. Subroutine PLOW

This subroutine selects a disk plow based upon the area to be plowed, calculated by the main program, and the time available. The subroutine also determines the hours spent plowing and the power required by the selected plow.

A flowchart for subroutine PLOW is presented in Figure 4.15.

4.2.4. Subroutine DISK and DISK2

Subroutine DISK selects an off-set disk harrow; when the number of disk passes is greater than two and only one tractor will be necessary the subroutine also selects a grain seeder, otherwise the grain seeder is selected by subroutine HARROW or SDR2.

Subroutine DISK may stop the program whenever the seeded area increases to such an extent that the largest disk will not handle all the work in the time available. This subroutine may also send the program into the two tractor situation whenever the largest disk and largest grain seeder are not able to do all the work in the time available during the seeding period.

An iterative process of disk size incrementation is carried out later by the subroutine in order to allocate time to select the grain seeder. This process occurs when three or four disk passes are used and the last pass must be carried out during the seeding period.

The subroutine also determines the hours spent disking, the power required by the disk harrow selected, and will update the power required by the system every time the power required by the disk is greater than the power required by the plow that was selected previously.

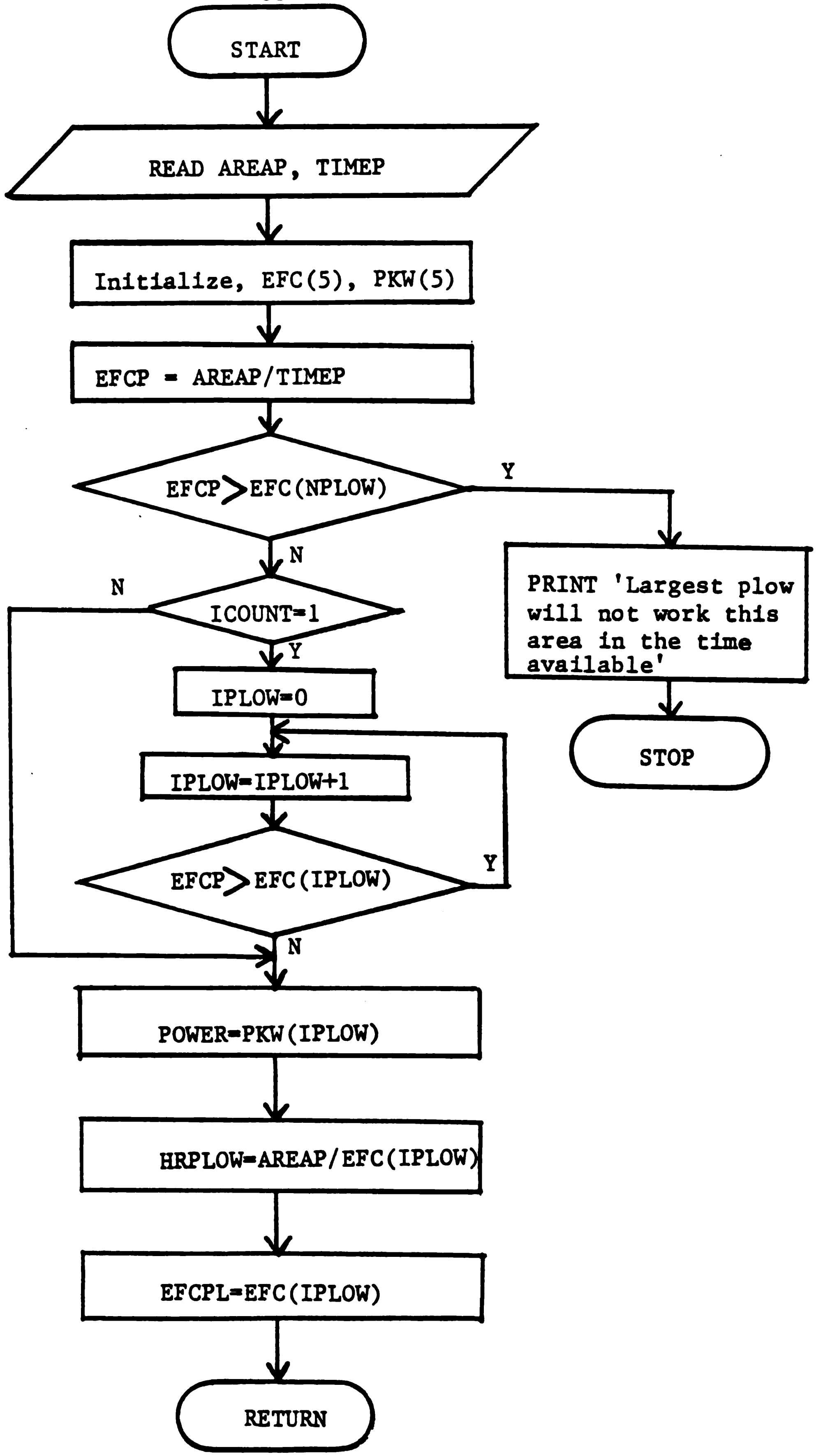

Figure 4.15. Flowchart for subroutine PLOW.

A flowchart for subroutine DISK is presented in Figure 4.16.

Subroutine DISK2 is used only when two tractors are required. The subroutine selects a disk harrow in accordance with the algorithm depicted in Figure 4.17.

Disk size, tractor power required and hours spent disking are determined by subroutine DISK2.

4.2.5. Subroutines HARROW and HARR2

Subroutine HARROW selects a spike-tooth harrow and a grain seeder whenever the number of disk passes is two and only one tractor is required.

The subroutine starts by selecting a harrow using 0.30 of the time available during the seeding period. This is only a starting point based upon the effective field capacities of harrows and seeders considered in this model. The rest of the time is allocated to size the grain seeder and while doing this the size of the harrow may be further increased to free more time for the grain seeder. When there is not enough time for both operations to be performed, the harrow size incrementation process may send the program into the two tractor situation whereas other subroutines are used. A flowchart for subroutine HARROW is presented in Figure 4.18.

Subroutine HARR2 is used whenever two disk passes are used and two tractors are required. The subroutine selects a spike-tooth harrow in accordance with the algorithm depicted in Figure 4.19.

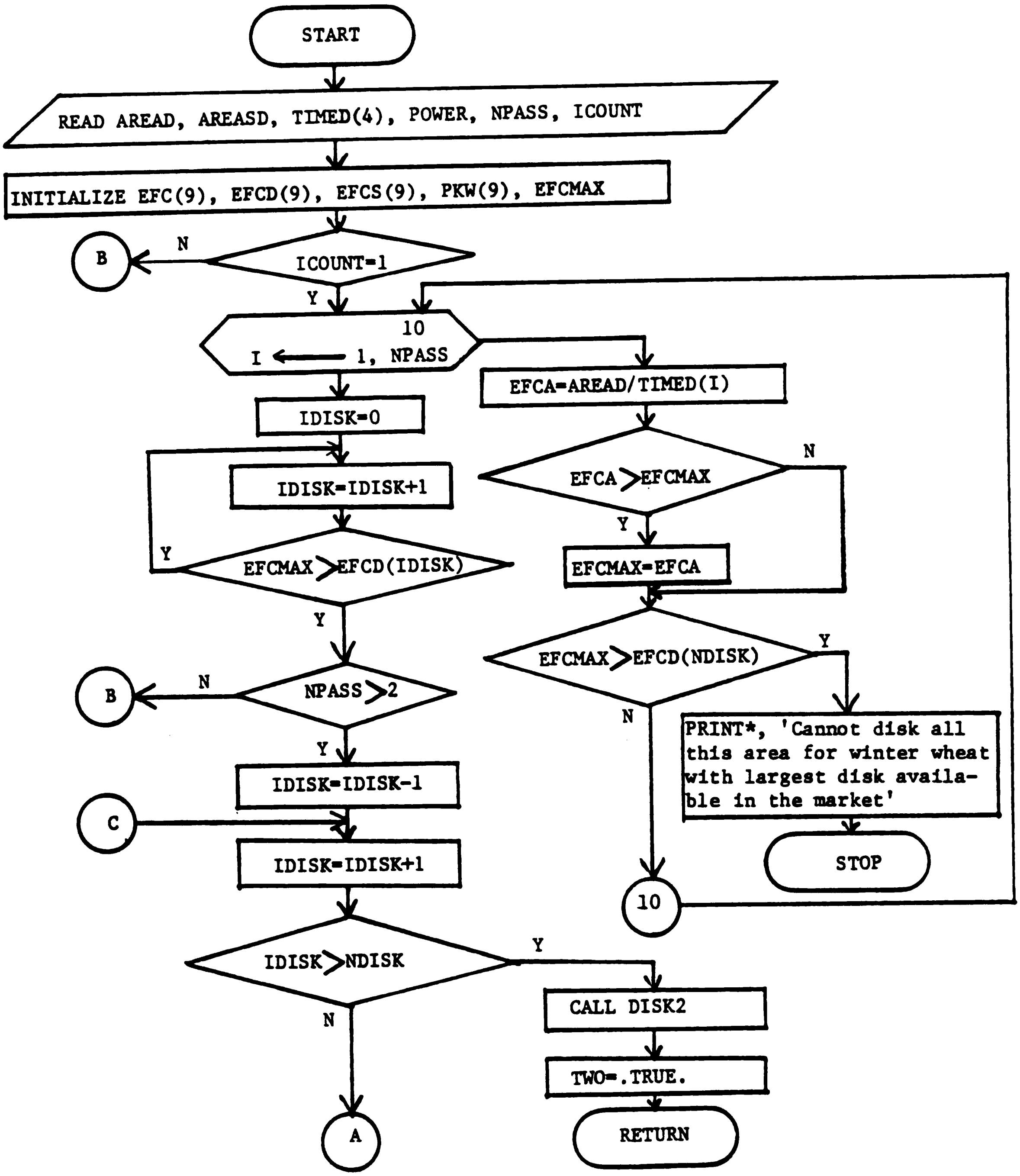

Figure 4.16. Flowchart for subroutine DISK.

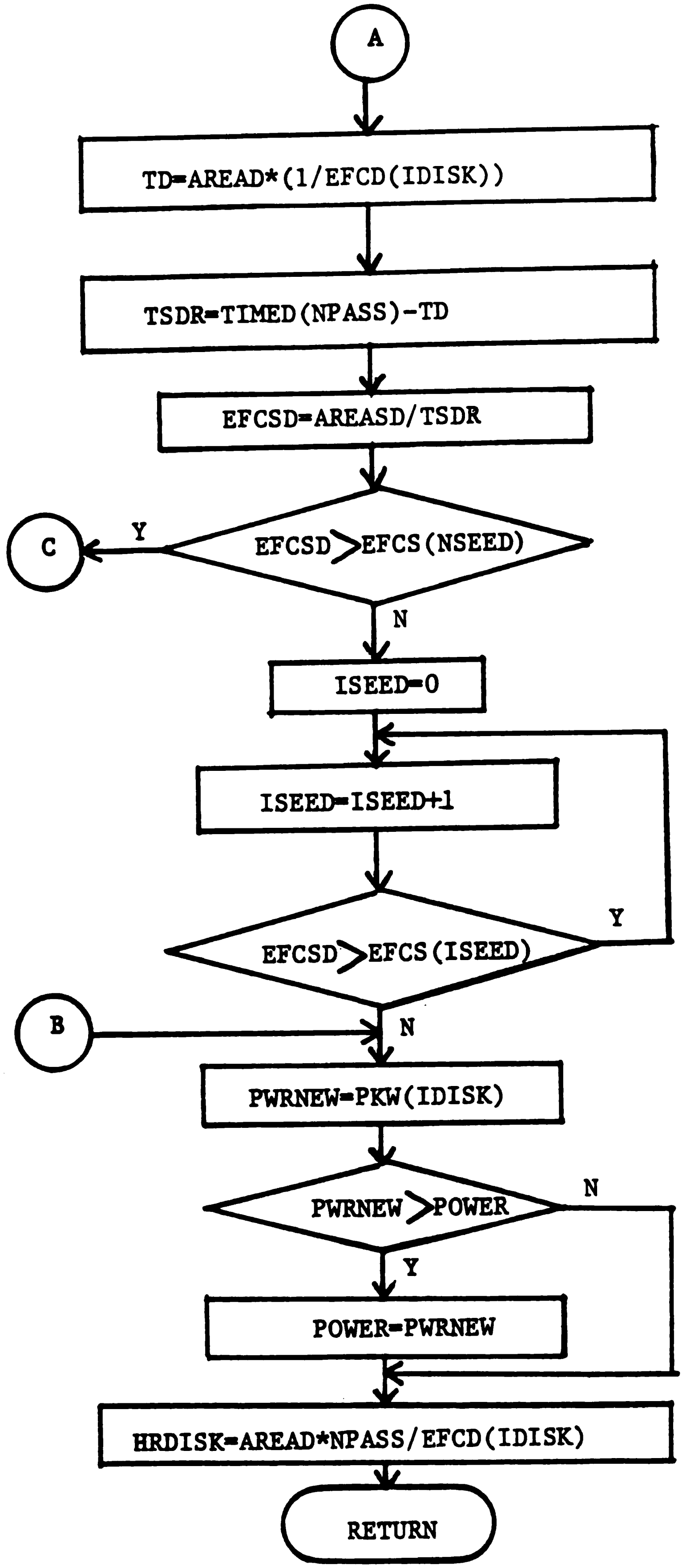

Figure 4.16. (Cont'd.).

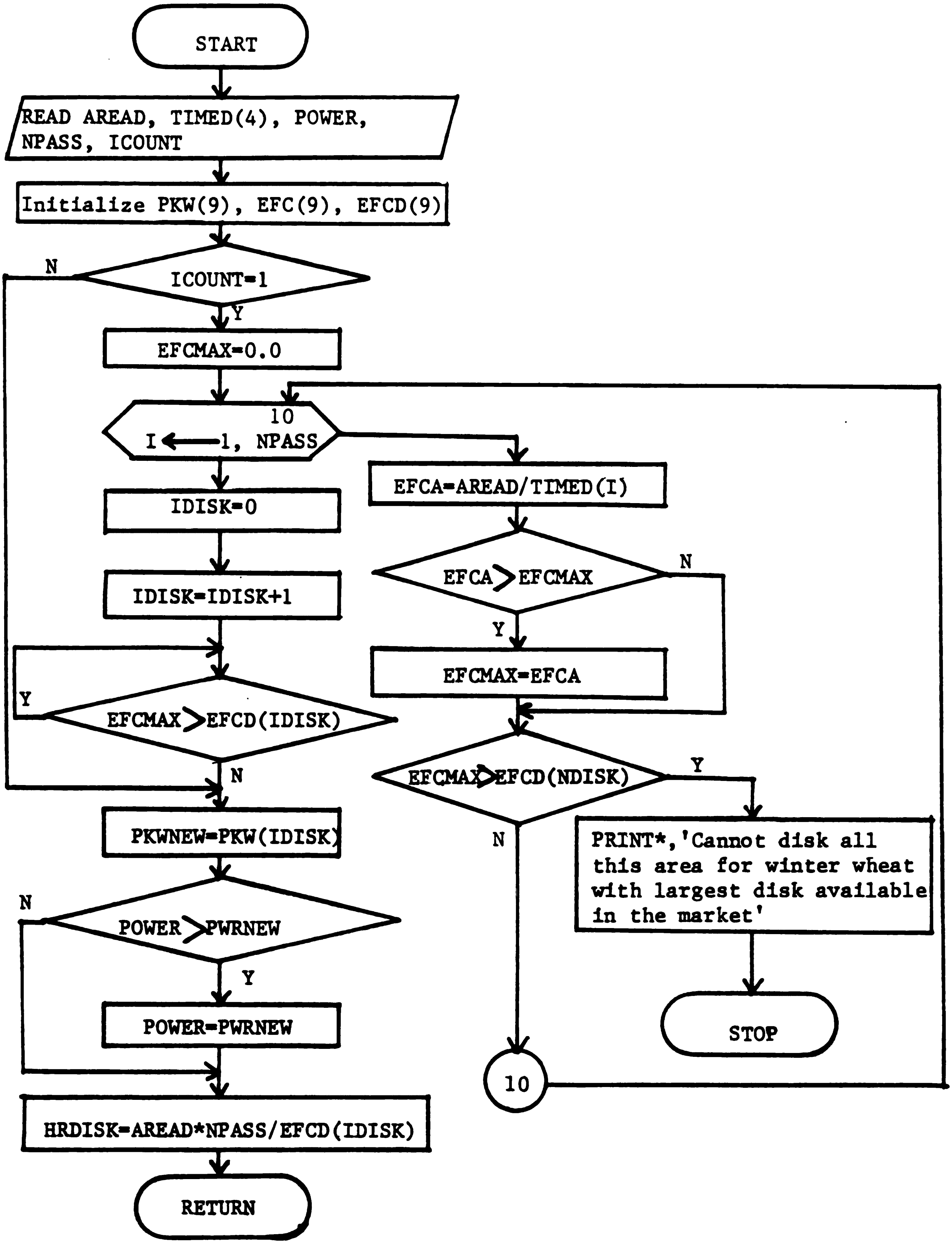

Figure 4.17. Flowchart for subroutine DISK2.

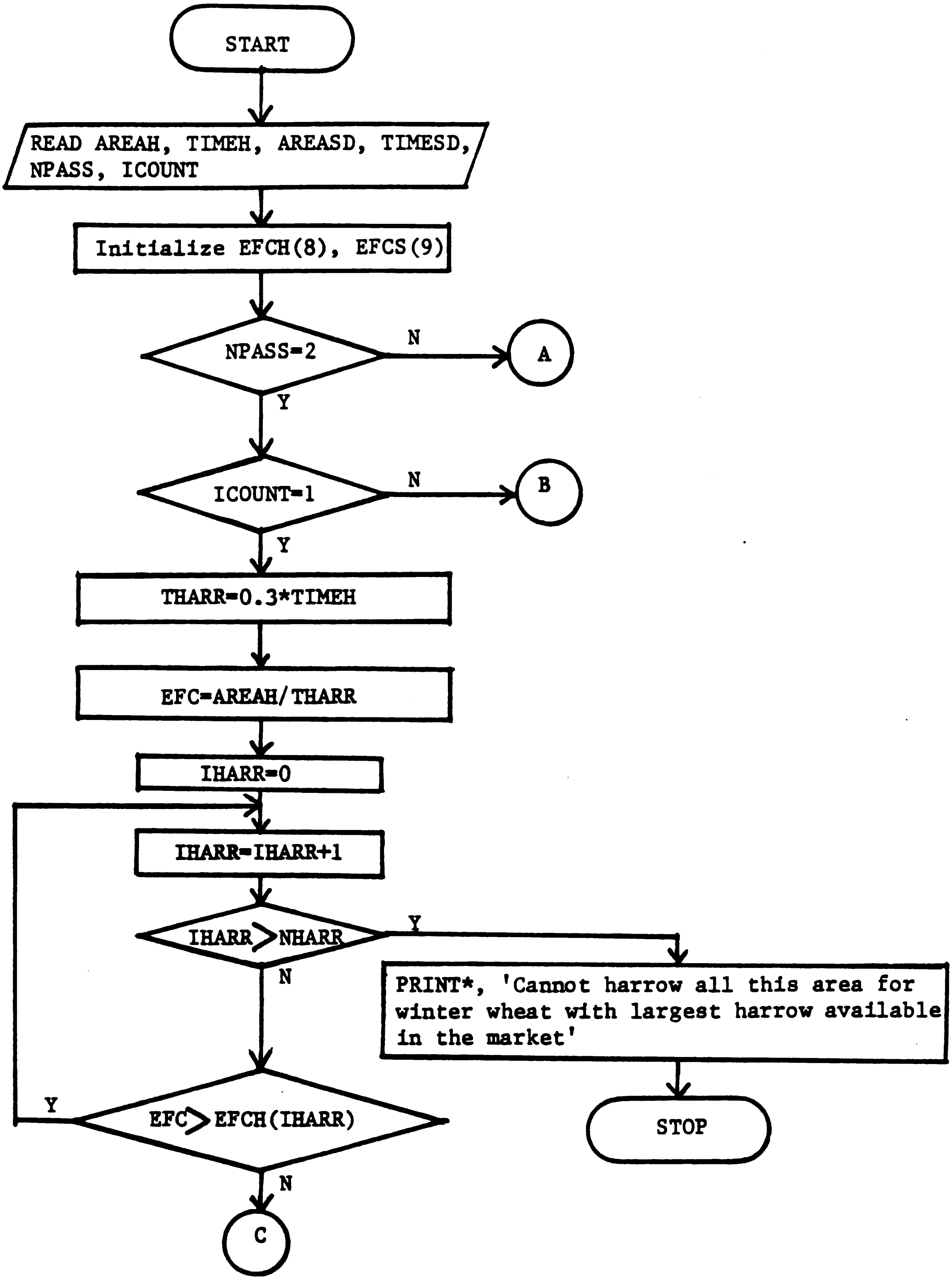

Figure 4.18. Flowchart for subroutine HARROW.

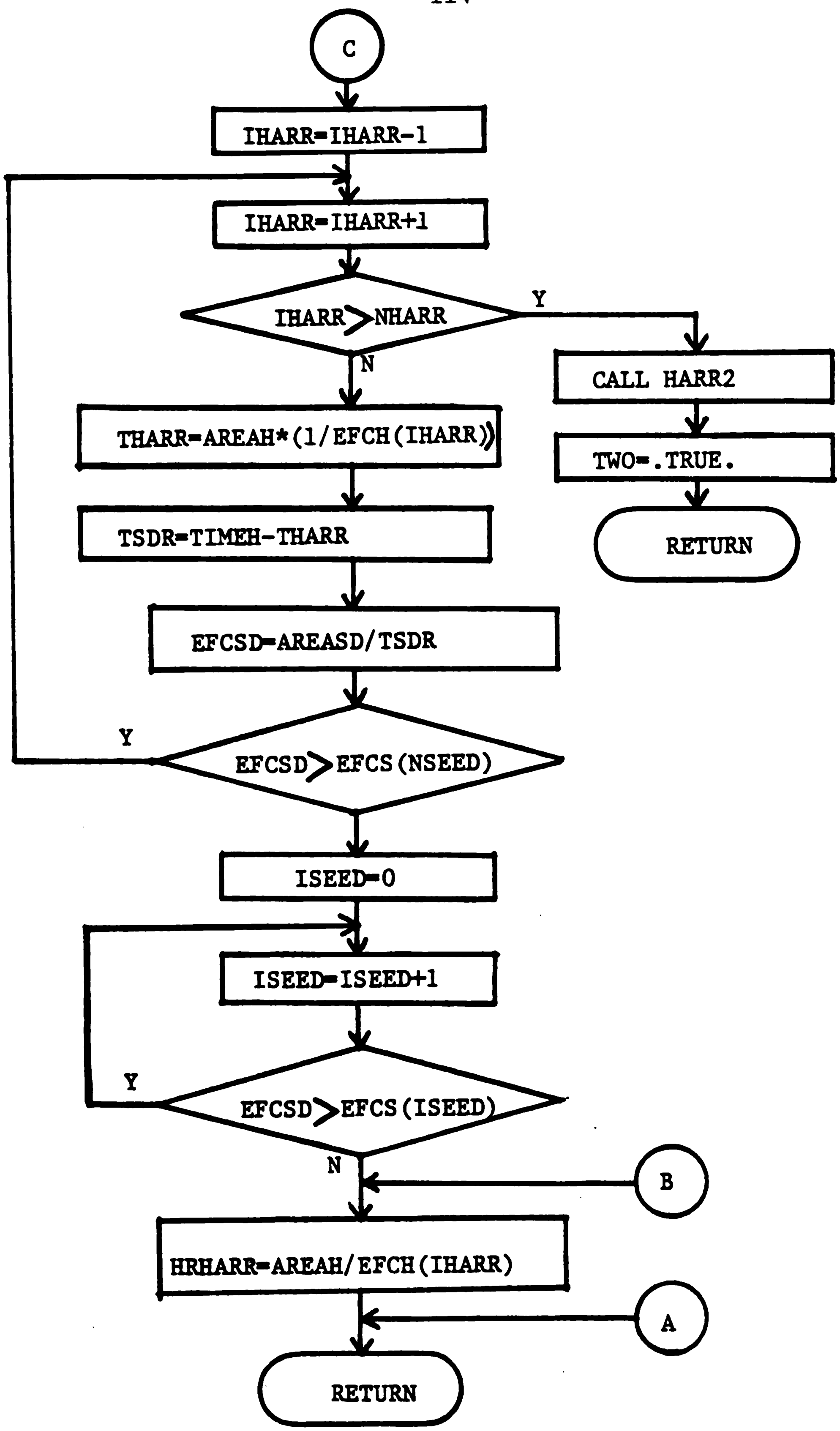

Figure 4.18. (Cont'd.).

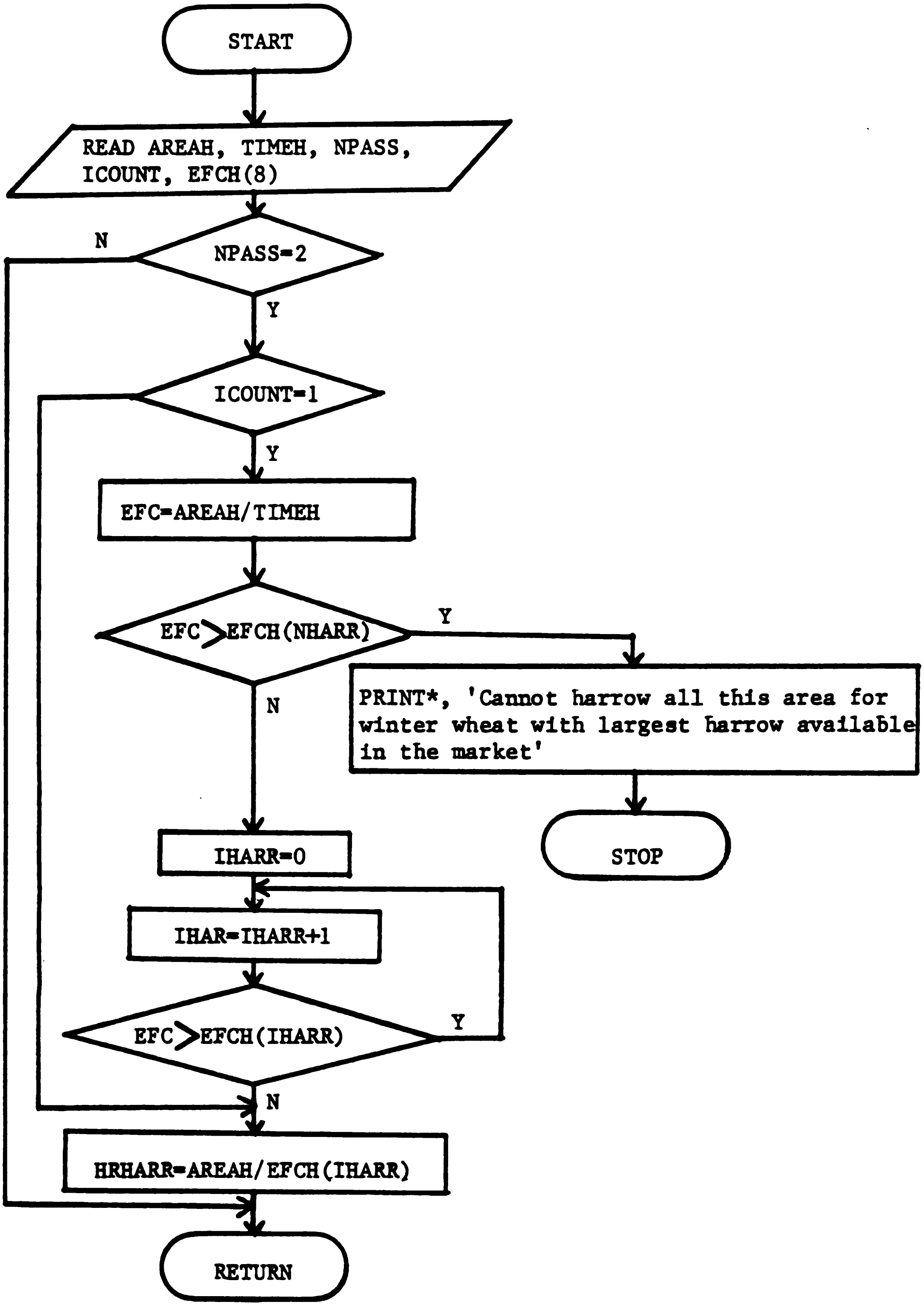

Figure 4.19. Flowchart for subroutine HARR2.

4.2.6. Subroutines SEEDER and SDR2

Subroutine SEEDER is used when only one tractor is required and its function is to determine the hours spent seeding and to provide the seeder's effective field capacity needed in the timeliness cost calculation. A flowchart for subroutine SEEDER is presented in Figure 4.20.

Subroutine SDR2 is used when two tractors are required and its function is to select a grain seeder in accordance with the algorithm presented in Figure 4.21.

Since the power required by the largest seeder is 28.6 kW and this number is only slightly larger than the power of the smallest tractor available in the market, this power is assigned to the second tractor which also powers the fertilizer broadcaster and the field sprayer.

4.2.7. Subroutine FERTIL

This subroutine selects a fertilizer broadcaster upon the basis of the area to be fertilized, hectares seeded with wheat and oats, and the time available. The number of hours spent fertilizing are also calculated and provided for the cost calculations.

A flowchart for subroutine FERTIL is presented in Figure 4.22.

4.2.8. Subroutine SPRAYR

This subroutine selects a field sprayer based upon the area to be sprayed and the time available. The number of hours spent spraying are also determined and provided for the cost calculations.

