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AN ECONOMIC COMPARISON OF CONVENTIONAL AND CONSERVATION TILLAGE SYSTEMS IN THE SOUTHEAST SAGINAW BAY COASTAL DRAINAGE BASIN

By

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ABSTRACT

An Economic Comparison of Conventional and Conservation Tillage Systems in the Southeast Saginaw Bay Coastal Drainage Basin.

by

Hannibal Muhtar

There is concern over the quality of Michigan lakes and waterways, and over decreasing soil productivity due to the loss of top soil as a result of water and wind erosion. This concern has prompted the Agricultural Conservation Program (ACP), a USDA agency, to promote, through cost share programs, conservation tillage practices that are known to reduce erosion and the associated pollution. Voluntary adoption, however, is uncertain because of the lack of knowledge of the economic impacts of such practices on farmers. Therefore, this study was initiated to make comparative economic analysis of the conservation tillage systems being encouraged to the tillage practices traditionally used in the Southeast Saginaw Bay Watershed area.

Cooperating farmers were asked to set aside a parcel of land (2 to 4 hectares) and to prepare half of it with a normal method of tillage and the other half using conservation tillage equipment like the regular or modified chisel plow. Data on machinery management, agronomic requirements and crop performance were collected from these side-by-side plots.

Results of the first two years of a three year study show that conservation tillage performed as well or better than conventional tillage in most areas. No increase in pesticides use was required due to conservation tillage. Seed moisture at harvest was not significantly

different between the two types of systems. Soil moisture was available to plants for a longer period in conservation tilled plots. There was no statistically discernible difference in yield between systems in 1980. In the 1981 season differences were statistically discernable between individual plots due to abnormal weather patterns.

A machinery selection model was developed to analyze machinery requirements for different tillage systems. The model was used to determine the optimum size machinery for conservation and conventional tillage based upon performance and economic criteria.

Only input/output items that differ across both systems were considered. Partial budgeting techniques were used to evaluate the economics of conservation tillage systems relative to conventional systems. Results for different crop sequences on different farm sizes depict that conservation tillage can always provide a lower cost of producing the same crop or crop sequence. Conservation tillage costs $13.55 to $59.96 less per hectare and can withstand a loss in yields of 1.9 to 9.5 percent (depending on the cropping sequence) before it loses its economic advantage over conventional tillage.

Approved ______________________
Major Professor

Approved ______________________
Department Chairman

DEDICATED TO THE ONE WHO:

- Knew me when I was lost, deserving hell and had compassion over me
- Loved me beyond human comprehension that He willingly laid down His life on the cross that I might have life
- Rose triumphant over death and is alive today, sitting at the right side of the Father interceeding for me
- Still calls sinners and all that are burdened and heavy laden to Him promising them forgiveness and rest
- Is not willing that any should perish but come to the saving knowledge of God
- Is the author and finisher of my faith
- Is God almighty

To my Lord and Savior Jesus Christ, to Him the glory, power and dominion for ever and ever.

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I would like to thank Mary, my loving wife, for her encouragement, support and patience over these three years and for helping me make this venture a success; and my father and mother who labored, suffered and sacrificed a lot to give their children what they themselves were not able to have: good schooling and education.

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CHAPTER 1

INTRODUCTION

1.1. Reason for Conducting the Study

The focus of this study was to compare the profitability of conventional tillage to conservation tillage for crop sequences grown on the fine textured soils in Tuscola and Huron counties that drain into the southeast Saginaw Bay. The coastal drainage basin of the southeast Saginaw Bay has been selected by the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture, as an agricultural water pollution control site. This special project was authorized and funded under the Agricultural Conservation Program (ACP) of ASCS. The project area was 96,800 hectares, of which 87,200 were devoted to intensive agriculture. Under this program, cost-share payments were offered to farm owners and operators as incentives to adopt conservation practices which minimize agriculturally related contributions of sediments and nutrients to surface waters. There were 1,850 farm owners and operators in the project area.

The project was approved for implementation in April 1979, and announcements to the farmers in the area were sent during the 4th week of April. Farmers began signing up to cooperate shortly thereafter. Conservation tillage was one of the conservation practices encouraged through cost-share incentive payments. These practices were defined by ACP as systems which reduce the theoretically calculated erosion rates to less than one-half of that estimated to be tolerated for maintaining soil productivity. Thus, the goal of this study is to make a comparative economic analysis of the conservation tillage systems being encouraged and the tillage practices which are traditionally used in the project area.

1.2. Definition of Terms

Conventional tillage refers to the traditional method of preparing the seedbed for planting. It can include chopping stalks (if present), plowing, disking, harrowing and planting. There are variations in the number of operations, especially in disking, harrowing, and cultivating. There are also differences in the kinds of machinery used; stalk choppers, for example, in place of a disk for cutting stalks or a spring-tooth harrow or field cultivator in place of a disk for secondary tillage. The results are the same: a smooth seedbed that is free of residue and trash, Figure 1.1.

Conservation tillage systems are those which do not cause total inversion of the soil. Required amounts of residue are left on the soil surface. Tillage operations are reduced to the minimum necessary to secure good seed germination and an adequate plant population. Weed control is achieved primarily by properly applied herbicides, except in the ridge-till systems where cultivation is practiced, (Quisenberry, Tillage System Definition, prepared for MSU-SCS Tillage Crop Budgets, 1981). Figures 1.2 and 1.3 depict two conservation tillage implements in action.

Residual plant matter remaining on the surface of the soil after planting is the "criterion" for evaluating whether conservation tillage has been achieved. For the soil types in the drainage basin, 1.7 tonnes/hectare of plant residue are required on the surface to qualify as conservation tillage, subject to modification for site-specific soil

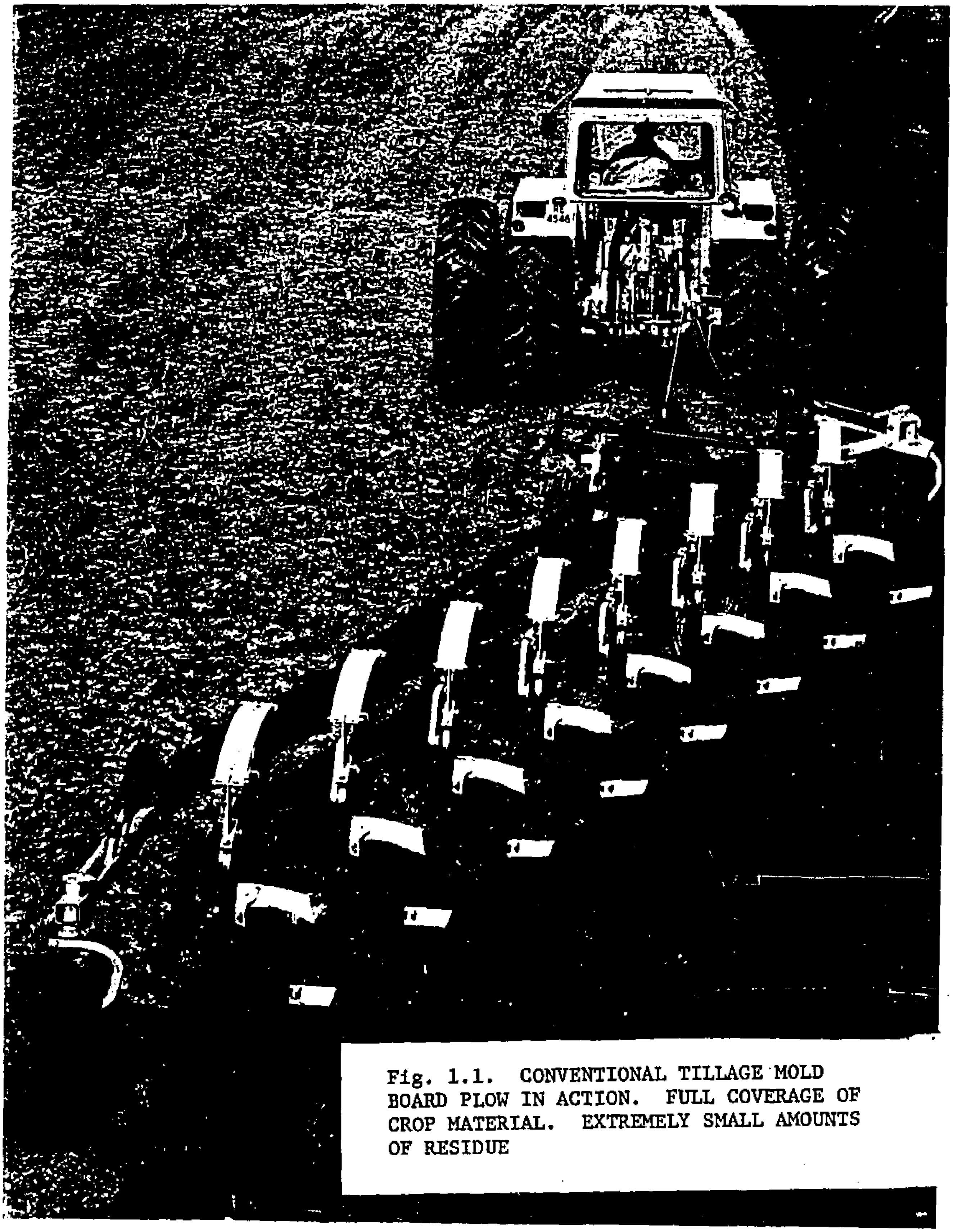

Fig. 1.1. CONVENTIONAL TILLAGE MOLD BOARD PLOW IN ACTION. FULL COVERAGE OF CROP MATERIAL. EXTREMELY SMALL AMOUNTS OF RESIDUE

Fig. 1.2 CONSERVATION TILLAGE
MODIFIED CHISEL PLOW ALLOWS CROP RESIDUE TO REMAIN ON THE SURFACE

Fig. 1.3 CONSERVATION TILLAGE:
V-RIPPER. SUBSOILING LEAVES CROP RESIDUE ON THE SURFACE

types (ECMPDR, 1980). Specific tillage implements are not a condition of the conservation tillage system.

1.3. Traditional Tillage Methods

A baseline survey was conducted in the winter of 1980 to determine the tillage methods commonly used by farmers producing corn, navy beans, sugar beets and soybeans in Tuscola County, Michigan. Farmers were asked about implements used, timing of operation, and frequency of use.

Eighty-three percent[1], 89.4%, 68.8% and 59.9% respectively of the farmers sampled who grew corn, navy beans, sugar beets and soybeans used conventional tillage methods. Seventeen percent, 10.6%, 31.2% and 40.5% respectively used a chisel plow. None of the farmers sampled followed a no-till system (see Appendix G for questionnaire and detailed results). The high percentage of farmers chisel plowing navy bean fields was a reflection of the status of the field after harvest. The crop residue was almost negligible and the soil surface was already disturbed only once by the bean puller.

1.4. Soil Management Groups in the Project Area

The soil management groups are a primary determinant of candidate tillage systems. For example, a review of the literature indicates yields under conservation tillage methods on compact soil are reduced more than with conventional tillage. Excessively compact soil must be loosened to be successful with conservation tillage methods. This can

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[1]Since some farmers stated that they practiced more than one operation in one season, for example disc till and moldboard plow the same field, percentages reported here are based on total number of operations performed and not on total number of farmers surveyed.

be best done in conservation tillage with a chisel plow when the soil is relatively dry. Fall chisel plowing can be done with little or no soil erosion on farms with land or water erosion problems which are closely associated with moldboard plowing. The best chisel plows for conservation tillage are those that are heavy enough and strong enough to penetrate the compact zone. Thus the approach to conservation tillage must be cognizant of the soils of an area. Similarly, experience with no-till management techniques have been disappointing on fine textured clay soils as contrasted to well drained, coarse-textured soils (Robertson, 1976).

Descriptions of the soil management groups for the cooperating farms are presented in Appendix F. The principle series are in soil association 20, and include Simms, Parkhill, Pawpawlin, Capac, and Iosco, and in soil association 21 which occurs along the Saginaw Bay, and includes Wisner, Thomas, and Essexville soils, which are limey on the surface (Whiteside, et al., 1968).

The soils of this division were developed under poor natural drainage conditions from loam, clay loam, or silty clay loam parent material. The soils are relatively high in organic matter, nitrogen and lime. They are moisture retentive, have good natural fertility, and are durable under cultivation. Closely associated are various sized sub areas with .46-1.07 meters of loamy sand or sandy loams covering the clay loams or silty clay loams (Iosco or Essexville). The topography is nearly level, with some low depressions and narrow sandy ridges. Most of this land was wet, swampy, and heavily timbered in its native state. The principle hazards to crop production are naturally poor drainage and poor tilth (soil structure). When tile drainage with adequate outlets is provided, the soils are very productive because the surface is deep, fine textured, and well supplied with humus. The soils do tend to be cold in the spring.

1.5. Geographic Area

The project area is described in Figure 1.4. The primary agriculture in the area is cash crop, with corn, dry beans, small grains, sugar beets and soybeans being the principal crops. Crops are grown in sequences adjusted from year-to-year based on deviations in prices, and as a result of labor scheduling, need to avoid soil compaction. This adjustment also heps partially mitigate disease and weed problems, and to reduce price and yield risk management.

Nine percent of the crop land average in 1978 was in farms[1] with 20 to 39 hectares, 16.5% with 40 to 79 hectares, 36.77% with 80 to 199 hectares, 23.8% with 200 to 399 hectares, and 14.1% with 400 hectares or more.[2] Farmers' average age in 1978 was 49.4 years, with 83% of the farmers being between 25 and 64. Twenty-five percent of the crop land area in 1978 was farmed by full owners, 68.2% by part-owners and 6.5% by full tenants.

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[1] Farm has been (arbitrarily) defined as being at least 20 hectares. Total crop land area would be 4.6% larger if the Census of Agriculture definition of a farm were used.

[2] Matching Census of Agriculture and Michigan State University Statistics baseline data to the project area is a problem since the project area is defined in the context of the Saginaw Bay Drainage Basin, not according to political jurisdiction boundaries. Nevertheless, Tuscola county data provides a useful perspective.

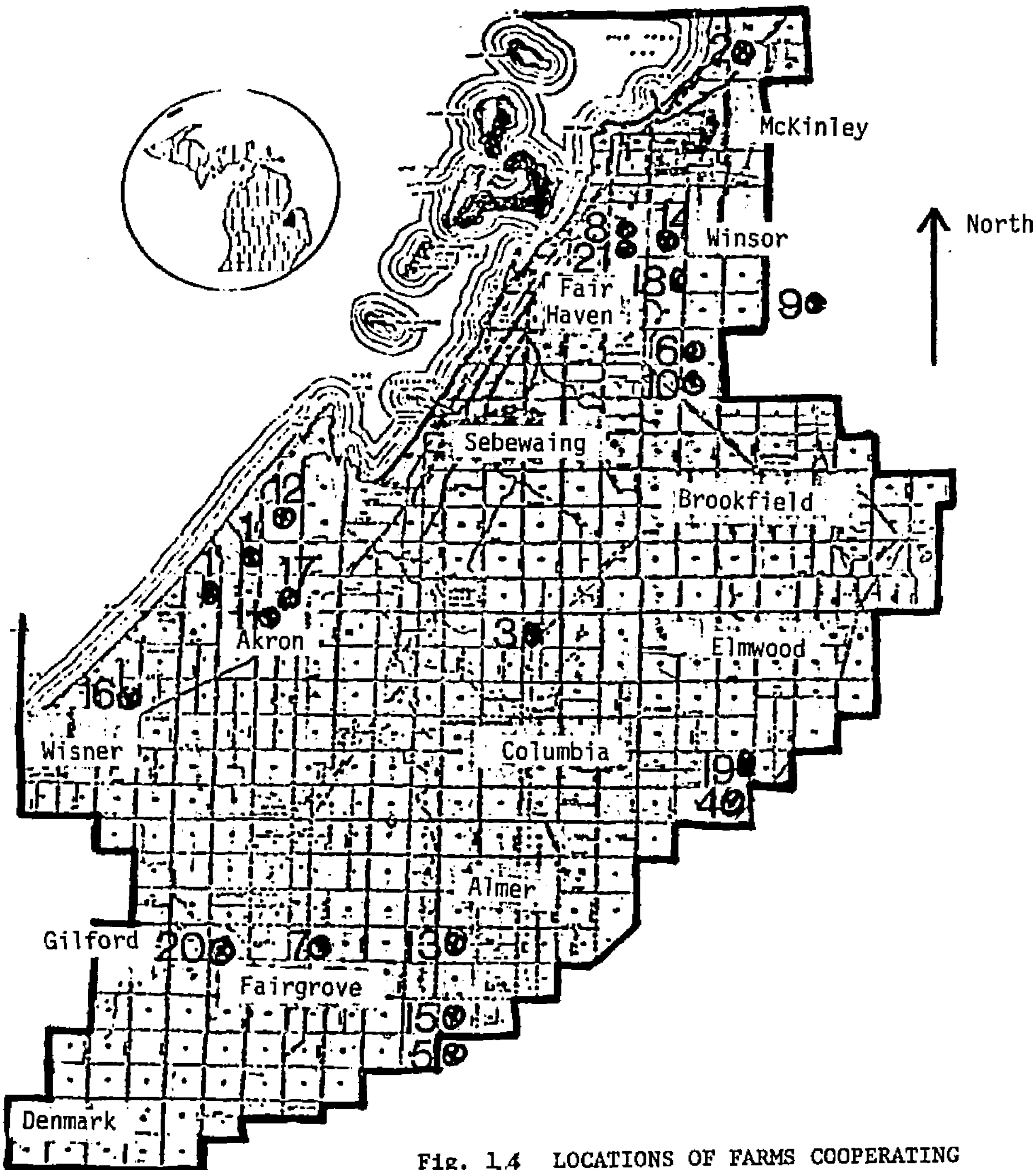

Fig. 1.4 LOCATIONS OF FARMS COOPERATING IN THE ECONOMIC ASSESSMENT OF CONVENTIONAL Vs CONSERVATION TILLAGE IN THE S.E. SAGINAW BAY DRAINAGE BASIN*

*The numbers on the watershed map represent the farms cooperating with the project.

1.6. Work Plan

The project thrust has a whole farm perspective. The logic is that the primary purpose of the project is to reduce pollution of the Saginaw Bay which comes from agricultural sources. Since crop sequence as well as the tillage system may be a control variable, the methodology, particularly in machinery selection and economic analysis, permits an examination of both tillage system and crop sequence and their effect on the economic performance of the farm.

The Water Quality Planning Agency and the involved branches of the United States Department of Agriculture are interested in methods which will ensure the continued use of agricultural production control practices by farmers after the cost-sharing incentive payments have ceased. While use of conservation tillage practices is currently achieved through cost-share incentive payments, continued voluntary adoption is uncertain because of lack of knowledge of the impact on the farmer.

The results are preliminary since they represent only the first and second year of a three year study; most agronomic experiments must be repeated over a minimum of three years because of year-to-year variation in weather and the fact that "treatment" differences (e.g., conservation tillage versus conventional tillage) often differ under alternative weather scenarios. Also, many treatment effects are cumulative; the experimental effects (positive or negative) may take several years to develop.

CHAPTER 2

OBJECTIVES

The overall objective of the study was to do a comparative economic analysis of conservation tillage systems encouraged in the project area to traditional tillage practices in the area. In order to meet the overall objective, specific objectives were:

1. To extensively review the literature for information on conservation tillage relevant to the corn belt and Michigan areas.

2. To measure under both types of tillage systems on actual farms a) crop residue on the soil surface b) plant population, c) plant growth, d) incidence and damage of pests, e) crop yield, f) grain moisture at harvest and g) machinery requirements.

2. To develop a machinery selection model which utilizes parameters collected in the field and from pertinent literature to select near optimum machinery sets for various production systems.

4. To determine production costs and returns under both types of tillage systems and analyze the sensitivity of the returns to various levels of crop yield.

CHAPTER 3

LITERATURE REVIEW

The primary objective of farmers should be to get the maximum possible profit from their resources. In these days this objective is coupled with a conscious effort on the part of the farmer to help improve the positive impact on the environment. Negative impact is due to chemicals in the drainage flow, and wind and water erosion with the resulting sedimentation in lakes and waterways.

Major variables which are influenced by tillage systems and have an important impact on yield include:

a. Soil temperature during the first three weeks following planting;

b. Soil moisture availability throughout the growing season;

c. Weed and insect population;

d. Soil aggregation;

e. Erosion losses;

f. Crop residues on the soil surface;

g. Fertility and pH of the soil;

h. Planting dates;

i. Length of growing season;

j. Soil organic matter; and

k. Soil compaction.

This review of literature will consider the impact of conservation tillage practices on the above factors for crops primarily grown in the northern corn belt regions, and in particular the study area of Michigan.

Moldboard plowing and subsequent tillage has been the traditional method in the U.S. of working the soil in order to provide a uniform, structured seedbed. This permits easier planting, more effective pest control, and more flexibility in management of crop rotations. It also permits easier placement of fertilizers and pesticide sprays for maximum effect (Constein et al., 1976).

Adoption of conservation tillage practices has been slow primarily because they create rough, porous surfaces very different from conventional tillage. Such surfaces make it harder to plant, and the partially inverted soil results in high concentrations of fertilizers and lime in the top eight centimeters of the soil profile, which increases soil acidity (Crosson, 1981). Conservation tillage systems may require increased chemical applications for adequate control of weeds and other pests (Constein et al., 1976; Crosson, 1981).

Recent concern of production agriculture and government agencies regarding adverse consequences of conventional tillage have resulted in the development of alternative tillage methods for crop production. Such alternate methods reduce fuel consumption, soil erosion, machinery costs, and labor requirements by eliminating some field operations and leaving crop residues on the soil surface after planting while maintaining yields in most soils (Crosson, 1981). Crop residue on the soil surface reduces crusting and increases infiltration. Conservation tillage also reduces erosion and is reported to reduce soil compaction, and maintain, where suitable, yields comparable to conventional systems (Griffith, et al., 1973).

3.1. Tillage System of the Northern Corn Belt

Tillage practices vary widely in terms of equipment, tillage depth, and amount of soil pulverization. Most farmed areas receive some form of primary tillage to a depth of 20 to 25 centimeters (Griffith et al., 1977). Tillage planting systems that have been evaluated in research trials and are currently used by some farmers in Michigan are as follows:

3.1.1. Conventional Tillage

This refers to the traditional method of preparing the seedbed for planting. It can include chopping stalks if present, plowing, disking, harrowing, and planting. There are variations in the number of operations, especially in disking, harrowing and cultivating. There are also differences in the kind of machinery used; stalk choppers,[1] for example, in place of a disk for breaking up corn stalks prior to plowing. The ultimate results are the same: a smooth seedbed that is free of residue and trash (Quisenberry, 1981).

3.1.2. Conservation Tillage

Several systems have been developed under conservation tillage guidelines including no-till planting, ridge-till planting, chisel plow tillage, disk till, tandem disk and offset disk tillage systems. Conservation tillage systems are defined as those that do not result in total inversion of the soil and allow required amounts of residue to be

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[1]Implements like flail choppers that will chop the crop residue without disturbing the soil

left on the soil surface after planting to reduce erosion.[1] Tillage operations should be reduced to the minimum necessary to secure a good crop seed germination and an adequate stand. Weed control is achieved by herbicide application except in the ridge-till systems (Quisenberry, 1981). Major conservation tillage systems used in the project area include the following:

3.1.2.1. No-Till. Planting is in narrow slots opened by a narrow chisel, fluted, ripple, or smooth coulter or other device in undisturbed residues of the previous crop. Also, planting could be in soil covered with manure, when applied after corn is removed for silage, or following a winter cover crop. Residues may be shredded in the fall, winter, or spring prior to planting or may be left unshredded. No more than ten percent of the soil surface is disturbed. Seedbed preparation and planting are done in one operation. Crop residues are left on the soil surface during the growing season. The minimum amount of surface residue is 454 kilograms of corn residue per hectare equivalent or 30 percent of ground cover. Weeds are controlled by herbicides (Quisenberry, 1981).

3.1.2.2. Ridge-Till Planting. Ridge-till planting is planting the crop on ridges built with a special cultivator during the previous growing season. The seedbed is prepared with a sweep that cuts and pushes the ridge top and all crop residue between the rows. There is no other tillage before planting. Seedbed preparation and planting are accomplished in one trip over the field (not counting ridge formation). Crop

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[1]In some cropping sequences rye is used as a cover crop after fall plowing. It is sprayed by a contact killer in spring.

residue from the previous crop is left on the soil surface (Quisenberry, 1981).

3.1.2.3. Chisel Tillage. Chisel plows are used to prepare the seedbed by mixing the soil and the residue without total inversion of the soil; the entire soil surface is disturbed. Usually only one chiseling operation is performed; it is typically done in the fall. Secondary tillage, usually a spring operation with a tandem disk or a field cultivator, is used to prepare the field for planting. Seedbed preparations and planting are done in different operations. A chisel plow has one or more rows of shanks with straight or twisted teeth or shovels on the shanks (Quisenberry, 1981).

The chisel plow system is the most extensively used of the conservation tillage systems in Michigan (Cook and Robertson, 1979). Chisel plowing is preferable on soils that benefit from fall tillage and where water and wind erosion hazards are high (Amemiya, 1977). It is effective in loosening compacted soil and it works reasonably well on stoney fields. Chisel plow systems are ideal for locations where soil freezing is common because it increases the water intake of the frozen layer (Pappendik and Miller, 1981).

To eliminate a separate residue chopping operation, chisel plows are combined with a gang of disks or straight coulters ahead of the chisel shanks. This combination is gaining wide acceptance. Twisted (helical) chisel blades are also replacing straight blades. This give the chisel plow an added ability for partial inversion of the soil while maintaining the needed crop residue cover on the surface.

3.2. Effects of Conservation Tillage

3.2.1. Soil Temperature

An obstacle to adoption of conservation tillage in the Southeast Saginaw Drainage Basin is the impact of reduced soil temperature in the top ten centimeters of the soil at planting time and during the first six weeks. This temperature reduction is due to the mulching effect of crop residue on the subsequent crop.

Van Bavel (1972) defines mulching as the "providing or maintaining of a relatively thin surface layer of some suitable material on the soil surface". Research done in West Virginia showed soil temperature in corn sod-planted in grass to be 10 degrees Celcius (^{o}C) lower than soil temperature under conventional tillage (Bennet, Mathias, and Sperow, 1976). Various tillage practices affect soil temperatures differently according to Willis and Amemiya, (1973). Fall plowed soil, for example, warms up more quickly in the spring than soil which is not fall plowed. Also, soil temperature in the top ten centimeters under fall plowing is approximately 3^{o}C higher in May than under grass sod (Emerson and Olson, 1970). Schuler, (1979) reported that soil temperature taken two weeks after spring moldboard plowing was 5^{o}C higher in the top ten centimeters than in the conservation tilled soil. The difference was attributed to large amounts of crop residue on the surface. The primary reason for this effect is the increased water retention in soils with higher organic matter levels due to the crop residue.

Lower soil temperature in sod may reduce germination and suppress early growth (Griffith, et al., 1977), especially when crops like corn are planted early to take advantage of the full growing season (Bennet, 1977; Amemiya, 1977). Lower soil temperature will have a large impact on the growth of stems and roots of a wide range of plants (Canam, 1962). When the temperature drops below 4.5°C, growth of most plants practically stops (Weaver, 1926, as quoted by Willis and Amemiya, 1973). As a result, it may be necessary to delay planting in the northern states of the corn belt for a few days (Bennet, 1977). Glere, et al., (1980), stated that W.M. Lewis, an agronomist at North Carolina State University warns that due to this drop in temperature, planting in conservation tilled soil in the Northern corn belt states may need to be delayed by as much as ten days in relation to conventional tillage. This recommendation, however, is changing. Robertson (1982) stated that there are now new corn hybrids on the market that are cold tolerant. He also stated that with proper chemical treatment seeds will no longer rot due to prolonged periods in moist and cool soil. Personal communication with farmers practicing conservation tillage revealed the same.

Allmars et al., (1964), Jones et al., (1963), Ketchenson (1970), Medreski et al., (1963) and William et al., (1967) conducted experiments in which heating cables were placed in the soil and used to control the temperature of the top ten centimeters of the soil. Willis and Amemiya (1973), citing literature written on these experiments, stated that the typical response to temperature was an increase in germination, rate of emergence, nutrient uptake, yield, weight and height as temperature increased to the optimum. Also, according to Knoll et al., (1964) a 15°C root temperature for fifteen days early in the growing season affected production of dry matter.

The root system of a plant is affected by soil temperature in taking up nutrients, absorbing water, producing metabolites for growth, and, providing a storage place in the above-the-ground portion of the plant (Willis and Amemiya, 1973). Moncrief et al., (1979), found a statistically discernible relationship between reduced yield in conservation planted corn and a drop in soil temperature.

3.2.2. Soil Moisture.

There is scarcely a year when available soil moisture is sufficient for optimal crop growth at all points in the growing season. Crop production depends on water availability. Periods of high rainfall and drought occur in many areas within the growing season of the crop, each with an adverse effect on yield and quality of the crop. To assure a more uniform supply, water that is in excess of plant needs at one time must be conserved for later use through storage in the soil. Even under irrigated conditions, water must be temporarily stored in the soil. High soil moisture evaporation rates and low storage efficiencies, however, have defeated efforts to increase crop production in many areas (Amemiya, 1977).

Lemon (1976) classified evaporation of water from soil into three stages. In the first stage water loss is relatively fast and depends on the evaporative demands of the above-ground environment. The second is characterized by a rapid decline of water loss and is controlled by unsaturated conductivity rather than evaporation potential of the soil surface. In the third stage, water losses are relatively low and essentially constant, and:

> "are governed by absorption forces of molecular distances at the soil liquid-solid interface. During this stage, a solid layer of increasing thickness, which approaches air-dryness, forms at the surface. Water lost by evaporation in this stage may diffuse as vapor through dry soil." (Conservation Tillage, 1973, p. 42).

It is specified that the highest evaporation loss occurs during the first stage, and, therefore, the greatest potential for reducing evaporation lies in this stage also.

Conservation tillage utilizes the surface residue to reduce the impact of solar radiation and wind movement. This reduces the rate of surface evaporation and permits the water to penetrate deeply into the soil where it is less affected by evaporation. Evaporation reduction is a function of the percent of the crop cover on the soil surface (Unger and Parks, 1976). The value of the systems used in conservation tillage is closely related to the amount of crop residues left on the soil surface, and the number of treatments after plowing. Moisture is closely related to the amount of crop residues left on the soil surface and the number of field treatments after plowing (Cook and Robertson, 1979).

Surface residues increase infiltration and reduce evaporation (Bennet, 1979; Reicosky et al., 1979; and Griffith et al., 1977). This results in more water availability for plant growth throughout the growing season, which reduces the need for supplemental moisture. Hence it is easier for plants to use moisture from the small rains because roots grow near the soil surface under the mulch. Larson (1979) states that the primary benefit of conservation is reduced irrigation water usage.

Researchers have found that soils in mulch tilled corn plots are higher in moisture than those in conventionally tilled plots during the same growing season (Hayes, 1971; Triplett, 1968). Even though the increase is not always statistically discernible (Schuler, 1979) the fact that standing stubble will hold more snow than cultivated fields is also an important consideration when looking at the impact of tillage treatments on moisture. Slow drying characteristics in spring under the stubble continue throughout the season "which is the secret to moisture conservation" (Klocke, 1979).

A primary advantage of conservation tillage methods is increased infiltration (Reicosky, 1979; Griffith, et al., 1977). This provides more water for transpiration by plants. Reicosky (1979) also reported that evaporation was 2.4 times higher under conventional than under conservation treatments in maury silt loam for the period between May and September. This was translated into an 18 percent higher water availability for transpiration for the no-till corn. Griffth et al., (1977) indicated that while surface roughness promotes better infiltration, most research points out that surface residue is the most important factor for this increased infiltration and that more than 50 percent of the soil surface should remain covered with residue to get significant benefits.

Van Doren, Triplett and Henry (1975) reported that in Ohio a mulch covering 70-80 percent of the surface improved corn yields in the Wooster silt loam soil but not on fine textured soils such as Hoytville. The benefits of the mulch were associated with increased soil moisture. In well drained, sandy loam, conservation tillage had a striking moisture advantage; as much as 1.3 centimeters more moisture were available in the top 15 centimeters when conservation tillage was used.

3.2.3. Yield.

Adoption of conservation tillage has resulted in increased crop yields on some soils and locations and decreased yields on others. Generally, improved yields with conservation tillage practices have occurred on better drained soils. Yield decreases have occurred on imperfectly or poorly drained soils. Yields of corn following some other crop in rotation on such soils have been in general, equivalent to or better than yields with late spring tillage (Van Doren et al., 1976).

Yields with no-tillage or reduced tillage systems vary significantly when compared with conventional practices, the major variable being soil type. The use of reduced tillage on some soil types has resulted in reduced yields; however, different crop rotations might improve lower yields on such crops (Van Doren et al., 1976; Glere et al., 1980). Corn yields are typically increased under conservation tillage where these soils favor shallow tillage and surface residue but yields are likely to decline where these factors create a negative influence due to shallow tillage or crop residue. Most erosive soils in the eastern corn belt are favorable for conservation tillage. This includes the rolling soils subject to water erosion in southern areas and excessively drained coarse textured soils subject to wind erosion (Griffith et al., 1977). Table 3.1 depicts the impact of tillage systems on corn yield, in the western corn belt.

Several other crops have been successfully produced with conservation tillage systems. Schuler (1979) reported that potatoes yielded highest in conservation tilled plots. Larson (1979) and Wilkes and Underbrink (1979) reported that cotton growth under conservation tillage

Table 3.1

Influence of Tillage Treatments on Corn Yield
In The Western Corn Belt*

Source	Location	Tillage System: Conventional	Tillage System: Conservation
		Tonnes/hectare	Tonnes/hectare
Wittmus, et al 1971	Nebraska (average of 15 locations)	7.9	8.0
Rehm, Moomaw 1976	Concord, Nebraska	6.4[a]	6.8[b]
Witmuss 1972-75	Lincoln, Nebraska	5.3[c]	5.9[d]
Erback 1971-75	Ames, Iowa	9.6[e]	8.8[f]

*Adapted from Amemiya, 1977.

[a]Disk, moldboard plow, disk plant
[b]Shred stalks, till plant
[c]Chop stalks, disc, plow in fall, disk, plant
[d]Coulter chisel in fall, disk, plant in spring
[e]Fall mold board plow, disk, harrow, plant
[f]Fall chisel plow, field cultivate, plant

produced just as well as conventional tillage. In a study where deep chiseling was used as a conservation tillage system, and tested on soybeans and corn, results showed that deep chiseled treatments produced yields that were 18% and 50% higher for both corn and soybeans respectively (Camp et al., 1981). In the same experiment, conservation tillage with the chisel plow produced higher yields than other deep tillage treatments for soybeans but not for corn.

A seven year study in Indiana compared yields under conventional, chisel, and no-till systems. There were four sites with variable soil textures. The difference in latitude between plots was 280 kilometers. In northern Indiana the plots were close to a Michigan latitude. Yields were 8.3 tonnes/hectare for conventional and 8.5 tonnes/hectare for conservation tillage systems, respectively on a well drained sandy loam. On a poorly drained sandy loam, no-till corn yields were at least 1.0 tonne/hectare lower than conventional tilled plots (Griffith, Mannering and Moldenhauer, 1977).

Table 3.2 summarizes influence of tillage treatment by soil type on corn in the corn belt region. It is clear that on poorly drained soils conventional tillage practices outyield conservation tillage systems.

In Ohio, the previous crop significantly affected corn yields where no-till was practiced. No-till and conventional till systems were compared in a 12 year study for the following crop sequences: continuous corn, corn after soybeans, and corn after meadow in a three year rotation. No-till produced significantly higher yields on a silt loam with an unstable surface, while conventional tillage surpassed no-till on poorly drained clay soils. When corn followed soybeans on a Hoytville

Table 3.2

Corn and Soybean Yield Response to Tillage Treatments
Under Different Crop Sequences*

Source	Crop Sequence	Crop	Location	- - - - Tillage System - - - -	
				Conventional	Conservation
				Tonnes/hectare	Tonnes/hectare
Randel & Swan 1976	Corn after soybean	Corn	Waseca, Minn.	7.2[a]	7.8[b]
Van Doren & Triplett, 1975	Corn after soybean	Corn	Ohio	9.5[a]	10.3[c]
Ross, 1974	Corn after soybean	Corn	Sutherland, Iowa	7.3[a]	7.3[d]
Amemiya, 1975	Corn after soybean	Corn	N.W. Iowa	7.1[a]	7.1[e]
Randel & Swan 1976	Corn after Corn	Corn	Waseca, Minn.	6.7[a]	4.7[b]
Van Doren & Triplett, 1975	Corn after Corn	Corn	Ohio	9.1[a]	10.2[e]
Ross, 1974	Corn after corn	Corn	Sutherland, Iowa	6.8[a]	6.7[d]
Amemiya, 1975	Corn after corn	Corn	N.W. Iowa	6.5[a]	6.6[e]
Randel & Swan	Soybean after corn	Soybean	Waseca, Minn.	2.9[a]	2.9[b]
Ross, 1974	Soybean after corn	Soybean	Sutherland, Iowa	2.4[a]	2.3[d]
Amemiya, 1975	Soybean after corn	Soybean	N.W. Iowa	2.3[a]	2.3[e]

*Adapted from Amemiya, 1977.

[a]Fall mold board plow, field cultivate, plant

[b]Fall chisel plow, field cultivate, plant

[c]No-till

[d]Spring disk

[e]Till plant

clay, the decrease in yields was less than the decrease in continuous corn. When corn followed meadow, no statistically discernible difference in yield occurred between the two tillage systems (Griffith et al., 1977). Table 3.3 depicts the influence of tillage system and crop sequence on the yield of corn and soybeans.

Miller and Shrader (1976) developed yield response curves for moisture and for estimating the potential effect of conservation tillage systems on corn yields in western Iowa. Their data showed that when soil moisture levels were 100 percent of plant available water capacity, tillage practices had little effect on yields. At average and below average spring moisture levels, conservation tillage increased yield estimates over those obtained with conventional tillage.

A USDA Agrisearch Report (1981) indicated that McGregor and Creer after working for three years on different tillage systems on grain corn and sorghum in the Mississippi Valley silty uplands reported the following: Erosion and Watershed plots planted no-till or reduced till had better yields than conventionally tilled plots. The average yield over three years was 7.5 tonnes/hectare for conventional corn, 7.8 tonnes/hectare for no-till corn, and 8.3 tonnes/hectare for reduced till corn. Wittmuss and Yazar (1981) reported that conservation tilled plots in Nebraska had the highest and conventional plots the lowest four year average yields. One conservation treatment was 76% higher than conventional control plots.

With conservation tillage in Quebec, Canada, corn was grown for three consecutive years on a clay soil. Results showed that in a season of moderate and regular rainfall conservation tilled plots produced

Table 3.3

Corn Yield Response to Tillage Systems Under Different Soils*

Source	Soil Type	Location	- - - - -Tillage System- - - - - Conventional	Conservation
			Tonnes/hectare	Tonnes/hectare
Griffith, et al. 1976	Tracy sandy loam	N.W. Indiana	8.3[a]	8.5[b]
"	Runnymede loam	N.W. Indiana	8.5 [a]	8.8[b]
"	Blount silt loam	E.C. Indiana	8.1[a]	7.3[b]
"	Bedford silt loam	Southern Indiana	6.3[a]	6.9[b]
Oschwald & Seimus 1976	Flanagan silt loam	Illinois	10.6[c]	10.0[b]
"	Catlin silt loam	Illinois	10.5[a]	10.4[c]
Van Doren & Triplett 1975	Wooster silt loam	Ohio	10.2[d]	9.1[d]
"	Hoytville silty clay	Ohio	8.7[d]	7.4[d]

*Adapted from Griffith, et al, 1977.

[a]Spring plow, disc twice, plant

[b]Fall chisel, field cultivate, plant

[c]Fall plow, disc twice, plant

[d]Equal stand, good weed control, continuous corn

higher yields than conventional tilled plots. Whereas in a season where rainfall at certain times was very high, yields were as much as eight percent lower than conventional tilled plots. The reason was attributed to increased water in the soil:

> "study of bulk density and moisture data showed that the overall soil volume occupied by soil particles decreased by about two percent" with conservation tillage management and in the "wet year", air was a limiting factor in the soil under study".

This meant that there was more space for soil and water to share and therefore in a year in which rainfall was normal, soil had adequate air supplies. However, in a high rainfall year air-filled porosity was lower and approached zero in the conservation tilled soil (Taylor et al., 1981). This yield differential due to moisture fluctuation is reported frequently in literature. Studies in Iowa on Moody Silt loam lasting eleven years showed that in severe water deficits lister planted (a conservation tillage method) corn out yielded conventionally planted corn by 2.8 tonnes/hectare. Under favorable weather conditions, there was little difference (Amemiya, 1977).

Unfortunately, crops other than corn which are prominent in the Saginaw Bay Watershed are the crops with the least amount of available conservation tillage yield data. Soybeans and corn yields were reported by Phillips et al., (1980) to be as high or higher than on conservation tilled soils when compared to conventional tilled soils on large areas of agricultural lands.

Robertson et al., (1979) conducted a study comparing conservation tillage on dry beans and sugar beets, in the Saginaw Valley area. Four locations were chosen for the study. Dry bean plots harvested showed that conservation tillage outyielded conventional tillage by 740 kilograms/hectare. Conservation tillage also improved the germination of the dry beans and gave a superior plant growth for all varieties at all locations. In the same study sugar beets yielded 16 percent more, on conservation tillage plots.

3.2.4. Management.

All conservation tillage systems require a higher level of management skill than conventional tillage (Cook and Robertson, 1979). These factors must be recognized when making changes in tillage systems. Having a positive attitude is important to make the system work. With this frame of mind, a farmer will maintain if not improve, on suitable soils, current yield levels while reducing erosion and improving water quality of the rivers and lakes (Cook and Robertson, 1979). Conservation tillage allows for very few errors.

> "Clean till lets a farmer correct a maximum number of mistakes with another trip across the field. With conservation tillage the farmer cannot afford such practices" (Kelly, 1977).

Many farmers report poor stand with conservation tillage. This problem can often be traced to poor equipment adjustment, inexperience with planting in residues, poor seed placement, or improper use of pesticides (LeGlere, 1981). Indiana studies (Griffith et al., 1973) of tillage systems on five soils showed few stand differences on sandy loam soil but up to 15 percent variation on silty clay loam. No-till stands were always within 5 percent of conventional stands. For this reason planting rates are recommended to be at least 10 percent higher than conventional (Robertson et al., 1979).

Table 3.4

Influence of Tillage System on the Use of Herbicide.
Figures are in Dollars per Hectare

Crop	Source	Tillage System			% Increase Over Conventional Tillage
		Conventional	Conservation	N.T.*	
Wheat	Taylor, 1979 (Texas)	8.75	8.75	39.13	350
Corn	Doster, 1973 (Indiana)	--	--	--	50
Corn (in a Corn-corn-soybean sequence)	Walker, 1977 (Iowa)	74.0	100.7	--	36
Sorghum	Crosson, 1981	16.58	16.58	58.45	253
	Phillips, 1974	--	--	--	50

* No tillage

To use conservation tillage techniques most effectively, a farmer must know his soil types and must be able to match them with appropriate tillage practices. He thus needs to command greater technical skills to use these methods compared to conventional tillage practices. However, the costs of acquiring the necessary skills are low and not an important obstacle to the spread of conservation tillage (Crosson, 1981). The farmer using conservation tillage has less margin of error because he often cannot go back over a field with a cultivator to control weed problems not handled by herbicides. Greater economic risk is thus associated with adoption of conservation tillage (Glere et al., 1980). It should be emphasized during this transition period of tillage systems that conservation tillage may produce lower yields until farmers gain experience with more variables introduced by the system.

3.2.5. Pest Control

3.2.5.1. Herbicides. Under conventional tillage systems, farmers control weeds by plowing them under with the use of a tillage implement before planting, and by spraying herbicides during secondary tillage operations. When tillage is reduced, alternate weed control methods must be implemented to accomplish this essential step of early reduction in weed population.

Conservation tillage systems rely primarily on chemical applications to check weed establishments. Other forms of conservation tillage may include some cultivator, but most usually require more kilograms of herbicide for weed control than conventional tillage (Crosson, 81). However, judging from literature this increase is highly variable as can be seen from Table 3.4. Crosson (1981) gave three major reasons for this increase in quantity: 1) substitution effect, where due to reduced tillage, chemicals should handle a larger population of weeds; 2) efficiency effect where new herbicide must be applied to achieve a given level of weed control because some of the herbicide gets tied up by the crop residue; and 3) environmental effect where increased moisture in the conservation tilled soil improves the conditions for germination and growth of weeds. Sod planting under no-till utilizes a combination of Paraquat and Atrazine to control weeds in corn. On rough tilled surfaces, pre-emergents such as Atrazine, Lasso and Amiben are not effective. Pre-plant incorporated (PPI) herbicides must be applied on a relatively well prepared surface to obtain uniform effectiveness. A trashy, cloddy surface will inhibit PPI performance.

Post emergent herbicides are most effective when conservation tillage is used. This, however, may cause problems especially where early crop growth is suppressed by low temperatures because a height differential between crop plants and weeds is required for effective results. This limits good control early in the season when weed growth is most detrimental to crop yields. Slow germinating weeds, or weeds which grow at the same rate as the crop cannot be controlled effectively with post emergents (Erbach and Lovely, 1974).

Weed control by mechanical cultivation is difficult in heavy residue when tools such as sweep cultivators, and rotary hoes are used. Rotary tillers and disks work in heavy residue but they bury much of the residue, reducing the conservation values of the system. A rolling cultivator works well in crop residue, and only buries a small fraction of the residue (Erbach and Lovely, 1974).

3.2.5.2. Insecticides. Insect and disease problems are most severe in conservation tillage than in conventional tillage. Conservation tillage may require heavier application of insecticides and fungicides to achieve proper control. This is attributed to the crop residue left on the soil surface which provides a favorable habitat for some insects and diseases.

Researchers are divided on this idea. Philips et al., (1980) stated that this varies with conservation tillage practices. They also state that because of higher soil moisture and less soil compaction plants are healthier and can resist insect and disease pressure (Crosson, 1981). On the other hand, Kelly (1977), reported black cutworm in no-till crop production, particularly when corn followed soybeans. This is due to the insect affinity for soybean stubble, lower temperature, and high moisture conditions resulting from increased soil organic matter. Seed corn maggot and seed corn beetle are also favored in cold wet springs under conservation tillage.

Root aphid and white grubs were found in higher populations in conservation tillage. Overwintering insects were not killed because they were less exposed under conservation than conventional systems. Other pests seen in higher populations are armyworms, slugs, and flea beetles (Constein et al., 1976).

Control of insect populations under conservation tillage through the use of chemicals is dependent on the climate to a great extent. Rains after insecticide applications may render the insecticide less effective or ineffective; and as the number of tillage operations decrease seed treatment becomes very important. This treatment should

Table 3.5. Estimates of the Effect of Different Tillage Practices on Insect Populations in Corn.*[a]

Pest	Spring Plowing	Fall Plowing	Reduced Tillage	No-till[b]	Effective Chemical Control
Seed-corn beetles	0	0	?	+	Yes
Seed-corn maggots	0	0	?	+	Yes
Wireworms	0	-	?	+(sod)	Yes
White grubs	0	-	?	+(sod)	No
Corn root aphids	-	-	?	+(sod)	?
Corn rootworm	-?	-?	+?	+(corn)	Yes
Black cutworms	?	?	?	+	Yes
Billbugs	-	-	-	+(sod)	Yes
European corn borer	-	-	+	+	Yes
True armyworms	-	-	-	+(sod)	Yes
Common stalk borer	-	-	-	+	No
Slugs	-	-	-	+	No
Mice	-	-	-	+(sod)	Yes

*The practice will increase the population or the potential for damage by the pest (+); it will reduce the population or potential for damage (-); no effect on the pest (0); effect unknown to the pest (?).

[a]University of Illinois, Circular 1172.

[b]The preceding crop will have a direct influence on the pest problem(s) in no-till corn.

be coupled with an increased understanding of pest population parameters. Anticipation of where potential insect problems will occur becomes crucial in pest control under conservation tillage practices.

The University of Illinois (1979) found a direct relationship between tillage systems and insect management (Table 3.5). According to this table "reduced tillage" may increase populations of corn rootworm relative to conventional tillage.

Where cutworms and wireworms are a problem, sprays, granules or fertilizer-insecticide combination of Aldrin or Meptachlor are effective. They should be applied by broadcast on the surface prior to planting, and immediately incorporated with a field cultivator within the upper eight or thirteen centimeters of the soil (Constein et al., 1976).

Granular pesticides should be applied to control rootworms in a 13 to 17 centimeters band behind the planter shoe, but in front of the covering device and packer wheel. All soil applied insecticides are more effective when incorporated to a one to two centimeter depth and packed. With no-till equipment, placing granules directly in the seed furrow is one of the only choices available. Only a limited number of insecticides are regulated for such use. Granules must be lightly covered and the furrow sealed for this method to be environmentally safe (Constein et al., 1976).

3.2.6. Soil Aggregation

Soil aggregation is an index of soil resistance to dispersion, compaction, plant emergence, soil aeration, drainage, water intake and soil erosion (Griffith et al., 1977). Soil aggregation was studied for conservation and conventional systems used with continuous corn in Indiana. After five years, results showed that aggregation increased as tillage decreased. In most cases aggregation was higher in the zero to five centimeter zone than in the five to fifteen centimeter zone with no-tillage (Mannering et al., 1976).

When crop residues are incorporated in the top soil, regardless of how they are managed, soil erosion is immediately reduced. This decrease is due to cementing agents produced by microbial organisms which stick soil particles together, forming aggregates greater than 0.84 mm in diameter. Aggregation declines as other micro-organisms attack these products breaking into friable, erodible humus (Chepil and Woodruff, 1963).

3.3. Economics of Conservation Tillage

Several researchers have published results of their experiments dealing with various tillage systems and the impact of such systems on crop production. Detailed farm budget studies could describe the cost differences between conventional and conservation tillage technologies under the variety of conditions in which they are actually used by farmers. Information about differences between these two tillage systems in quantities of resources used and yields obtained is presented below under labor, equipment, fertilizers and fuel.

3.3.1. Labor.

There is agreement that less labor per hectare is needed with conservation tillage. Even though harvest activities show no difference

Table 36. Estimates of Labor Hours Required Per Acre in Conventional Tillage Relative to Conservation Tillage*†

Comment	Ratio, Conventional Tillage To Conservation Tillage	Source
No-till, crop or other details not specified	As much as 3.0	Triplett and Van Doren, 1977
Data for 1969, area not specified		USDA, 1975
Corn	2.1	
Sorghum	2.1	
Soybeans	2.4	
Cotton	2.4	
Irrigated winter wheat, area not specified		Allen, R. et al 1976
No-till	2.0	
"Limited" till	1.4	
Corn in Nebraska	2.0	Derscheid et al
Corn in Michigan	1.7	Mannering, J. and Burwell, 1968
Corn in Central Indiana		Doster, H. and Philips, J. 1973.
Chisel Plow	1.6	
Till-plant	2.5	
No-till	2.3	
Corn in Piedmont in North Carolina	2.7	
Dryland continuous grain sorghum, Texas Panhandle	1.6-1.7	Shiply and Osburn, 1973
Dryland wheat-grain sorghum rotation, Texas Panhandle	1.75	"
No-till spring wheat in southern Alberta	1.25-1.40	Zenter, and Lindwall, 1978

†Adapted from Crosson, 1981

*Differences are assumed to refer to pre-harvest labor requirements. The literature is not always clear on this.

NOTE: Research results received too late for detailed consideration here show that labor required for conventional tillage of corn exceeded that required by various conservation tillage systems by 30 to 50 percent. However, these estimates evidently are total labor required. Most estimates in this table apparnetly are pre-harvest labor only.

between systems, preharvest activities show a reduction of one half the requirement (Crosson, 1981). Table 3.6 shows estimates of labor required in conventional tillage relative to conservation tillage.

3.3.2. Equipment.

A survey of literature on conservation and conventional tillage systems shows that data on machinery investment costs for the two classes of technology are meager, scattered and specific to soil types, location and farm size. These data, however, are almost unanimous that conservation tillage costs are less than conventional (Crosson, 81). Table 3.7 shows a summary of estimates of machinery costs of both systems.

Machinery requirements per hectare are less with conservation tillage for a farmer who converts completely to this system. In terms of annual costs per hectare, the saving is on the order of three to ten dollars. However, many farmers likely will want to retain the option of conventional tillage and for them machinery costs likely would be higher than for farmers who forego this option (Crosson, 1981).

3.3.3. Fuel

Conservation tillage requires less pre-harvest fuel than conventional tillage because of fewer passes over the field. Conservation tillage saves ten to thirty liters of diesel fuel equivalent per hectare relative to conventional tillage. No-tillage saves thirty to forty liters of fuel per hectare. Table 3.8 depicts fuel requirements for the two tillage systems based on literature published.

Table 3.7

Estimates of Machinery Costs for Conventional and Conservation Tillage Per Hectare*†

Source	Conventional Tillage		Conservation Tillage								
	Fall Plow	Spring Plow	Chisel	Partial Chisel	Disk Chisel	Coulter Chisel	Disk	Till-Plant	Limited	No-till	Minimum Till
Siemens & Oschwalb 1978[a]											
200 hectares	76.90	73.38	74.13	77.75	81.90	82.63	63.03			62.05	
400 hectares	61.25	61.78	55.20	62.15	49.78	58.80	50.18			41.65	
Dobster & Phillips 1973[b]	20.55	33.40	20.95					15.40		16.00	
Taylor, Reneau & Trimble 1979											
Furrow-irrigated winter wheat[c]	27.10								20.60	15.73	
Dryland grain sorghum[d]	37.15								22.43	12.93	
Walker[e], 1977	79.73	104.70									73.90

*Data are not comparable among sources.

†Adapted from Crosson, 1981.

[a]Corn and soybeans in Illinois.

[b]Corn in central Indiana; 240 hectare farm.

[c]Bushland, Texas; size of farm not given. Based on average yields 1974-1976.

[d]Rio Grande Valley, Texas; size of farm not given. Based on average yields, 1974-1976.

[e]Southwest Iowa: corn-corn-soybean rotation; 128 hectare farm.

3.3.4. Fertilizer

There are differing views about whether conservation tillage and conventional tillage have different fertilizer requirements. One of the problems in assessing the literature on this point is that the concept of fertilizer requirements often is not defined. From the farmer's standpoint, the definition presumably is economic: The fertilizer required is the amount that will yield a return equal to the cost of the fertilizer, allowing for risk. To be sure, the farmer may not define his fertilizer requirements in these terms, but as a profit maximizer, that is what he has in mind (Crosson, 1981).

The definition of fertilizer requirements in the literature while unclear, is not the economic definition that one would expect farmers to employ. It is instead a technical definition reflecting judgements of agronomists and soil scientists on the amounts of fertilizer needed under given conditions of soil type, structure, temperature, moisture and available requirements of nutrients. Often, the yield responses to the fertilizer requirements of conservation tillage and conventional tillage are not given. Clearly, if conservation tillage systems require more fertilizer than conventional tillage systems, but there is an off-setting increase in yield, the difference in requirements has no bearing on the farmer's choice between the two types of technology (Crosson, 1981).

The evidence in the literature on differences in fertilizer requirements between conservation and conventional tillage is not adequate to reach a firm conclusion.

Table 3.8

Fuel Requirements for Conventional Tillage and Conservation Tillage*

Tillage System	Liters Diesel Fuel Per Hectare	Comment	Source
Tillage System			
Conventional	68.14	Furrow irrigated continuous wheat, southern High Plains	Allen, et al. 1976
Limited-till	41.64		
No-till	26.50		
Tillage System			
Conventional	38.42	Corn	Witmuss et al. 1975
Disk and Plant	15.52		
Till-plant	14.29		
No-till	10.13		
Tillage System			
Conventional	50.16	Crop not specified	USDA, 1975
Till-plant	23.28		
No-till	8.52		
Tillage System			
Conventional	53.00	Corn in South Dakota	Derscheid et al. 1980
Reduced-till	42.59		
No-till	27.44		

*Adapted from Crosson, 1981.