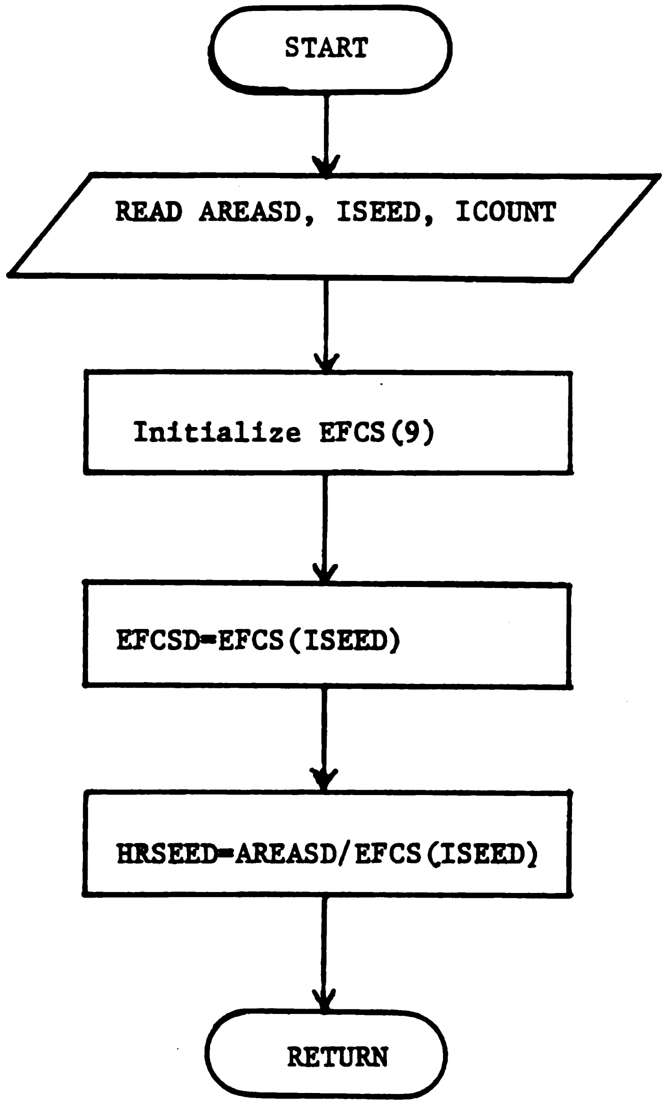

Figure 4.20. Flowchart for subroutine SEEDER.

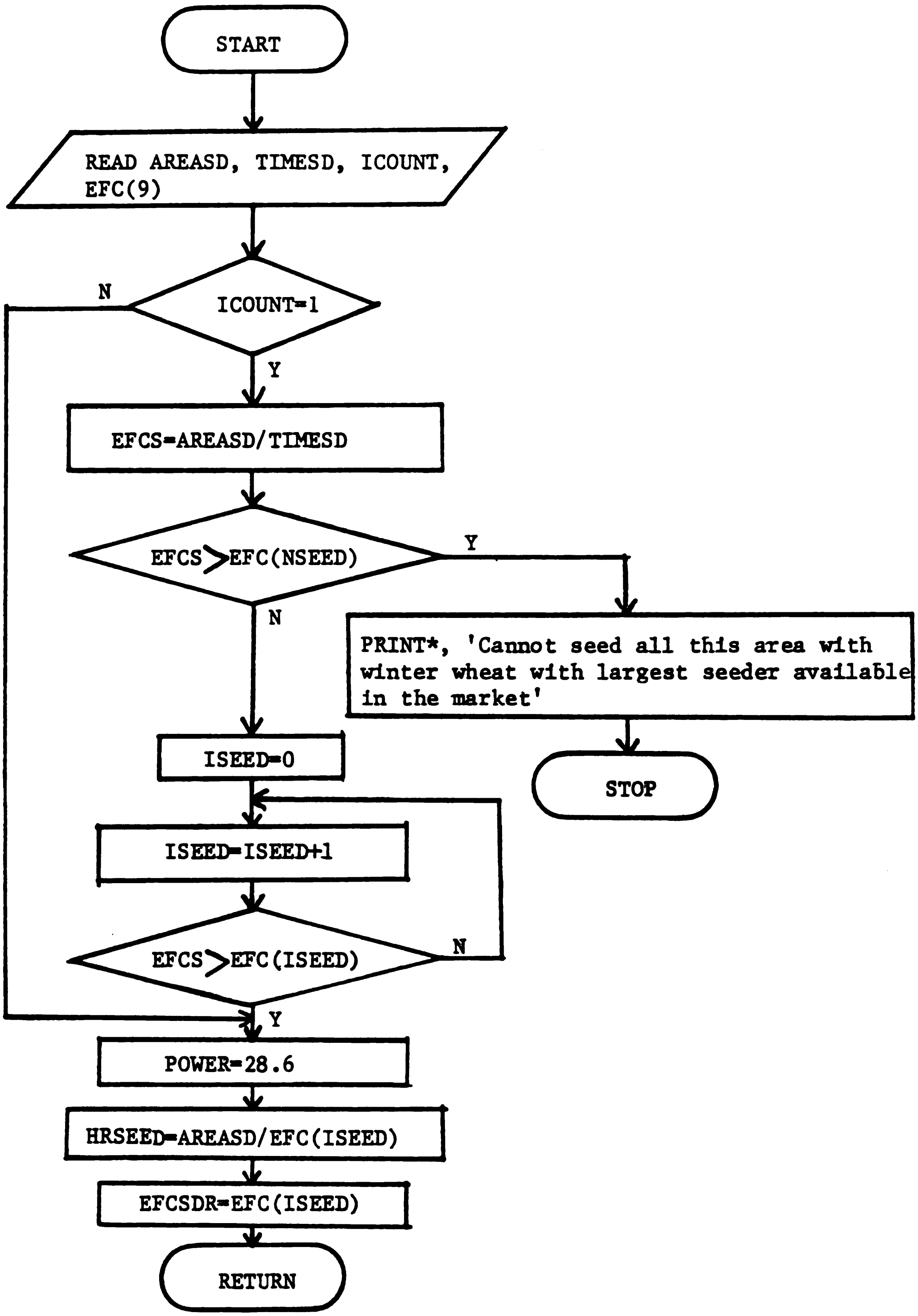

Figure 4.21. Flowchart for subroutine SDR2.

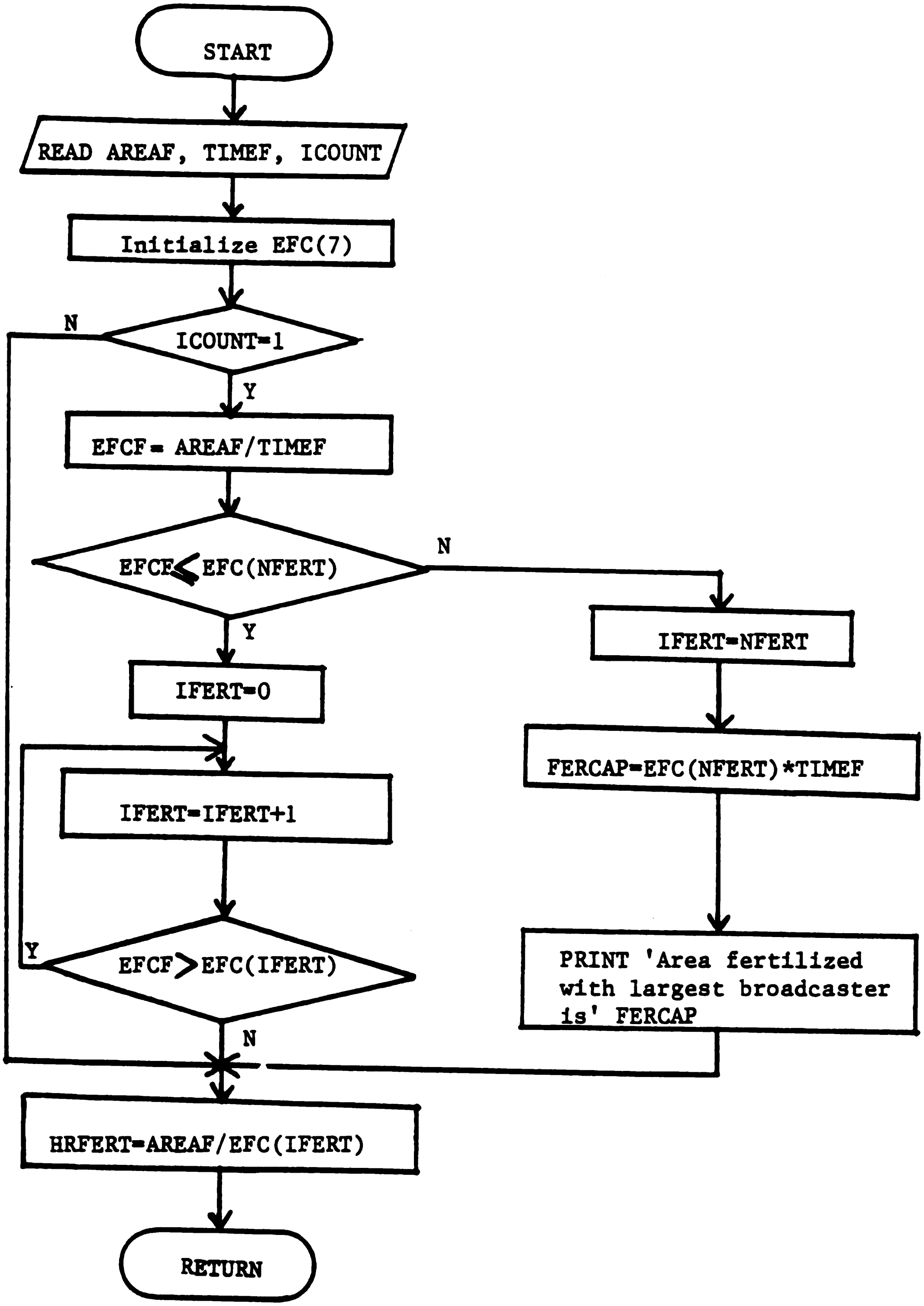

Figure 4.22. Flowchart for subroutine FERTIL.

A flowchart for subroutine SPRAYR is presented in Figure 4.23.

4.2.9. Subroutine COST

The total present value cost of a machinery system is calculated, using the cash flow method proposed by Rotz et al. (1981), by subroutine COST in accordance with the algorithm depicted in Figure 4.24.

Five components make up the total cost of a machinery system. They are the fuel and lubrication cost, labor cost, timeliness cost, repairs/maintenance and shelter cost, and the ownership cost. Only repairs/maintenance and shelter and ownership costs are calculated for all machines in a system. Fuel costs are calculated only for machines with an engine. Labor costs are calculated only for the tractor, grain seeder and combine. As suggested by researchers in Chile and because of the lack of good data on timeliness losses for other operations, timeliness costs are calculated only for plowing, seeding and harvesting.

Subroutine COST is called first to determine the cost of the minimum size machinery system. During the system size incrementation process subroutine COST is called each time a machine size is increased in order to establish the cost of the new system. Following this procedure the model is able to determine the minimum size system with its cost and the three lowest cost machinery systems.

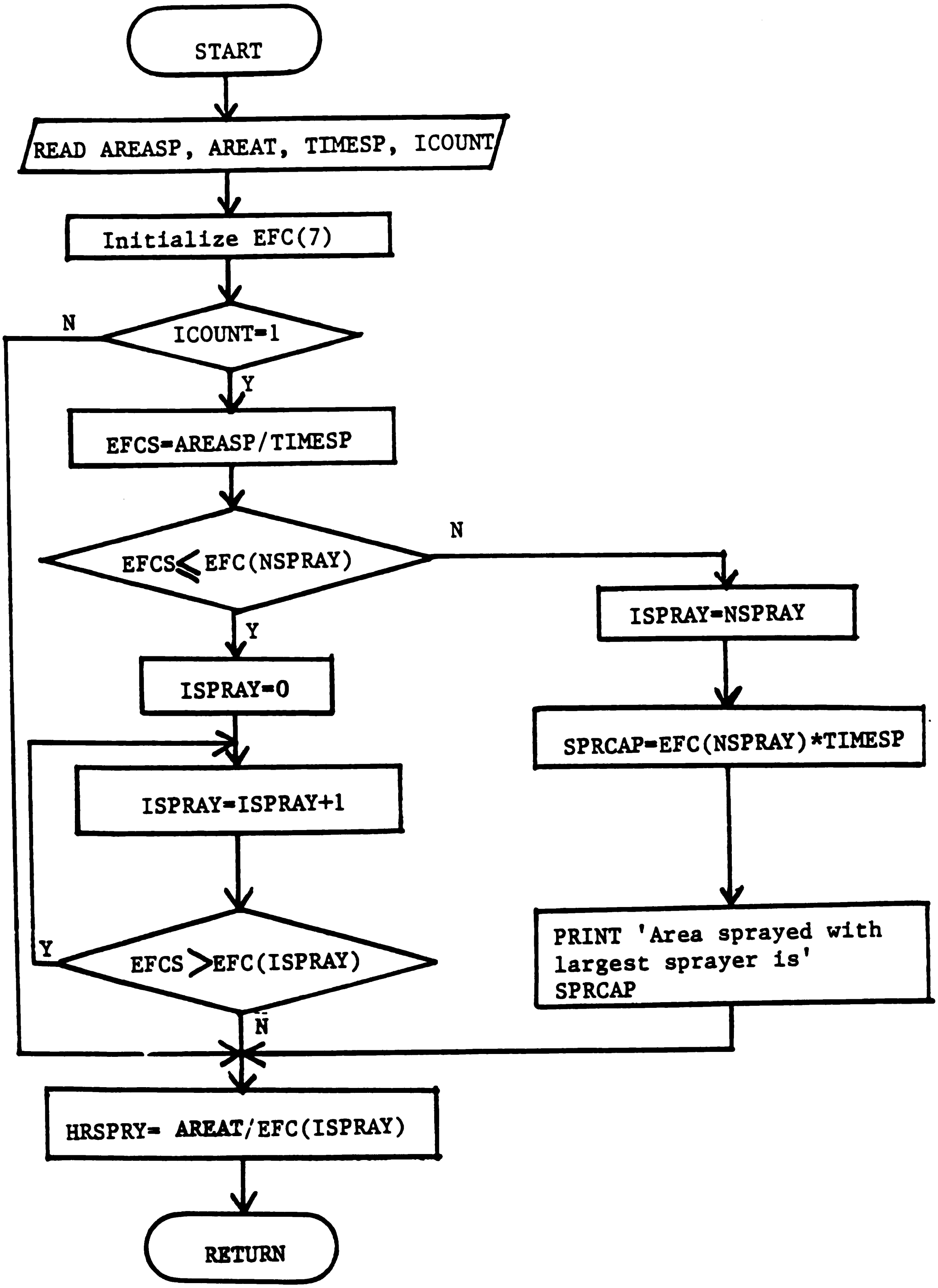

Figure 4.23. Flowchart for subroutine SPRAYR.

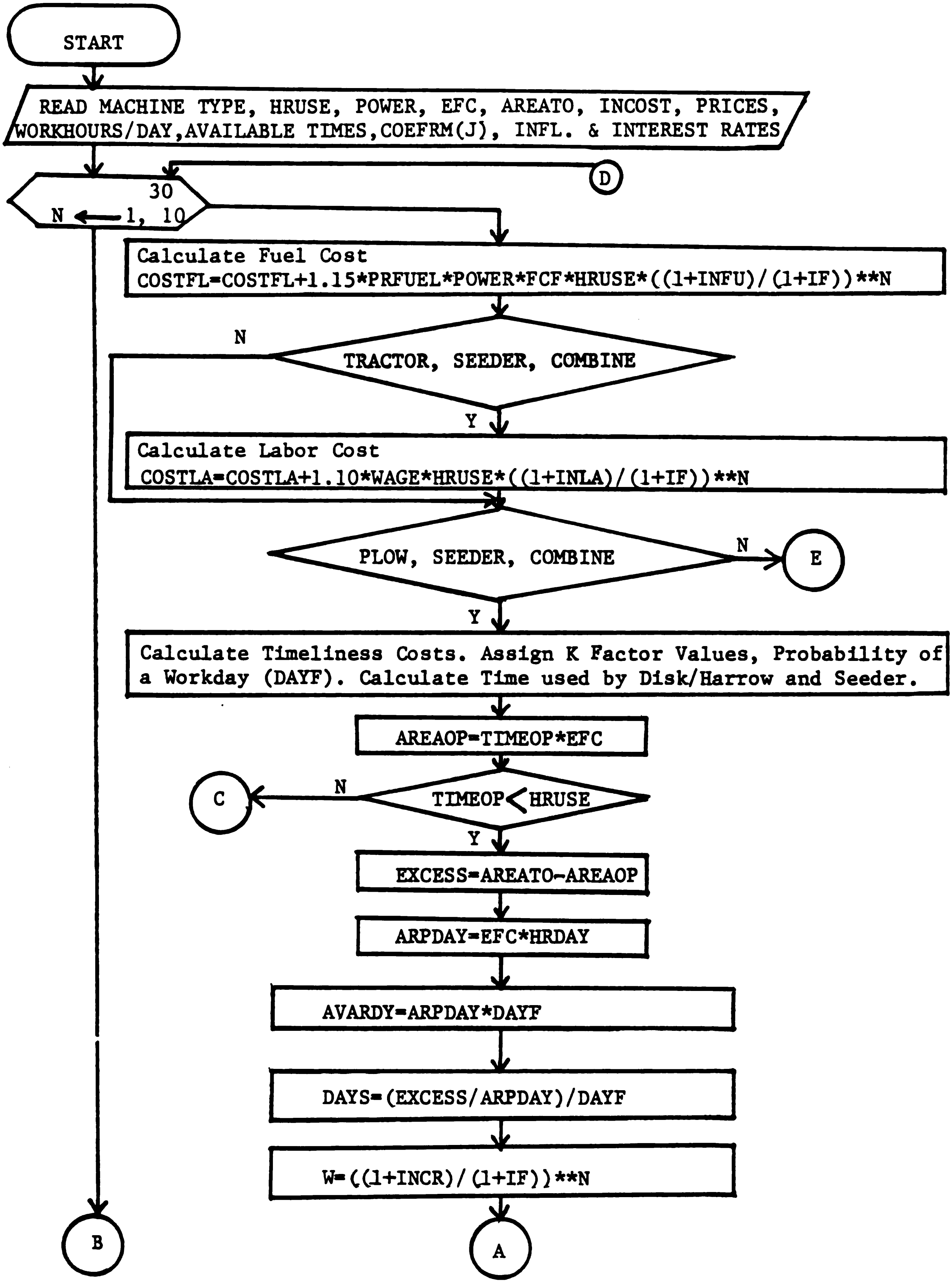

Figure 4.24. Flowchart for subroutine COST.

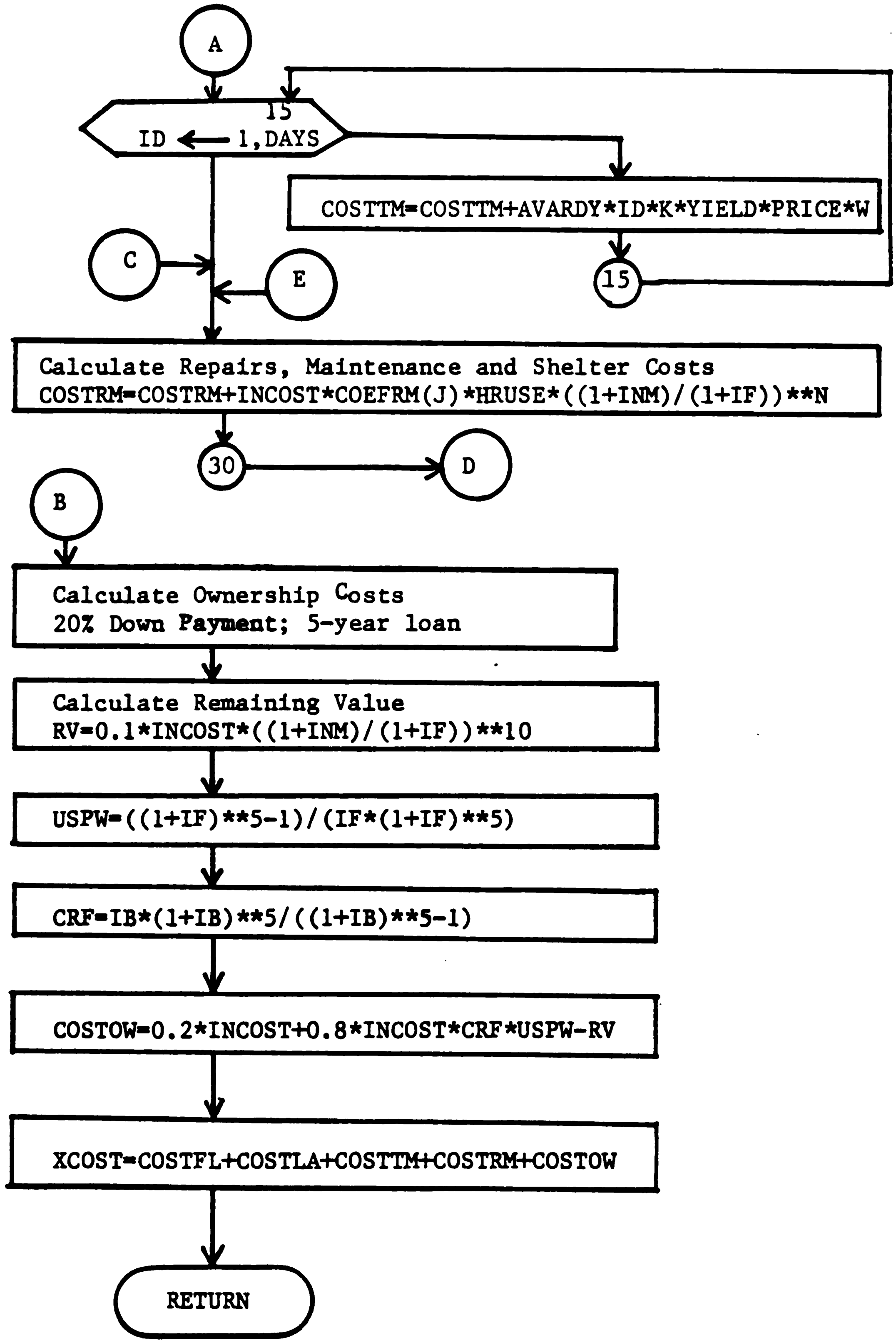

Figure 4.24. (Cont'd.).

5. MODEL VALIDATION

One important step in modeling is to establish how well the model represents the actual system under study, which is referred to as model validation.

Validation is generally thought of as a two phase process: a) verification of the model being the process by which the programming logic is compared with our intentions--that is, the programming logic of the model should accurately do what we intended for it to do (Loewer et al., 1980); and b) the model validation phase during which the model assessed in relation to its prescribed use; this could involve comparing the performance of the model either against recorded data for the system or against a subjective judgement of what the output should be, given a broad understanding of the system which the model represents (Dent and Blackie, 1979). Thus, a model is verified in relation to absolute truth, whereas the model is validated in relation with the purpose for which it was constructed.

The model verification procedure followed here consisted of testing all the subroutines, previous to their final assembly, in order to detect and correct all anomalies and errors in sintax and program logic. During the validation process data collected in Chile through the farmers' survey, relating to available working days and machinery systems, were used to analyze the model behavior.

5.1. Available Field Working Days

Original results from the farmers' survey, concerning available field working days, are presented in Table 5.1. Considering that tillage and seeding in the fall and spring are the most critically time constrained operations, of which farmers are aware, farmers and machinery operators were asked during the survey to estimate the average number of days suitable for soil engaging operations by half-month periods, between April 1 and September 30.

The results show that there seems to be a continuous deterioration of the weather conditions from April to July, with the later part of that period being the worse, and from then on a continuous improvement on the weather conditions related to soil engaging operations.

The method proposed by Fulton et al. (1976), was used to allocate the number of working days in the half-month periods to the adjacent biweekly climatic periods which are used in the computer model, and thus be able to compare the farmers' survey results with the computer prediction.

Table 5.2 depicts a comparison between the results of the farmers' survey and the computer output at the 0.50, 0.60, 0.70, 0.80, and 0.90 design probability levels. The opinions of the surveyed farmers were matched most closely by the 0.70 probability level. This shift can be interpreted in the context of the conservative nature of farmers the world over, their innate desire to reduce risks, short term records versus human memory and the model's suitable day criteria being slightly off target. For 10 of the 12 biweekly periods the 0.70 design probability values are found to be within 10% of the farmers' estimates, with a correlation coefficient $r = 0.91$.

TABLE 5.1. Expected number of days suitable for soil engaging operations, in eastern Nuble province, Chile. Farmers' Survey Results.

Respondent No.	APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
	1-15	16-30	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30
1	15	15	12	12	8	8	6	6	6	8	8	8
2	10	10	10	8	8	6	6	5	8	10	12	12
3	14	13	12	10	10	8	10	10	10	11	11	12
4	15	12	7	6	6	6	8	10	10	12	12	12
5	12	12	8	6	6	5	5	5	6	10	10	10
6	11	11	9	5	7	7	7	7	9	9	9	12
7	12	9	8	7	7	5	4	4	8	10	10	12
8	13	13	9	8	8	8	7	7	9	9	9	11
9	15	15	13	8	5	4	4	4	6	8	10	12
10	13	12	10	10	7	6	8	8	10	10	11	11
11	12	12	7	7	6	4	4	3	7	10	12	11
12	13	13	9	7	7	7	7	7	9	9	9	11
13	13	10	8	7	7	7	5	4	8	11	11	12
14	12	11	8	5	5	5	5	5	5	8	8	11
15	11	10	10	5	5	5	5	5	7	8	10	10
16	10	10	10	10	8	8	8	8	8	10	10	10
17	10	10	10	8	5	5	5	5	8	8	10	12
18	13	13	9	6	8	7	7	7	9	9	9	11
19	12	11	9	6	7	7	7	7	9	10	10	12
20	13	11	8	6	6	6	6	4	6	11	11	12
21	12	12	10	10	10	10	10	8	8	10	10	12
22	11	11	7	7	7	7	7	7	6	8	8	11
23	12	10	9	8	6	5	4	4	4	8	10	12
24	13	11	8	6	6	6	6	6	6	11	11	12
25	11	11	10	8	6	6	6	6	10	10	12	12
$\overline{X}$	12.3	11.5	9.2	7.4	6.8	6.3	6.3	6.1	7.7	9.5	10.1	11.4
S	1.5	1.5	1.6	1.8	1.4	1.4	1.7	1.8	1.7	1.2	1.2	1.0

TABLE 5.2. Farmers' survey and computer model results for expected number of days suitable for soil engaging operations, in eastern Nuble province, Chile.

Climatic Biweekly Period	Farmers' Survey	Model results at indicated probability level				
		0.50	0.60	0.70	0.80	0.90
March 29 - April 11	----	13.1	12.7	12.2	11.6	10.6
April 12-25	10.9	11.6	10.9	10.3	9.6	8.6
April 26 - May	9.4	11.2	10.5	9.4	8.1	4.8
May 10-23	7.6	7.0	6.1	5.5	4.8	3.8
May 24 - June 6	6.7	8.2	7.6	6.9	5.1	0.8
June 7-20	6.2	7.4	6.9	6.3	5.1	3.1
June 21 - July 4	5.9	6.8	6.2	5.6	5.0	2.6
July 5-18	5.8	8.1	7.6	6.9	5.6	3.8
July 19 - August 1	5.7	8.0	7.1	5.9	4.6	1.8
August 2-15	7.2	9.1	8.1	7.5	6.4	3.5
August 16-29	8.9	11.2	10.5	9.4	7.6	6.4
August 30 - Sept. 12	9.4	11.0	10.1	9.0	8.1	6.8
September 13-26	10.4	12.3	11.7	11.1	10.3	6.6
September 27 - Oct. 10	----	10.4	9.7	9.0	8.2	7.4
Number of periods within 10% of survey results		2	4	10	2	0

The discrepancy that exists in the other two periods may be due to the transfer of values from the original half-month periods of the survey to the biweekly periods of the model, and to the fact that while the farmers think there is a continuous seasonal deterioration and improvement of the weather conditions, the model is more sensitive to changes in the actual precipitation pattern and soil moisture conditions responding accordingly, i.e. May 24 - June 6 and July 5 - July 18 periods.

Considering the values presented in Table 5.2 indication of an acceptable behavior by the weather model, other results were obtained using program WEATHR. These results are presented in Tables 5.3 through 5.8, and they provide expected number of suitable days for soil engaging, above ground, and cereal harvesting operations.

It should be noted that the probability estimates are not additive over periods longer than one week. Multiweek periods with each having a high number of suitable days, or with each having only a few suitable days, do not usually occur in the same year. Consequently, the total number of suitable days at a low probability level, below the median for example, will be smaller for a multiweek period than the sum of the number of days expected for individual weeks. Conversely, the total number of suitable days at a probability of 0.90 will be greater for a multiweek period than the sum of the number of days expected for the individual weeks.

Estimates by weeks and biweekly periods are presented in order to provide farmers, custom operators, researchers, extension personnel, and enterprises serving agriculture with the only data on suitable days available in Chile now, which may help them organize and plan their activities.

TABLE 5.3. Expected number of days per week suitable for soil engaging operations in eastern Nuble province, Chile.

Climatic Week No.	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-7	6.8	6.6	6.3	6.1	5.9
2	March 8-14	6.5	6.3	6.1	5.6	5.1
3	March 15-21	6.8	6.6	6.3	6.1	4.6
4	March 22-28	6.6	6.4	6.2	6.0	5.7
5	March 29 - April 4	6.7	6.5	6.2	6.0	5.3
6	April 5-11	6.5	6.2	5.8	5.0	3.8
7	April 12-18	6.1	5.7	5.3	4.8	3.8
8	April 19-25	5.9	5.3	4.8	4.2	2.8
9	April 26 - May 2	6.2	5.7	5.1	4.1	2.8
10	May 3-9	5.8	5.1	3.4	1.8	0.9
11	May 10-16	4.5	3.7	3.1	2.4	1.1
12	May 17-23	3.0	2.4	1.8	1.2	0.6
13	May 24-30	2.9	2.5	2.1	1.5	0.8
14	May 31 - June 6	5.4	4.6	3.7	2.6	0.4
15	June 7-13	3.8	2.9	1.9	0.8	0.0
16	June 14-20	4.1	3.5	2.8	2.2	1.6
17	June 21-27	3.2	2.6	2.1	1.3	0.2
18	June 28 - July 4	4.3	3.4	2.3	1.3	0.4
19	July 5-11	4.4	3.6	2.8	2.2	0.8
20	July 12-18	3.5	3.2	2.8	2.0	1.3
21	July 19-25	3.7	3.2	2.1	1.7	0.5
22	July 26 - Aug. 1	3.8	2.9	1.9	0.8	0.0
23	August 2-8	3.9	3.3	2.8	2.2	1.4
24	August 9-15	5.0	4.4	3.8	3.0	0.5
25	August 16-22	5.1	4.6	4.1	3.4	2.1
26	August 23-29	6.2	5.8	5.3	4.1	2.1

TABLE 5.3. (Continued)

Climatic Week No.	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
27	Aug. 30 - Sept. 5	5.4	5.0	4.5	3.8	2.8
28	September 6-12	5.1	4.7	4.4	4.0	3.3
29	September 13-19	5.9	5.4	5.0	4.1	2.6
30	September 20-26	6.5	6.2	6.0	5.2	3.6
31	Sept. 27 - Oct. 3	5.1	4.7	4.2	3.5	2.5
32	October 4-10	5.7	5.3	4.8	4.2	2.8
33	October 11-17	6.4	6.0	5.5	4.9	4.3
34	October 18-24	6.3	6.0	5.8	5.2	4.7
35	October 25-31	5.9	5.6	5.3	4.8	4.1
36	November 1-7	6.4	6.2	5.8	5.3	4.1
37	November 8-14	6.5	6.3	6.0	5.8	5.6
38	November 15-21	6.3	6.0	5.2	3.7	2.1
39	November 22-28	6.5	6.3	6.1	5.2	4.2
40	Nov. 29 - Dec. 5	6.4	6.2	5.9	5.4	5.0
41	December 6-12	6.5	6.2	5.7	4.7	3.1
42	December 13-19	6.6	6.3	6.1	5.7	5.2
43	December 20-26	6.7	6.5	6.2	6.0	5.3
44	Dec. 27 - Jan. 2	6.6	6.4	6.1	5.7	5.1
45	January 3-9	6.9	6.7	6.5	6.2	6.0
46	January 10-16	6.8	6.5	6.3	6.1	5.4
47	January 17-23	6.7	6.5	6.3	6.0	4.8
48	January 24-30	6.8	6.5	6.3	6.1	5.4
49	Jan. 31 - Feb. 6	6.9	6.7	6.5	6.2	6.0
50	February 7-13	6.5	6.3	6.1	5.6	5.1
51	February 14-20	6.7	6.5	6.3	6.1	5.9
52	February 21-27	6.9	6.5	6.0	5.6	5.2

TABLE 5.4. Expected number of days per biweekly period suitable for soil engaging operations in eastern Nuble province, Chile.