Allen et al., (1976) reported that corn production costs for no-tillage nearly equaled the cost for conventional tillage. Labor, fuel and overhead costs were lower but fertilizer costs were higher. Griffith et al., (1977) reported that even though conservation tillage systems are likely to reduce production costs "Maximum savings for no-till versus fall plowing are not likely to exceed the value of .35 to .70 tonnes per hectare. As a summary Table 3.9 estimates costs of conventional and conservation tillage systems for some selected crops in 1979.

3.4. Literature Summary

In a report on model development to determine a "low cost strategy for reducing agricultural non-point pollution in Lake Erie", Forster (1979) indicated that yield indices used in his model were 100-105 for conservation compared to 100 for conventional tillage for Indiana and Ohio. For Michigan he used the same yield indices for both tillage systems indicating that there were no significant yield differences between them.

Griffith et al., (1977) summarized the factors that influence crop response to conservation tillage as follows:

a. Soil Drainage. Shallow tillage and/or surface residue systems are more likely to succeed on well drained soils.

b. Previous Crop. Shallow tillage and no-till for corn are more likely to succeed on poorly drained soils when corn follows anything but corn.

c. Soil Structure. Corn on poorly structured soils with low organic matter is likely to react positively to conservation tillage.

Many researchers have reported that the immediate benefits to farmers of conservation tillage are increased yields from moisture

Table 3.9

Estimates of Costs Per Hectare for Conservation Tillage And Conventional Tillage for Selected Crops*

	Total Costs[b]		Labor		Machinery		Fuel		Pesticides	
Crop	Conv. Tillage[a]	Cons. Tillage	Conv. Tillage[a]	Cons. Tillage	Conv. Tillage[a]	Cons. Tillage	Conv. Tillage[a]	Cons. Tillage	Conv. Tillage[a]	Cons. Tillage
Crop	412.50	385.00	33.10	16.55	90.80	78.30	22.55	17.55	21.80	29.08
Sorghum	285.00	252.50	33.58	16.80	87.88	75.38	26.65	21.65	7.70	10.28
Wheat	197.50	170.00	23.13	11.58	63.25	50.75	13.93	8.93	3.03	4.03
Soybeans	262.15	237.50	30.53	15.25	78.20	65.70	17.08	12.08	22.83	30.43

*Adapted from Crosson, 1981.

Source: Conventional tillage from U.S. Senate, Committee on Agriculture, 1979. Conservation tillage: labor costs are assumed to be one-half those for conventional tillage; machinery costs (annual) are assumed to be $5 less; fuel requirements (diesel equivalent) is assumed to be 7.6 liters less at $0.26/liter; pesticide costs are assumed to be one-third more (see Walker, "An Economic Analysis of Alternative Environmental and Resource Policies"). All costs other than those listed are assumed to be the same for both tillage systems.

[a]Estimates by USDA of costs per hectare in 1979 for each crop nationally. The estimates thus reflect costs of conservation tillage as well as conventional tillage since about 25 percent of crop land was in conservation tillage in 1979.

[b]Exclusive of land.

saved, reduced crop losses from wind and water erosion, and in some cases, labor and energy savings (Pappendik and Miller, 1981; Unger et al., 1977). Others emphasize that the tillage influence on yield is usually more important than any possible cost savings in determining profits (Griffith et al., 1977). Farmers are not likely to adopt conservation tillage when there is a risk of lower yields even though costs are lower.

CHAPTER 4

METHODOLOGY

4.1. Systems Approach

It is essential to think of the farm as a system made up of subsystems or components. Such subsystems (for example: machinery, soil type and suitable work days) can be isolated and studied by researchers; however, solutions suggested must bear in mind the impact on other components. The following example depicts how a decision to use a remedy for a problem cannot be treated in isolation from the rest of the system.

A farmer would not spray herbicides to kill this year's weeds without thinking of the residual effect this herbicide would have on next year's crop. A farmer would not spray for leaf hoppers on alfalfa if there would not be a positive cost-benefit effect to offset the expense incurred through spraying. If this same farmer does not allow enough time for the pesticide to be broken down, he cannot feed a freshly sprayed, cut, and baled alfalfa without worrying about the level of pesticide in the milk. This illustrates that many farm management decisions will influence the farm system as a whole.

The system bounds are the farm as a whole. The study will focus on the economics of the whole farm and will not take into consideration outside environmental effects. The focus of this chapter is description of the methodology used in the analysis. The discussion is divided into three components: (1) economics, (2) agronomics, and (3) machinery selection.

4.2 Economic Approach

The methodology employed differs from most other studies, in that the focus is on the development of a series of "representative" farms which are typical of the area, as contrasted to providing detailed evaluations of all sample farms. As such, rather than reporting on all practices and economics for all individual sample farms, the practices and procedures are aggregated to provide a sequence of farms representative of the area.

The impact on average net farm income and on the variability of net farm income are among the most important performance measures the farm family considers when evaluating the adoption of a new technology or management system. The hypothetical probability distributions of net farm income under a new farming system technology (Tillage System B) would be easy to estimate under the conditions depicted under Figure 4.1. In this case net farm income under the new farming system is nearly always larger than under the existing system. The choice becomes more difficult under the conditions depicted in Figure 4.2. Net farm income under the new system has a higher average, but there are instances where values occur lower than those under the currently used farming system.

4.2.1. Definition of Terms

The concept of net farm income used in this study is defined in an operational manner. Net farm income, for our purposes, is gross revenue minus cost. Gross revenues (e.g., price times yield), are relatively easy to identify. Costs are more difficult. For our purposes, we will

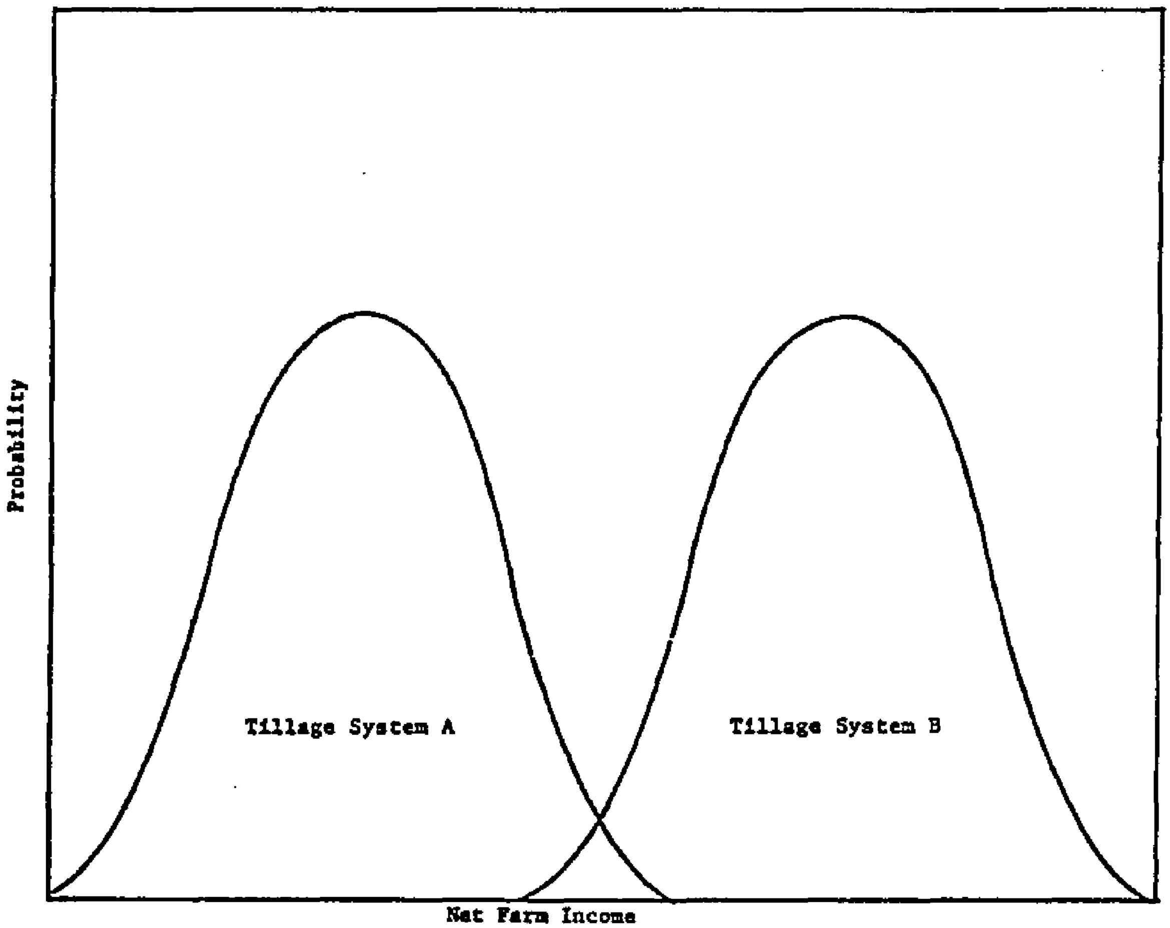

Figure 4.1

Hypothetical Probability Distribution of Net Farm Income Under New Farming Technology. Benefits From System "B" Are Clearly Superior to Those From System "A".

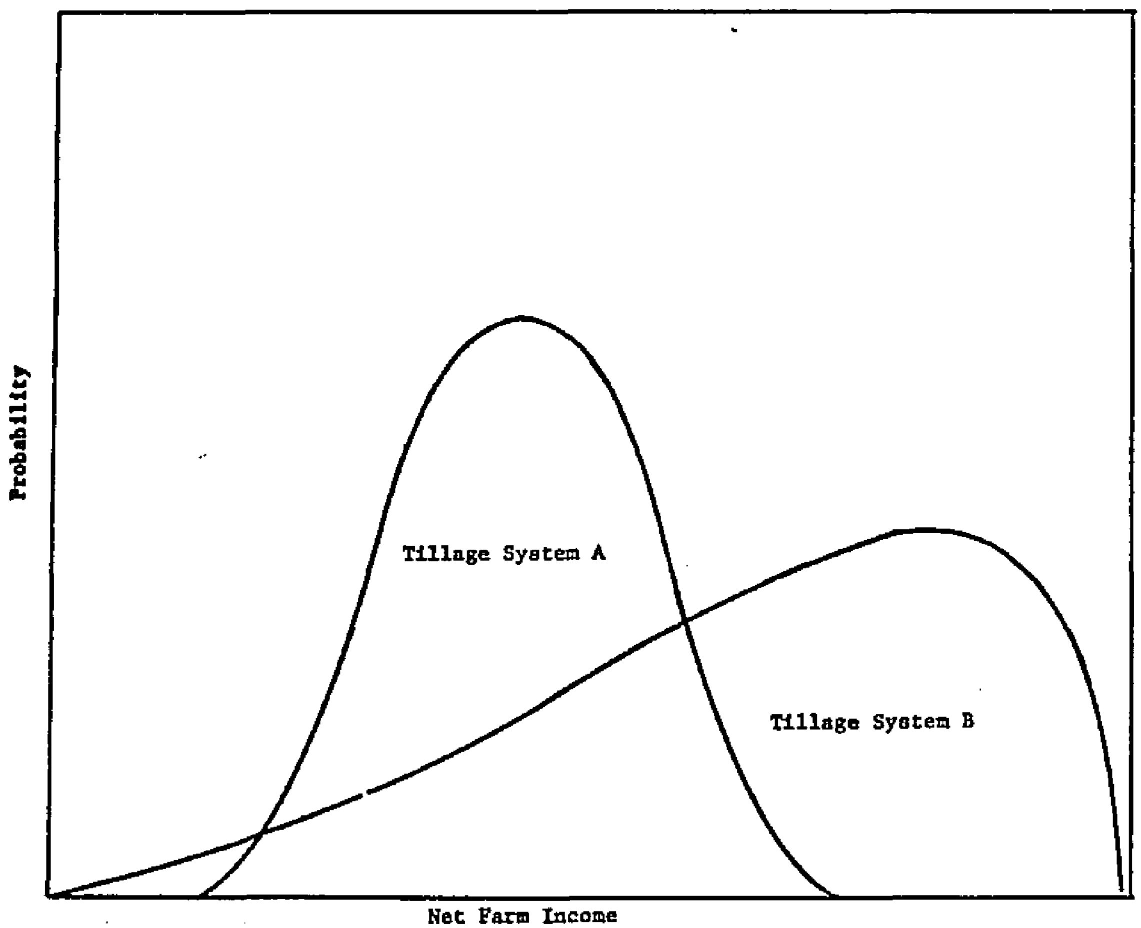

Figure 4.2

Hypothetical Probability Distribution of Net Farm Income Under New Farming Technology. Benefits From System B Have A Higher Average But Decision Making in This Case Is More Difficult.

4.2

focus on the net return to land; the costs subtracted from gross revenue to arrive at this estimate will include those costs incurred in crop production (variable costs), costs incurred irrespective of whether production takes place (fixed cost), and the cost of "labor". Labor is singled out because it must be priced on an opportunity cost basis. If labor is saved, does it have an economic value in alternative uses or a minimum "reservation" price? Variable costs will include seed, fertilizer, herbicides, pesticides, fuel, and repairs. Fixed costs will include capital costs on machinery, shelter, and insurance. Also, a management charge should be imposed; however, at least initially, we will abstain from making that assessment. Labor will be priced at a value of $4.50 per hour to reflect average earnings in alternative uses.

Time will be considered from two perspectives. In the initial analysis, focus will be on whether conservation tillage is expected to be more profitable than conventional tillage when a new conservation tillage system is compared with a new conventional tillage system. That is, a minimum size machinery complement is developed for each case and the total machinery system is optimized taking into consideration the implications for all crops in the cropping sequence. If conservation tillage is economically superior under those conditions, the next step will be to assess whether it is economically feasible to make the adjustments from the existing conventional tillage system, taking explicit account of the cost of adjustment. Or, to put the question in an alternative framework, at what point in time should the shift between tillage systems take place? Here, the age in existing equipment and the projected rate of interest in field prices become important variables.

Economic analysis will include focus on the dynamics of the adjustment from conventional to conservation tillage, including an accounting of the additional managerial requirements and the "learning-by-doing" costs that are incurred in the transition. Part of the rationale behind the research and extension out-reach project is to better define the condition for success and to minimize managerial and "learning-by-doing" costs associated with the adoption of conservation tillage.

4.3 Agronomic Practices

The agronomic measure of primary interest is yield. If yields on conservation tilled fields were less than those on conventional tilled fields, it would be important to know if the difference was due to factors that could be corrected. Also, a factor such as residue cover may have no impact on yield up to a threshold level; beyond this level, additional residue may reduce yield in proportion to the extent of coverage. Thus, a series of measurements was taken to improve our understanding of the factors that potentially influence yield.

The measurements were not as comprehensive as those typically made in intensive experimental plot studies, but were consistent with the available budget and isolation of factors expected to be important from a review of the literature. They include: crop history; crop residue cover; soil type, management group, and the extent of tilling; fertilizer program; pesticide program; plant variety; date of planting; seeding rate; date of plant emergence; percent germination; row spacing; insect and weed populations; disease incidence; stages of growth; soil moisture on selected farms; yield; and grain moisture at harvest time.

The crops considered include corn grain, navy beans, and sugar beets. These are the dominant crops in the wathershed.

Measurements were carried out for crop population, crop residue cover, growth stages, soil moisture, soil analysis, grain moisture, and yield.

4.3.1. Crop population (after full emergence).

4.3.1.1. Corn. The number of corn plants per 17 foot (5.2 meters) of row were counted in three random locations of the field. The average of the three was multiplied by 2500.

Example: If the numbers were 19, 20, and 21,

then (19 + 20 + 21)/3 = 20

20 x 2500 = 50,000 plants/hectare

4.3.1.2. Dry beans and soybeans.[1] The number of bean plants per 10 foot (3 meters) of row in 10 random locations was counted. The numbers were totalled and divided by 100 to get the number of plants per foot of row. The row width in feet was divided into 43560 and multiplied by the number of plants per foot of row to get plants/hectare.

Example: (Total for 10 locations)/10 = 8.16 plants/foot of row

43,560 ÷ 2.5 (30" rows expressed in feet) = 17,425

17,425 x 8.16 = 14,218 plants/acre.

This value was multiplied by 2.5 to convert to plants per hectare.

142188 x 2.5 = 355470 plants/hectare

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[1]Method proposed by Dr. Zane Helsel, Formerly of the Crop and Soil Sciences Department, Michigan State University.

4.3.2. Crop Residue and Soil Cover.

Crop residue was collected at three different times: in the fall after tillage; in the spring before any tillage had been done, and after the crop was planted. The "collect, dry and weigh"[1] method was used. Crop residue contained within the bounds of a one square yard ($0.8m^2$) frame was collected form three random locations, air dried, and weighed. The combined dry residue weight in ounces was multiplied by 100 to determine the weight of residue per acre. This value was multipled by a factor of 1.14 to arrive at the weight in kilograms per hectare. In order to measure soil cover, crop residue was collected using the line point sampling technique.[1] A 50 or a 100 foot (15 or 30 meters) tape or line was laid on the ground diagonal to the rows. Crop residue touching the foot mark (or one-half foot mark for the 50 foot (15 meters) tape) were counted. Each point represents a percent. Thus if 52 points were counted the field would have a 52 percent cover. This procedure was done at three random locations in each field and the percentages reported were averaged.

4.3.3. Growth Stages.

Measurements were conducted to determine how fast or slow the crops were developing. Table 4.1 and Figures 4.3, 4.4, and 4.5 show numerically and graphically growth stages for the crops, namely, corn, wheat, oats, sugar beets, and beans. Crops in the field were compared weekly to these figures to determine the stage of growth.

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[1]Method is based on the USDA/SCS Technical notes (Agronomy #16), March 1980.

Table 4.1

Coded Crop Growth Stages

General life stages - Numberical stages may vary with crop, e.g., corn, small grains, sugar beets, etc.

Stage 0.1	Stage 5.5
Stage 0.5	Stage 6
Stage 1	Stage 7
Stage 2	Stage 8
Stage 3	Stage 9
Stage 4	Stage 10
Stage 5	Stage 10.1
	Stage 10.5

Vegetative and reproductive stages (dry beans and soybeans)

VE, VC - Emergence, sotyledon	R1 - Beginning bloom
V1 - First node	R2 - Full bloom
V2 - Second node	R3 - Beginning pod
V3 - Third node	R4 - Full pod
V4 - Fourth node	R5 - Beginning Seed
V5 - Fifth node	R6 - Full seed
V6 - Sixth node	R7 - Beginning maturity
V7 - Eighth node	
V9 - Ninth node	
V10- Tenth node	

Figure 4.3

GROWTH STAGES OF CORN

Growth Type	Diagnostic Character	Stage or Numberical	Approximate Time After Emergency
Pre-emergence	Seed planted	0	
Emergence	Coleoptile above soil	0.1	0
Two-leaved	2 leaves fully open	0.5	1 week
Early whorl	4 to 6 leaves fully emerged	1	2 to 3 weeks
Mid-whorl	8 to 10 leaves fully emerged	2	4 to 5 weeks
Late whorl	12 to 14 leaves fully emerged	3	6 to 7 weeks
Tassel	16 leaves fully emerged	4	8 weeks
Silk	Silks emerging, pollen shedding	5.0	66 days
	Plant pollinated; silks green to brown	5.5	
Maturity	Brown silk, cob full sized, blister stage	6	12 days after silking
	Kernels in "soft dough"	7	24 days after silking
	Few kernels with dents, embryos developing	8	36 days after silking
	All kernels with dents	9	48 days after silking
	Grain mature and drying	10	60 days after silking

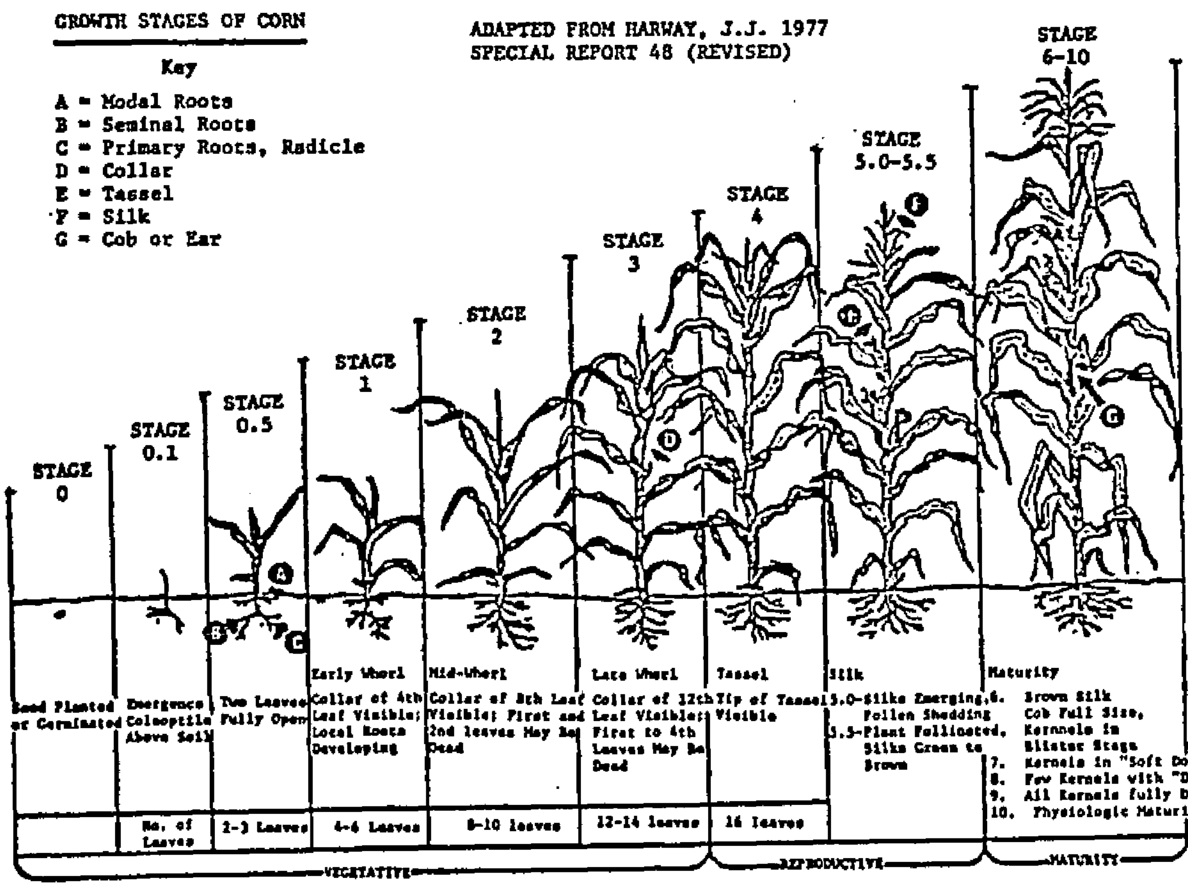
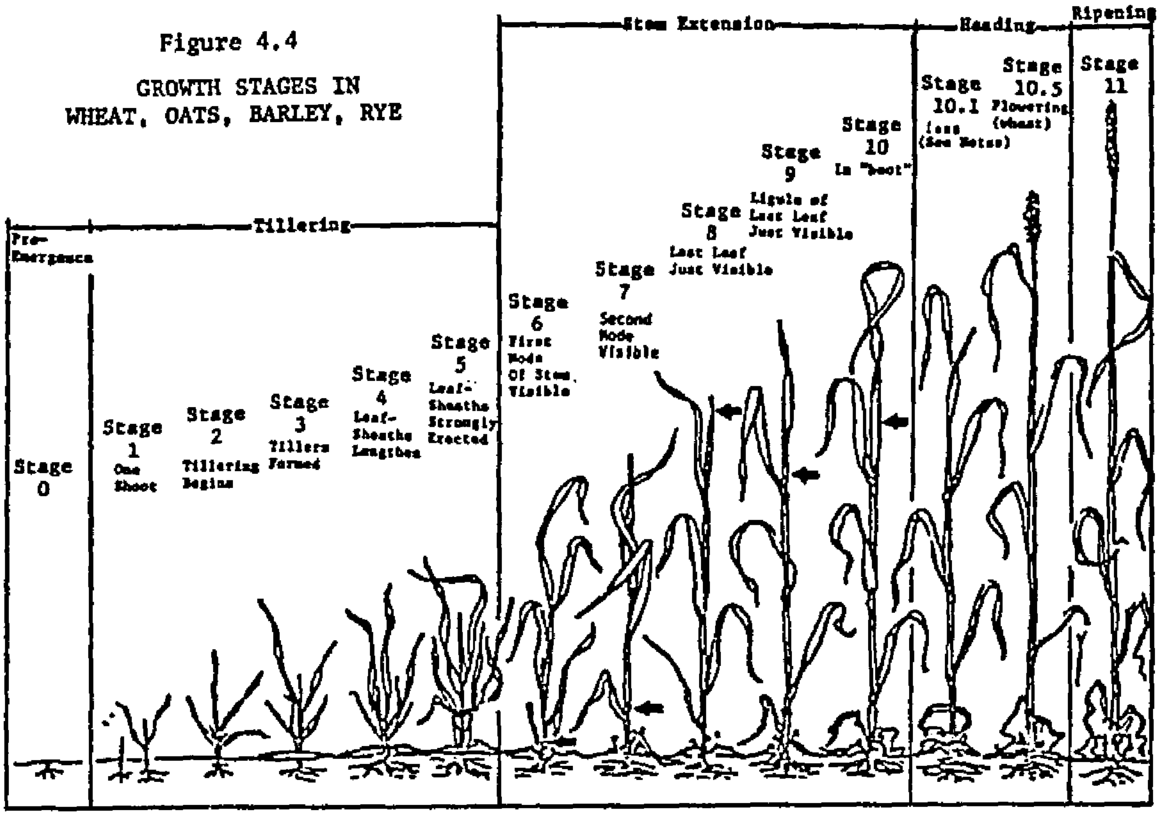


Figure 4.4

GROWTH STAGES IN WHEAT, OATS, BARLEY, RYE



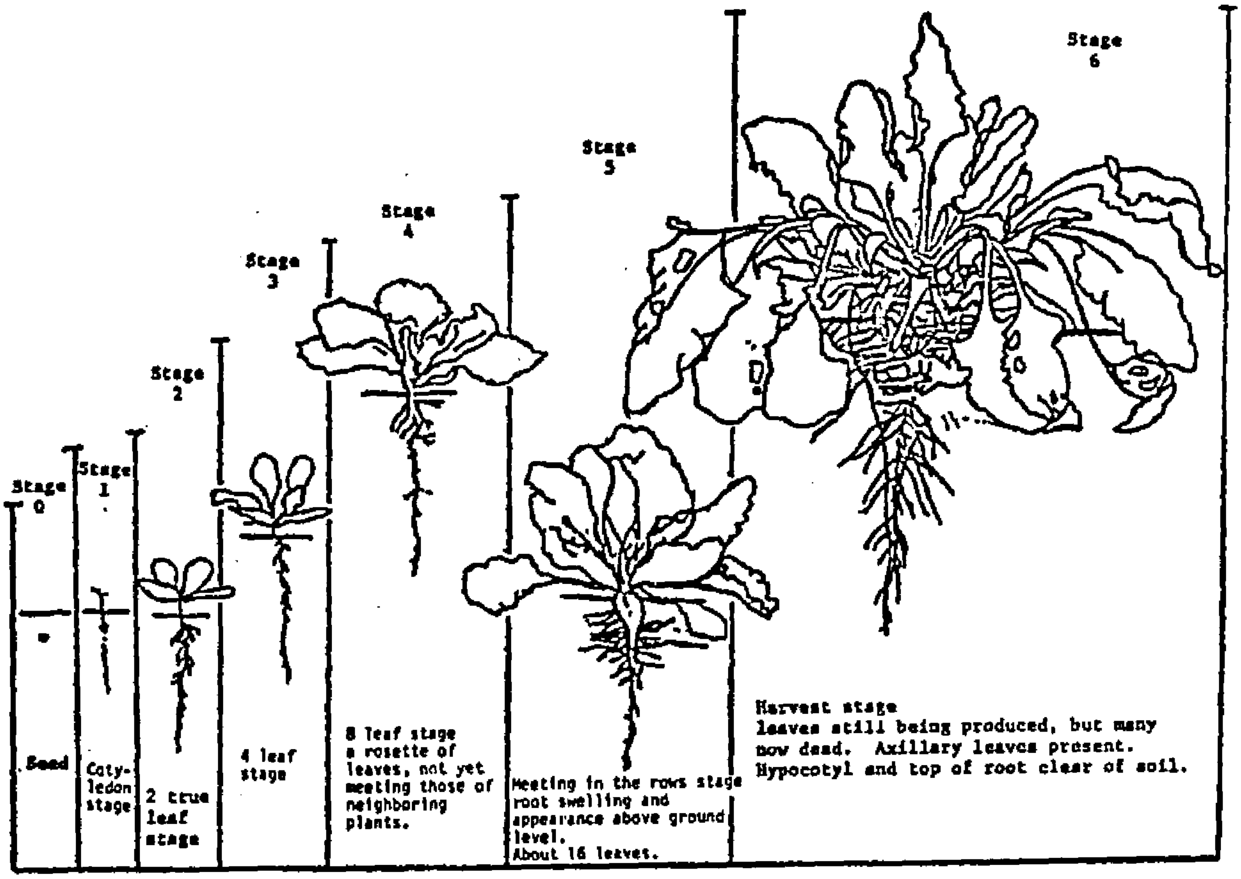
GROWTH STAGES IN WHEAT, OATS, BARLEY AND RYE
(Modified from drawings by E.C. Large, (1954), Plant Pathol. 3:128-129)

Stage		
0	Pre-emergence	TILLERING
1	One sprout (Number of leaves can be added) ="Grairding"	
2	Beginning of tillering	
3	Tillers formed, leaves often twisted spirally. In some varieties of winter wheats plants may be "creeping" or prostrate.	
4	Beginning of the erection of the pseudo-stem, leaf sheaths beginning to lengthen.	
5	Pseudo-stem (formed by sheaths of leaves) strongly erected.	
6	First node of stem visible at base of shoot.	STEM EXTENSION
7	Second node of stem formed, next-to-last leaf just visible.	
8	Last leaf visible, but still rolled up, ear beginning to swell.	
9	Ligule of last leaf just visible.	
10	Sheath of last leaf completely grown out, ear swollen but not yet visible.	
10.1	First ears just visible (Awns just showing in barley, ear escaping through split of sheath in wheat or oats).	HEADING
10.2	One-quarter of heading process completed.	
10.3	One-half of heading process completed.	
10.4	Three-quarters ofheading process completed.	
10.5	All ears out of sheath.	
10.5.1	Beginning of flowering (wheat).	FLOWERING (WHEAT)
10.5.2	Flowering complete to top of ear.	
10.5.3	Flowering over at base of ear.	
10.5.4	Flowering over, kernel watery ripe.	
11.1	Milky ripe	RIPENING
11.2	Mealy ripe, contents of kernel soft but dry.	
11.3	Kernel hard (difficult to divide by thumb-nail).	
11.4	Ripe for cutting. Straw dead.	

Figure 4.5

GROWTH STAGES OF THE SUGAR BEET

ROOT CROP



4.3.4. Soil Moisture.

To study the effect that surface residue may have on conserving soil moisture, two types of testing were performed:

(a) The relationship between soil moisture and soil water tension was determined through laboratory analysis for the surface and subsurface horizons. These tests determined the percent moisture in the soil below which plants cannot use.

(b) Soil moisture content in the root zone of each plot was monitored during the growing season. Sampling began after the soil was saturated by rainfall (evidenced by subsurface tile flow) and continued at two day intervals. Moisture content was determined by gravimetric[1] methods.

4.3.5. Soil Analysis.

Once a year, after harvest (normally fall) and before fertilizer was applied, soil samples were taken from the top 25 centimeters of soil. About 15 cores were taken per treatment. The soil was mixed and one sample was taken and used for mechanical and chemical analysis, done at the Crops and Soils Laboratory, MSU.

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[1]The gravimetric method consists of weighing the soil samples in their field condition, then oven drying and weighing the samples again. Moisture percentage was then determined by dividing the amount of water by the dried soil weight and multipling by one hundred.

4.3.6. Crop Moisture.

Crop moisture was measured using moisture meters at the time of harvest. Several samples were taken at random from the bin and then the average percent moisture were reported.

4.3.7. Crop Yield.

Several pre-measured areas of the field were harvested and weighed. The weights were interpolated to weight per hectare. The average weight per hectare was reported.

Accurate assessment of the impact of alternative tillage treatments required comparison on an equivalent or "side-by-side" basis. The budget did not permit standard experimental design procedures with randomization and replication; nevertheless, equivalence was required. Contiguous fields were selected that were judged to be as comparable as possible. Also, selection of small fields permitted them to be farmed as they would in standard practice. Thus, two objectives were met: 1) equivalence, and 2) farming methods reflective of standard practice. When applicable paired "T" tests were run on the "side-by-side" data obtained.

4.4 Machinery Selection

4.4.1. Model Requirement.

Field machinery was a major subsystem of the farm system. Several constraints in the farm system affect the selection of a machinery complement. Such constraints include: a) type of crop and the cropping sequence; b) the area to be farmed and field size and shape; c) the predominant soil type on the farm; d) geographic location and weather conditions; e) implements and machines that already exist on the farm; f) storage and grain drying facilities; g) labor availability for peak season demands, and h) field operations to be done by the farm's crew or through the custom hire. In case of custom hiring an operation, there will not be a need to purchase the implement needed for such an operation.

In this particular study the following parameters were dealt with: 1) crop sequences used in the study area (Table 4.2). These crop sequences were chosen because they are the more common ones used by farmers and represent the seven most commonly grown crops in the project area. 2) soil types, namely: fine textured, medium textured and coarse textured; 3) tillage systems, namely: conventional or the commonly used methods versus conservation tillage types and in specific the chisel plow systems; 4) availability of suitable days for field operations (go-no go days, see Appendix D); and 5) suitable periods for certain operations that could best be performed given the location and weather of the project, Tables 4.3 and 4.4. In these tables the beginning and ending date of the periods suitable for a field operation to be performed on a specific crop are reported. For example in Table 4.3 a farmer should harvest corn between the ninth of October (10/09) and the thirteenth of November (11/13).

In order to exhaustively study a system one must rely on computer simulation. With this technique, one can vary the level of one or more components, and observe the impact. Such methods of experimentation are less expensive, less risky and faster than experimentation of the actual

Table 4.2

Cropping Sequences Considered in the Model

Corn-Navy Bean
Corn-Soybean
Corn-Corn-Soybean
Corn-Navy Bean-Sugar Beet
Corn-Soybean-Sugar Beet
Corn-Navy Bean-Wheat-Sugar Beet
Corn-Soybean-Navy Bean-Sugar Beet
Corn-Navy Bean-Navy Bean-Sugar Beet
Corn-Corn-Navy Bean-Wheat
Navy Bean-Corn-Soybean
Corn-Corn-Navy Bean-Sugar Beet
Oat-Navy Bean-Sugar Beet

TABLE 4.3

Calendar Days Within Which Field Operations Can be Performed Using *Conventional* tillage*

Operation	Crops					
	Corn	Navies	Soys	Beets	Wheat	Oats
Harvest	1009/1113	828/1002	925/1023	925/1113	717/807	724/814
Fertilizer	A/1127	w/plant	w/plant	A/1127	A/1016	A/1127
Fall Disk[1]	1009/1127	1009/1127	1009/1127	1009/1127	A/1016	1009/1127
Plow	A/515	A/619	A/605	A/1127		A/1127
Spring Disk[1]		410/619 515/619	410/605	410/515		410/588
Field cult.	424/515	522/619	515/605	410/515	925/1016	410/508
Plant	424/515	522/619	515/605	410/515	925/1016	410/508
Spray	424/515	515/619	515/605		501/508	
Row Cultivate	529/619	619/710	612/703	522/619 612/703		
NH3	529/619			605/626		
Bale Straw						724/821

[1]Fall disking only if preceding crop is corn except for wheat which is always disked.

NOTE: A beginning date (A) equals previous crop's harvest date

A (w/plant) implies that this operation can be done with planting.

These numbers show month and date of operations; for example:

1009/1113 = Begin operation on Oct. 9 and end same operation on Nov. 13.

*Adapted from Wolak, (1981).

TABLE 4.4

Calendar Days Within Which Field Operations Can Be Performed Using *Chisel* Plow Alternative*

Operation	CROPS					
	Corn	Navies	Soys	Beets	Wheat	Oats
Harvest	1009/1113	828/1002	925/1023	925/1113	717/807	724/814
Fertilizer	A/1127	w/plant	w/plant	A/1127	A/1016 320/424	A/1127
Chisel Plow	A/515 515/619	A/619	A/605 410/515	A/1127	A/1016	A/1127
Field Cult.	501/515	529/619	522/605	417/515	925/1016	417/508
Plant	501/515	529/619	522/605	417/515	925/1016	417/508
Spray	501/515	522/619	522/605		501/508	
Field Cult.	529/619	619/710	612/703	522/619		
NH3	605/619			605/626		
Bale Straw						

NOTE: A beginning date (A) equals previous crop's harvest date.
A (w/plant) implies that this operation can be done with planting.
These numbers show month and date of operations; for example:
1009/1113 = Begin operation on October 9 and end same operation on Nov. 13.

*Adapted from Wolak, (1981).

farm. Simulation is a very useful tool that saves time and in determining the optimum or "best" solution.

As was mentioned earlier, the project area was 96,800 hectares. We had several farms to monitor and collect data on. Therefore given the logistics of the problem, and the fact that machinery data was to be based on properly matched sizes, we could not rely on what farmers owned (See Section 6.1 for details). Therefore we decided that the best approach was to simulate existing farming conditions and generate machinery complements needed for such specific situations.

When the decision was made to use some means of computerized techniques, different machinery selection models were checked and based on what the project needs were, a new model had to be designed. In the sections that follow criteria for models, previous investigation and our approach will be discussed.

4.4.2. Machinery Selection Model Development Criteria.

No model will generate trustworthy output if the algorithms used and the data and parameters used are not reliable. Therefore, the foremost criterion to look for in any computer simulation model is the procedure it follows to generate its output and the data base that supports it. In this respect one can list a series of qualities desired to be in a model. It should:

a. Permit estimation of cost differentials among various systems studied.

b. Let the deduced complement be the best economic comparison and stay as close to reality as possible.

c. Be flexible enough to fit the farm.

d. Be adequate for applied research where one can assess differences in machinery requirement.

e. Be useful as an instruction tool for students as well as farmers, and

f. Be transferable to microcomputers.

4.4.3. Previous Investigation

Several approaches have been developed to help select machinery requirements and associated costs. These are divided into four distinct categories outlined by Wolak (1981):

a. enterprise budgets and custom hire rates;

b. whole farm, profit maximizing linear programming models;

c. least cost models which seek a minimum cost machinery complement for a given management structure; and

d. heuristic models for selecting multiple enterprise machinery sets.

Each of these four categories have its advantages and drawbacks, as discussed below.

4.4.3.1. Enterprise Budgets and Custom Hire Rates. Custom rates provide a useful approximation of capturing cost differences for labor and machinery. This is a very low cost and fast method of providing an estimate. They provide quick cost-benefit trade-off figures for broad screening economics (Black, 1982). However custom rates have some drawbacks.

a. No farmer will go out and custom hire all of the farm work. Because of that the costs given for a custom performed operation are not a true reflection of the actual cost incurred by owning and using a machine to perform the same operation.

b. When using custom rates one assumes that the field operation can be performed immediately or when needed. This is not a valid assumption. Farmers that do custom hire know that they have to accept an early or late job often when the custom operator can only make it at that time, or because of weather uncertainties.

c. Custom rates do not reflect timeliness costs incurred by the farmer due to early or delayed field operations. Therefore custom rates are not sufficient to determine total true cost incurred.

4.4.3.2. Linear Programming Models. Linear programming models are used to maximize net profit to available resources and are useful for organizing the cropping sequence with that end in mind. They are divided into two classes: a) the first is a user specified class where they need to have a machinery complement in order to give the best crop mix and show where the machinery complement is not adequate or too large. They also help show how to improve the situation (example is the Purdue 'Top Crop' farm model, and Michigan State University TELPLAN models.) The second class is the mixed integer linear programming where several alternate machinery components are stored in data blocks. The model will search for the best set to match the best crop mix (example is the Forage Mixed Integer Model). These have one drawback that lies in the enormity of input data required and subsequent complicated instructions that a farmer has to go through, and another in the cost incurred running such models.

4.4.3.3. Least Cost Minimization Models. The Least Cost Models are such that the minimum cost combination of machinery is calculated for specific situations (Hunt, 1977; Hughes and Holtman, 1973). Timeliness cost of operations is considered as a penalty so that profits are increased by minimizing costs. In this respect timeliness cost and its interaction with weather is the most popular specific item dealt with in conjunction with machinery selection problems. However, such models do not profit maximize enterprise combination (Brown, 1981).

Other models developed with cost minimization in mind deal with timeliness cost and determine the least cost machinery set but are limited to one or two crops. This makes the crop variety and sequence used in the project area difficult to represent in such models.

4.4.3.4. Heuristic Models. Heuristic models developed at Michigan State University (Singh, 1979, Wolak, 1981), take the following approach: field operations must be done within specific calendar periods. Machine productivity is matched to available time during scheduled calendar periods such that all operations are completed on time (Wolak, 1981). These models have the following restrictions:

a. timeliness of operations was considered as a constraint and not as a penalty

b. only one type of soil was considered

c. area of the farm was restricted from 80-400 hectares

d. the farmer was restrained to buy new machines

e. the farmer could not use custom hire

A revised heuristic model was developed for this project which overcame the above restrictions. A detailed description of the model is presented in the next chapter. No restrictions were placed on the number of implements and/or power units (tractor or combines).

CHAPTER 5

MACHINERY SELECTION PROGRAM

5.1. Model Description

Constraints influencing machinery selection for a farm include: a) types of crops and the cropping sequence; b) area to be farmed and field size and shape; c) predominant soil type; d) available days suitable for field work; e) labor availability for peak demands; f) implements and machines that already exist on the farm; g) grain drying facilities and storage; and h) field operations to be done by the farm crew or through custom hire. In case of custom hiring an operation, there will not be a need to purchase an implement for the operation.

The model developed, "MACHSEL", was designed with these features in mind. This model was developed for the analysis of the impact of tillage systems and crop sequence on the size and number of machines required. It is a heuristic model that gives the user the most economic machinery complement that is not necessarily profit maximizing or cost minimizing but close enough to be a "ball park" optimum.

This machinery selection model (MACHSEL) was designed as a tool to help systems analysts, instructors, extension agents or farmers to improve on some farm management aspects, or simply, select a machinery complement needed for a grain farm with a specified cropping sequence. The model can take into account equipment that is already owned by the farmer, and operations that the farmer prefers to have done by custom hire. The model can also select implements based upon three different types of soil, two types of tillage systems (conventional and conservation), and three levels of risk the user is willing to take with weather.

The farmer's fear of risk has been an important reason in delayed adoption of conservation tillage systems on fine textured soils. Farmers typically start planting conservation tilled fields later in the spring than they do conventionally tilled fields (Klocke, 1979). It is for this reason that the model uses suitable work day probabilities generated from actual weather data (Rosenberg et al, 1982). These probabilities provide estimates of how many suitable days a farm manager can expect for performing field operations.

The model matches machine productivity to available time. Machine productivity depends upon machine sizes, allowable operational speeds, implement draft for the soil type under consideration, field efficiencies and scheduling and efficiencies related to size and shape. Available time is determined by work day length, availability of good weather, scheduled periods for operations, and soil type.

The model selects the most economical machinery set that can finish all farming operations specified within given time constraints. Timeliness and machinery costs are computed as machinery complements are determined. The complement that proves to be the least cost complement given timeliness, labor, ownership, and operation cost is selected. The machine sizes available within the model are actual implement and tractor sizes found on the market.

The machinery selection process involves several steps. First the model selects the smallest machinery complement that can finish the field operation within the specified time boundaries. This includes harvesting, seedbed preparation, planting and other needed operations. The model then chooses the minimum number of suitable tractors that match the implements chosen.

The model determines the total cost of the machinery set. This cost includes the timeliness cost incurred for harvesting, planting and tillage operations. A second machinery set is selected by increasing the capacities of the selected implements which cause a timeliness cost by one increment of size. Tractors that properly match the new capacities are then selected; field operations get rescheduled; and the total cost of the new complement is determined. The total costs of both complements are then compared. If the set first chosen proves to be less expensive or the same cost as the second set, it is selected. However, if the set chosen last is less expensive than the first set it is temporarily chosen and another incrementation of size and calculation of costs is done. This process continues until such time when the total cost of the new set is equal to or more expensive than the previous set. At this point the incrementation is stopped and the set prior to the last one is chosen.

The cropping sequences[1] used in the model are depicted in Table 4.2. After discussions with county extension agents concerning the more widely used management practices, primary focus was placed upon sequence 1 (corn-navy bean), sequence 4 (corn-navy bean-sugar beet), sequence 6 (corn-navy bean- wheat-sugar beets), and sequence 11 (corn-corn-navy bean-sugar beet). The economic assessment presented in Chapter 8 focuses on these four sequences because they are most commonly used in the project area.

A flow chart of the model algorithm and detailed description of the model follows. A user's guide, the model code, and definition of variables is included in Appendices A and B.

5.1.1. Program: MACHSEL

The body of the main program MACHSEL (Appendix B) is very small and is made up mainly of call statements that summon subroutines to do a specific task. The algorithm was designed to provide a model that was simple and easy to follow and understand (Fig.5.1). Comment statements in the main program and the subroutines act as guide posts to advise the user of what will be happening next. The total program is briefly

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[1]As used here, the term cropping sequence refers to the sequence in which crops are grown. For example, a 240 hectare corn-navy bean farm (C-NB) would find:
--120 hectares of corn following navy beans
--120 hectares of navy beans following corn
Similarly, a corn-corn-navy bean-sugar beet farm (C-C-NB-SB)
--60 hectares of corn following sugar beets
--60 hectares of corn following corn
--60 hectares of navy bean following corn
--60 hectares of sugar beets following navy beans

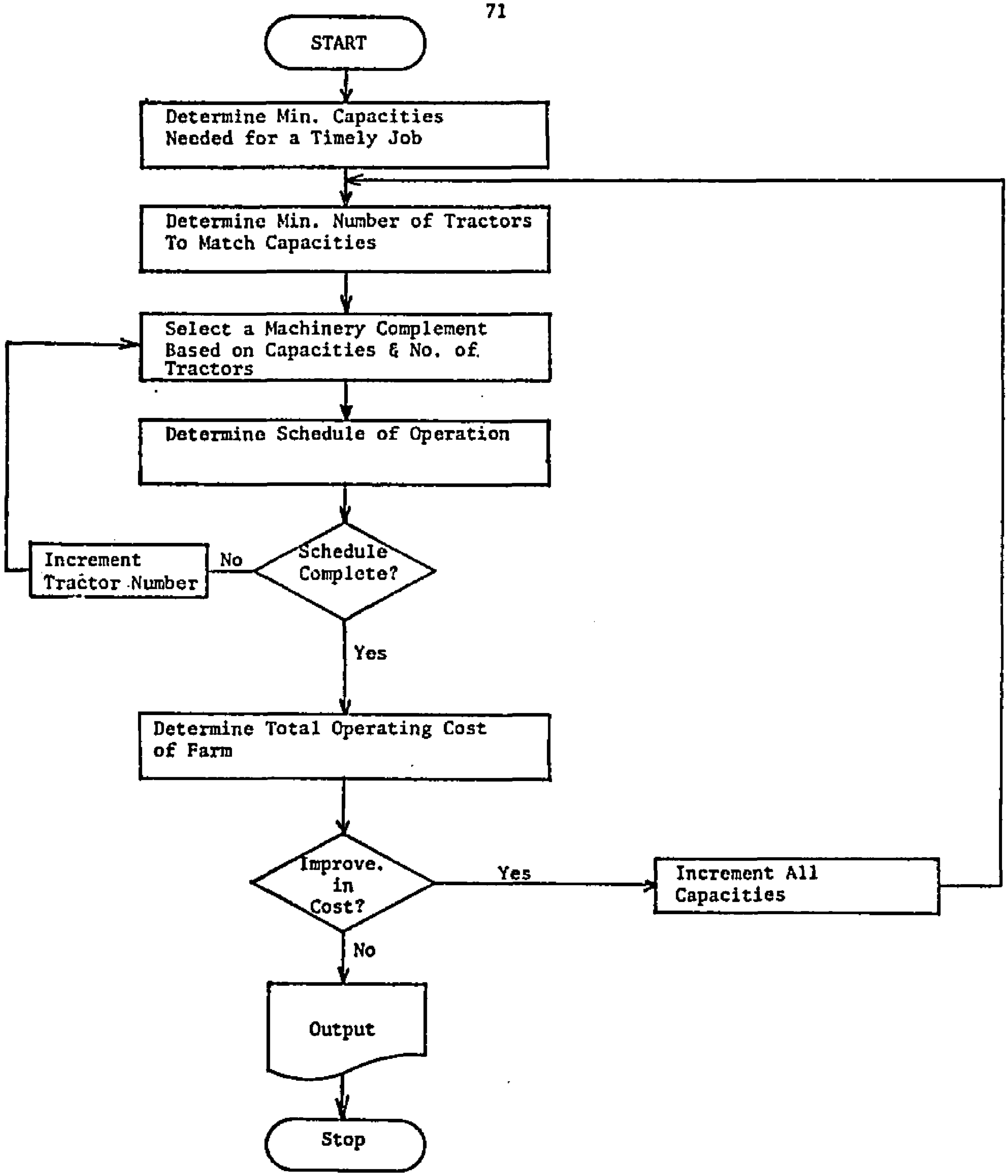

Figure 5.1
FLOW CHART OF "MACHSEL" PROGRAM

described here and detailed descriptions of the subroutines can be found in the subsections which follow.

The first thing the model does is call subroutine READIN which interacts with the user and checks what parameters need to be entered. It prompts the user to re-enter data, if needs arise, and to validate others. After the user is through entering the input for the farm, MACHSEL will call subroutine INIT which processes the input and initializes the farm constants. INIT contains most of the relevant data needed throughout the selection process. No flow chart was presented for INIT because it is a very simple subroutine to arrange the input data. The next subroutine to be called is MINCAP which determines the sizes of minimum machinery complements capable of completing all field tasks within the total number of hours available as specified by the user.

MACHSEL then calls subroutine MINTRAC. This subroutine determines the minimum number of tractors needed to be assigned to the current machinery complement. Subroutine IMPSEL is called next to select a new machinery complement and compares the new set to the one selected previously. It also determines the number of tractors that are associated with this complement. Subroutine SCHED is then called in order to test the machinery complement and check if it can be scheduled to do a satisfactory job on all the operations required. If SCHED is unable to do a full schedule, program MACHSEL will call subroutines HARVINC, TILLINC, AND PLNTINC, which will increment the combine, tillage implements and the planters respectively to a larger size.

When subroutine SCHED is satisfied with the scheduling of field operations, subroutine TOTCOST is called to determine the total cost of the machinery complement that can do a satisfactory task. TOTCOST will in turn call subroutine ALCOST which computes costs of the machinery complement including capital, interest, repair, labor, taxes, shelter, insurance, and fuel. In order to determine the cost of fuel used. Subroutine ALCOST calls subroutine FUELFIG which determines the amount of fuel each implement requires to do the task assigned to it.

HARVINC, TILLINC AND PLNTINC are called again to increment the machinery complement one more time. Costs are determined again and compared with the costs of the previous selection. SETSEL subroutine, which always updates the machinery complements, is called and the least cost complement is decided upon.

Subroutine OUTPUT is then called to organize the data generated to send it to the printer as a final output.

5.1.2. Subroutine READIN

This subroutine is the channel through which the model interacts with the user (User's Guide, Appendix A). If the user enters data that is wrong, READIN will point out the error and prompt the user for the right entry. The user will also have a chance to validate and change that section. It also totals the area in each section (parcel) of the farm. It arranges the operations that are to be custom hired, and the implements that are owned by the farmer.

5.1.3. Subroutine INIT

This subroutine processes all the data read in subroutine READIN. It initializes all the farm constants defined in Sections 5.2-5.4. It contains data pertaining to soil resistance (draft), available hours (based on chance constraints), soil types, speeds, efficiencies, timeliness costs, and sizes of the equipment and related prices.

5.1.4. Subroutine MINCAP

In this subroutine the minimum machinery complement capable of completing all tasks required in the maximum time available is developed (Figure 5.2). In this respect if three weeks are assigned for an operation, the total number of hours suitable for work in these three weeks is determined. The size of the first machinery complement is built around the maximum number of hours available for each operation. MINCAP determines which weeks are used for each operation based on the user's input. It determines which week is used for each operation based on the crops farmed (seven possible) and the beginning and ending dates for each operation (20 operations total). When the operations are assigned to crops and weeks, the acronym ACOPDAT (Hectares/Operation/Week) is used to determine the number of hours available for each operation. A Do Loop going through the whole year (52 weeks) determines the number of hours for each operation in each week. The first fifteen weeks have no hours available for tillage operations due to frozen soil.

Then based on the formula:

Field Capacity (Hectares/hr) = Speed (kph) * Width (m) * EFF/10

A minimum width is determined as

Width (m) = Hectares * 10/hours * Speed (kph) * Efficiency.

This width obtained is not the size of an implement yet; it is simply the total width of an implement needed to perform the task. It can be

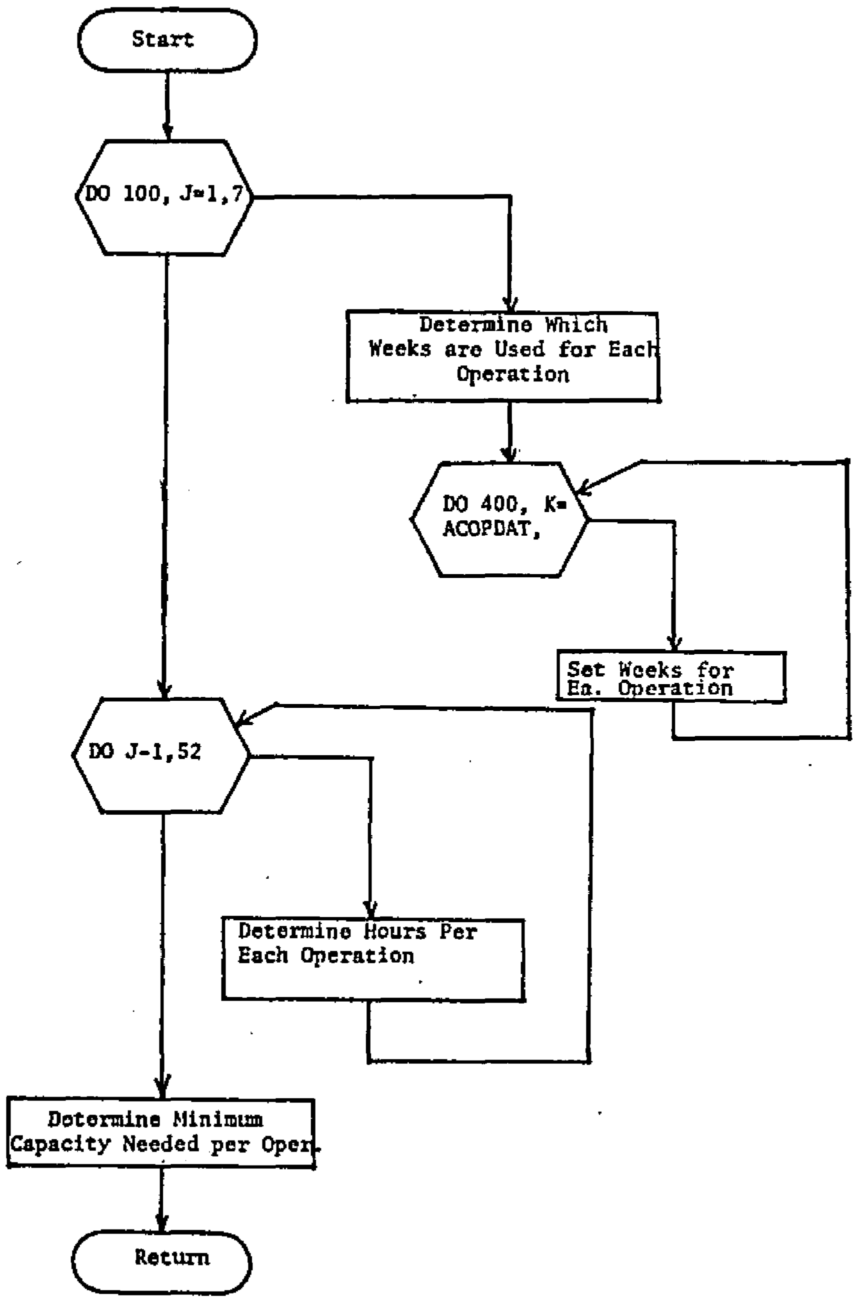

Figure 5.2
Flowchart of Subroutine MINCAP

equivalent to three units of one implement, or any multiple of implements. The model translates this total width to the most suitable number of units. Based on this total width, proper sizing and implement numbers are chosen in subroutine IMPSEL.