Climatic Bi-weekly Period	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-14	13.3	13.0	12.7	12.4	12.1
2	March 15-28	13.4	13.2	12.8	12.3	10.6
3	Mar. 29 - Apr. 11	13.1	12.7	12.2	11.6	10.6
4	April 12-25	11.6	10.9	10.3	9.6	8.6
5	Apr. 26 - May 9	11.2	10.5	9.4	8.1	4.8
6	May 10-23	7.0	6.1	5.5	4.8	3.8
7	May 24 - June 6	8.2	7.6	6.9	5.1	0.8
8	June 7-20	7.4	6.9	6.3	5.1	3.1
9	June 21 - July 4	6.8	6.2	5.6	5.0	2.6
10	July 5-18	8.1	7.6	6.9	5.6	3.8
11	July 19 - Aug. 1	8.0	7.1	5.9	4.6	1.8
12	August 2-15	9.1	8.1	7.5	6.4	3.5
13	August 16-29	11.2	10.5	9.4	7.6	6.4
14	Aug. 30 - Sept. 12	11.0	10.1	9.0	8.1	6.8
15	September 13-26	12.3	11.7	11.1	10.3	6.6
16	Sept. 27 - Oct. 10	10.4	9.7	9.0	8.2	7.4
17	October 11-24	12.4	11.9	11.5	11.1	10.4
18	Oct. 25 - Nov. 7	12.3	11.9	11.4	10.6	8.8
19	November 8-21	12.7	12.2	11.5	10.1	8.5
20	Nov. 22 - Dec. 5	13.0	12.6	12.2	11.3	9.8
21	December 6-19	12.9	12.3	11.8	11.2	9.8
22	Dec. 20 - Jan. 2	13.4	13.1	12.6	12.0	11.2
23	January 3-16	13.7	13.4	13.2	12.8	12.1
24	January 17-30	13.5	13.2	13.0	12.2	11.2
25	Jan. 31 - Feb.13	13.5	13.2	13.0	12.5	11.8
26	February 14-27	13.7	13.5	13.2	13.0	11.6

TABLE 5.5. Expected number of days per week suitable for above ground operations in eastern Nuble province, Chile.

Climatic Week No.	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-7	6.8	6.6	6.3	6.1	5.9
2	March 8-14	6.5	6.3	6.1	5.6	5.1
3	March 15-21	6.8	6.6	6.3	6.1	4.8
4	March 22-28	6.6	6.4	6.2	6.0	5.8
5	Mar. 29 - Apr. 4	6.8	6.5	6.3	6.1	5.4
6	April 5-11	6.5	6.2	5.8	5.0	3.8
7	April 12-18	6.2	5.8	5.4	4.8	4.1
8	April 19-25	6.0	5.5	5.0	4.4	3.1
9	April 26 - May 2	6.2	5.9	5.4	4.7	3.1
10	May 3-9	6.0	5.1	4.2	3.5	2.9
11	May 10-16	5.3	4.8	4.3	3.6	2.6
12	May 17-23	4.5	3.9	3.0	2.1	1.2
13	May 24-30	4.4	3.9	3.5	3.0	1.0
14	May 31 - June 6	6.0	5.4	4.6	3.3	1.8
15	June 7-13	4.1	3.6	3.0	2.1	1.2
16	June 14-20	4.8	4.4	4.0	3.5	2.9
17	June 21-27	4.2	3.6	3.0	2.5	1.9
18	June 28 - July 4	5.0	4.3	3.7	3.3	2.8
19	July 5-11	5.1	4.6	4.1	3.3	1.6
20	July 12-18	4.5	4.3	3.9	2.7	1.5
21	July 19-25	4.3	3.8	3.3	2.4	1.2
22	July 26 - Aug.1	4.3	3.6	2.8	2.0	0.6
23	August 2-8	4.7	4.2	3.7	3.2	2.4
24	August 9-15	5.1	4.6	4.1	3.3	0.6
25	August 16-22	5.1	4.7	4.2	3.6	2.8
26	August 23-29	6.2	5.8	5.3	4.1	2.1

TABLE 5.5. (Continued)

Climatic Week No.	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
27	Aug. 30 - Sept.5	5.5	5.1	4.7	4.2	3.4
28	September 6-12	5.3	4.9	4.5	4.1	3.4
29	September 13-19	6.0	5.6	5.1	4.4	2.6
30	September 20-26	6.5	6.3	6.1	5.5	4.4
31	Sept. 27 - Oct.3	5.4	5.0	4.5	3.7	2.5
32	October 4-10	5.8	5.4	5.0	4.4	3.1
33	October 11-17	6.4	6.1	5.6	5.0	4.3
34	October 18-24	6.4	6.2	5.9	5.4	5.0
35	October 25-31	5.9	5.6	5.3	5.0	4.3
36	November 1-7	6.5	6.2	6.0	5.4	4.5
37	November 8-14	6.5	6.3	6.1	5.9	5.7
38	November 15-21	6.3	6.0	5.2	4.1	2.6
39	November 22-28	6.5	6.3	6.1	5.2	4.2
40	Nov. 29 - Dec. 5	6.4	6.2	5.9	5.4	5.0
41	December 6-12	6.5	6.3	5.9	4.7	3.1
42	December 13-19	6.6	6.3	6.1	5.7	5.2
43	December 20-26	6.7	6.5	6.3	6.1	5.9
44	Dec.27 - Jan. 2	6.6	6.4	6.2	5.9	5.3
45	January 3-9	6.9	6.7	6.5	6.2	6.0
46	January 10-16	6.8	6.5	6.3	6.1	5.4
47	January 17-23	6.7	6.5	6.3	6.0	4.8
48	January 24-30	6.8	6.6	6.4	6.1	5.5
49	Jan. 31 - Feb. 6	6.9	6.7	6.5	6.2	6.0
50	February 7-13	6.5	6.3	6.1	5.6	5.1
51	February 14-20	6.7	6.5	6.3	6.1	5.9
52	February 21-27	6.9	6.5	6.0	5.6	5.2

TABLE 5.6. Expected number of days per biweekly period suitable for above ground operations in eastern Nuble province, Chile.

Climatic Biweekly Period	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-14	13.3	13.0	12.7	12.4	12.1
2	March 15-28	13.4	13.2	12.8	12.3	11.5
3	Mar. 29 - Apr.11	13.2	12.8	12.3	11.6	10.6
4	April 12-25	11.9	11.3	10.8	10.0	8.6
5	April 26 - May 9	11.6	10.9	10.3	9.6	8.1
6	May 10-23	9.1	8.6	8.1	6.7	5.1
7	May 24 - June 6	10.5	9.7	7.9	6.6	4.1
8	June 7-20	8.6	8.1	7.5	6.8	5.8
9	June 21 - July 4	9.0	7.9	7.0	6.4	5.8
10	July 5-18	9.8	9.1	8.4	6.8	4.8
11	July 19 - Aug. 1	8.5	7.7	6.9	5.1	4.2
12	August 2-15	10.0	9.4	8.7	7.6	4.6
13	August 16-29	11.3	10.7	9.9	8.1	6.3
14	Aug. 30 - Sept.12	11.1	10.5	9.6	8.6	7.5
15	September 13-26	12.4	11.9	11.4	10.4	7.5
16	Sept. 27 - Oct.10	10.8	10.1	9.4	8.6	7.5
17	October 11-24	12.7	12.3	11.8	11.3	10.5
18	Oct. 25 - Nov. 7	12.4	12.0	11.5	11.0	9.6
19	November 8-21	12.8	12.3	11.7	10.6	8.8
20	Nov. 22 - Dec. 5	13.0	12.6	12.2	11.3	9.8
21	December 6-19	13.0	12.5	12.0	11.2	9.8
22	Dec. 20 - Jan. 2	13.4	13.1	12.7	12.3	11.8
23	January 3-16	13.7	13.4	13.2	12.8	12.1
24	January 17-30	13.6	13.3	13.1	12.3	11.2
25	Jan. 31 - Feb.13	13.5	13.2	13.0	12.5	11.8
26	February 14-27	13.7	13.5	13.2	13.0	11.6

TABLE 5.7. Expected number of days per week suitable for cereal harvesting operations in eastern Nuble province, Chile.

Climatic Week No.	Date	Probability level 0.60	0.70	0.80	0.90
1	December 20-26	6.2	5.8	5.0	4.1
2	Dec. 27 - Jan. 2	5.6	5.0	4.5	3.9
3	January 3-9	6.4	6.2	5.8	5.1
4	January 10-16	6.3	6.0	5.0	4.1
5	January 17-23	6.4	6.1	5.3	2.4
6	January 24-30	6.2	5.8	5.4	4.9
7	Jan. 31 - Feb. 6	6.5	6.3	6.1	5.1
8	February 7-13	6.1	5.3	4.3	3.1

TABLE 5.8. Expected number of days per biweekly period suitable for cereal harvesting operations in eastern Nuble province, Chile.

Climatic Biweekly Period	Date	Probability level 0.60	0.70	0.80	0.90
1	Dec. 20 - Jan. 2	11.9	11.1	10.4	8.9
2	January 3-16	12.5	11.9	11.4	10.9
3	January 17-30	13.2	12.7	11.2	7.9
4	Jan. 31 - Feb. 13	12.9	12.2	10.5	8.7

Figure 5.1 depicts a comparison between the expected number of field workdays for above ground, soil engaging and cereal harvesting operations, at the 0.80 design probability level. The values for soil engaging and above ground operations follow very closely the opposite trend of the rainfall distribution, which was shown in Figure 3.1. Figure 5.1 also shows that, in general, there is a fairly large span of time available for fieldwork, except in the period between May 10 (week No. 11) and August 1 (week No. 22), in which the probability of a good field working day falls below 0.50. This fact should be carefully considered when planning agricultural operations which are to be performed during this period.

Finally, two important anomalies in the results concerning expected number of fieldwork days should be pointed out and analyzed. They relate to the available days in climatic week 14 (May 31 - June 6) shown in Table 5.3 and climatic biweekly period 15 (September 13-26), shown in Table 5.4 and Figure 5.1. Both of these periods are expected to have substantially more days suitable for fieldwork than both the previous or following periods.

Clarification of these anomalies was intended by going back to the daily weather records and examining the precipitation data for each period. The results of this revision are presented in Table 5.9.

The values shown in Table 5.9 indicate that the periods with higher expected number of workdays do indeed have significantly lower amounts of rainfall, which translates into more time available for fieldwork. Of particular importance is climatic week 14 (May 31 - June 6), which is located in the middle of the period recommended as adequate for seeding winter cereals and lentils, and the farmers should plan their activities accordingly.

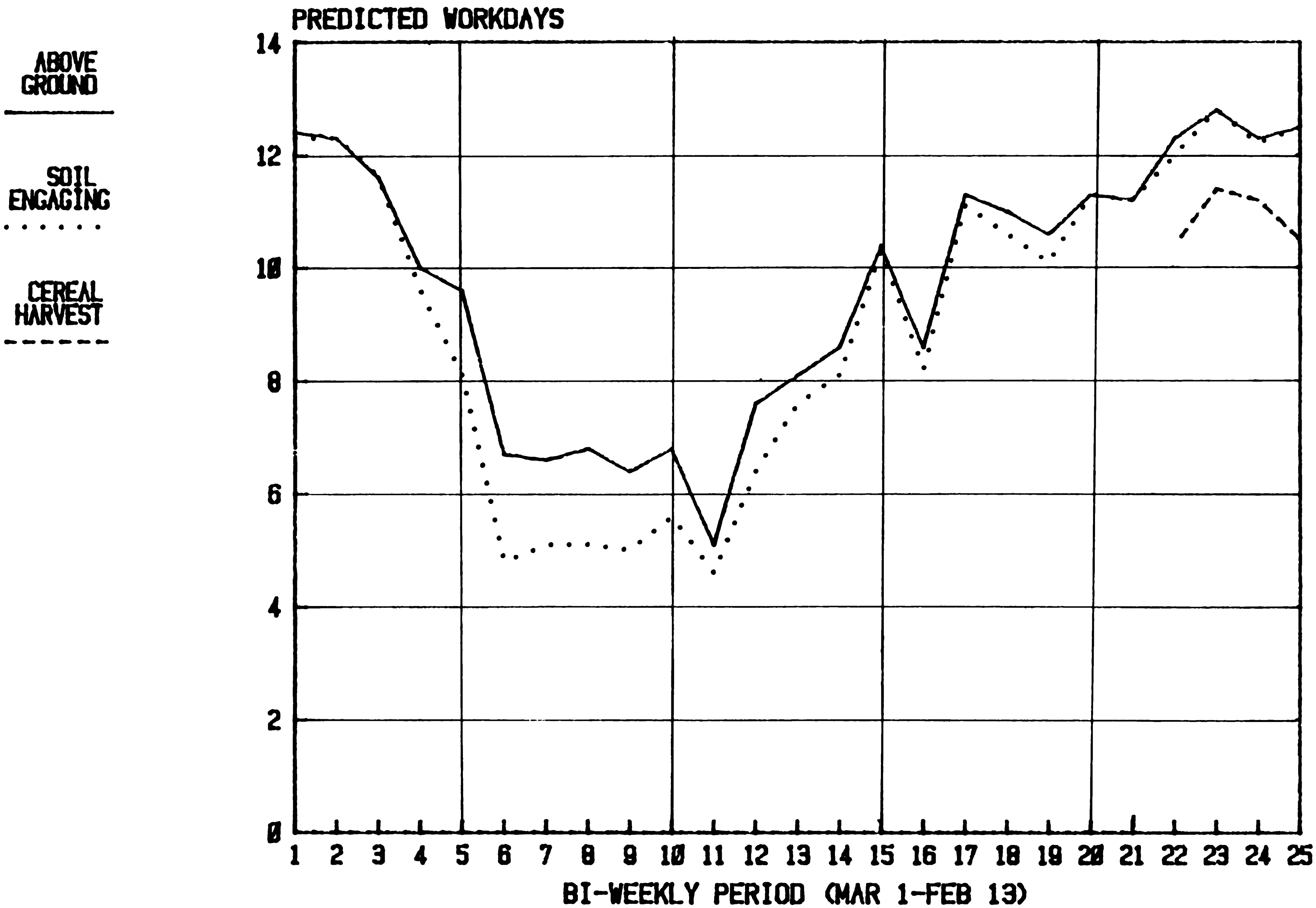

Figure 5.1. Expected number of field workdays at the 0.80 probability level.

TABLE 5.9. Effect of the Precipitation Pattern upon the Expected Number of Workdays in two Contiguous Periods. Probability Level = 0.70

	Expected Number of Workdays and Mean Rainfall for Climatic Periods:		
	May 24-30	May 31-June 6	June 7-13
Expected Workdays	2.1	3.7	1.9
Mean Rainfall (mm)	51.5	24.2	55.1
	Aug 30-Sept 12	September 13-26	Sept 27-Oct 10
Expected Workdays	9.0	11.1	9.0
Mean Rainfall (mm)	39.6	27.6	36.1

5.2. Farm Survey of Machinery Systems and Model Results

Twenty farmers were randomly selected among the ones actively participating in the Technology Transfer Program being carried out by I.N.I.A. The only condition was that they owned at least one tractor.

A summary of the survey results, concerning tractor characteristics, is presented in Table 5.10 and it shows a very diversified and aging agricultural machinery system in much need of replacement. The average tractor age is 10.5 years, with 11 makes imported from seven countries being represented. The power range goes from 37.3 to 73.1 PTO-kW (50 to 98 PTO-HP). The mean tractor PTO power is 50.2 kW with a standard deviation of 8.5 kW (67.5 and 11.3HP, respectively).

Average power per unit cultivated area was found to be 0.55

TABLE 5.10. Average Yearly Seeded Area and Power Source Characteristics. Farmers' Survey Results.

Farm No.	$\bar{X}$ Seeded Area (ha)	No. of Tractors	Make	Year	PTO-Power kW	PTO-Power HP	Power/Seeded Area kW/ha	Power/Seeded Area HP/ha
1	58	1	John Deere-2130	1975	50.7	68	0.87*	1.16
2	70	1	Fordson Major	1962	37.3	50	0.53	0.71
3	78	1	Universal-650 M	1972	48.5	65	0.62	0.83
4	86	1	Nuffield-465	1958	44.7	60	0.52	0.70
5	86	1	Fordson Major	1958	37.3	50	0.43	0.57
6	92	1	Ford-5000	1976	52.9	71	0.56	0.75
7	103	1	John Deere 2130	1974	50.7	68	0.49	0.66
8	108	1	Belaruz MTZ-50	1972	52.2	70	0.48	0.64
9	109	1	Belaruz MTZ-50	1972	52.2	70	0.48	0.64
10	109	1	Belaruz MTZ-50	1972	52.2	70	0.48	0.64
11	121	1	Ford-5000	1970	52.9	71	0.44	0.59
12	150	2	IH-624	1970	41.7	56		
			IH-WD6	1960	37.3	50		
					74.0	106	0.53	0.71
13	150	2	Ford-5000	1977	52.9	71		
			Nuffield-465	1969	44.7	60		
					97.6	131	0.64	0.85
14	156	2	David Brown	1978	52.2	70		
			Belaruz MTZ-50	1972	52.2	70		
					104.4	140	0.67	0.89
15	164	1	IH-656	1969	56.7	76	0.35**	0.47

TABLE 5.10. (Continued)

Farm No.	$\bar{X}$ Seeded Area (ha)	No. of Tractors	Make	Year	PTO-Power kW	PTO-Power HP	Power/Seeded Area kW/ha	Power/Seeded Area HP/ha
16	170	2	Massey Ferguson 1075	1978	55.9	75		
			Belaruz MTZ-50	1972	52.2	70		
					108.1	145	0.64	0.85
17	225	2	Fiat-750	1980	55.9	75		
			Fordson Major	1968	43.3	58		
					99.3	133	0.44	0.59
18	242	3	IH-624	1970	41.7	56		
			ZT-300	1973	73.1	98		
			Nuffield-465	1960	44.7	60		
					159.5	214	0.66	0.88
19	250	3	Belaruz MTZ-50	1971	52.2	70		
			Ford-5000	1972	52.9	71		
			Fordson Major	1960	37.3	50		
					142.4	191	0.57	0.76
20	550	5	John Deere-2420	1974	55.9	75		
			John Deere-2420	1974	55.9	75		
			Ford-5000	1975	52.9	71		
			ZT-300	1973	73.1	98		
			IH-624	1970	41.7	56		
					279.5	375	0.51	0.68

*This person is also a merchant and has reduced considerably his agricultural activity since 1978.

**Co-operative use.

kW/ha (0.73 HP/ha), which is far above the country's average of about 0.30 kW/ha (Ibanez et al., 1979), and falls in the upper part of the range proposed by Giles (1967), of 0.5 to 0.8 HP/ha, as the minimum power necessary to obtain respectable yields.

Sixty percent of the farmers report owning one tractor and seeding 121 hectares or less per year, with the exception of one tractor owned in a co-operative fashion that reportedly works 164 hectares per year. Twenty five percent of the farmers own two tractors and seed up to 225 hectares per year. Only 15% of the farmers own three or more tractors seeding between 242 and 550 hectares per year.

A very good correlation (r = 0.95) was found between the yearly seeded area and the total power available on the farm. Equation 5.1 can be used to predict the power required in relation with the proposed yearly seeded area, based upon the results from the farmers' survey.

$$Y(kW) = 9.999 + 0.489 \times \text{Seeded hectares} \qquad (5.1)$$

No acceptable correlation (r = 0.08) was found between the total seeded area and the power available per hectare. This fact seems to indicate a lack of sound management practices among the surveyed farmers.

The presence of other machines needed to produce wheat and other small grain cereals, among the surveyed farmers, is reported in Table 5.11.

Only 65% of the surveyed farmers reported owning a fertilizer broadcaster and a combine harvester. This low percentage can be explained, in the case of the fertilizer broadcaster by the fact that many small farmers apply the nitrogen by hand broadcasting. The low overall percentage of combine harvesters reported seems to be caused by the lack of combine ownership among farmers seeding less than around 100 hectares per year. This situation agrees well with the model prediction which establishes a lower cost for custom harvest than for combine ownership for areas smaller than about 125 hectares, depending upon the risk factor assigned to the custom harvest.

TABLE 5.11. Percent of Wheat Producers Reporting Use of Different Machines. Farmers' Survey Results.

Machine	Percent of Farmers
Disk plow	95
Off-set disk harrow	95
Spike-tooth harrow	90
Grain seeder	90
Fertilizer broadcaster	65
Field sprayer	70
Combine harvester	65
Transport wagon	80

A comparison between the machinery systems reported (SR) at 18 farms and the model results (MR) for the same farms including the rotation being used, is depicted in Table 5.12. Farms number one (1) and 20 of Table 5.10 were not used in this comparison because they are not wholly representative of the wheat producers addressed by program TRIGO.

This comparison is intended as a validation of the model, although several factors work against a close correlation of survey and simulated results. Most of the machinery reported in the survey was acquired between seven to 10 years ago, when the decision of what and how much to buy was overwhelmingly done on the basis of purchase price and the availability of subsidized lines of credit with the government. Therefore, during that period many farmers bought machinery without giving a great deal of thought to their real needs.

TABLE 5.12. Comparison of Farmers' Machinery Systems and Model Results.*

Farm No.	Area (ha) O	W	L	(@)	Power (kW)	Plow Dsk	(m)	Disk.Harr. Dsk	(m)	Harr. (m)	Seeder Rws	(m)	Ferti-lizer (m)	Sprayer Nozz.	(m)	Combine (ft)	(m)	Wgn (T)
2	12	55	3	MR	32.1	3	0.72	6	1.37	np	14	2.49	10	14	7	12	3.65	4.0
				SR	37.3	3	0.72	7	1.61	4	13	2.31	np	np		np		np
3	0	78	0	MR	32.1	3	0.72	6	1.37	np	15	2.67	10	16	8	12	3.65	4.0
				SR	48.5	4	0.96	8	1.83	np	12	2.13	np	np		np		4.0
4	36	50	0	MR	32.1	3	0.72	6	1.37	np	17	3.02	11	16	8	12	3.65	4.0
				SR	44.7	4	0.96	7	1.61	4	16	2.84	np	12	6	12	3.65	4.0
5	20	56	10	MR	32.1	3	0.72	6	1.37	np	17	3.02	10	16	8	12	3.65	4.0
				SR	37.3	np		8	1.83	3.2	14	2.49	np	np		np		np
6	20	60	12	MR	36.7	3	0.72	7	1.61	np	17	3.02	11	16	8	12	3.65	4.0
				SR	52.9	4	0.96	9	2.06	4	14	2.49	np	np		np		4.0
7	30	58	15	MR	42.6	4	0.96	8	1.83	np	18	3.20	12	16	8	12	3.65	4.0
				SR	50.7	4	0.96	9	2.06	4	13	2.31	10	12	6	12	3.65	4.0
8	48	60	0	MR	47.2	4	0.96	9	2.06	np	18	3.20	12	16	8	12	3.65	4.0
				SR	52.2	4	0.96	9	2.06	3	18	3.20	10	12	6	12	3.65	4.0
9	29	80	0	MR	47.2	4	0.96	9	2.06	np	18	3.20	12	16	8	12	3.65	4.0
				SR	52.2	4	0.96	9	2.06	3	15	2.67	10	12	6	12	3.65	4.0
10	16	78	15	MR	47.2	4	0.96	9	2.06	np	18	3.20	12	16	8	12	3.65	4.0
				SR	52.2	4	0.96	np		4	np		np	np		np		np
11	40	81	0	MR	57.6	5	1.20	11	2.51	np	18	3.20	12	16	8	12	3.65	4.0
				SR	52.9	5	1.20	9	2.06	5	16	2.84	12	12	6	12	3.65	4.0
12	50	100	0	MR	36.7, 28.6	3	0.72	7	1.61	np	15	2.67	12	16	8	12	3.65	4.0
				SR	41.8, 37.3	5	1.20	9	2.06	4	17	3.02	12	14	7	14	4.26	5.0

TABLE 5.12. (Continued)

Farm No.	Area (ha) O	W	L	(@)	Power (kW)	Plow Dsk	Plow (m)	Disk.Harr. Dsk	Disk.Harr. (m)	Harr. (m)	Seeder Rws	Seeder (m)	Fertilizer (m)	Sprayer Nozz.	Sprayer (m)	Combine (ft)	Combine (m)	Wgn (T)
13	55	80	15	MR	36.7, 28.6	3	0.72	7	1.61	np	15	2.67	12	16	8	12	3.65	4.0
				SR	52.9, 44.7	8	1.92	8,9	3.87	4.5	15,17	5.68	12	12	6	14	4.26	9.0
14	56	80	20	MR	36.7, 28.6	3	0.72	7	1.61	np	16	2.84	12	16	8	12	3.65	4.0
				SR	52.2, 52.2	5	1.20	9	2.06	4	18	3.20	12	14	7	13	3.95	4.0
15	74	60	30	MR	32.1	3	0.72	6	1.37	6#	18	3.20	12	16	8	12	3.65	4.0
				SR	56.7	5	1.20	10	2.30	6	15	2.67	12	14	7	np		5.0
16	75	80	15	MR	42.6, 28.6	4	0.96	8	1.83	np	17	3.02	12	16	8	12	3.65	4.0
				SR	55.9, 52.2	5	1.20	12	2.76	5	14	2.49	12	14	7	14	4.26	9.0
17	100	100	25	MR	53.2, 28.6	5	1.20	10	2.29	np	18	3.20	12	16	8	12	2.65	4.0
				SR	55.9, 43.3	8	1.92	9,9	4.12	6	18	3.20	14	16	8	14	4.26	np
18	27	200	15	MR	63.9, 28.6	6	1.44	12	2.74	np	18	3.20	13	16	8	12	3.65	4.0
				SR	73.1, 44.7, 41.8	10	2.40	9,14	5.26	4,4	29	5.15	14	16	8	24	7.30	14.0
19	0	250	0	MR	63.9, 28.6	6	1.44	12	2.74	np	18	3.20	14	16	8	12	3.65	4.0
				SR	52.9, 52.2, 37.3	9	2.16	10,11	4.80	4,4	27	4.80	14	16	8	14	4.26	10.0

*All runs using 0.70 as design probability level, medium intensity tillage level, a custom harvest risk factor equal 1.05, all other input variables were kept constant.

@ O= oats; W= wheat; L= lentils.

np = not present

#Use a spike-tooth harrow before seeding, instead of a disk harrow.

MR = Model results.

SR = Survey results.

Agricultural machinery dealers, on the other hand, would also suggest to the farmers the acquisition of power sources larger than really necessary. As it can be seen in Table 5.10, the majority of the tractors, 52%, is in the range of 52.2 to 55.9 kW (70 - 75 HP). Ford-5000 and Belaruz MTZ-50 tractors make up more than 33% of the tractors reported in the survey. A large number of Ford-5000 tractors were brought to the country through the Alliance for Progress and the Agrarian Reform Program of the Frei Government. All the Belaruz MTZ-50 tractors were imported from the USSR to serve the goals of the Agrarian Reform Program of the Allende Government.

As stated in the first chapter of this dissertation, the area seeded yearly with wheat in Chile has decreased from 780,000 hectares in 1966 to 546,000 in 1980. Many of the farmers in the survey acquired their machinery systems in the early seventies when they also were seeding a larger area. Therefore, in general most of the machinery systems reported in the survey seem oversized for the area they work now. The high power/area value for these farmers (0.55 kW/ha), is evidence of the reduction in cultivated area together with an initial purchase of a large power source.

Rotations seem to have changed slightly, also, during the last five years. The percentage distribution of area per crop, found in the survey is as follows: 65% wheat, 28% oats, 5% lentils, and 2% other crops (barley, rapeseed). These percentages are somewhat different from the ones found in the region in 1976 and reported in INIA (1980), which present values near 68% for wheat, 21% for oats, and 11% for other crops (lentils, barley, rapeseed). The survey results show an increment of the area seeded with oats and lentils and a reduction in the area planted with wheat. These results were corroborated by Chavarria (1981), who also reported a strong reduction of the area planted with rapeseed.

Despite the many factors pointing towards a changing technology and economic environment, the values presented in Table 5.12 do compare reasonably well in a general way. As pointed out by Wollak (1981), it is important that model results be in the ballpark of what is expected by the farmer. When this occurs, it is possible to rationalize the differences between actual and generated machinery systems, commonly caused by different management alternatives.

The main discrepancies between actual and simulated machinery systems occur with the power level and the plow size, for which the model consistently predicts smaller units. The discrepancy with the seeder size is opposite, since the model chooses, in many cases, a larger seeder than the one reported by the farmers.

The difference in the power level has already been analyzed and most of the farmers would agree with the statement that they tend to oversize their tractors. The case of the plow is different. Plows appear oversized because many farmers do not use the recommended period for plowing but a shorter one for reasons, it appears, of pasture utilization (Chavarria, 1981), needing therefore, a larger effective field capacity which usually also means a higher power level.

In the case of the seeder, the model goes to larger sizes because of the timeliness costs associated with late seeding, to which the farmers do not respond in the same fashion. Farmers tend to have a larger disk, which also increases the size of their tractors. Confronted with unsuitable weather and late seeding many farmers would resort to spring seeding despite the lower yields and drought risks.