5.1.5. Subroutine MINTRAC

This subroutine initializes a minimum of two tractors (one tillage and one utility) for each farm. This choice is revoked if the farm has no need for two tractors. This step of choosing two tractors simply cuts down on computer time and iteration otherwise required to select the number of tractors needed. No flow chart was presented for MINTRAC because it is very small and straightforward.

5.1.6. Subroutine IMPSEL

The first thing dealt with in this subroutine is the machinery which the farmer owns. IMPSEL determines whether power available (if the farmer owns tractors) is sufficient or what size tractor needs to be selected if available power is insufficient (Figure 5.3). The next thing that IMPSEL does is to select a machinery complement given the total widths chosen in MINCAP.

The smallest number of each implement type is selected based on sizes available on the market. Power is then selected based on the power requirements of implements given power needed per unit of implement width and the width chosen. The model then makes sure that row implements are properly matched; row planter, combine, row cultivator and NH3 applicator have to match each other. This means that if an eight row combine is needed, and a twelve row planter is required for a

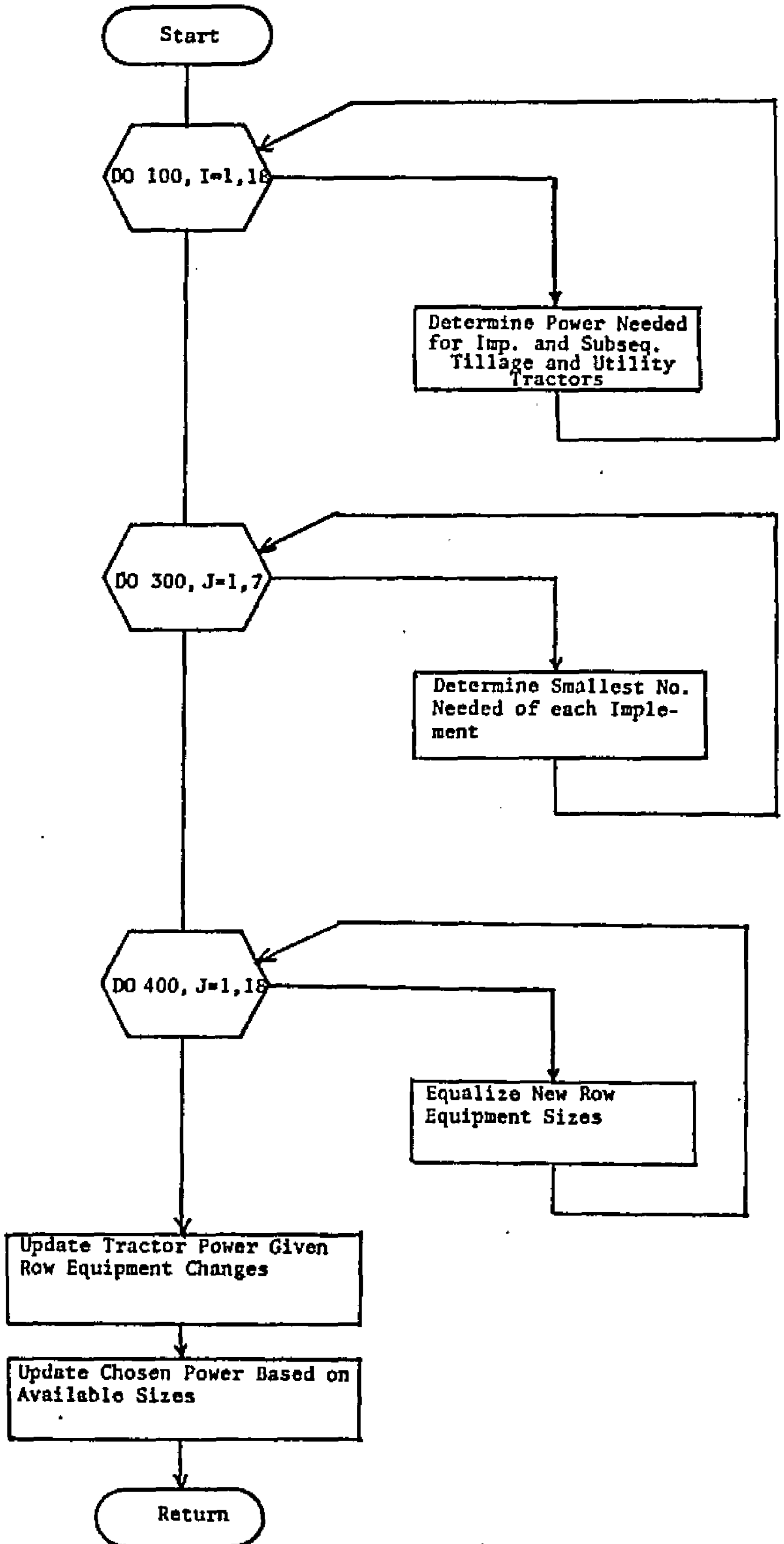

Figure 5.3

Flowchart of Subroutine IMPSEL

timely job, the model will select a twelve row planter and a twelve row combine. The increase in cost will be offset by reduced operating costs on the combine.

IMPSEL will then update the power requirement, now that row equipment are matched, to sizes available on the market.

5.1.7. Subroutine SCHED

This subroutine (Figure 5.4), checks to determine if the complement of implements and tractors chosen can do a timely job of all the tasks required. It schedules operations to be done within the time frame set by the user. The first operation done is harvesting. It then determines the hours available for each tractor. This will be the total number of hours available for work since implements need tractors for power. SCHED then goes through all the operations that need to be performed by order of priority. The next step is to start with the first week and the first crop available for work. At this point subroutine CUSTOM is called to schedule custom hired work. SCHED will then schedule owned equipment which fit the desired operations, and determine the hours required. NEXTWK is then called to assess the area left to be done for that operation. When SCHED is through scheduling owned implements to operations, it will schedule implements that are purchased, determine the number of hours spent, and the time left for the next operation.

5.1.8. Subroutine NEXTWK.

Subroutine NEXTWK (Figure 5.5), is called from subroutines SCHED and CUSTOM to check through the crops planted to determine the area

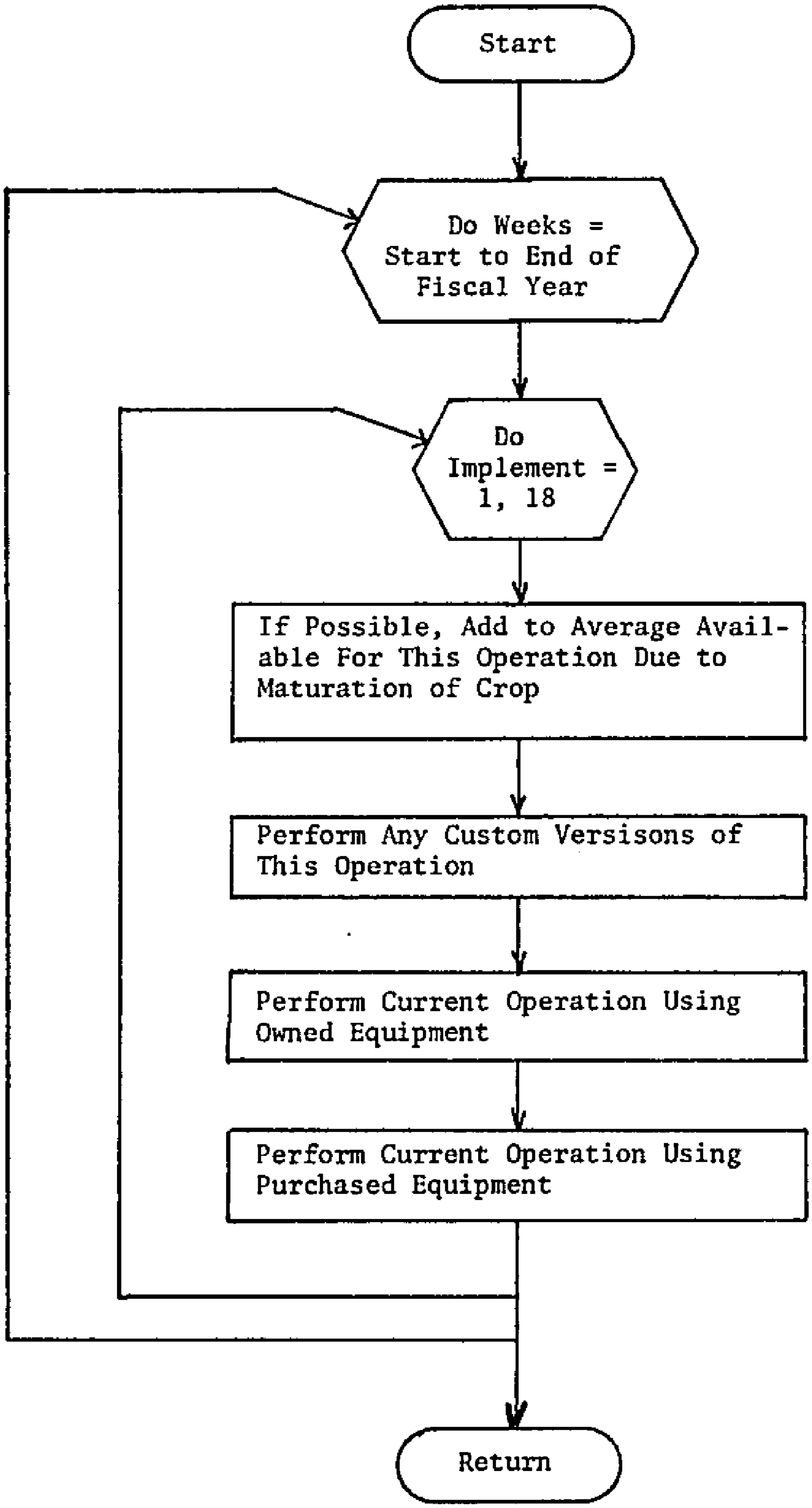

Figure 5.4
FLOW CHART OF SCHEDULING SUBROUTINE

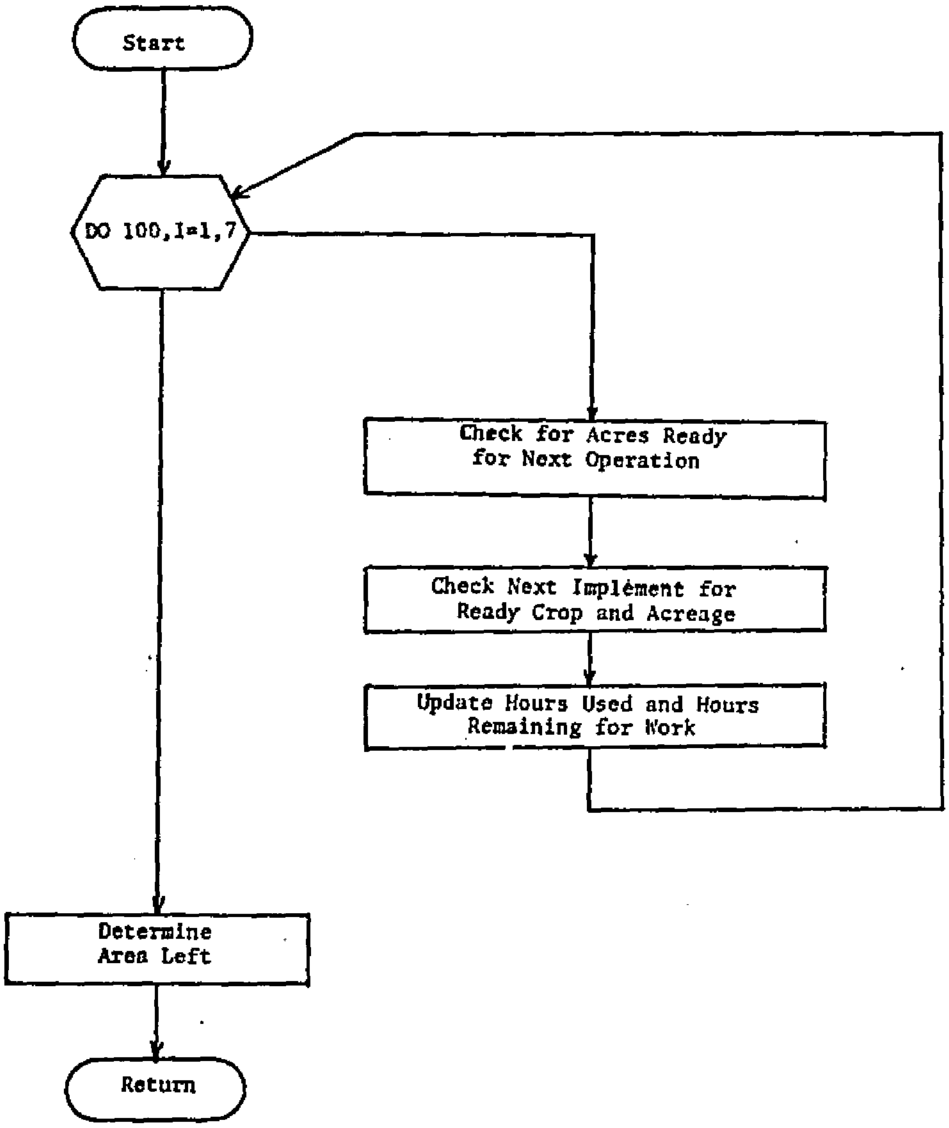

Figure 5.5
Flowchart of Subroutine NEXTWK

ready for the next operation. It checks on the crops and area that are ready, goes through the hours available for work left after the last operation was performed. It checks the number of hectares which can be done given these hours and determines the number of hectares left to be done to finish that operation.

5.1.9. Subroutine CUSTOM

This subroutine (Figure 5.6), checks through the crops planted and determines the operations to be done through custom hire. It calculates a price for such operations given the area and the cost per unit area of custom hiring that operation. It checks the area to be custom hired and calls subroutine NEXTWK in order to determine how many hectares are left undone to be scheduled for the next week. Final custom cost is determined by inflating and discounting the cost over ten years in real terms to bring it to present value dollars.

5.1.10. Subroutine TOTCOST

This subroutine (Figure 5.7), determines the total costs incurred by owning the machinery complement for the farm described by the user. It calls subroutine ALCOST several times in each of five distinct possible cost groups being (1) costs of owned implements; (2) costs of owned tractors; (3) costs of newly selected implements; (4) costs of newly selected tractors; and (5) timeliness costs incurred by using the complement. TOTCOST is made up of do loops that cycle through sets of implements. It calls ALCOST to determine costs of: labor, fuel, capital, taxes, insurance, and shelter for each implement.

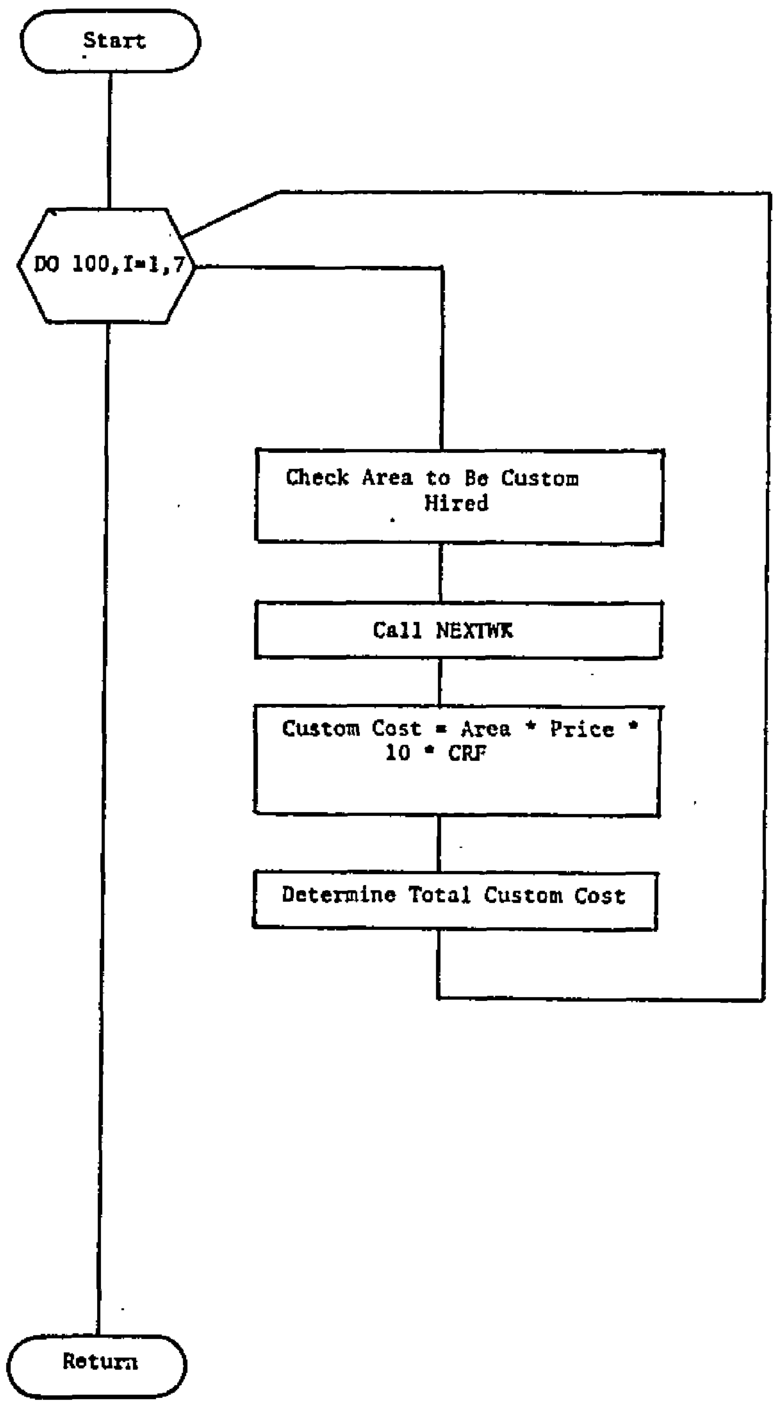

Figure 5.6
Flowchart of Subroutine CUSTOM

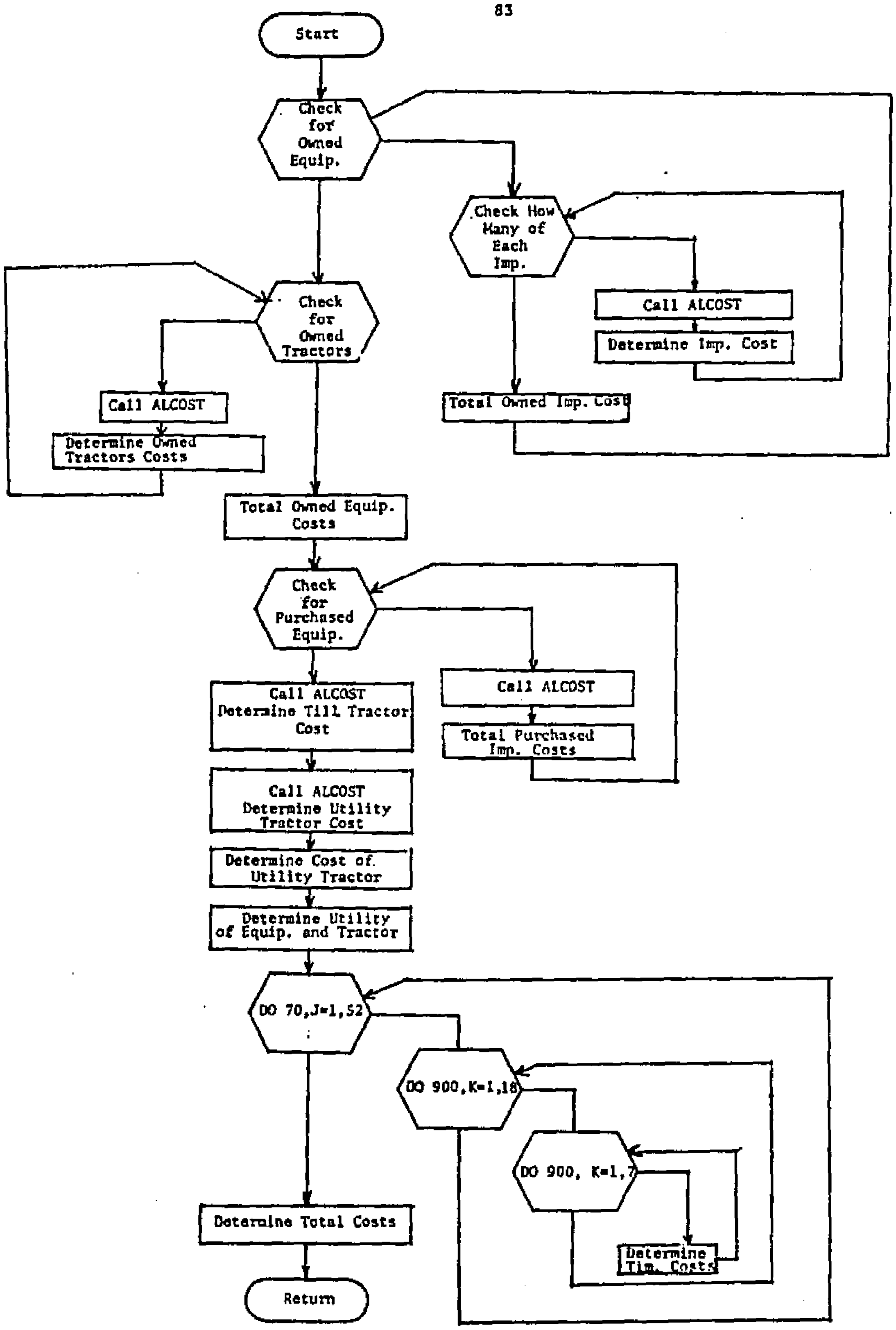

Figure 5.7

Flowchart of Subroutine TOTCOST

5.1.11 Subroutine FUELFIG

This subroutine (Figure 5.8), determines the fuel requirements of different operations. FUELFIG sorts through the operations performed by the tillage tractors using owned equipment, if any. It then goes through operations performed by the tillage tractors using purchased implements. FUELFIG then does the same search to check for operations performed by owned and purchased utility equipment and tractors.

When the power ratio for each operation is developed a factor for fuel efficiency (Liter/Kw*Hr) is determined. This factor is multiplied by the power of the tractor and the number of hours spent performing that operation. Fuel is totaled for all operations and then transferred to ALCOST. If the implement happens to be a combine FUELFIG will use a constant multiplier (Liter/hectare) adapted from Helsel (1981). This value is multiplied by the area harvested and transferred to ALCOST.

5.2. Model Equations

The mathematical relationships used in the model are based on relationships outlined in the ASAE Yearbook (1981) Section D230. The major equations used can be grouped under machine productivity, timeliness and fuel consumption.

5.2.1. Machinery Productivity Parameters

The Effective Field Capacity (EFC) of a machine, or the measure of how many hectares it covers in one hour was determined using the following equation:

$$EFC = \frac{S \times W \times EFF}{C}$$

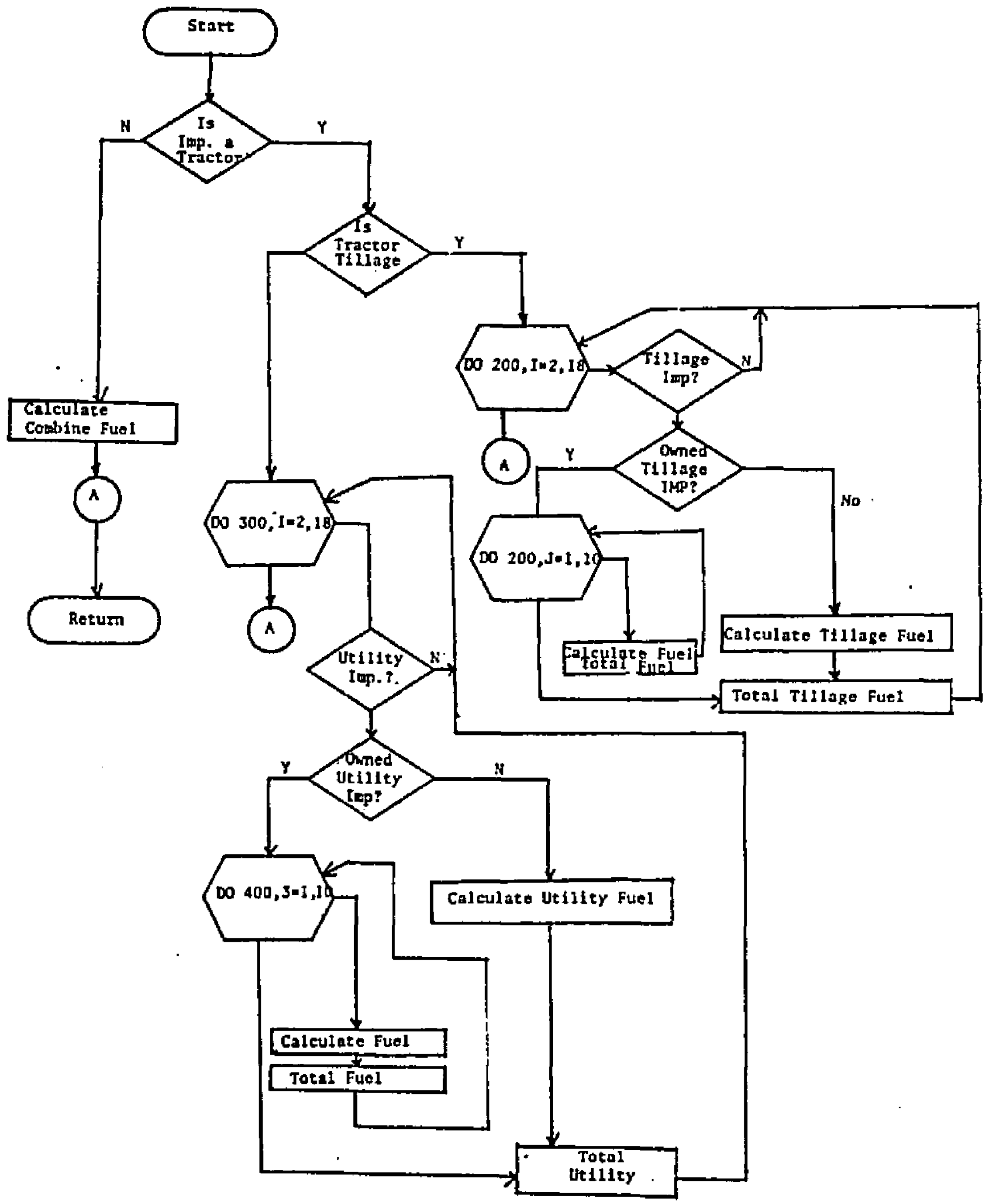

Figure 5.8

Flowchart of Subroutine FUELFIG

where

S = Implement speed (kilometers/hr)

W = Implement width (m)

EFC = Effective field capacity (hectares/hr)

EFF = Field efficiency (decimal)

C = 10.0

5.2.2. Timeliness Cost

Timeliness cost was based on a linear simplification of the actual cost incurred for not doing a timely job. An operation influencing crop yield was given a period of time in which it was not charged any timeliness costs. Any time used before or after that period to finish the operation was charged a cost per day. This cost was then added to other farm expenses. This implies that timeliness, as viewed here, is based on the farmer and his allocation of the dates assigned to do a certain operation. As depicted in Table 5.10, planting and harvesting operations have been assigned a timeliness cost for certain periods based on agronomist's recommendations, average production per unit area and market price of the crop. The number of hectares planted or harvested in such periods will be charged. For example a hectare of corn not planted by May 15 will be charged $44.0 per hectare If the farmer wishes the minimum timeliness cost he should schedule his operation as much as possible within the periods specified in Tables 4.3 and 4.4

5.2.3. Fuel Consumption

Fuel consumption was based on the method outlined in Section D230 of the ASAE yearbook, (1981) as modified by Fontana, (1981). Prediction of fuel consumption for a particular operation required determination of the total tractor power for that operation. The equivalent PTO power was then divided by the rated minimum to get a percent load for the engine. The fuel consumption at that load was obtained from:

$$\text{Diesel (Liter/Kw h)} = 2.64\,X + 3.91 - 0.2\sqrt{738\,X + 173}$$

where X is the ratio of equivalent PTO power required by an operation to the maximum available from the PTO. In order to determine the amount of fuel consumed the following equation was used:

$$\text{Fuel (liter)} = \text{Diesel (liter/kw*h)} * \text{PTO power (kw)} * \text{use (h)}$$

5.3. Machinery Parameters and Their Sources

Required machinery parameters of the model include:

a. Implement power requirement (Table 5.1)

b. Field efficiency of implements (Table 5.2).

c. Allowable operating speeds (Table 5.3)

d. Sizes of machines available on the market (Table 5.4).

e. Service life and repair data of all implements (Table 5.5)

f. Available work (go-no-go) hours or days (Table 5.6)

g. Purchase prices of implements (Table 5.7)

h. Data constraints for conventional and conservation tillage systems (Tables 4.3 and 4.4)

i. Implements considered in the model (Table 5.8)

j. Custom rates in Michigan (Table 5.9)

k. Timeliness cost for planting and harvesting (Table 5.10)

l. Average yields and market price per bushel (Table 5.11).

Table 5.1

Power Requirement for Implement in kw/meter

Implement	- - - - - - Soil Texture - - - - - - Coarse	Medium	Fine
Combine	0	0	0
Bean Puller	7.31	7.31	7.31
Beet Topper	9.8	9.8	9.8
Beet Lifter	39.1	39.1	39.1
Soil Saver	18.3	24.4	33.6
V-Ripper	19.6	26.9	36.7
Fert. Spreader	3.7	3.7	3.7
Chisel Plow	18.3	24.4	33.6
MB Plow	16.0	27.9	37.0
Disk Harrow (Tandem)	12.2	14.2	16.0
Disk Harrow (Offset)	17.1	24.4	29.3
Field Cultivator	7.3	8.55	9.8
Grain Drill	3.2	4.9	6.4
Row Planter	7.3	8.8	10.3
N.T. Planter	7.3	8.3	9.3
Sprayer	3.6	3.6	3.6
Row Cultivator	4.9	7.2	7.2
NH_3 App.	19.6	24.4	28.5

Modified from: Hunt, 1977; White, 1978.

Table 5.2

Field Efficiency of Implements Used

Implement	Farm Size $\leq$ 160 Hectares	Farm Size $\geq$ 160 Hectares
Combine	.55	.70
Bean Puller	.65	.75
Beet Topper	.60	.70
Beet Lifter	.60	.70
Soil Saver	.74	.88
V-Ripper	.74	.88
Fert. Spreader	.65	.80
Chisel Plow	.75	.90
MB Plow	.74	.88
Disk Harrow (Tandem)	.77	.90
Disk Harrow (Offset)	.77	.90
Field Cultivator	.75	.90
Grain Drill	.65	.76
Row Planter	.60	.76
N.T. Planter	.60	.65
Sprayer	.55	.90
Row Cultivator	.68	.90
NH_3 App.	.55	.65

Source: ASAE Yearbook, 1981; White, 1978.

Table 5.3

Average Allowable Operating Speeds for Implements

Implement	Average Speed (kph)
Combine	4.8
Bean Puller	5.6
Beet Topper	4.8
Beet Lifter	4.8
Soil Saver	7.2
V-Ripper	4.8
Fert. Spreader	8.1
Chisel Plow	7.2
MB Plow	7.2
Disk Harrow (Tandem)	8.1
Disk Harrow (Offset)	8.1
Field Cultivator	7.2
Grain Drill	6.4
Row Planter	8.1
N.T. Planter	4.8
Sprayer	8.1
Row Cultivator	4.8
NH_3 App.	5.6

Modified from ASAE Yearbook, 1981; Hunt, 1977; White, 1978.

Table 5.4

Size Increments of Power Units and Implements Available On the Market In Michigan

Implement	Market in Michigan								
Tillage Tractor (KW)	48.5	59.7	74.6	89.5	96.9	119.3	141.7	171.5	208.8
Utility Tractor (KW)	37.3	48.5	59.7	74.6	89.5				
Combine (Row)	4	6	8	12					
Bean Puller (Row)	4	6							
Beet Topper (Row)	3	4							
Beet Lifter (Row)	3	4							
Soil Saver (Meter)	2.0	2.7	3.4	4.2	5.0	5.7	6.5		
V-Ripper (Shank)	3	5	7						
Fert. Spreader (Meter)	12.2	18.3							
Chisel Plow (Meter)	2.4	3.1	3.4	4.0	4.6	5.2	5.8		
MB Plow (bottom)[1]	3	4	5	6	7	8	9		
Disk Harrow (Tandem)	3.5	4.4	5.2	6.6	7.8	9.1	11.0		
Disk Harrow (Offset)	3.5	4.4	5.2	6.6	7.8	9.1	11.0		
Field Cultivator (Meter)	3.8	4.7	5.6	6.6	7.8	8.7	10.5		
Grain Drill (Meter)	4.0	4.0							
Row Planter (Row)	4.0	6.0	8.0	12.0					
N.T. Planter (Row)	4.0	6.0	8.0	12.0					
Sprayer (ft)	3.1	4.6	6.1	9.1					
Row Cultivator (Row)	4.0	6.0	8.0	12.0					
NH_3 App. (Row)	4.0	6.0	8.0	12.0					

[1]Bottom width is 0.4 meters.

Modified from: Blue Book, 1981; Hunt, 1977, Personal Communication with Dealers (1981).

Table 5.5

Remaining and Repair Values for Power Units and Implements

Implement	RC_1	RC_2	RV_1	RV_2
Tractor	.025	1.6	.75	.87
Combine	.144	1.8	.75	.88
Bean Puller	.23	1.8	.70	.90
Beet Topper	.26	1.6	.70	.90
Beet Lifter	.41	1.3	.70	.90
Soil Saver	.23	1.8	.70	.90
V-Ripper	.23	1.8	.70	.90
Fert. Spreader	.24	1.3	.70	.90
Chisel Plow	.23	1.8	.70	.90
MB Plow	.61	1.3	.70	.90
Disk Harrow (Tandem)	.23	1.8	.70	.90
Disk Harrow (Offset)	.23	1.8	.70	.90
Field Cultivator	.23	1.8	.70	.90
Grain Drill	.208	1.6	.70	.90
Row Planter	.67	1.6	.70	.90
N.T. Planter	.67	1.6	.70	.90
Sprayer	.71	1.4	.70	.90
Row Cultivator	.23	1.8	.70	.90
NH_3 App.	.23	1.8	.70	.90

Source: Hunt, 1977; Hotz, 1981.

Table 5.6

Available Suitable Hours for Field Work Per Week For
Three Levels of Risk and Three Types of Soil

Week	Confidence Level of Available Hours Per Week (Percent)								
	50			30			20		
	Soil Texture			Soil Texture			Soil Texture		
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse
1-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	8.0	12.0	13.0	7.0	6.0	12.0	7.0	5.0	11.0
17	30.0	42.0	44.0	27.0	27.0	41.0	24.0	25.0	38.0
18	50.0	56.0	58.0	42.0	36.0	52.0	37.0	31.0	49.0
19	58.0	56.0	60.0	48.0	36.0	55.0	41.0	31.0	49.0
20	64.0	54.0	60.0	54.0	36.0	55.0	44.0	31.0	47.0
21	63.0	70.0	63.0	62.0	40.0	58.0	56.0	45.0	56.0
22	60.0	67.0	65.0	62.0	57.0	61.0	58.0	50.0	59.0
23	67.0	67.0	68.0	62.0	61.0	65.0	60.0	57.0	62.0
24	67.0	64.0	68.0	59.0	56.0	62.0	54.0	52.0	58.0
25	67.0	56.0	65.0	51.0	44.0	53.0	40.0	38.0	50.0
26	67.0	58.0	69.0	54.0	47.0	56.0	43.0	41.0	53.0
27	70.0	69.0	69.0	68.0	65.0	67.0	67.0	62.0	63.0
28	70.0	69.0	69.0	68.0	65.0	67.0	67.0	62.0	63.0
29	71.0	70.0	75.0	67.0	65.0	69.0	63.0	60.0	65.0
30	71.0	70.0	75.0	67.0	65.0	69.0	63.0	60.0	65.0
31	69.0	70.0	71.0	66.0	65.0	66.0	61.0	60.0	65.0
32	69.0	70.0	69.0	66.0	65.0	64.0	61.0	60.0	64.0
33	69.0	70.0	69.0	66.0	65.0	62.0	58.0	58.0	62.0
34	69.0	69.0	69.0	67.0	62.0	62.0	58.0	58.0	62.0
35	69.0	69.0	67.0	67.0	60.0	62.0	58.0	58.0	60.0
36	67.0	67.0	64.0	67.0	52.0	62.0	62.0	58.0	60.0
37	67.0	67.0	64.0	65.0	52.0	62.0	60.0	58.0	60.0
38	61.0	59.0	63.0	53.0	53.0	60.0	49.0	50.0	55.0
39	61.0	59.0	63.0	53.0	53.0	60.0	49.0	50.0	55.0
40	60.0	62.0	63.0	51.0	53.0	60.0	46.0	51.0	55.0
41	60.0	62.0	63.0	51.0	53.0	60.0	46.0	51.0	55.0
42	58.0	62.0	63.0	51.0	52.0	60.0	50.0	48.0	58.0
43	58.0	60.0	63.0	51.0	52.0	60.0	50.0	48.0	58.0
44	55.0	60.0	62.0	51.0	52.0	60.0	49.0	47.0	58.0
45	51.0	58.0	60.0	51.0	52.0	60.0	49.0	47.0	57.0
46	37.0	58.0	60.0	32.0	32.0	60.0	29.0	22.0	57.0
47	19.0	25.0	29.0	77.0	4.0	25.0	4.0	4.0	22.0
48	14.0	14.0	21.0	5.0	3.0	18.0	3.0	3.0	16.0
49-52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.7

Purchase Price of Implements and Power Units
(in dollars per meter of width)

Implement	
Tractor (per kw)	224.00
Combine	35,000.00 base plus $2,297.00 per meter of header
Bean Puller	492.00
Beet Topper	3,281.00
Beet Lifter	7,218.00
Soil Saver	2,707.00
V-Ripper	2,707.00
Fert. Spreader	328.00
Chisel Plow	1,312.00
MB Plow	2,707.00
Disk Harrow (Tandem)	1,477.00
Disk Harrow (Offset)	1,477.00
Field Cultivator	656.00
Grain Drill	328.00
Row Planter	1,969.00
N.T. Planter	2,625.00
Sprayer	2,000.00 base price plus $66.00 per meter
Row Cultivator	984.00
NH_3 App.	820.00

Modified from Tractor Blue Book, 1981, and local machinery dealers.

Table 5.8

Implements Used in MACHSEL and Their Corresponding Code

Implement	Code
Combine	1
Bean Puller	2
Beet Topper	3
Beet Lifter	4
Coulter Chisel (soil saver)	5
Subsoiler (v-ripper)	6
Fertilizer Spreader	7
Chisel Plow	8
Mold Board Plow	9
Disk Harrow (offset)	10
Disk Harrow (tandem)	11
Field Cultivator	12
Grain Drill	13
Row Planter	14
No-till Planter	15
Sprayer	16
Row Crop Cultivator	17
Ammonia Applicator	18
Spring Fertilizer Spreader	19
Second Row Cultivation	20

Table 5.9

Custom Rate in Michigan

Implement	Custom Rate $/hectare
Combine	40.00
Bean Puller	17.50
Beet Topper	37.50
Beet Lifter	61.25
Soil Saver	20.63
V-Ripper	25.00
Fert. Spreader	6.25
Chisel Plow	20.63
MB Plow	23.88
Disk Harrow (Tandem)	11.50
Disk Harrow (Offset)	11.50
Field Cultivator	9.38
Grain Drill	12.00
Row Planter	16.38
N.T. Planter	16.38
Sprayer	7.50
Row Cultivator	9.38
NH_3 App.	8.50

Modified from Schwab, 1980.

Table 5.10

Timeliness Costs for Planting and Harvesting Operations

			- - - -Penalty- - -	
			$/week	$/week
Crop	Planting	Harvesting	Planting	Harvesting
Corn †	1 percent per day after May 15	1 percent per day after Nov. 15	17.5	17.5
Wheat*	1 percent per day after Sept. 30	0.5 percent per day after July 30	12.4	12.4
Oats**	2.4 percent per day after April 20	0.5 percent per day after Aug. 23	17.4	4.0
Rye***	-----	-----	----	----
Soybean †	1 percent per day after May 20	1 percent per day before Oct. 1 and after Oct. 15	14.0	14.0
Navy bean††	.7 percent per day before June 10 and after June 20	.7 percent per day before Sept. 1 and after Sept. 10.	14.2	14.2
Sugarbeet****	1 percent per day after May 4 3 percent per day after May 10	-----	28.2 and 35.2	

* Connor, et al, 1967.

** Personal communication with Dr. Copland, Crop and Soil Dept. MSU, 1982.

*** Rye was not penalized for timeliness because it is assumed to be act winter crop.

**** Personal communication and unpublished data from Dr. Don Christenson, Crop and Soil Dept., MSU, 1982.

† Data Source: Lehrmann, 1976, as adapted by Rosenberg, 1982.

††Data Source: Drs. L. Robertson and M. Erdman, Crop & Soil Dept., MSU

Table 5.11

Average Yields Reported for the Project Area And Market Price of the Seven Crops Studied (1981)*

Crop	Average Yield (Tonnes/hectare)	Price ($/Tonne)
Corn	6.80	97.53
Wheat	3.13	138.23
Oats	4.08	63.07
Rye**	--	--
Soybean	2.11	243.10
Navybean	1.59	453.20
Sugarbeets	50	25.20

*Source of Data: Modified from USDA - Michigan Agriculture Statistics, Michigan Crop Reporting Service.

**Rye was not penalized for timeliness because it is assumed to be a winter course crop.

In order to obtain values for such data, field experimentation or relevant available sources of data were used. Actual field measurement was done to determine draft and fuel consumption for some specialized implements (Chapter 6, Section 6.1.1). Data on power requirement and machine efficiency were taken from the ASAE Yearbook (1981), Machinery capacity, power requirements and speeds were from White (1978) and Hunt (1977). Suitable hours for field work were obtained from Rosenberg (1981) and remaining and repair values for Machinery came from Rotz et al., (1981).

5.4. Model Assumptions

The following assumptions and limitations were used in the model so as to maintain a manageable and realistic output. They are divided into three broad categories:

5.4.1 Management Assumptions

a. A range of 80 to 20000 hectare farm size.

b. The minimum number of full time* laborers was chosen. This is based on the selection of the minimum cost complement which implies the minimum number of tractors operating in the field at the same time. The farmer would have to judge how many part-time laborers would be needed based on total hours of field work.

c. Three textures of soils in the Saginaw Bay drainage watershed were fine, medium, and coarse.

d. Table 5.12 depicts the number of hours of work allocated per day for each operation. These are based on observation of actual farming operations and on agronomist recommendations.

*A full-time operator works at least 40 hours a week. A 1/2 full-time operator works at least 20 hours. This implies that there are times when an operator works more hours than that, depending on the crop and time of year.

Table 5.12

Number of Working Hours Assigned to Field Operation[1]

Operation	Number of Hours Per Workday
Fertilizer Spreading	12
Spraying	12
Tillage	12
Planting	12
Cultivator	12
Ammonia Application	12
Soybean Harvesting	8
Wheat Harvesting	8
Alfalfa Harvesting	9
Field Bean Harvesting	6
Corn Harvesting	10
Oats Harvesting	7
Sugarbeet Harvesting	11

[1]Adapted from Wolak (1981).

e. Table 5.13 depicts calendar dates assignment to model weeks.

f. Costs for crop transport, drying and/or processing were not included in the main program but were accounted for when the total farm cost was determined.

g. The design probability was determined by the available work day data set. A work day data set at the 80 percent level implies that the given weekly available field work time would occur or be exceeded eight out of ten years. The machinery set developed for the 80 percent workday data set has a design probability of 80 percent. The farmer has a range of three decision probabilities from which to choose.

h. Purchase price of the power units and implements is based on actual market figures (Blue Book, 1981).

i. Annual use cost is based on a cash flow with interest, discount and inflation rates to reflect the present economic environment (Rotz, 1981).

5.4.2. Agronomic Assumptions

a. Crops handled are: corn, soybeans, navy beans, oats, wheat, sugar beets, and rye.

b. Twelve cropping systems (Table 4.2) commonly found in the Saginaw Valley area are used. The model is general enough to handle all these sequences under different tillage systems.

c. Based on experimental data collected from the project site, personal communication with farmers practicing conservation tillage, and relevant literature available, date constraints for conservation tillage are set differently from those for conventional tillage because:

   1. The soil is generally wetter and cooler in spring, indicating a later start than conventionally tilled soils.

   2. The soil will "ready" faster, i.e. permits earlier access to the soil, after rains. This allows farmers to have more suitable days to work the conservation tilled fields.

   3. One will be able to harvest sooner after rains because the crop residue on the soil gives good support for combines.

Table 5.13

Calendar Dates Assigned To Week Codes

Week	Corresponding Date		Week	Corresponding Date	
1	Jan.	1-7	27	Jul.	2-8
2		8-14	28		9-15
3		15-21	29		16-22
4		22-28	30		23-29
5	Jan.	29-31/Feb. 1-4	31	Jul.	30-31/Aug. 1-5
6	Feb.	5-11	32	Aug.	6-12
7		12-18	33		13-19
8		19-25	34		20-26
9	Feb.	26-28/Mar. 1-4	35	Aug.	27-31/Sept. 1-2
10	Mar.	5-11	36	Sept.	3-9
11		12-18	37		10-16
12		19-25	38		17-23
13	Mar.	16-31/Apr. 1	39		24-30
14	Apr.	2-8	40	Oct.	1-7
15		9-15	41		8-14
16		16-22	42		15-21
17		23-29	43		22-28
18	Apr.	30/May 1-6	44	Oct.	29-31/Nov. 1-4
19	May	7-13	45	Nov.	5-11
20		14-20	46		12-18
21		21-27	47		19-25
22	May	28-31/June 1-3	48	Nov.	26-30/Dec. 1-2
23	June	4-10	49	Dec.	3-9
24		11-17	50		10-16
25		18-24	51		17-23
26	June	25-30/July 1	52		24-31

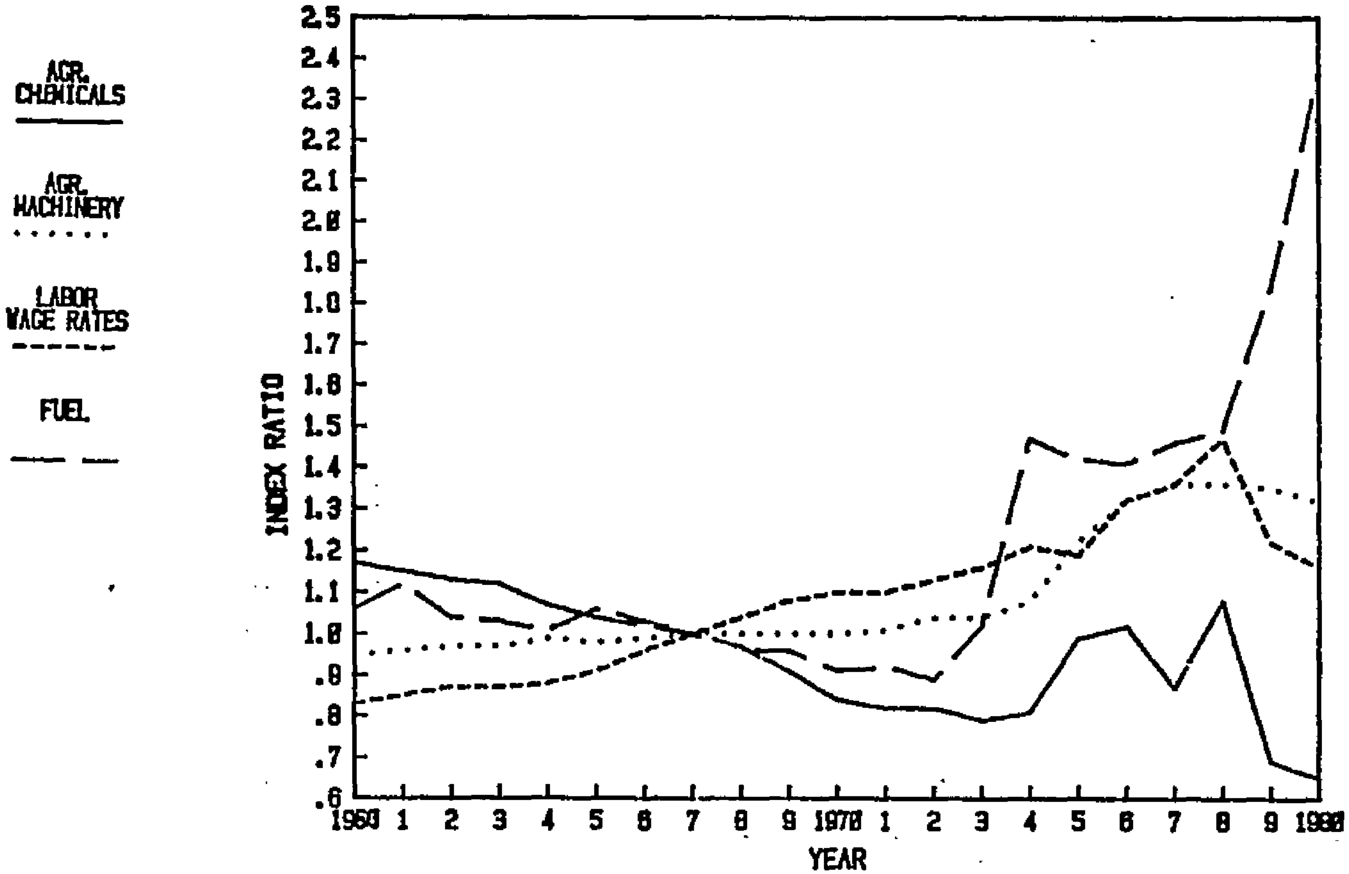

Figure 9.5

Selected Price Trends For Economic Parameters Over The Past Twenty Years Adjusted For Inflation (Agricultural Prices, Statistical Reporting Service, USDA, 1982).

5.4.3. Machinery Assumptions

a. Assignment of operations to tractors (Table 5.14)

b. No upper limit on numbers of combines, tillage tractors, utility tractors, or implements

c. Self-propelled combines are used and 4-wheel drive tillage tractors are considered, if necessary.

d. Maximum power of tillage tractor is 209 kw (centrally articulated four wheel drive). This limit was imposed based on the upper bounds of tractor sizes found in the project area.

e. Maximum power of utility tractor is 89 kw. This tractor can be used for tillage operations on smaller farms requiring only one or two tractors.

f. Maximum size of combine is twelve rows for corn.

g. Row spacing for all row crop equipment is fixed at 0.75 meters.

h. Area to be sprayed in one week must be equal or less to the area planted that same week.

i. Row crop cultivators and ammonia applicator sizes have to match the planter size. Even though ammonia applicators do not necessarily match the planter size, especially if ammonia is applied in fall ahead of planting, this decision was made to cut down on computer time and model iterations.

j. Power requirement for implements under recommended speeds and efficiencies for given soils were predetermined from relevant research and literature. Therefore it is not calculated internally. This decision was made for logistic reasons.

5.4.4. Economic Assumptions

Real figures for inflation, interest and discount rates were based on price indices. Table 5.15 depicts numerically and Figure 5.9 graphically how such figures compare to the Consumer Price Index (CPI). Based

Table 5.14

Operation Assignment to Power Source

Operation/Implement	Power Source: Tillage Tractor	Utility Tractor	Combine
Moldboard Plow	X		
Disk Harrow	X		
Disk Plow	X		
Chisel Plow	X		
Field Cultivator		X	
Sugar Beet Topper		X	
Sugar Beet Lifter	X		
No-till Planter	X		
NH3 Applicator	X		
Grain Drill		X	
Row Cultivator		X	
Row Planter	X		
Fertilizer Spreader		X	
Sprayer		X	
Navy Bean Puller		X	
Corn Head			X
Wheat Harvester			X
Soybean Harvester			X
Navy Bean Harvester			X
Oat Harvester			X

Table 5.15

Selected Input Prices Adjusted for Inflation

Year	CPI	Ag. Chem.	Ag/CPI	Ag. Mach.	AM/CPI	Wate	W/CPI	Fuel	F/CPI
1960	88.7	104	1.17	84	0.95	74	0.83	94.1	1.06
1961	89.6	103	1.15	86	0.96	76	0.85	100.0	1.12
1962	90.6	102	1.13	88	0.97	78	0.87	94.1	1.04
1963	91.7	103	1.12	89	0.97	80	0.87	94.1	1.03
1964	92.9	99	1.07	92	0.99	82	0.88	94.1	1.01
1965	94.5	98	1.09	93	0.98	86	0.91	100.0	1.06
1966	97.2	99	1.02	96	0.99	93	0.96	100.0	1.03
1967**	100.0	100	1.00	100	1.00	100	1.00	100.0	1.00
1968	104.2	101	0.97	104	1.00	108	1.04	100.0	0.96
1969	109.8	100	0.91	110	1.00	119	1.08	105.9	0.96
1970	116.3	98	0.84	116	1.00	128	1.10	105.9	0.91
1971	121.3	100	0.82	122	1.01	134	1.10	111.8	0.92
1972	125.3	103	0.82	130	1.04	152	1.13	111.8	0.89
1973	133.1	105	0.79	139	1.04	155	1.16	135.3	1.02
1974	147.7	119	0.81	159	1.08	178	1.21	217.7	1.47
1975	161.2	160	0.99	197	1.22	192	1.19	229.4	1.42
1976	170.51	174	1.02	225	1.32	210	1.32	241.2	1.41
1977	181.5	157	0.87	246	1.36	226	1.36	264.7	1.47
1978	195.3	147	1.08	266	1.36	242	1.47	270.6	1.49
1979	217.7	150	0.69	293	1.35	265	1.22	400.0	1.84
1980	247.0	160	0.65	326	1.32	286	1.16	582.4	2.36

**1976 was considered as 100.

Source: Agricultural Prices, Statistical Reporting Service, USDA, 1982.

CPI - Consumer Price Index
AG - Agricultural Chemicals
AM - Agricultural Machinery
W - Wages
F - Fuel Price
(1) - ratio of one index over the CPI

on these values and the projections adopted for the few coming years the following rates were assumed (Black, 1982).

a. General inflation = 8%

b. Machinery price inflation = 8%

c. Labor inflation = 8%

d. Fuel inflation = 12%

e. Discount rate = 13%

CHAPTER 6

MACHINERY PERFORMANCE AND MODEL VALIDATION

The focus of this chapter is to present estimates of some of the machinery parameters found on farms in the project area and to present a method used to validate the model discussed in Chapter 5. Tractor speed, tillage implement depth, tillage implement width, required tractor horsepower required, soil temperature, and soil type were recorded for the conventional and conservation tilled fields. The data presented were recorded during the 1980 and 1981 growing seasons. Fuel consumption, draft and slippage were measured on selected primary and secondary tillage implements.

6.1 Machinery Performance

Table 6.1 describes how farmers managed their newly introduced conservation tillage implements and their perception of the conditions of their fields after the use of these implements. The conservation tilled fields were perceived to be more cloddy and wetter. They believed the crop residue made planting operations difficult. Their field work, however, was done with minor difficulties and few adjustments. This was reflected by the good germination rate obtained in 1980 and 1981 seasons (Section 7.3).

Implements were not matched to the tractors used. For example, the power available to the cultivator varied from 16.63 kw/m for farmer number 20 to 24.5 kw/m for farmer number 4, even though their speeds were almost the same, 10.0 and 10.2 kph respectively (Table 6.2). Only 20% of the difference, 3.42 kw/m can be attributed to the difference in tillage depth. Similarly, the power available to the moldboard plow

Table 6.1

Observations on Selected Field Operations Performed in Spring (1980)

Farmer	Date	Soil Type	Tillage System	Implement	Depth (cm)	Speed (KPH)	Comments
12	Spring 1980	Tappan loam	Cons.	Field Cult.	16.2	12.0	
12	"	"	Conv.	M B Plow	15.2	12.0	
12	"	"	Cons.	Row Planter	6.4	10.4	Rough seed bed - lots of stalks
12	"	"	Conv.	Row Planter	6.4	9.6	Excellent seed bed
16	Spring 1980	Tappan loam	Conv.	Row Planter	3.8	5.6	
16	"	"	Cons.[1]	Row Planter	3.8	5.6	A little wet in places
4	Spring 1980	Guelph	Cons.	Field Cult.	8.9	8.0	Field was wetter than conventional
4	"	"	Conv.	Field Cult.	8.9	8.0	
20	Spring 1980	Tappan loam	Conv.	Field Cult.	12.7	8.8	
20	"	"	Cons.	Field Cult.	10.2	8.8	

[1] This farmer had one strip subsoiled, and one no-till planted under the conservation tillage category.

Table 6.2

Fall 1980 Field Operations

Farmer	Date	Soil Type	Tillage System	Residue (kg/hectare)	Implement	Implement Width (meters)	Depth (cm)	Speed (kph)	Tractor Size (kw)	kw/meter of width
4	11/6/80	Guelph	Cons.	1,648	Soil Saver	4.5	15.2	6.4	168	36.7
	11/6/80	Guelph	Conv.		MB Plow	3.7	10.2	7.7	261	71.4
11	11/5/80	Essexville loamy sand	Cons.	2,428		4.9	8.9	11.0	97	19.8
	11/5/80	Essexville loamy sand	Conv.		Tandem Disk	4.9	8.9	11.0	97	19.8
20	11/4/80	Tappan loam	Cons.	3,125	Soil Saver	3.1	20.3	7.7	75	24.5
	11/4/80	Kilmanagh loam	Conv.		MB Plow		22.9	5.9	110	52.1
21	11/7/80	Kilmanagh loam	Cons.	3,040	Offset disk with chisel	2.3	27.9	6.2	101	41.3
	11/7/80	Kilmanagh loam	Conv.		MB Plow	2.3	20.3	6.9	101	44.0
5	11/7/80	Guelph	Cons.	1,364	Chisel plow	7.6	17.8	8.0	231	30.3
	11/7/80	Guelph	Conv.		MB Plow	4.11	25.4	8.0	231	56.3
Extension Demonstration Plots	9/12/80	Brookston	Cons.	1,032	Soil Saver	3.7	15.2	4.8	97	26.4
	9/12/80		Cons.	4,236	Subsoil	5.7	34.2	5.4	131	23.0
	9/12/80		Conv.	1,909	Disk	6.1	11.4	7.7	186	30.6
	9/17/80		Conv.		MB Plow	3.3	22.9	4.9	231	70.9

varied from 36.0 kw/m for farmer number 14[1] to 71.0 kw/m for the tillage depth (23 cm) and speed (6.4 kph) were similar. The power available to the moldboard plow was 56 kw/m for farmer number 5 compared to 71 kw/m for farmer number 4; they were operating at 7.7 kph. Table 6.3 also shows that planting equipment were not well matched to the power units used. Farmer 21 used 33 kw/m of planter while farmer 14 used only 11 kw/m. This suggests that when farmers purchase implements they do not match them to the tractors they have or that the original implement purchase was matched and they purchased new larger tractors.

Harvesting speeds differ between conventionally tilled and conservation tilled fields (Table 6.4). In all cases, the combine was operated slightly faster for the conservation tilled fields. Note specifically the data for farmer number 4. The soil was wet and it was raining when the farmer was combining. There was noticeable wheel slippage with 17% more time consumed on the conventionally tilled field than on the conservation tilled field. This implies that 17% more area can be covered in the same amount of time. Absence of crop residue was perceived to be the cause since other factors (slope, crop, length of run and engine rpm) were constant.

6.1.1. Fuel Consumption

Measurement of fuel consumption was not carried out on tractors of the cooperating farmers. Tests were done, however, at the Michigan

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[1]The Cooperative Extension Service conservation tillage demonstration plots.

Table 6.3

Spring Field Operations (1981)

Farmer[1]	Date	Soil Type	Tillage System	Cover Residue (kg/hectare)	Soil Temperature (°C)	Operation	Width (ft)	Speed (kph)	Depth (cm)	Power (kw)	kw/meter of width
14	5/8/81	Condo Sandy loam	Conv.		20.0	M B plow	2.3	6.4	22.9	82	36.0
14	5/8/81	"	Conv.		20.0	Row planting	6.1	3.4	5.1	67	11.0
14	4/21/81	"	Cons.	852	28.2	F. cult.	6.4	6.2	12.7	112	17.4
14	5/4/81	"	Cons.	568	23.3	Row planting	6.1	6.1	5.1	67	11.0
21	4/21/81	Kilmanagh	Conv.		18.9	Row planting	3.1	7.4	5.1	101	33.0
21	4/21/81	"	Cons.	2,443	20.0	F. cult.	5.5	7.8	12.7	101	18.3
21	4/2/81	"	Cons.	2,102	20.0	Row planting	5.5	12.5	5.1	101	18.3
4	5/4/81	Guelph	Conv.		15.6	F. cult.	9.5	10.2	12.7	321	24.5
4	5/4/81	"	Conv.		15.6	Row planting	9.1	8.6	7.6	104	11.5
20	5/4/81	Tappan loams	Cons.	1,534	21.1	F. cult.	6.7	10.1	10.2	112	16.6
	5/4/81	"	Cons.	1,534	21.1	Row planting	9.1	7.8	2.5	112	12.2

[1]Farmer 11 decided he was not able to go ahead with the project, so no spring data were collected on his farm. Farmer 8 planted his field without notifying the project, so spring data were not collected.

Table 6.4

Corn Harvesting Operations Fall (1980)

Farmer	Date	Soil Type	Tillage System	Residue (kg/hectare)	Speed (kph)	Percent Moisture	Yield (tonnes/hectare)
	11/5/80	Essexville loamy sand	Cons.	2,537	5.1	19.7	7.0
11	"	Essexville loamy sand	Conv.	--	5.0	20.0	7.2
13	11/3/80	Tappan loam	Cons.	2,394	5.1	25.2	8.6
13	"	Tappan loam	Conv.	--	4.8	26.8	8.4
12	11/13/80	Tappan loam	Cons.	350[a]	4.8	30.0	6.2
12	11/13/80	Tappan loam	Conv.	--	4.5	30.0	6.3
4	10/16/80	Guelph	Cons.	1,653	7.8	30.2	10.1
4	"	Guelph	Conv.	--	6.4	29.6	10.2

[a]Previous crop was cucumber.

State University research farms on selected primary and secondary tillage operations. The purpose for conducting the study was to determine values of parameters needed for the selection of newly introduced conservation tillage equipment. The first phase was conducted in the Fall of 1981. Each field operation was repeated ten times. Averages of all parameters collected was obtained and reported in Table 6.5. Data collected for different implements was compared with that reported in literature, where available, for similar conditions. The data on the moldboard plow and the disk harrow were used as a test for the accuracy of the results obtained. The data collected from this test was used in the computer model described in Chapter 5. Reductions in fuel use can be estimated based upon tillage operations conducted by cooperating farmer's and on estimates of fuel disappearance per hectare according to standards of the American Society of Agricultural Engineers.[2] Total fuel consumption was estimated to be less under conservation tillage than under conventional tillage, with a range in savings of 18.75 to 32.5 liters of diesel fuel per hectare. This is primarily the result of farmers reducing their trips over the field. One farmer, for example, pulled an anhydrous ammonia tank behind his 4.6 m. modified chisel plow. The power needed to pull the chisel plow and pull the ammonia tank was the same as that needed to pull a 7-40 cm. bottom, moldboard plow. The saving was in the reduction of one trip over the field.

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[1]Estimates must be regarded as very preliminary since standards are tentative assessments for many of the new tillage tools. Indeed, most have not been analyzed for the soil types in the study area.

Table 6.5

Draft and Fuel Consumption of Selected Implements on a Sandy Clay Loam

Operation	Av. Speed (kph)	Depth (cm)	Implement Width (meter)	Slippage (%)	Draft (kw/meter)	Fuel Consumption (liter/hr)	(liter/hectare)
Moldboard plow	5.9	25.4	.81	16.3	15.84	*	*
Moldboard plow	6.7	20.3	.81	8.6	8.75	*	*
Coulter/chisel[1]	6.6	20.3	2.4[2]	33[3]	6.36	23.9[4]	20.8
Disk harrow (tandem)	7.0	12.7	3.4	13.0	2.14	19.3	11.4[5]
Field cultivator after M.B. plow	6.2	12.7	3.4	13.5	2.92	16.7	11.4
Field cultivator after soil saver	6.6	12.7	3.4	13.4	3.68	18.2	11.4
Field cultivator after disk harrow	6.7	12.7	3.4	8.0	3.44	17.0	10.4
2nd Field cultivator after M.B. plow	6.4	12.7	3.4	11.5	3.50	17.0	11.4
2nd Field cultivator after soil saver	6.7	12.7	3.4	8.5	3.44	19.3	12.3
2nd Field cultivator	6.6	12.7	3.4	10.6	3.57	17.8	11.4

*The fuel consumption in the case of the mold board plow could not be accurately determined. The method of measuring the plow draft required pulling a second tractor with the mounted plow, thus the fuel consumption was not accurate.

[1]Glencoe soil saver.

[2]Tool bar width is 3.4 meters, however 2 shanks had to be removed so that the tractor could pull the soil saver. The 8 foot is the width of the 5 shanks used.

[3]Even with the two shanks removed the tractor still had a hard time pulling the soil saver.

[4]Since slippage was excessive, this fuel value is higher than would be normally expected.

[5]These values are rounded up to the nearest one decimal; calculation was done before rounding up.

6.1.2. Field Labor

There was a reduction in labor required as a result of conservation tillage proportional to the reduction in the number of trips made over the field with various tillage instruments. There was (and will be) an increase in time required initially, particularly managerial time, when conservation tillage is introduced because of the need to better understand crop growth, disease and weed incidence under a new system. Each farmer will need to develop the best set of cultural practices for the soil type and micro-climates on his farm.

6.1.3. Field Entry Data

Based on soil temperature, field entry should have been delayed by two to four days under conservation tillage, depending on soil texture and residue levels. However, because of practical considerations, project farmers worked conventional and conservation areas at the same time in spring, both cultivating and planting. Conservation tilled fields were wetter at planting.

6.1.4. Tractability and Ease of Operations

There was better traction on plots that had crop residue (conservation systems) than on conventionally tilled plots. The machinery was better supported and time consumed to do certain operations was reduced noticeably. For example, it took a combine an average of 5 units of time working on a conservation tilled field while it took the same combine 6 units of time to harvest an equal area of similar growth in a conventionally tilled field.

6.2. Model Validation

Validation of 'MACHSEL' was done in two stages, the first stage entailed testing the sensitivity of the model to changing situations, namely: soil type, area, and risk involving weather. The second stage took into account comparisons between farm machinery complements owned by some farmers in Tuscola County and a simulated complement for the same farms.

6.2.1. Sensitivity Analysis.

The sensitivity analysis studied the reaction of the model to changing parameters. The analysis took into consideration: (1) timeliness costs as a cost for not doing a timely job; (2) sizing and selecting implements and power units as the confidence level [1] of available working hours changed from 50 to 80 percent; (3) power requirements as soil types changed under the two above mentioned and changing parameters.

While doing the tests, only one parameter was changed at one time. This permitted easy recognition of what happened as a result and tied it directly to that parameter.

6.2.1.1. Sensitivity to Timeliness Costs. As stated previously the model selects the least cost machinery complement that will do a

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[1]A 50 percent confidence level as understood in the model context means the percent probability that will give the farmer the needed number of suitable hours to finish his field work at least five years out of ten. An 80 percent confidence level means the farmer will finish his work eight or more years out of ten with the selected machinery set.

timely job within the assigned period. If the period assigned includes a week or more that bears a timeliness cost, then a charge will be tagged on areas that end up being done in that period. The model iterated and increased the size of the implements until the least cost complement is obtained. If the assigned period falls within the timeliness bounds then no extra costs were included.

The iterations and the least cost machinery complement eventually chosen were based on the number of hours available for a job. This number of available hours was the bound around which the first complement was designed. Accordingly, the least cost complement was influenced by this underlying value. So if, for example, one was dealing with a farm under two different weather confidence levels like 80 and 50 percent probabilities, one would find an appreciably smaller machinery complement for the 50 percent probability. This was due to the larger number of hours available for the higher probability level of 50 percent.

An example farm was studied and timeliness costs were monitored as land area changed. Special print statements were included in the model in order to show how the model dealt with such costs and scheduled operations that bear a costs when performed outside the timeliness periods. The farm studied was a continuous corn farm (one of the more commonly practiced crop sequences in the project area), managed with conservation tillage techniques, i.e., no moldboard plowing, and all the chisel plowing was done in the fall. In the spring one field cultivation was done followed by planting and spraying. The soil was fine textured and the probability of available good weather was 80 percent. The farmer desired to buy all new equipment and did not want any custom hired operations. The same farm was studied with the area ranging from 40 to 520 hectares, in increments of 40 hectares. Emphasis was placed on 200 and 400 hectares, which represent average and large farm sizes respectively, and 600 hectares, which represents very large farm sizes not commonly found in the project area.

In order to observe how the model selected the least cost machinery complements for a farm, the same farm was simulated in two different methods. In the first case there were no timeliness costs associated with any operation. In the second run timeliness costs were used where they were required. The field operations performed, area farmed, and the period chosen to do the work were identical for both farms. Comparing detailed output of these two situations shows how the model behaves and how it tries to choose the least cost set. Special commands were used in the model to print the data depicted in Table 6.6.

Table 6.6 depicts the iterations of the model as the proper machinery complement was selected for two situations studied for the same farm; one with and the other without timeliness costs. The total machinery cost per hectare for the 200 hectare farm with timeliness costs shifted from $105.45 down to $97.60. It must be noted that no timeliness costs were incurred after the second iteration. This came about because the second set selected was less costly than the one with timeliness costs. Therefore, the model avoided that size which caused a timeliness cost whenever possible. The cost per hectare for the same farm without timeliness cost changed from $100.78 after the first iteration to $97.60 in the last one.

Table 6.6

Example of How "MACHSEL" Iterates and Changes Sizes Until The Least Cost is Arrived At--Three Areas are Shown

Area (hectare)	Implement	Iteration 1 No Penal.	Iteration 1 W/Penal.	Iteration 2 No Penal.	Iteration 2 W/Penal.	Iteration 3 No Penal.	Iteration 3 W/Penal.	Iteration 4 No Penal.	Iteration 4 W/Penal.	Iteration 5 (Set Selected) No Penal.	Iteration 5 (Set Selected) W/Penal.
200	Till Tractor (kw)	119	119	119	119	119	119	119	119	119	119
	Util Tractor (kw)	48	48	75	75	75	75	75	75	75	75
	Combine (m)	6.1	6.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	Fer. Spr. (m)	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Soil Saver (m)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
	Field Cult. (m)	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	N.T. Planter (m)	6.1	6.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	Sprayer (m)	12.2	12.2	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3
	Timliness Cost ($)	--	934	--	--	--	--	--	--	--	--
	Machinery Cost ($)	20154	20154	19518	19518	19518	19518	20650	20650	19578	19578
	Cost/Hectare ($)	100.78	105.45	97.60	97.60	97.60	97.60	103.25	103.25	97.60	97.60
400	Till Tractor (kw)	209	209	209	209	142	142	209	209	142	142
	Util Tractor (kw)	89	89	89	89	89	89	89	89	89	89
	Combine (m)	6.1	6.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	Fer. Spr. (m)	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Soil Saver (m)	6.5	6.5	6.5	6.5	4.2	4.2	5.7	5.7	5.7	5.7
	Field Cult. (m)	7.8	7.8	7.8	7.8	10.5	10.5	6.6	6.6	10.5	10.5
	N.T. Planter (m)	6.1	6.1	9.1	9.1	9.1	6.0	9.1	9.1	6.1	9.1
	Sprayer (m)	12.2	12.2	18.3	18.3	12.2	18.3	18.3	18.3	12.2	18.3
	Timliness Cost ($)	--	1869	--	9145	--	1869	--	1860	--	1869
	Machinery Cost ($)	46350	46354	40514	40514	32175	33708	40454	41639	32175	33708
	Cost/Hectare ($)	115.88	120.55	101.28	124.15	80.45	88.95	101.13	108.78	80.45	63.95
600	Till Tractor (kw)	171	171	171	171	209	209	209	209	209	171
	Util Tractor (kw)	75	75	75	75	89	89	89	89	89	89
	Combine (m)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	Fer. Spr. (m)	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Soil Saver (m)	5.0	5.0	5.0	5.0	6.5	6.5	5.7	5.7	6.5	6.5
	Field Cult. (m)	5.6	5.6	5.6	5.6	7.8	7.8	10.5	10.5	7.8	7.8
	N.T. Planter (m)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
	Sprayer (m)	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3
	Timliness Cost ($)	--	2804	--	2804	--	2804	--	2804	--	2804
	Machinery Cost ($)	49625	49625	52322	52322	48385	48385	48428	48428	48385	48385
	Cost/Hectare ($)	82.70	87.38	87.20	91.88	80.65	80.33	80.73	85.35	80.65	85.33

The period assigned for planting was 3 weeks long. The first two weeks (May 1-May 14) bore no timeliness cost. The weeks starting with May 15 had a timeliness cost of $43.75 per hectare. The model tried to schedule planting operations that bore timeliness costs within the first two weeks when such costs were not incurred. By selecting larger implements and moving operations around within the time frame assigned, the model dropped the costs from $120.55 after the first iteration to $63.95 after the last one for the 400 hectare farm with timeliness costs. The total machinery costs per hectare ranged from $115.88 to $80.45 for a similar farm with the same time frame but with no timeliness costs assigned to operations.

The 600 hectares farm costs ranged from $91.88 to $85.33 per hectare for the farm with timeliness costs. In this case 36 hectares were left to be planted in the third week and were therefore charged extra costs. The costs for the 600 hectare farm with no timeliness costs ranged from $87.20 to $81.05 per hectare.

The machinery complements finalized for the farms with and without timeliness costs were identical in the case of the 200 hectare farm. The timeliness costs, when incurred, were the causing factor for the difference in the total machinery cost per hectare. (Table 6.6, Iteration I, 200 hectares). The same was true for the 240 hectare farm. In the case of the 400 hectare farm, the two complements differed in planter and combine sizes. In the case where timeliness costs were charged, the model found that a smaller set was the least cost given the costs incurred for late performed jobs. A larger size would cost a lot more and therefore the cost/benefit effect would not be realized. In the case where no timeliness costs were incurred the model found that a larger set was less expensive. In this case the labor and other costs reduced by spending lesser time in the field made up for the increased cost due to a larger machine.

6.2.1.2. Sensitivity to Changing Soil Types. In this test the weather confidence level was maintained at 80 percent probability while the area changed from 200 to 600 hectares with 200 hectare increments. The soil was also changed from fine textured to coarse textured. Because of soil types and the underlying assumption of naturally relatively well drained soils, drying rates were not the same. This implied that there were a different number of hours available in any one soil for a certain operation to be performed. In other words, time available for operations in the field were not the same for all three soils.

Tables 6.7, 6.8 and 6.9 depict the sizes chosen for the 200, 400 and 600 hectare farm respectively for the three types of soil. In Table 6.7 the cost per hectare for the loamy soil was $105.87 while it was $98.63 for the fine textured soil and $91.50 for the coarse textured soil. This occurs because according to the available hours for such soils (Rosenberg, 1981), there will be more available hours for fine textured soils in few weeks of the year than for medium textured soil (Table 5.6). This forces the complement initially selected to be larger and therefore the final set slightly larger and therefore pushes the cost per hectare higher. Table 6.7 also depicts, as expected, a small machinery complement for the farm with the coarse textured soil. The same trend is depicted in Table 6.8. In this case, however, the cost per hectare is less. This is expected because as area increases,

Table 6.7

Machinery Selected for a 200 Hectare Farm Under Three Types of Soil

	Fine Textured		Medium Textured		Coarse Textured	
Implement	Size	Annual Use Hrs	Size	Annual Use Hrs	Size	Annual Use Hrs
Combine (rows)	8	98	12	66	6	131
Fer. Sp. (m)	12.2	26	12.2	26	12.2	26
Soil Saver (m)	2.7	119	5.0	64	1.9	167
F. Cult. (m)	3.8	82	5.6	55	3.8	82
N.T. Plnt. (rows)	8	91	12	60	6	121
Sprayer (m)	12.2	32	18.3	21	9.1	42
Till. Trac. (kw)	97	210	152	124	48	287
Util. Trac. (kw)	48	139	75	102	48	150
Tim. Cost		684		---		2313
Mach. Cost		19043		21176		16018
Cost/Hectare		98.63		105.88		91.50

Table 6.8

Machinery Selected for a 400 Hectare Farm
Under Three Different Soils

Implement	Fine Textured Size	Fine Textured Annual Use Hrs	Medium Textured Size	Medium Textured Annual Use Hrs	Coarse Textured Size	Coarse Textured Annual Use Hrs
Combine (rows)	2*8	131	2*12	66	12	131
Fer. Sp. (m)	12.2	52	12.2	52	12.2	52
Soil Saver (m)	2*4.2	76	2*4.2	75	4.2	152
F. Cult. (m)	7.8	80	6.6	47	7.8	80
N.T. Plnt. (rows)	2*8	60	2*12	60	12	121
Sprayer (m)	18.3	42	18.3	42	18.3	42
Till. Trac. (kw)	142	136	142	136	89	272
Util. Trac. (kw)	89	174	89	94	75	174
Tim. Cost		1368		---		4625
Mach. Cost		36265		34882		24286
Cost/Hectare		94.00		87.20		72.28

The number preceding the asterisk (*) is the number of units needed of the implement size specified after the (*).

Table 6.9

Machinery Selected for a 600 Hectare Farm
With Three Different Soils

	Fine Textured		Medium Textured		Coarse Textured	
Implement	Size	Annual Use Use	Size	Annual Use Use	Size	Annual Use Use
Combine (rows)	2*12	98	2*12	98	2*12	98
Fer. Sp. (m)	2*15.2	31	12.2	77	12.2	77
Soil Saver (m)	2*6.5	74	2*5.0	114	2*4.2	114
F. Cult. (m)	2*8.7	54	2*7.8	89	2*7.8	60
N.T. Plnt. (rows)	2*12	91	2*12	91	2*12	91
Sprayer (m)	18.3	64	18.3	64	12.2	64
Till. Trac. (kw)	2*209	164	3*119	204	2*89	204
Util. Trac. (kw)	2*89	116	3*89	115	2*75	130
Tim. Cost		2052		---		---
Mach. Cost		50260		49461		37566
Cost/Hectare		87.18		82.43		62.60

The number preceding the asterisk (*) is the number of units needed of the implement size specified after the (*).

machinery efficiency tends to increase and machinery was better utilized. The increased costs of implements was spread over larger area and therefore costs per hectare will be lower.

This trend goes in cycles. Since the model selects only machinery in sizes available on the market, there are times when the complement finally selected, even though it is least in cost for the situation, it is slightly oversized. Then as area increases, the machinery is more efficiently utilized until another complement of a larger size will be needed. This trend can be clearly seen when Tables 6.7, 6.8, and 6.9 are compared, and Table 6.10 studied. In Table 6.10, the influence of area increases and machine size interaction on the cost per hectare is seen as area increases in increments of 40 hectares from 40 to 520 hectares for the same farm. Tables 6.7, 6.8, and 6.9 depict costs per hectare change from $91.5 to $75.75 and to $84.25 per hectare for the 200, 400 and 600 hectares of coarse textured soil, respectively. The same trend is observed for the farms with medium and fine textured soils. It ought to be noted that even though the cost for the 100 hectares is higher than that of the 400 hectare farm it is still lower than that of the 200 hectare farm. This implies that around the 360 hectare mark, machinery tend to be well utilized. As area increases, a need for larger and therefore initially oversized machinery is obtained.

6.2.1.3. <u>Sensitivity to Changing Weather Probability</u>. In this test the soil type was maintained as a fine textured soil. The areas tested were again 200, 400 and 600 hectares. The probability levels of having suitable hours for field work were 80, 70 and 50 percent. This implies that 2, 3 and 5 years out of ten the complement selected will

Table 6.10

Influence of Area on Machinery Utilization and Efficiency

Area (hectare)	Cost Per Hectare
40	331.18
80	209.45
160	181.5
200	152.05
240	137.10
280	163.95
320	151.03
360	145.15
400	149.35
440	150.08
480	150.20
520	140.10
560	139.93

not finish the job required on times and that 8, 7 and 5 years out of ten the job will be done on time. This also implies that the number of hours available for work increase as the probability level changes from 80 to 50 percent.

Tables 6.11, 6.12 and 6.13 depict the complements selected for the three farm sizes at different levels of risk. In all three cases costs per hectare decrease as probability level changes from 80 to 50 percent. Costs per hectare change from $98.63 to $89.20 for the 200 hectare farm; from $94.08 to $85.75 for the 400 hectare farm; and from $87.10 to $84.75 for the 600 hectare farm.

In general size of machinery and tractor power decrease as confidence level of available suitable work hours change from 80 to 50 percent. This is true in all three cases. In the 200 hectare farm power requirement drops from 97 kw for the 80 percent level to 75 kw for the 50 percent level. The sizes of implements other than tillage tools are the same for the three levels. One must note however that timeliness cost is nonexistent for the 70 and 50 percent levels. This indicates that given the fewer number of available hours at the 80 percent level forces the farmer to work in a period where there is a timeliness cost.

In the 400 and 600 hectare farms the differences in sizes were more pronounced. One twelve row planter for the 50 percent level rather than two eight row planters for the 80 percent level. Also only one 5.0 m soil saver was required for the 50 percent level while two 4.2 m soil savers were required for the 80 percent level. The power requirement also drops from two 142 kw to only one 209 kw.

Table 6.11

Machinery Selected for a 200 Hectare Farm
Under Three Weather Confidence Levels

Implement	80 percent		70 percent		50 percent	
	Size	Annual Use Hrs	Size	Annual Use Hrs	Size	Annual Use Hrs
Combine (rows)	8	98	8	98	8	98
Fer. Spr. (m)	12.2	26	12.2	26	12.2	26
Soil Saver (m)	2.7	119	3.4	93	1.9	168
F. Cult. (m)	3.8	83	3.8	82	3.8	82
N.T. Plnt. (rows)	8	91	8	91	8	91
Sprayer (m)	12.2	32	12.2	32	12.2	32
Till. Trac. (kw)	97	210	11.9	183	75	257
Util. Trac. (kw)	48	139	48	139	48	139
Tim. Cost		684		---		---
Mach. Cost		19043		18829		17838
Cost/Hectare		98.63		94.15		89.25

Table 6.12

Machinery Selected for a 400 Hectare Farm
Under Three Weather Confidence Levels

Implement	80 percent		70 percent		50 percent	
	Size	Annual Use Hrs	Size	Annual Use Hrs	Size	Annual Use Hrs
Combine (rows)	2*8	131	2*12	121	12	121
Fer. Sp. (m)	12.2	52	12.2	52	12.2	52
Soil Saver (m)	4.2	76	4.2	76	5.0	128
F. Cult. (m)	7.8	80	6.6	95	4.7	131
N.T. Plnt. (rows)	2*8	60	12	121	12	121
Sprayer (m)	12.2	42	12.2	42	12.2	42
Till. Trac. (kw)	2*142	166	2*142	136	171	249
Util. Trac. (kw)	89	174	75	189	75	225
Tim. Cost		368		3498		---
Mach. Cost		36265		36225		34195
Cost/Hectare		94.08		87.20		85.50

The number preceding the asterisk (*) is the number of units needed of the implement size specified after the (*).

Table 6.13

Machinery Selected for a 600 Hectare Farm
With Three Weather Confidence Levels

Implement	80 percent		70 percent		50 percent	
	Size	Annual Use Hrs	Size	Annual Use Hrs	Size	Annual Use Hrs
Combine (rows)	2*12	98	2*12	98	2*8	147
Fer. Sp. (m)	2*15.2	77	12.2	77	12.2	77
Soil Saver (m)	2*6.5	83	2*3.4	139	2*5.2	114
F. Cult. (m)	2*8.7	60	6.6	142	6.6	142
N.T. Plnt. (rows)	2*12	91	2*12	91	2*8	136
Sprayer (m)	18.3	64	18.3	64	18.3	95
Till. Trac. (kw)	2*209	164	2*119	229	2*119	249
Util. Trac. (kw)	2*89	116	75	142	75	157
Tim. Cost		2052		---		4812
Mach. Cost		50260		42023		45956
Cost/Hectare		47.10		70.05		84.75

The number preceding the asterisk (*) is the number of units needed of the implement size specified after the (*).

In the case of the 600 hectare farms a similar trend is observed. Planter sizes drop from 12 to 8 rows and the soil saver size drops from 6.5 m to 4.2 m as the confidence level changes from 80 to 50 percent. Also power requirement is reduced from 209 kw to 142 kw. It is of interest to note that there is a timeliness cost associated with the machinery complement selected for the 50 percent confidence level. This implies that the investment cost in a large complement will have much higher costs than that of the selected set (timeliness cost included).

6.2.2. Simulated vs. Real Farms

Three representative real farms in Tuscola County were simulated and studied. One was a 100 hectare farm growing mainly corn, one was a 400 hectare farm with a corn-corn-navy bean-wheat rotation and the third was a 360 hectare farm with a corn-corn-navy bean-sugar beets rotation. The cropping sequences practiced on these farms is typical of the county and the farmers are cooperators in the project. It was assumed, based on the algorithm followed, that the model produced the most economic set for the farm under study. The aim of this comparison was to study how farmers' sets compared with the deduced sets.

In order to fit the real farms to a simulation, some rounding of area was made. For instance in farm number two the actual area farmed was 380 hectares while in the model it was 400 hectares. Wheat area was increased from 64 to 80 hectares while bean area was reduced from 94 to 80 hectares and corn was increased from 222 to 240 hectares. These changes, while they change the farm slightly, were needed to match the farms to the model input. Similar changes were made to the other farms.

The results show that in several instances farmers tend to oversize their implements. This is due to weather uncertainties. In a few cases an implement was substituted by another (Example: A moldboard plow replaced by a soil saver). The farmer still has the moldboard plow and only uses it occasionally. Size comparisons in cases like this were not made.

In general, comparisons were quite close as can be seen from Tables 6.14, 6.15 and 6.16. There are times where the simulated number of tractors are less than the real (owned) tractors. The reason is farmers do not replace their tractors as often as is assumed in the development of this computer model. This is clear from Tables 6.14, 6.15 and 6.16.

In all thee farms studied, farm machinery owned by the farmer (except for tillage equipment) was close in size to those simulated in most cases. For the 100 hectare farm only the field cultivator was not close to the simulated one, where the owned size was 7.3 m and the simulated one was 3.8 m.

In the case of the 400 hectare corn-corn-navybean-wheat farm the owned soil saver was 5.3 m while the simulated one was 4.1 m, and the owned disk harrow was 5.6 m wide while the simulated one was 3.5 m wide. The same trend can be seen for the 360 hectare corn-corn-navy bean-sugar beet farm where the owned disk harrow was 5.6 m wide while the simulated one was 3.5 m wide and the owned soil saver was 5.3 m wide while the simulated one was 2.7 m wide.

This oversizing of tillage implements implies larger power requirements which is also clear from the same comparisons. It is clear from

Table 6.14

Comparison of Simulated and Real Machinery for A 100 Hectare Continuous Corn Farm

Implement	Simulated	Actual	Age (yrs)
Tractor 1	89 kw	97 kw	8
Tractor 2	37 hp	45 kw	10
Tractor 3	--	67 kw	15
Tractor 4	--	52 kw	15
Disk Harrow	3.5 m	4.4 m	
Field Cultivator	3.8 m	7.3 m	
Row Planter	6 row	6 row	
Chisel Plow	3.1 m	3.8 m	

Table 6.15

Comparison of Simulated and Actual Equipment
For a 400 Hectare Corn-Corn-Navy Bean-Wheat Farm

Implement	Simulated	Qctual	Age (yrs)
Tractor 1	142 kw	231 kw	2
Tractor 2	142 kw	108 kw	10
Tractor 3	60 kw	56 kw	15
Tractor 4	60 kw	52 kw	25
Tractor 5	-----	34 kw	29
Combine	8 row	6 row	
Bean Puller	8 row	6 row	
Soil Saver	4.1 m	5.3 m	
Disk Harrow	3.5 m	5.6 m	
Field Cultivator	3.8 m	9.1 m	
Grain Drill	4.0 m	4.0 m	
Row Planter	8 row	6 row	
Row Cultivator	2*8 row	12 row	

Table 6.16

Comparison of Simulated and Actual Equipment for a 360 Hectare Corn-Corn-Navy Bean-Sugar Beet Farm

Implement	Simulted	Actual	Age (hrs)
Tractor 1	89 kw	171 kw	4
Tractor 2	89 kw	134 kw	1
Tractor 3	60 kw	97 kw	6
Tractor 4	60 kw	67 kw	10
Tractor 5	-----	67 kw	12
Tractor 6	-----	45 kw	20
Combine	6 row	8 row	
Bean Puller	6 row	8 row	
Beet Topper	6 row	8 row	
Beet Lifter	3 row	4 row	
Soil Saver	2.7 m	5.3 m	
V Ripper	1.8 m	not reported	
Disk Harrow	3.5 m	5.6 m	
Field Cultivator	3.8 m	not reported	
Row Planter	6 row	8 row	
Sprayer	2*9.1m	2*0.1m	
Row Cultivator	2*6 row	2*8 row	

this comparison and from personal communications with farmers in the project area that farmers like to get their land "ready" as soon as possible so they can plant on time. This oversizing in the extent seen here, however, is not justified due to the high capital investment required.

CHAPTER 7

AGRONOMIC RESULTS (1979-80 AND 1980-81 CROP YEARS)

The results of the "side-by-side" field comparisons of conventional vs. conservation tillage are summarized in this chapter. Individual farm field data are presented in Appendix B. The results presented in this chapter are based upon seven[1] farms that participated in the 1979-1980 and 16 in the 1980-1981 crop year. All seven farms participating in 1980/81 had corn. One farm had two corn fields, while two had navy beans as well as corn, and another had sugar beets.

Nineteen farmers started to participate in the project in the 1980-1981 season. Two dropped out and one had to be disregarded because soils were not comparable on conservation and conventional tillage plots.

Paired "t" tests were used to compare tillage systems for percent germination, percent grain moisture and yield for corn and dry beans grown. A three way analysis of variance was used to determine if the moisture availability in the conservation tilled soils was statistically different from the conventional tilled soils. A null hypothesis for all "t" tests done was that the mean of a parameter observed under conservation tillage was equal to the mean of the same parameter under conventional tillage.

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[1]Due to fire, one farmer lost most of his records; yield data, however were retained. Yields for another farm were measured by the farmer when, as a result of harvest scheduling difficulties, project personnel could not be notified on time.

7.1. Crop Residue

Quantities of crop residue are reported in Table 7.1. The average preplant measurement,[1] in kilograms/hectare were made in the spring of 1981, are higher than the measurement made in the fall of 1980. For farms where the fall measurement (made after tillage) was less than the spring measurement, in most cases a modified chisel plow[2] was used which covered some of the residue in the top 5-8 centimeters of soil. As a result, this residue does not get counted in the fall. However, in the spring, a field cultivator working at a depth of ten or twelve centimeters will bring this covered residue up to the surface. Up to 25% more residue in spring is normal[3], especially in a sandy soil where covering action is very rapid.

The size of the plots exceeded two hectares in many cases. This made the sampling of crop residue difficult. This does not mean, however, that there were sampling biases, because out of 25 fields observed, only four cases needed explanation. Of all the others, 10 farms had a slightly higher count in the spring than in the fall and the remaining 11 had what would be normal trend, i.e., highest count in fall, slightly less in spring before planting, and still less for post planting in spring.

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[1] The methodology used follows Soil Conservation Service guidelines and is outlined in Section 2 of Chapter 2.

[2] A modified chisel plow, for example "Glencoe" soil saver, does partial soil inversion.

[3] Personal communication with Jerry Lemunyon, Soil Conservation Service Specialist, Saginaw, MI.

Table 7.1

Crop Residue Cover

Farmer	Fall 1980			Spring 1981			Spring 1981 Post Planting		
	Date	tonnes/hectare	% Cover*	Date	tonnes/hectare	% Cover	Date	tonnes/hectare	% Cover
1	11/12/80	2.04	51	4/6/81	2.72	60	5/7/81	1.25	35
2	--	--	--	4/1/81	3.06	67	--	--	--
3	12/1/80	3.40	30	4/6/81	2.04	51	6/23/81	0.85	25
4	11/13/80	1.93	50	3/31/81	3.52	70	5/7/81	2.44	59
5	11/7/80	1.36	40	4/3/81	3.86	72	--	--	--
6	11/17/80	2.66	60	4/2/81	2.89	63	6/19/81	2.21	52
7	11/17/80	2.29	55	4/3/81	2.66	60	5/7/81	2.64	50
8	11/17/80	2.83	63	4/2/81	2.86	63	6/25/81	1.56	42
9	11/11/80	3.06	67	4/2/81	4.17	76	4/27/81	1.81	45
10	11/11/80	2.28	55	4/2/81	2.00	50	--	--	--
11	11/8/80	2.52	60	Farmer Terminated Participation					
12[a]	11/19/80	0.35	15	4/10/81	0.68	35	5/22/81	0.74	22
13	11/19/81	1.81	45	4/10/81	2.49	60	--	--	--
14	11/17/81	1.33	35	4/8/80	0.88	25	5/8/81	0.57	32
15	11/18/80	2.15	51	4/3/81	2.61	50	5/18/81	1.36	40
16	--	--	--	4/6/81	2.66	60	5/18/81	4.22	80
17	11/11/80	3.15	67	3/31/81	3.35	70	--	--	--
18	12/1/80	3.69	71	4/6/81	2.81	63	6/8/81	1.84	49
19	11/18/80	3.01	64	Farmer Terminated Participation					
20	11/10/80	3.12	67	3/31/81	3.37	70	5/6/81	1.53	42
21	11/7/81	3.03	66	3/31/81	2.44	60	4/27/81	2.10	51
<u>Demonstration Plots</u>									
Fall Planted Rye Cover Crop				4/6/81	0.62	15	5/18/81	4.99	28
Soil Saved				4/6/81	1.03	28	5/18/81	0.77	24
V-Ripped				4/6/81	4.23	80	5/18/81	0.92	28
Disked				4/6/81	1.91	49	5/18/81	0.70	22

*Where percent cover was not measured, percent cover was estimated using the USDA Chart for estimating percentage of conopy and mulch covers, USDA, Agriculture Handbook Number 537, December 1978, page 50.

[a]Previous crop was cucumber.

7.2. Plant Population and Early Season Growth Rates

Corn in conservation tilled plots grew more slowly in the spring of the 1980 season and were 8 to 13 centimeters shorter four weeks after emergence than corn in conventionally tilled plots. However, they recovered as the season progressed. Poor plant appearance was probably due to cool, wet soil conditions which decrease early season nutrient uptake. The number of times when a difference was noted in the rate of plant growth between conservation and conventional tillage in the 1981 season was very few (Table 7.2). In week numbers eight and ten respectively, 17 percent of the farms had the conventionally grown corn ahead of conservation grown corn by one half growth stage. conservation grown corn. On the other hand in week 11 the conservation corn on eight percent of the farms was ahead of conventional grown corn by one full growth stage. In all cases the difference was gone by the time the next observation was made. No difference in growth stages was recorded after week number twelve. In the case of navybeans growth rates were the same under both systems throughout the season. Tables 7.2 and 7.3 depicts stages of growth by week for corn and navy bean respectively during the 1980-1981 season. Stages reported are the average of several observations made in each field.

7.3. Plant Population

Target seeding rates were held constant across tillage systems; seeding rate was not an experimental variable. In such instances where plant population was reduced by conservation tillage, it was found that

Table 7.2

Stages of Growth for Corn Grown in 1981 Season

Farmer		1		4		7		8		9		10		12		14		15		16		20		20		
Week		CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	CO	CT	Week
June	1	1	1	.5	.5	1	1	1	1	-	-	-	-	.5	.5	-	-	.5	.5	.5	.5	1	1	-	-	1
	2	-	-	1	1	-	-	1	1	1	1	1	1	-	-	1	1	-	-	-	-	-	3	1	1	2
	3	2	2	2	2	2	2	-	-	1	1	2	2	2	2	1	1	2	2	2	2	2	2	2	2	3
	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4
July	1	3	3	2	2	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	2
	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	4	4	3	3	3	3	3	3	4	4	3
	4	5	5	5	5	5.5	5	5.5	5.5	4	4	5.5	5.5	4	4	5.5	5.5	5	4	4	4	5	5	5.5	5.5	4
	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5	5	5	5	5.5	5.5	5
August	1	5.5	5.5	6	6	6	6	6	6	5.5	5.5	6	5.5	5.5	5.5	6	6	5.5	5.5	6	5.5	6	6	6	6	1
	2	5.5	5.5	6	6	6	6	6	6	5.5	5.5	6	6	5.5	5.5	6	7	7	7	6	6	7	7	6	6	2
	3	7	7	7	7	8	7	7	7	6	6	7	7	7	7	8	8	7	7	8	8	7	7	7	7	3
	4	7	7	8	8	8	8	8	8	7	7	8	8	*	*	8	8	7	7	8	8	8	8	8	8	4
	1	7	7	8	8	9	9	9	9	8	8	9	8	8	8	8	8	8	8	9	9	9	9	9	8	1
	2	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	2
	3	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3
	4	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	4

*Too muddy to get into the field

Please refer to Figure 4.3 for explanation of these stages.

Degree Days Units from Average Planting Date (May 16) to Average Fall Safe - from - frost date = 2200 units (USDA Agr. Statistics, 1980) and Michigan Department of Agriculture, Michigan Agriculture Statistics, 1981).

CO = Conventional Tillage
CT = Conservation Tillage
(-) = Not monitored that week

Table 7.3

Stages of Growth for Dry Beans Grown in 1981 Season

Farmer		3		5		13		17	
Week		CO	CT	CO	CT	CO	CT	CO	CT
June	1								
	2								
	3			V_1	V_1	V_3	V_3	V_1	V_1
	4	V_1	V_1	V_3	V_3	V_4	V_4	V_3	V_3
July	1	V_2	V_2					V_3	V_3
	2	V_3	V_3	V_7	V_7	R_1	R_1	V_6	V_6
	3	V_7	V_7	R_1	R_1	R_1	R_1	R_1	R_1
	4	R_2	R_2	R_2	R_2	R_3	R_3	R_1	R_1
	5	R_2	R_2	R_3	R_3	R_3	R_3	R_3	R_3
September	1	-	-	R_4	R_4	R_4	R_4	R_3	R_3
	2	R_3	R_3	-	-	R_4	R_4	-	-
	3	R_5	R_5	-	-	R_6	R_6	R_6	R_6
	4	R_6	R_6	R_6	R_6	R_6	R_6	R_6	R_6
	1	R_7	R_7	R_7	R_7	R_6	R_6	R_7	R_7
	2	R_8	R_8	R_8	R_8	R_7	R_7	R_8	R_8
	3	Harvested		Harvested		Harvested		Harvested	
	4								

Average Growing Degree Units accumulation = 1600 (Michigan Department of Agr., Michigan Agr. Statistics, 1981)

VE, VC--Emergence, cotyledon
V1--First node
V2--Second node
V3--Third node
V4--Fourth node
V5--Fifth node
V6--Sixth node
V7--Eighth node
V9--Ninth node
V10--Tenth node
CO--Conventional tillage
CT--Conservation tillage
(-)--Not monitored that week

R1--Beginning bloom
R2--Full bloom
R3--Beginning pod
R4--Full pod
R5--Beginning seed
R6--Full seed
R7--beginning maturity

the planter did not properly place the seed into the soil[1], primarily because of residue interference. Other reasons included planter wheel slippage and excessive packing from planter packing wheels because of higher soil moisture conditions. Percent germination for conservation and conventional tilled corn was 84.0 and 83.6 percent respectively for 1980 and 80.7 and 87.2 percent for 1981. Percent germination for beans was 86.7 and 88.5 percent for conservation and conventional tillage respectively in 1981. Table 7.4 depicts the seeding rate and percentage germination for farms growing corn in the spring of 1980 and 1981.

The paired "t" tests reveal that the hypothesis which states that the means are equal is rejected. In other words, the percent germination in the conservation tilled corn in 1981 can be verified at least 95 times out of 100 to be higher than conventional tillage. For our 1981 test this difference was observed to be seven percent. In 1980 the hypothesis is not rejected and there was not enough evidence to show statistical difference in germination rate. Table 7.5 depicts the seeding rate and percent germination for farms growing navy beans in the spring of 1981 season. Here too, there was not enough evidence to show statistical difference in dry and navy bean germination rates.

7.4. Fertilizer Rate

Target rates and types of fertilizers were held constant across tillage systems; rates and types were not experimental variables. Table

[1]In most cases farmers did not have access to no-till planters, and had to use regular row crop planters. This caused problems with penetration, seed depth, and covering. In cases where farmers did some alteration to their regular row planters, seed placement and depth were improved.

Table 7.4

Seeding Rate and Percent Germination for Farms Growing Corn Spring (1980 and 1981)

	1980			1981		
		Tillage Method			Tillage Method	
Farm Number	Seeding Rate (seeds/hectare)[a]	CO Percent Germination	CT Percent Germination	Seeding Rate (seeds/hectare)[a]	CO Percent Germination	CT Percent Germination
1						
(field 1)	-	-	-	55,000	68	80
(field 2)	-	-	-	55,000	85	88
4	68,750	62[b]	78	68,950	87	76
7	-	-	-	60,000	99	98
8	-	-	-	75,000	82	93
9	-	-	-	75,000	87	96
10	-	-	-	75,000	76	80
11	67,500	88	78	c	c	c
12	67,500	95	91	75,000	84	96
14	-	-	-	65,000	78	83
15	-	-	-	75,000	81	91
16	62,500	89	89	65,000	60	82
20	-	-	-	61,250	86	76
21	-	-	-	75,000	76	94
Average		83.6	84 (P>.2)	--	80.7	87.2 (P=.05)

[a]The seeding rate was the same for conventional and conservation tillage.

[b]This farmer had a problem with his 12 row planter. He had uneven depth and poor coverage. The 1981 crop was planted with a newly purchased, 12 row maxemerge planter.

[c]Did not cooperate this year.

Table 7.5

Seeding Rate and Percent Germination for Farms Growing Beans (Spring 1981)

Farmer	Variety	Seeding Rate[a] Kilograms/hectare	Tillage Method CO	CT
			Percent Germination	
3	Navy bean (seafarer)	47.6	89.1	94.4
5	Black turtle	48.6	70.7	72.9
13	Soybean	425000[c]	97.1	86.7
17	Black turtle	47.6	97.1	86.7
Average			88.5	86.7

[a]Seeding rate was the same on both systems.

[b]It was assumed that there are 5,500 seeds per kilogram of navy beans.

[c]Narrow planted soybeans (seeds/hectare)

7.6 and 7.7 show fertilizer rates and kinds applied on corn and navy beans respectively and the yield obtained in 1980 and 1981 at the cooperating farms.

7.5. Weed Control and Herbicide Rates

Rates of application and types of herbicides were equivalent for the conservation and conventionally tilled plots; rates and types were not experimental variables. There were no differences in weed control attributable to tillage method for the corn or navy bean plots.

The cooperators were very good farm managers. They were very careful when it came to proper pest control, and in particular weed control. The fields were in general very clean and weed free. There were, however, isolated cases of annual or perennial grasses that occurred on the conventional as well as conservation tillage. Conservation tillage plots tended to have more perennial grasses while conventional tillage plots had more annual grasses and broad leaves. The most commonly observed weeds were quack grass, nut sedge, Canadian thistle and pig weed. One farm had a weed problem on both tillage systems due to the farmer's sickness for a period of two weeks. Another farmer used rye as a cover crop after fall moldboard plowing. In spring the farmer sprayed the rye with a contact killer and planted with a no-till planter. The spraying was not well timed and as a result the rye was not fully controlled. Tables 7.8 and 7.9 depict the rates and kinds of herbicides used and crop yields obtained over the 1980 and 1981 season for corn and navy beans.

Table 7.6

Target Rates and Kinds of Fertilizers for Corn Used and Yields Obtained
Rates and Kinds Were the Same for Conventional and Conservation Tillage Systems

	1980				1981			
Farmer	Fertilizer	Rate kg/hectare	Yield tonnes/hectare		Fertilizer	Rate kg/hectare	Yield tonnes/hectare	
			CO	CT			CO	CT
1			--	--	10-26-26- with 2% Zn	342	7.4	7.2
					Nitrogen			
4	K_2O	342	10.2	10.1	5-14-13	365	9.9	8.9[b]
	6-41-0	125			8-25-5	23		
	NH3							
7			--	--	0-0-60	228	8.6	8.0
					8-40-5, 2%zan, 1% S,	465		
					28% N 1/2% FE	57		
8			--	--	13-35-3	262	10.9	10.7
					Actual N	154		
9					K_2O	342	10.6	9.7
					7-40-10	450		
					NH3			
10					6-18-36, 1%Mn, 2%Zn	326	--	--
					NH3			
11 Field 1	6-18-6	228	6.9	7.4	C	--	--	--
	30-0-8	179						
	Chicken Manure	28,300[a]	7.0	6.6				
12			6.3	6.2	9-32-20, 1% Zn, 2%Mn	684	8.6	8.4
13	K_2O	137	8.4	8.6	--	--	--	--
14					4-11-44	456	8.4	8.2
					10-34-0, 2% Zn	114		
					28% N			
15					0-0-60	285	9.5	9.9
					Lime	12.5[d]		
					9-37-7, 2% Zn	285	9.5	9.6
16	K_2O	228	9.8	9.5	11-54-0, 2%Mn, 2% Zn	125	9.5	9.6
	7-30-15	280			Actual N	200		
	NH3	160						
20	Not Given				10-20-20	365	9.0	8.7
					NH3	160		
21					14-35-3	143	11.3	11.2
					K_2O (Potash)	228		
					Hog Manure	47,318		

[a]Liters per hectare

[b]Average of 2 fields (8.8 and 9.0 hectares/acre)

[c]Did not cooperate this season

[d]Tonnes/hectare

[e]Planted beans this season.

Table 7.7

Target Rates and Kinds of Fertilizers Used for Beans and Yields Obtained in 1980-1981 Season. Rates and Kinds Were The Same for Conventional and Conservation Tillage

Farmer	Fertilizer	Rate Kilogram/hectare	Yield Tonnes/hectare CO[a]	CT[b]
3[c]	Urea	56.8		
	6-22-22, 2% Zn, 2% Mn	272.2	1.8	1.5
5	10-34-0	170.1	2.8	2.9
13	0-0-60	113.4		
	12-34-14	226.8	3.3	3.1
17	10-20-20, 2% Zn, 2% Mn	311.8	3.0	3.1

[a]Conventional tillage

[b]Conservation tillage

[c]Planted navy beans

Table 7.8

Target Rates and Kinds of Herbicides Used on Corn and Yields Obtained
Rates and Kinds Were the Same for Conventional and Conservation Tillage Systems

Farmer	Herbicide	Rate Per Hectare	Yield (kg/hectare) CO	CT	Herbicide	Rate Per Hectare	Yield (tonnes/hectare) CO	CT
1					Atrazine	5.8 liters	7.4	7.2
					Banvel	1.8 liters		
4	Atrazine	2.2 kg	10.2	10.1	Atrazine	2.3 kg	9.9	8.9
	Lasso	4.8 liters			Lasso	4.8 liters		
					Bladex	3.8 liters		
7					Atrazine	.6 kg	8.6	8.0
					Sutan	2.3 kg		
					Bladex	1.8 kg		
8					Dual	2.5 liters	10.9	10.7
					Dacamine	.8 liters		
9					Banvel	1.0 liters	10.6	9.7
					Esterone	1.0 liters		
10					Banvel	1.0 liter	--	--
					Formula 40	1.0 liter		
11 Field 1	Lasso	4.8 liters	6.9	7.4	--	--	--	--[a]
	Bladex	418 liters						
Field 2	Lasso	4.8 liters	7.0	6.6	--	--	--	--
	Bladex	4.8 liters						
12	Lasso	2.5 liters	6.3	6.1	Bannel	1.0 liter	8.6	8.4
	Banuel	.6 kg			Atrazine	.6 kg		
	Atrazine	1.3 kg			Lasso	2.5 liters		
13	Bladex	2.3 kg	8.4	8.6				
	Atrazine	.6 kg						
	Lasso	4.8 liters						
	Rougue w/ Basagran							
14					Atrazine	1.3 liters	8.4	8.2
					Formula 50	1.3 liters		
					Banvel	.6 liters		
15					Atrazine	2.6 kg	9.5	9.9
					Lasso	4.8 liters		
16	Bladex	4.8 liters	9.8	9.5	Lasso	4.8 liters	9.5	9.6
	Lasso	2.8 liters			Atrazine	1.0 kg		
	Atrazine	.6 kg			Roundup (spot application)			
20	Sutan	4.8 liters	--	--	Sutan	4.8 liters	9.0	9.6
	Atrazine	2.4 liters			Atrazine	2.4 liters		
21			--	--	Dual	3.0 liters	11.3	11.2
					Banvel	1.3 liters		
					99 Concentrate	3.1 liters		

[a]Did not cooperate.

Table 7.9

Target Rates and Kinds of Herbicides Used on Dry Beans and Yields Obtained in 1980-81 Season. Rates and Kinds Were The Same for Conventional and Conservation Tillage

Farmer	Herbicide	Rate Per Hectare	Yield tonnes/hectare CO	Yield tonnes/hectare CT
	Eptam	2.5 liters		
3	Amiben	9.0 kg.[a]	1.8	1.5
	Treflan	1.5 liters		
	Eptam	2.5 liters		
5	Treflan	1.3 liters	2.8	2.9
	Amiben	3.1 liters		
	Amiben	9.5 liters		
	Lasso	5.0 liters	3.3	3.1
13	Basagram with oil	1.9 liters		
	Hoelon[1]	3.3 liters		
17	Amiben	4.4 liters	3.0	3.1

[a]Kilogram

[1]Used on conservation tillage only.

7.6. Insect Populations

Increased armyworm and corn borer populations were observed for the conservation tillage treatment in some corn fields (however, the populations were not high enough to have an important impact on yield). Armyworm populations were present where small grain cover crops were not effectively killed by spring herbicide applications. In other corn fields, and on bean and beet fields, insect populations were not increased where residues were left on the soil surface. Tables 7.10 and 7.11 depict the kinds and rates of insecticides used in 1980 and 1981 seasons and yields obtained.

7.7. Crop Diseases

No crop diseases were observed that could be attributed to differences in tillage systems. One farm had eye spot on corn on both sections of the field. It was noticed first on the conservation tilled side and was not sprayed early. Yield in the conservation plot was one tonne/hectare less than the conventional plot. The eye spot might have caused some of this difference.