In other aspects, the behavior of the model is quite acceptable. Using the 0.70 design probability level for available days and the most common management practices followed by the farmers the model starts selecting two tractors once the cultivated area exceeds 121 hectares/ year, coinciding with the number of tractors reported by the farmers in the survey. Although the model selects a combine harvester for all areas inputted, it also calculates the cost of the custom harvest alternative and these results agree very well with the combine ownership pattern among the farmers, as it was pointed out earlier. The presence of many 14-foot combine harvesters among the surveyed farmers has, most likely, been caused by the massive importation of John Deere-960 model combines during the late sixties. The extra capacity provided by a 14-foot harvester is used by the farmers to do some custom work among their neighbors who plant smaller areas and do not own a combine harvester.

6. SENSITIVITY ANALYSIS

6.1. Machinery System Requirements

As the values presented in Table 5.12 are in indication of adequate behavior of the machinery selection model, program TRIGO was used to analyze the effects of various factors upon the machinery system requirements and their respective costs. The following tables present the machinery systems selected for different areas, tillage intensity levels, crop rotations, workhours per day, and design probability levels, under a standard set of common conditions encountered among the wheat producers of the region. Information presented in later tables show the fuel consumption and the costs associated with the different machinery systems. These results should be seen as examples of the kinds of analyses that can be made with model TRIGO using the inputs of interested farmers.

Program TRIGO prints out four machinery systems with their corresponding partial and total costs, as well as other types of information: 1) least cost system; 2) second least cost system; 3) third least cost system; and 4) minimum size system. This has been done in order to be able to use the program as an educational tool later in Chile. The discussion that follows is based upon the least cost machinery system.

6.1.1. Effects of Cultivated Area

Table 6.1 depicts the variations in machinery system requirements in relation to changes in the cultivated area from 50 to 230 hectares. Sizes of all machines increase with increments in the area, with the exception of the spike-tooth harrow which decreases in width as soon as two tractors are selected. The largest change in size occurs in the case of the disk plow which goes from 0.72 m (3 disk plow) to 1.44 m (6 disk plow). As expected, total power increases with the area from 32.1 kW to 92.5 kW. However, the power per unit area initially decreases as the area increases and later is stabilized at a value close to 0.45 kW/ha. Tractor use per year increased with the cultivated area, except for a small reduction at 110 hectares for which implements much larger than the ones used at 90 hectares were selected, demanding consequently less hours per year on the power source.

Fertilizer broadcaster and field sprayer sizes do not change a great deal with changes in the cultivated area. These two machines have large effective field capacities, low purchase price and negligible power requirements, therefore, the model selects larger than minimum sizes to save on field hours, fuel consumption and labor costs.

For all inputted areas, program TRIGO selects a combine harvester and calculates the cost of custom harvest. The asterisks in the column before the last on the right side of Table 6.1 indicate those areas for which custom cost is less than combine harvester ownership, for a risk factor of 1.05. For the areas that can be worked with two tractors (up to 270 hectares for 10 work hours per day) the program selects a 3.65 m wide combine (12-foot). This seems to be caused by the large amount of time available for harvesting (negligible timeliness cost) and by the

TABLE 6.1. Effect of the Yearly Seeded Area Upon Machinery Requirements.

Area (ha) O	W	L	Plow (m)	Disk (m)	Harr. (m)	Seeder (m)	Fert. (m)	Spry. (m)	No. Trac.	Power (kW)	kW/ha	Tractor Use (hr/yr)	Combine (m)	Wagon (T)
0	50	0	0.72	1.37	3.5	1.78	10	6	1	32.1	0.64	381	3.65*	4.0
0	70	0	0.72	1.37	4.0	2.31	10	7	1	32.1	0.46	500	3.65*	4.0
0	90	0	0.72	1.37	4.5	2.99	11	8	1	32.1	0.36	626	3.65*	4.0
0	110	0	0.96	1.83	5.5	3.02	12	8	1	42.6	0.39	601	3.65*	4.0
0	130	0	0.96	1.83	6.0	3.20	12	8	1	42.6	0.33	702	3.65*	4.0
0	150	0	1.20	1.83	6.0	3.20	12	8	1	53.2	0.35	752	3.65	4.0
0	170	0	1.20	1.83	3.5	3.20	12	8	2	81.8	0.48	886	3.65	4.0
0	190	0	1.44	2.06	3.5	3.20	12	8	2	92.5	0.49	900	3.65	4.0
0	210	0	1.44	2.29	3.5	3.20	13	8	2	92.5	0.44	955	3.65	4.0
0	230	0	1.44	2.06	3.5	3.20	12	8	2	92.5	0.40	1085	3.65	4.0

*Custom Cost less than Combine Harvester Ownership.
Low Tillage Intensity Level; Wheat-Pasture Rotation; Weather Confidence Level=0.70; Workhours/Days=8.0 except for the 230 hectares run where 9.0 hr/day are needed to be able to seed all this area.

In all computer runs, unless otherwise specified, the rest of the variables are kept constant at the following values: wheat yield=3500 kg/ha; crop price=0.25 \$/kg; diesel fuel price=0.45 \$/L; labor cost= 1.00 \$/hr; bank interest=18%; farmer's rate of return=18%; inflation on machinery=18%; inflation on fuel=16%; inflation on labor=10%; inflation on crop price=12%; custom harvest risk factor=1.05.

large augment in combine harvester purchase price per unit width increment (a predicted average of US $ 11,296 per foot between 12 and 16-foot combines).

6.1.2. Effects of Tillage Intensity Level

Table 6.2 depicts the effects of the tillage intensity level upon the machinery system size. The table shows that for all areas and rotations the low tillage intensity level is the less demanding on sizes of tractor and implements. The main difference between the low tillage intensity level and the medium and high tillage intensity levels is that in the case of the low tillage level a spike-tooth harrow is used in conjunction with the seeder instead of an off-set disk harrow.

Spike-tooth harrows have a much larger effective field capacity than disk harrows (1.50 to 3.60 ha/hr versus 0.82 to 1.90 ha/hr for available sizes) and a considerably smaller draft per unit width (0.8 kN/m versus 4.5 kN/m). These facts reduce substantially the size of the disk harrow needed for the first two disk passes and, consequently, the size of the tractor which remains at 32.1 kW even for 150 hectares.

It is unfortunate that many farmers favor the use of the medium and high tillage intensity levels, in spite of recent recommendations to the contrary by the Extension Service personnel.

There are no differences between the medium and high tillage intensity levels in relation to the machinery system sizes required. However, costs are different as it will be shown later.

TABLE 6.2. Effect of the Tillage Intensity Level Upon Machinery Requirements.

Tillage Level (Disk Passes)	Area (ha) O	W	L	Total Area (ha)	Plow (m)	Disk (m)	Harr. (m)	Sdr. (m)	Fert. (m)	Spry. (m)	No. Trac.	Power (kW)	kW/ha	Tractor Use (hr/yr)
WHEAT-PASTURE ROTATION														
Low (2)	0	90	0	90	0.72	1.37	4.5	2.49	11	8	1	32.1	0.36	626
Medium (3)	0	90	0	90	0.96	1.83	np	3.20	12	8	1	42.6	0.47	544
High (4)	0	90	0	90	0.96	1.83	np	3.20	12	8	1	42.6	0.47	626
OATS-WHEAT-PASTURE ROTATION														
Low (2)	75	75	0	150	0.72	1.37	6.0	3.20	12	8	1	32.1	0.21	804
Medium (3)	75	75	0	150	0.96	1.83	np	3.02	12	8	2	71.2	0.47	761
High (4)	75	75	0	150	0.96	1.83	np	3.02	12	8	2	71.2	0.47	898
OATS-LENTILS-WHEAT-PASTURE ROTATION														
Low (2)	55	55	20	130	0.72	1.37	6.0	3.20	12	8	1	32.1	0.25	664
Medium (3)	55	55	20	130	0.72	1.61	np	2.67	12	8	2	65.3	0.50	739
High (4)	55	55	20	130	0.72	1.61	np	2.67	12	8	2	65.3	0.50	872

np = not present

Weather Confidence Level = 0.70

Work hours/day = 8.0

All other variables kept constant.

6.1.3. Effects of Crop Rotation

Table 6.3 depicts the effects of crop rotation upon the machinery system requirements. The three rotations compared differ in the number of crops that each rotation has. Many farmers still use the Wheat-Pasture rotation, although more and more farmers are going into the Oats-Wheat-Pasture rotation. The Extension Service personnel are trying to increase the use of the more complete and better balanced Oats-Lentils-Wheat-Pasture rotation.

Table 6.3 shows that the inclusion of oats and lentils in the rotation decreases the power required and the sizes of the disk plow and disk harrow, especially in larger areas. This is a positive result brought about by the reduction in the area that has to be plowed each year, according to the field operations calendar. Because a smaller plow is needed less power is required and it does not pay now to increase the size of the disk harrow.

The power required per unit area and the plow and disk sizes for the Wheat-Pasture rotation are consistently larger than the power required by the rotations that include oats and lentils. Unfortunately, the area seeded with lentils cannot be increased by larger amounts because of weather, price risks and labor bottlenecks.

6.1.4. Effects of Available Time for Fieldwork

Available time for fieldwork is affected directly by the number of hours worked each day and by the design probability level. Tables 6.4 and 6.5 depict the effects of workhours per day and design probability level, respectively, upon the machinery system requirements. It

TABLE 6.3. Effect of the Crop Rotation Upon Machinery Requirements.

Rotation	Area (ha) O	Area (ha) W	Area (ha) L	Total Area (ha)	Plow (m)	Disk (m)	Harr. (m)	Sdr. (m)	Fert. (m)	Spry. (m)	No. Trac.	Power (kW)	kW/ha	Tractor Use (hr/yr)
					MEDIUM TILLAGE INTENSITY LEVEL									
W-P-P	0	70	0	70	0.72	1.37	np	2.49	10	7	1	32.1	0.46	556
O-W-P-P	35	35	0	70	0.72	1.37	np	2.49	10	7	1	32.1	0.46	461
O-L-W-P-P	25	25	20	70	0.72	1.37	np	2.49	10	7	1	32.1	0.46	429
					LOW TILLAGE INTENSITY LEVEL									
W-P-P	0	150	0	150	1.20	1.83	6.0	3.20	12	8	1	53.2	0.35	752
O-W-P-P	75	75	0	150	0.72	1.37	6.0	3.20	12	8	1	32.1	0.21	804
O-L-W-P-P	65	65	20	150	0.72	1.37	6.0	3.20	12	8	1	32.1	0.21	771
					HIGH TILLAGE INTENSITY LEVEL									
W-P-P	0	150	0	150	1.20	2.29	np	3.02	12	8	2	81.8	0.54	881
O-W-P-P	75	75	0	150	0.96	1.83	np	3.02	12	8	2	71.2	0.47	898
O-L-W-P-P	70	70	10	150	0.96	1.83	np	3.02	12	8	2	71.2	0.47	886
					MEDIUM TILLAGE INTENSITY LEVEL									
W-P-P	0	210	0	210	1.44	2.74	np	3.20	13	8	2	92.5	0.44	933
O-W-P-P	105	105	0	210	1.20	2.51	np	3.20	13	8	2	86.2	0.41	856
O-L-W-P-P	95	95	20	210	1.20	2.51	np	3.20	13	8	2	86.2	0.41	839

Weather Confidence Level = 0.70
Work hours/Day = 8.0

np = not present
All other variables kept constant.

TABLE 6.4. Effect of Work Hours per Day Upon Machinery Requirements.

Area (ha) O	W	L	Total Area (ha)	Work Hours (hr/day)	Plow (m)	Disk (m)	Harr. (m)	Sdr. (m)	Fert. (m)	Spry. (m)	No. Trac.	Power (kW)	kW/ha	Tractor Use (hr/yr)
					MEDIUM TILLAGE INTENSITY LEVEL									
50	50	0	100	7	0.96	2.74	np	3.20	12	8	1	62.9	0.63	413
50	50	0	100	8	0.96	2.29	np	3.20	12	8	1	52.4	0.52	450
50	50	0	100	9	0.96	1.83	np	3.20	12	8	1	42.6	0.43	504
50	50	0	100	10	0.72	1.61	np	3.20	12	8	1	36.7	0.37	580
50	50	0	100	11	0.72	1.61	np	3.02	12	8	1	32.1	0.32	634
50	50	0	100	12	0.72	1.37	np	2.84	12	8	1	32.1	0.32	639
					LOW TILLAGE INTENSITY LEVEL									
90	90	0	180	7	0.72	1.61	3.5	3.20	13	8	2	65.3	0.36	937
90	90	0	180	8	0.72	1.61	3.5	3.20	12	8	2	65.3	0.36	940
90	90	0	180	9	0.72	1.37	3.5	3.20	12	8	2	60.7	0.34	1000
90	90	0	180	10	0.72	1.37	6.0	3.20	12	8	1	32.1	0.18	964
90	90	0	180	11	0.72	1.37	6.0	3.20	12	8	1	32.1	0.18	964
90	90	0	180	12	0.72	1.37	5.5	3.20	12	8	1	32.1	0.18	969

np = not present

Weather Confidence Level = 0.70

Oats-Wheat Rotation

All other variables kept constant.

TABLE 6.5. Effect of the Design Probability Level Upon Machinery Requirements.

Area (ha) O	W	L	Total Area (ha)	Prob. Level	Plow (m)	Disk (m)	Harr. (m)	Sdr. (m)	Fert. (m)	Spry. (m)	No. Trac.	Power (kW)	kW/ha	Tractor Use (hr/yr)
25	25	0	50	0.70	0.72	1.37	np	1.96	10	6	1	32.1	0.64	345
25	25	0	50	0.80	0.72	1.37	np	1.96	10	6	1	32.1	0.64	345
25	25	0	50	0.90	0.96	3.20	np	3.20	12	8	1	73.4	1.47	193
35	35	0	70	0.70	0.72	1.37	np	2.49	10	7	1	32.1	0.46	462
35	35	0	70	0.80	0.72	1.61	np	3.02	10	8	1	36.7	0.52	412
35	35	0	70	0.90	0.96	2.06	np	3.02	10	8	2	75.8	1.08	338
85	85	0	170	0.70	0.96	2.06	np	3.20	12	8	2	71.2	0.42	807
85	85	0	170	0.80	1.20	2.29	np	3.20	12	8	2	81.6	0.48	731
85	85	0	170	0.90	Not enough time to seed all this area.									

np = not present

Medium Tillage Intensity Level

Oats-Wheat-Pasture Rotation

Work hours/Day = 8.0

All other variables kept constant.

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can be seen in Table 6.4 that as the number of workhours per day increases from seven to 12 the size of the machinery system and the power required decrease from 62.9 kW to 32.1 kW in one case, and from 65.3 kW and two tractors to 32.1 kW and one tractor. This is an important factor that the farmers should consider while in the process of reaching their machinery management decisions.

Table 6.5 depicts the machinery system size increment as the design probability level changes from 0.70 to 0.90. The number of hours the tractor is used each year also decreases notoriously. The effect is especially important for the 0.90 design probability level, at which the time available is so small that even areas of moderate size cannot be seeded within the time constraints established by the agronomists, with the largest equipment available in the market.

As the design probability level changes from 0.70 to 0.80 the increment in machinery system size is not so notorious. Farmers should be aware of the large system size required if they want to finish their work on time nine out of 10 years. It seems preferable to design the machinery system for a 0.80 or 0.70 probability level keeping in mind that more workhours per day might be necessary for crucial field operation events.

6.1.5. Diesel Fuel Requirements

Fuel usage in crop production is very important in Chile, where more than 65% of the fuel consumption is imported and where the price of fuel paid by the farmers is almost double that paid in the USA.

Fuel requirements are directly related to the amount of work performed and to the power level needed. Therefore, tillage intensity and crop rotation have an important effect upon the fuel consumption of different wheat production systems.

Table 6.6 depicts the variations in fuel consumption for the different crop rotations and tillage intensity levels. The amounts of fuel used vary from 38.4 to 76.7 litres per hectare as the crop production system changes from the low tillage intensity level and the Oats-Lentils-Wheat-Pasture rotation to the high tillage intensity level and the Wheat-Pasture rotation.

Combine harvester fuel requirements are not included in Table 6.6. The combine harvester fuel requirements vary from 16.3 to about 21.5 litres per hectare, depending upon the proportion of lentils in the crop rotation. Fuel requirements for harvesting lentils increase with the area seeded with lentils because the combine has to be manually fed at a work capacity of only 0.40 hectares per hour instead of the 1.06 ha/hr while harvesting oats or wheat.

The fuel requirements calculated for these farmers at the lov tillage intensity level compare very closely with the values presented by other researchers, especially with the amounts reported by Singh (1978), who estimated the range to be from 37.4 to 45.5 L/ha, for somewhat similar tillage practices. The high fuel consumption values for the medium and high tillage intensity levels reflect the excessive tillage practices followed by many of the farmers in Chile.

From Table 6.6 it is also possible to estimate that the effect of the crop rotation upon the fuel consumption is smaller (15.9 L/ha) than the effect of the tillage intensity level (27.0 L/ha), at the 110 hectares of cultivated area. These possible savings in diesel fuel requirements for crop production become all the more important when all the cultivated area of Chile is considered at the Government level, which is responsible for the importation of these large quantities of fuel.

TABLE 6.6. Fuel Consumption as Influenced by Tillage Intensity and Crop Rotation.

Tillage Intensity (Disk Passes)	Rotation	Area (ha) O	Area (ha) W	Area (ha) L	Total Area (ha)	No. Trac.	Power (kW)	kW/ha	Fuel* Use (L/ha)	Increment %**	Increment %***
Low (2)	O-L-W-P-P	45	45	20	110	1	32.1	0.29	38.4	0	0
Medium (3)	O-L-W-P-P	45	45	20	110	1	57.6	0.52	54.4	42	42
High (4)	O-L-W-P-P	45	45	20	110	1	57.6	0.52	64.4	68	68
Low (2)	O-W-P-P	55	55	0	110	1	32.1	0.29	40.5	0	5
Medium (3)	O-W-P-P	55	55	0	110	1	57.6	0.52	57.5	42	50
High (4)	O-W-P-P	55	55	0	110	1	57.6	0.52	67.5	67	76
Low (2)	W-P-P	110	0	0	110	1	42.6	0.39	54.3	0	41
Medium (3)	W-P-P	110	0	0	110	1	57.6	0.52	66.7	23	74
High (4)	W-P-P	110	0	0	110	1	57.6	0.52	76.7	41	100

*Does not include fuel for harvesting

**In relation to the low tillage intensity level.

***In relation to the low tillage intensity level and the Oats-Lentils-Wheat-Pasture Rotation.

Weather Confidence Level = 0.70

Work hours/Day = 8.0

All other variables kept constant.

6.2. Machinery System Cost Analysis

The machinery system total cost, as reported in this dissertation, comprises five major items: 1) ownership cost; 2) fuel and lubrication costs; 3) repair, maintenance and shelter costs; 4) labor cost; and 5) timeliness cost. They have been calculated for a 10 year planning horizon, using different inflation rates, and reported as system present value cost for 10 years or annual equivalent cost.

6.2.1. Machinery System Cost Components

Table 6.7 depicts the relative importance of each of the components of the machinery system cost. The combine harvester and transport wagon are presented separately because the harvester is by far the most expensive machine in the system, accounting for nearly 50% of the system's cost for small areas.

Table 6.7 shows that the ownership cost is consistently the largest item among the components, especially for small areas and particularly so in the case of the combine harvester. This fact reflects the high purchase price of agricultural machinery in Chile, and agrees with what has been reported by Ibanez et al. (1979) and Ibanez and Rojas (1979). However, as the cultivated area increases from 70 to 210 hectares the relative importance of the ownership cost decreases from 41% to 36% of the total system cost. In the case of the combine harvester the reduction goes from 75% to 48% for the same areas.

The items that follow ownership cost in relative importance are the fuel and lubrication and the repairs and maintenance costs making up about 50% of the system's cost. They do not change a great deal with

TABLE 6.7. Relative Importance of the Machinery System Cost Components. All Values in U.S. $.

Cost Component	Machinery System Present Value Cost ($/10 years) Cultivated Area (ha)			
	70	110	170	210
1. Machinery System without Harvester				
Ownership	31,840	48,218	68,548	78,187
% of total	41	39	38	36
Fuel & Lubrication	20,383	34,620	47,377	58,341
% of total	26	28	27	27
Repairs & Maintenance	18,445	30,180	45,576	57,875
% of total	24	25	26	26
Labor	5,220	5,485	8,743	9,736
% of total	6	5	5	4
Timeliness	2,183	4,185	7,525	15,434
% of total	3	3	4	7
Total	78,071	122,688	177,769	219,573
2. Harvester & wagon				
Ownership	47,714	47,714	47,714	47,714
% of total	75	66	55	48
Fuel & Lubrication	5,365	8,431	13,029	16,095
% of total	8	11	15	16
Repairs & Maintenance	7,002	11,003	17,005	21,006
% of total	11	15	20	21
Labor	3,527	5,542	8,565	10,580
% of total	6	8	9.7	10
Timeliness	0.00	0.00	224	4,674
% of total	0	0	0.3	5
Total	63,608	72,690	86,537	100,069
% System Cost	45	37	33	31
Machinery System Present				
Value Cost ($/10 yr)	141,679	195,378	264,306	319,643
Annual Equiv. Cost ($/yr)	31,526	43,474	58,812	71,125
A.E. Gross Income ($/yr)	103,438	162,545	251,206	310,314
AEC/AE Gross Income	0.305	0.267	0.234	0.229

Weather Confidence Level = 0.70; Wheat-Pasture Rotation; Medium Tillage Intensity Level; Work hours/Day = 8.0; All other variables kept constant.

changes in the cultivated area when the machinery system without the combine and wagon is considered. However, for the combine and wagon these two components increase in importance as the area increases. This is caused by the large reduction in the relative importance of the ownership cost and by the increment in the number of hours the machine is used yearly.

Labor costs are low in comparison with the previous items, reflecting the low wage earned by workers in Chile and the extent of mechanization of cereal crops. Labor costs for the combine and wagon increase more rapidly with the area than for the rest of the machinery system because of the large number of people involved in the harvesting operation, which includes two persons on the combine and five persons collecting the sacks.

The last item is timeliness cost which has a low relative importance, reflecting the generally large amount of time available for fieldwork and the low price of wheat relative to the other products used in wheat production. However, Table 6.7 also shows that the timeliness cost increases as the area increases because when larger areas are cultivated more hectares are worked in the penalty period of the different field operations.

The lower lines in Table 6.7 present the Annual Equivalent Cost, Annual Equivalent Gross Income and their relationship. The annual equivalent cost to annual equivalent gross income ratio decreases with increments in the cultivated area, pointing to larger profits for larger cultivated areas, all other factors unchanged.

It should be remembered here that the figures presented in Table 6.7 are accurate for comparison purposes only. Their absolute values depend upon the rest of the information with which the computer runs were made. This information has been presented at the bottom of Table 6.1.

6.2.2. Effects of the Cultivated Area

The effects of the cultivated area upon the machinery system cost are presented in Table 6.8. The table shows that the total machinery present value cost increases consistently as the cultivated area increases. However, the cost per unit area has a different behavior. In general, the cost per hectare decreases as the seeded area increases, which is to be expected because of a lower investment per unit area.

For the low tillage intensity level the cost per hectare decreases with increments in the area as long as one tractor is required. As soon as two tractors are required the cost per hectare goes up and tends to remain at this higher value.

When the medium tillage intensity level is used the cost per hectare decreases as the seeded area increases, independently of the number of tractors required. There is one exception to this behavior at 110 hectares where the cost per hectare increases transitorily for that area. As this area is near the maximum that can be worked with one tractor and the model tries to work the maximum area without going into two tractors, the result is a large power source, which has a considerable higher fuel consumption rate (57.6 L/ha) than the tractor used at 90 hectares (50.9 L/ha). The same types of results are obtained when the area is increased from 40 to 220 hectares, in which case the transitory increase in cost per hectare occurs at 120 hectares. These results point to the need for further research focusing upon the cost of performing work with one and two tractors at sensitive size areas.

TABLE 6.8. Effect of the Yearly Seeded Area Upon the Machinery System Cost. All Values in U.S. $.

Area (ha) W	O	L	Total Area (ha)	No. Trac.	Power (kW)	Machinery System Pres. Val. Cost* ($/10 yr)	Annual Equivalent Cost ($/ha)*	($/ha)**
				LOW TILLAGE INTENSITY LEVEL				
25	25	0	50	1	32.1	55,661	248	511
35	35	0	70	1	32.1	65,876	209	411
45	45	0	90	1	32.1	76.401	189	357
55	55	0	110	1	32.1	86,427	175	322
65	65	0	130	1	32.1	96,961	166	298
75	75	0	150	1	32.1	108,544	161	282
85	85	0	170	2	60.7	132,613	174	287
95	95	0	190	2	65.3	151,614	177	283
105	105	0	210	2	71.2	168,011	178	280
				MEDIUM TILLAGE INTENSITY LEVEL				
25	25	0	50	1	32.1	58,594	261	524
35	35	0	70	1	32.1	71,109	226	428
45	45	0	90	1	42.6	89,446	221	389
55	55	0	110	1	57.6	113,825	230	372
65	65	0	130	2	65.3	124,162	213	345
75	75	0	150	2	71.2	138,773	206	327
85	85	0	170	2	71.2	156,477	205	318
95	95	0	190	2	81.8	174,783	205	311
105	105	0	210	2	86.2	193,691	205	307

*Does not include combine harvester cost.

**Includes combine harvester cost.

Weather Confidence Level = 0.70

Work hours/day = 8.0

Oats-Wheat-Pasture Rotation

All other variables kept constant.

6.2.3. Effects of Tillage Intensity Level

Table 6.9 depicts the effects of the tillage intensity level upon the machinery system cost. The effect is rather clear and logical. As the tillage intensity level increases the cost per hectare also increases. The effect is especially notorious when the change is made from the low tillage intensity level to the medium and high tillage intensity levels.

As the difference between the medium and high tillage intensity levels is one disk pass, it is reasonable to conclude from the results presented in Table 6.9 that the annual equivalent cost of one disk pass is $20.00, under the conditions used in the model runs. This cost does not include the cost associated with the higher erosion levels brought about by more intensive tillage practices, which have been found to occur in this area (Pena, 1978).

6.2.4. Effects of Crop Rotation

Table 6.10 depicts the effects of the crop rotations upon the machinery system cost.

The table shows that as the number of crops in the rotation increases the cost per hectare decreases. This result is caused by a reduction in the amount of work that needs to be performed, especially plowing.

When the cost of the combine harvester is included, there is a small increment in the cost per hectare as lentils appear in the rotation. This cost increment is caused by the slow harvesting rate of lentils (0.40 ha/hr).

Considering both Tables 6.9 and 6.10 it is possible to estimate

TABLE 6.9. Effect of the Tillage Intensity Level Upon the Machinery System Cost.* All Values in U.S. $.

Tillage Level (Disk Passes)	Area (ha) O	W	L	Total Area (ha)	Machinery System Pres.Value Cost* ($/10 yr)	Annual Eq. Cost ($/ha)	Cost Increment ($/ha)
				WHEAT-PASTURE ROTATION			
Low (2)	0	150	0	150	142,770	212	0
Medium (3)	0	150	0	150	162,770	241	29
High (4)	0	150	0	150	175,883	261	49
				OATS-WHEAT-PASTURE ROTATION			
Low (2)	75	75	0	150	108,544	161	0
Medium (3)	75	75	0	150	138,773	206	45
High (4)	75	75	0	150	152,198	226	65
				OATS-LENTILS-WHEAT-PASTURE ROTATION			
Low (2)	65	65	20	150	107,124	159	0
Medium (3)	65	65	20	150	137,621	204	45
High (4)	65	65	20	150	151,046	224	65

*Does not include combine harvester cost.

Weather Confidence Level = 0.70

Work hours/day = 8.0

All other variables kept constant.

TABLE 6.10. Effect of the Crop Rotation Upon the Machinery System Cost. All Values in U.S. $.

Crop Rotation	Area (ha) O	Area (ha) W	Area (ha) L	Total Area (ha)	Machinery System Pres.Value Cost* ($/10 yr)	Annual Equivalent Cost per hectare ($/ha)*	Annual Equivalent Cost per hectare ($/ha)**
				MEDIUM TILLAGE INTENSITY LEVEL			
W-P-P	0	70	0	70	78,071	248	450
O-W-P-P	35	35	0	70	71,109	226	428
O-L-W-P-P	25	25	20	70	69,635	221	447
				LOW TILLAGE INTENSITY LEVEL			
W-P-P	0	150	0	150	142,770	212	333
O-W-P-P	75	75	0	150	108,544	161	282
O-L-W-P-P	65	65	20	150	107,124	159	291
				HIGH TILLAGE INTENSITY LEVEL			
W-P-P	0	150	0	150	175,883	261	382
O-W-P-P	75	75	0	150	152,198	226	347
O-L-W-P-P	70	70	10	150	151,622	225	352
				MEDIUM TILLAGE INTENSITY LEVEL			
W-P-P	0	210	0	210	219,573	233	339
O-W-P-P	105	105	0	210	193,691	205	307
O-L-W-P-P	95	95	20	210	192,776	204	313

*Does not include combine harvester cost.

**Combine harvester cost included.

Weather Confidence Level = 0.70
Work hours/day = 8.0
All other variables kept constant.

that the tillage level has a larger effect upon machinery system cost per hectare than the crop rotation used.

6.2.5. Effects of Available Time for Fieldwork

The effects of available time for fieldwork upon the machinery system cost are depicted in Table 6.11 and 6.12.

The effect of the workhours per day upon the system's cost is presented in Table 6.11. The table shows that as the number of working hours per day increases from seven to 12 the machinery system cost decreases by $56.00, from 407 to 351 $/ha for the medium tillage intensity level, and by $36.00, from 294 to 258 $/ha in the case of the low tillage intensity level.

These reductions in cost per hectare as the number of working hours per day increases are caused especially by smaller ownership costs and timeliness costs.

The effects of the design probability level upon the machinery system cost are depicted in Table 6.12. The table shows that as the design probability increases from 0.70 to 0.90 the cost per hectare can increase by as much as 132 $/ha. The cost increment is especially large when the design probability increases from 0.80 to 0.90.

The large cost increments associated with the 0.90 design probability level indicate that it might be more profitable to use a lower design probability level for the selection of a machinery system.

TABLE 6.11. Effect of Work Hours per Day Upon the Machinery System Cost. All Values in U.S. $.

Area (ha) O	W	L	Total Area (ha)	Work Hours (hr/day)	Mach. System Pr.Val.Cost* ($/10 yr)	Annual Equiv. Cost per ha. ($/ha)*	($/ha)**	Cost Reduction ($/ha)
				MEDIUM TILLAGE INTENSITY LEVEL				
50	50	0	100	7	112,491	250	407	0
50	50	0	100	8	103,027	229	386	21
50	50	0	100	9	94,855	211	368	39
50	50	0	100	10	91,730	204	361	46
50	50	0	100	11	87,794	195	352	55
50	50	0	100	12	87,310	194	351	56
				LOW TILLAGE INTENSITY LEVEL				
90	90	0	180	7	148,788	184	294	0
90	90	0	180	8	145,103	179	289	5
90	90	0	180	9	136,208	168	278	16
90	90	0	180	10	122,284	151	261	33
90	90	0	180	11	120,583	149	259	35
90	90	0	180	12	119,643	148	258	36

*Combine harvester cost not included.

**Combine harvester cost included.

Weather Confidence Level = 0.70
Oats-Wheat-Pasture Rotation.
All other variables kept constant.

TABLE 6.12. Effect of the Design Probability Level Upon the Machinery System Cost. All Values in U.S. $.

Area (ha) O	W	L	Total Area (ha)	Prob. Level	Mach. System Pr.Val.Cost* ($/10 yr)	Annual Equiv. Cost per ha. ($/ha)*	($/ha)**	Cost Increment ($/ha)
25	25	0	50	0.70	58,594	261	524	0
25	25	0	50	0.80	59,190	263	526	2
25	25	0	50	0.90	88,249	393	656	132
35	35	0	70	0.70	71,109	226	428	0
35	35	0	70	0.80	75,268	239	441	13
35	35	0	70	0.90	100,570#	320	522	94
85	85	0	170	0.70	156,477	205	318	0
85	85	0	170	0.80	165,362	216	329	11
85	85	0	170	0.90	Not enough time to seed all this area.			

*Combine harvester cost not included.

**Combine harvester cost included.

#Needs two tractors.

Medium tillage intensity level
Work hours/day = 8.0
Oats-Wheat-Pasture Rotation
All other variables kept constant.

6.2.6. Effects of Wheat Yield and Wheat Price

The effects of wheat yield and wheat price upon the machinery system cost are depicted in Tables 6.13 and 6.14.

Table 6.13 shows that as the wheat yield increases from 1500 to 5100 kg/ha the machinery system cost only increases by 6.0 \$/ha, from 354 to 360 \$/ha. The effect of the increment in wheat yield is only evident in the timeliness cost, which increases proportionally with the increments in yield. The other cost components remain at the same value regardless of the wheat yield.

The last two columns in Table 6.13 show an increment in the annual gross income and a reduction in the annual equivalent cost/gross income ratio proportional to the changes in the yield.

The effect of the wheat price is similar to that of the wheat yield. Table 6.14 shows the changes in timeliness cost, system's cost per hectare, gross income per hectare, and annual equivalent cost/gross income ratio, as the wheat price changes from 0.15 to 0.39 \$/kg.

The effect of both wheat yield and wheat price upon the machinery system cost is not very large because they only affect one of the components of the total cost and also because for these areas there are no timeliness costs for the combine harvester.

6.2.7. Effect of Fuel Cost

Table 6.15 depicts the effects of changes in fuel cost upon the machinery system cost. Again, only the fuel cost component is affected in the same proportion as the fuel cost changes. The effect upon the

TABLE 6.13. Effects of Wheat Yields Upon Machinery System Cost. All Values in U.S. $.

Area (ha)	Wheat Yield (kg/ha)	System Present Value Cost ($/10 yr)					An. Eq. Cost* ($/ha)	An. Eq. Cost** ($/ha)	An. Eq. Gross Inc. ($/ha)	AEC/Gr.Inc.
		Ownership	Fuel	R&M	Labor	Timeliness				
110	1500	41,024	28,170	26,013	5,997	1,203	207	354	633	0.56
110	2100	41,024	28,170	26,013	5,997	1,684	208	355	887	0.40
110	2700	41,024	28,170	26,013	5,997	2,165	209	356	1140	0.31
110	3300	41,024	28,170	26,013	5,997	2,646	210	357	1393	0.26
110	3900	41,024	28,170	26,013	5,997	3,127	211	358	1646	0.22
110	4500	41,024	28,170	26,013	5,997	3,608	212	359	1900	0.19
110	5100	41,024	28,170	26,013	5,997	4,089	213	360	2153	0.17

*Does not include combine harvester.

**Combine harvester included.

Machinery system selected: plow = 0.96m; disk = 1.83m; harrow = 5.5m; seeder = 3.02m; fertilizer = 12m; sprayer = 8m. Wheat-Pasture rotation; Low tillage intensity level; Weather confidence level = 0.70; Work hours/day = 8.0.
All other variables kept constant at: wheat price = 0.25 $/kg; fuel cost = 0.45 $/L; Wage = 1.00 $/hr; bank interest, farmer's rate of return and machinery inflation = 18%; fuel cost inflation = 16%; labor cost inflation = 10%; crop price inflation = 12%; custom harvest risk factor = 1.05.

TABLE 6.14. Effects of Wheat Prices Upon Machinery System Cost. All Values in U.S. $.

Area	Wheat Price	System Present Value Cost ($/10 yr)					An. Eq. Cost*	An. Eq. Cost**	An. Eq. Gross Inc.	
(ha)	($/kg)	Ownership	Fuel	R&M	Labor	Timeliness	($/ha)	($/ha)	($/ha)	AEC/Gr. Inc.
130	0.15	41,632	33,001	30,511	6,978	2,971	197.0	329.2	886	0.37
130	0.19	41,632	33,001	30,511	6,978	3,764	198.4	330.6	1123	0.29
130	0.23	41,632	33,001	30,511	6,978	4,556	199.7	331,9	1359	0.24
130	0.27	41,632	33,001	30,511	6,978	5,349	201.1	333.3	1596	0.21
130	0.31	41,632	33,001	30,511	6,978	6,141	202.4	334.6	1832	0.18
130	0.35	41,632	33,001	30,511	6,978	6,934	203.8	336.0	2069	0.16
130	0.39	41,632	33,001	30,511	6,978	7,726	205.1	337.3	2305	0.14

*Does not include combine harvester.

**Combine harvester included.

Machinery system selected: plow = 0.96m; disk = 1.83m; harrow = 6.0m; seeder = 3.20m; fertilizer = 12m; sprayer = 8m. Wheat-Pasture rotation; Low tillage intensity level; Weather confidence level = 0.70; Work hours/day = 8.0; All other variables kept constant at: wheat yield = 3500 kg/ha; fuel cost = 0.45 $/L; Wage = 1.00 $/hr; Bank interest, farmer's rate of return and machinery inflation = 18%; fuel cost inflation = 16%; labor cost inflation = 10%; crop price inflation = 12%; custom harvest risk factor = 1.05.

TABLE 6.15. Effects of Fuel Cost Upon Machinery System Cost. All Values in U.S. $.

Area (ha)	Fuel Cost ($/L)	System Present Value Cost ($/10 yr) Ownership	R&M	Labor	Timeliness	Fuel	An. Eq. Cost ($/ha)	An. Eq. Gross Income ($/ha)	AEC/Gross Inc.
110	0.37	88,738	37,016	11,535	2,806	30,094	344	1,477	0.233
110	0.45	88,738	37,016	11,535	2,806	36,601	357	1,477	0.242
110	0.53	88,738	37,016	11,535	2,806	43,108	371	1,477	0.251
110	0.61	88,738	37.016	11,535	2,806	49,615	384	1,477	0.260
110	0.69	88,738	37,016	11,535	2,806	56,122	391	1,477	0.265
110	0.77	88,738	37,016	11,535	2,806	62,628	410	1,477	0.277

Machinery System Selected: plow = 0.96m; disk = 1.83m; harrow = 5.5m; seeder = 3.02m; fertilizer = 12m; sprayer = 8m. Wheat-Pasture rotation; Low tillage intensity level; Weather confidence level = 0.70; Work hours/day = 8.0; All other variables kept constant at: wheat yield = 3500 kg/ha; wheat price = 0.25 $/kg; Wage = 1.00 $/hr; Bank interest, farmer's rate of return and machinery inflation = 18%; fuel cost inflation = 16%; labor cost inflation = 10%; crop price inflation = 12%; custom harvest risk factor = 1.05.

system's cost per hectare is slightly larger than the effects of wheat yield and price, reflecting the larger cost of fuel in relation to wheat price.

6.3. Summary

The machinery selection model (Program TRIGO), was developed to analyze the impact of different tillage intensity levels and crop rotations upon the size, number and cost of machinery systems used by wheat producers in south central Chile. It is a heuristic model in which field operations must be done within specific calendar periods.

The model can be used by farmers in their decision-making process because it gives the user a range of alternative machinery systems that are not necessarily profit maximizing or cost minimizing but close enough to be a ballpark optimum.

This machinery selection model (TRIGO) has been designed as an educational tool to help college students, instructors, extension agents and farmers to improve on some farm management aspects and to select a machinery system for wheat production using specific tillage practices and crop rotations.

The model matches machine productivity to available time. The model selects the most economical machinery system that can finish all required field operations within specified time constraints. Machinery and timeliness costs are established each time a different machinery system is tried out. The system that proves the least cost, considering ownership, labor, timeliness and operational cost, is selected. Only machine sizes available in the Chilean market are considered in the selection process.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

From the results obtained in this research project the following conclusions are made:

7.1.1. In Relation with the Farmer's Survey

a) The large majority of the surveyed farmers (85%) owned one (60%) or two (25%) two-wheel drive tractors. The machines represented at the lowest percentage level were the fertilizer broadcaster and the combine harvester, both being reported only by 65% of the farmers. Other machines were reported by a large percentage of the wheat producers (90-95%).

b) The machinery system owned by the surveyed farmers is old, with tractors having an average of 10.5 years of use. This fact reflects the difficult economic times these wheat producers face, brought about to a large extent by rising production costs and low crop prices.

c) A very good correlation ($r = 0.95$) was found between the yearly seeded area and the total power available on the farm. The individual tractor power range was found to vary from 37.3 to 73.1 PTO-kW, with an average power per unit cultivated area of 0.55 kW/ha. This value puts these farmers at a high mechanization level, far above the country's average power of 0.30 kW/ha.

d) Near 125 hectares seems to be the upper limit to the area that can be cultivated with one tractor, and around 225 hectares when two tractors are available. These results agree very closely with the computer model predictions which give a range, including both limits, in accordance with the time available used as input in each run.

e) The crop rotation used by the farmers in the study area has changed somewhat in the last five years. The main changes relate to an increment in the area seeded with oats, from 21 to 28% of the total area, and a slight increment in the area seeded with lentils. Both these changes have been recommended by the Extension Service personnel for some time and these results are seen as positive extension accomplishments. The area seeded with rapeseed has decreased notoriously.

7.1.2. In Relation with Time Available for Fieldwork (Simulation Results)

a) In general, time available for fieldwork was found to be abundant in the eastern part of the province of Nuble. However, the results also show that during the seeding period (May-June) the expected number of suitable days for fieldwork is greatly reduced, making necessary a careful approach to the selection and management of agricultural equipment in order to complete field operations on time. The number of days suitable for fieldwork does not increase substantially until September.

b) Computer predictions of days suitable for fieldwork at the 0.70 probability were matched very closely by the results from the farmers' survey. For 10 of the 12 biweekly periods the 0.70 design probability values were found to be within 10% of the farmers' estimates, with a correlation coefficient r = 0.91.

c) The values of suitable days presented at different probability levels in Tables 5.3 through 5.8 are to be interpreted as the minimum expected number of days suitable for fieldwork for that many years out of one hundred. These results should only be used in connection with field operations performed upon the loam textured soils of eastern Nuble province.

d) The computer program counts only whole suitable days, not fractions of days. Therefore, farmers can expect to have a somewhat larger span of time available considering that they would, most likely, work quarter and half-days, or as long as the weather permits at critical times.

e) Farmers should be prepared to perform a large amount of work during the important seeding period of the first week in June. Because of the specific precipitation pattern in the area, this week shows consistently a considerable larger amount (an average of 85% at the 0.70 probability level) of time suitable for fieldwork than both the previous and following weeks.

7.1.3. In Relation with Machinery System Requirements and Costs (Simulation Results)

a) The wheat production machinery selection model, program TRIGO, is a powerful and useful analytical tool that can be used successfully to study the effects of cultivated area, tillage intensity level, crop rotation, available time for fieldwork, and an array of economic factors upon the machinery system requirements and its associated costs.

b) The model predicts the number and size of machines required for a given set of conditions, estimating the system's cost and pointing out relative differences in management strategies. Absolute values are only as reliable as the quality and reliability of the input data.

c) Ownership cost was consistently the largest of the system cost components, with values ranging from 41 to 36% (75 to 45% for the combine harvester) of the total system cost, in accordance with the cultivated area. Fuel and Lubrication and Repairs and Maintenance costs, which together make up 50% of the system's cost, followed ownership cost in relative importance. Labor and timeliness costs had the lowest relative importance among the cost components.

d) Machinery requirements and total system cost increased with increments in the cultivated area. However, costs per hectare decreased as the cultivated area increases.

e) The number of tillage operations affects both the machinery system size requirements and fuel use. The effect was especially notorious as the change is made from the low tillage intensity level to the medium and high tillage intensity levels.

f) As the number of crops in the rotation increased to include oats and lentils, the machinery system size requirements decrease along with the costs per hectare. This result is caused by a reduction in the amount of work to be performed, especially plowing.

g) The number of working hours per day and the design probability level affected both the machinery system size requirements and its associated costs. The effect was so extreme at the 0.90 design probability level that its use in the machinery selection process is open to debate. Results using different amounts of time available for fieldwork also point out the need for grain seeders with larger work capacities, of which the farm machinery dealers seem to be aware. However, this would require the elimination of obstacles (stones, stumps) in many fields and improvements in the rural roads.

h) Diesel fuel requirements per hectare were affected by both the tillage intensity level and the crop rotation. The effect of the first factor can be more important than the effect of the crop rotation, generating savings of up to 27.0 L/ha in a 110 hectare farm, when changing from high to low tillage intensity level.

i) Changes in wheat yield and price affected only to a small extent the machinery system cost. The system size requirements were not affected. Changes in the fuel cost had a more important impact upon the system's cost. However, when these changes were kept within expected variations the effects were much smaller than the effects produced by changes in the tillage intensity, crop rotation or time available.

7.2. Recommendations for Future Work

It is suggested that future research be carried out along the following lines:

a) Set up a network of field observers and rain gages to collect data on days suitable for fieldwork.

b) Analyze the cost of performing work with one and two tractors on critically sized areas.

c) Enlarge the machinery selection model to include the operations necessary for spring wheat production and other production inputs (i.e. seed, fertilizer, chemicals, etc.) in order to estimate net returns to land, through a complete analysis of each crop production system.

d) Develop a specific algorithm to analyze custom harvest work operations.

e) Adapt program WEATHR to estimate the number of days suitable for fieldwork for other soil types and areas, especially in the Central Valley.

f) Collect more data related to implement draft, work speed, field efficiency, slippage, and tractive efficiency in order to improve the predictions of effective field capacities and power requirements.

g) More agronomic experiments are needed in order to collect better data on timeliness losses for different crops, operations and regions.

h) Develop specific algorithms to analyze the machinery system requirements and their associated costs for other crops grown under irrigated conditions in the Central Valley.

APPENDICES

APPENDIX A

Data Collection Methodology and Worksheets

APPENDIX A

Data Collection Methodology and Worksheets

A. Data Collection Methodology.

The data collection process was carried out in November and December of 1981, in the Andes Pre-Cordillera area of the provinces of Nuble and Bio-Bio, and in the City of Chillan, Chile.

During this phase of the project the author joined the extension specialists of the Technology Transfer Program of the Quilamapu Experiment Station of the Institute of Agricultural Research (INIA). Much of the fieldwork was carried out with the help of Mr. Jorge Chavarria of INIA.

Worksheets to collect the necessary data had been prepared previously at Michigan State University in East Lansing. From among the farmers participating voluntarily in the Technology Transfer Program completely random samples of different sizes were taken. Twenty farmers were sampled to be interviewed using Worksheets No. 4 and 6. Twenty five farmers and machinery operators were interviewed using Worksheet No. 5.

All agricultural machinery dealers (6) represented in the Chillan area were interviewed using Worksheet No. 3a, in order to obtain the sizes of machines available and their respective costs.

Fifteen researchers and faculty members of the Quilamapu Experiment Station (INIA) and the College of Agriculture of the Univerity of Concepcion, at Chillan, were also interviewed using Worksheets No. 1, 2, 3b, 3c, and 4.

All the existing climatological records (June 1964 to February

1982) of the Agrometeorological Station of the University of Concepcion, at Chillan, were collected and brought to East Lansing to be used in the computer model that estimates the time available for fieldwork (Program WEATHR).

B. Data Collection Worksheets.

Worksheet No. 1. Climatological Data and Soil Parameters

Sources: Agrometeorological Station, Department of Soils, Department of Agricultural Engineering, Univeristy of Concepcion - Chillan - Chile. Direct measurement of values not available was also carried out.

1) Collect 18 years of daily weather observations, including rainfall, hours of sunshine, maximum and minimum air and soil temperatures, relative humidity, dew point, wind velocity, open pan evaporation and others.

2) Soil slope; representative range: ____________%

3) Soil texture: light - medium - heavy; clay % ______; silt % _____; sand % _____

4) Soil total porosity: ___________%

5) Soil bulk density: ____________g/cc

6) Soil real density: ____________g/cc

7) Soil moisture content at Saturation, upper 15 cm layer: __________mm

8) Soil moisture content at Field Capacity, upper 15 cm layer: _________mm

9) Soil moisture content at Permanent Wilting Point, upper 15 cm layer: _________mm

10) Infiltration coefficient: ________decimal

11) Soil drainage: excellent - good - moderate - bad - very bad

12) Atterberg's soil plastic limit: ____________

Worksheet No. 2. Agricultural Engineering Data

Sources: Department of Agricultural Engineering - University of Concepcion - Chillan - Chile.
Agricultural Machinery Dealers-Chillan-Chile.

Machine	Draft Range (kN/m)	Speed Range (km/h)	Field Efficiency Range (decimal)	Available sizes or working widths Minimum	Maximum	
Tractor	______	______	_____	_______	_______	kW or HP
Disk plow	______	______	_____	_______	_______	disks
Disk harrow	______	______	_____	_______	_______	disks
Spike-tooth harrow	______	______	_____	_______	_______	metres
Grain drill	______	______	_____	_______	_______	rows
Field Sprayer	______	______	_____	_______	_______	nozzles or m.
Fertilizer broadcaster	______	______	_____	_______	_______	metres
Combine harvester	______	______	_____	_______	_______	feet
Transport wagon	______	______	_____	_______	_______	tonnes

Worksheet No. 3a. Economic Information. Agricultural Machinery Prices

Source: Agricultural Machinery Dealers - Chillan - Chile.

Tractor	Make/Model	Power (HP)	Price (US$)
1	- - -	- - -	- - -
2	- - -	- - -	- - -
3	- - -	- - -	- - -
4	- - -	- - -	- - -
5	- - -	- - -	- - -
6	- - -	- - -	- - -
7	- - -	- - -	- - -
8	- - -	- - -	- - -
9	- - -	- - -	- - -
10	- - -	- - -	- - -

Disk plow	Make/Model	No. of disks	Working width(m)	Price(US$)
1	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -
5	- - -	- - -	- - -	- - -
6	- - -	- - -	- - -	- - -
7	- - -	- - -	- - -	- - -
8	- - -	- - -	- - -	- - -
9	- - -	- - -	- - -	- - -
10	- - -	- - -	- - -	- - -

Worksheet No. 3a. (Continued)

Disk harrow	Make/Model	No. of disks	Working width(m)	Price(US$)
1	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -
5	- - -	- - -	- - -	- - -
6	- - -	- - -	- - -	- - -
7	- - -	- - -	- - -	- - -
8	- - -	- - -	- - -	- - -
9	- - -	- - -	- - -	- - -
10	- - -	- - -	- - -	- - -

Spike-tooth harrow	Make/Model	Working width(m)	Price(US$)
1	- - -	- - -	- - -
2	- - -	- - -	- - -
3	- - -	- - -	- - -
4	- - -	- - -	- - -
5	- - -	- - -	- - -
6	- - -	- - -	- - -
7	- - -	- - -	- - -
8	- - -	- - -	- - -
9	- - -	- - -	- - -
10	- - -	- - -	- - -

Worksheet No. 3a. (Continued)

Grain drill	Make/Model	No. of rows	Row width(cm)	Price(US$)
1	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -
5	- - -	- - -	- - -	- - -
6	- - -	- - -	- - -	- - -
7	- - -	- - -	- - -	- - -
8	- - -	- - -	- - -	- - -
9	- - -	- - -	- - -	- - -
10	- - -	- - -	- - -	- - -

Field sprayer	Make/Model	No. nozzles	Nozzle width(m)	Working width(m)	Price(US$)
1	- - -	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -	- - -
5	- - -	- - -	- - -	- - -	- - -
6	- - -	- - -	- - -	- - -	- - -
7	- - -	- - -	- - -	- - -	- - -
8	- - -	- - -	- - -	- - -	- - -
9	- - -	- - -	- - -	- - -	- - -
10	- - -	- - -	- - -	- - -	- - -

Worksheet No. 3a. (Continued)

Fertilizer broadcaster	Make/Model	Working width(m)	Price(US$)
1	- - -	- - -	- - -
2	- - -	- - -	- - -
3	- - -	- - -	- - -
4	- - -	- - -	- - -
5	- - -	- - -	- - -
6	- - -	- - -	- - -
7	- - -	- - -	- - -
8	- - -	- - -	- - -
9	- - -	- - -	- - -
10	- - -	- - -	- - -

Combine Harvester	Make/Model	Cutting width(ft or m)	Engine power(HP)	Price(US$)
1	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -
5	- - -	- - -	- - -	- - -
6	- - -	- - -	- - -	- - -
7	- - -	- - -	- - -	- - -
8	- - -	- - -	- - -	- - -
9	- - -	- - -	- - -	- - -
10	- - -	- - -	- - -	- - -

Worksheet No. 3a. (Continued)

Wagon	Make/Model	Load capacity(tonnes)	Price(US$)
1	- - -	- - -	- - -
2	- - -	- - -	- - -
3	- - -	- - -	- - -
4	- - -	- - -	- - -
5	- - -	- - -	- - -
6	- - -	- - -	- - -
7	- - -	- - -	- - -
8	- - -	- - -	- - -
9	- - -	- - -	- - -
10	- - -	- - -	- - -

Worksheet No. 3b. Economic Information. Owning and Operating Agricultural Machinery Costs.

Sources: Departments of Agricultural Engineering and Agricultural Economics - University of Concepcion - Chillan - Chile.

Machine	Machine life Hours	Machine life Years	Annual Use (hr)	Remaining Value (% new cost)	Repairs, Maintenance & Shelter (% of Purchase Price)
Tractor	- - -	- - -	- - -	- - -	- - -
Disk Plow	- - -	- - -	- - -	- - -	- - -
Disk harrow	- - -	- - -	- - -	- - -	- - -
Spike-tooth harrow	- - -	- - -	- - -	- - -	- - -
Grain drill	- - -	- - -	- - -	- - -	- - -
Field sprayer	- - -	- - -	- - -	- - -	- - -
Fertilizer broadcaster	- - -	- - -	- - -	- - -	- - -
Combine harvester	- - -	- - -	- - -	- - -	- - -
Transport wagon	- - -	- - -	- - -	- - -	- - -

Worksheet No. 3c. Economic Information. Prices of Inputs and Products, Interest Rates and Inflation.

Sources: Department of Agricultural Economics - University of Concepcion - Chillan - Chile. Official Public and Private Publications, Bulletins, Magazines and Newspapers in Chile.

1)	Gasoline cost	___ $/L	8)	Interest rate	___ %/year
2)	Diesel fuel cost	___ $/L	9)	Inflation rate for year:	
3)	Engine oil cost	___ $/L		a. 1981	___ %/year
4)	Transmission oil cost	___ $/L		b. 1980	___ %/year
5)	Lubricant (grease) cost	___ $/kg		c. 1979	___ %/year
6)	Labor cost	___ $/h		d. 1978	___ %/year
7)	Custom hire cost for:			e. 1977	___ %/year
	a. plowing	___ $/ha		f. 1976	___ %/year
	b. disk harrowing	___ $/ha	10)	Wheat price	___ $/kg
	c. spike-tooth harrowing	___ $/ha	11)	Oats price	___ $/kg
	d. seeding	___ $/ha	12)	Hay price	___ $/kg
	e. aerial spraying	___ $/ha	13)	Lentils price	___ $/kg
	f. terrestrial spraying	___ $/ha	14)	Rapeseed price	___ $/kg
	g. combining	___ $/ha	15)	Barley price	___ $/kg

Worksheet No. 4. Agronomic Information on Wheat Production Systems.

Sources: Technology Transfer Program - Quilamapu Experiment Station - Agricultural Research Institute - Chillan - Chile. Wheat producers.

A. CROP ROTATIONS

Rotation 1: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _;

Rotation 2: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _;

Rotation 3: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _;

B. CROP YIELDS

1. Wheat ____ kg/ha
2. Oats ____ kg/ha
3. Hay ____ kg/ha
4. Lentils ____ kg/ha
5. Rapeseed ____ kg/ha
6. Barley ____ kg/ha

C. TIMELINESS COSTS (seeding and harvesting)

Crop	Operation	Timeliness losses after optimum period		
		kg-ha/day	kg-ha/week	kg-ha/month
Wheat	Seeding	- - -	- - -	- - -
Wheat	Harvesting	- - -	- - -	- - -
Oats	Seeding	- - -	- - -	- - -
Oats	Harvesting	- - -	- - -	- - -

Worksheet No. 4. (Continued)

D. CULTURAL PRACTICES - OPTIMUM PERIODS.

Cultural practice	Optimum period for Wheat	Optimum period for Oats	Optimum period for Pasture
Field cleaning	- - -	- - -	- - - -
Plowing	- - -	- - -	- - - -
Disking 1	- - -	- - -	- - - -
Disking 2	- - -	- - -	- - - -
Disking 3	- - -	- - -	- - - -
Disking 4	- - -	- - -	- - - -
Harrowing 1	- - -	- - -	- - - -
Harrowing 2	- - -	- - -	- - - -
Harrowing 3	- - -	- - -	- - - -
Seeding	- - -	- - -	- - - -
Spraying 1	- - -	- - -	- - - -
Spraying 2	- - -	- - -	- - - -
Fertilizer broadcasting	- - -	- - -	- - - -
Harvesting of cereals	- - -	- - -	- - - -

Worksheet No. 5. Estimation of Days Suitable for Field Work with Agricultural Machinery (tillage and planting).

Sources: Wheat Producers, Extension Specialists, Machinery Operators and Agricultural Researchers.

The interviewed person should estimate the number of days suitable for field work (tillage and seeding) in each of the 15 and 16 day periods, including Sundays and holidays.

Period	Estimated number of suitable days, according to respondent No.: 1	2	3	4	5	6	7	8	9	N=25
Apr 1 - Apr 15 (15 days)	---	---	---	---	---	---	---	---	---	----
Apr 16 - Apr 30 (15 days)	---	---	---	---	---	---	---	---	---	----
May 1 - May 15 (15 days)	---	---	---	---	---	---	---	---	---	----
May 16 - May 31 (16 days)	---	---	---	---	---	---	---	---	---	----
Jun 1 - Jun 15 (15 days)	---	---	---	---	---	---	---	---	---	----
Jun 16 - Jun 30 (15 days)	---	---	---	---	---	---	---	---	---	----
Jul 1 - Jul 15 (15 days)	---	---	---	---	---	---	---	---	---	----
Jul 16 - Jul 31 (16 days)	---	---	---	---	---	---	---	---	---	----
Aug 1 - Aug 15 (15 days)	---	---	---	---	---	---	---	---	---	----
Aug 16 - Aug 31 (16 days)	---	---	---	---	---	---	---	---	---	----
Sep 1 - Sep 15 (15 days)	---	---	---	---	---	---	---	---	---	----
Sep 16 - Sep 30 (15 days)	---	---	---	---	---	---	---	---	---	----

Worksheet No. 6a. Model Validation Data. (To compare the performance of the model either against recorded data for the system or against a subjective judgement of what the output should be, given a broad understanding of the system (Dent and Blackie, 1979).

Source: Interviews with wheat producers in the Andes Pre-Cordillera area.

A. AREA WORKED WITH THE MACHINERY COMPLEMENT (LAST 3 YEARS). YIELDS OBTAINED.

Crops	Area (ha)				Yield (kg/ha)
	79	80	81	$\bar{X}$	
Wheat	---	---	---	---	---
Oats	---	---	---	---	---
Lentils	---	---	---	---	---
Barley	---	---	---	---	---
Rapeseed	---	---	---	---	---

Worksheet No. 6b. (Continued). Model Validation Data.

B. CULTURAL PRACTICES FOR DIFFERENT CROPS.

Cultural practice	No. of passes	Wheat	Oats	Lentils	Barley	Rapeseed
Field cleaning	- - -	- - -	- - -	- - -	- - -	- - -
Plowing	- - -	- - -	- - -	- - -	- - -	- - -
Disking	- - -	- - -	- - -	- - -	- - -	- - -
Harrowing	- - -	- - -	- - -	- - -	- - -	- - -
Seeding	- - -	- - -	- - -	- - -	- - -	- - -
Spraying	- - -	- - -	- - -	- - -	- - -	- - -
Fertilizer broadcasting	- - -	- - -	- - -	- - -	- - -	- - -
Cereal harvesting	- - -	- - -	- - -	- - -	- - -	- - -

Worksheet No. 6c. (Continued). Model Validation Data.

C. **MACHINERY COMPLEMENT**

Tractor	Make/Model	Year	Engine Power (HP)
1	- - -	- - -	- - - -
2	- - -	- - -	- - - -
3	- - -	- - -	- - - -
4	- - -	- - -	- - - -

Disk plow	Make/Model	Year	No. of disks	Working width (m)
1	- - -	- - -	- - -	- - - -
2	- - -	- - -	- - -	- - - -
3	- - -	- - -	- - -	- - - -
4	- - -	- - -	- - -	- - - -

Disk harrow	Make/Model	Year	No. of disks	Working width (m)
1	- - -	- - -	- - -	- - - -
2	- - -	- - -	- - -	- - - -
3	- - -	- - -	- - -	- - - -
4	- - -	- - -	- - -	- - - -

Worksheet No. 6c. (Continued)

Spike-tooth harrow	Make/Model	Year	Working width (m)
1	- - -	- - -	- - -
2	- - -	- - -	- - -
3	- - -	- - -	- - -
4	- - -	- - -	- - -

Grain drill	Make/Model	Year	No. of rows	Row Width (m or inches)	Working width (m)
1	- - -	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -	- - -

Field sprayer	Make/Model	Year	No. of nozzles	Nozzle width (m or in.)	Working width (m)
1	- - -	- - -	- - -	- - -	- - -
2	- - -	- - -	- - -	- - -	- - -
3	- - -	- - -	- - -	- - -	- - -
4	- - -	- - -	- - -	- - -	- - -

Worksheet No. 6c. (Continued)

Fertilizer broadcaster	Make/Model	Year	Working Width (m)
1	- - -	- - -	- - - -
2	- - -	- - -	- - - -
3	- - -	- - -	- - - -
4	- - -	- - -	- - - -

Combine Harvester	Make/Model	Year	Engine Power (HP)	Working width (m or ft)
1	- - -	- - -	- - - -	- - - - -
2	- - -	- - -	- - - -	- - - - -
3	- - -	- - -	- - - -	- - - - -
4	- - -	- - -	- - - -	- - - - -

Transport wagon	Make/Model	Year	Load capacity (tonnes)
1	- - -	- - -	- - - - -
2	- - -	- - -	- - - - -
3	- - -	- - -	- - - - -
4	- - -	- - -	- - - - -

Worksheet No. 6c. (Continued)

OTHER MACHINES (animal traction equipment, haying equipment and other).