7.8. Crop Yield

Differences in yield per hectare for corn grown under conservation vs. conventional tillage were small; the average yields were 8.12 tonnes/hectare for corn grown under conventional tillage vs. 8.07 tonnes/hectare for conservation tillage when averaged across all "fields" for the 1980 season. While they were 9.5 tonnes/hectare and 9.1 tonnes/hectare for conventional and cnservation systems respectively for the 1981 season (Table 7.12). Average yields were 8.4 and 8.3 tonnes/hectare respectively, for conventional and conservation tillage

Tablle 7.10

Target Rates and Kinds of Insecticides Used on Corn and Yields Obtained. Rates and Kinds Were the Same on Conventional and Conservation Tillage.

Farmer	Insecticide	Rate Per Hectare	Yield tonnes/hectare		Insecticide	Rate Per Hectare	Yield tonnes/hectare	
			CO	CT			CO	CT
1					None	--	7.4	7.2
4	None	--	10.2	10.1	Dyfonate	7.9 kg[a]	9.9	8.9
7					Dyfonate	3.1 liters	8.6	8.0
8					Counter	9.1 kg	10.9	10.7
9					Lorsban	7.9 kg	10.6	9.7
10					None	--		
11								
Field 1			6.9	7.4				
Field 2			7.0	6.6				
12	Lorsban	7.9 kg	6.3	6.2	Lorsban	2.5 liter	8.7	8.3
13	Dyfonate	7.9 kg	8.4	8.6				
14					Counter	9.1 kg	8.4	8.2
15					Dyfonate	7.9 kg	9.5	9.9
16	Counter	9.1 kg	9.8	9.5	Counter	9.1 kg	9.5	9.6
20					Tursban	7.4 kg	9.0	8.7
21					Counter	9.1 kg	11.3	11.2

[a]Kilogram

Table 7.11

Target Rates of Insecticides Used on Beans and Yields Obtained in 1980-1981 Season. Rates and Kinds Were the Same For Conventional and Conservation Tillage

Farmer	Insecticide	Rate Per Acre	Yield Tonnes/hectare CO	CT
3	None	--	1.8	1.5
5	CyGon	Not Reported	2.8	2.9
13	None	--	3.3	3.1
17	CyGon	Not Reported	3.0	3.1
Average Across Fields			2.7	2.6
Average Across Farms			2.7	2.6

Table 7.12

Comparative Corn Yields on Conservation Vs. Conventional Tillage for 1980 and 1981 Seasons (Tonnes/Hectare)

Farmer	1980 CO	1980 CT	1981 CO	1981 CT
1 Field 1			7.4	7.2
Field 2			9.3	9.5
4 Field 1	10.2	10.1	9.9	8.8
Field 2			9.9	9.0
7			8.6	8.0
8			10.9	10.7
9			10.6	9.7
11 Field 1	6.9	7.4		
Field 2	7.0	6.6		
12	6.3	6.1	8.6	8.4
13	8.4	8.6		
14			8.4	8.2
15			9.5	9.9
16	9.8	9.5	9.5	9.6
20			9.0	8.7
21			11.3	11.2
Average Across Fields	8.1 P>.2	8.1	9.5 P=0.035	9.1
Average Across Farms	8.4	8.3	9.5	9.2

when averaged across farms for the 1980 season. However, for the 1981 season they were 9.5 and 9.2 tonnes/hectare respectively for conventional and conservation tillage. The null hypothesis which states that mean yield of the two tillage treatments are assumed to be equal cannot be rejected for 1980 corn yield. However for 1981 it is rejected because there is a discernible difference in yield at the 5% level (Table 7.12). As for bean yields for the 1981 season the hypothesis cannot be rejected because even at 20% level there was no discernible difference between yield due to tillage treatments. Average navy bean yield for 1981 season across all fields was 2.7 tonnes/hectare for conventional and 2.6 tonnes/hectare for conservation tillage. Average yields across the farms (total number of cooperating farms) was the same as that across the fields (total number of fields from which data was collected) for both tillage treatments (Table 7.13). The rain pattern for spring of 1981 was abnormal in distribution as well as intensity. This is believed to be the cause for such a difference in yield. In cold, very moist soil conservation planted will have a date start and if these conditions persist then they will not grow normally. This finding is consistent with reports cited in Section 3.2.3.

During the 1980 season navy bean and sugar beet yield data were not sufficient to draw any conclusions. Navy bean yield was lower where conservation tillage was practiced, but weed control was a problem. Sugar beet yield was slightly higher under conservation tillage. More work is needed to define the optimal set of cultural practices for navy bean and sugar beets. However, in the 1981 season there was no statistically discernible difference in dry bean yields between both tillage

Table 7.13

Bean Yield on Conservation Vs. Conventional Tillage for 1981 (Tonnes/Hectare)

Farmer	Variety	CO	CT
3	Navy beans Sea farer	1.8	1.5
	Black Turtle Beans	2.8	2.9
13	Soybeans GHL 150	3.3	3.1
17	Black Turtle Beans	3.0	3.1
Average Across Fields		2.7	2.6
Average Across Fields		2.7 P>.2	2.6

systems. This was due to better management practices on the part of the farmers than was practiced in the 1980 season.

7.9. Grain Moisture at Harvest

The average moisture content of corn at harvest was essentially the same for both tillage treatments in 1980; 24.7% for conventional tillage vs. 25.0% for conservation tillage when averaged across farms. It was 24.8% and 25.8% for conventional and conservation tillage respectively in the 1981 season. Table 7.14 and 7.15 depicts the average percentage moisture of corn and navy bean for 1980 and 1981 seasons respectively.

Based on the results of the statistical tests carried out, the null hypothesis of the means being equal will not be rejected for 1980 corn moisture (Table 7.14). This implies that there was a statistically discernible difference in moisture content due to tillage practices. On the other hand the hypothesis cannot be rejected for moisture content in beans at harvest time (Table 7.15). This implies no statistically significant difference in moisture content due to tillage practices.

7.10. Soil Moisture

There was a statistically discernible difference between the main effects (depth and days) but not tillage, as is evident in Table 7.16. Also, there was a discernible difference due to the interaction between depth and tillage practice (Table 7.17).

Since main effects of a certain variable "should be individually interpreted only if there is no evidence that the variable interacts

Table 7.14

Corn Moisture Content at Harvest for 1980 and 1981 Seasons

Farmer	1980		1981	
	CO	CT	CO	CT
	- - - - - - - -Percent Moisture- - - - - - - -			
1 Field 1			25.9	31.5
Field 2			22.3	25.0
4 Field 1	29.6	30.2	24.8	24.6
Field 2			24.8	25.1
7			29.6	30.9
8			23.7	24.8
9			23.4	25.3
10			20.6	21.4
11 Field 1	20.0	19.3	--	--
Field 2	20.0	20.0		
12	30.0	30.0	28.6	29.7
13	25.1	25.2	--	--
14			23.1	22.0
15			28.7	28.2
16	23	23.5 subsoiled 25.9 subsoiled 26.0 no tilled	22.2	23.7
20	25.0	25.0	24.7	25.0
21			24.6	25.0
Average Across Fields	24.7	25.0 P=0.117	24.8	25.9 P=.05
Average Across Farms	25.5	25.8	24.8	25.8

Table 7.15

Dry Bean Moisture Content of Harvest (1981 Season)

Farmer	CO	CT
3	20.70	19.90
5	16.00	16.00
13	16.10	16.30
17	15.40	16.40
Average Across Fields	17.11	17.20
Average Across Farms	17.11	17.2 P > .2

Table 7.16

Analysis of Variance of Interaction of Depth, Drying Days, and Tillage System on Moisture in Clay Soil

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main Effects	2805.757	7	400.822	59.525	.001
V1 = Day	2283.616	4	570.904	84.783	.001
V2 = Tillage	5.586	1	5.586	.830	.365
V3 = Depth	516.555	2	258.278	38.356	.001
2-Way Interactions	120.741	14	8.624	1.281	.235
V1 X V2	28.940	4	7.235	1.074	.374
V1 X V3	53.147	8	6.643	.987	.452
V2 X V3	38.654	2	19.327	2.870	.062
3-Way Interactions	34.927	8	4.366	.648	.735
V1 X V2 X V3	34.927	8	4.366	.648	.735
Explained	2961.426	29	102.118	15.165	.001
Residual	606.031	90	6.734		
Total	3567.457	119	29.979		

V1 Day
V2 Tillage
V3 Depth

Table 7.17

Average Values of Moisture Content in Clay Soil at 15.2 and 76.2 cm Deep, Sampled Every Day Two Days After Soil Saturation

	15.2 cm		76.2 cm	
Day	CO	CT	CO	CT
	- - - - Percent Moisture - - - -			
1	32.1	31.1	26.8	28.1
3	26.8	30.6	24.6	25.1
5	27.1	29.5	23.2	24.8
7	27.9	29.3	22.4	25.1
9	16.9	17.8	14.7	13.90

with other variables"[1], the only significant main effect is the day (duration of the experiment). The interaction between depth and tillage makes it imperative to consider them jointly. Therefore based on this interaction the hypothesis which assumes equal means should be rejected at the 5% level. However, at the 10% level there would be no reason to reject it. In other words this interaction was not significant at the 5 percent level, but was at the 6 percent level which means that these results can be repeated 94 times out of a 100 when the same test is run. The Analysis of Variance for the interaction between tillage system, depth, and drying days and their effect on soil moisture is presented in Table 7.16.

The reason there was not a more pronounced difference in moisture content between both tillage systems is the unusually high precipitation experienced through out the 1981 growing season. Had the rainfall pattern been altered to give low precipitation, a statistically discernible difference in soil moisture content would be expected.

[1]Box, G.E., W.G. Hunter and J.S. Hunter, 1978. Statistics for Experiments--An Introduction to Design, Data Analysis and Model Building. pp. 317-318. J. Wiley and Sons, Inc., N.Y.

CHAPTER 8

ECONOMIC COMPARISON OF CONSERVATION AND CONVENTIONAL TILLAGE

The focus of this chapter is upon the estimation of profitability of conservation tillage relative to conventional tillage for the major crop sequences grown on the lake plain soils in the Saginaw Bay Watershed in Tuscola and Huron Counties. The analysis was conducted from a whole farm perspective with the least cost machinery complement for each tillage system given the crop sequence. The analysis was conducted for farms of 160, 240 and 320 hectares, which are common sizes in the study area. As described in Section 2.1, our method of analysis was to construct a hypothetical "representative" farms based on coefficients developed from the field comparisons and complementary Michigan State University experiments. Also, consideration was only given to those aspects of the farm business that differ as a result of the tillage system used. The economic results were generated for the areas mentioned above in particular, and for other farms ranging from 120 to 480 hectares, covering most of the areas of farms in the project area.

The assumption was made in the economic comparison that the conservation tillage implement used for primary tillage was a chisel plow or a modified chisel plow (soil saver), while for the conventional tillage the implement used was a moldboard plow. A field cultivator rather than a disc-harrow was assumed to be used for secondary tillage. The comparison was based upon input/output relationships derived from the literature, modified by the results of the comparisons of conservation vs. conventional tillage in the project when there were differences between the literature and the field comparisons as discussed in Chapter 7 and Section 8.2.

8.1. Machinery Complements

The sequence of field operations and the machinery complements selected for the corn-navy bean (C-NB) corn-navy bean-sugar beet (C-NB-SB), corn-corn navy bean-sugar beet (C-C-NB-SB), and corn-navy bean-wheat-sugar beet (C-NB-WT-SB) sequences are presented in Tables 8.1 through 8.4. Field operations are listed in the sequence with which they are performed.

The chisel plow replaced the moldboard plow in the conservation tillage system and the disk harrow as was not used. One field cultivation was performed for the conservation tilled farms while disk harrowing and field cultivation were done more than once on the conventional tilled areas. Also, only one row cultivation was done under the conservation tillage compared to two row cultivations under conventional tillage. All chisel plowing was finished by November 27 for all fields. The harvesting operations were the same for the conventional and conservation systems. The machinery complements chosen, as indicated in the methodology, achieved the timeliness constraints set in Table 4.3 and 4.4 (Section 4.4) in eight years out of ten.

The conservation tillage machinery complements were based on the assumption that corn planting must be completed by the same date as for conventional tillage. This implies that there are fewer days for spring tillage and planting to be completed.

The field operation sequence and the resultant machinery complements for each cropping sequence for conservation and for conventional tillage follow. For the C-NB sequence (Table 8.1) the tractors and implements vary in size with different areas and the combine is two rows larger for the conventional tillage system for 160 and 240 hectares. This occurs because a four row planter and a four row combine do a timely job for the conservation tilled 160 and 240 hectares. On the conventionally tilled 160 and 240 hectares, a six row planter was needed due to the number of operations taking place in spring. This forces the combine size to be larger in order to match the planter size. Combines selected for the 320 hectare C-NB farms were the same size.All tractors needed for the 320 hectare farms under both systems were equal in size. Power needed for conventional tillage under 160 and 240 hectares was larger because of the large implements like the disk harrows chosen. There were few changes in other implement sizes since all row equipment must match. As long as the combine or planter sizes did not change from one area to another, the sprayer, row cultivator, and NH3 applicator retained the same size. Costs of conventional tillage per hectare for the three farm sizes considered was always higher than that for the conservation tillage. The conservation tillage was $62.88, $40.58 and $21.2/hectare lower for the 160, 240 and 320 hectares respectively.

In the C-NB-SB sequence (Table 8.2) the combine is two rows larger for the conventionally tilled 160 and 240 hectares for the same reason stated above, while it is two rows smaller for the 320 hectare farm. The increase in area by 80 hectares with chisel plowing to be done in fall for conservation tillage demands more time for plowing. Therefore a larger combine will take less time harvesting and leave more time that

Table 8.1

Comparison of Costs and Machinery Sizes for a Corn-Navy Bean Farm at 160, 240, and 320 Hectares
Soil is Fine and Confidence Level is 80%

	160 hectares				240 hectares				320 hectares			
	Conventional		Conservation		Conventional		Conservation		Conventional		Conservation	
Implement	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours
Combine (Row)	6	67	4	100	6	79	4	118	6	105	6	105
Bean Pull. (Row)	6	73	4	73	6	94	4	94	6	126	6	126
Fer. Spr. (M)	12.2	13	12.2	13	12.2	16	12.2	16	12.2	21	12.2	21
M.B. Plow (Bottom)	3	243	-	-	3	313	-	-	3	417	-	-
Soil Saver (M)	-	-	1.9	159	-	-	1.9	200	-	-	1.9	267
Disk Harr. (M)	3.5	37	-	-	3.5	48	-	-	3.5	64	-	-
Tandem Harr. (M)	3.5	37	-	-	3.5	48	-	-	3.5	64	-	-
F. Cult. (M)	3.8	78	12.5	78	3.8	98	3.8	98	3.8	130	3.8	130
Row Plnt. (Row)	6	73	4	183	6	87	4	217	6	116	6	193
Sprayer (M)	9.1	20	6.1	30	9.1	25	6.1	38	9.1	34	9.1	34
Row Cult. (Row)	6	216	4	86	6	73	4	183	2*6	163	6	163
NH3 App. (Row)	6	57	4	86	6	73	4	109	6	197	6	97
Till. Trac. (Kw)	2*142	263	2*90	250	2*142	331	2*90	310	2*142	441	2*142	341
Util. Trac. (Kw)	48	327	48	283	48	383	2*48	167	2*48	255	2*48	175
Tim. Cost ($)	-		1450		-		2707		2339		3128	
Mach. Cost ($)	38329		26818		44289		32014		54677		47104	
Cost/Ha.	239.55		176.68		184.53		143.95		178.18		156.98	

Table 8.2

Comparison of Costs per Hectare for a Corn-Navy Bean-Sugar Beet Farm at 160, 240 and 320 Hectares
Soil is Fine and Confidence Level is 80%

	160 hectares				240 hectares				320 hectares			
	Conventional		Conservation		Conventional		Conservation		Conventional		Conservation	
Implement	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours
Combine (Row)	6	44	4	67	8	39	6	52	6	70	8	52
Bean Pull. (Row)	6	48	4	48	8	42	6	63	6	84	8	56
Beet Topp. (Row)	3	81	3	81	3	105	3	105	3	140	4	105
Beet Lift. (Row)	3	81	3	81	3	105	3	105	3	140	4	105
Fer. Spr. (M)	12.2	17	12.2	17	12.2	21	12.2	21	12.2	26	12.2	26
M.B. Plow (Bottom)	3	247	-	-	3	315	-	-	3	417	-	-
Soil Saver (M)	-	-	1.9	158	-	-	2.7	143	-	-	4.2	121
Disk Harr. (M)	3.5	25	-	-	3.5	32	-	-	3.5	43	-	-
Tandem Disk (M)	3.5	50	-	-	3.5	64	-	-	3.5	85	-	-
F. Cult. (M)	3.8	78	12.5	78	3.8	98	3.8	98	12.5	131	6.6	76
Row Plnt. (Row)	6	73	4	183	8	65	6	145	6	116	8	145
Sprayer (M)	30	27	20	40	40	25	30	34	30	45	40	34
Row Cult. (Row)	6	235	4	161	8	73	6	97	2*6	163	8	122
NH3 App. (Row)	6	76	4	114	8	73	6	97	2*6	65	8	97
Till. Trac. (Kw)	142	600	2*90	292	172	432	142	552	2*142	507	172	524
Util. Trac. (Kw)	48	418	48	377	48	432	48	379	2*48	335	75	365
Tim. Cost ($)	-		202		-		-		6060		-	
Mach. Cost ($)	39106		30904		50450		37160		60320		45118	
Cost/Ha. ($)	245.03		194.95		210.2		154.83		207.18		140.83	

could be allocated for plowing. Since all row equipment should match, and since there was a large competition for time in spring, the planter needed to be larger in order to finish the job in a timely manner, and therefore the need arose for a larger set for conventional tillage for the 160 and 240 hectares. When area was increased to 320 hectares there was enough increase in area to cause competition in fall and the conservation tillage required a larger combine for a faster harvest and thus leaving more time for tillage tasks. The combine and planter chosen for the 240 hectare conventional farm was only six rows. The reason was that two sets of the row cultivators and the NH3 applicator were chosen. This implies that the row cultivation and the NH3 application were done earlier and therefore the planter had more hours to plant the navy bean crop with a six row planter. Again for the conservation tillage farms, the number of tractors selected as well as total power requirement was generally less. The 320 hectare farm required only one 172 kw and one 75 kw tractor while the conventional tillage farm required two 142 kw and two 48 kw tractors. Here again the cost per hectare was $50.08, $55.38 and $66.35 lower for conservation tillage on 160, 240 and 320 hectares respectively.

The C-C-NB-SB (Table 8.3) rotation required a six row planter for all three areas tested, except for the 320 hectares conservation tillage. In the case of the 160 hectare farm a four row planter was small given the complexity of the rotation. The six row planter was slightly oversized for this area and therefore fit the 240 and 320 hectare farms better as was evident from the cost per hectare of the 160, 240 and 320 hectare farms. For the conservation tilled 320 hectare farm, an eight row combine row was selected. This is due to the larger area chiseled

Table 8.3

Comparison Costs Per Hectare and Machinery Sizes for a Corn-Corn-Navy Bean-Sugar Beet Farm at 160, 240 and 320 Hectares
Soil is Fine and Confidence Level is 80%

	160 hectares				240 hectares				320 hectares			
	Conventional		Conservation		Conventional		Conservation		Conventional		Conservation	
Implement	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours
Combine (Row)	6	67	6	67	6	79	6	79	6	105	8	79
Bean Pull. (Row)	6	36	6	36	6	47	6	47	6	63	8	42
Beet Topp. (Row)	3	61	3	61	3	79	3	79	3	105	3	105
Beet Lift. (Row)	3	61	3	61	3	79	3	79	3	105	3	105
Fer. Spr. (M)	12.2	19	12.2	19	12.2	23	12.2	23	12.2	31	12.2	31
M.B. Plow (Bottom)	3	248	-	-	3	313	-	-	4	315	-	-
Soil Saver (M)	-	-	1.9	159	-	-	1.9	200	-	-	3.4	148
Disk Harr. (M)	3.5	18.6	-	-	3.5	24	-	-	3.5	32	-	-
Tandem Disk (M)	3.5	56	-	-	3.5	72	-	--	3.5	96	-	-
F. Cult. (M)	3.8	78	3.8	98	3.8	98	3.8	98	3.8	130	5.6	88
Row Plnt. (Row)	6	55	6	122	6	65	65	145	6	70	8	145
Sprayer (M)	9.1	20	9.1	20	9.1	38	9.1	25	9.1	51	12.2	51
Row Cult. (Row)	6	189	6	108	6	124	6	122	6	143	8	122
NH3 App. (Row)	6	86	6	86	6	109	6	109	6	73	8	109
Till. Trac. (Kw)	142	560	142	473	142	619	142	579	2*142	421	172	548
Util. Trac. (Kw)	48	377	48	282	65	452	48	347	2*48	301	60	371
Tim. Cost ($)	-		-		2209		-		1961		-	
Mach. Cost ($)	37132		32752		47178		39041		51144		44177	
Cost/Ha. ($)	232.08		204.7		205.78		159.5		165.95		138.05	

in the fall after harvesting the navy bean, lifting the sugar beets and harvesting the corn. As stated earlier, a larger combine would allow more time for the chisel plow, especially if labor was limited. Again power requirement was smaller for the conservation than that for the conventional tilled farms. Costs per hectare for the 160, 240 and 320 hectares in conservation tillage were $27.38, $47.28 and $22.90 respectively lower than conventional tillage.

All conventionally tilled C-NB-WT-SB (Table 8.4) farms required larger combines than the conservation tilled farms. In this case spring activities for conventional tillage competed for time. This required a larger planter which in turn required a larger combine. As shown conservation tilled farms required smaller row equipment than conventionally tilled farms. Here again conservation tillage costs less per hectare than conventional tillage. Savings were $11.38; $52.60 and $38.10/hectare for the 160, 240 and 320 hectares respectively.

In order to monitor how machinery complements change in number and size for such cropping sequences as farm areas got considerably larger, one sequence which is commonly practiced in the project area was selected.

Two hundred and forty, 480 800 and 2000 hectare farms were chosen for this study (Table 8.5). The 240 and 480 hectares represent an average and a larger than average farm size in the project area. The 800 and 2000 hectares are not common sizes in the project area, however, they do indicate how costs behave when areas farmed become very large.

Table 8.4

Comparison Costs per Hectare and Machinery Sizes for a Corn-Navy Bean-Wheat-Sugar Beet Farm at 160, 240 and 320 Hectares
Soil is Clay and Confidence Level is 80%

	160 hectares				240 hectares				320 hectares			
	Conventional		Conservation		Conventional		Conservation		Conventional		Conservation	
Implement	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours	Size	Annual Use Hours
Combine (Row)	6	100	4	100	6	79	4	118	8	98	6	105
Bean Pull. (Row)	6	24	4	36	6	60	4	47	8	31	6	48
Beet Topp. (Row)	3	61	3	61	3	79	3	79	3	105	3	105
Beet Lift. (Row)	3	61	3	61	3	61	3	79	3	105	3	105
Fer. Spr. (M)	12.2	19	12.2	19	12.2	23	12.2	23	12.2	31	12.2	31
M.B. Plow (Bottom)	3	186	-	-	3	234	-	-	3	313	-	-
Soil Saver (M)	-	-	1.9	159	-	-	1.9	-	200	-	6.3	267
Disk Harr. (M)	3.5	56	-	-	3.5	72	-	-	3.5	32	-	-
Tandem Disk (M)	3.5	17	-	-	3.5	24	-	-	3.5	32	-	-
F. Cult. (M)	3.8	78	3.8	78	3.8	98	3.8	98	3.8	130	3.8	130
Gr. Drill (M)	4.0	24	4.0	24	4.0	26	4.0	26	4.0	35	4.0	35
Row Plnt. (Row)	6	55	4	138	6	65	4	163	8	65	6	145
Sprayer (M)	9.1	30	6.1	45	9.1	38	6.1	50	12.2	38	9.1	51
Row Cult. (Row)	6	162	4	121	6	183	4	138	8	183	2*6	61
NH3 App. (Row)	6	57	4	86	6	73	4	109	8	73	2*6	61
Till. Trac. (Kw)	142	458	2*190	249	2*142		2*90	311	2*97	357	2*142	254
Util. Trac. (Kw)	48	375	48	349	48		48	210	48	261	48	237
Tim. Cost ($)	2764		5235		9627		7276		12479		10224	
Mach. Cost ($)	34155		29063		44909		34391		59692		49752	
Cost/Ha. ($)	230.75		219.38		227.23		173.63		225.53		187.43	

Table 8.5

Influence of Area on Machinery Number and Sizes in a Corn-Corn-Navy Bean-Sugar Beet Farm

Implement	240 Hectares		480 Hectares		800 Hectares		2000 Hectares	
	CO	CT	CO	CT	CO	CT	CO	CT
Combine (rows)[a]	6	6	8	12	2*8	2*12	4*12	3*12
Bean Puller (rows)	6	6	8	12	8	12	2*12	2*12
Beet Topper (rows)	3	3	4	4	2*4	2*3	4*4	4*4
Beet Lifter (rows)	3	3	4	4	2*4	2*3	4*4	4*4
Fertilizer Spreader (m)	12.2	12.2	12.2	12.2	12.2	12.2	18.3	15.2
Moldboard Plow (bottom)[b]	3	-	8	-	2*6	-	4*9	-
Soil Saver (m)	-	1.9	-	5.7	-	5.7	-	6.5
Disk Harrow (m)	3.5	-	3.5	-	4.4	-	9.1	-
Field Cultivator (m)	3.8	3.8	6.6	8.7	10.5	8.7	10.5	10.5
Row Planter (row)	6	6	2*8	12	3*8	2*12	4*12	4*12
Sprayer (m)	30	30	2*40	24	3*8	40	3*60	4*60
Row Cultivator (row)	6	6	2*8	12	3*8	2*12	4*12	4*12
NH3 Applicator (row)	6	6	2*8	12	3*8	2*12	4*12	4*12
Till. Tractor (hp)	142	142	172	209	172	209	209	209
Util. Tractor (hp)	48	48	75	89	89	89	89	89
Tim. Cost ($)	2209	-	7107	-	8960	-	-	-
Mach. Cost ($)	47178	39041	65190	57725	96536	83475	154948	158528
Cost/Hectare ($)	205.78	158.50	150.63	120.25	131.90	104.35	77.48	79.28

[a]Row width was maintained at 0.75 m.

[b]Bottom width was maintained at 0.41 m.

Multiples of implements and power units were selected where needed. Two and four twelve-row combines and planters were needed for the conservation tilled 800 and 2000 hectares respectively. Three eight row and four twelve row planters were needed for the conventional tilled 800 and 2000 hectares respectively. Tillage implements also changed in size and number in both systems. The mold board plow changed in size from one three bottom to four nine bottoms, while the soil saver changed from one 1.9 m to four 6.5 m as area changed from 240 to 2000 hectares.

Costs per hectare for both systems decreased as area increased. However, the advantage of conservation tillage systems over conventional tillage in cost per hectare decreased as area increased. This advantage changed from \$47.28 to \$30.38 to \$27.55 and to \$1.8 per hectare as area changed from 240 to 480, to 800 and finally to 2000 hectares. This is due to the increasing difficulty of selecting machinery complements as areas increase considerably.

8.2. Assumptions for Economic Analysis

Data collected during the first and second years in the Saginaw Bay Watershed Area revealed the following:

1. Planting population and percent germination were comparable between tillage systems.

2. Rates of crop growth under both systems were comparable throughout the season. This is in contrast to results reported in the literature which typically show a reduction in early season growth rates under conservation tillage.

3. Rates of fertilizer applied were the same for both tillage systems. Interviews with farmers, county extension agents and soil conservation agents throughout Michigan revealed that farmers practicing conservation tillage do not apply any more fertilizer on their conservation plots than on their conventionally tilled plots.

4. Rates of pesticides applied were the same for both tillage systems. Interviews with farmers and county extension agents and soil conservation agents throughout Michigan revealed that farmers practicing the chisel plow conservation tillage system use the same kinds and application rates of herbicides, insecticides, and fungicides for both tillage systems.

5. Average corn yields across the farms in 1980 were comparable on both tillage systems (Table 7.12). When isolating farms by soil type, corn grown on coarse textured conservation tilled soils out-yielded corn grown on conventional tilled ones by seven percent. On fine textured soils, conventional tillage out-yielded conservation tillage by three percent. In 1981, a year with abnormally high rainfall in July and August, average yields across the farms favored conventional tillage by four percent. Corn grown on coarse textured soils conservation tillage out-yielded corn grown on conventional tillage by five percent. On fine textured soils, conventional tillage out-yielded conservation tillage by ten percent, while there was no statistically discernible difference in bean yields between tillage systems in 1981 (Table 7.13).

Rainfall patterns during the growing season (June-September) for 1980 and 1981 in Caro, Michigan (Tuscola County) were compared with the 30 year summary. Probabilities of rates of precipitation at least as large as the amounts in each of the years are reported in Table 8.6. The year 1980 was relatively normally with July and September being slightly wetter than normal with the probability of more rainfall than observed being 40 percent; in contrast, June and August were slightly dryer than normal with the probability of more rainfall than observed being 69 percent. In 1981, June and July had normal precipitation; probabilities were 60 percent and 40 percent, respectively. But, August and September were very wet, with probabilities of 8.1 percent and 1.1 percent respectively. Corn is in an active physiological growing and seed setting stage during the period of late July to early September. Soils during this period in 1981 were constantly wet (76 mm and 127 mm of precipitation above the 30 year means during August and September, respectively). This caused the air spaces in the conventional tilled soil to be reduced, while in the conservation tilled soil they were practically eliminated. Such an environment, especially if prolonged due to poor drainage or high rainfall, is unfavorable for the root and plant development and yields suffer.

Table 8.6

Probability of Recurrence of the 1980 and 1981 Years Over a 30 Year Period[1]

	- - - - - -1980- - - - - -			- - - - - -1981- - - - - -		
Month (mm)	PPT (mm)	Mean (mm)	Prob. %	PPT (mm)	Mean (mm)	Prob. %
June	83.06	56.90	40	63.75	56.90	60
July	133.60	72.64	19	78.23	72.64	40
Aug.	52.07	57.66	69	132.84	57.66	8
Sept.	134.34	64.01	10	195.58	64.01	1.1

The probability distribution function used for this table was the gamma distribution (Winkler, 1972. Introduction to Bayesian Inference and Decision, HRH Inc., pp. 180-181).

[1]Source: Dr. Fred Nurnburger, (1982), Michigan Department of Agriculture, Michigan State University.

PPT = precipitation

Prob. = Percent chance at which certain amount of precipitation within a specific month can be expected. For example June of 1980 will have a chance of 40% or less of having 83.06 mm again.

8.2.1. Synthesis of Information from Literature and Field Research

The parameters used in the economic analysis comparing conventional tillage with the chisel plow variant conservation tillage system are presented in this section. The estimate are:

8.2.1.1. Yield. Projected yield differentials between conservation and conventional tillage for fine, medium and coarse textured soils under dry, average and wet growing season moisture regimes are presented in Table 8.7. A dry season is defined for our purposes as a season in which the probability of more rainfall than actually observed is 90 percent. A wet season is defined as a season in which the probability of more rainfall than observed is only 10 percent. For coarse textured soils, under conservation tillage corn yields are projected to be 10 percent and 5 percent higher, respectively, than under conventional tillage in years that have significantly below average and average rainfall during July and August. For significantly higher than average rainfall, only a slight increase in yield under conservation tillage is projected. For medium textured soils, yields under both systems are estimated to be the same regardless of rainfall patterns. For fine textured soils, comparable yields are projected for both systems under dry and average rainfall regimes. However for years in which significantly higher than average rainfall occurs, yields under conservation tillage are estimated to be reduced by five percent.

Sugar beet yields are assumed to be similar under both tillage systems. This assumption is consistent with the comparisons of the cooperating farmers but conservative relative to the experimental results of Robertson, et al., (1979). The number of observations from

Table 8.7

Estimated Influence of Moisture and Soil Type on Corn Yield For Conservation Tillage Compared to Conventional Tillage for Saginaw Valley, Michigan (Based on Literature Studied and Field Research)

Soil Texture	Moisture: Dry	Moisture: Average	Moisture: Wet
Coarse	10% increase in yield	5% increase in yield	Slight increase in yield
Medium	No change to slight increase in yield	No change	No change to slight increase in yield
Fine	No change	No change to slight decrease in yield	5% decrease in yield

cooperating farmers is too small to be meaningful except to note none suffered performance losses as the result of using conservation tillage. Navy bean yields under both tillage systems are assumed to be the same based on field results, but conservative relative to Robertson et al., (1979). Sugar beet and navy bean yield differentials between tillage systems were not varied according to either soil type or rainfall. This is primarily the result of a lack of information and therefore should be regarded should be regarded as very provisional.

8.2.1.2. Pesticide Costs. Projected to be the same for both tillage systems during the first four years, after which some weed species like perennial grasses or insect species may become more abundant and therefore may require more chemical application.

8.2.1.3. Fertilizer Costs. Projected to be the same for both tillage systems.

8.2.1.4. Labor Requirements. Projected to be less for conservation tillage because of fewer hours spent in the field. This is true of all conservation tillage systems. The costs used are based upon farm results in Section 8.2.

8.2.1.5. Annual Capital and Operating Costs of Machinery. Due to logistic and other factors (Muhtar et al., 1982) the annual machinery use costs presented are not based on the machinery complements cooperating farmers owned. Machinery complements for three sizes of "representative" farms,(Section 8.1), based on a whole farm concept, were calculated using field measurements of cooperating farmers, ASAE yearbook, complementary experiments, and values reported in the literature.

Annual machinery use costs are projected to be lower for conservation tillage. The costs are based on results in Section 8.2.

8.2.1.6. Corn Drying Costs. Projected to be higher for conservation tillage only on fine soils under significantly higher than average moisture conditions. The cost of removing one extra percentage point is added as a cost.

8.2.1.7 Commodity Prices. The following commodity prices were used in the analysis:

Corn Drying:	$2.5/ha for each percentage point of moisture.
Corn Grain:	$106.88/tonne
Wheat Grain:	$141.38/tonne
Navy Bean:	$463.5/tonne
Sugar Beet:	$28.0/tonne

8.2.1.8 Selected Input Prices.

Fuel:	$0.30 per liter and inflating at a "real" rate of 4 percent per year.
Labor:	$4.50 per hour
Interest (Discount Rate):	A "real" rate of 5 percent per year.

8.3. Comparative Economic Analysis

8.3.1. Methodology

The analysis focuses only on those items affecting costs and returns that were found to be influenced by tillage system. All costs and returns are computed on an annual basis; thus, the machinery costs reflect the initial investment on a new cost basis, multiplied by a capital recovery factor (Rotz, et al., 1981). The "real" interest rate of five percent was used in the calculations, and therefore, costs are stated in 1982 dollars. The capital recovery charge is a measure of the accounting literature concepts of depreciation and interest.

The impact of year to year variation in growing season rainfall is dealt with by calculating weighted average gross returns across all possible weather events as depicted in the following formula:

$$WAA = \sum_{i=1}^{3} p_i \left(\sum_{j=1}^{4} w_j g_{ij} \right)$$

Where:

WAA (in dollars) is the weighted average advantage to conservation tillage;

p_i is the probability of the i^{th} moisture event (dry, average, wet);

w_j is the proportion of area in the j^{th} crop (corn, wheat, sugar beets and navy beans); and

g_{ij} is the gain in gross returns per hectare, in dollars, from conservation tillage relative to the conventional tillage system given the i^{th} weather event and the j^{th} crop (e.g., on a coarse textured soil in a dry year corn yields are projected to be 9 percent higher under conservation tillage than under conventional tillage; thus based on $106.88/tonne corn,(Table 5.11), gross return is projected to be $59.90/hectare more than under conventional tillage.)

The cost advantage due to conservation tillage is given by:

CA = WAA + LCS - ACDC

Where:

MCS = Machinery cost saving;
LCS = Labor cost saving;
ACDC = Added corn drying cost.

No differences were projected in any of the other costs. Long term gains in productivity that result from reducing wind and water erosion are not taken into account. Also, no credit was given to the reduction in replanting of sugar beets that occurs sometimes under conventional tillage as a result of blowing soil from sand ridges. Thus, the cost advantages stated are lower bounds.

8.3.2. Projected Impact on Annual Machinery and Labor Costs.

Crops commonly used in the project area are corn, navy beans, sugar beets, wheat and oats. Cropping sequences are practiced depending on the farm's soil type. Of the more common sequences (Muhtar et al., 1982) corn-navy bean (C-NB), corn-navy bean-sugar beets (C-NB-SB), corn-corn-navy bean-sugar beets (C-C-NB-SB) and corn-navy bean-wheat-sugar beets (C-NB-WT-SB) will be discussed in the economic analysis[1].

The differences in machinery and labor cost differentials between conventional and the chisel plow variant of conservation tillage for 160, 240 and 320 hectare "representative" farms are presented below. The economic advantage, in all cases, is for conservation tillage. Cost savings for the corn-navy bean crop sequence (C-NB) are $62.88, $40.58 and $22.60/ha for the 160, 240 and 320 hectare farms, respectively. The saving in cost for the C-NB-SB farm was $50.08, $55.38 and $66.35 for 160, 240 and 320 hectares respectively. The C-C-NB-SB had a cost saving of $27.38, $53.60 and $27.90/ha for 160, 240 and 320 hectares respectively. As for the C-NB-WT-SB farm the cost savings were $16.38, $47.28 and $38.10/ha for the 160, 240 and 320 hectare farm respectively.

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[1]The cropping sequences outlined are appropriate for fine textured and, in most instances, medium textured soils but some of the sequences are less appropriate for coarse textured soils. Nevertheless, in this preliminary analysis, all of the cropping sequences have been maintained for completeness and illustrative purposes. Also there would be a different size of machinery complement for each soil type because of the impact of soil type on go-no go days and draft.

8.3.3. Projected Impact on All Costs

The economic advantage (cost reduction) that is estimated to result from the adoption of conservation tillage is discussed in this section. The calculations require two steps. First, the estimated cost advantage for each crop and for each of the soil textures by moisture condition case outlined in Table 8.7 is estimated. In the second step, the weighted average for all crops across the dry, average and wet moisture regimes is calculated for each soil type.

There are, in principle, nine soil texture by moisture condition combinations; that is, three soil textures by three moisture conditions. However, the nine combinations can be reduced to three since the impact of conservation tillage on yield is similar for the medium and fine textured soils under the dry regime, the medium and fine textured soils under the average moisture regime, and the coarse textured soil under the wet moisture regime; namely, that there is no change to a slight increase or decrease in yield. However, tables must be worked out for the coarse textured soil under dry conditions before it is estimated that yields increase 10 percent due to conservation tillage and for the fine textured soil under wet conditions where it is estimated that yields decrease 5 percent under conservation tillage. The impact of conservation tillage on cost for the four cropping sequences considered under the cases where there is no change in yield are outlined in Table 8.8. For the corn-navy bean sequence, the cost advantage is $62.88 per hectare for the 160 hectare farm and falls to $22.60 per hectare for the 320 hectare farm. Similar calculations are outlined for the remaining sequences by farm size. The case of the fine textured soil under wet

Table 8.8

Estimates of Cost Advantage for Conservation Tillage Over Conventional Tillage for Four Rotations and Three Farm Sizes for a Medium Textured Soil Under All Conditions, for Fine Textured Soils Under Dry and Average Conditions and for Coarse Textured Soil Under Wet Conditions

Rotation	160 (ha) $/ha	240 (ha) $/ha	320 (ha) $/ha
C-NB	62.88	40.58	22.60
C-NB-SB	50.08	55.38	66.35
C-C-NB-SB	27.38	53.60	27.90
C-NB-WT-SB	16.38	47.28	38.10

Table 8.9

Estimates of Cost Advantage for Conservation Tillage Over Conventional Tillage for Fine Textured Soil Under Wet Conditions

Rotation	160 (ha) $/ha	240 (ha) $/ha	320 (ha) $/ha
C-NB	58.70	36.40	19.53
C-NB-SB	46.48	51.78	59.78
C-C-NB-SB	22.15	49.43	23.50
C-NB-WT-SB	13.05	44.78	34.78

Table 8.10

Estimates of Cost Advantage for Conservation Tillage Over Conventional Tillage For Coarse Textured Soils Under Dry Conditions

Rotation	160 (ha) $/ha	240 (ha) $/ha	320 (ha) $/ha
C-NB	66.03	42.60	24.88
C-NB-SB	51.75	57.23	68.55
C-C-NB-SB	28.75	56.28	29.30
C-NB-WT-SB	16.78	48.45	39.05

conditions is outlined in Table 8.9. The cost advantage for the corn-navy bean sequence is $58.70 per hectare on the 160 hectare farm and falls to $19.53 per hectare on the 320 hectare farm. The estimated cost advantage for the coarse textured soil in dry conditions is depicted in Table 8.10. The economic advantage for the conservation tillage for the corn-navy bean sequence rotation is $66.03 for the 160 hectare farm and falls to $24.88 per hectare for the 320 hectare farm.

The estimated weighted average (across weather events) cost advantage for the adoption of conservation tillage for coarse, medium and fine textured soils is depicted in Tables 8.11, 8.12 and 8.13, respectively. Also, these tables depict the percentage yield reduction that could occur, relative to the projected conservation tillage yields, before the profitability would be equivalent between conservation and conventional tillage. Conservation tillage, in all instances, has a cost advantage over conventional tillage. The biggest gains are for the corn-navy bean crop sequence and the corn-navy bean-sugar beet sequence. Typically, gains are smaller for the corn-navy bean-wheat-sugar beet crop sequence with the corn-corn-navy bean-sugar beet sequence being intermediate. There are interactions in the sense that the economic advantage to conservation tillage is estimated to decline under the corn-navy bean sequence as size of farm increases, whereas it increases as size of farm increases under the corn-navy bean-sugar beet sequence. Also, in some instances such as the corn-corn-navy bean-sugar beet sequence cost is higher for the intermediate farm size than for the small and larger farm sizes, a result due in part to the fact that machinery complements were budgeted for existing machines on the market. Existing machines match the requirements of large or small farms better

Table 8.11

Estimated Cost Reduction That Would Result from the Adoption of Conservation Tillage on Coarse Textured Soils and the Percentage Reduction in Conservation Tillage Yields, Relative to Those Projected, That Could Occur Under Conservation Tillage Before Profitability Would be Equal Between Conservation and Conventional Tillage

	160 (ha)		240 (ha)		320 (ha)	
Rotation	$/ha	% yld.	$/ha	% yld.	$/ha	% yld.
C-NB	64.46	9.51	41.59	6.13	23.97	3.54
C-NB-SB	50.92	8.17	56.32	0.94	67.43	10.86
C-C-NB-SB	28.07	3.45	58.94	6.80	28.60	3.51
C-NB-WT-SB	16.58	2.17	47.87	6.29	38.58	5.07

C = Corn; NB = Navy Beans; SB = Sugar Beets; WT = Wheat

Table 8.12

Estimated Cost Reduction That Would Result From The Adoption of Conservation Tillage on Medium Textured Soils and the Percentage Reduction in Conservation Tillage Yields, Relative to Those Projected, That Could occur Under Conservation Tillage Before Profitability Would be Equal Between Conservation and Conventional Tillage

	160 (ha)		240 (ha)		320 (ha)	
Rotation	$/ha	% yld.	$/ha	% yld.	$/ha	% yld.
C-NB	62.88	9.07	40.58	5.85	22.60	3.48
C-NB-SB	50.08	5.17	55.38	6.28	66.35	7.52
C-C-NB-SB	27.38	3.31	53.60	6.48	27.90	3.37
C-NB-WT-SB	16.38	2.13	47.28	6.14	38.10	4.91

C = Corn; NB = Navy Beans; SB = Sugar Beets; WT = Wheat

Table 8.13

Estimated Cost Reduction That Would Result From the Adoption of Conservation Tillage on Fine Textured Soils and the Percentage Reduction in Conservation Tillage Yields, Relative to Those Projected, That Could Occur Under Conservation Tillage Before Profitability Would be Equal Between Conservation and Conventional Tillage

	160 (ha)		240 (ha)		320 (ha)	
Rotation	$/ha	% yld.	$/ha	% yld.	$/ha	% yld.
C-NB	59.96	8.80	37.66	5.57	19.79	3.12
C-NB-SB	47.77	5.02	52.52	6.12	63.19	7.45
C-C-NB-SB	24.36	3.06	50.68	6.25	24.97	3.19
C-NB-WT-SB	13.55	1.90	44.53	6.05	35.27	4.78

C = Corn; Navy Beans; SB = Sugar Beets; WT = Wheat than those of the intermediate farm for this sequence. The cost increase probably overstates the true cost disadvantage due to the intermediate size farms.

The results indicate that advantages are sensitive to both size of farm and crop sequence. This illustrates the importance of defining the system's boundaries for the economic and mechanization analysis as the whole farm, as contrasted to the individual enterprise.

The decreases in yields that could occur before conservation and conventional tillage would be equivalent in profits per hectare range from 9-10 percent for the 160 hectare corn-navy bean farms to 2-3 percent for the corn-navy bean-sugar beet sequence for 160 hectare farms. These estimates provide farmers with a perspective on how much conservation tillage yields could fall relative to conventional tillage yields before the economic advantage to conservation tillage would be wiped out.

8.3.4. Risk

Farmers view the risk associated with the adoption of conservation tillage from two perspectives. First, they analyze the risk that if they adopted conservation tillage their results would be less favorable, for whatever reason, than implied by our analysis and by the experience of their neighbors. An estimate of grower's perspective of risk can be obtained by examining the variations in yield observed in our sample, for they provide the grower with insight into the prospects for doing worse than average, and the worst that perhaps could possibly happen if he were to have adopted conservation tillage. The worst case in 1981 for the use of conservation tillage on corn was a disadvantage of 1.1 tons per hectare, a 10 percent decrease; while the highest advantage was 1.0 tons. The second type of risk is that which is the result of year to year variation, primarily due to weather, for a given farmer as was outlined in Table 6. If there are significant differences in risk which are not adequately compensated for by increased earnings, risk averse farmers will prefer the conventional system. Thus, it becomes important to understand the risk-return trade-offs between systems.

8.4 Summary

Conservation tillage costs significantly less per hectare than conventional tillage for well drained soils in the Southeast Saginaw Bay Watershed based on an analysis of results reported in the literature and on field research. There is no economic advantage to conservation tillage on fine textured poorly drained soils since corn yields are estimated to be 8% less than under conventional tillage. The economic results indicate that advantages to conservation tillage are sensitive to both size of farm and crop sequence. Thus, the systems boundaries for the economic and mechanization analysis must be the whole farm, as contrasted to the individual enterprise.

CHAPTER 9

SUMMARY AND CONCLUSIONS

9.1. Summary

The coastal drainage basin of the southeast Saginaw Bay was selected by the Agricultural Stabilization and Conservation Service (ASCS) as an agricultural water pollution control project. This project was authorized and funded under the Agricultural Conservation Program (ACP) of ASCS. The project area was slightly over 96,800 hectares, of which 87,200 were devoted to intensive agricultural uses.

The adoption of conservation tillage systems which reduce erosion rates to less than one-half of that which can be tolerated for maintaining soil productivity are being encouraged in this project area through the use of cost-share incentive payments by ACP. The technical criterion for evaluating whether "conservation tillage" has been achieved is the residual plant matter remaining on the surface of the soil after planting. Based upon the predominant soil types of the basin, the typical technical standard for conservation tillage is a requirement that 1.7 tonnes/hectare. of plant residue remain on the soil after planting, subject to modification depending upon site-specific soil types. Specific tillage implements and methods are not a condition of the conservation tillage system.

The results of the first two years (Phase I and II) of a three-year study to compare the economics of conservation versus conventional tillage in the watershed are reported. Farmers were selected who had fields which met the ASCS/SCS definition of conservation tillage and had a contiguous field of comparable soil types and slope that would be farmed using conventional, moldboard plow techniques. Seven farmers participated in the first year, while twenty-one participating during the second year.[1] Preliminary results include:

1. Conservation tillage resulted in a lower total production cost per hectare, while maintaining yield per hectare in the medium and fine textured soils under normal rainfall of the southeast Saginaw Bay watershed in Tuscola and Huron counties. The annual cost savings for conservation tillage over conventional tillage were $62.88, $50.08 and $27.38 and $16.38 per hectare for the corn-navy bean, corn-navy bean-sugar beets, and corn-corn-navy bean-sugar beets and corn-navy bean-wheat-sugar beets cropping sequences, respectively, for a 160 hectare farm representative of the area. The annual cost savings for 240 hectare farms for the same rotations were: $40.58, $55.38, $53.60 and $47.78/hectare, respectively, and for the 320 hectare farms they were: $23.63, $66.35, $27.90 and $38.10, respectively. Viewed from an alternative perspective, these results showed that as labor becomes more scarce relative to land area, the economic advantage of conservation tillage increases, because fewer field labor hours are spent relative to conventional tillage.

On fine textured soils under wet (high rainfall) conditions, expected in one year out of ten, the savings per hectare are reduced because yield for conservation tillage is depressed by around five

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[1]The small number of farmers participating during the first year was due to project initiation sufficiently late in the fall of 1979 to preclude meeting the contiguous field (side-by-side requirement) and in part, the need to shakedown project methodology.

percent. However, for the corn-navy bean rotation savings per hectare are $61.20, $38.90 and $22.03 for 160, 240 and 320 hectares respectively and for the corn-navy bean-sugar beet farm the savings were $48.98, $54.28 and $65.25/hectare for the same areas respectively. As for corn-corn-navy bean-sugar beet the savings were $25.70, $51.93 and $26.00/hectare and for the corn-navy bean-wheat-sugar beet they were $15.55, $47.28 and $37.28 per hectare for the 160, 240 and 320 hectare farms respectively.

On coarse textured soils under dry (low rainfall) conditions, the savings per hectare increased because yield is expected to increase by 10%. Thus for a 160 hectare farm savings will be $66.03, $51.75, $78.75 and $16.78/hectare for the corn-navy bean, corn-navy bean-sugar beets, corn-corn-navy beans-sugar beets and corn-navy bean, wheat-sugar beet respectively. As for the 240 and 320 hectares the savings will be $67.60, $57.23, $56.28, and $24.88, $68.55, $29.30 and $39.05/hectare for the same crop sequences respectively.

2. A sensitivity analysis was carried out to determine how much lower yields under conservation tillage could be, on medium textured soils relative to those of conventional tillage, before the economic advantage to conservation tillage broke even with conservation tillage. For the 160 hectare representative farm, yields can fall by 9.1%, 5.17% and 3.31% and 2.13% for corn-navy bean; corn-navy bean-sugar beet; corn-corn-navy bean-sugar beet; and navy bean-wheat-sugar beet sequences respectively, before the economic advantage is lost. As for the 240 and 320 hectare farms, average yields across all crops can drop by 5.85%, 6.28%, 6.48% and 6.14%, and by 3.48%,

7.52%, 3.37% and 4.91% for all four rotations respectively. The same sensitivity test was conducted for coarse and fine textured soils. The estimated field reduction that would have to result on conservation tillage relative to conventional tillage before profitability would be equal between both tillage systems on coarse textured soils is as follows: 9.51%, 8.17%, 3.45%, and 2.17% for C-NB, C-NB-SB, C-C-NB-SB, and C-NB-WT-SB respectively on 160 hectares. 6.13%, 6.94%, 6.80% and 6.29% respectively for the C-NB-SB for 240 hectares respectively. 3.54%, 10.86%, 3.51%, and 5.07% respectively for the same sequence under 320 hectares. As for fine textured soils the reduction in yield would have to be: 8.8%, 5.02%, 3.06% and 1.9%; 5.57%, 6.12%, 6.25% and 6.05%; and 3.12%, 7.45%, 3.19%, and 4.78% respectively for C-NB, C-NB-SB, C-C-NB-SB, and C-NB-WT-SB on 160, 240 and 320 hectares.

3. All farmers had corn in their conservation versus conventional tillage comparison. Average corn yields were equivalent. Also, one farmer had sugar beet comparison plots and yields were equivalent. Two farmers had navy bean comparisons, however, only one comparison could be used, as a result of reporting difficulties. Yields under conservation tillage were inferior to those under conventional tillage. However, literature and preliminary 1981 results suggest no difference when cultural practices are appropriate for conservation tillage. The economic analysis reported was conducted on the assumption that the yields of navy beans for both systems would be the same.

4. There was no measurable difference in the average moisture content of corn at harvest time between conservation and conventional tillage for the 1980 season. However, there was a statistically discernible difference in the 1981 season.

5. There was no difference in the incidence of pests between conservation and conventional tillage.

6. Corn plants under conservation tillage started more slowly, but caught up to conventional tilled plants before the end of the season.

7. Based upon a review of the literature and previous experiences of farmers in the project area prior to project inauguration, a good understanding of the cultural practices, appropriate for conservation tillage is necessary for success with conservation tillage. Proper implements specific for conservation tillage must be used. Several farmers had poor stands, or suffered reduced yields due to use of unsuitable implements in the project area. Similarly, failures were reported due to poor planter design in complimentary projects in the conservation tillage research area.

8. Some of the cooperating farmers did not expect the extent of problems (as perceived by themselves) that resulted from the amount of residue on the surface that they believed made field operations difficult and the fields made to look unclean. In general farmers like to see nicely plowed fields with no weeds or uncovered residue, so for some of them it was not easy to make a quick switch to accept

crop surface residue. However, the increased adoption rate of conservation tillage in the project area and the willingness of 18 new cooperators to participate in two of the studies show the recognition of the maintenance of yields and reduction of costs will lead to adoption if these results are maintained.

9. Risk analysis is important to the adoption of conservation tillage. Determination of the properties of conservation tillage under alternative weather regimes, particularly adverse wet harvest conditions, will be critical in determination of economic viability and farmer adoption.

9.2. Conclusions

Even though literature in general paints a dim picture for the prospects of conservation tillage, our field experience at the Saginaw Bay Watershed points to the following positive aspects:

1. Soil temperature will be cooler and its moisture higher in spring under conservation tillage. However this does not create an insurmountable problem because new cold tolerant varieties of corn are being introduced.

2. Planting in crop residue was not a problem when farmers adjusted their equipment and used proper management techniques. Farmers have even row cultivated conservation tilled dry beans grown after corn.

3. Pests in general have not been a problem specific to conservation tillage. Pesticide costs were the same throughout the project area under both tillage systems.

4. There has been no evidence that more fertilizers were needed or applied under conservation tillage systems.

5. Farmers in the project area planted their conservation tillage fields at the same date they did the conventional ones.

6. Crop residue on the surface helped provide better surface and improved traction for harvesting machinery in the fall. Crop residue also helped cut down on soil water loss during the growing season.

7. Yields obtained on coarse and medium textured soils under conservation tilled fields in the project areas were as good or better than those produced under conventional tillage, regardless of soil moisture content; yields were also as good on dry or average moist fine textured soils, but were lower when these fine soils were wet.

8. Overall production costs per unit area were always lower for conservation tillage systems when compared with conventional systems.

9. A multi-crop machinery selection model has been developed. This model is user oriented and has a large potential for use by extension agents as they advise farmers on machinery problems. It handles farms of various crops, soil types, tillage systems, levels of risk the farmer wishes to tackle and permits custom hire operations and farmer owned equipment.

9.2.1. Scope and Limitations

The results outlined are illustrative of a methodology that takes explicit account of the whole farm nature of the comparison of conservation and conventional tillage. Several refinements and generalizations will be needed before a definitive assessment can be made, but the methodology outlined appears fruitful. Generalizations must include: more explicit consideration of interactions between cropping sequence and yield and input requirement differences due to tillage system; study of the problems of the transition from existing to conservation tillage systems and finding economically desirable time paths for the adjustment; more explicit consideration of the role risk makes in farmers choices between systems; explicit account of the economic value to the farmer of reducing wind and water erosion as a result of its impact on the soil productivity; and attitudes that influence rates of adoption of tillage practices. Clearly, off-site impacts must be considered in cost-benefit analyses from society's point of view, but we have limited our scope to the conditions necessary for voluntary adoption by farm families.