	Machine	Make/Model	Year	Working capacity (power, width, units)
1)				
2)				
3)				
4)				
5)				
6)				
7)				
8)				
9)				
10)				
11)				
12)				

APPENDIX B

Sizes and Prices of Machines Available from the Agricultural Machinery Dealers in Chillan - Chile

APPENDIX B

Sizes and Prices of Machines Available from the Agricultural Machinery Dealers in Chillan - Chile

TABLE B-1. Tractor Power - Price Relationship.

Tractor Identification	Power at P T-O kW	HP	Price (US $)#
M.F. - 240 (United Kingdom)	28.13	37.70	17,880
J.D. - 1040 (Germany)	32.06	43.00	17,940
D.B. - 1190 (United Kingdom)	33.79	45.28	18,120
Ford - 4600 (Brazil)	38.02	50.94	18,750
M.F. - 265 (Brazil)	39.18	52.50	19,668
J.D. - 1640 (Germany)	40.30	54.00	21,480
M.F. - 265 (United Kingdom)	41.42	55.50	21,540
D.B. - 1390 (United Kingdom)	47.17	63.21	23,160
Ford - 6600 (Brazil)	49.28	66.04	20,420
M.F. - 290 (Brazil)	52.48	71.00	21,564
M.F. - 290 (United Kingdom)	55.62	74.52	24,000
J.D. - 2140 (Germany)	63.36	84.90	28,728
D.B. - 1690 (United Kingdom)	72.51	97.17	33,612
J.D. - 3140 (Germany)	73.79	99.05	36,168

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.94^{**}$

$a = 4993.91$

$b = 379.14$

$\hat{Y}(\$) = 4993.91 + 379.14 \times \text{Power in kW}$

TABLE B-2. Disk Plow Size - Price Relationship.

Plow Identification	Number Disks	Working Width (m)	Price# (US $)
Pascualli (Italy)	2	0.48	1,206
Ramsomes-3 (Chile)	3	0.72	1,990
M.F.-204-3 (United Kingdom)	3	0.72	2,292
Jumil (Brazil)	3 (rev.)	0.69	2,950
Ramsomes-4 (Chile)	4	0.96	2,490
M.F.-204-4 (United Kingdom)	4	0.96	2,820
Bamford-634 (United Kingdom)	4	1.20	3,324
Ramsomes-5 (Chile)	5	1.20	2,700
M.F.-206 (United Kingdom)	5	1.20	3,720
Bamford 635 (United Kingdom)	5	1.20	3,950

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.82^{**}$

$a = 284.3$

$b = 647.3$

$\hat{Y} = 284.3 + 647.3 \times \text{Number of Disks}$

TABLE B-3. Off-set Disk Harrow Size - Price Relationship.

Harrow Identification	Number Disks	Working Width Disks	Working Width Metres	Price# (US $)
Giambenedetti G-H6 (Argentina)	12	6	1.37	3,560
Breuer (Chile)	14	7	1.60	3,995
TATU-Marchesan GNL-C (Brazil)	16	8	1.83	5,568
Giambenedetti G-H8 (Argentina)	16	8	1.83	4,435
TATU-Marchesan GNL-C (Brazil)	18	9	2.06	6,120
John Deere 225 (USA)	18	9	2.06	7,176
Connor Shea (Australia)	18	9	2.06	7,260
Bamford (United Kingdom)	22	11	2.51	7,560
John Deere (USA)	22	11	2.51	8,268
Bamford (United Kingdom)	24	12	2.74	8,688

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.94^{**}$

$a = -1906.5$

$b = 907.7$

$\hat{Y} = -1906.5 + 907.7 \times \text{Number Working Disks}$

TABLE B-4. Spike-Tooth Harrow Size - Price Relationship.

Harrow Identification	Working Width (Metres)	Price# (US $)
Local Manufacturing (Chile)	2.40	700
P.J. Zweegers (Holland)	2.44	892
Local Manufacturing (Chile)	3.20	1,000
P.J. Zweegers (Holland)	3.66	1,235
P.J. Zweegers (Holland)	4.88	1,560
Local Manufacturing (Chile)	6.40	1,625
P.J. Zweegers (Holland)	6.40	1,970

#Source: Agricultural Machinery Dealers - Chillan - Chile.

r = 0.96**

a = 220.68

b = 253.14

$\hat{Y}$ = 220.68 + 253.14 x Working Width in Metres

TABLE B-5. Grain Seeder Size - Price Relationship.

Seeder Identification	Number of Rows	Seeding Width (metres)	Price# (US $)
Connor Shea (Australia)	10	1.78	6,240
M.F.-33 (United Kingdom)	15	2.66	8,220
Connor Shea (Australia)	14	2.49	8,400
John Deere 8250 (USA)	14	2.49	8,880
M.F.-33 (United Kingdom)	17	3.02	9,576
Connor Shea (Australia)	18	3.20	9,840
John Deere (USA)	18	3.20	11,868

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.91^{*}$

$a = 699.29$

$b = 548.38$

$\hat{Y} = 699.29 + 548.38 \times \text{Number of Rows}$

TABLE B-6. Fertilizer Broadcaster Size - Price Relationship.

Broadcaster Identification	Working Width (metres)	Price# (US $)
VICON PS - 302 (Holland)	12	1,272
LELY 1000 (United Kingdom)	12	1,740
VICON PS - 402 (Holland)	14	1,794
P.J. Zweegers Vebrax 400 (Holland)	14	1,980
VICON PS - 602 (Holland)	16	2,160
VICON PS - 802 (Holland)	18	2,280

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.87$*

$a = -55.61$

$b = 134.41$

$\hat{Y} = -55.61 + 134.41 \times$ Working Width in metres

TABLE B-7. Field Sprayer Size - Price Relationship.

Sprayer Identification	Number of Nozzles	Working Width (metres)	Price# (US $)
Parada (Chile)	14	7	2,690
Hatsuta H-320 (Japan)	14	7	2,862
Tecnoma T-400 (Brazil)	16	8	3,084
K.O. - 400 (Brazil)	16	8	3,540
Hatsuta H-420 (Japan)	18	9	4,490
Tecnoma T-600 (Brazil)	18	9	4,150
Parada (Chile)	20	10	4,340
F.M.C. - D010150 (USA)	20	10	5,302
K.O. - 540 (Brazil)	24	12	4,656

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.84^{**}$

$a = -261.66$

$b = 234.18$

$\hat{Y} = -261.66 + 234.18 \times \text{Number of Nozzles}$

TABLE B-8. Combine Harvester Size - Price Relationship.
Combine Harvester Size - Power Relationship.

Combine Identification	Cutting width ft	m	Engine Power HP	kW	Price# (US $)
MF - 310	12	3.65	105	78.30	45,000
MF - 3640	12	3.65	105	78.30	64,200
New Holland-Clayson 1530	13	3.96	111	82.77	64,920
HD - 960	14	4.26	116	86.50	54,000
HD - 955	14	4.26	116	86.50	54,000
John Deere 4420	14	4.26	120	89.48	82,800
New Holland-Clayson 4040	15	4.57	144	107.38	85,588
John Deere 6620	16	4.87	150	111.85	105,600

#Source: Agricultural Machinery Dealers - Chillan - Chile.

Size-Price Relationship: r = 0.77*

a = -85805.48

b = 11295.92

$\hat{Y}$ (\$) = -85805.48 + 11295.92 x Width in Feet

Size-Power Relationship: r = 0.93**

a = -27.38

b = 8.55

$\hat{Y}$ (kW) = -27.38 + 8.55 x Width in feet

TABLE B-9. Transport Wagon Load Capacity - Price Relationship.

Wagon Identification	Load Capacity (Tonnes)	Price# (US $)
Coloso (Chile)	2.0	2,100
SOGECO T - 25 M (Chile)	2.5	3,180
Coloso (Chile)	4.0	3,240
SOGECO T - 40 S (Chile)	4.0	3,300
Gehl - 500 (USA)	5.0	4,880
SOGECO T - 60 S (Chile)	6.0	6,030
Coloso (Chile)	8.0	8,140
SOGECO T - 80 S (Chile)	8.0	8,310

#Source: Agricultural Machinery Dealers - Chillan - Chile.

$r = 0.98^{**}$

$a = -151.78$

$b = 1022.64$

$\hat{Y} = -151.78 + 1022.64 \times$ Load Capacity in Tonnes

APPENDIX C

FORTRAN Program Listing

```
      PROGRAM TRIGO(INPUT,OUTPUT,TAPE6=OUTPUT)
C              PROGRAM TRIGO
C   THIS PROGRAM SELECTS FIELD MACHINERY FOR WHEAT PRODUCERS
C   LOCATED IN SOUTH-CENTRAL CHILE. THE MACHINERY SYSTEM CON-
C   SISTS OF TRACTOR(S), DISK PLOW, OFF-SET DISK HARROW,
C   SPIKE-TOOTH HARROW, GRAIN SEEDER, FERTILIZER BROADCASTER,
C   FIELD SPRAYER, SELF-PROPELLED COMBINE HARVESTER AND WAGON.
C              VARIABLE DICTIONARY
C   ALENT= AREA SEEDED WITH LENTILS (HA)
C   AOAT=  AREA SEEDED WITH OATS (HA)
C   AREAC= AREA USED TO SIZE THE COMBINE; EQUIVALENT TO 2/3 AOAT
C         PLUS AWHEAT
C  AREAD= AREA TO BE DISKED (HA)
C  AREAF= AREA TO BE FERTILIZED WITH THE BROADCASTER
C  AREAH= AREA TO BE HARROWED (HA)
C  AREAP= AREA TO BE PLOWED (HA)
C  AREASP= AREA TO BE SPRAYED (HA)
C  AREASD= AREA TO BE SEEDED (HA)
C  AREAOP= AREA COMPLETED IN THE OPTIMUM PERIOD (HA)
C  AREATI= AREAP WHEN J=1(PLOWING); =AREASD WHEN J=4(SEEDING); (HA)
C  AREATO= TOTAL AREA WE WANT TO PLOW, SEED OR HARVEST (HA)
C  ARLAST= AREA LEFT UNDONE AFTER USING INTEGER PART OF VARIABLE DAYS
C  ARPDAY= AREA WORKED EACH SUITABLE DAY (HA)
C  AVARDY= AVERAGE AREA WORKED EACH CALENDAR DAY (HA)
C  AWHEAT= AREA SEEDED WITH WHEAT (HA)
C  COSTFL= FUEL COST
C  COSTLA= LABOR COST
C  COSTTM= TIMELINESS COST
C  COSTRM= REPAIR & MAINTENANCE COST
C  COSTOW= OWNERSHIP COST
C  CRF= CAPITAL RECOVERY FACTOR. TAKES A PRESENT VALUE COST
C       AND DISTRIBUTES IT INTO ANNUAL EQUIVALENT COSTS OVER THE
C       GIVEN NUMBER OF YEARS WITH COMPOUND INTEREST CONSIDERED
C  CSTFL1= FUEL COST FOR LOWEST COST SYSTEM
C  CSTLA1= LABOR COST FOR LOWEST COST SYSTEM
C  CSTTM1= TIMELINESS COST FOR LOWEST COST SYSTEM
C  CSTRM1= REPAIR & MAINTENANCE COST FOR LOWEST COST SYSTEM
C  CSTOW1= OWNERSHIP COST FOR LOWEST COST SYSTEM
C  CSTFLT= FUEL COST FOR 2ND LOWEST COST SYSTEM
C  CSTLAT= LABOR COST FOR 2ND LOWEST COST SYSTEM
C  CSTTMT= TIMELINES COST FOR 2ND LOWEST COST SYSTEM
C  CSTRMT= REPAIR & MAINTENANCE COST FOR 2ND LOWEST COST SYSTEM
C  CSTOWT= OWNERSHIP COST FOR 2ND LOWEST COST SYSTEM
C  CSTFL3= FUEL COST FOR 3RD LOWEST COST SYSTEM
C  CSTLA3= LABOR COST FOR 3RD LOWEST COST SYSTEM
C  CSTTM3= TIMELINESS COST FOR 3RD LOWEST COST SYSTEM
C  CSTRM3= REPAIR & MAINTENACE COST FOR 3RD LOWEST COST SYSTEM
C  CSTOW3= OWNERSHIP COST FOR 3RD LOWEST COST SYSTEM
C  DAYF1= PROBABILITY OF A SUITABLE DAY FOR PLOWING (PENALTY PERIOD)
C  DAYF4= PROBABILITY OF A SUITABLE DAY FOR SEEDING (PENALTY PERIOD)
C  DAYF8= PROB. OF A SUITABLE DAY FOR HARVESTING (PENALTY PERIOD)
C  DAYS= CALENDAR DAYS USED TO FINISH "EXCESS" AREA
C  EFCA= TEMPORARY EFFECTIVE FIELD CAPACITY (HA/HR)
C  EFCAP= EFCPL WHEN J=1(PLOW); =EFCSD WHEN J=4(SEEDER) (HA/HR)
C  EFCMAX= TEMPORARY EFFECTIVE FIELD CAPACITY (HA/HR)
C  EFCP= PLOWING EFFECTIVE FIELD CAPACITY NEEDED (HA/HR)
C  EFCPL= EFFECTIVE FIELD CAPACITY OF SELECTED PLOW (HA/HR)
C  EFCSD= EFFECTIVE FIELD CAPACITY OF SELECTED SEEDER (HA/HR)
C  EXCESS= AREA COMPLETED OUTSIDE OPTIMUM PERIOD (HA)
C  FERCAP= WORK CAPACITY OF FERTILIZER (HA)
C  HRCOMB= HOURS WORKED BY THE COMBINE (HR/YR)
C  HRDISK= TOTAL HOURS SPENT DISKING (HR/YR)
C  HRFERT= TOTAL HOURS SPENT FERTILIZING (HR/YR)
C  HRHARR= TOTAL HOURS SPENT FERTILIZING (HR/YR)
C  HRPDAY= HOURS WORKED PER DAY
C  HRPLOW= TOTAL HOURS SPENT PLOWING (HR/YR)
C  HRSEED= TOTAL HOURS SPENT SEEDING (HR/YR)
C  HRSPRY= TOTAL HOURS SPENT SPRAYING (HR/YR)
C  HRUSE= HRPLOW WHEN J=1; =HRDISK WHEN J=2; =HRHARR WHEN J=3;
C  HRUSE= HRSEED WHEN J=4; =HRFERT WHEN J= 5; =HRSPRY WHEN J=6
C  HRUSE= HRPLOW+HRDISK+HRHARR+HRSEED+HRFERT+HRSPRY+HRCOMB WHEN J=7
C  HRUSE1= HOURS OF USE FOR THE LOWEST COST SYSTEM
C  HRUSE2=HOURS OF USE FOR 2ND LOWEST COST SYSTEM
C  HRUSE3= HOURS OF USE FOR 3RD LOWEST COST SYSTEM
C  HRUSEW= HOURS OF USE OF WAGON
C  IB= BANK'S INTEREST
C  ICOUNT= FLAG TO SELECT THE MINIMUM SIZE COMBINATION (=1) AND TO CARRY
C  OUT INCREMENTATION OF SIZES (=2)
C  IDAYS= INTEGER PART OF "DAYS" USED TO FINISH "EXCESS" AREA
C  IDAYL= DAYS "ARLAST" WILL BE PENALIZED
C  IDISK= SIZE OF A GIVEN DISK (6 TO 14 DISKS)
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C   IF= FARMER'S RATE OF RETURN
C   INFU= FUEL INFLATION (PERCENT/YR)
C   INCR= CROP INFLATION (PERCENT/YR)
C   INCOST=PURCAHSE COST OF A MACHINE ($)
C   IFERT= SIZE OF A GIVEN FERTILIZER (METRES)
C   IHARR= SIZE OF A GIVEN HARROW (METRES)
C   INLA= LABOR INFLATION (PERCENT/YR)
C   INM= MACHINERY INFLATION (PERCENT/YR)
C   I3FERT= FERTILIZER SIZE FOR 3RD LOWEST COST SYSTEM (METRES)
C   I3HARR= HARROW SIZE FOR 3RD LOWEST COST SYSTEM (METRES)
C   I3PLOW= PLOW SIZE FOR 3RD LOWEST COST SYSTEM (DISKS)
C   I3SEED= SEEDER SIZE FOR 3RD LOWEST COST SYSTEM (ROWS)
C   I3SPRY= SPRAYER SIZE FOR 3RD LOWEST COST SYSTEM (METRES)
C   ITDISK= DISK SIZE FOR 2ND LOWEST COST SYSTEM (DISKS)
C   ITFERT= FERTILIZER SIZE FOR 2ND LOWEST COST SYSTEM (METRES)
C   ITHARR= HARROW SIZE FOR 2ND LOWEST COST SYSTEM (METRES)
C   ITPLOW= PLOW SIZE FOR 2ND LOWEST COST SYSTEM (DISKS)
C   ITSEED= SEEDER SIZE FOR 2ND LOWEST COST SYSTEM (ROWS)
C   ITSPRY= SPRAYER SIZE FOR 2ND LOWEST COST SYSTEM (METRES)
C   J= MACHINE IDENTIFICATION NUMBER; 1=PLOW; 2=DISK; 3=HARROW; 4=SEEDER;
C      5=FERTILIZER; 6=SPRAYER; 7=TRACTOR; 8=COMBINE; 9=WAGON.
C   KJ= INDICATES MACHINE SIZE IN UNITS OF DISKS, METRES OR ROWS
C   LCOSCW= LEAST COST OF COMBINE AND WAGON ($)
C   LCOST2= 2ND LOWEST TOTAL COSTS SYSTEM ($)
C   LCOST3= 3RD LOWEST TOTAL COST SYSTEM ($)
C   LCOSTC= LEAST TOTAL COST SYSTEM WITHOUT COMBINE AND WAGON ($)
C   LCOSTS= LEAST TOTAL COST SYSTEM WITH COMBINE AND WAGON ($)
C   NPASS= INDICATES NUMBER OF DISKS PASSES (2, 3, OR 4)
C   PKW(1) TO PKW(5)= POWER REQUIRED BY THE DIFFERENT PLOWS (KW)
C   PKW(1) TO PKW(9)= POWER REQUIRED BY THE DIFFERENT DISKS (KW)
C   POWER= POWER NEEDED TO OPERATE AN IMPLEMENT (KW)
C   POWER(1,1)= TRACTOR POWER FOR THE LEAST COST SYSTEM (KW)
C   POWERT= TRACTOR POER FOR THE 2ND LEAST COST SYSTEM (KW)
C   POWER3= TRACTOR POWER FOR THE 3RD LEAST COST SYSTEM (KW)
C   PRCROP= CROP PRICE ($/KG)
C   PRFUEL= PRICE OF DIESEL FUEL ($/L)
C   PRICEW= PRICE OF WHEAT ($/KG)
C   PROB= PROBABILITY LEVEL TO SELECT SUITABLE DAYS
C   PWRNEW= CALCULATED NEW POWER (KW)
C   RV= REMAINING VALUE OF A MACHINE (10 PERCENT OF INCOST)
C   ROTATN= ROTATION USED (1, 2, OR 3)
C   SPRCAP= SPRAYER WORK CAPACITY (HA)
C   TCOSTC= TEMPORARY STORAGE FOR TOTAL SYSTEM COST ($)
C   TCSTFL= TOTAL FUEL COST ($)
C   TCSTLA= TOTAL LABOR COST ($)
C   TCSTOW= TOTAL OWNERSHIP COST ($)
C   TCSTRM= TOTAL REPAIR & MAINTENANCE COST ($)
C   TCSTTM= TOTAL TIMELINESS COST ($)
C   THARR= INITIAL TIME ASSIGNED TO HARROW A GIVEN AREA (HR)
C   TIMED= TIME AVAILABLE FOR DISKING (DAYS)
C   TIMED(4)= TIME AVAILABLE FOR EACH OF THE 4 DISKING OPERATIONS (DAYS)
C   TIMEF= TIME AVAILABLE FOR FERTILIZING (DAYS)
C   TIMEH= TIME AVAILABLE FOR HARROWING (DAYS)
C   TIMEOP= TIME AVAILABLE IN THE OPTIMUM PERIOD (DAYS)
C   TIMEP= TIME AVAILABLE FOR PLOWING (DAYS)
C   TIMESD= TIME AVAILABLE FOR SEEDING (DAYS)
C   TIMESP= TIME AVAILABLE FOR SPRAYING (DAYS)
C   TIMEW= TIME AVAILABLE FOR HARVESTING WHEAT (DAYS)
C   TIMOP1= TIME AVAILABLE FOR PLOWING IN THE OPTIMUN PERIOD (DAYS)
C   TIMOP4= TIME AVAILABLE FOR SEEDING IN THE OPTIMUM PERIOD (DAYS)
C   TIMOP8= TIME AVAILABLE FOR HAVESTING IN THE OPTIMUM PERIOD (DAYS)
C   TSDR= TIME ALOCATED TO THE SEEDER (HR)
C   USPW= UNIFORM SERIES PRESENT WORTH FACTOR.(THE RECIPROCAL OF CRF).
C         CONVERTS FUTURE UNIFORM SERIES OF COSTS INTO PRESENT VALUE
C   WAGE= LABOR COST ($/HR)
C   WKHRS1= WORK HOURS PER DAY FOR PLOWING AND HARVESING
C   WKHRS2= WORK HOURS PER DAY FOR OTHER OPERATIONS
C   XCOST= TOTAL COST FOR 10 YEARS OF A GIVEN MACHINE ($)
C   XDISK(9)= NINE SIZES OF DISKS
C   XFERT(7)= SEVEN SIZES OF FERTILIZERS
C   XHARR(8)= EIGHT SIZES OF HARROWS
C   XPLOW(5)= FIVE SIZES OF PLOWS
C   XSEED(9)= NINE SIZES OF SEEDERS
C   XSPRAY(7)= SEVEN SIZES OF SPRAYERS
C   YIELDW= YIELD OF WHEAT (KG/HA)
C   YLDWH= YIELD OF WHEAT (KG/HA)
C   MINFLG=LOGICAL VARIABLE - TRUE IF MINIMUM SET IS BEING COMPUTED
C   LCOSTCO=COST OF COMBINE AND WAGON
C   TCOSTFL=COST OF FUEL FOR COMBINE
C   TCOSTLA=COST OF LABOR FOR COMBINE AND WAGON
C   TCOSTTM=COST OF TIMELINESS FOR COMBINE
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C  TCOSTOW=COST OF OWNERSHIP FOR COMBINE
C  FEET=SIZE OF LEAST COST COMBINE
C  CUCOST=COST OF CUSTOM HARVEST
C  AECCOM=ANNUAL EQUIVALENT COST OF COMBINE AND WAGON
C  HRCOMB=HOURS REQUIRED FOR COMBINE
C  POWERCO=POWER REQUIRED FOR COMBINE
C  TWO=LOGICAL VARIABLE - TRUE IF TWO TRACTORS ARE REQUIRED
C  POWER1=POWER SENT TO COST
C  POWER2=POWER OF SECOND TRACTOR
C   COST1LA=COST FO ONE LABORER FOR COMBINE
C  ICOST1=COST OF COMBINE WITHOUT WAGON
C  PPRHA=COST PER HECTARE FOR TEN YEARS
C
C  INDEXES FOR THE FOLLOWING VARIABLES:
C  (X,Y)  X=1 FOR FIRST LEAST COST SET
C          X=2 FOR SECOND LEAST COST SET
C         X=3 FOR THIRD LEAST COST SET
C         X=4 FOR MINIMUM SET
C         X=5 FOR COMBINE
C
C  GPRYR(5,5)=FUEL CONSUMPTION PER YEAR FOR EACH SET
C  GPRHA(5)=ANNUAL FUEL CONSUMPTION PER HECTARE
C  AEC(5,2)=ANNUAL EQUIVALENT COST-(X,1)
C          =ANNUAL EQUIVALENT COST PER HECTARE-(X,2)
C  HRTRC(5,2)=HOURS REQUIRED FOR TRACTOR #1-(X,1)
C            =HOURS REQUIRED FOR TRACTOR #2-(X,2)
C  HRLABR(5,2)=HOURS OF LABOR REQUIRED FOR TRACTOR #1-(X,1)
C             =HOURS OF LABOR REQUIRED FOR TRACTOR #2-(X,2)
C  TLABR(5,2)=TOTAL HOURS OF LABOR-(X,1)
C            =TOTAL HOURS OF LABOR PER HECTARE-(X,2)
C
      REAL IB,IF,INM,INFU,INLA,INCR,INCOST,LCOSTCO,LCOSTC,LCOST2,LCOST3,
     +LCOSTS1,LCOSTS2,LCOSTM,LCOSTSM,LCOSTS3,ICOST1
      REAL MCSTFL,MCSTLA,MCSTTM,MCSTRM,MCSTOW
      LOGICAL MINFLG,TWO
      INTEGER PROB
      DIMENSION TIMED(4),XPLOW(5),XDISK(9),XHARR(8),XSEED(9),
     +XFERT(7),XSPRAY(7)
      DIMENSION GPRYR(5,5),GPRHA(5),AEC(5,2),HRTRC(5,2),HRLABR(5,2),
     +TLABR(5,2),POWERP(5,3),PPRHA(5)
      COMMON/TIMELI/DAYF1,DAYF4,DAYF8,TIMOP1,TIMOP4,TIMOP8,PRICEW,YLDWH
      COMMON/COSTC/IB,IF,INM,INFU,INLA,INCR,WAGE,PRFUEL
      COMMON/COMB/YIELDW,PRCROP,AWHEAT,AOAT,ALENT
      COMMON/TEMP/TIMEP,TIMED,TIMEH,TIMESD,TIMEF,TIMESP,TIMEW
      COMMON /ZZZ/ HRHARR,HRDISK,NPASS
      COMMON/COMPCOM/COST1LA,ICOST1
      COMMON/FLAG/TWO
      COMMON/M/MINFLG
      DATA IDASH,GPRYR,GPRHA,AEC,HRTRC,HRLABR,TLABR,POWERP,PPRHA
     +/1H-,90*0/
      PRINT*, 'ENTER ROTATION TO BE USED'
      PRINT*, 'OATS-LENTILS-WHEAT-PASTURE  ROTATION=1'
      PRINT*, 'OATS-WHEAT-PASTURE  ROTATION=2'
      PRINT*, 'WHEAT-PASTURE  ROTATION=3'
      READ*, ROTATN
      PRINT*, 'ENTER AREA OATS, AREA WHEAT, AND AREA LENTILS'
      PRINT*, 'ENTER ALL ON ONE LINE SEPARATED BY COMMAS AS REAL '
      PRINT*, 'NUMBERS  LENTILS NOT TO EXCEED 10 PERCENT OF TOTAL'
      PRINT*, 'AREA'
      READ*, AOAT,AWHEAT,ALENT
      PRINT*, 'ENTER NUMBER OF DISK PASSES 2, 3, OR 4 AS INTEGER'
      READ*, NPASS
      PRINT*, 'ENTER WEATHER PROBABILITY LEVEL 70, 80, OR 90'
      PRINT*, 'AS INTEGER'
      READ*, PROB
      PRINT*, 'ENTER NO. OF HRS. PER DAY FOR PLOWING AND HARVEST'
      READ*, WKHRS1
      PRINT*, 'ENTER NO. OF HRS. PER DAY FOR OTHER OPERATIONS'
      READ*, WKHRS2
      PRINT*, 'ENTER YIELD OF WHEAT EXPECTED IN KG/HA'
      READ*, YLDWH
      PRINT*, 'ENTER PRICE OF WHEAT EXPECTED IN $/KG'
      READ*, PRICEW
      PRINT*, 'ENTER THE PRICE OF FUEL IN $/L'
      READ*, PRFUEL
      PRINT*, 'ENTER WAGE IN $/HR'
      READ*, WAGE
      PRINT *,'ENTER BANK INTEREST,FARMER*S RATE OF RETURN, INFLATION
     +FOR MACHINERY, FUEL INFLATION, LABOR INFLATION, AND CROP INFLATION
     + ON ONE LINE SEPARATED BY COMMAS AND IN DECIMAL FORM.'
      READ *,IB,IF,INM,INFU,INLA,INCR
```

```
C C

C INC
C  TH
C  IM
C  IN

1
C CALC

2
C CALC

3
C CALC

4
C CALC

5
C CALCU
```

```
      PRINT*,'ENTER RISK FACTOR'
      READ*,RISK
      AREATI=0.0
      EFCAP=0.0
      TWO=.FALSE.
C  THE FOLLOWING THREE LINES INITIALIZE THE LEAST COST
C  STORAGE VARIABLES WITH ARBITRARILY HIGH FIGURES.
      LCOSTC=10000000000.
      LCOST2=10000000000.
      LCOST3=1000000000.
      ICOUNT=1
      MINFLG=.TRUE.
      POWERP(1,2)=0
      IPLOW=1
      IDISK=1
      IHARR=1
      ISEED=1
      IFERT=1
      ISPRAY=1
      NPLOW=5
      NDISK=9
      NSEED=9
      NFERT=7
      NSPRAY=7
      NHARR=8
      POWER=0.0
      TCOSTC=0.0
C CALCULATE AREA FOR EACH IMPLEMENT
      IF(AOAT.GT.AWHEAT)THEN
      AREAP=AOAT
      ELSE
      AREAP=AWHEAT
      ENDIF
      IF(ROTATN.EQ.1)THEN
      AREAD=AOAT+ALENT+AWHEAT
      AREAH=AREAD
      AREASD=AREAD
      AREAC=AREAD
      AREAF=AOAT+AWHEAT
      AREASP=AREAF
      ELSE IF(ROTATN.EQ.2)THEN
      AREAD=AOAT+AWHEAT
      AREAH=AREAD
      AREASD=AREAD
      AREAC=AREAD
      AREAF=AREAD
      AREASP=AREAD
      ELSE
      AREAD=AWHEAT
      AREAH=AWHEAT
      AREASD=AWHEAT
      AREAC=AWHEAT
      AREAF=AWHEAT
      AREASP=AWHEAT
      ENDIF
      AREAT=AWHEAT+AOAT+ALENT
C  INCOST(J)=INITAL COST OF PLOW,DISK,......TRACTOR
C   THE EQUATIONS THAT PREDICT THE COST OF DIFFERENT SIZE
C   IMPLEMENTS WERE DERIVED FROM A SURVEY OF FARM MACHINERY
C   IN CHILE IN DEC. 1981 BY EDMUNDO HETZ.
      DO 1 J=1,5
      KJ=J+1
1     XPLOW(J)=284.3+647.3*KJ
C CALCULATE INITIAL COST OF DISK
      DO 2 J=1,9
      KJ=J+5
2     XDISK(J)=-1906.5+907.7*KJ
C CALCULATE INITIAL COST OF HARROW
      DO 3 J=1,8
      KJ=J+4
3     XHARR(J)=220.68+253.14*0.5*KJ
C CALCULATE INITIAL COST OF SEEDER
      DO 4 J=1,9
      KJ=J+9
4     XSEED(J)=699.29+548.38*KJ
C CALCULATE INITIAL COST OF FERTILIZER APPLICATOR
      DO 5 J=1,7
      KJ=J+9
5     XFERT(J)=-55.61+134.41*KJ
C CALCULATE INITIAL COST OF SPRAYER
      DO 6 M=1,8
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      KJ=M+11
6     XSPRAY(M)=-261.66+234.18*KJ
      CALL TIMEAV(PROB,NPASS,WKHRS1,WKHRS2)
      CALL COMBINE(TIMEW,RISK,LCOSTCO,TCOSTFL,TCOSTLA,
     +TCOSTTM,TCOSTOW,TCOSTRM,FEET,CUCOST,AECCOM,
     +WKHRS1,WKHRS2,HRCOMB,POWERCO)
C  SELECT THE SMALLEST IMPLEMENT THAT CAN DO THE JOB
C  IN THE TIME AVAILABLE FOR THE SELECTED ROTATION,AREA,ETC.
      CALL PLOW(AREAP,TIMEP,POWER,IPLOW,HRPLOW,EFCPL,ICOUNT)
      CALL DISK(AREAD,TIMED,POWER,EFCSD,IDISK,AREASD,HRDISK,
     +ISEED,HRSEED,NPASS,ICOUNT)
      IF (NPASS.LE.2.AND..NOT.TWO) THEN
      CALL HARROW(AREAH,TIMEH,AREASD,TIMESD,IHARR,HRHARR,ISEED,
     +HRSEED,EFCSD,NPASS,ICOUNT)
      ELSEIF (NPASS.LE.2.AND.TWO) THEN
      CALL HARR2(AREAH,TIMEH,IHARR,HRHARR,NPASS,ICOUNT)
      ELSE
      IHARR=0
      ENDIF
      IF (TWO) CALL SDR2(AREASD,TIMESD,ISEED,POWER2,HRSEED,EFCSD,
     +ICOUNT)
      IF (.NOT.TWO) CALL SEEDER(AREASD,ISEED,HRSEED,ICOUNT,EFCSD)
      CALL FERTIL(AREAF,TIMEF,IFERT,HRFERT,ICOUNT)
      CALL SPRAYR(AREASP,TIMESP,ISPRAY,HRSPRY,ICOUNT,AREAT)
      I=IPLOW
      MM=IDISK
      K=IHARR
      M=IFERT
      L=ISEED
      N=ISPRAY
      IF(I+2.LT.NPLOW) NPLOW=I+2
      IF(MM+2.LT.NDISK) NDISK=MM+2
      IF(K+2.LT.NHARR)NHARR=K+2
      IF(L+4.LT.NSEED) NSEED=L+4
      IF(M+2.LT.NFERT)NFERT=M+2
      IF (NPASS.GT.2)NHARR=0
      IF(N+2.LT.NSPRAY)NSPRAY=N+2
      ICOUNT=2
      DO 11 IPLOW=I,NPLOW
      CALL PLOW(AREAP,TIMEP,POWER,IPLOW,HRPLOW,EFCPL,ICOUNT)
      DO 12 IDISK=MM,NDISK
      IF (.NOT.TWO) CALL DISK(AREAD,TIMED,POWER,EFCSD,IDISK,
     +AREASD,HRDISK,ISEED,HRSEED,NPASS,ICOUNT)
      IF (TWO) CALL DISK2(AREAD,TIMED,IDISK,POWER,HRDISK,NPASS,
     +ICOUNT)
      DO 13 IHARR=K,NHARR
      IF (.NOT.TWO)
     +CALL HARROW(AREAH,TIMEH,AREASD,TIMESD,IHARR,HRHARR,ISEED,HRSEED,
     +EFCSD,NPASS,ICOUNT)
      IF (TWO) CALL HARR2(AREAH,TIMEH,IHARR,HRHARR,NPASS,
     +ICOUNT)
      DO 14 ISEED=L,NSEED
      IF (.NOT.TWO)
     +CALL SEEDER(AREASD,ISEED,HRSEED,ICOUNT,EFCSD)
      IF (TWO) CALL SDR2(AREASD,TIMESD,ISEED,POWER2,HRSEED,
     +EFCSD,ICOUNT)
      DO 15 IFERT=M,NFERT
      CALL FERTIL(AREAF,TIMEF,IFERT,HRFERT,ICOUNT)
      DO 16 ISPRAY=N,NSPRAY
      CALL  SPRAYR(AREASP,TIMESP,ISPRAY,HRSPRY,ICOUNT,AREAT)
C SUBR COST REQUIRES EFC FOR TIMELINESS (PLOW,SEEDER,COMBINE)
C SUB COST REQUIRES AREA FOR TIMELINESS (PLOW,SEEDER,COMBINE)
C SUBR COST REQUIRES HOURS OF USE OF EACH MACHINE FOR EACH
C COMBINATION
C LCOSTC=LEAST COST COMBINATION
C TCOSTC=TOTAL COST OF COMBINATION
C CALCULATE COST OF THE 7 MACHINES OF EACH COMBINATION
C PLOW, DISK, ... SPRAYER, TRACTOR
C  THE FOLLOWING VARIABLES (HRCOMB AND LCOSCW) ARE DUMMY VALUES
C  THAT REPRESENT HOURS FOR COMBINE AND COST OF COMBINE.
      TCOSTC=0.0
      TCSTTM=0.
      TCSTFL=0.
      TCSTLA=0.
      TCSTRM=0.
      TCSTOW=0.
      DO 21 J=1,8
      IF(J.EQ.1)  INCOST=XPLOW(IPLOW)
      IF(J.EQ.2)  INCOST=XDISK(IDISK)
      IF(J.EQ.3)  INCOST=XHARR(IHARR)
      IF(J.EQ.4)  INCOST=XSEED(ISEED)
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      IF(J.EQ.5)  INCOST=XFERT(IFERT)
      IF(J.EQ.6)  INCOST=XSPRAY(ISPRAY)
      IF(J.EQ.7)  INCOST=4993.91+379.14*POWER
      IF(J.EQ.1)  EFCAP=EFCPL
      IF(J.EQ.4)  EFCAP=EFCSD
      IF(J.EQ.1)  AREATI=AREAP
      IF(J.EQ.4)  AREATI=AREASD
      IF(J.EQ.1)  HRUSE=HRPLOW
      IF(J.EQ.2)  HRUSE=HRDISK
      IF(J.EQ.3)  HRUSE=HRHARR
      IF(J.EQ.4)  HRUSE=HRSEED
      IF(J.EQ.5)  HRUSE=HRFERT
      IF(J.EQ.6)  HRUSE=HRSPRY
      IF(NPASS.NE.2.AND.J.EQ.7)  HRHARR=0.
      IF  (TWO.AND.(J.EQ.1.OR.J.EQ.2.OR.J.EQ.3))  THEN
      POWER1=POWER
      ELSEIF  (TWO)  THEN
      POWER1=POWER2
      ELSE
      POWER1=POWER
      ENDIF
      IF  (TWO.AND.J.EQ.7)  THEN
      HRUSE=HRPLOW+HRDISK+HRHARR
      ELSEIF  (.NOT.TWO.AND.J.EQ.7)  THEN
      HRUSE=HRPLOW+HRDISK+HRHARR+HRSEED+HRFERT+HRSPRY+HRCOMB
      ENDIF
      IF  (.NOT.TWO.AND.J.EQ.8)  GO TO 21
      IF  (TWO.AND.J.EQ.8)  HRUSEF=HRSEED+HRFERT+HRSPRY+
     +HRCOMB
      IF(NPASS.NE.2.AND.J.EQ.3)GO TO 21
      IF  (TWO.AND.J.EQ.8)THEN
      JJ=7
      CALL  COST(JJ,HRUSEF,POWER2,EFCAP,AREATI,INCOST,XCOST,
     +WKHRS1,WKHRS2,COSTFL,COSTLA,COSTTM,COSTRM,COSTOW)
      ELSE
      CALL  COST(J,HRUSE,POWER1,EFCAP,AREATI,INCOST,XCOST,
     +WKHRS1,WKHRS2,COSTFL,COSTLA,COSTTM,COSTRM,COSTOW)
      ENDIF
      TCOSTC=TCOSTC+XCOST
      TCSTRM=TCSTRM+COSTRM
      TCSTTM=TCSTTM+COSTTM
      TCSTFL=TCSTFL+COSTFL
      TCSTLA=TCSTLA+COSTLA
      TCSTOW=TCSTOW+COSTOW
21    CONTINUE
      IF  (MINFLG)  THEN
      MPLOW=IPLOW
      MDISK=IDISK
      MHARR=IHARR
      MSEED=ISEED
      MFERT=IFERT
      MSPRY=ISPRAY
      LCOSTM=TCOSTC
      MCSTFL=TCSTFL
      MCSTLA=TCSTLA
      MCSTTM=TCSTTM
      MCSTRM=TCSTRM
      MCSTOW=TCSTOW
      IF  (.NOT.TWO)  POWER2=POWER
      GPRYR(4,1)=(HRPLOW+HRDISK)*0.26*POWER+(HRHARR*0.17)*POWER
      GPRYR(4,2)=(HRSEED+HRFERT+HRSPRY)*POWER2
     +*0.17
      IF  (.NOT.TWO) GPRYR(4,1)=GPRYR(4,1)+GPRYR(4,2)
      IF  (.NOT.TWO) GPRYR(4,2)=0
      POWERP(4,1)=POWER
      POWERP(4,2)=POWER2
      LCOSTSM=LCOSTM+LCOSTCO
      HRTRC(4,1)=HRUSE
      HRTRC(4,2)=HRSEED+HRFERT+HRSPRY+HRCOMB
      IF  (.NOT.TWO) HRTRC(4,2)=0
      HRLABR(4,1)=HRTRC(4,1)+HRTRC(4,2)+(HRCOMB*6)+HRSEED
      MINFLG=.FALSE.
      ENDIF
      IF(TCOSTC.LT.LCOSTC)  THEN
      LCOST3=LCOST2
      LCOST2=LCOSTC
      LCOSTC=TCOSTC
      I3PLOW=ITPLOW
      I3DISK=ITDISK
      I3HARR=ITHARR
      I3SEED=ITSEED
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      I3FERT=ITFERT
      I3SPRY=ITSPRY
      CSTFL3=CSTFLT
      CSTLA3=CSTLAT
      CSTTM3=CSTTMT
      CSTRM3=CSTRMT
      CSTOW3=CSTOWT
      HRTRC(3,1)=HRTRC(2,1)
      HRTRC(3,2)=HRTRC(2,2)
      HRLABR(3,1)=HRLABR(2,1)
      HRTRC(2,1)=HRTRC(1,1)
      HRTRC(2,2)=HRTRC(1,2)
      HRLABR(2,1)=HRLABR(1,1)
      POWERP(3,1)=POWERP(2,1)
      POWERP(2,1)=POWERP(1,1)
      POWERP(3,2)=POWERP(2,2)
      POWERP(2,2)=POWERP(1,2)
      ITPLOW=I2PLOW
      ITDISK=I2DISK
      ITHARR=I2HARR
      ITSEED=I2SEED
      ITFERT=I2FERT
      ITSPRY=I2SPRY
      CSTFLT=CSTFL1
      CSTLAT=CSTLA1
      CSTTMT=CSTTM1
      CSTRMT=CSTRM1
      CSTOWT=CSTOW1
      CSTFL1=TCSTFL
      GPRYR(3,1)=GPRYR(2,1)
      GPRYR(3,2)=GPRYR(2,2)
      GPRYR(2,1)=GPRYR(1,1)
      GPRYR(2,2)=GPRYR(1,2)
      IF (.NOT.TWO) POWER2=POWER
      GPRYR(1,1)=(HRPLOW+HRDISK)*0.26*POWER+(HRHARR*0.17)*POWER
      GPRYR(1,2)=(HRSEED+HRFERT+HRSPRY)*
     +POWER2*0.17
      IF (.NOT.TWO) GPRYR(1,1)=GPRYR(1,1)+GPRYR(1,2)
      IF (.NOT.TWO) GPRYR(1,2)=0
      CSTLA1=TCSTLA
      CSTTM1=TCSTTM
      CSTRM1=TCSTRM
      CSTOW1=TCSTOW
      I2PLOW=IPLOW
      I2DISK=IDISK
      I2HARR=IHARR
      I2SEED=ISEED
      I2FERT=IFERT
      I2SPRY=ISPRAY
      HRTRC(1,1)=HRUSE
      HRTRC(1,2)=HRSEED+HRFERT+HRSPRY+HRCOMB
      IF (.NOT.TWO) HRTRC(1,2)=0
      HRLABR(1,1)=HRTRC(1,1)+HRTRC(1,2)+(HRCOMB*6)+HRSEED
      POWERP(1,1)=POWER
      POWERP(1,2)=POWER2
      ELSEIF(TCOSTC.LT.LCOST2)THEN
      LCOST3=LCOST2
      LCOST2=TCOSTC
      I3PLOW=ITPLOW
      I3DISK=ITDISK
      I3HARR=ITHARR
      I3SEED=ITSEED
      I3FERT=ITFERT
      I3SPRY=ITSPRY
      ITPLOW=IPLOW
      ITDISK=IDISK
      ITHARR=IHARR
      ITSEED=ISEED
      ITFERT=IFERT
      ITSPRY=ISPRAY
      GPRYR(3,1)=GPRYR(2,1)
      GPRYR(3,2)=GPRYR(2,2)
      IF (.NOT.TWO) POWER2=POWER
      GPRYR(2,1)=(HRPLOW+HRDISK)*0.26*POWER+(HRHARR*0.17)*POWER
      GPRYR(2,2)=(HRSEED+HRFERT+HRSPRY)
     +*POWER2*0.17
      IF (.NOT.TWO) GPRYR(2,1)=GPRYR(2,1)+GPRYR(2,2)
      IF (.NOT.TWO) GPRYR(2,2)=0
      POWERP(3,1)=POWERP(2,1)
      POWERP(2,1)=POWER
      POWERP(3,2)=POWERP(2,2)
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```
      POWERP(2,2)=POWER2
      CSTFL3=CSTFLT
      CSTLA3=CSTLAT
      CSTTM3=CSTTMT
      CSTRM3=CSTRMT
      CSTOW3=CSTOWT
      CSTFLT=TCSTFL
      CSTLAT=TCSTLA
      CSTTMT=TCSTTM
      CSTRMT=TCSTRM
      CSTOWT=TCSTOW
      HRTRC(3,1)=HRTRC(2,1)
      HRTRC(3,2)=HRTRC(2,2)
      HRLABR(3,1)=HRLABR(2,1)
      HRTRC(2,1)=HRUSE
      HRTRC(2,2)=HRSEED+HRFERT+HRSPRY+HRCOMB
      IF (.NOT.TWO) HRTRC(2,2)=0
      HRLABR(2,1)=HRTRC(2,1)+HRTRC(2,2)+(HRCOMB*6)+HRSEED
      ELSEIF(TCOSTC.LT.LCOST3) THEN
      LCOST3=TCOSTC
      I3PLOW=IPLOW
      I3DISK=IDISK
      I3HARR=IHARR
      I3SEED=ISEED
      I3FERT=IFERT
      I3SPRY=ISPRAY
      IF (.NOT.TWO) POWER2=POWER
      GPRYR(3,1)=(HRPLOW+HRDISK)*0.26*POWER+(HRHARR*0.17)*POWER
      GPRYR(3,2)=(HRSEED+HRFERT+HRSPRY)
     +*POWER2*0.17
      IF (.NOT.TWO) GPRYR(3,1)=GPRYR(3,1)+GPRYR(3,2)
      IF (.NOT.TWO) GPRYR(3,2)=0
      POWERP(3,1)=POWER
      POWERP(3,2)=POWER2
      CSTFL3=TCSTFL
      CSTLA3=TCSTLA
      CSTTM3=TCSTTM
      CSTRM3=TCSTRM
      CSTOW3=TCSTOW
      HRTRC(3,1)=HRUSE
      HRTRC(3,2)=HRSEED+HRFERT+HRSPRY+HRCOMB
      IF (.NOT.TWO) HRTRC(3,2)=0
      HRLABR(2,1)=HRTRC(3,1)+HRTRC(3,2)+(HRCOMB*6)+HRSEED
      END IF
C AFTER COMPLETING ALL COMBINATIONS OF MACHINES
C CALCULATE LEAST COST SYSTEM
16    CONTINUE
15    CONTINUE
14    CONTINUE
13    CONTINUE
12    CONTINUE
11    CONTINUE
      HRLABR(5,1)=HRCOMB
      GPRYR(5,1)=POWERCO*0.22*HRCOMB
      GPRYR(5,2)=0
      GPRYR(5,3)=HRCOMB*POWERCO*0.22
      DO 339 J=1,5
      TLABR(J,1)=0
339   CONTINUE
      DO 338 J=1,5
      DO 333 N=1,10
      TLABR(J,1)=TLABR(J,1)+1.1*HRLABR(J,1)*WAGE*((1.+INLA)
     +/(1.+IF))**N
333   CONTINUE
      TLABR(J,2)=TLABR(J,1)/AREAT
338   CONTINUE
      CRF=IF*(1.+IF)**10./((1.+IF)**10.-1)
      AEC(1,1)=LCOSTC*CRF
      AEC(1,2)=AEC(1,1)/AREAT
      AEC(2,1)=LCOST2*CRF
      AEC(2,2)=AEC(2,1)/AREAT
      AEC(3,1)=LCOST3*CRF
      AEC(3,2)=AEC(3,1)/AREAT
      AEC(4,1)=LCOSTM*CRF
      AEC(4,2)=AEC(4,1)/AREAT
      AEC(5,1)=LCOSTCO*CRF
      AEC(5,2)=AEC(5,1)/AREAT
      DO 500 J=1,5
      GPRYR(J,3)=GPRYR(J,1)+GPRYR(J,2)
      GPRYR(J,4)=GPRYR(J,3)/AREAT
500   CONTINUE
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      DO 551 J=1,5
      HRLABR(J,2)=HRLABR(J,1)/AREAT
      TLABR(J,2)=TLABR(J,1)/AREAT
551   CONTINUE
      LCOSTS1=LCOSTC+LCOSTCO
      LCOSTS2=LCOST2+LCOSTCO
      LCOSTS3=LCOST3+LCOSTCO
      IF (.NOT.TWO) THEN
      DO 340 J=1,4
      POWERP(J,2)=0
340   CONTINUE
      ENDIF
      IF(NPASS.NE.2)THEN
      MHARR=0
      I2HARR=0
      ITHARR=0
      I3HARR=0
      END IF
      PPRHA(5)=LCOSTCO/AREAT
      PPRHA(4)=LCOSTM/AREAT
      PPRHA(3)=LCOST3/AREAT
      PPRHA(2)=LCOST2/AREAT
      PPRHA(1)=LCOSTC/AREAT
C  NOW PRINT OUT THE TABLE
C
      WRITE(6,600)
600   FORMAT(1H1,57X,'COMBINE',8X,'MINIMUM',9X,'FIRST',
     +7X,'SECOND',11X,'THIRD')
      WRITE(6,601)
601   FORMAT(1H ,132(1H-)///)
      WRITE(6,602) FEET,MPLOW,MDISK,MHARR,MSEED,MFERT,MSPRY,
     +I2PLOW,I2DISK,I2HARR,I2SEED,I2FERT,I2SPRY,ITPLOW,ITDISK,ITHARR,
     +ITSEED,ITFERT,ITSPRY,I3PLOW,
     +I3DISK,I3HARR,I3SEED,I3FERT,I3SPRY
602   FORMAT(1H0,10X,'MACHINE COMBINATION',24X,5X,F3.0,' - FOOT',
     +2X,4(I1,1X,I1,1X,I1,1X,I1,1X,I1,1X,I1,4X))
      WRITE(6,603) IDASH,LCOSTM,LCOSTC,LCOST2,LCOST3
603   FORMAT(1H0,10X,'COST OF COMBINATION',24X,7X,A1,7X,
     +4(F10.2,5X))
      WRITE(6,604)
604   FORMAT(1H ,10X,'(WITHOUT COMBINE AND WAGON)')
      WRITE(6,605) IDASH,LCOSTSM,LCOSTS1,LCOSTS2,LCOSTS3
605   FORMAT(1H0,10X,'COST OF COMBINATION',24X,7X,A1,
     +7X,4(F10.2,5X))
      WRITE(6,606)
606   FORMAT(1H ,10X,'(WITH COMBINE AND WAGON)')
      WRITE(6,607) CUCOST,IDASH,IDASH,IDASH,IDASH
607   FORMAT(1H0,10X,'CUSTOM COST',32X,F10.2,4X,4(7X,A1,6X))
      WRITE(6,608) ICOST1,IDASH,IDASH,IDASH,IDASH
608   FORMAT(1H0,10X,'COST OF COMBINE',28X,F10.2,4(11X,A1,2X))
      WRITE(6,609)
609   FORMAT(1H ,10X,'(WITHOUT WAGON)')
      WRITE(6,610) LCOSTCO,IDASH,IDASH,IDASH,IDASH
610   FORMAT(1H0,10X,'COST OF COMBINE',28X,F10.2,4(11X,A1,2X))
      WRITE(6,611)
611   FORMAT(1H ,10X,'(WITH WAGON)')
      WRITE(6,612) TCOSTFL,MCSTFL,CSTFL1,CSTFLT,CSTFL3
612   FORMAT(1H0,10X,'COST OF FUEL',31X,5(F10.2,5X))
      WRITE(6,613) HRLABR(5,1) ,HRLABR(4,1), (HRLABR(J,1),J=1,3)
613   FORMAT(1H0,10X,'HOURS OF LABOR',29X,5(F10.2,5X))
      WRITE(6,614) HRLABR(5,2),HRLABR(4,2), (HRLABR(J,2),J=1,3)
614   FORMAT(1H0,10X,'HOURS OF LABOR PER HECTARE',17X,
     +5(F10.2,5X))
      WRITE(6,615) IDASH,MCSTLA,CSTLA1,CSTLAT,CSTLA3
615   FORMAT(1H0,10X,'COST OF LABOR',30X,7X,A1,7X,4(F10.2,5X))
      WRITE(6,616)
616   FORMAT(1H ,10X,'(WITHOUT COMBINE AND WAGON)')
      WRITE(6,617) TCOSTLA,TLABR(4,1), (TLABR(J,1),J=1,3)
617   FORMAT(1H0,10X,'TOTAL COST OF LABOR',24X,5(F10.2,5X))
      WRITE(6,618)
618   FORMAT(1H ,10X,'(WITH COMBINE AND WAGON)')
      WRITE(6,619) TCOSTTM,MCSTTM,CSTTM1,CSTTMT,CSTTM3
619   FORMAT(1H0,10X,'TIMELINESS COST',28X,5(F10.2,5X))
      WRITE(6,620) TCOSTRM,MCSTRM,CSTRM1,CSTRMT,CSTRM3
620   FORMAT(1H0,10X,'COST OF REPAIRS AND MAINTENANCE',
     +13X,5(F10.2,5X))
      WRITE(6,621) TCOSTOW,MCSTOW,CSTOW1,CSTOWT,CSTOW3
621   FORMAT(1H0,10X,'COST OF OWNERSHIP',27X,5(F10.2,5X))
      WRITE(6,622) POWERCO,POWERP(4,1), (POWERP(J,1),
     +J=1,3)
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622   FORMAT(1H0,10X,'POWER REQUIRED BY TRACTOR #1',15X,
     +5(F10.2,5X))
      WRITE(6,623) IDASH,POWERP(4,2),(POWERP(J,2),J=1,3)
623   FORMAT(1H0,10X,'POWER REQUIRED BY TRACTOR #2',21X,
     +A1,8X,4(F10.2,5X))
      WRITE(6,624) HRCOMB,HRTRC(4,1),(HRTRC(J,1),J=1,3)
624   FORMAT(1H0,10X,'HOURS USED BY TRACTOR #1',19X,
     +5(F10.2,5X))
      WRITE(6,625) IDASH,HRTRC(4,2),(HRTRC(J,2),J=1,3)
625   FORMAT(1H0,10X,'HOURS USED BY TRACTOR #2',25X,
     +A1,8X,4(F10.2,5X))
      WRITE(6,626) AEC(5,1),AEC(4,1),(AEC(J,1),J=1,3)
626   FORMAT(1H0,10X,'ANNUAL EQUIVALENT COST',21X,
     +5(F10.2,5X))
      WRITE(6,627) AEC(5,2),AEC(4,2),(AEC(J,2),J=1,3)
627   FORMAT(1H0,10X,'ANNUAL EQUIVALENT COST PER HECTARE',9X,
     +5(F10.2,5X))
      WRITE(6,628) PPRHA(5),PPRHA(4),(PPRHA(I),I=1,3)
628   FORMAT(1H0,10X,'COST PER HECTARE FOR TEN YEARS',13X,5(F10.2,5X))
      WRITE(6,629) IDASH,GPRYR(4,1),(GPRYR(J,1),J=1,3)
629   FORMAT(1H0,10X,'ANNUAL FUEL CONSUMPTION',20X,
     +7X,A1,7X,4(F10.2,5X))
      WRITE(6,630)
630   FORMAT(1H ,10X,'OF TRACTOR #1 (LITRES)')
      WRITE(6,631) IDASH,GPRYR(4,2),(GPRYR(J,2),J=1,3)
631   FORMAT(1H0,10X,'ANNUAL FUEL CONSUMPTION',26X,A1,
     +8X,4(F10.2,5X))
      WRITE(6,632)
632   FORMAT(1H ,10X,'OF TRACTOR #2 (LITRES)')
      WRITE(6,633) GPRYR(5,3),GPRYR(4,3),(GPRYR(J,3),J=1,3)
633   FORMAT(1H0,10X,'TOTAL ANNUAL FUEL CONSUMPTION(LITRES)',
     +6X,5(F10.2,5X))
      WRITE(6,634) GPRYR(5,4),GPRYR(4,4),(GPRYR(J,4),J=1,3)
634   FORMAT(1H0,10X,'ANNUAL FUEL CONSUMPTION',20X,5(F10.2,
     +5X))
      WRITE(6,635)
635   FORMAT(1H ,10X,'PER HECTARE (LITRES/HA)'//)
      TYIELD=(AWHEAT*YLDWH)+(AOAT*.8*YLDWH)
      PROFIT=0
      DO 1000 N=1,10
      A=((1.+INCR)/(1.+IF))**N
      PROFIT=PROFIT+TYIELD*PRICEW*A
1000  CONTINUE
      AECP=PROFIT*CRF
      PRINT *,'AE GROSS INCOME =',AECP
      PRINT*, 'TOTAL YIELD EXPECTED WHEAT AND OATS KG.=  ',TYIELD
      PRINT*, 'TOTAL GROSS RETURN FOR TEN YEARS FROM SALES = ',PROFIT
      END
      SUBROUTINE TIMEAV(PROB,NPASS,WKHRS1,WKHRS2)
      COMMON /TEMP/ TIMEP,TIMED,TIMEH,TIMESD,TIMEF,TIMESP,TIMEW
      COMMON/TIMELI/DAYF1,DAYF4,DAYF8,TIMOP1,TIMOP4,TIMOP8,PRICEW,YLDWH
      INTEGER PROB,NPASS
      REAL TIMED(4)
1     IF(PROB.EQ.70)THEN
      TIMEP=36.6
      TIMOP1=26.6
      DAYF1=.91
      TIMESD=18.8
      TIMOP4=7.6
      DAYF4=.65
      TIMEF=7.5
      TIMESP=13.7
      TIMEW=32.6
      TIMOP8=19.1
      DAYF8=.90
      ELSE IF(PROB.EQ.80) THEN
      TIMEP=35.5
      TIMOP1=25.5
      DAYF1=.91
      TIMESD=15.9
      TIMOP4=6.1
      DAYF4=.57
      TIMEF=6.7
      TIMESP=12.1
      TIMEW=30.8
      TIMOP8=17.4
      DAYF8=.89
      ELSE IF(PROB.EQ.90) THEN
      TIMEP=33.1
      TIMOP1=24.1
      DAYF1=.81
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      TIMESD=7.7
      TIMOP4=4.0
      DAYF4=.2
      TIMEF=6.0
      TIMESP=11.2
      TIMEW=25.8
      TIMOP8=14.7
      DAYF8=.74
      ELSE
      PRINT*, 'YOU ENTERED WRONG PROB LEVEL REENTER 70, 80, OR 90'
      READ*, PROB
      GO TO 1
      END IF
2     IF(PROB.EQ.70.AND.NPASS.EQ.2)THEN
      TIMED(1)=28.3
      TIMED(2)=27.2
      TIMED(3)=0.
      TIMED(4)=0.
      TIMEH=18.8
      ELSE IF(PROB.EQ.80.AND.NPASS.EQ.2)THEN
      TIMED(1)=27.5
      TIMED(2)=26.4
      TIMED(3)=0.
      TIMED(4)=0.
      TIMEH=15.9
      ELSE IF(PROB.EQ.90.AND.NPASS.EQ.2) THEN
      TIMED(1)=24.0
      TIMED(2)=24.0
      TIMED(3)=0.
      TIMED(4)=0.
      TIMEH=7.7
      ELSE IF(PROB.EQ.70.AND.NPASS.EQ.3) THEN
      TIMED(1)=28.3
      TIMED(2)=27.2
      TIMED(3)=18.8
      TIMED(4)=0.
      TIMEH=0.
      ELSE IF(PROB.EQ.80.AND.NPASS.EQ.3) THEN
      TIMED(1)=27.5
      TIMED(2)=26.4
      TIMED(3)=15.9
      TIMED(4)=0.
      TIMEH=0.
      ELSE IF(PROB.EQ.90.AND.NPASS.EQ.3) THEN
      TIMED(1)=24.0
      TIMED(2)=24.0
      TIMED(3)=7.7
      TIMED(4)=0.
      TIMEH=0.
      ELSE IF(PROB.EQ.70.AND.NPASS.EQ.4) THEN
      TIMED(1)=28.3
      TIMED(2)=27.2
      TIMED(3)=24.1
      TIMED(4)=18.8
      TIMEH=0.
      ELSE IF(PROB.EQ.80.AND.NPASS.EQ.4) THEN
      TIMED(1)=27.5
      TIMED(2)=26.4
      TIMED(3)=22.8
      TIMED(4)=15.9
      TIMEH=0.
      ELSE IF(PROB.EQ.90.AND.NPASS.EQ.4) THEN
      TIMED(1)=24.0
      TIMED(2)=24.0
      TIMED(3)=16.0
      TIMED(4)=7.7
      TIMEH=0.
      ELSE
      PRINT*, 'REENTER NPASS AS 2, 3, OR 4'
      READ*, NPASS
      GO TO 2
      END IF
      TIMEP=TIMEP*WKHRS1
      TIMOP1=TIMOP1*WKHRS1
      TIMED(1)=TIMED(1)*WKHRS2
      TIMED(2)=TIMED(2)*WKHRS2
      TIMED(3)=TIMED(3)*WKHRS2
      TIMED(4)=TIMED(4)*WKHRS2
      TIMEH=TIMEH*WKHRS2
      TIMESD=TIMESD*WKHRS2
      TIMOP4=TIMOP4*WKHRS2
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      TIMEF=TIMEF*WKHRS2
      TIMESP=TIMESP*WKHRS2
      TIMEW=TIMEW*WKHRS1
      TIMOP8=TIMOP8*WKHRS1
      RETURN
      END
      SUBROUTINE PLOW(AREAP,TIMEP,POWER,IPLOW,HRPLOW,EFCPL,ICOUNT)
      DIMENSION EFC(5),PKW(5)
      NPLOW=5
C  INITIALIZE EFFECTIVE FIELD CAPACITY OF THE 5 PLOWS (HA/HR)
      EFC(1)=.25
      EFC(2)=.37
      EFC(3)=.50
      EFC(4)=.62
      EFC(5)=.75
C  INITIALIZE POWER REQUIRED BY EACH OF THE 5 PLOWS (KW)
      PKW(1)=28.2
      PKW(2)=32.1
      PKW(3)=42.6
      PKW(4)=53.2
      PKW(5)=63.9
      EFCP=AREAP/TIMEP
      IF(EFCP.GT.EFC(NPLOW))THEN
      PRINT*,'ONE TRACTOR WILL NOT PLOW ALL THIS AREA BETWEEN
     +DECEMBER 1 AND JANUARY 10.'
      STOP
      ENDIF
      IF (ICOUNT.EQ.1)THEN
      IPLOW=0
1     CONTINUE
      IPLOW=IPLOW+1
      IF(EFCP.GT.EFC(IPLOW))GOTO 1
      ENDIF
      POWER=PKW(IPLOW)
      HRPLOW=AREAP/EFC(IPLOW)
      EFCPL=EFC(IPLOW)
      RETURN
      END
      SUBROUTINE DISK (AREAD, TIMED,POWER,EFCSD,IDISK,AREASD,HRDISK,
     +ISEED,HRSEED,NPASS,ICOUNT)
      DIMENSION TIMED(4),PKW(9),EFC(9),EFCD(9),EFCS(9)
      LOGICAL TWO
      COMMON/FLAG/TWO
      NDISK=9
      NSEED=9
C  INITIALIZE EFFECTIVE FIELD CAPACITY OF THE 9 DISKS FOR THE FIRST PASS
C  AFTER PLOWING (HA/HR)
      EFC(1)=0.76
      EFC(2)=0.88
      EFC(3)=1.01
      EFC(4)=1.14
      EFC(5)=1.26
      EFC(6)=1.39
      EFC(7)=1.52
      EFC(8)=1.64
      EFC(9)=1.77
C  INITIALIZE EFFECTIVE FIELD CAPACITY OF THE 9 DISKS FOR THE 2ND, 3RD
C  AND 4TH PASSES (HA/HR)
      EFCD(1)=0.82
      EFCD(2)=0.95
      EFCD(3)=1.09
      EFCD(4)=1.22
      EFCD(5)=1.36
      EFCD(6)=1.50
      EFCD(7)=1.63
      EFCD(8)=1.77
      EFCD(9)=1.90
C  INITIALIZE POWER REQUIRED BY EACH OF THE 9 DISK SIZES (KW)
      PKW(1)=31.4
      PKW(2)=36.7
      PKW(3)=41.9
      PKW(4)=47.2
      PKW(5)=52.4
      PKW(6)=57.6
      PKW(7)=62.9
      PKW(8)=68.1
      PKW(9)=73.4
C  INITIALIZE EFFECTIVE FIELD CAPACITY OF THE 9 SEEDERS (HA/HR)
      EFCS(1)=0.81
      EFCS(2)=0.89
      EFCS(3)=0.97
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      EFCS(4)=1.05
      EFCS(5)=1.13
      EFCS(6)=1.21
      EFCS(7)=1.29
      EFCS(8)=1.37
      EFCS(9)=1.45
      EFCMAX=0.0
      IF(ICOUNT.EQ.1)THEN
      DO 1 I=1,NPASS
      EFCA=AREAD/TIMED(I)
      IF(EFCA.GT.EFCMAX)THEN
      EFCMAX=EFCA
      ENDIF
      IF(EFCMAX.GT.EFCD(NDISK))THEN
      PRINT*,'YOU NEED TWO TRACTORS'
      CALL DISK2(AREAD,TIMED,IDISK,POWER,HRDISK,NPASS,ICOUNT)
      TWO=.TRUE.
      RETURN
      ENDIF
1     CONTINUE
      IDISK=0
2     CONTINUE
      IDISK=IDISK+1
      IF(EFCMAX.GT.EFCD(IDISK)) GO TO 2
      IF(NPASS.GT.2)THEN
      IDISK=IDISK-1
3     CONTINUE
      IDISK=IDISK+1
      IF(IDISK.GT.NDISK)THEN
      PRINT*,'YOU NEED TWO TRACTORS'
      CALL DISK2(AREAD,TIMED,IDISK,POWER,HRDISK,NPASS,ICOUNT)
      TWO=.TRUE.
      RETURN
      ENDIF
      TD=(1./EFCD(IDISK))*AREAD
      TSDR=TIMED(NPASS)-TD
      EFCSD=AREASD/TSDR
      IF(EFCSD.GT.EFCS(NSEED)) GO TO 3
      ISEED=0
4     CONTINUE
      ISEED=ISEED+1
      IF(EFCSD.GT.EFCS(ISEED)) GO TO 4
      ENDIF
      ENDIF
      PWRNEW=PKW(IDISK)
      IF(PWRNEW.GT.POWER)THEN
      POWER=PWRNEW
      ENDIF
      HRDISK=AREAD*NPASS/EFCD(IDISK)
      RETURN
      END
      SUBROUTINE HARROW (AREAH,TIMEH,AREASD,TIMESD,IHARR,HRHARR,
     +ISEED,HRSEED,EFCSD,NPASS,ICOUNT)
      DIMENSION EFCH(8), EFCS(9)
      LOGICAL TWO
      COMMON/FLAG/TWO
      NHARR=8
      NSEED=9
C INITIALIZE EFFECTIVE FIELD CAPACITY OF EIGHT HARROWS (HA/HR)
      EFCH(1)=1.5
      EFCH(2)=1.8
      EFCH(3)=2.1
      EFCH(4)=2.4
      EFCH(5)=2.7
      EFCH(6)=3.0
      EFCH(7)=3.3
      EFCH(8)=3.6
C  INITIALIZE EFFECTIVE FIELD CAPACITY OF NINE SEEDERS
      EFCS(1)=0.81
      EFCS(2)=0.89
      EFCS(3)=0.97
      EFCS(4)=1.05
      EFCS(5)=1.13
      EFCS(6)=1.21
      EFCS(7)=1.29
      EFCS(8)=1.37
      EFCS(9)=1.45
C  WHEN MORE THAN 2 PASSES OF DISK ARE MADE, FARMERS DO NOT
C  USE A SPIKE-TOOTH HARROW AND THIS SUBROUTINE IS SKIPPED
      IF(NPASS.LE.2)THEN
      IF(ICOUNT.EQ.1)THEN
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      THARR=0.3*TIMEH
      EFC=AREAH/THARR
      IHARR=0
1     CONTINUE
C                     INCREASE SIZE UNTIL HARROW CAN HANDLE
C                     TOTAL AREA IN AVAILABLE TIME.
      IHARR=IHARR+1
      IF(IHARR.GT.NHARR)THEN
      PRINT*,'YOU NEED TWO TRACTORS'
      CALL HARR2(AREAH,TIMEH,IHARR,HRHARR,NPASS,ICOUNT)
      TWO=.TRUE.
      RETURN
      ENDIF
      IF(EFC.GT.EFCH(IHARR))GO TO 1
      IHARR=IHARR-1
2     CONTINUE
      IHARR=IHARR+1
C                     CALCULATE TIME USED BY HARROW
      THARR=(1./EFCH(IHARR))*AREAH
C                     INCREASE SIZE UNTIL THERE IS ENOUGH TIME
C                     FOR HARROWING AND SEEDING.
      IF(IHARR.GT.NHARR)THEN
      PRINT*,'YOU NEED TWO TRACTORS'
      CALL HARR2(AREAH,TIMEH,IHARR,HRHARR,NPASS,ICOUNT)
      TWO=.TRUE.
      RETURN
      ENDIF
C                     CALCULATE TIME LEFT FOR SEEDING.
      TSDR=TIMEH-THARR
      EFCSD=AREASD/TSDR
      IF(EFCSD.GT.EFCS(NSEED))GO TO 2
      ISEED=0
3     CONTINUE
      ISEED=ISEED+1
      IF(EFCSD.GT.EFCS(ISEED))GO TO 3
      ENDIF
      HRHARR=AREAH/EFCH(IHARR)
      ENDIF
      RETURN
      END
      SUBROUTINE SEEDER(AREASD,ISEED,HRSEED,ICOUNT,EFCSD)
      DIMENSION EFCS(9)
      EFCS(1)=0.81
      EFCS(2)=0.89
      EFCS(3)=0.97
      EFCS(4)=1.05
      EFCS(5)=1.13
      EFCS(6)=1.21
      EFCS(7)=1.29
      EFCS(8)=1.37
      EFCS(9)=1.45
      EFCSD=EFCS(ISEED)
      HRSEED=AREASD/EFCS(ISEED)
      RETURN
      END
      SUBROUTINE FERTIL(AREAF,TIMEF,IFERT,HRFERT,ICOUNT)
      DIMENSION EFC(7)
      NFERT=7
      EFC(1)=3.3
      EFC(2)=3.63
      EFC(3)=3.96
      EFC(4)=4.29
      EFC(5)=4.62
      EFC(6)=4.95
      EFC(7)=5.28
      IF(ICOUNT.EQ.1)THEN
      EFCF=AREAF/TIMEF
      IF(EFCF.LE.EFC(NFERT))THEN
      IFERT=0
1     CONTINUE
      IFERT=IFERT+1
      IF(EFCF.GT.EFC(IFERT))GO TO 1
      ELSE
      IFERT=NFERT
      FERCAP=EFC(NFERT)*TIMEF
      PRINT 10, FERCAP
      ENDIF
      ENDIF
      HRFERT=AREAF/EFC(IFERT)
10    FORMAT('AREA EXCEEDS LARGEST FERTILIZER BROADCASTER CAPACITY.
     +MAXIMUM AREA FERTILIZED=',F5.0)
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      RETURN
      END
      SUBROUTINE SPRAYR(AREASP,TIMESP,ISPRAY,HRSPRY,ICOUNT,AREAT)
      DIMENSION EFC(7)
      NSPRAY=7
      EFC(1)=2.16
      EFC(2)=2.52
      EFC(3)=2.88
      EFC(4)=2.97
      EFC(5)=3.30
      EFC(6)=3.63
      EFC(7)=3.96
      IF(ICOUNT.EQ.1)THEN
      EFCS=AREASP/TIMESP
      IF(EFCS.LE.EFC(NSPRAY))THEN
      ISPRAY=0
1     CONTINUE
      ISPRAY=ISPRAY+1
      IF(EFCS.GT.EFC(ISPRAY))GO TO 1
      ELSE
      ISPRAY=NSPRAY
      SPRCAP=EFC(NSPRAY)*TIMESP
      PRINT 10, SPRCAP
      ENDIF
      ENDIF
      HRSPRY=AREAT/EFC(ISPRAY)
10    FORMAT (' AREA EXCEEDS LARGEST SPRAYERS CAPACITY
     +MAXIMUM AREA SPRAYED WITHOUT PENALTY=',F5.0)
      RETURN
      END
      SUBROUTINE COST(J,HRUSE,POWER,EFC,AREATO,INCOST,XCOST,
     +WKHRS1,WKHRS2,COSTFL,COSTLA,COSTTM,COSTRM,COSTOW)
C CALCULATES COST OF MACHINE J
C J=1 PLOW, J=2 DISK, J=3 HARROW, J=4 SEEDER, J=5 FERTILIZER,
C J=6 SPRAYER, J=7 TRACTOR, J=8 COMBINE, J=9 WAGON
C DAY1, DAY4, DAY8, ARE COEFF OF SUITABLE DAY/TOTAL DAYS
      COMMON /TIMELI/ DAYF1, DAYF4, DAYF8, TIMOP1, TIMOP4, TIMOP8,
     +PRICEW,YLDWH
      COMMON /COSTC/IB,IF,INM,INFU,INLA,INCR,WAGE,PRFUEL
      COMMON/FLAG/TWO
      COMMON /ZZZ/ HRHARR,HRDISK,NPASS
      COMMON/COMPCOM/COST1LA,ICOST1
      COMMON/M/MINFLG
      LOGICAL TWO,MINFLG
      REAL IB,IF,INM,INFU,INLA,INCR,K,INCOST,HRUSE
      INTEGER PROB
      DIMENSION COEFRM(9)
      DATA (COEFRM(I),I=1,9) /0.00027, 0.00023, 0.0004, 0.00036, 0.00047
     +,0.00053,0.00012,0.00020,0.0002/
C IB:BANK INTEREST
C IF :FARMER'S RATE OF RETURN
C INM:INFLATION FOR MACHINERY
C INFU: FUEL INFLATION
C INLA:LABOR INFLATION
C INCR:CROP INFLATION
C PRFUEL:PRICE OF FUEL
C COEFRM:REPAIR AND MAINTENANCE COEFFICIENT
C INCOST:INITIAL COST OR PRICE OF MACHINE
      COSTFL=0.0
      XCOST=0.
      COSTLA=0.
      COSTTM=0.
      COSTRM=0.
      DO 30 N=1, 10
      IF(J.EQ.7) GO TO 11
C CALCULATE COST OF FUEL: COSTFL
C  FCF= FUEL CONSUMPTION FACTOR FOR LOW, MEDIUM AND HIGH
C  LOADS. AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS YEARBOOK 1982
      FCF=0.17
      IF(J.EQ.1 .OR.J.EQ.2) FCF=0.26
      IF(J.EQ.8) FCF=0.22
      X=((1.+INFU)/(1.+IF))**N
C  1.15 ASSIGNS 15 PERCENT MORE FUEL COST TO COVER LUBRICATION COST
      COSTFL=COSTFL+1.15*PRFUEL*POWER*FCF*HRUSE*X
C CALCULATE LABOR COST: COSTLA
11    IF(J.EQ.4 .OR. J.EQ.7 .OR.J.EQ.8) THEN
      Y=((1.+INLA)/(1.+IF))**N
C  1.1 ASSIGNS 10 PERCENT MORE LABOR HOURS TO ACCOUNT FOR TIME SPENT
C  CONNECTING AND DISCONNECTING IMPLEMENTS AND MACHINES
      COSTLA=COSTLA+1.1*WAGE*HRUSE*Y
      COST1LA=COSTLA
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      ENDIF
C CALCULATE TIMELINESS COST
C AREATO:TOTAL AREA WE WANT TO PLOW, SEED OR HARVEST
C AREAOP:AREA COMPLETED IN OPTIMUM PERIOD
C EXCESS:AREA COMPLETED OUTSIDE OF OPTIMUM PERIOD
C AVARDY:AVERAGE AREA WORKED EACH CALENDAR DAY
C DAYF:SUITABLE DAYS/TOTAL DAYS
C COSTTM:TIMELINESS COST
C TIMEOP:TIME DURING OPTIMUM PERIOD (NO PENALTY)
C K:TIMELINESS FACTOR
      HRPDAY=WKHRS2
      IF(J.EQ.1 .OR. J.EQ.8)HRPDAY=WKHRS1
      K=0.0009
      IF(J.EQ.4) K=0.002
      IF(J.EQ.8) K=0.004
      IF(J.EQ.1) DAYF=DAYF1
      IF (J.EQ.4) DAYF=DAYF4
      IF(J.EQ.8) DAYF=DAYF8
      IF(J.EQ.1) TIMEOP=TIMOP1
      IF (.NOT.TWO) THEN
      IF(NPASS.GT.2.AND.J.EQ.4) THEN
      PASS=NPASS
C  THE FOLLOWING EQUATION REDISTRIBUTES THE HOURS AVAILABLE
C  FOR SEEDING BASED UPON THE AMOUNT OF TIME SPENT DISKING
C  DURING THE SAME PERIOD.
      TIMEOP=TIMOP4-TIMOP4*(HRDISK/PASS)/
     +((HRDISK/PASS)+HRUSE)
      ELSE IF(NPASS.EQ.2.AND.J.EQ.4) THEN
C  THE FOLLOWING EQUATION REDISTRIBUTES THE HOURS AVAILABLE
C  FOR SEEDING BASED UPON THE AMOUNT OF TIME SPENT HARROWING
C  DURING THE SAME PERIOD.
      TIMEOP=TIMOP4-TIMOP4*(HRHARR/(HRHARR+HRUSE))
      END IF
      ENDIF
      IF(J.EQ.8) TIMEOP=TIMOP8
      IF (TWO.AND.J.EQ.4) TIMEOP=TIMOP4
      IF(J.EQ.1 .OR. J.EQ.4 .OR. J.EQ.8) THEN
      AREAOP=EFC*TIMEOP
      IF(TIMEOP.LT.HRUSE) THEN
      EXCESS=AREATO-AREAOP
      IF(EXCESS.LT.0.) EXCESS=0.
C CALCULATE AREA PER DAY AND DAYS REQUIRED TO COMPLETE HARVEST
      ARPDAY=EFC*HRPDAY
      AVARDY=ARPDAY*DAYF
      DAYS=(EXCESS/ARPDAY)/DAYF
      IDAYS=DAYS
C CALCULATE TOTAL TIMELINESS COST: COSTTM
      W=((1.+INCR)/(1.+IF))**N
      DO 15 ID=1,IDAYS
15    COSTTM=COSTTM+AVARDY*ID*K*YLDWH*PRICEW*W
      ARLAST=EXCESS-AVARDY*IDAYS
      IDAYL=IDAYS+1
      COSTTM=COSTTM+ARLAST*IDAYL*K*YLDWH*PRICEW*W
      ENDIF
      ENDIF
C CALCULATE COST OF  REPAIRS AND MAINTENANCE
      Z=((1.+INM)/(1.+IF))**N
21    COSTRM=COSTRM+INCOST*COEFRM(J)*HRUSE*Z
30    CONTINUE
      IF (J.EQ.8) COSTLA=COSTLA*7
C CALCULATE OWNERSHIP COST: COSTOW
      RV=0.1*INCOST*((1.+INM)/(1.+IF))**10.
      USPW=((1.+IF)**5.-1.)/(IF*(1.+IF)**5.)
      CRF=IB*(1.+IB)**5./((1.+IB)**5.-1.)
      COSTOW=0.2*INCOST+0.8*INCOST*CRF*USPW-RV
C CALCULATE TOTAL COST OF THE MACHINE
      XCOST=COSTFL+COSTLA+COSTTM+COSTRM+COSTOW
      RETURN
      END
      SUBROUTINE COMBINE(TIMEW,RISK,LCOSTC,TCOSTFL,
     +TCOSTLA,TCOSTTM,TCOSTOW,TCOSTRM,FEET1,CUCOST,AECCOM,
     +WKHRS1,WKHRS2,HRUSE1,POWERCO)
      DIMENSION EFCC(5),KW(5)
      REAL LCOSTC,ICOST1
      REAL INCOST,KW,HRUSE
      REAL IB,IF,INM,INFU,INLA,INCR
      INTEGER PROB
      COMMON/TIMELI/DAYF1,DAYF4,DAYF8,TIMOP1,TIMOP4,TIMOP8,PRICEW,YLDWH
      COMMON/COMB/YIELDW,PRCROP,AWHEAT,AOAT,ALENT
      COMMON/COSTC/IB,IF,INM,INFU,INLA,INCR,WAGE,PRFUEL
      COMMON/COMPCOM/COST1LA,ICOST1
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      DATA EFCC/1.06,1.16,1.25,1.44,1.54/
      DATA KW/78.3,82.8,89.5,107.4,111.9/
      LCOSTC=1000000.
      HRUSEW=0.
*COMPUTE CUSTOM COST
      CUSTPR=192.*PRICEW
      AREAT=AWHEAT+AOAT+ALENT
      TCOST1=0.
      DO 1 N=1,10
      CUSTCO=AREAT*RISK*CUSTPR*((1.+INM)/(1.+IF))**N
      TCOST1=TCOST1+CUSTCO
1     CONTINUE
      CUCOST=TCOST1
*NOW SELECT COMBINE AND CALCULATE COST BY CALLING
*SUBROUTINE COST.
      AREAC=AWHEAT+2.*AOAT/3.
      EFCREQ=AREAC/TIMEW
      ICOMB=0
2     CONTINUE
      ICOMB=ICOMB+1
      IF (ICOMB.EQ.6) GO TO 999
      IF (EFCREQ.GT.EFCC(ICOMB)) GO TO 2
      POWER=KW(ICOMB)
      EFC=EFCC(ICOMB)
      IF (ICOMB.EQ.1) FEET=12.
      IF (ICOMB.EQ.2) FEET=13.
      IF (ICOMB.EQ.3) FEET=14.
      IF (ICOMB.EQ.4) FEET=15.
      IF (ICOMB.EQ.5) FEET=16.
      HRLENT=ALENT*2.5
      HROAT=AOAT/EFC
      HRUSE=HRLENT+HROAT/3+AREAC/EFC
      INCOST=-85805.48+11295.92*FEET
      J=8
      CALL COST(J,HRUSE,POWER,EFC,AREAC,INCOST,XCOST,WKHRS1,WKHRS2,
     +COSTFL,COSTLA,COSTTM,COSTRM,COSTOW)
      IF (XCOST.LT.LCOSTC) THEN
      LCOSTC=XCOST
      TCOSTFL=COSTFL
      TCOSTLA=COSTLA
      TCOSTTM=COSTTM
      TCOSTOW=COSTOW
      TCOSTRM=COSTRM
      ICOST1=COSTFL+COST1LA+COSTTM+COSTRM+COSTOW
      HRUSE1=HRUSE
      ICOM=ICOMB
      FEET1=FEET
      POWERCO=POWER
      GO TO 2
      ENDIF
999   CONTINUE
*ASSIGN APPROPRIATE WAGON AND COMPUTE COST
      HRUSE=HRUSE1
      POWER1=0.
      EFC=0.
      INCOST=4880.
      IF (ICOM.EQ.1.OR.ICOM.EQ.2) INCOST=3270.
      J=9
      CALL COST(J,HRUSE,POWER1,EFC,AREAC,INCOST,XCOST,WKHRS1,WKHRS2,
     +COSTFL,COSTLA,COSTTM,COSTRM,COSTOW)
      LCOSTC=LCOSTC+XCOST
      TCOSTFL=TCOSTFL+COSTFL
      TCOSTLA=TCOSTLA+COSTLA
      TCOSTRM=TCOSTRM+COSTRM
      TCOSTTM=TCOSTTM+COSTTM
      TCOSTOW=TCOSTOW+COSTOW
      CRF=IF*(1.+IF)**10./((1.+IF)**10.-1)
      AECCOM=LCOSTC*CRF
      RETURN
      END
      SUBROUTINE DISK2(AREAD,TIMED,IDISK,POWER,HRDISK,
     +NPASS,ICOUNT)
      DIMENSION TIMED(4),PKW(9),EFC(9),EFCD(9)
      DATA EFC/0.76,0.88,1.01,1.14,1.26,1.39,1.52,1.64,1.77/
      DATA EFCD/0.82,0.95,1.09,1.22,1.36,1.50,1.63,1.77,1.9/
      DATA PKW/31.4,36.7,41.9,47.2,52.4,57.6,62.9,68.1,73.4/
C
      NDISK=9
      EFCMAX=0.0
      IF (ICOUNT.EQ.1) THEN
      DO 1 I=1,NPASS
```

```
      EFCA=AREAD/TIMED(I)
      IF (EFCA.GT.EFCMAX) THEN
      EFCMAX=EFCA
      ENDIF
      IF (EFCMAX.GT.EFCD(NDISK)) THEN
      PRINT*,'CANNOT DISK ALL THIS AREA FOR WINTER WHEAT WITH
     +LARGEST DISK'
      STOP
      ENDIF
1     CONTINUE
      IDISK=0
2     CONTINUE
      IDISK=IDISK+1
      IF (EFCMAX.GT.EFCD(IDISK)) GO TO 2
      ENDIF
      PWRNEW=PKW(IDISK)
      IF (PWRNEW.GT.POWER) THEN
      POWER=PWRNEW
      ENDIF
      HRDISK=AREAD*NPASS/EFCD(IDISK)
      RETURN
      END
      SUBROUTINE HARR2(AREAH,TIMEH,IHARR,HRHARR,NPASS,ICOUNT)
      DIMENSION EFCH(8)
      DATA EFCH/1.5,1.8,2.1,2.4,2.7,3.0,3.3,3.6/
      NHARR=8
      IF (NPASS.EQ.2) THEN
      IF (ICOUNT.EQ.1) THEN
      EFC=AREAH/TIMEH
      IF (EFC.GT.EFCH(NHARR)) THEN
      PRINT*,'CANNOT HARROW ALL THIS AREA FOR WINTER WHEAT WITH
     +LARGEST HARROW'
      STOP
      ENDIF
      IHARR=0
1     CONTINUE
      IHARR=IHARR+1
      IF (EFC.GT.EFCH(IHARR)) GO TO 1
      ENDIF
      HRHARR=AREAH/EFCH(IHARR)
      ENDIF
      RETURN
      END
      SUBROUTINE SDR2(AREASD,TIMESD,ISEED,POWER,HRSEED,EFCSD,
     +ICOUNT)
      DIMENSION EFC(9)
      DATA EFC/0.81,0.89,0.97,1.05,1.13,1.21,1.29,1.39,1.45/
      NSEED=9
      IF (ICOUNT.EQ.1) THEN
      EFCS=AREASD/TIMESD
      IF (EFCS.GT.EFC(NSEED)) THEN
      PRINT*,'CANNOT SEED ALL THIS AREA WITH WINTER WHEAT WITH
     +LARGEST SEEDER'
      STOP
      ENDIF
      ISEED=0
1     CONTINUE
      ISEED=ISEED+1
      IF (EFCS.GT.EFC(ISEED)) GO TO 1
      ENDIF
      POWER=28.6
      HRSEED=AREASD/EFC(ISEED)
      EFCSD=EFC(ISEED)
      RETURN
      END
```