The crop sequences considered in the analysis are not all appropriate for each of the soil types. In subsequent studies, the appropriate crop sequences must be more carefully matched to the soil types. Also, the size of machinery complements are influenced by soil type in as much as the ability of the machines to perform field operations is dependent upon the tractability of the soil, hence soil type. The methodology developed is capable of handling these issues, but they were deemed beyond the scope of this exploratory study. The framework outlined for dealing with weather events needs to be generalized to permit simulation of the impact on yield differences due to the tillage system of alternative weather patterns. Thus, empirical probability distributions of yield differentials and cost advantages could be deduced, which would be conservation and conventional tillage. Several refinements and generalizations will be needed before a definitive assessment can be made, but the methodology outlined appears fruitful. Generalizations must include: more explicit consideration of interactions between cropping sequence and yield and input requirement differences due to tillage system; study of the problems of the transition from existing to conservation tillage systems and finding economically desirable time paths for the adjustment; more explicit consideration of the role risk makes in farmers choices between systems; explicit account of the economic value to the farmer of reducing wind and water erosion as a result of its impact on the soil productivity; and attitudes that influence rates of adoption of tillage practices. Clearly, off-site impacts must be considered in cost-benefit analyses from society's point of view, but we have limited our scope to the conditions necessary for voluntary adoption by farm families.

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9.2.2. Future Research Needs

The author believes that further attention and field research is needed in the following areas:

1. Since very little is known about sugar beet and dry beans in conservation tillage more agronomic study is needed on these two crops.

2. There are other conservation tillage systems on the market that may prove to be beneficial and need to be tried. Examples are ridge-till and strip tillage systems.

3. More machinery management data is needed. In specific: fuel consumption, draft, speeds, slippage, etc. under various soils and tillage systems need to be collected.

4. We need to understand more clearly why yields are depressed in conservation tilled fine soils during "wet years".

5. The question of machinery rotation needs to be tackled. Is there a need for multiple machinery systems on one farm? Is there really a need to bring back the moldboard plow after few years?

6. We need to know more definitely how and when to make the transition from the present farm system to a newly proposed one. The economics of this question need to be resolved.

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APPENDICES

APPENDIX A

MACHINERY SELECTION PROGRAM
USER'S GUIDE

MACHINERY SELECTION MODEL USER GUIDE

Introduction

This machinery selection model (MACHSEL) is a tool that helps systems analysts, extension agents or farmers to improve on some farm management aspects, or select a machinery complement needed for a grain farm with a specified cropping sequence. The model can take into account equipment that is already owned by the farmer, and operations that the farmer prefers to have done by custom hire. The model also takes into consideration three different types of soil, two types of tillage systems, and various levels of risk the user is willing to take with weather.

The model proceeds to choose the most economical machinery set that can finish all the farming operations specified within the given time. Timeliness and other costs are, therefore, computed as machinery complements are being selected and the complement that proves to be the least cost complement will be chosen. The sizes that are available within the model are actual implement and tractor sizes found on the market.

How to use MACHSEL

MACHSEL can be used interactively where the user is prompted for inputs with a chance to change the data if necessary, or by the use of computer cards. In either case the user needs to have some familiarity wit the limitations of the model.

MACHSEL was designed for actual farming situations, therefore, the user needs to be careful that the crop sequence and farm operations simulated are carefully and realistically chosen. For instance, one cannot harvest more area than was planted, nor can a crop be planted in an area that has not yet been harvested. This is why the user needs to prepare the input data ahead of time to be sure it represents a real farm.

To help the user in this respect several tables of informative data have been attached. For instances, Tables 1 and 2 will help the user specify when farm operations are done in Michigan for conventional or conservation tillage systems. Table 3 will help the user change actual dates to week codes which the model will accept. Table 4 depicts the implements for certain operations, while Table 5 lists the crops that the model can use and Table 6 lists suggested cropping sequences (rotations) used in east central Michigan. Finally, Table 7 provides an example of input data for farming operations of a rotation which will help the user get a better feel for preparing the input data.

The model permits the user to enter up to seven crops for one farm if they are arranged in a rotation form. In cases where there is more than one crop to be grown on the farm, the model expects the user to indicate the area that a crop will occupy and the previous crop on that location (called Parcel). For example, assume that the user's farm is six hundred acres and it follows a corn, navy bean rotation. In this case a three hundred acre parcel is planted with corn following navy beans and another three hundred acre parcel with navy beans following corn. Assume on the other hand that the user has the same area (six hundred acres) and the same two crops, but he would like to have two hundred acre of beans and four hundred acres of corn. In this case the farm follows a corn, corn, navy bean rotation and the farm is divided into three parcels each, totaling two hundred acres of land. In this case the parcels would be two hundred acres of corn following corn, two hundred acres of corn following navy beans and two hundred acres of navy beans following corn.

The model was designed to be as foolproof as possible. That is why all data required for input will be free formated, and is in integer form. The farm operations inputed into the model must follow the chronological sequence with which they occur in real life. Take time to look at the example farm in Table 7 before you proceed.

Login Commands for Interactive Users:

```
ATTACH, LGO, USERMACHSEL, MR=1.          (Return)
CONNECT, INPUT, OUTPUT, TAPE1, TAPE2.    (Return)
PROMPT=ON.                               (Return)
% RMARGIN, 140.                          (Return)
LGO.                                     (Return)
```

Two sample inputs will be used. The first one depicts a farm where the farmer owns some of the implements. The second one depicts a case where no implements are owned. The sample outputs shown here is for the second case.

Sample Input #1

This farm is 150 acres with a corn-soybean rotation. The soil texture is heavy, and the farmer wants to own a machinery complement that can finish the farming operations at least eight years out of ten. He owns a combine, a moldboard plow and a chisel plow. He does not custom hire any work. The model prompts the user for basic details.

```
ENTER USAGE MODE,1=INTERACTIVE,2=BATCH
*1
ENTER SOIL TYPE, 1=LIGHT,2=MEDIUM,3=HEAVY
*3
ENTER CONFIDENCE LEVEL FOR WEATHER,1=30,2=70,3=50 .
*1
IF SOME EQUIPMENT IS OWNED,ENTER 1
IF NO EQUIPMENT IS OWNED,ENTER 0
*1
```

Then it will check if the farmer owns any machinery. In this example we show a farm with owned equipment. The user is prompted to enter specific data needed for each owned implement. The user can own up to ten units of each kind of implement. These ten units can be of equal or unequal sizes. Here the user owns a combine, a moldboard plow, and a disk harrow.

```
IF SOME EQUIPMENT IS OWNED,ENTER 1
IF NO EQUIPMENT IS OWNED,ENTER 0
*1
FOR EACH IMPLEMENT, INPUT THE FOLLOWING QUANTITIES;
SIZE                 (METERS OR FEET)
PURCHASE PRICE       (DOLLARS)
AGE                  (YEARS)
CURRENT TOTAL USAGE  (HOURS)
TERMINATE LISTS WITH ALL O'S
          COMBINE
*10,40000,3,200
*0,0,0,0
     BEAN PULLER
*0,0,0,0
     BEET TOPPER
*0,0,0,0
     BEET LIFTER
*0,0,0,0
      SOIL SAVER
*0,0,0,0
FERTILIZER SPREADER
*0,0,0,0
     CHISEL PLOW
*0,0,0,0
     MOLDBOARD PLOW
*10,4000,4,300
*0,0,0,0
     DISK HARROW
*16,450003,150
*0,0,0,0
       DISK PLOW
```

```
*0,0,0,0
   FIELD CULTIVATOR
*0,0,0,0
     GRAIN DRILL
*0,0,0,0
     ROW PLANTER
*0,0,0,0
     NO TILL PLANTER
*0,0,00,0
          SPRAYER
*0,0,0,0
      ROW CULTIVATOR
*0,0,0,0
      NH3 APPLICATOR
*0,0,0,0
```

When the user is done entering owned units of one kind of machine, or does not own any of the implements the user is asked about, the following must be entered:

0,0,0,0

This lets the model know that the use is ready for the next stage. When all implements are entered in, the model will prompt the user for tractor sizes. Again a maximum of ten tractors can be owned. In this case the user owns two tractors.

```
INPUT INDIVIDUAL OWNED TRACTOR QUANTITIES AS FOLLOWS:
POWER RATING        (KW OR HP)
PURCHASE PRICE      (DOLLARS)
AGE                 (YEARS)
CURRENT TOTAL USAGE (HOURS)
TERMINATE LIST WITH ALL O'S
*150,45000,3,600
*75,23000,6,450
*0,0,0,0
```

When all implements are entered the model asks for crops and operations as is shown in sample 2.

Example Input #2

In this farm the crops are corn and soybeans and the land is six hundred acres of fine textured soil. The farmer owns no equipment or tractors and does not want to custom hire any job (i.e., he wants to own all the equipment needed). He would like to have as little risk as possible.

The model will then start prompting the user:

```
ENTER USAGE MODEL,1=INTERACTIVE,2=BATCH
*1
ENTER SOIL TYPE,1=LIGHT,2-MEDIUM,3=HEAVY
*3
ENTER CONFIDENCE LEVEL FOR WEATHER,1=30,2=70,3=50
*1
ENTER CHOICE OF UNITS,1=ENGLISH,2=SI
*1
IF SOME EQUIPMENT IS OWNED,ENTER 1
IF NO EQUIPMENT IS OWNED,ENTER 0
*0
```

Since no equipment are owned the model skips the machinery list and prompts the user for area, crops and operations.

```
FOR EACH FARM PARCEL, INPUT NUMBER OF ACRES TO
BE FARMED ON THE PARCEL, ALONG WITH HARVEST
CROP INDEX AND PLANTED CROP INDEX, THEN INPUT
OPERATION SCHEDULE AS INSTRUCTED.

PARCEL NO. 1 ACREAGE,HARVEST CROP, PLANTED CROP?  *300,1,5 INPUT  OPERA-
TIONS  AS FOLLOWS : OPERATION INDEX INITIAL WEEK OF OPERATION FINAL WEEK
OF OPERATION CUSTOM OPERATION,1=CUSTOM,2=NO CUSTOM  BEGIN  WITH  HARVEST
OPERATIONS, END WITH ALL O'S *1,41,45,2

*8,41,48,2

*8,42,17,2

*12,18,22,2

*14,18,22,2

*17,25,27,2

*0,0,0,0
```

At this point the user will be asked to check the data entered for the parcel and confirm its correctness.

```
          PARCEL NUMBER A ACREAGE    300
          HARVEST CROP CORN       PLANTED CROP SOYBEANS
          OPERATION              COMPLETION   DATES
                       COMBINE    OCT.   8  TO  NOV.  5
                   CHISEL PLOW    OCT.   8  TO  NOV. 26
              FIELD CULTIVATOR    APRIL 30  TO  MAY  28
                   ROW PLANTER    APRIL 30  TO  MAY  28
                ROW CULTIVATOR    JUNE  18  TO  JULY  2
IF THIS IS CORRECT,ENTER 1
IF THIS IS INCORRECT,ENTER 0
*1
```

If the answer was (0), the user would have been asked to re-enter data for the parcel in question. But since the answer was (1), the model proceeds on:

```
PARCEL NO. 2 ACREAGE,HARVEST CROP, PLANTED CROP?
*300,5,1
INPUT OPERATIONS AS FOLLOWS :
OPERATION INDEX
INITIAL WEEK OF OPERATION
FINAL WEEK OF OPERATION
CUSTOM OPTION,1=CUSTOM,2=NO CUSTOM
BEGIN WITH HARVEST OPERATIONS, END WITH ALL 0'S
*1,40,45,2

*10,40,48,2

*12,17,20,2

*14,17,20,2

*17,25,27,2

*18,25,28,2

*0,0,0,0
```

```
               PARCEL NUMBER  2  ACREAGE     300
               HARVEST CROP  SOYBEANS    PLANTED CROP  CORN
               OPERATION                COMPLETION      DATES
                                COMBINE    OCT.    1    TO    NOV.  5
                            DISK HARROW    OCT.    1    TO    NOV. 26
                       FIELD CULTIVATOR    APRIL  23    TO    MAY  14
                            ROW PLANTER    APRIL  23    TO    MAY  14
                         ROW CULTIVATOR    JUNE   18    TO    JULY  2
                         NH3 APPLICATOR    JUNE   18    TO    JULY  9
IF THIS IS CORRECT,ENTER 1
IF THIS IS INCORRECT,ENTER 0
*1
```

The user will be prompted for another set of data. Since all the data has been supplied the user should enter zero (0) for all three variables required.

```
PARCEL NO. 3 ACREAGE,HARVEST CROP, PLANTED CROP?
*0,0,0
```

At this point the model will start giving out the farm statistics and operating parameters.

Operating Parameters

```
TOTAL FARM AREA                    600 ACRES
SOIL TEXTURE                       HEAVY
WEATHER CONFIDENCE LEVEL          80 PERCENT

FIELD OPERATION SCHEDULE

PARCEL NUMBER  1  ACREAGE    300
HARVEST CROP  CORN        PLANTED CROP  SOYBEANS
OPERATION                COMPLETION     DATES
             COMBINE      OCT.    8    TO    NOV.   5
         CHISEL PLOW      OCT.    8    TO    NOV.  26
    FIELD CULTIVATOR      APRIL  30    TO    MAY   28
         ROW PLANTER      APRIL  30    TO    MAY   28
      ROW CULTIVATOR      JUNE   18    TO    JULY   2

PARCEL NUMBER  2  ACREAGE    300
HARVEST CROP  SOYBEANS    PLANTED CROP  CORN
OPERATION                COMPLETION     DATES
             COMBINE      OCT.    1    TO    NOV.   5
         DISK HARROW      OCT.    1    TO    NOV.  26
    FIELD CULTIVATOR      APRIL  23    TO    MAY   14
         ROW PLANTER      APRIL  23    TO    MAY   14
      ROW CULTIVATOR      JUNE   18    TO    JULY   2
      NH3 APPLICATOR      JUNE   18    TO    JULY   9
```

Operating Statistics

PURCHASED IMPLEMENTS

IMPLEMENT	SIZE	NUMBER	HRS/UNIT	COST/UNIT
COMBINE	4.0 ROWS	1	157.1	6637.92
CHISEL PLOW	8.0 FEET	1	76.4	456.18
DISK HARROW	11.5 FEET	1	47.8	497.50
FIELD CULTIVATOR	12.5 FEET	1	97.8	290.25
ROW PLANTER	4.0 ROWS	1	86.8	1398.63
ROW CULTIVATOR	4.0 ROWS	1	104.8	538.83
NH3 APPLICATOR	4.0 ROWS	1	50.8	557.77

NEW TILLAGE TRACTORS	SIZE(HP)	NUMBER	HRS/TRACTOR	COST/TRACTOR
	120.0	1	261.8	11388.69

NEW UTILITY LTRACTORS	SIZE (HP)	NUMBER	HRS/TRACTOR	COST/TRACTOR
	43.8	1	202.5	4170.37

TOTAL MACHINERY COST	25936.14
TOTAL TIMELINESS COST	83.37
TOTAL OPERATING COST	26019.51

At this point the user may repeat a new run for a different farm or "logout" of the interactive system.

APPENDIX B

MACHINERY SELECTION MODEL: FORTRAN CODE AND DEFINITION OF VARIABLES

```
      PROGRAM MACHSEL(TAPE1,TAPE2,INPUT,OUTPUT)

C       **********************************************************************
C       *
C       *              PROGRAM TO SELECT A FARM MACHINERY
C       *              COMPLEMENT IN SOUTHERN MICHIGAN
C       *
C       **********************************************************************


      IMPLICIT INTEGER (A-Z)
      REAL CAPCST
      REAL TRACCST,COST,TEMPCST,HARVCST,TILLCST,PLNTCST
      LOGICAL FLAG



C         OBTAIN INPUT

      CALL READIN

C         PROCESS INPUT AND INITIALIZE FARM CONSTANTS

      CALL INIT

C         DETERMINE MINIMUM MACHINERY COMPLEMENTS CAPABLE OF
C         COMPLETING ALL TASKS IN MAXIMUM AVAILABLE TIME

      CALL MINCAP

C         INITIALIZE LOOP FLAGS

      HARVIND=1
      TILLIND=PLNTIND=0
      HARVCST=TILLCST=PLNTCST=0.
      CAPCST=0.

C          PROVIDE STARTING POINT FOR FURTHER TRACTOR SIZING
C          INCREMENTATION

  100 CONTINUE

C       DETERMINE MINIMUM NUMBER OF TRACTORS THAT CAN BE
C       ASSIGNED TO THE CURRENT MACHINERY CAPACITY COMPLEMENT

      CALL MINTRAC(MINNUM)
      TRACNUM=MINNUM

C       PREPARE TO SELECT AND COMPARE A MACHINERY COMPLEMENT
C       FOR THE GIVEN CAPACITY COMPLEMENT AND TRACTOR NUMBER

      TRACCST=0.
  200 CONTINUE

C     FIND THE NUMBER OF TRACTORS THAT CAN BE ASSOCIATED WITH
C     THE CURRENT MACHINERY SET TO PRODUCE A COMPLETE SCHEDULE
C     IF NO SET CAN BE FOUND INCREASE THE MACHINERY CAPACITIES.


      CALL IMPSEL(TRACNUM)
      CALL SCHED(TRACNUM,FLAG)

      IF (FLAG) THEN
```

```
      TRACNUM=TRACNUM+1
      IF (TRACNUM.GT.MINNUM*4) THEN
      CALL HARVINC(1.3)
      CALL TILLINC(1.7)
      CALL PLNTINC(1.3)
      TRACNUM=MINNUM
      ENDIF
C    REPEAT SEARCH FOR TRACTOR NUMBER WITH NEW CAPACITIES
      CALL SETSEL(0)
      GOTO 200
      ELSE
      CALL TOTCOST(COST,TRACNUM)
      IF (TRACCST.EQ.0. .OR. COST.LT.TRACCST) THEN
         TRACCST=COST
C            CHOOSE MOST ECONOMICAL SET BY TRACTOR NUMBER
         CALL SETSEL(1)
      ENDIF
       ENDIF
C      CAPACITY INCREMENTATION AND SELECTION FOR SLIGHTLY
C      REDUCED RUN-TIME
C      IF (CAPCST.EQ.0. .OR. TRACCST.LT.CAPCST) THEN
C      CAPCST=TRACCST
C      CALL SETSEL(2)
C      CALL HARVINC(1.3)
C      CALL TILLINC(1.3)
C      CALL PLNTINC(1.3)
C      GOTO 100
C      ELSE
C      GOTO 500
C      ENDIF
       IF (HARVIND .EQ. 1) THEN
          IF (HARVCST.EQ.0. .OR. TRACCST.LT.HARVCST) THEN
C                UPDATE MOST ECONOMICAL CAPACITY COMPLEMENT
C                AND CONTINUE HARVESTING INCREMENTATION
            HARVCST=TRACCST
            CALL SETSEL(2)
            CALL HARVINC(1.3)
          ELSE
C                BEGIN INCREMENTING TILLAGE EQUIPMENT
            HARVIND=0
            TILLIND=1
            TILLCST=HARVCST
       CALL HARVINC(1/1.3)
```

```
              CALL TILLINC(1.3)
        CALL SETSEL(0)

           ENDIF

        ELSEIF (TILLIND.EQ.1) THEN

          IF (TRACCST .LT. TILLCST) THEN

C                  UPDATE MOST ECONOMICAL CAPACITY COMPLEMENT
C                    AND CONTINUE TILLAGE INCREMENTATION

             TILLCST=TRACCST
             CALL SETSEL(2)
             CALL TILLINC(1.3)

           ELSE

C                  BEGIN INCREMENTING PLANTING EQUIPMENT

              TILLIND=0
              PLNTIND=1
              PLNTCST=TILLCST
              CALL PLNTINC(1.3)
        CALL TILLINC(1/1.3)
        CALL SETSEL(0)

           ENDIF

        ELSEIF (PLNTIND.EQ.1) THEN

          IF (TRACCST .LT. PLNTCST) THEN

C                  UPDATE MOST ECONOMICAL CAPACITY COMPLEMENT

             PLNTCST=TRACCST
            CALL SETSEL(2)
            CALL PLNTINC(1.3)

        ELSE
        GOTO 500
        ENDIF

        ENDIF

C                  RE-INITIALIZE TRACTOR INCREMENTATION FOR
C                  NEW CAPACITY COMPLEMENT SELECTION

        GOTO 100

C                  PROVIDE EXIT ACCESS

500     CONTINUE

        CALL OUTPUT(PLNTCST)
        END
        SUBROUTINE MINCAP

C         DETERMINE MINIMUM CAPACITIES NECESSARY TO COMPLETE ALL TASKS

        IMPLICIT INTEGER (A-Z)
```

```
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      REAL TIMPHRS,TEMP(20)
      DIMENSION WEEKFLG(52)
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
      DATA TEMP,WKCAPAC /20*0.,18*0./

      DO 100 I=1,20
         TIMPHRS=0.
         DO 200 J=1,52
            WEEKFLG(J)=0
200      CONTINUE

C        DETERMINE WHICH  WEEKS ARE USED FOR EACH OPERATION

         DO 300 J=1,7
      IF  (ACOPDAT(J,I,1).GT.0 .AND. ACOPDAT(J,I,4).NE.1)  THEN
      END=ACOPDAT(J,I,3)
      IF  (ACOPDAT(J,I,3).LE.ACOPDAT(J,I,2))END=52
               DO 400 K=ACOPDAT(J,I,2),END
                  WEEKFLG(K)=1
400            CONTINUE
      IF  (END.NE.ACOPDAT(J,I,3))THEN
      DO 450 K=1,ACOPDAT(J,I,3)
      WEEKFLG(K)=1
450   CONTINUE
      ENDIF
            ENDIF
300      CONTINUE

C          DETERMINE TOTAL HOURS AVAILABLE FOR EACH OPERATION

         DO 500 J=1,52
            IF  (WEEKFLG(J)  .NE.  0)  TIMPHRS=TIMPHRS+AVALHRS(J)
500      CONTINUE

C          BASED ON TOTAL ACREAGE FOR EACH OPERATION,DETERMINED IN INIT,
C          DETERMINE NECESSARY CAPACITIES TO COMPLETE TASKS

         IF  (TIMPHRS.GT.0.)  THEN
            TEMP(I)=ACRES(I)*8.25/(TIMPHRS*SPEED(I)*EFF(I))
         ENDIF
```

```
100   CONTINUE
      IF (TEMP(19).GT.TEMP(7)) TEMP(7)=TEMP(19)
      IF (TEMP(20).GT.TEMP(17)) TEMP(17)=TEMP(20)
      DO 600 I=1,18
      CAPAC(I)=TEMP(I)
600   CONTINUE
      RETURN
      END
      SUBROUTINE MINTRAC(MINNUM)

C       ROUTINE TO DETERMINE MINIMUM NUMBER OF TRACTORS THAT CAN BE
C       ASSIGNED TO CURRENT CAPACITY COMPLEMENTS

      IMPLICIT INTEGER(A-Z)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT

      MINNUM=2
      DO 100 I=2,18
      IF (CAPAC(I).GT.0. .AND. MAX(I).GT.0.) THEN
      NUM=(CAPAC(I)/MAX(I))+.99
      IF (NUM.GT.MINNUM) MINNUM=NUM
      ENDIF
100   CONTINUE
      RETURN
      END
      SUBROUTINE IMPSEL(NUMTRAC)

C       ROUTINE TO DETERMINE MACHINERY COMPLEMENT BASED ON
C       AVAILABLE CAPACITIES, NUMBER OF TRACTORS AND DESIRED
C       SIZE OF IMPLEMENTS

      IMPLICIT INTEGER (A-Z)
      LOGICAL TILLIMP,UTILIMP,LINKED
      REAL POSSTIL(9),POSSUTL(5)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
```

```
      +RMULT,TRCMULT,LENMULT
       REAL EXTRCAP(18),SIZES(7,18,2)
       DIMENSION LINKSIZ(2)
       COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
      +18),IMPSIZE(18),IMPHRS(18),
      +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
      +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
      +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
      +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
      +UEL(20),TILFUE
      +L,UTLFUEL
       COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
      +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
      +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
      +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
      +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
      +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
      +,TRCMULT,LENMULT

C     TILLAGE AND UTILITY TRACTOR SIZES AVAILABLE ON THE MARKET
C POSSIBLE TILLAGE TRACTOR SIZES
       DATA POSSTIL/65.,80.,100.,120.,130.,160.,190.,230.,280./
C POAAIBLE SIZES FOR UTILITY TRACTOR
       DATA POSSUTL/50.,65.,80.,100.,120./

C    IMPLEMENT SIZES IN FEET

       DATA ((SIZES(I,J,1),I=1,7),J=1,18)/
      +10.,10.,15.,15.,20.,20.,30.,
      +10.,10.,10.,10.,15.,15.,15.,
      +7.5,7.5,7.5,10.,10.,10.,10.,
      +7.5,7.5,7.5,10.,10.,10.,10.,
      +6.25,8.75,11.25,13.75,16.25,18.75,21.25,
      +6.,6.,10.,10.,14.,14.,14.,
      +40.,40.,50.,50.,50.,60.,60.,
      +8.,10.,11.,13.,15.,17.,19.,
      +4.,5.3,6.7,8.,9.3,10.7,12.,
      +11.5,14.5,17.,21.5,25.5,30.,36.,
      +11.5,14.5,17.,21.5,25.5,30.,36.,
      +12.5,15.5,18.5,21.5,25.5,28.5,34.5,
      +13.,13.,13.,13.,20.,20.,20.,
      +10.,10.,15.,15.,20.,20.,30.,
      +10.,10.,15.,15.,20.,20.,30.,
      +20.,20.,30.,30.,40.,40.,60.,
      +10.,10.,15.,15.,20.,20.,30.,
      +10.,10.,15.,15.,20.,20.,30./

C     IMPLEMENT SIZES IN ROWS OR BOTTOMS

       DATA ((SIZES(I,J,2),I=1,7),J=1,18)/
      +4.,4.,6.,6.,8.,8.,12.,
      +4.,4.,4.,4.,6.,6.,6.,
      +3.,3.,3.,4.,4.,4.,4.,
      +3.,3.,3.,4.,4.,4.,4.,
      +28*0.,
      +3.,4.,5.,6.,7.,8.,9.,
      +28*0.,
      +4.,4.,6.,6.,8.,8.,12.,
      +4.,4.,6.,6.,8.,8.,12.,
      +8.,8.,12.,12.,16.,16.,24.,
      +4.,4.,6.,6.,8.,8.,12.,
```

```
     +4.,4.,6.,6.,8.,8.,12./
C     INITIALIZE TRACTOR SIZES AND NUMBERS AND SIZE OF ROW EQUIPMENT
      UTILSIZ=0.
      TILLSIZ=0.
      TILLNUM=(NUMTRAC+1)/2
      UTILNUM=NUMTRAC/2
      LINKSIZ(1)=LINKSIZ(2)=1
C      CORRECT FOR OWNED EQUIPMENT
      DO 100 I=1,18
      EXTRCAP(I)=CAPAC(I)
      DO 200 J=1,10
      IF (OWNIMP(J,I).LE.0.) GOTO 201
      EXTRCAP(I)=EXTRCAP(I)-OWNIMP(J,I)
      IF ((DRAFT(I)*OWNIMP(J,I).GT.UTILSIZ).AND.UTILIMP(I))
     +    UTILSIZ=DRAFT(I)*OWNIMP(J,I)
      IF ((DRAFT(I)*OWNIMP(J,I).GT.TILLSIZ).AND.TILLIMP(I))
     +    TILLSIZ=DRAFT(I)*OWNIMP(J,I)
200   CONTINUE
201   CONTINUE
      IF (EXTRCAP(I).GT.0.) THEN
C    FOR EACH IMPLEMENT, FIND THE SMALLEST NUMBER OF
C    MACHINES SUFFICIENT TO FULFILL NEEDED CAPACITIES.
C    FOR EQUAL NUMBERS CHOOSE SMALLER SIZES.
      DO 300 J=7,1,-1
      NUM=(EXTRCAP(I)/SIZES(J,I,1))+.999
      IF (IMPNUM(I).EQ.0 .OR. NUM.LE.IMPNUM(I)) THEN
      IMPNUM(I)=NUM
      IMPSIZE(I)=SIZES(J,I,1)
      NAMSIZ(I)=SIZES(J,I,2)
      ELSEIF (LINKED(I,LINKIND) .AND. LINKSIZ(LINKIND).EQ.1) THEN
      LINKSIZ(LINKIND)=J+1
      ENDIF
300   CONTINUE
      ENDIF
100   CONTINUE
      DO 400 I=1,18
C    EQUALIZE SIZES OF ROW EQUIPMENT
      IF (LINKED(I,LINKIND) .AND. EXTRCAP(I).GT.0.) THEN
      IMPSIZE(I)=SIZES(LINKSIZ(LINKIND),I,1)
      NAMSIZ(I)=SIZES(LINKSIZ(LINKIND),I,2)
      IMPNUM(I)=(EXTRCAP(I)/IMPSIZE(I))+.99
      ENDIF
```

```
C   UPDATE TRACTOR SIZE NECESSARY TO POWER IMPLEMENTS
     IF (UTILIMP(I)) THEN
     IF (IMPNUM(I)+OWNTOT(I).GT.UTILNUM)
    +       IMPNUM(I)=UTILNUM-OWNTOT(I)
     IF (DRAFT(I)*IMPSIZE(I).GT.UTILSIZ)
    +          UTILSIZ=DRAFT(I)*IMPSIZE(I)
     ELSEIF (TILLIMP(I)) THEN
     IF (IMPNUM(I)+OWNTOT(I).GT.TILLNUM)
    +     IMPNUM(I)=TILLNUM-OWNTOT(I)
     IF (DRAFT(I)*IMPSIZE(I).GT.TILLSIZ)
    +    TILLSIZ=DRAFT(I)*IMPSIZE(I)
     ENDIF
     DO 500 J=1,9
     IF (POSSTIL(J).GE.TILLSIZ .OR. J.EQ.9) THEN
     TILLSIZ=POSSTIL(J)
     GOTO 501
     ENDIF
500  CONTINUE
501  CONTINUE
     DO 600 J=1,5
     IF (POSSUTL(J).GE.UTILSIZ .OR. J.EQ.5) THEN
     UTILSIZ=POSSUTL(J)
     GOTO 601
     ENDIF
600  CONTINUE
601  CONTINUE
     WKCAPAC(I)=(CAPAC(I)-EXTRCAP(I))+IMPNUM(I)*IMPSIZE(I)
400  CONTINUE
     RETURN
     END
     SUBROUTINE SCHED(NUMTRAC,FLAG)
C      ROUTINE TO SCHEDULE FIELD OPERATIONS BASED ON A
C      GIVEN MACHINERY COMPLEMENT,AVAILABLE HOURS AND
C      PRIORITY OF OPERATIONS
     IMPLICIT INTEGER(A-Z)
     LOGICAL HARVIMP,FLAG
     REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
    +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
    +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
    +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
    +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
    +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
    +RMULT,TRCMULT,LENMULT
     REAL ACRSDN,WKACRE,WKHRS,HRS,FDCAPAC,COMHRS
     REAL TILLHRS,UTILHRS,IMPTIM(18)
     COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
    +18),IMPSIZE(18),IMPHRS(18),
    +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
    +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
    +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
    +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
    +UEL(20),TILFUE
    +L,UTLFUEL
     COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
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     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
      LOGICAL TILLIMP,UTILIMP
      DATA COMBINE/1/

C        SCHEDULE OPERATIONS ONE WEEK AT A TIME, BEGINNING WITH FIRST
C        POSSIBLE WEEK OF HARVESTING OPERATIONS

      FLAG=.FALSE.
      TILLTIM=0.
      UTILTIM=0.
      DO 100 I=1,52
         IF (I.LE.(52-(STARTTM-1))) THEN
            WEEK=I+STARTTM-1
          ELSE
            WEEK=I-(52-(STARTTM-1))
         ENDIF

C           FOR ALL EXCEPT COMBINE OPERATIONS, HOURS DEPEND ON TRACTOR
C           AVAILABILITY AND CAN BE SUBDIVIDED IN ANY MANNER
      UTILHRS=UTILNUM*AVALHRS(WEEK)
      TILLHRS=TILLNUM*AVALHRS(WEEK)

         DO 200 J=1,20
      IMP=J
      IF (IMP.EQ.19) IMP=7
      IF (IMP.EQ.20) IMP=17

C      UPDATE ACRES AVAILABLE THIS WEEK DUE TO CROP MATURATION

            DO 150 M=1,7
               IF (HARVIMP(J) .AND. ACOPDAT(M,J,2).EQ.WEEK) THEN
                  CPACRDY(M,J)=ACOPDAT(M,J,1)
                  ACRSRDY(J)=ACRSRDY(J)+ACOPDAT(M,J,1)
               ENDIF
               IF (WAITING(M,J).NE.0. .AND. ACOPDAT(M,J,2).EQ.WEEK) THEN
                  CPACRDY(M,J)=CPACRDY(M,J)+WAITING(M,J)
                  ACRSRDY(J)=ACRSRDY(J)+WAITING(M,J)
                  WAITING(M,J)=0.
               ENDIF
150         CONTINUE

      IF (AVALHRS(WEEK).GT.0.) THEN

C     AN IMPLEMENT CAN ONLY BE SCHEDULED FOR THE AVAILABLE NO. OF HOURS

      IF (J.LT.19) IMPTIM(J)=AVALHRS(WEEK)
            ACRSDN=0.

C                 ALLOW FOR THE POSSIBILITY OF CUSTOM OPERATIONS FIRST

            CALL CUSTOM(J,WEEK)

C                 ONLY ATTEMPT TO SCHEDULE AN OPERATION IF THERE IS
C                 ACREAGE CURRENTLY AVAILABLE TO PERFORM THE OPERATION

            IF (ACRSRDY(J).LE. .1 ) ACRSRDY(J)=0.
```

```
               IF (ACRSRDY(J).GT.O.) THEN
                  WKACRE=ACRSRDY(J)

C                        SCHEDULE PRESENTLY OWNED MACHINERY FIRST

                  DO 300 K=1,10
          IF (WKACRE.LE.O. .OR. OWNIMP(K,IMP) .LE.O.) GOTO 400

                     HRS=WKACRE*8.25/(OWNIMP(K,IMP)*EFF(IMP)*SPEED(IMP))

                     IF (HRS.GT.AVALHRS(WEEK)) HRS=AVALHRS(WEEK)
          IF (HRS.GT.TILLHRS .AND. TILLIMP(IMP)) HRS=TILLHRS
          IF (HRS.GT.UTILHRS .AND. UTILIMP(IMP)) HRS=UTILHRS

                     ACRSDN=HRS*SPEED(IMP)*EFF(IMP)*OWNIMP(K,IMP)/8.25
                     CALL NEXTWK(ACRSDN,WEEK,J,OWNIMP(K,IMP),FLAG)
          IF (FLAG) RETURN
                        HRS=ACRSDN*8.25/(OWNIMP(K,IMP)*EFF(IMP)*SPEED(IMP))
                        OWNIHRS(K,IMP)=OWNIHRS(K,IMP)+HRS

C        UPDATE TRACTOR HOURS

          IF (UTILIMP(IMP)) THEN
          UTILTIM=UTILTIM+HRS
          UTILHRS=UTILHRS-HRS
          ELSEIF (TILLIMP(IMP)) THEN
          TILLTIM=TILLTIM+HRS
          TILLHRS=TILLHRS-HRS
          ENDIF

C                UPDATE NUMBER OF ACRES REMAINING AND AVAILABLE FOR NEXT
C                OPERATION

                     WKACRE=WKACRE-ACRSDN
  300                CONTINUE
  400                CONTINUE

C                      REPEAT FOR TOTAL CAPACITY OF PURCHASED MACHINERY
                     FDCAPAC=IMPSIZE(IMP)*IMPNUM(IMP)
          IF (FDCAPAC.GT.O. .AND. WKACRE.GT.O.) THEN
          HRS=WKACRE*8.25/(FDCAPAC*EFF(IMP)*SPEED(IMP))
          IF (HRS.GT.TILLHRS/IMPNUM(IMP) .AND. TILLIMP(IMP)) HRS=TILLHRS/IMP
         +NUM(IMP)
          IF (HRS.GT.UTILHRS/IMPNUM(IMP) .AND. UTILIMP(IMP)) HRS=UTILHRS/IMP
         +NUM(IMP)
          IF (HRS.GT.IMPTIM(IMP)) HRS=IMPTIM(IMP)
                     ACRSDN=FDCAPAC*EFF(IMP)*SPEED(IMP)*HRS/8.25
                     CALL NEXTWK(ACRSDN,WEEK,J,FDCAPAC,FLAG)
          IF (FLAG) RETURN
                     IF (ACRSDN.GT.O.) THEN
                        HRS=ACRSDN*8.25/(FDCAPAC*EFF(IMP)*SPEED(IMP))
                        IMPHRS(IMP)=IMPHRS(IMP)+HRS
          IMPTIM(IMP)=IMPTIM(IMP)-HRS

          IF (TILLIMP(IMP)) THEN
          TILLTIM=TILLTIM+HRS*IMPNUM(IMP)
          TILLHRS=TILLHRS-HRS*IMPNUM(IMP)
          ELSEIF (UTILIMP(IMP)) THEN
          UTILTIM=UTILTIM+HRS*IMPNUM(IMP)
          UTILHRS=UTILHRS-HRS*IMPNUM(IMP)
          ENDIF
```

```
                    ENDIF

                ENDIF
            ENDIF
            ENDIF
200           CONTINUE
100         CONTINUE
            RETURN
            END
            SUBROUTINE TOTCOST(COST,NUMTRAC)
            IMPLICIT INTEGER(A-Z)
            COMMON/ECOUT/TOWN,TREP,TFUEL,TLAB,TCOST,CRF
            REAL FIXED(18),TCOST,COST,IMPCST,NCOST,DUMFUEL,PARTHRS,BTUTCST,BTT
           +LCST,TOWN,TREP,TFUEL,TLAB,TOTAL,CRF
            REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
           +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
           +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
           +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
           +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
           +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
           +RMULT,TRCMULT,LENMULT

            COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
           +18),IMPSIZE(18),IMPHRS(18),
           +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
           +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
           +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
           +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
           +UEL(20),TILFUE
           +L,UTLFUEL
            COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
           +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
           +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
           +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
           +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRF(7),
           +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
           +,TRCMULT,LENMULT

C          SOME IMPLEMENTS HAVE BASE COSTS SEPARATE FROM SIZE-RELATED COSTS

            DATA FIXED /32562.,1440.,2500.,0.,2000./

            COST=0
            DO 100 I=1,18
               DO 200 J=1,10

C          DETERMINE OWNED IMPLEMENT COSTS

                  IF (OWNIMP(J,I).EQ.0) GOTO 150
            NCOST=OWNIMP(J,I)*SIZCST(I)+FIXED(I)
            CALL ALCOST(OWNIHRS(J,I),OWNIAGE(J,I),NCOST,J,OWNIUTM(J,I),
           +OWNICST(J,I),DUMFUEL)
            OWNIAC(J,I)=TCOST
                  COST=COST+TCOST
200            CONTINUE
150            CONTINUE
100         CONTINUE

C          DETERMINE OWNED TRACTOR COSTS

            GOODTIL=0
```

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      GOODUTL=0
      DO 600 I=1,20
         IF (OWNTRAC(I).LE.0) GOTO 650
      TRACIND=4
      IF (OWNTRAC(I).GE.TILLSIZ .AND. GOODTIL.LT.TILLNUM) THEN
      TRACIND=19
      GOODTIL=GOODTIL+1
      OWNTHRS(I)=TILLTIM/TILLNUM
      ELSEIF (OWNTRAC(I).GE.UTILSIZ.AND.GOODUTL.LT.UTILNUM) THEN
      TRACIND=20
      OWNTHRS(I)=UTILTIM/UTILNUM
      GOODUTL=GOODUTL+1
      ENDIF

      NCOST=OWNTRAC(I)*TRACINC
      CALL ALCOST(OWNTHRS(I),OWNTAGE(I),NCOST,TRACIND,OWNTUTH(I),
     +OWNTCST(I),OWNFUEL(I))
      IF (UNITIND.EQ.2) OWNFUEL(I)=OWNFUEL(I)*3.75
      OWNTAC(I)=TCOST
         COST=COST+TCOST
600   CONTINUE
650   CONTINUE

C    DETERMINE PURCHASED IMPLEMENT COSTS

      DO 700 I=1,18
      IF (IMPHRS(I).GT.0.) THEN
         IMPCST=(IMPSIZE(I)*SIZCST(I))+FIXED(I)
      CALL ALCOST(IMPHRS(I),0.,IMPCST,1,0.,0.,DUMFUEL)
         COST=COST+TCOST*IMPNUM(I)
      IMPCOST(I)=TCOST
      ENDIF
700   CONTINUE

C DETERMINE PURCHASED TRACTOR COSTS

      BTTLNUM=TILLNUM-GOODTIL

      IF (BTTLNUM.GT.0 .AND. TILLTIM.GT.0.) THEN
      BTTLHRS=TILLTIM/TILLNUM
      BTTLCST=TILLSIZ*TRACINC
      CALL ALCOST(BTTLHRS,0.,BTTLCST,19,0.,0.,TILFUEL)
      IF (UNITIND.EQ.2) TILFUEL=TILFUEL*3.75
      TILLCST=TCOST
      COST=COST+TILLCST*BTTLNUM
      ENDIF

      BTUTNUM=UTILNUM-GOODUTL

      IF (BTUTNUM.GT.0 .AND. UTILTIM.GT.0.) THEN
      BTUTHRS=UTILTIM/UTILNUM
      BTUTCST=UTILSIZ*TRACINC
      CALL ALCOST(BTUTHRS,0.,BTUTCST,20,0.,0.,UTLFUEL)
      IF (UNITIND.EQ.2) UTLFUEL=UTLFUEL*3.75
      UTILCST=TCOST
      COST=COST+UTILCST*BTUTNUM
      ENDIF

C     DETERMINE TOTAL TIMELINESS COST

      TTIMCST=0.
```

```
      DO 800 I=1,18
         DO 900 J=1,52
            DO 1000 K=1,7
      IF(OPACRWK(K,I,J).GT.O.)THEN
               TTIMCST=TTIMCST+OPACRWK(K,I,J)*TIMCST(K,I,J)
      PRINT *,'WK,IMP,AC,TCOST ',J,I,OPACRWK(K,I,J),TIMCST(K,I,J)
      PRINT*,'IMPSIZE,UITLSIZE,TILLSIZE',IMPSIZE(I),TILLSIZ,UTILSIZ
      PRINT*,'COST  ',COST
      ENDIF
1000        CONTINUE
900      CONTINUE
800   CONTINUE
      PRINT*,TTIMCST
      PRINT*,CRF
      TTIMCST=TTIMCST*10*CRF
      PRINT*,TTIMCST
      COST=COST+TTIMCST
      COST=COST+TCUSCST
      RETURN
      END
      SUBROUTINE NEXTWK(ACRSDN,WEEK,OP,FDCAPAC,FLAG)
      IMPLICIT INTEGER (A-Z)
      LOGICAL FLAG
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      REAL ACRSDN,CPIMACR,ACREIMP,HRS,FDCAPAC
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT

C     INITIALIZE ACRES COMPLETED BUT NOT YET MATURE FOR NEXT OPERATION

      DATA WAITING /140*0./

      IMP=OP
      IF (OP.EQ.19) IMP=7
      IF (OP.EQ.20) IMP=17
      FLAG=.FALSE.
      ACREIMP=ACRSDN

      DO 100 I=1,7

         CPIMACR=CPACRDY(I,OP)
         IF (CPIMACR.GT.O .AND. ACREIMP.GT.O) THEN
```

```
        IF (CPIMACR.GT.ACREIMP) CPIMACR=ACREIMP

C     UPDATE NEXT OPERATION INFORMATION IN THE APPROPRIATE MANNER

        IF (NEXTOP(I,OP).NE.0) THEN
      NEXTIMP=NEXTOP(I,OP)
          IF ((WEEK.GE.STARTTM .AND. WEEK.GE.ACOPDAT(I,NEXTIMP,2)
     +     .AND. ACOPDAT(I,NEXTIMP,2).GE.STARTTM) .OR. (WEEK.LT.
     +     STARTTM.AND. ACOPDAT(I,NEXTIMP,2).LE.WEEK)) THEN
            CPACRDY(I,NEXTIMP)=CPACRDY(I,NEXTIMP)+CPIMACR
            ACRSRDY(NEXTIMP)=ACRSRDY(NEXTIMP)+CPIMACR

          ELSE

            WAITING(I,NEXTIMP)=WAITING(I,NEXTIMP)+CPIMACR
          ENDIF
        ENDIF

        ACREIMP=ACREIMP-CPIMACR
        CPACRDY(I,OP)=CPACRDY(I,OP)-CPIMACR
        ACRSRDY(OP)=ACRSRDY(OP)-CPIMACR

C    UPDATE ACREAGE AND HOURS MATRICES

      IF (CPIMACR.GT. .1) THEN

        OPACRWK(I,IMP,WEEK)=OPACRWK(I,IMP,WEEK)+CPIMACR

      IF (TIMCST(I,IMP,WEEK).GT.1.E+50) THEN
      FLAG=.TRUE.
      ENDIF

      IF (FDCAPAC.GT.0.) THEN
      HRS=CPIMACR*8.25/(EFF(IMP)*SPEED(IMP)*FDCAPAC)
      OPHRSWK(I,IMP,WEEK)=OPHRSWK(I,IMP,WEEK)+HRS*IMPNUM(IMP)
      ENDIF

      ENDIF
        ENDIF
100   CONTINUE
      ACRSDN=ACRSDN-ACREIMP
      RETURN
      END
      SUBROUTINE CUSTOM(IMP,WEEK)
      IMPLICIT INTEGER (A-Z)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      REAL ACRSDN,CUSDOL
      LOGICAL FLAG
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
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      +UEL(20),TILFUE
      +L,UTLFUEL
       COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
      +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
      +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
      +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
      +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
      +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
      +,TRCMULT,LENMULT

       DO 100 I=1,7

          IF (CPACRDY(I,IMP).LE.0) GOTO 200

          IF (ACOPDAT(I,IMP,4).EQ.1) THEN

             ACRSDN=ACOPDAT(I,IMP,1)
             CALL NEXTWK(ACRSDN,WEEK,IMP,0.,FLAG)
       IF (FLAG) RETURN
       CUSDOL=ACRSDN*CUSTPRC(IMP)*10*(.12*(1.+.12)**10)/((1.+.12)**10-1.)
       CUSTCST(IMP)=CUSTCST(IMP)+CUSDOL
       TCUSCST=TCUSCST+CUSDOL

          ENDIF

200       CONTINUE
100    CONTINUE
       RETURN
       END

       SUBROUTINE READIN
       IMPLICIT INTEGER (A-Z)
       LOGICAL OWNED,OWNEDT,HARVIMP
       REAL AREA
       REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
      +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
      +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
      +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
      +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
      +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
      +RMULT,TRCMULT,LENMULT
       DIMENSION CROPNAM(7),AREANAM(2),CUSTNAM(2),OPNAM(2,20)
       COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
      +18),IMPSIZE(18),IMPHRS(18),
      +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
      +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
      +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
      +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
      +UEL(20),TILFUE
      +L,UTLFUEL
       COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
      +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
      +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
      +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
      +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
      +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
      +,TRCMULT,LENMULT
       COMMON /CROPNAM/ CROPNAM
       COMMON /IMPNAM/OPNAM
       COMMON /DATNAM/ DATNAM(52)
       DATA AREANAM/10H     ACRES,10H  HECTARES/
```

```
      DATA CUSTNAM /10H    CUSTOM,10H NO CUSTOM /
      DATA CROPNAM/4HCORN,4HOATS,5HWHEAT,3HRYE,8HSOYBEANS,
     +10HNAVY BEANS,10HSUGAR BEET/

C   OWNIMP        OWNED IMPLEMENT SIZE
C   OWNTRAC        OWNED TRACTOR SIZE
C   OWNIAGE        OWNED IMPLEMENT AGE
C   OWNTAGE        OWNED TRACTOR AGE
C   OWNTCST        OWNED TRACTOR COST

      DATA OWNIMP,OWNTRAC,OWNIAGE,OWNTAGE,OWNTCST/420*0./
      DATA OWNED,OWNEDT/2*.FALSE./
      DATA TOTACR,CROPACR /8*0/

C    OWNTOT      TOTAL NUMBER OWNED OF EACH IMPLEMENT

      DATA OWNTOT/18*0/

      PRINT *,'ENTER SOIL TYPE,1=LIGHT,2=MEDIUM,3=HEAVY '
      READ *,SOIL
      PRINT *,'ENTER CONFIDENCE LEVEL FOR WEATHER,1=80,2=70,3=50'
      READ *,CONLEV
      PRINT *,'ENTER CHOICE OF UNITS,1=ENGLISH,2=SI '
      READ *,UNITIND

C     SET UP CORRECTION FACTORS FOR METRIC CONVERSIONS

      IF (UNITIND.EQ.2) THEN

      ACRMULT=2.471
      TRCMULT=1.333
      LENMULT=3.3

      ELSE

      UNITIND=1
      ACRMULT=TRCMULT=LENMULT=1.
      ENDIF

      PRINT *,'IF SOME EQUIPMENT IS OWNED,ENTER 1'
      PRINT *,'IF NO EQUIPMENT IS OWNED,ENTER   0'
      READ *,OWNIND

      IF (OWNIND.EQ.1) THEN

      PRINT *,'FOR EACH IMPLEMENT, INPUT THE FOLLOWING QUANTITIES: '
      PRINT *,'SIZE                   (METERS OR FEET) '
      PRINT *,'PURCHASE PRICE         (DOLLARS) '
      PRINT *,'AGE                    (YEARS) '
      PRINT *,'CURRENT TOTAL USAGE    (HOURS) '
      PRINT *,'TERMINATE LISTS WITH ALL 0''S '

      DO 300 I=1,18
      WRITE (2,2000) OPNAM(1,I),OPNAM(2,I)

      DO 400 J=1,10
      READ *,OWNIMP(J,I),OWNICST(J,I),OWNIAGE(J,I),OWNIUTM(J,I)
      OWNIMP(J,I)=OWNIMP(J,I)*LENMULT
      IF (OWNIMP(J,I).EQ.0) GOTO 299
      OWNED=.TRUE.
      OWNTOT(I)=OWNTOT(I)+1
```

```
400   CONTINUE
299   CONTINUE
300   CONTINUE

      PRINT *,'INPUT INDIVIDUAL OWNED TRACTOR QUANTITIES AS FOLLOWS: '
      PRINT *,'POWER RATING           (KW OR HP)  '
      PRINT *,'PURCHASE PRICE         (DOLLARS)   '
      PRINT *,'AGE                   .(YEARS)     '
      PRINT *,'CURRENT TOTAL USAGE    (HOURS)    '
      PRINT *,'TERMINATE LIST WITH ALL O''S  '

      DO 500 I=1,18
      READ *,OWNTRAC(I),OWNTCST(I),OWNTAGE(I),OWNTUTM(I)
      OWNTRAC(I)=OWNTRAC(I)*TRCMULT
       IF (OWNTRAC(I) .EQ. 0) GOTO 999
       OWNEDT=.TRUE.
500    CONTINUE
       ENDIF

999    CONTINUE
       STARTTM=52
       PRINT *,'FOR EACH FARM PARCEL, INPUT AREA (ACRES OR HECTARES) TO '
       PRINT *,'BE FARMED ON THE PARCEL, ALONG WITH HARVEST '
       PRINT *,'CROP INDEX AND PLANTED CROP INDEX. THEN INPUT '
       PRINT *,'OPERATION SCHEDULE AS INSTRUCTED. '

       DO 600 PARCEL=1,7

       LASTOP=0
601    CONTINUE
       WRITE (2,2010) PARCEL
       READ *,ACREAGE,HARVCRP(PARCEL),PLNTCRP(PARCEL)
       IF ((ACREAGE.NE.O. .AND. (HARVCRP(PARCEL).LT.1 .OR.
      +HARVCRP(PARCEL).GT.7 .OR. PLNTCRP(PARCEL).LT.1 .OR.
      +PLNTCRP(PARCEL).GT.7)).OR.(ACREAGE.EQ.O. .AND. PARCEL.EQ.1)) THEN
       PRINT *,'INVALID INPUT, PLEASE TRY AGAIN'
       GOTO 601
       ENDIF
       ACREAGE=ACREAGE*ACRMULT
       IF (ACREAGE.EQ.O) GOTO 900
       CROPACR(PARCEL)=ACREAGE

       PRINT *,'INPUT OPERATIONS AS FOLLOWS :'
       PRINT *,'OPERATION INDEX'
       PRINT *,'INITIAL WEEK OF OPERATION'
       PRINT *,'FINAL WEEK OF OPERATION '
       PRINT *,'CUSTOM OPTION,1=CUSTOM,2=NO CUSTOM'
       PRINT *,'BEGIN WITH HARVEST OPERATIONS, END WITH ALL O''S'
602    CONTINUE
       READ *,OP,BEGIN,END,CUSTOM
       PRINT *,' '
       IF (OP.EQ.O) GOTO 699

       IF (OP.EQ.LASTOP) THEN

       ACOPDAT(PARCEL,OP,1)=ACOPDAT(PARCEL,OP,1)+ACREAGE

       ELSE

       ACOPDAT(PARCEL,OP,1)=ACREAGE
       ACOPDAT(PARCEL,OP,2)=BEGIN
```

```
      IF (HARVIMP(OP).AND.BEGIN.LT.STARTTM) STARTTM=BEGIN
      ACOPDAT(PARCEL,OP,3)=END
      IF (CUSTOM.NE.1) CUSTOM=2
      ACOPDAT(PARCEL,OP,4)=CUSTOM
      IF (LASTOP.NE.0) NEXTOP(PARCEL,LASTOP)=OP
      LASTOP=OP
      ENDIF
      GOTO 602
699   CONTINUE
      AREA=CROPACR(PARCEL)/ACRMULT
      WRITE (2,1080) PARCEL,AREA,AREANAM(UNITIND)
      WRITE (2,1085) CROPNAM(HARVCRP(PARCEL)),CROPNAM(PLNTCRP(PARCEL))
      WRITE (2,1090)
      IF (ACOPDAT(PARCEL,1,1).GT.0) THEN
      START=1
      ELSEIF (ACOPDAT(PARCEL,2,1).GT.0) THEN
      START=2
      ELSEIF (ACOPDAT(PARCEL,3,1) .GT. 0) THEN
      START=3
      ENDIF
      NEXT=START
1     CONTINUE
      WRITE (2,1100) OPNAM(1,NEXT),OPNAM(2,NEXT),DATNAM(ACOPDAT(PARCEL,N
     +EXT,2
     +)),
     +DATNAM(ACOPDAT(PARCEL,NEXT,3)),CUSTNAM(ACOPDAT(PARCEL,NEXT,4))
      NEXT=NEXTOP(PARCEL,NEXT)
      IF (NEXT.NE.0) GOTO 1
      PRINT *,'IF THIS IS CORRECT,ENTER 1 '
      PRINT *,'IF THIS IS INCORRECT,ENTER 0'
      READ *,VALID
      IF (VALID.NE.1) THEN
      DO 800 I=1,20
      ACOPDAT(PARCEL,I,1)=ACOPDAT(PARCEL,I,2)=ACOPDAT(PARCEL,I,3)=
     +ACOPDAT(PARCEL,I,4)=NEXTOP(PARCEL,I)=0
800   CONTINUE
      GOTO 601
      ELSE
      TOTACR=TOTACR+CROPACR(PARCEL)
      ENDIF
600   CONTINUE
1080  FORMAT (16X,'PARCEL NUMBER  ',I1,'  AREA  ',F5.0,A10)
1085  FORMAT (16X,'HARVEST CROP  ',A10,'  PLANTED CROP  ',A10)
1090  FORMAT (16X,'OPERATION',15X,'COMPLETION     DATES')
1100  FORMAT (6X,2A10,4X,A10,'  TO  ',2A10)
2000  FORMAT (' ',2A10)
```

```
2010  FORMAT ('OPARCEL NO. ',I1,' AREA,HARVEST CROP, ',
     +'PLANTED CROP?')
900   CONTINUE
      RETURN
      END
      SUBROUTINE OUTPUT(COST)
      IMPLICIT INTEGER (A-Z)
      LOGICAL OWNED,OWNEDT
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      REAL COST,FUELL,TMCHCST,ACRCST
      DIMENSION OPNAM(2,20),AREANAM(2),DATNAM(52),SOILNAM(2,3),PWRNAM(2)
     +,S
     +IZNAM(18,2)
     +,CONNAM(3),FUELNAM(2)
      COMMON /FINAL/DUMMY(13966),IMPNUM(18),UTILNUM,BTUTNUM,
     +TILLNUM,BTTLNUM,WKCAPAC(18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
      COMMON /CROPNAM/CROPNAM(7)
      COMMON /IMPNAM/ OPNAM
      COMMON /DATNAM/ DATNAM

      DATA AREANAM/7H  ACRES,10H  HECTARES/
      DATA FUELNAM/10H   GALLONS,10H    LITERS/
      DATA OPNAM /
     +10H          ,10H   COMBINE,10H         B,10HEAN PULLER,
     +10H         B,10HEET TOPPER,10H         B,10HEET LIFTER,
     +10H          ,10HSOIL SAVER,10H          ,10H  V RIPPER,
     +10H FERTILIZE,10HR SPREADER,10H         C,10HHISEL PLOW,
     +10H      MOLD,10HBOARD PLOW,10H         D,10HISK HARROW,
     +10H          ,10H DISK PLOW,10H    FIELD ,10HCULTIVATOR,
     +10H         G,10HRAIN DRILL,10H         R,10HOW PLANTER,
     +10H     NO TI,10HLL PLANTER,10H          ,10H   SPRAYER,
     +10H      ROW ,10HCULTIVATOR,10H      NH3 ,10HAPPLICATOR,
     +10H FERTILIZE,10HR SPREADER,10H      ROW ,10HCULTIVATOR/
      DATA SOILNAM/10HCOARSE (SA,4HNDY),10H MEDIUM (L,4HOAM),
     +            10H   FINE (C,4HLAY)/
      DATA CONNAM/10H80 PERCENT,10H70 PERCENT,10H50 PERCENT/
      DATA DATNAM/10H JAN.    1 ,10H JAN.    8 ,10H JAN.   15 ,
     +10H JAN.   22 ,10H JAN.   29 ,10H FEB.    5 ,10H FEB.   12 ,
     +10H FEB.   19 ,10H FEB.   26 ,10H MARCH   5 ,10H MARCH  12 ,
     +10H MARCH  19 ,10H MARCH  26 ,10H APRIL   2 ,10H APRIL   9 ,
     +10H APRIL  16 ,10H APRIL  23 ,10H APRIL  30 ,10H MAY     7 ,
     +10H MAY    14 ,10H MAY    21 ,10H MAY    28 ,10H JUNE    4 ,
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     +10H JUNE   11 ,10H JUNE  18 ,10H JUNE  25 ,10H JULY   2 ,
     +10H JULY    9 ,10H JULY  16 ,10H JULY  23 ,10H JULY  30 ,
     +10H AUG.    6 ,10H AUG.  13 ,10H AUG   20 ,10H AUG.  27 ,
     +10H SEPT.   3 ,10H SEPT. 10 ,10H SEPT. 17 ,10H SEPT. 24 ,
     +10H OCT.    1 ,10H OCT.   8 ,10H OCT.  15 ,10H OCT.  22 ,
     +10H OCT.   29 ,10H NOV.   5 ,10H NOV.  12 ,10H NOV.  19 ,
     +10H NOV.   26 ,10H DEC.   3 ,10H DEC.  10 ,10H DEC.  17 ,
     +10H DEC.   24 /
      DATA PWRNAM/2HHP,2HKW/
      DATA SIZNAM/7H   ROWS,7H   ROWS,7H   ROWS,7H   ROWS,7H   FEET,7H
     + FEET,7H   FEET
     +,
     +7H   FEET,7HBOTTOMS,7H   FEET,7H   FEET,7H   FEET,7H   FEET,7H   R
     +OWS,7H   ROWS,
     +7H   ROWS,7H   ROWS,7H   ROWS,
     +7H   ROWS,7H   ROWS,7H   ROWS,7H   ROWS,7H METERS,7H METERS,7H MET
     +ERS,
     +7H METERS,7HBOTTOMS,7H METERS,7H METERS,7H METERS,7H METERS,
     +7H   ROWS,7H   ROWS,7H   ROWS,7H   ROWS,7H   ROWS/

C     PRINT HEADER

      WRITE (1,1000)
      WRITE (1,2000)
      WRITE (1,2000)
      WRITE (1,1010)
      WRITE (1,1020)
      WRITE (1,2000)
      TOTACR=TOTACR/ACRMULT
      WRITE (1,1030) TOTACR,AREANAM(UNITIND)
      WRITE (1,1040) SOILNAM(1,SOIL),SOILNAM(2,SOIL)
      WRITE (1,1050) CONNAM(CONLEV)
      WRITE (1,2000)
      WRITE (1,1070)

C     PRINT SCHEDULES FOR EACH PARCEL

      DO 100 I=1,7

      IF (CROPACR(I).GT.0) THEN

      WRITE (1,2000)
      CROPACR(I)=CROPACR(I)/ACRMULT
      WRITE (1,1080) I,CROPACR(I),AREANAM(UNITIND)
      WRITE (1,1085) CROPNAM(HARVCRP(I)),CROPNAM(PLNTCRP(I))
      WRITE (1,1090)
      WRITE (1,2000)

      IF (ACOPDAT(I,1,1).GT.0) THEN
      START=1
      ELSEIF (ACOPDAT(I,2,1).GT.0) THEN
      START=2
      ELSEIF (ACOPDAT(I,3,1) .GT. 0) THEN
      START=3
      ENDIF

      NEXT=START
1     CONTINUE
      WRITE (1,1100) OPNAM(1,NEXT),OPNAM(2,NEXT),DATNAM(ACOPDAT(I,NEXT,2
     +)),
     +DATNAM(ACOPDAT(I,NEXT,3))
```

```
      NEXT=NEXTOP(I,NEXT)
      IF (NEXT.NE.0) GOTO 1
      ENDIF

100   CONTINUE

C PRINT EQUIPMENT STATISTICS

      WRITE (1,2000)
      WRITE (1,1110)
      WRITE (1,1120)
      WRITE (1,2000)
      IF (OWNED) THEN
      WRITE (1,1130)
      WRITE (1,2000)
      WRITE (1,1140)
      WRITE (1,2000)
      DO 200 I=1,18
      DO 300 J=1,10
      IF (OWNIMP(J,I).LE.O.) GOTO 299
      OWNIMP(J,I)=OWNIMP(J,I)/LENMULT
      WRITE (1,1150) OPNAM(1,I),OPNAM(2,I),OWNIMP(J,I),OWNIHRS(J,I),OWNI
     +AC(J,I)
300   CONTINUE
299   CONTINUE
200   CONTINUE
      ENDIF

      IF (OWNEDT) THEN
      WRITE (1,2000)
      WRITE (1,1160)
      DO 400 I=1,18
      IF (OWNTRAC(I).LE.O.) GOTO 499
      OWNTRAC(I)=OWNTRAC(I)/TRCMULT
      WRITE (1,1170) OWNTRAC(I),PWRNAM(UNITIND),OWNTHRS(I),OWNTAC(I),OWN
     +FUEL(I),FUELNAM(UNITIND)
400   CONTINUE
      ENDIF

499   CONTINUE
      WRITE (1,2000)
      WRITE (1,1180)
      WRITE (1,1190)
      WRITE (1,2000)

      DO 500 I=1,18

      IF (IMPNUM(I).GT.0) THEN
      IF (NAMSIZ(I).EQ.O.) THEN
      IMPSIZE(I)=IMPSIZE(I)/LENMULT
      WRITE (1,1200) OPNAM(1,I),OPNAM(2,I),IMPSIZE(I),SIZNAM(I,UNITIND),
     +IMPNUM(I
     +),IMPHRS(I
     +),
     +IMPCOST(I)

      ELSE

      WRITE (1,1200) OPNAM(1,I),OPNAM(2,I),NAMSIZ(I),SIZNAM(I,UNITIND),
     +IMPNUM(I),IMPHRS(I),IMPCOST(I)
      ENDIF
```

```
      ENDIF

500   CONTINUE

      IF (BTTLHRS.GT.0.) THEN

      WRITE (1,2000)
      WRITE (1,1210)
      TILLSIZ=TILLSIZ/TRCMULT
      WRITE (1,1220) TILLSIZ,PWRNAM(UNITIND),BTTLNUM,BTTLHRS,TILLCST,TIL
     +FUEL,FUELNAM(UNITIND)
      WRITE (1,2000)

      ENDIF

      IF (BTUTHRS.GT.0.) THEN

      WRITE (1,2000)
      WRITE (1,1215)
      UTILSIZ=UTILSIZ/TRCMULT
      WRITE (1,1220) UTILSIZ,PWRNAM(UNITIND),BTUTNUM,BTUTHRS,UTILCST,UTL
     +FUEL,FUELNAM(UNITIND)
      WRITE (1,2000)

      ENDIF

      WRITE (1,2000)

      IF (TCUSCST.GT.0.) THEN

      WRITE (1,1240)
      WRITE (1,1250)

      DO 600 I=1,18

      IF (CUSTCST(I).GT.0.) THEN

      WRITE (1,1260) OPNAM(1,I),OPNAM(2,I),CUSTCST(I)

      ENDIF

600   CONTINUE
      WRITE (1,2000)
      WRITE (1,1270) TCUSCST

      ENDIF

      TMCHCST=COST-(TCUSCST+TTIMCST)
      WRITE (1,1230) TMCHCST
      WRITE (1,1280) TTIMCST
      ACRCST=COST/TOTACR
      WRITE (1,1290) AREANAM(UNITIND),ACRCST
      WRITE (1,1291) COST

      DO 700 I=1,7

      IF (CROPACR(I).GT.0) THEN

      WRITE (1,1300) I,CROPNAM(HARVCRP(I)),CROPNAM(PLNTCRP(I))
      WRITE (1,2000)

```

```
C         PRINT HEADER OF IMPLEMENTS

           WRITE (1,1310)
           WRITE (1,1320)
           WRITE (1,1330)
           WRITE (1,1340)
           WRITE (1,1350)
           WRITE (1,1360)
           WRITE (1,1370)
           WRITE (1,1380)
           WRITE (1,1390)
           WRITE (1,1400)
           WRITE (1,1410)
           WRITE (1,1420)
           WRITE (1,1430)
           WRITE (1,1440)
           WRITE (1,1450)
           WRITE (1,1460)
           WRITE (1,1470)
           WRITE (1,1480)
           WRITE (1,1490)

           DO 800 K=1,52
           DO 801 J=1,18
           OPACRWK(I,J,K)=OPACRWK(I,J,K)/ACRMULT
801        CONTINUE
           WRITE (1,1500) DATNAM(K),(OPACRWK(I,J,K),J=1,18),K
800        CONTINUE
           WRITE (1,1510) I,CROPNAM(HARVCRP(I)),CROPNAM(PLNTCRP(I))
           WRITE (1,2000)
           WRITE (1,1310)
           WRITE (1,1320)
           WRITE (1,1330)
           WRITE (1,1340)
           WRITE (1,1350)
           WRITE (1,1360)
           WRITE (1,1370)
           WRITE (1,1380)
           WRITE (1,1390)
           WRITE (1,1400)
           WRITE (1,1410)
           WRITE (1,1420)
           WRITE (1,1430)
           WRITE (1,1440)
           WRITE (1,1450)
           WRITE (1,1460)
           WRITE (1,1470)
           WRITE (1,1480)
           WRITE (1,1490)
           DO 900 K=1,52
           WRITE (1,1500) DATNAM(K),(OPHRSWK(I,J,K),J=1,18),K
900        CONTINUE
           ENDIF
700        CONTINUE
1000       FORMAT ('T',10X,'F A R M   M A C H I N E R Y   S E L E C T I '
          +,'O N   M O D E L   F O R   E A S T E R N   M I C H I G A N')
1010       FORMAT (24X,'OPERATING  PARAMETERS')
1020       FORMAT (24X,'---------  ----------')
1030       FORMAT (16X,'TOTAL  FARM  AREA',15X,F5.0,2X,A10)
1040       FORMAT (16X,'SOIL   TEXTURE',18X,2A10)
1050       FORMAT (16X,'WEATHER  CONFIDENCE  LEVEL',10X,A10)
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```
14130=1070  FORMAT (16X,'FIELD  OPERATION  SCHEDULE')
14140=1080  FORMAT (16X,'PARCEL NUMBER  ',I1,'  AREA  ',F5.0,A10)
14150=1085  FORMAT ('0',15X,'HARVEST CROP  ',A10,'  PLANTED CROP  ',A10)
14160=1090  FORMAT ('0',15X,'OPERATION',15X,'COMPLETION     DATES')
14170=1100  FORMAT (16X,2A10,4X,A10,'   TO   ',A10)
14180=1110  FORMAT ('T',23X,'OPERATING  STATISTICS')
14190=1120  FORMAT (24X,'---------  ----------')
14200=1130  FORMAT (16X,'OWNED',6X,'IMPLEMENTS')
14210=1140  FORMAT (16X,'IMPLEMENT',15X,'SIZE    ',12X,
14220=     +'USAGE (HRS)    OPERATING  COST')
14230=1150  FORMAT (16X,2A10,6X,F4.1,17X,F5.1,10X,F8.2)
14240=1160  FORMAT (16X,'OWNED',8X,'TRACTORS          SIZE',20X,
14250=     +'USAGE (HRS)    OPERATING  COST          FUEL  USAGE')
14260=1170  FORMAT (41X,F5.1,2X,A10,16X,F6.1,10X,F8.2,4X,F8.2,A10)
14270=1180  FORMAT (16X,'PURCHASED  IMPLEMENTS')
14280=1190  FORMAT (16X,'IMPLEMENT',26X,'SIZE',6X,'NUMBER     HRS/U',
14290=     +'NIT           COST/UNIT')
14300=1200  FORMAT (16X,2A10,6X,F4.1,2X,A10,7X,I2,7X,F6.1,10X,F8.2)
14310=1210  FORMAT (16X,'NEW TILLAGE TRACTORS          POWER           NUMBER
14320=     +',
14330=     +'HRS/TRACTOR       COST/TRACTOR    FUEL USAGE/TRACTOR')
14340=1215  FORMAT (16X,'NEW UTILITY TRACTORS          POWER           NUMBER
14350=     +',
14360=     +'HRS/TRACTOR       COST/TRACTOR    FUEL USAGE/TRACTOR')
14370=1220  FORMAT (41X,F5.1,2X,A10,7X,I2,7X,F6.1,9X,F9.2,4X,F8.2,A10)
14380=1230  FORMAT (16X,'TOTAL   MACHINERY  COST',17X,F10.2)
14390=1240  FORMAT (16X,'CUSTOM  COST  BY  IMPLEMENT')
14400=1250  FORMAT (16X,'IMPLEMENT',69X,'COST')
14410=1260  FORMAT (16X,2A10,53X,F9.2)
14420=1270  FORMAT (16X,'TOTAL  CUSTOM  COST',22X,F9.2)
14430=1280  FORMAT (16X,'TOTAL  TIMELINESS  COST',18X,F9.2)
14440=1290   FORMAT  ('0',15X,'OPERATING  COST  PER',A10,12X,F8.2)
14450=1291   FORMAT  (16X,'TOTAL  OPERATING  COST',18X,F10.2)
14460=1300  FORMAT ('T  AREA  COMPLETED,  WEEKLY  TOTAL',
14470=     +' BY IMPLEMENT, PARCEL NUMBER ',I1,' HARVEST CROP ',A10,
14480=     +' PLANTED CROP ',A10)
14490=1310  FORMAT('  W',15X,'C     B     B     B     S     V     F     C
14500=     +M     D     D     F     G     R     N     S     R     N    W')
14510=1320  FORMAT('  E',15X,'O     E     E     E     O           E     H
14520=     +O     I     I     I     R     O     O     P     O     H    E')
14530=1330  FORMAT('  E',15X,'M     A     E     E     I     R     R     I
14540=     +L     S     S     E     A     W           R     W     3    E')
14550=1340  FORMAT('  K',15X,'B     N     T     T     L     I     T     S
14560=     +D     K     K     L     I           T     A                K')
14570=1350  FORMAT('  .',15X,'I                             P     I     E
14580=     +B                 D     N     P     I     Y     C     A    .')
14590=1360  FORMAT('  .',15X,'N     P     T     L     S     P     L     L
14600=     +O     H     P           L     L     E     U     P    .')
14610=1370  FORMAT('  .',15X,'E     U     O     I     A     E     I
14620=     +A     A     L     C     D     A     L     R     L     P    .')
14630=1380  FORMAT('  .',15X,'.     L     P     F     V     R     Z     P
14640=     +R     R     O     U     R     N           .     T     L    .')
14650=1390  FORMAT('  .',15X,'.     L     P     T     E     .     E     L
14660=     +D     R     W     L     I     T     P     .     I     I    .')
14670=1400  FORMAT('  .',15X,'.     E     E     E     R     .     R     O
14680=     +      O     .     T     L     E     L     .     V     C    .')
14690=1410  FORMAT('  .',15X,'.     R     R     R     .     .           W
14700=     +P     W     .     I     L     R     A     .     A     A    .')
14710=1420  FORMAT('  .',15X,'.     .     .     .     .     .     S     .
14720=     +L     .     .     V     .     .     N     .     T     T    .')
14730=1430  FORMAT('  .',15X,'.     .     .     .     .     .     P     .
```

```
     +0      .      .      A      .      .      T      .      0      0    .')
1440 FORMAT('   .',15X,'.     .      .      .      .      .      R     .
     +W      .      .      T      .      .      E      .      R      R    .')
1450 FORMAT('   .',15X,'.     .      .      .      .      .      E     .
     +.      .      .      0      .      .      R      .      .      .    .')
1460 FORMAT('   .',15X,'.     .      .      .      .      .      A     .
     +.      .      .      R      .      .      .      .      .      .    .')
1470 FORMAT('   .',15X,'.     .      .      .      .      .      D     .
     +.      .      .      .      .      .      .      .      .      .    .')
1480 FORMAT('   .',15X,'.     .      .      .      .      .      E     .
     +.      .      .      .      .      .      .      .      .      .    .')
1490 FORMAT('   .',15X,'.     .      .      .      .      .      R     .
     +.      .      .      .      .      .      .      .      .      .    .')
1500 FORMAT ('  ',A10,2X,18F6.1,I4)
1510 FORMAT ('T   HOURS SPENT, WEEKLY TOTAL BY IMPLEMENT, PARCEL NUMBER
     + ',I1,' HARVEST CROP ',A10,' PLANTED CROP ',A10)
2000 FORMAT (' ')
      RETURN
      END
      SUBROUTINE INIT
      IMPLICIT INTEGER (A-Z)
      REAL SOILDFT,TAVLHRS,MAXACR,SIZEFF(20,2),TMWKCST,TIMINC,CPMTCST(7,
     +18,52)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS

     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      LOGICAL HARVIMP
      DIMENSION SOILDFT(18,3),TAVLHRS(52,3,3)
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITINO,ACRMULT
     +,TRCMULT,LENMULT
      DATA TAVLHRS
C DATA FOR SANDY SOIL  (RELATIVELY WELL DRAINED )
C DATA FOR SANDY SOIL AT 80 PERCENT  (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +/15*0.,11.,38.,2*49.,47.,56.,59.,62.,58.,50.,53.,2*63.,3*65.,
     +64.,2*62.,3*60.,4*55.,3*58.,2*57.,22.,16.,4*0.,
C DATA FOR SANDY SOIL AT 70  (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,12.,41.,52.,2*55.,58.,61.,65.,62.,53.,56.,2*67.,2*69.,
     +66.,64.,5*62.,9*60.,25.,18.,4*0.,
C DATA FOR SANDY SOIL AT 50 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,13.,44.,58.,2*60.,63.,65.,2*68.,65.,3*69.,2*75.,71.,3*69.,
     +67.,2*64.,6*63.,62.,2*60.,29.,21.,4*0.,
C DATA FOR SANDY LOAM SOIL ( RELATIVELY WELL DRAINED)
C DATA FOR LOAMY SOIL AT 80 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
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     +15*0.,5.,25.,3*31.,45.,50.,57.,52.,38.,41.,2*62.,4*60.,5*58.,
     +2*50.,2*51.,2*48.,2*47.,22.,4.,3.,4*0.,
C DATA FOR LOAMY SOIL AT 70 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,6.,27.,3*36.,40.,57.,61.,56.,44.,47.,7*65.,62.,60.,2*52.,
     +4*53.,4*52.,32.,4.,3.,4*0.,
C DATA FOR LOAMY SOIL AT 50 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,12.,42.,2*56.,54.,70.,2*67.,64.,56.,58.,2*69.,5*70.,2*69.,
     +2*67.,2*59.,3*62.,2*60.,2*58.,25.,14.,4*0.,
C DATA FOR CLAY LOAM SOIL ( RELATIVELY WELL DRAINED)
C DATA FOR CLAY SOIL AT 80 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,7.,24.,37.,41.,44.,56.,58.,60.,54.,40.,43.,2*67.,2*63.,
     +2*61.,3*58.,62.,60.,2*49.,2*46.,2*50.,2*49.,29.,4.,3.,4*0.,
C DATA FOR CLAY SOIL AT 70 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,7.,27.,42.,48.,54.,3*62.,59.,51.,54.,2*68.,2*67.,3*66.,
     +3*67.,65.,2*53.,6*51.,32.,7.,5.,4*0.,
C DATA FOR CLAY SOIL AT 50 PERCENT (HOURS PER WEEK-- 52 WEEKS TOTAL)
     +15*0.,8.,30.,50.,58.,64.,63.,60.,4*67.,2*70.,2*71.,5*69.,2*67.,
     +2*61.,2*60.,2*58.,55.,51.,37.,19.,14.,4*0.
     +/

C   EFFICIENCIES FOR IMPLEMENTS BY SIZE OF FARM,UNDER 400 ACRES/
C                                              OVER   400 ACRES

      DATA SIZEFF/
     +.55,.65,2*.6,.74,.74,.65,.75,.74,2*.77,.75,.65,.6,.6,.55,.68,.55,.
     +65,.68,
     +.7,.75,.7,.7,.88,.88,.8,.9,.88,.9,.9,.9,.9,.76,.76,.65,.9,.65,.8,
     +.9/
      DATA SPEED/
     +3.,3.5,3.,3.,4.5,3.,5.,4.5,4.5,5.,5.,4.5,4.,5.,3.,5.,3.,
     +3.5,5.,3./

C  DRAFTS FOR IMPLEMENTS IN HP/FOOT BY SOIL TYPE SANDY/LOAM/CLAY

      DATA SOILDFT/
C DATA FOR POWER REQUIREMENT ON SANDY SOIL--(18 IPLEMENTS IN ORDER)
     +0.,3.,4.,16.,7.5,5.4,1.5,7.5,6.5,5.,7.,3.,1.3,2*3.,1.5,2.,8.,
C DATA FOR POWER REQUIREMENT ON LOAMY SAND SOIL--(18 IPLEMENTS IN ORDER)
     +0.,3.,4.,16.,10.,11.,1.5,9.,11.4,5.8,10.,3.5,2.,3.6,3.4,
     +1.5,3.,10.,
C DATA FOR POWER REQUIREMENT ON CLAY SOIL--(18 IPLEMENTS IN ORDER)
     +0.,3.,4.,16.,13.8,15.,1.5,13.8,15.1,6.6,12.,4.,2.6,4.2,
     +3.8,1.5,3.,11.5/

C    MAXIMUM IMPLEMENT SIZES IN FEET

      DATA MAX/
     +30.,20.,2*10.,21.3,14.,60.,19.,12.,2*36.,34.5,20.,2*30.,60.,2*30./

C   IMPLEMENT SIZE-BASED COSTS IN DOLLARS/FOOT

      DATA SIZCST/
     +700.,150.,1000.,2200.,825.,825.,100.,400.,825.,450.,450.,200.,100.
     +,
     +600.,800.,20.,300.,250./

C   TRACTOR COSTS IN DOLLARS/HP

      DATA TRACINC/300./

C   TIMELINESS COSTS IN DOLLARS/WEEK/ACRE/CROP
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      DATA TIMCST/
     +6552*1.0E+100/

C    CUSTOM COSTS IN DOLLARS/ACRE--(18 OPERATIONS IN ORDER)

      DATA CUSTPRC/
     +16.,7.,0.,39.5,8.25,10.,2.5,8.25,9.35,2*4.6,3.75,4.8,
     +2*6.55,3.,3.75,3.4/

C    ACRES--ACREAGE TOTAL FOR EACH IMPLEMENT
C    NEXTOP--LINKED LIST OF OPERATIONS

      DATA ACRES,NEXTOP/20*0.,140*0/

C     TCUSCST      TOTAL CUSTOM COST
C     ACRSRDY      ACRES READY FOR EACH OPERATION
C     CPACRDY       ACREST READY FOR EACH OPERATION BY PARCEL
C     IMPHRS        HOURS PER IMPLEMENT
C     OWNIHRS       HOURS FOR EACH OWNED IMPLEMENT
C     OWNTHRS       HOURS FOR EACH OWNED TRACTOR
C     OPACRWK       ACRES/OPERATION/WEEK
C     OWNICST       OWNED IMPLEMENT PURCHASE PRICE
C     TTIMCST       TOTAL TIMELINESS COST
C     IMPSIZE     IMPLEMENT SIZE IN FEET
C    IMPNUM         NUMBER OF EACH IMPLEMETNT
C    CUSTCST      CUSTOM COST BY IMPLEMENT

      DATA TCUSCST,ACRSRDY,CPACRDY,IMPHRS,OWNIHRS,OWNTHRS,
     +OPACRWK,OWNICST,TTIMCST,IMPSIZE,IMPNUM,CUSTCST/
     +0.,20*0.,140*0.,18*0.,180*0.,20*0.,
     +6552*0.,180*0.,0.,18*0.,18*0,18*0./

C    TIMELINESS COSTS IN DOLLARS/ACRE/WEEK
C     TIMELINESS COST IS STORED IN THE FOLLOWING ORDER:
C GROUPS OF SEVEN REPRESENTING CROPS ; IN GROUPS OF EIGHTEEN
C REPRESENTING THE IMPLEMENTS. THE FIRST SEVEN VALUES ARE
C FOR HARVESTING BY COMBINE ALL SEVEN CROPS. WHERE THE
C CROP IS NOT HARVESTED BY COMBINE, THE VALUE IS ZERO.
C EACH IMPLEMENT WILL HAVE SEVEN SLOTS ONE FOR EACH CROP.
C
C TIMELINESS COSTS FOR COMBINE OPERATIONS FOR SEVEN CROPS

      DATA((CPMTCST(J,1,I),I=1,52),J=1,7)/
C CORN HARVEST TIMELINESS
     +40*0.,2*17.5,4*0.,6*7.5,
C WHEAT HARVEST TIMELINESS
     +27*0.,2*12.4,2*0.,21*6.,
C OATS HARVEST TIMELINESS
     +28*0.,2*4.,2*0.,20*4.,
C RYE HARVEST TIMELINESS
     +52*0.,
C NAVYBEAN HARVEST TIMELINESS
     +37*0.,2*14.,2*0.,11*14.,
C SOYBEAN HARVEST TIMELINESS
     +32*0.,2*9.8,2*0.,16*9.8,
C SUGAR BEET COMBINE TIMELINESS
     +52*0./

C TIMELINESS COSTS FOR NAVYBEAN PULLER

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      DATA((CPMTCST(J,2,I),I=1,52),J=1,7)/
C FOR CORN, WHEAT, OATS, RYE, SOYBEAN
     +52*0.,52*0.,52*0.,52*0.,52*0.,
C FOR NAVYBEAN
     +37*0.,2*7.,2*0.,11*7.,
C FOR SUGAR BEETS
     +52*0./

C TIMELINESS COST FOR SUGAR BEET TOPPER
      DATA((CPMTCST(J,3,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR SUGAR BEET LIFTER
      DATA((CPMTCST(J,4,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINSS COST FOR SOIL SAVER
      DATA((CPMTCST(J,5,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR SUBSOILER
      DATA((CPMTCST(J,6,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR FERTILIZER SPREADER
      DATA((CPMTCST(J,7,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR CHISEL PLOW
      DATA((CPMTCST(J,8,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR MOLDBOARD PLOW
      DATA((CPMTCST(J,9,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR OFFSET DISK HARROW
      DATA((CPMTCST(J,10,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR TANDEM DISK HARROW
      DATA((CPMTCST(J,11,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR FIELD CULTIVATOR
      DATA((CPMTCST(J,12,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR GRAIN DRILL
      DATA((CPMTCST(J,13,I),I=1,52),J=1,7)/
     +52*0.,39*0.,13*0.,17*0.,35*17.34,
     +52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR ROW CROP PLANTER
      DATA((CPMTCST(J,14,I),I=1,52),J=1,7)/
     +20*0.,32*17.5,52*0.,52*0.,52*0.,
     +21*0.,2*14.2,2*0.,27*14.2,21*0.,31*14.39,15*0.,2*28.22,
     +2*0.,33*35.2/

C TIMELINESS COST FOR NO TILL ROW PLANTER
      DATA((CPMTCST(J,15,I),I=1,52),J=1,7)/
```

```
     +20*0.,32*17.5,52*0.,52*0.,52*0.,
     +21*0.,2*14.2,2*0.,27*14.2,21*0.,31*14.39,15*0.,2*28.22,
     +2*0.,33*35.2/

C TIMELINESS COST FOR SPARYER
      DATA((CPMTCST(J,16,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR ROW CULTIVATOR
      DATA((CPMTCST(J,17,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C TIMELINESS COST FOR NH3 APPLICATOR
      DATA((CPMTCST(J,18,I),I=1,52),J=1,7)/
     +52*0.,52*0.,52*0.,52*0.,52*0.,52*0.,52*0./

C   HOURS/OPERATION/WEEK

      DATA OPHRSWK/6552*0./

C       BTTLHRS     BOUGHT TILLAGE TRACTOR HOURS
C       BTUTHRS     BOUGHT UTILITY TRACTOR HOURS

      DATA BTTLHRS,BTUTHRS/2*0./

C    OPERATION SCHEDULES
C    1=ACREAGE
C    2=BEGIN WEEK
C    3=END WEEK
C    4=CUSTOM INDEX

      DATA ACOPDAT /560*0/

      DO 50 I=1,18
      DRAFT(I)=SOILDFT(I,SOIL)
50    CONTINUE

      DO 100 I=1,20
      DO 200 J=1,7
      IF (ACOPDAT(J,I,4).NE.1) THEN
      ACRES(I)=ACRES(I)+ACOPDAT(J,I,1)
      ENDIF
200   CONTINUE
100   CONTINUE

      MAXACR=0.

      DO 400 I=1,20
      IF (ACRES(I).GT.MAXACR) MAXACR=ACRES(I)
400   CONTINUE

      DO 500 I=1,52
      AVALHRS(I)=TAVLHRS(I,CONLEV,SOIL)
500   CONTINUE

      SIZIND=1
      IF (MAXACR.GT.400.) SIZIND=2

      DO 600 I=1,20
      EFF(I)=SIZEFF(I,SIZIND)
600   CONTINUE
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      DO 700 I=1,7
      DO 800 J=1,20
      IMP=J
      IF (IMP.EQ.19) IMP=7
      IF (IMP.EQ.20) IMP=17
      IF (ACOPDAT(I,J,1).LE.0) GOTO 750
      END=ACOPDAT(I,J,3)
      IF (ACOPDAT(I,J,3).LE.ACOPDAT(I,J,2) ) END=52

      IF (HARVIMP(IMP)) THEN
       CROP=HARVCRP(I)
      ELSE

       CROP=PLNTCRP(I)

      ENDIF

      DO 900 K=ACOPDAT(I,J,2),END
      TIMCST(I,IMP,K)=CPMTCST(CROP,IMP,K)
900   CONTINUE

      IF (END.NE.ACOPDAT(I,J,3) ) THEN

      DO 1000 K=1,ACOPDAT(I,J,3)
      TIMCST(I,IMP,K)=CPMTCST(CROP,IMP,K)
1000  CONTINUE

      ENDIF

750   CONTINUE
800   CONTINUE
700   CONTINUE
      RETURN
      END
      SUBROUTINE SETSEL(LEVEL)
      IMPLICIT INTEGER (A-Z)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      REAL RDUMMY(13966)
      COMMON /WKDATA/ DUMMY(13966)
      EQUIVALENCE (DUMMY,RDUMMY)
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
      COMMON /FINAL/ FINAL(13966,2)

      IF (LEVEL.EQ.1) THEN

      DO 100 I=1,13966
      FINAL(I,1)=DUMMY(I)
100   CONTINUE
```

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      ELSEIF(LEVEL.GT.1) THEN

      DO 200 I=1,13966
      FINAL(I,LEVEL)=FINAL(I,LEVEL-1)
200   CONTINUE

      ENDIF

      DO 300 I=1,22
      DUMMY(I)=0
300   CONTINUE

      DO 400 I=23,13966
      RDUMMY(I)=0.
400   CONTINUE

      RETURN
      END
      SUBROUTINE HARVINC(INC)
      IMPLICIT INTEGER (A-Z)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT
      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
      REAL INC
      DO 100 I=1,4
      IF (CAPAC(I).GT.0.)CAPAC(I)=CAPAC(I)*INC
100   CONTINUE
      RETURN
      END
      SUBROUTINE TILLINC(INC)
      IMPLICIT INTEGER (A-Z)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT

      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
```

```
      +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
      +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
      +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
      +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
      +UEL(20),TILFUE
      +L,UTLFUEL
       COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
      +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
      +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
      +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
      +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
      +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
      +,TRCMULT,LENMULT
       REAL INC
       DO 100 I=5,12
       IF (CAPAC(I).GT.0.) CAPAC(I)=CAPAC(I)*INC
100    CONTINUE
       RETURN
       END
       SUBROUTINE PLNTINC(INC)
       IMPLICIT INTEGER (A-Z)
       REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
      +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
      +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
      +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
      +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
      +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
      +RMULT,TRCMULT,LENMULT

       COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
      +18),IMPSIZE(18),IMPHRS(18),
      +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
      +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
      +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
      +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
      +UEL(20),TILFUE
      +L,UTLFUEL
       COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
      +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
      +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
      +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
      +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
      +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
      +,TRCMULT,LENMULT
       REAL INC
       DO 100 I=13,18
       IF (CAPAC(I).GT.0.) CAPAC(I)=CAPAC(I)*INC
100    CONTINUE
       RETURN
       END
       LOGICAL FUNCTION HARVIMP(IMPNUM)
       IMPLICIT INTEGER (A-Z)
       HARVIMP=.FALSE.
       IF (IMPNUM.LT.4) HARVIMP=.TRUE.
       RETURN
       END
       SUBROUTINE ALCOST(USE,AGE,NCOST,T,OLDUSE,PCOST,FUELUSE)
       COMMON/ECOUT/AOWN,AREP,AFUEL,ALAB,AC,CRF
       REAL NCOST,INT,LABOR,ACRF(5),IR,CRF
       INTEGER T
       DIMENSION RC1(20),RC2(20),RV1(20),RV2(20)
```

```
C
C INITIAL INPUT DATA
      DATA RC1/.144,.23,.26,.41,.23,.23,.24,.61,.23,.23,.23,
     +.23,.208,.67,.67,.71,.23,.23,.025,.025/
      DATA RC2 /1.8,1.8,1.6,1.3,1.8,1.8,1.3,1.3,1.8,1.8,1.8,1.8,
     +1.6,1.6,1.6,1.4,1.8,1.8,1.6,1.6/
      DATA RV1/.75,17*.7,2*.75/, RV2/.88,17*.9,2*.87/
      DATA ACRF/.15,.22,.21,.21,.21/, NN/10/, TRI/.25/
      DATA TISR/.01/,G/.08/,A/.13/,B/.12/,C/.08/,DPAY/.2/,NM/5/,IR/.12/
      DATA FP/.32/,WAGE/4.25/

      AR = A - G
      CRF = (AR*(1.+AR)**NN)/((1.+AR)**NN-1.)
      TARO=PVC=TOWN=TREP=TFUEL=TTD=TLAB=0.0
C
C FUEL USE & USED EQUIPMENT
      CALL FUELFIG(T,FUELUSE)
      FUEL=FP*FUELUSE*3.75
40    RVO = NCOST
      IF (AGE.EQ.0.) GO TO 45
      RVO = PCOST
      TARO = NCOST*RC1(T)*(OLDUSE/1000.)**RC2(T)
45    J = AGE
      END = AGE + NN
      RV = NCOST*RV1(T)*RV2(T)**END
C
C   LOAN COST
      DPAYM = DPAY*RVO
      PAY = (RVO-DPAYM)*(IR*(1.+IR)**NM)/((1.+IR)**NM-1.)
      MORT = PAY*NM
      DO 50 I = 1,NN
      J = J + 1
C
C   CAPITAL COST
      CAP = PAY
      IF(I.GT.NM)CAP = 0.
      IF(I.EQ.1)CAP = CAP + DPAYM
      IF(I.EQ.NN) CAP = CAP - RV*(1.+G)**NN
C
C   OWNERSHIP COSTS
      TIS = TISR*NCOST*(RV1(T)*RV2(T)**J+.5)*(1.+G)**I
      TOWN = TOWN + (CAP+TIS)/(1.+A)**I
C
C   OPERATING COSTS
      TAR = NCOST*RC1(T)*((OLDUSE+USE*(J-AGE))/1000.)**RC2(T)
      REP = (TAR-TARO)*(1.+G)**I
      TARO = TAR
      TREP = TREP + REP/(1.+A)**I
      FUELL = 1.15*FUEL*(1.+B)**I
      TFUEL = TFUEL + FUELL/(1.+A)**I
      LABOR = 1.1*WAGE*USE*(1.+C)**I
      IF(T.GT.3)LABOR = 0.
      TLAB = TLAB + LABOR/(1.+A)**I
C
C   INCOME TAX DEDUCTIONS
      D = 0.0
      IF(I.LT.6) D = ACRF(I)*RVO
      MORT = AMAX1(0.,MORT-PAY)
      IT = IR*MORT
      TD = TRI*(D+IT+TIS+REP+FUELL+LABOR)
      IF(I.EQ.1.AND.TRI.NE.0)TD = TD + .1*RVO
```

```
      TTD = TTD + TD/(1.+A)**I
C
C   TOTAL COST
      TOTAL = CAP+TIS+REP+FUELL+LABOR-TD
      PVC = PVC + TOTAL/(1.+A)**I
50    CONTINUE
C
C   PRESENT VALUE COSTS
      AOWN = TOWN*CRF
      AFUEL = TFUEL*CRF
      ALAB = TLAB*CRF
      AC = PVC*CRF
      RETURN
      END
      LOGICAL FUNCTION TILLIMP(IMP)
      IMPLICIT INTEGER(A-Z)

      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      DIMENSION TILLIND(20)
      DATA TILLIND /0,1,0,1,1,1,0,1,1,1,1,0,0,1,1,0,0,1,0,0/
      TILLIMP=.FALSE.
      IF (TILLIND(IMP).EQ.1 .OR. UTILNUM.EQ.0) TILLIMP=.TRUE.
      IF (IMP.EQ.1) TILLIMP=.FALSE.
      RETURN
      END
      LOGICAL FUNCTION UTILIMP(IMP)
      IMPLICIT INTEGER (A-Z)

      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      DIMENSION UTILIND(20)
      DATA UTILIND  /0,0,1,0,0,0,1,0,0,0,0,1,1,0,0,1,1,0,1,1/
      UTILIMP=.FALSE.
      IF (UTILNUM.EQ.0 .OR. IMP.EQ.1) RETURN
      IF (UTILIND(IMP).EQ.1) UTILIMP=.TRUE.
      RETURN
      END

      LOGICAL FUNCTION LINKED(IMP,INDEX)
      IMPLICIT INTEGER (A-Z)

      DIMENSION LINKIND(18,2)
      DATA LINKIND /0,0,1,1,14*0,1,1,11*0,1,1,1,1,1/
      LINKED=.FALSE.
      DO 100 I=1,2
      IF (LINKIND(IMP,I).EQ.1) THEN
      LINKED=.TRUE.
      INDEX=I
```

```
      GOTO 99
      ENDIF
100   CONTINUE
99    CONTINUE
      RETURN
      END
      SUBROUTINE FUELFIG(IMP,FUELUSE)
      IMPLICIT INTEGER(A-Z)
      LOGICAL TILLIMP,UTILIMP
      REAL FUELUSE,IMPFUEL(20)
      REAL WKCAPAC,IMPSIZE,IMPCOST,UTILTIM,UTILSIZ,BTUTHRS,UTILCST,
     +TILLTIM,TILLSIZ,BTTLHRS,TILLCST,CUSTCST,TCUSCST,TTIMCST,
     +ACRSRDY,CPACRDY,OPHRSWK,OPACRWK,OWNIHRS,OWNIAC,OWNTHRS,OWNTAC,
     +CAPAC,ACRES,AVALHRS,SPEED,EFF,MAX,TOTACR,CROPACR,OWNIMP,OWNIUTM,
     +OWNTRAC,OWNTCST,OWNTUTM,SIZCST,TRACINC,TIMCST,CUSTPRC,DRAFT,OWNICS
     +T,IMPHRS,OWNIAGE,OWNTAGE,NAMSIZ,WAITING,OWNFUEL,TILFUEL,UTLFUEL,AC
     +RMULT,TRCMULT,LENMULT

      COMMON /WKDATA/IMPNUM(18),UTILNUM,BTUTNUM,TILLNUM,BTTLNUM,WKCAPAC(
     +18),IMPSIZE(18),IMPHRS(18),
     +IMPCOST(18),UTILTIM,UTILSIZ,BTUTHRS,UTILCST,TILLTIM,TILLSIZ,
     +BTTLHRS,TILLCST,CUSTCST(18),TCUSCST,TTIMCST,ACRSRDY(20),
     +CPACRDY(7,20),OPHRSWK(7,18,52),OPACRWK(7,18,52),OWNIHRS(10,18),
     +OWNIAC(10,18),OWNTHRS(20),OWNTAC(20),NAMSIZ(18),WAITING(7,20),OWNF
     +UEL(20),TILFUE
     +L,UTLFUEL
      COMMON /FRMDATA/ CAPAC(18),ACRES(20),AVALHRS(52),ACOPDAT(7,20,4),
     +SPEED(20),EFF(20),MAX(18),OWNIMP(10,18),OWNIUTM(10,18),
     +OWNTRAC(20),OWNTCST(20),OWNTAGE(20),OWNTUTM(20),NEXTOP(7,20),
     +SIZCST(18),TRACINC,TIMCST(7,18,52),CUSTPRC(18),SOIL,CONLEV,
     +CROPACR(7),TOTACR,OWNED,OWNEDT,STARTTM,OWNTOT(18),HARVCRP(7),
     +PLNTCRP(7),DRAFT(18),OWNIAGE(10,18),OWNICST(10,18),UNITIND,ACRMULT
     +,TRCMULT,LENMULT
C     DATA IMPFUEL/
C    +1.51,.52,.83,1.37,1.45,1.54,.30,1.36,1.81,1.11,.93,.78,.56,.57
C    +,.68,.33,.58,.39,.30,.58/

C     IMP >=19  >>> TRACTOR

      IF (IMP.GE.19) THEN
      FUELUSE=0.
      DO 100 I=2,20

C      IMP=19    >>> TILLAGE TRACTOR

      IF (IMP.EQ.19) THEN
      IF (IMPSIZE(I).GT.0.) THEN
      IF(TILLIMP(I))FUELUSE=FUELUSE+.211*(IMPHRS(I))*TILLSIZ*(2.3*(DRAF
     +T(I)*
     +IMPSIZE(I)
     +/TILLSIZ)+3.4-0.174*(738*(DRAFT(I)*IMPSIZE(I)/TILLSIZ)
     ++173)**0.5)/TILLNUM
      ENDIF
C    IMP=20   >>> UTILITY TRACTOR

      ELSEIF (IMP.EQ.20) THEN
      IF (IMPSIZE(I).GT.0.) THEN
      IF(TILLIMP(I))FUELUSE=FUELUSE+.211*(IMPHRS(I))*UTILSIZ*(2.3*(DRAF
     +T(I)*
     +IMPSIZE(I)
     +/UTILSIZ)+3.4-0.174*(738*(DRAFT(I)*IMPSIZE(I)/UTILSIZ)
```

```
     ++173)**0.5)/UTILNUM
      ENDIF
      ENDIF
100   CONTINUE
C   IMP=1   >>> COMBINE
      ELSEIF (IMP.EQ.1) THEN
      FUELUSE=ACRES(1)/IMPNUM(1)*1.75
      ELSEIF (IMP.NE.1 .AND. IMP.LT.19) THEN
      FUELUSE=0.
      ENDIF
      RETURN
      END
```

Variable Definition

ACOPDATA Operating Data for each implement:

1= Acres

2= Begin Week

3= End Week

4= Custom = 1/ No Custom = 2

One set for each crop for each implement

ACRES Total Acres to be completed for each operation

ACRMULT Correction factor for acres/hectares

ACRSRDY Acres available due to maturation and previous operation for each crop

AVALHRS Hours available of useful time for each week.

BTTLNUM Number of purchased tillage tractors

BTUTHRS Usage in hours for each utility tractor

CAPAC Base total capacity (feet) to be used to determine implement sizes and actual capacity for each implement

CONLEV 1=80 percent 2=70 percent 3=50 percent

CPACRDY Acres available due to maturation and previous operation for each operation by parcel

CROPACR Acres for each parcel

CUSTCST Annual cost for custom operations

CUSTPRC Dollars per acre for custom operations

DRAFT Horsepower per foot for each implement

EFF Percentage of time actually performing operation

HARVCRP Harvest crop index 1-7 for each parcel. Completing new acreage

IMPCOST Annual cost (dollars) of operating each individual IMP

IMPHRS Hours for each individual implement (usage per year)

IMPNUM	Number of each implement
IMPSIZE	Size in feet of each individual implement
LENMULT	Correction factor for feet/meters
MAX	Maximum size in feet of each implement
NAMSIZ	Concurrent size in row or bottoms where applicable
NEXTOP	Linked set of operations for each parcel
OPHRSWK	Hours per operation per week per parcel
OWNED	Logical variable for owned implements
OWNEDT	Logical variable for owned tractors
OWNIAC	Annual cost for owned implements
OWNICST	Purchase price for each implement
OWNIHRS	Hours of use of each owned implement on the farm
OWNFUEL	Fuel in gallons for each owned tractor
OWNLAGE	Age in years for each owned implement
OWNIMP	Size in feet of owned implements
OWNIUTM	Previous usage of owned equipment
OWNTAGE	Age in years of owned tractors
OWNTHRS	Hours of usage of owned tractors
OWNTOT	Total number of owned implements of each implements
OWNTCST	Purchase price of owned equipment
OWNTRAC	Owned tractor size in horsepower
PLNTCRP	Planted crop index 1-7 for each parcel
SIZCST	Dollars per foot for each implement
SOIL	1 = coarse 2 = medium 3 = fine
SPEED	Miles per hour
STARTTM	First harvest date for farm

TILFUEL	Fuel in gallons for each individual tillage tractor
TILLNUM	Total number of tillage tractors
TIMCST	Dollars per acre per week for timeliness costs for each operation
TOTACR	Area of the whole farm
TRACINC	Dollars per horsepower for tractors
TRCMULT	Correction factor for hp/kw
TTIMCST	Total annual timeliness cost
UNITIND	Indicator of unit choice: =English/2=SI
UTILCST	Annual operating cost of each utility tractor
UTLFUEL	Fuel in gallons for each utility tractor
UTILNUM	Number of purchased utility tractors
UTILTIM	Total utility tractor size
UTILSIZ	Chosen size of utility tractor in horsepower
WAITING	Acres available due to previous operations but not due to crop maturation
WKCAPC	Total capacity of each implement

APPENDIX C

MACHINERY SELECTION MODEL: EXAMPLE RUNS

EXAMPLE FARM WITH OWNED EQUIPMENT

Example of a 300 acre farm. Farmer owns: a 12.5 foot chisel plow, a 15 foot offset disc harrow, a 6 row planter, and a 6 row cultivator. "MACHSEL" selects around the farmer's machines and incorporates them in the selection process.