APPENDIX D

Effective Field Capacities and Power Requirements of Implements and Machines

APPENDIX D

Effective Field Capacities and Power Requirements of Implements and Machines

D-1. DISK PLOW.

Plow N°	N° of Disks	Working Width (m)	Effective Field Capacity (ha/hr)	PTO Power kW	Equivalent HP
1	2	0.48	0.25	21.3	28.6
2	3	0.72	0.37	32.1	43.0
3	4	0.96	0.50	42.6	57.1
4	5	1.20	0.62	53.2	71.3
5	6	1.44	0.75	63.9	85.7

D-2. OFF-SET DISK HARROW.

Harrow N°	N° of Disks	Working Width (m)	EFC (ha/hr) Pass 1	EFC (ha/hr) 2,3,4	PTO Power kW	Equivalent HP
1	12 (6)	1.37	0.76	0.82	31.4	42.1
2	14 (7)	1.60	0.88	0.95	36.7	49.2
3	16 (8)	1.83	1.01	1.09	41.9	56.2
4	18 (9)	2.06	1.14	1.22	47.2	63.3
5	20 (10)	2.29	1.26	1.36	52.4	70.3
6	22 (11)	2.51	1.39	1.50	57.6	77.2
7	24 (12)	2.74	1.52	1.63	62.9	84.4
8	26 (13)	2.97	1.64	1.77	98.1	91.3
9	28 (14)	3.20	1.77	].90	73.4	98.4

*Numbers in parentheses refer to the number of disks in each gang used to obtain the working width.

D-3. SPIKE-TOOTH HARROW.

Harrow N°	Working Width (m)	Effective Field Capacity (ha/hr)	PTO Power kW	Equivalent HP
1	2.5	1.50		
2	3.0	1.80		
3	3.5	2.10		
4	4.0	2.40		
5	4.5	2.70		
6	5.0	3.00		
7	5.5	3.30		
8	6.0	3.6	25.6*	34.3

*Smallest tractor available on the market has 28.1 kW, which is used in all cases where power required is less than this value.

D-4. GRAIN SEEDER.

Seeder N°	Number of rows	Working Width (m)	Effective Field Capacity (ha/hr)	PTO Power kW	Equivalent HP
1	10	1.78	0.81		
2	11	1.96	0.89		
3	12	2.13	0.97		
4	13	2.31	1.05		
5	14	2.49	1.13		
6	15	2.67	1.21		
7	16	2.85	1.29		
8	17	3.02	1.37	27.0*	36.2
9	18	3.20	1.45	28.6	38.4

*Smallest tractor on the market has 28.1 kW.

D-5. FERTILIZER BROADCASTER AND FIELD SPRAYER.

Fertilizer Broadcaster			Field Sprayer		
Fertilizer No.	Working Width (m)	EFC ha/hr	Sprayer No.	Working Width (m)	EFC ha/hr
1	10	3.30	1	6	2.16
2	11	3.63	2	7	2.52
3	12	3.96	3	8	2.88
4	13	4.29	4	9	2.97
5	14	4.62	5	10	3.30
6	15	4.95	6	11	3.63
7	16	5.28	7	12	3.96

D-6. COMBINE HARVESTER.

Combine No.	Working Width Feet	Working Width Metres	EFC ha/hr	PTO Power Equivalent kW	PTO Power Equivalent HP
1	12	3.65	0.95	78.3	105.0
2	13	3.96	1.03	82.8	111.0
3	14	4.26	1.11	89.5	120.0
4	15	4.57	1.19	107.4	144.0
5	16	4.87	1.27	11.9	150.0

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