Crop = Corn

Area = 300 Acres

Soil = Clay

Conv. Level = 80%

Operations:

- Combine
- Chisel plow
- Disk
- Field cultivate
- Row plant
- Sprayer
- Row cultivate
- Apply ammonia

OPERATING PARAMETERS

TOTAL FARM AREA 300. ACRES
SOIL TEXTURE FINE (CLAY)
WEATHER CONFIDENCE LEVEL 80 PERCENT

FIELD OPERATION SCHEDULE

PARCEL NUMBER 1 AREA 300. ACRES

HARVEST CROP CORN PLANTED CROP CORN

OPERATION	COMPLETION		DATES
COMBINE	OCT. 22	TO	NOV. 5
CHISEL PLOW	NOV. 12	TO	APRIL 30
DISK PLOW	NOV. 12	TO	APRIL 30
FIELD CULTIVATOR	APRIL 16	TO	MAY 14
ROW PLANTER	APRIL 30	TO	MAY 14
SPRAYER	APRIL 30	TO	MAY 14
ROW CULTIVATOR	JUNE 11	TO	JUNE 25
NH3 APPLICATOR	JUNE 11	TO	JUNE 25

OPERATING STATISTICS

OWNED IMPLEMENTS

IMPLEMENT	SIZE	USAGE(HRS)	OPERATING COST
CHISEL PLOW	12.5	58.7	1774.03
DISK PLOW	14.5	37.0	1920.67
ROW PLANTER	15.0	45.9	2585.57
ROW CULTIVATOR	15.0	57.9	1629.73

OWNED TRACTORS	SIZE(HP)	USAGE(HRS)	OPERATING COST	FUEL COST	
	130.0 HP		125.7	3595.64	507.00
	90.0 HP		0.0	685.73	0.00

PURCHASED IMPLEMENTS

IMPLEMENT		SIZE	NUMBER	HRS/UNIT	COST/UNIT
COMBINE	8.0	ROWS	1	75.0	6516.34
FIELD CULTIVATOR	12.5	FEET	1	49.0	241.21
SPRAYER	16.0	ROWS	1	18.8	320.49
NH3 APPLICATOR	8.0	ROWS	1	37.6	654.19

NEW TILLAGE TRACTORS	POWER	NUMBER	HRS/TRACTOR	COST/TRACTOR	FUEL USAGE/TRACTOR
	160.0 HP	1	179.2	8681.97	975.00 GALLONS

NEW UTILITY TRACTORS	POWER	NUMBER	HRS/TRACTOR	COST/TRACTOR	FUEL USAGE/TRACTOR
	50.0 HP	1	0.0	0.00	0.00 GALLONS

TOTAL MACHINERY COST 28605.57
TOTAL TIMELINESS COST 238.38

OPERATING COST PER ACRES 96.15
TOTAL OPERATING COST 28843.94

WEEK	COMBINE	HAND PULLER	BEET TOPPER	BEET LIFTER	SOIL SAVER	V RIPPER	FERTILIZER SPREADER	CHISEL PLOW	MOLDBOARD PLOW	DISK HARROW	DISK PLOW	FIELD CULTIVATOR	GRAIN DRILL	ROW PLANTER	NO TILL PLANTER	SPRAYER	ROW CULTIVATOR	NH3 APPLICATOR	WEEK
JAN. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
JAN. 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
JAN. 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
JAN. 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4
JAN. 29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
FEB. 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6
FEB. 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7
FEB. 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8
FEB. 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9
MARCH 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10
MARCH 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11
MARCH 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12
MARCH 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13
APRIL 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14
APRIL 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15
APRIL 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16
APRIL 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.0	0.0	19.3	25.6	0.0	0.0	0.0	0.0	0.0	0.0	17
APRIL 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.7	23.4	0.0	11.3	0.0	4.6	0.0	0.0	18
MAY 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0	0.0	11.9	0.0	0.0	19
MAY 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	2.3	0.0	0.0	20
MAY 21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21
MAY 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22
JUNE 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23
JUNE 11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.0	29.9	24
JUNE 18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.9	7.7	25
JUNE 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26
JULY 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27
JULY 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28
JULY 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29
JULY 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30
JULY 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31
AUG. 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32
AUG. 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33
AUG. 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34
AUG. 27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35
SEPT. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36
SEPT. 10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37
SEPT. 17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38
SEPT. 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39
OCT. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40
OCT. 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41
OCT. 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42
OCT. 22	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43
OCT. 29	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44
NOV. 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45
NOV. 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46
NOV. 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47
NOV. 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48
DEC. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49
DEC. 10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50
DEC. 17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51
DEC. 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52

END MACHSEL
174300 MAXIMUM EXECUTION FL.
.069 CP SECONDS EXECUTION TIME.
GE-

AREA [illegible] UTILITY TOTAL BY IMPLEMENT [illegible] HARVEST CROP LOAD [illegible] PLANTED CROP LOAD

WEEK	COMBINE	BEAN PULLER	BEET TOPPER	BEET LIFTER	SOIL SAVER	V RIPPER	FERTILIZER SPREADER	CHISEL PLOW	MOLDBOARD PLOW	DISK HARROW	DISK PLOW	FIELD CULTIVATOR	GRAIN DRILL	ROW PLANTER	NO TILL PLANTER	SPRAYER	ROW CULTIVATOR	NH3 APPLICATOR	WEEK
JAN. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
JAN. 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
JAN. 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
JAN. 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4
JAN. 29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
FEB. 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6
FEB. 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7
FEB. 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8
FEB. 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9
MARCH 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10
MARCH 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11
MARCH 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12
MARCH 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13
APRIL 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14
APRIL 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15
APRIL 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16
APRIL 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.4	0.0	0.0	130.8	130.8	0.0	0.0	0.0	0.0	0.0	0.0	17
APRIL 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	119.7	119.7	0.0	41.7	0.0	41.7	0.0	0.0	18
MAY 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	158.2	0.0	158.2	0.0	0.0	19
MAY 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	30.7	0.0	0.0	20
MAY 21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21
MAY 28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22
JUNE 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23
JUNE 11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	199.1	199.1	24
JUNE 18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.5	51.5	25
JUNE 25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26
JULY 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27
JULY 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28
JULY 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29
JULY 23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30
JULY 30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31
AUG. 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32
AUG. 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33
AUG. 20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34
AUG. 27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35
SEPT. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36
SEPT. 10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37
SEPT. 17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38
SEPT. 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39
OCT. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40
OCT. 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41
OCT. 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42
OCT. 22	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43
OCT. 29	120.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44
NOV. 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45
NOV. 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	189.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46
NOV. 19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47
NOV. 26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48
DEC. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49
DEC. 10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50
DEC. 17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51
DEC. 24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52

EXAMPLE FARM WITH COMBINING, SPRAYING PESTICIDE, AND AMMONIA APPLICATION CUSTOM HIRED

Crop = Corn

Area = 800 acres

Soil Texture = heavy

Con. Level = 80%

Operations:

- Combine--custom
- Chisel plow
- Disk
- Field cultivate
- Row plant
- Spray--custom
- Row cultivate
- Apply NH_3--Custom

```
 EXEC . SUN.23.03.28.
ENTER SOIL TYPE,1=LIGHT,2=MEDIUM,3=HEAVY
*3
ENTER CONFIDENCE LEVEL FOR WEATHER,1=80,2=70,3=50
*1
ENTER CHOICE OF UNITS,1=ENGLISH,2=SI
*1
IF SOME EQUIPMENT IS OWNED,ENTER 1
IF NO EQUIPMENT IS OWNED,ENTER   0
*0
FOR EACH FARM PARCEL, INPUT AREA (ACRES OR HECTARES) TO
BE FARMED ON THE PARCEL, ALONG WITH HARVEST
CROP INDEX AND PLANTED CROP INDEX. THEN INPUT
OPERATION SCHEDULE AS INSTRUCTED.

PARCEL NO. 1 AREA,HARVEST CROP, PLANTED CROP?
*300,1,1
INPUT OPERATIONS AS FOLLOWS :
OPERATION INDEX
INITIAL WEEK OF OPERATION
FINAL WEEK OF OPERATION
CUSTOM OPTION,1=CUSTOM,2=NO CUSTOM
BEGIN WITH HARVEST OPERATIONS, END WITH ALL 0'S
*1,43,45,1

*8,45,18,2

*11,45,18,2

*12,18,20,2

*14,18,20,2

*16,18,29,1

*17,24,26,2

*18,24,26,1

*0,0,0,0

                PARCEL NUMBER  1  AREA   300.  ACRES
                HARVEST CROP  CORN       PLANTED CROP  CORN
                OPERATION             COMPLETION     DATES
                   COMBINE      OCT.  22   TO   NOV.   5     CUSTOM
               CHISEL PLOW      NOV.   5   TO   APRIL 30  NO CUSTOM
                 DISK PLOW      NOV.   5   TO   APRIL 30  NO CUSTOM
          FIELD CULTIVATOR      APRIL 30   TO   MAY   14  NO CUSTOM
               ROW PLANTER      APRIL 30   TO   MAY   14  NO CUSTOM
                   SPRAYER      APRIL 30   TO   JULY  16     CUSTOM
            ROW CULTIVATOR      JUNE  11   TO   JUNE  25  NO CUSTOM
            NH3 APPLICATOR      JUNE  11   TO   JUNE  25     CUSTOM
IF THIS IS CORRECT,ENTER 1
IF THIS IS INCORRECT,ENTER 0
*1

PARCEL NO. 2 AREA,HARVEST CROP, PLANTED CROP?
*0,0,0
```

```
F A R M   M A C H I N E R Y   S E L E C T I O N   M O D E L   F O R   E A S T E R N   M I C H I G A N

          OPERATING  PARAMETERS
          ---------  ----------

      TOTAL  FARM  AREA                300.  ACRES
      SOIL   TEXTURE                        FINE (CLAY)
      WEATHER  CONFIDENCE  LEVEL       80 PERCENT

      FIELD  OPERATION  SCHEDULE

      PARCEL NUMBER  1  AREA   300.  ACRES

      HARVEST CROP  CORN        PLANTED CROP  CORN

      OPERATION                COMPLETION    DATES

                 COMBINE     OCT.  22     TO     NOV.   5
             CHISEL PLOW     NOV.   5     TO     APRIL 30
               DISK PLOW     NOV.   5     TO     APRIL 30
        FIELD CULTIVATOR     APRIL 30     TO     MAY   14
             ROW PLANTER     APRIL 30     TO     MAY   14
                 SPRAYER     APRIL 30     TO     JULY  16
          ROW CULTIVATOR     JUNE  11     TO     JUNE  25
          NH3 APPLICATOR     JUNE  11     TO     JUNE  25

          OPERATING  STATISTICS
          ---------  ----------

      PURCHASED  IMPLEMENTS
      IMPLEMENT                      SIZE      NUMBER      HRS/UNIT          COST/UNIT
             CHISEL PLOW     10.0    FEET         1          73.3             559.00
               DISK PLOW     11.5    FEET         1          55.9             510.27
        FIELD CULTIVATOR     12.5    FEET         1          58.7             248.82
             ROW PLANTER      6.0    ROWS         1          55.0            1086.55
          ROW CULTIVATOR      6.0    ROWS         1          69.3             465.19

      NEW TILLAGE TRACTORS        POWER            NUMBER  HRS/TRACTOR     COST/TRACTOR    FUEL USAGE/TRACTOR
                             120.0  HP                1       184.2           7137.54      858.00   GALLONS

      NEW UTILITY TRACTORS        POWER            NUMBER  HRS/TRACTOR     COST/TRACTOR    FUEL USAGE/TRACTOR
                              50.0  HP                1       128.0           3331.47      408.00   GALLONS

      CUSTOM  COST  BY  IMPLEMENT
      IMPLEMENT                                              COST
                 COMBINE                                                      3900.00
                 SPRAYER                                                       750.00
          NH3 APPLICATOR                                                       900.00

      TOTAL  CUSTOM  COST                    9832.62
      TOTAL   MACHINERY  COST               13330.83
      TOTAL  TIMELINESS  COST                 186.31

      OPERATING  COST  PER  ACRES              77.83
      TOTAL  OPERATING  COST                23347.76
AREA  COMPLETED!
```

EXAMPLE FARM WITH METRIC UNITS

Crop = Corn

Area = 200 hectares

Soil texture = heavy

Confidence level = 80%

Operations:

Combine

Chisel plows

Disk harrow

Field cultivate

Row plant

Spray

Row cultivate

Apply NH_3

```
 EXEC BEGUN.22.52.21.
ENTER SOIL TYPE,1=LIGHT,2=MEDIUM,3=HEAVY
*
*3
ENTER CONFIDENCE LEVEL FOR WEATHER,1=80,2=70,3=50
*1
ENTER CHOICE OF UNITS,1=ENGLISH,2=SI
*2
IF SOME EQUIPMENT IS OWNED,ENTER 1
IF NO EQUIPMENT IS OWNED,ENTER   0
*0
FOR EACH FARM PARCEL, INPUT AREA (ACRES OR HECTARES) TO
BE FARMED ON THE PARCEL, ALONG WITH HARVEST
CROP INDEX AND PLANTED CROP INDEX. THEN INPUT
OPERATION SCHEDULE AS INSTRUCTED.

PARCEL NO. 1 AREA,HARVEST CROP, PLANTED CROP?
*200,1,1
INPUT OPERATIONS AS FOLLOWS :
OPERATION INDEX
INITIAL WEEK OF OPERATION
FINAL WEEK OF OPERATION
CUSTOM OPTION,1=CUSTOM,2=NO CUSTOM
BEGIN WITH HARVEST OPERATIONS, END WITH ALL 0'S
*1,43,45,2

*8,45,18,2

*11,45,18,2

*12,18,20,2

*14,18,20,2

*15,18,20,2

*17,24,26,2

*18,24,26,2

*0,0,0,0

              PARCEL NUMBER  1  AREA   200.  HECTARES
              HARVEST CROP  CORN          PLANTED CROP  CORN
              OPERATION               COMPLETION      DATES
                 COMBINE       OCT.  22   TO   NOV.   5  NO CUSTOM
             CHISEL PLOW       NOV.   5   TO   APRIL 30  NO CUSTOM
               DISK PLOW       NOV.   5   TO   APRIL 30  NO CUSTOM
        FIELD CULTIVATOR       APRIL 30   TO   MAY   14  NO CUSTOM
             ROW PLANTER       APRIL 30   TO   MAY   14  NO CUSTOM
                 SPRAYER       APRIL 30   TO   MAY   14  NO CUSTOM
         ROW CULTIVATOR        JUNE  11   TO   JUNE  25  NO CUSTOM
         NH3 APPLICATOR        JUNE  11   TO   JUNE  25  NO CUSTOM
IF THIS IS CORRECT,ENTER 1
IF THIS IS INCORRECT,ENTER 0
*1

PARCEL NO. 2 AREA,HARVEST CROP, PLANTED CROP?
*0,0,0
```

FARM MACHINERY SELECTION MODEL FOR EASTERN MICHIGAN

OPERATING PARAMETERS

TOTAL FARM AREA 200. HECTARES
SOIL TEXTURE FINE (CLAY)
WEATHER CONFIDENCE LEVEL 80 PERCENT

FIELD OPERATION SCHEDULE

PARCEL NUMBER 1 AREA 200. HECTARES

HARVEST CROP CORN PLANTED CROP CORN

OPERATION	COMPLETION		DATES
COMBINE	OCT. 22	TO	NOV. 5
CHISEL PLOW	NOV. 5	TO	APRIL 30
DISK PLOW	NOV. 5	TO	APRIL 30
FIELD CULTIVATOR	APRIL 30	TO	MAY 14
ROW PLANTER	APRIL 30	TO	MAY 14
SPRAYER	APRIL 30	TO	MAY 14
ROW CULTIVATOR	JUNE 11	TO	JUNE 25
NH3 APPLICATOR	JUNE 11	TO	JUNE 25

OPERATING STATISTICS

PURCHASED IMPLEMENTS

IMPLEMENT		SIZE	NUMBER	HRS/UNIT	COST/UNIT
COMBINE	8.0	ROWS	1	97.0	7728.27
CHISEL PLOW	2.4	METERS	1	125.8	613.87
DISK PLOW	3.5	METERS	1	53.8	506.86
FIELD CULTIVATOR	3.8	METERS	1	55.0	245.84
ROW PLANTER	8.0	ROWS	1	36.7	1264.22
SPRAYER	16.0	ROWS	1	21.4	326.21
ROW CULTIVATOR	8.0	ROWS	1	44.2	570.80
NH3 APPLICATOR	8.0	ROWS	1	42.9	663.41

NEW TILLAGE TRACTORS	POWER	NUMBER	HRS/TRACTOR	COST/TRACTOR	FUEL USAGE/TRACTOR
	120.0 KW	2	129.6	7791.05	3010.31 LITERS

NEW UTILITY TRACTORS	POWER	NUMBER	HRS/TRACTOR	COST/TRACTOR	FUEL USAGE/TRACTOR
	37.5 KW	1	120.7	4451.48	3130.73 LITERS

TOTAL MACHINERY COST 31953.05
TOTAL TIMELINESS COST 141.94

OPERATING COST PER HECTARES 160.54
TOTAL OPERATING COST 32095.00

AREA COMPLETED, WEEKLY TOTAL BY IMPLEMENT, PI

USER ABORT
OK-

APPENDIX D

PROBABILITY OF SUITABLE WORKDAYS

Suitable workday probabilities are an important input into the Machinery Component Selection model (Section 3, Chapter 2). A suitable workday is a day in which the farmer can do field work. For example, a calendar month in the spring may have only 11 suitable workdays. These probabilities provide estimates of the number of suitable days a farm manager can expect to have to perform field operations. Estimates of the probabilities of suitable days for Michigan, at project implementation, were limited and did not reflect differences due to region, soil texture, drainage class, and tillage system. To address these shortcomings, a computer model (FDPGEN) was developed by Rosenberg (1982) reference proposed report in a complementary project funded by Michigan State University.

FDPGEN uses historical weather records and information on soil characteristics and field operations to simulate the incidence of suitable workdays. FDPGEN simulates the incidence of suitable workdays by monitoring soil moisture level and tractability conditions. Tractability refers to the ability of a soil to support the weight of a tractor moving across a field without the tractor getting stuck. For nonharvest field operations, a day was considered a good workday if the soil was dry enough to be tractable. For harvest field operations, additional constraints were placed on permissible precipitation to ensure that moisture in the environment would not cause excessive harvest losses.

The number of suitable workdays in each period (e.g., May 1 to May 7) for each year (e.g., 1973) was estimated for the last 27 years by the FDPGEN model. The number of suitable workdays were ranked for each period in the year in an ascending order to form empirical cumulative probability distributions.[1] Figure D.1 portrays a hypothetical distribution (after being smoothed to eliminate sample roughness). The X-axis portrays suitable workdays for a week, (i.e., the number of suitable days can be small as zero but cannot exceed seven). The Y-axis portrays the probability that the number of suitable workdays out of seven is 75%. Similarly, point B indicates that the probability of having at least four suitable workdays is 60%.

The component of FDPGEN which simulates the incidence of work days was validated using observations recorded by 16 farmers for 3 years in Huron County, Michigan. Model predictions as to whether or not a day suitable for field work was compared to farmer's observations.

[1]Alternatively, the procedure can be thought of as generating a "histogram" describing the probability distribution of suitable workdays.

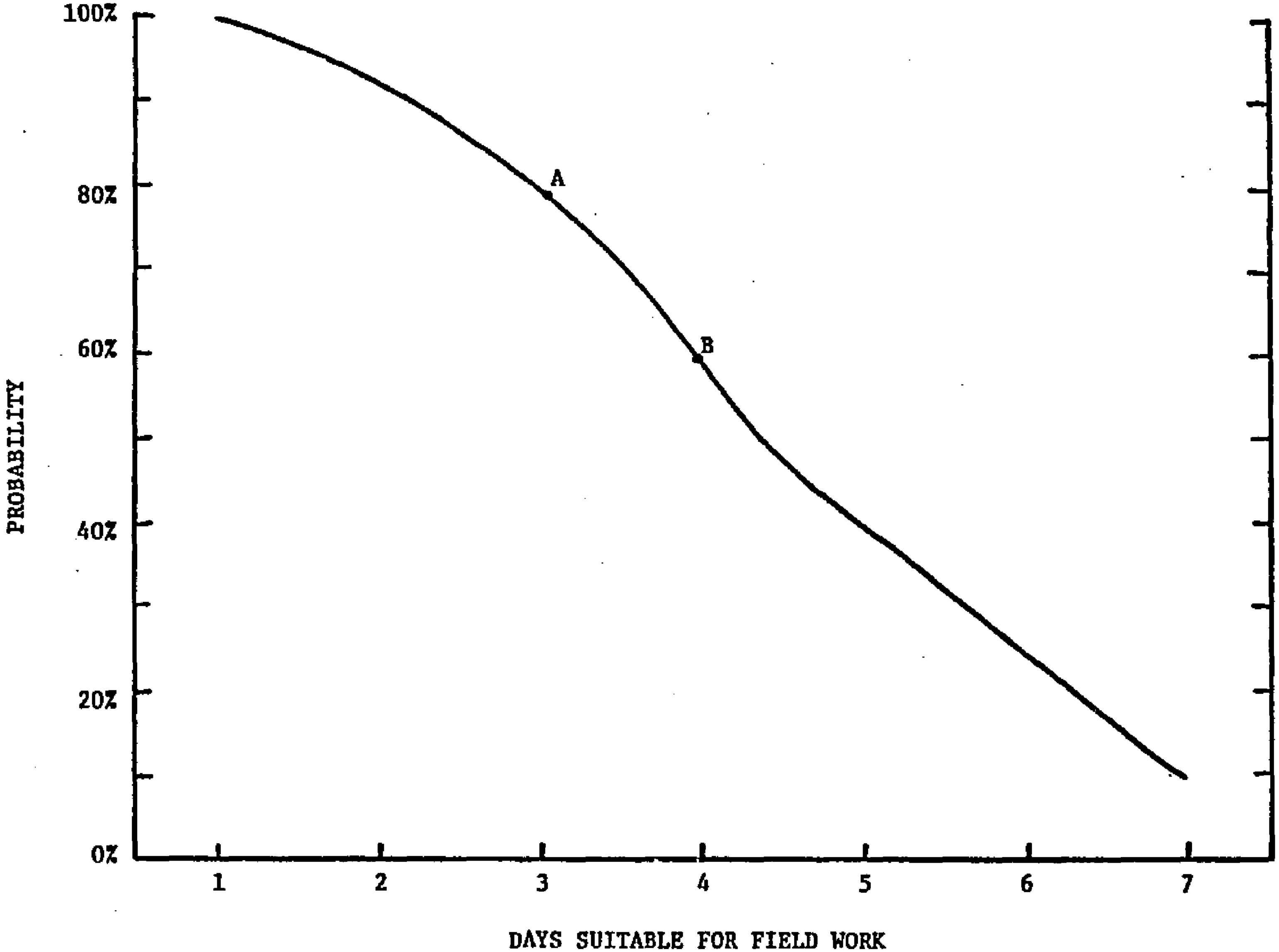

Figure D-1. Number of days per week in which field work can be conducted.

APPENDIX E

SAMPLE FORM USED FOR INDIVIDUAL FARM DATA

This appendix contains forms used to collect individual farm data for 1980 and 1981. Data on cropping sequence, soil types, crop residue, management practices, etc. were collected.

The cooperating farmers were selected by personnel in the Soil Conservation Service (SCS) and the Cooperative Extension Service (CES) in Tuscola and Huron Counties. A farmer is eligible if he leaves a specified amount of crop residue on the soil surface. If eligible, he can participate in Agricultural Stabilization and Conservation Service (ASCS) cost-share program for his conservation tilled acres. Those farmers who were eligible and had contiguous fields of comparable soil type were asked to cooperate. Thus, conventional tillage practices were followed on the companion field. The project had seven cooperators in 1979-80 and 21 cooperators in 1980-81.[1]

Measurements were taken by project staff stationed in Tuscola and Huron Counties and by campus-based Michigan State University personnel contributing to the project. The large geographic scope of the project area and impossibility of covering every cooperating farm in an exhaustive way forced the project to divide the farms into two categories. All operations, including machinery performance, were monitored in one subset; only agronomic and pest monitoring were conducted in the second subset.

[1]The use of the 1980-81 year means fall tillage occurred in the fall of 1980; the remaining operations were conducted in 1981.

The criteria used to select farms to be monitored exhaustively were: soil type, crops grown, proximity to other farms, and the level of willingness and cooperation of the farmer. Based on these criteria, 7 out of 21 participating farms were chosen for the 1980-81 crop year for complete monitoring.

The farm data sheets do not include the name of the farmer, but a number, to preserve participant privacy. The number assigned was based on an alphabetical order of the farmers' names and is not a scale to judge the level of managerial practices of the farmer.

1980

FARMER 4		CO	CT
CROP		Corn	Corn
CROP HISTORY		corn - corn	corn - corn
CROP RESIDUE			
SOIL			
TYPE		Guelph-Londo	Guelph-Londo
MANAGEMENT GROUP		2.5a - 2.5b	2.5a - 2.5b
TILING		Tiled	Tiled
FERTILIZER PROGRAM		300 lb/a K_2O 110 lb/a (16-41-0) 160 lb/a NH_3	300 lb/a K_2O 110 lb/a (16-41-0) 160 lb/a NH_3
PESTICIDE PROGRAM	Herbicide	Atrazine Lasso	Atrazine Lasso
NUTRIENT STATUS (PLANT CHARACTERISTICS)			

		CO	CT
PLANT			
VARIETY		66% (3901), 33% (3958)	66% (3901), 33% (3958)
SEED TREATMENT			
DATE OF PLANTING		5-18-80	5-18-80
SEEDING RATE		27500/acre	27500/acre
DATE OF EMERGENCE		13.50"	13.0"
PLANTS/ACRE (6/18)		17170/a	21500/a
HEIGHT AFTER 4 WEEKS (6/18)			
SPACING		28"	28"
YIELD			
TARGET		150 bu/a	150 bu/a
ACTUAL		148.1 bu/a	147.9 bu/a
OPERATIONS PERFORMED			
FALL		Plowed 9-10"	Soil saved 9"
SPRING		1 field cultivator	1 field cultivator
INSECT POPULATION		None	None
WEED POPULATION		None	None
DISEASE		None	None
OTHER OBSERVATIONS	Planter Tractor used	JD 12 row JD 4320 (planting) Steiger (tillage) Bear Cat	JD 12 row JD 4320 (planting) Steiger (tillage) Bear Cat

1981

FARMER 4		CO	CT
CROP		Corn	Corn
CROP HISTORY		corn, corn	corn, corn
CROP RESIDUE		1900 lb/a	1900 lb/a
SOIL			
TYPE		Guelph-Londo	Guelph-Londo
MANAGEMENT GROUP		2.5a-2.5b	2.5a-2.5b
TILING		Tiled	Tiled
FERTILIZER PROGRAM	Fall Spring	350 lb/a (5-14-13) 20 gal/a (8-25-3)	350 lb/a (5-14-13) 20 gal/a (8-25-3)
PESTICIDE PROGRAM	Insecticide Herbicide	7 lbs/a Dyfonate 2 lbs/a Atrazine 2 qt/a Lasso (20 gal H_2O)	7 lb/a Dyfonate 2 lbs/a Atrazine 2 qt/a Lasso (20 gal H_2O)
NUTRIENT STATUS (PLANT CHARACTERISTICS)			

	CO	CT
PLANT		
VARIETY	3901 Pioneer	3901 Pioneer
SEED TREATMENT		
DATE OF PLANTING		
SEEDING RATE	27850/a	27850/a
DATE OF EMERGENCE		
PLANTS/ACRE		
HEIGHT AFTER 4 WEEKS		
SPACING	30"	30"
YIELD		
TARGET	150 bu/a	150 bu/a
ACTUAL		
OPERATIONS PERFORMED	Moldboard plow	Soil save
FALL		
SPRING	Field cultivate	Field cultivate
INSECT POPULATION		
WEED POPULATION		
DISEASE		
OTHER OBSERVATIONS		
Planter	12 rows	12 rows
Planting tractor	JD 4320 (130 HP)	JD 4320 (130 HP)
Tillage tractor	Steiger (225 HP)	Steiger (225 HP)

APPENDIX F

SOIL MANAGEMENT GROUPS REPRESENTED IN THE PROJECT AREA

Soil Management Groups and Units[1]

Soil management groups are groups of soils (soil series) with similar properties and yield potentials. The groups are formed on the basis of the dominant texture of the upper 60 inches of the profile and the natural drainage conditions under which the soils were formed. Numbers are used to identify the dominant texture of the profile (from 0 for fine clays to 5 for sands) and lower case letters to indicate the natural drainage conditions ("a" for well drained to "c" for poorly drained). The interrelationships and symbols of soil management groups, as related to corn production in Michigan, are shown in Table D.1. In this table, the dominant texture of the profile is emphasized--not the texture of the surface soil, as in soil type identifications. Thus soil series serve as the basis for groupings.

Soil management units are less inclusive than soil management groups in that the unit concept recognizes the slope which is indicated with the capital letters A through F. Severe and very severe erosion conditions are shown by the numbers 3 and 4 respectively. Thus, a 1.5aC3 symbol for a soil management unit represents soils whose profiles are dominatey clay loam, naturally well drained, have a slope ranging between 6 and 12 percent and are severely eroded. Each characteristic is important in evaluating opportunities for success with alternative tillage systems.

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[1]Adapted from Robertson, et al (1976). The authors are Michigan State University and Soil Conservation Service Crop and Soils Scientists.

Opportunities and Problems

Minimum tillage is defined as "the least tillage necessary for rapid seed germination, and a good stand". No-till is a minimum tillage method. This definition does not state that tillage is essential. It implies that tillage should be done only if there is a good reason.

Degree of Slope

In general, where average slopes are less than 2 percent (Slope Class A) other minimum tillage methods usually result in fewer production problems, especially those related to soil structure, insects and rodents. Therefore, other minimum tillage methods are recommended over no-till unless slopes are long and unless wind erosion is a problem, which is likely on the more sandy (3, 3/1, 3/2, 3/5, 4, 4/1, 4/2, 5 or 5/2 groups) and organic soils (M, M/3, M/4 or M/m groups).

On steeper slopes, averaging between 2 and 6 percent (Slope Class B) soil erosion can be a significant problem. If soils are in good physical condition, minimum tillage methods can be successfully used not only to produce high yields, but to reduce soil erosion. Where soils are compact, other minimum tillage methods involving chisel plows have been more successful.

If slopes averaging 6 to 18 percent (Slope Classes C and D) are used for corn production, only no-till methods should be employed, preferably in combination with other conservation practices, such as strip-cropping. Otherwise, excessive erosion is likely to occur even with other minimum tillage methods. Where slopes are in excess of 18 percent (Slope Classes E and F), and especially if they are long, corn should not be grown because of excessive surface water runoff and perpetual erosion problems.

Soil Texture

The best no-till soils are the naturally well-drained sandy loam soils, 3a, 3/2a and 3/5a management groups. Most other soils, especially those with a fine-textured surface horizon, have real problems that must be recognized and solved if no-till methods are to be effective.

"Good" in Table F.2 suggests that these soils are best suited to no-till methods. This evaluation is based upon the assumption that the soils have a desirable physical condition and that herbicides are effective.

The finer-textured soils naturally tend to be compact and to crust. On such soils, this is likely to be a problem every year with no-till methods. If field operations occur at high moisture levels, the amount of compaction increases, thus reducing opportunities for success.

Natural Drainage

In general, the naturally somewhat poorly drained "b" soils and the poorly drained "c" soils should be tilled and (or) ditch drained before no-till methods are attempted. The high soil moisture problem may be intensified where large volumes of crop residues on the soil surface retard evaporation rates. No-till should not be considered as a substitute for artificial drainage in these groups.

Organic Matter

Success with minimum till depends upon the effective use of herbicides. Successful herbicide treatment is closely related to the colloidal content (clay and organic matter) of the soil. To date, herbicides have been less successful on the poorly and very poorly drained "c" soils, both mineral and organic, primarily because such soils have relatively high organic matter levels. Increased rates of herbicide application or different kinds of herbicides than normally considered are commonly needed for control of weeds on such soils.

Covert - Sand (5a)

Covert soils are nearly level or gently sloping and are moderately well drained. The surface layer typically is very dark grayish brown sand about 4 inches thick. The subsurface layer is light brownish gray sand about 6 inches thick. The subsoil, about 25 inches thick, is strong brown and brownish yellow loose sand.

The substratum is light yellowish brown sand to a depth of about 60 inches.

Bach Silty Loam (2.5c-cs)

Bach soils are nearly level and are poorly drained or very poorly drained. The surface layer typically is very dark grayish brown calcareous silk loam about 10 inches thick. The subsoil is light brownish gray very fine sandy loam about 20 inches thick. The substratum, to a depth of about 60 inches, is pale brown and brown, stratified.

Shebeon Loam (2.5b-d)

Minor soils in this map unit are the somewhat poorly drained Shebeon and Avoca soils, the poorly or very poorly drained Bach and Essexville soils, and the poorly drained Kilmanagh soils. Scattered raised areas are occupied by the Shebeon soils. Sandy ridges throughout the unit are occupied by the Avoca soils. Areas of the stratified Bach soils, the noncalcareous Kilmanagh soils, and the sandy Essexville soils are closely intermingled with areas of the Tappan soils.

Tappan London (2.4cc-2.5b)

Tappan soils are nearly level and are poorly drained. The surface layer typically is very dark grayish brown, calcareous loam about 13 inches thick. The subsoil, about 18 inches thick, is light brownish gray to dark yellowish brown loam and silt loam and gray loam. The substratum is yellowish brown loam and silt loam and gray loam. The substratum is yellowish brown loam to a depth of 60 inches.

Londo soils are nearly level and are somewhat poorly drained. The surface layer typically is very dark grayish brown loam about 9 inches thick. The subsoil is about 11 inches thick and is brown and yellowish brown, mottled loam and clay loam. The substratum is brown, mottled loam till to a depth of 60 inches.

Kilmanagh (2.5c)

Kilmanagh soils are nearly level and are poorly drained. The surface layer typically is very dark gray loam or cobbly loam about 9 inches thick. The subsoil is about 20 inches thick, and is gray and dark yellowish brown, mottled loam. It is underlain by dark yellowish brown and brown, mottled, friable and very firm loam to a depth of 60 inches.

Guelph (2.5a-2.5b)

Guelph soils are gently undulating or rolling and are moderately well or well drained. The surface layer typically is dark brown loam about 9 inches thick. The subsoil, about 12 inches thick, is dark brown and dark yellowish brown clay loam. The substratum is brown and dark brown loam to a depth of 60 inches.

Parkhill (2.5c)

Parkhill soils are nearly level and are poorly drained or very poorly drained. The surface layer typically is very dark grayish brown loam about 9 inches thick. The subsoil, about 23 inches thick, is grayish brown mottled, firable loam. The underlying material, to a depth of about 60 inches, is grayish brown, mottled loam.

Summary

Soils differ in their suitability to no-till methods. The use of the soil management group and unit concept is an aid in predicting where high or low levels of success are likely. Soils best suited to no-till methods are those that are sandy loam or loam textured and well drained. Production problems are usually greater on naturally poorly and very poorly drained soils and those which contain relatively large amounts of clay.

APPENDIX G

DATA AND GROUPING OF FARMERS ACCORDING TO TILLAGE PRACTICES IN TUSCOLA COUNTY

A survey (Figure G.1) was conducted in the winter of 1980 to determine tillage methods commonly used on corn, navy beans, sugar beets and soybeans in Tuscola County, Michigan. The questions farmers were asked are given in Table G.1. Farmers surveyed were cash crop farmers whose names were on the Tuscola Cooperative Extension Service mailing list. There were 122 valid responses out of 160 received; others were discarded because farmers leased their land or did not fill out the forms properly.

The detailed data are presented in the section that follows (pages 269-299). Most farmers did not practice reduced tillage, and none practiced no-till farming. A majority of the farmers moldboard plow their land in the fall. Only 20%, 16%, 16% and 21% of those who grew corn, navy beans, sugar beets, and soybeans respectively, practiced deep tillage in the fall using a subsoiler (Figure 1.3) which penetrated the soil to a depth of 14-26 inches.

Of those who deep till corn fields, 62% followed deep tillage with moldboard plowing; 78% performed in the fall and 22% in the spring. Of those who deep tilled harvested sugar beet fields, 64% followed deep tillage with moldboard plowing; 78% performed in the fall and 22% in the spring. Of those who deep tilled harvested sugar beet fields, 64% followed deep tillage with moldboard plowing with 57% performed in the fall and 43% in the spring. Of those that deep tilled soybeans, 50% moldboard plowed in the fall. Of those that deep tilled after navy beans, 88% used the moldboard plow; 53% plowed in the fall and 47% in the spring.

Of those who did not deep till, only 12% used a chisel plow on corn, 9% on navy beans, 21% on sugar beets and 34% on soybeans. Of the rest, 92% moldboard plowed corn fields in the fall, 52% navy beans, 98% sugar beets and 89% soybeans.

The raw data were arranged according to crop, tillage practices, and time of year when the tillage practice was performed. Following through an example of the flow charts will give a clear image of how farmers are grouped. Corn will be used as an example (color code yellow). Eighty-five farmers did not deep till; 21 did. Of those deep tilling, 18 used a multiple shank subsoiler while 3 used a single shank subsoiler. Of those using a multiple shank subsoiler, 16 used it in the fall and 2 used it in the spring. Of the 16 farmers using the multiple shank subsoiler in the fall, ten farmers went over the field once in the fall while 6 went over the field twice. Seven of those 10 farmers subsoiled no deeper than 14 inches, while 3 subsoiled deeper than 14 inches. We now turn to four pages later, following the OFF-THE-PAGE CONNECTOR E, to find the primary and secondary tillage practices of the 7 farmers of those who deep tilled to a depth of less than 14 inches. Three moldboard plowed; all moldboard plowing was conducted in the fall and at a depth in excess of 7 inches, the remainder chisel plowed. These 3 farmers used standard[1] row crop planters and cultivated 3 times and harrowed twice. Only one farmer used a row

[1]Standard row crop planters are not suitable for conservation tilled or no-till fields because they lack the special corrugated coulter needed in such cases.

crop planter larger than 6 rows; the others used planters that were 6 rows or less.

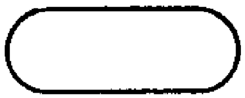
Name ______________________________ Address ______________________________

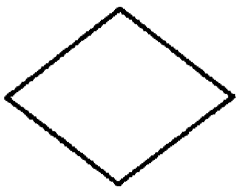
Township ____________________ Section ________________

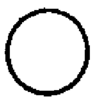
			Beans	Beets	Corn	Soys
I Deep Tillage						
1. Implement:	a.	Single chisel subsoiler	-	-	-	-
	b.	Multiple shank subsoiler	-	-	-	-
2. Time:	a.	August - September	-	-	-	-
	b.	October - November	-	-	-	-
	c.	March - April	-	-	-	-
3. Treatment:	a.	One	-	-	-	-
	b.	Two	-	-	-	-
4. Depth:	a.	10 - 14 inches	-	-	-	-
	b.	14 - 18 inches	-	-	-	-
	c.	18 - 22 inches				
II Primary Tillage						
1. Implement:	a.	Moldboard plow	-	-	-	-
	b.	Chisel plow	-	-	-	-
	c.	Rotary	-	-	-	-
	d.	Disc	-	-	-	-
2. Depth:	a.	4 - 7 inches	-	-	-	-
	b.	7 - 10 inches	-	-	-	-
	c.	More than 10 inches	-	-	-	-
3. Time:	a.	March - April	-	-	-	-
	b.	May - June	-	-	-	-
	c.	September - October	-	-	-	-
	d.	November - December	-	-	-	-
III Secondary Tillage						
1. Implement:	a.	Disc	-	-	-	-
	b.	Field cultivator	-	-	-	-
	c.	Harrow	-	-	-	-
	d.	Mulcher	-	-	-	-
	e.	Cultipacker	-	-	-	-
	f.	Rotary hoe	-	-	-	-
	g.	Two of above used in tandem	-	-	-	-
IV Planter						
1. Type	a.	Standard	-	-	-	-
	b.	No-Till	-	-	-	-
2. Size	a.	4 - 6 rows	-	-	-	-
	b.	8 - 12 rows	-	-	-	-
	c.	16 or more rows	-	-	-	-
V Average number of passes with tractor after primary tillage. (Include pesticide application, incorporation and planting.)						
	a.	1 - 2	-	-	-	-
	b.	3 - 4	-	-	-	-
	c.	5 - 6	-	-	-	-
	d.	7 - 8	-	-	-	-
	e.	More than 8	-	-	-	-

Figure G-1. Questionnaire Used for the Survey

KEY TO FLOWCHARTS

 = terminal (start or end)

 = decision

 = off-page connector

NP = not practiced

STD = standard planter type

NT = no-till planter

Secondary Tillage Implements:

a = disc

b = field cultivator

c = harrow

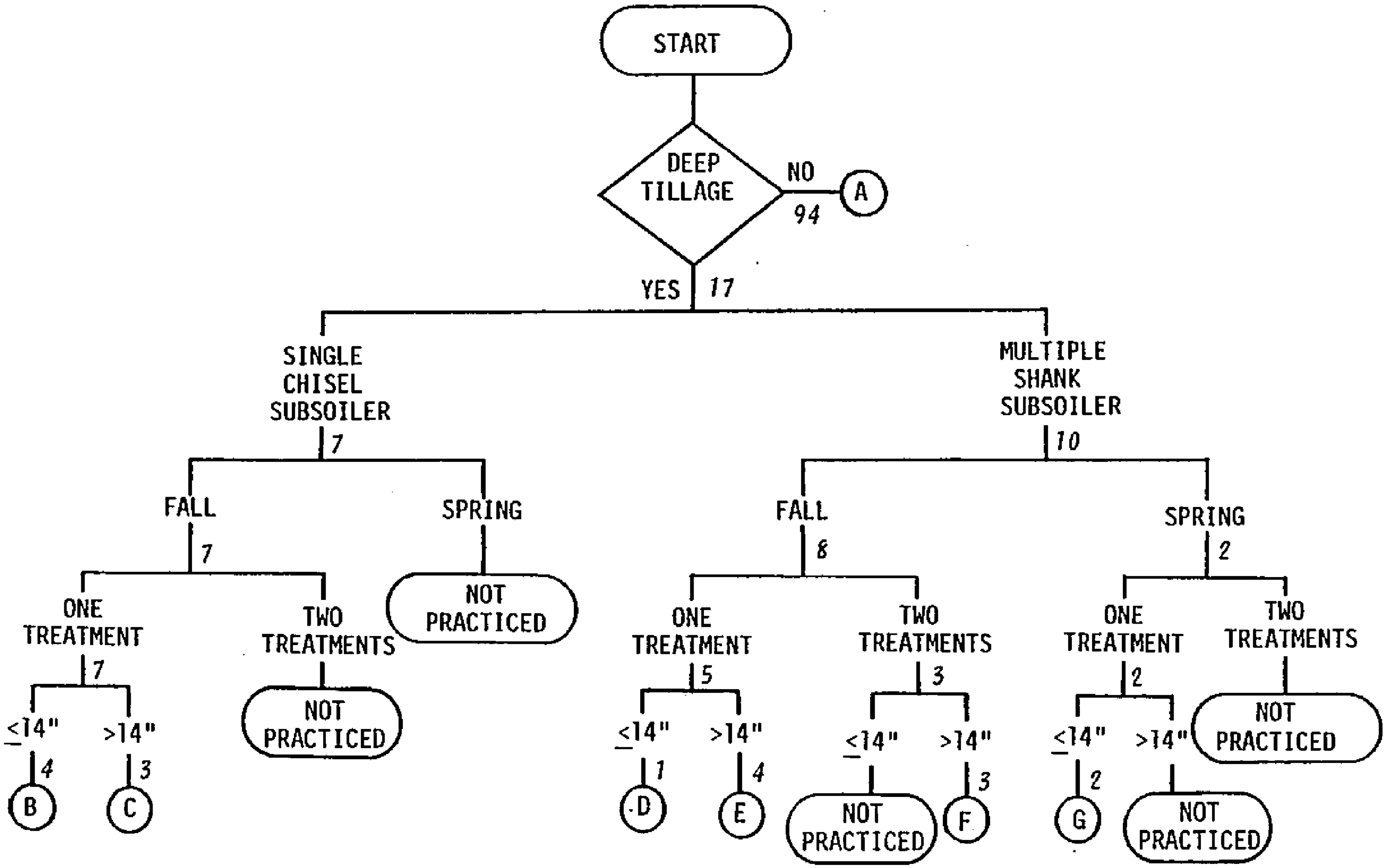
d = mulcher

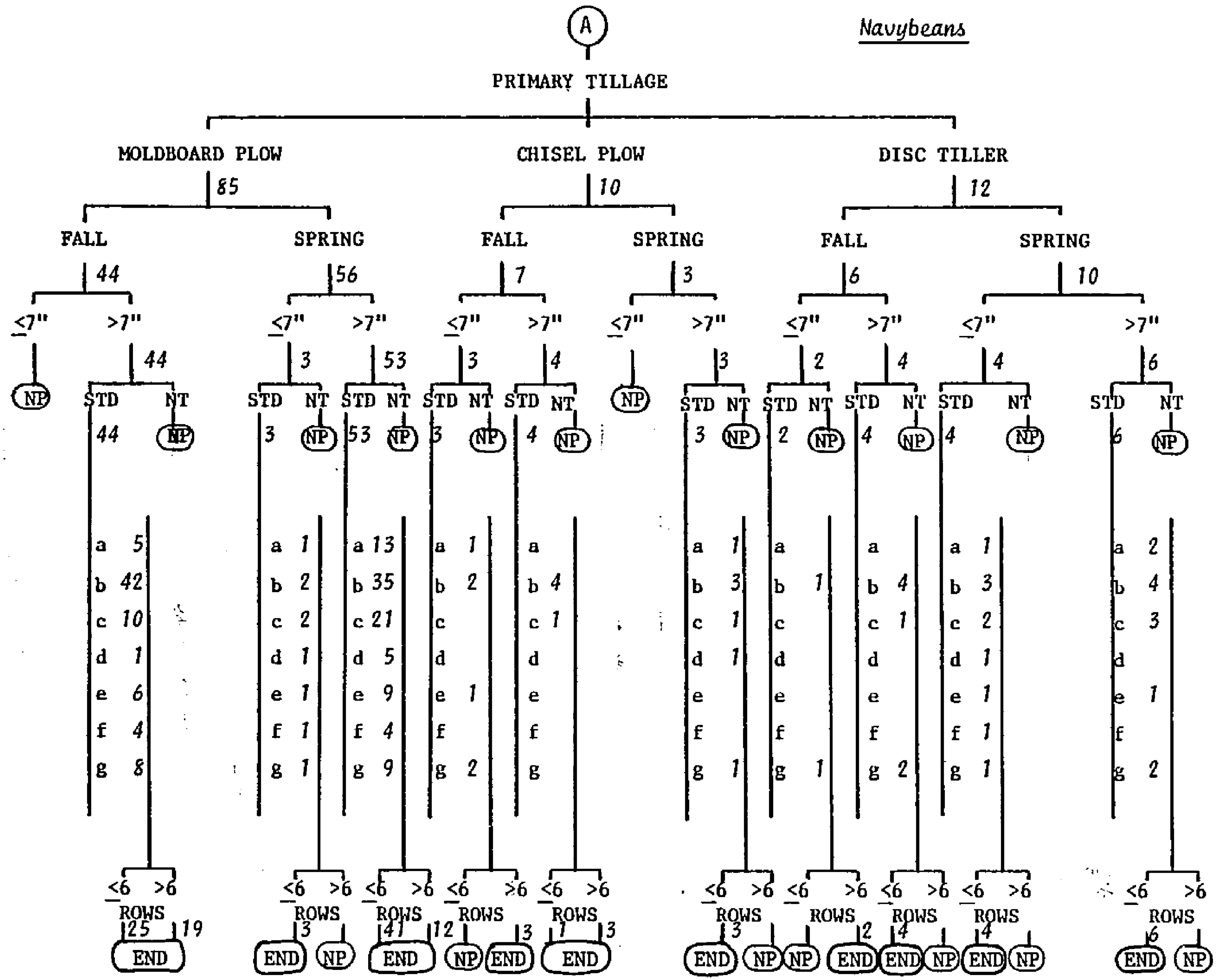
e = cultipacker

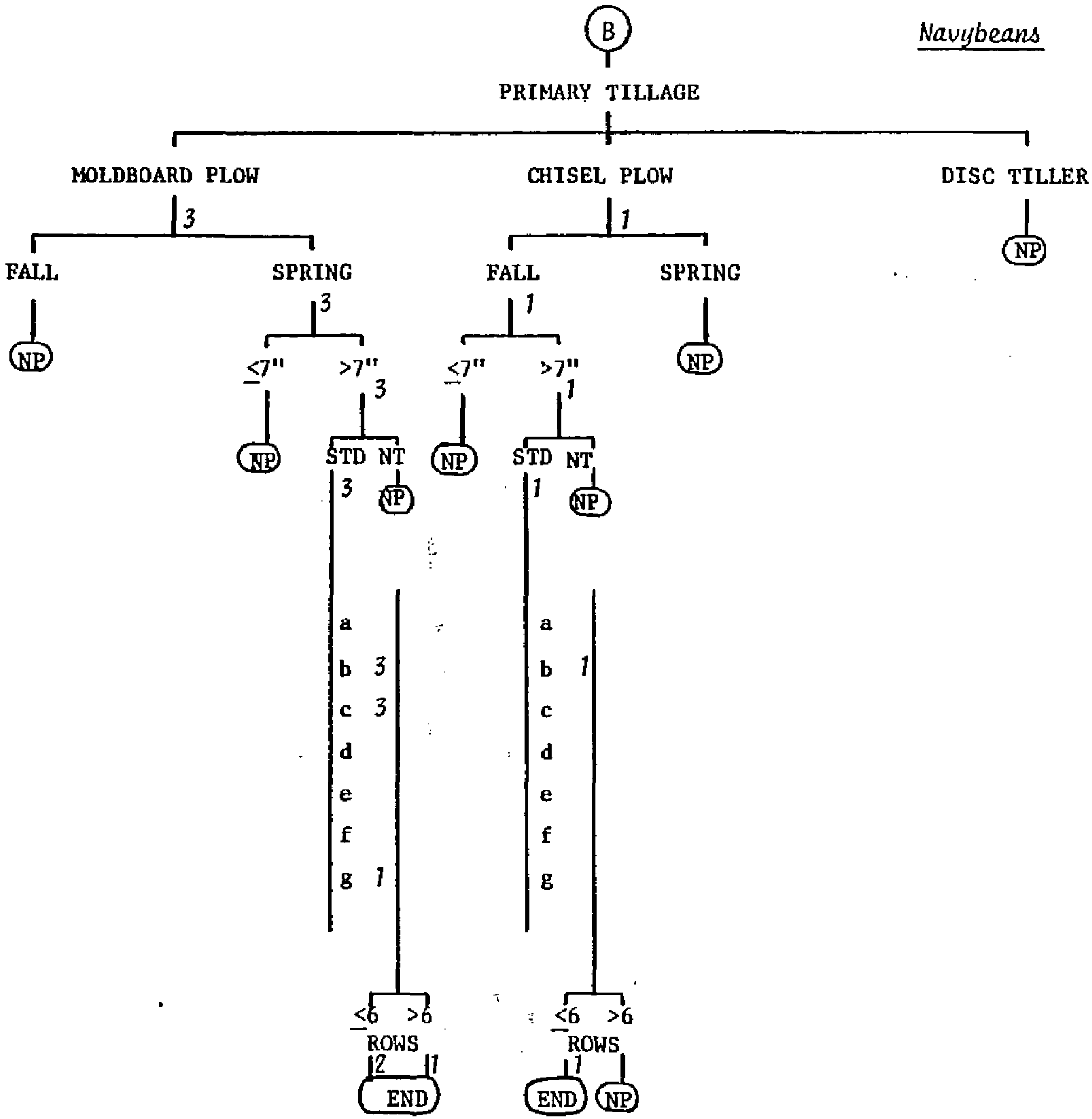
f = rotary hoe

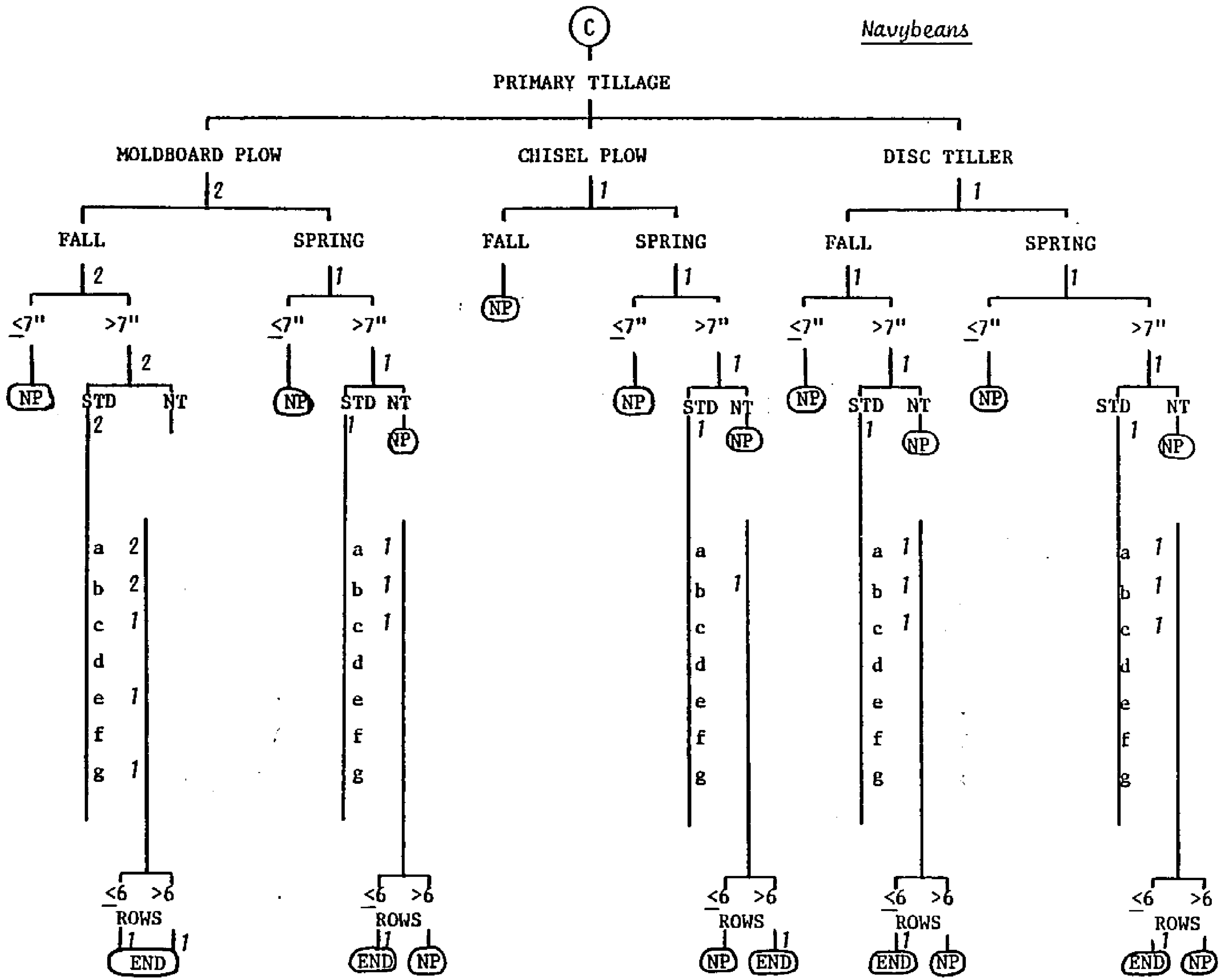
g = two of the above used in tandem

CROP *Navybeans*

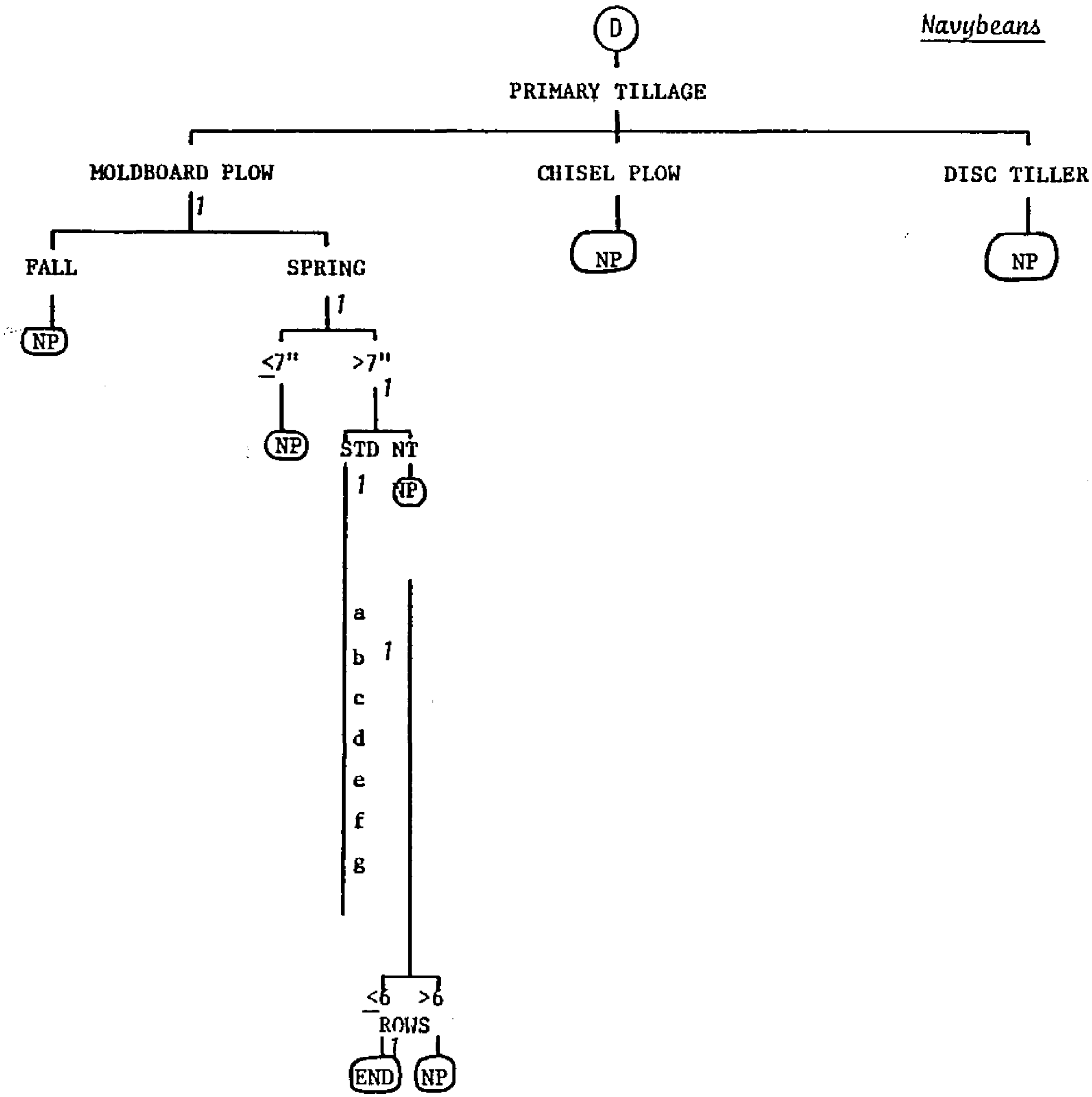


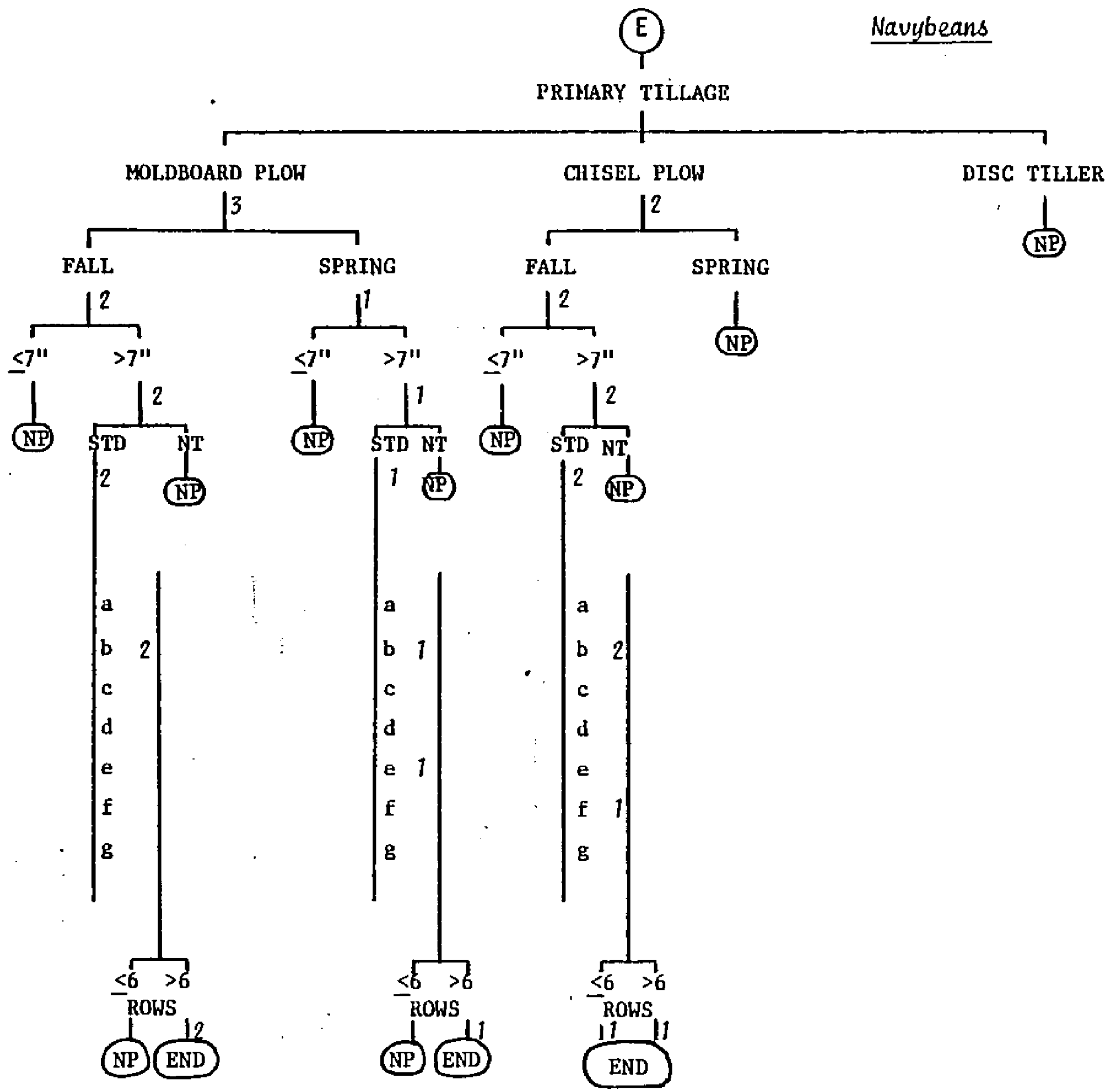

A
Navybeans
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
STD
NT
NP
END
ROWS


B
Navybeans
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
3
1
FALL
SPRING
FALL
SPRING
NP
NP
NP
3
1
≤7"
>7"
≤7"
>7"
3
1
NP
NP
STD
NT
STD
NT
3
1
NP
NP
a
b 3
c 3
d
e
f
g 1
a
b 1
c
d
e
f
g
≤6
>6
ROWS
≤6
>6
ROWS
2
1
1
END
END
NP

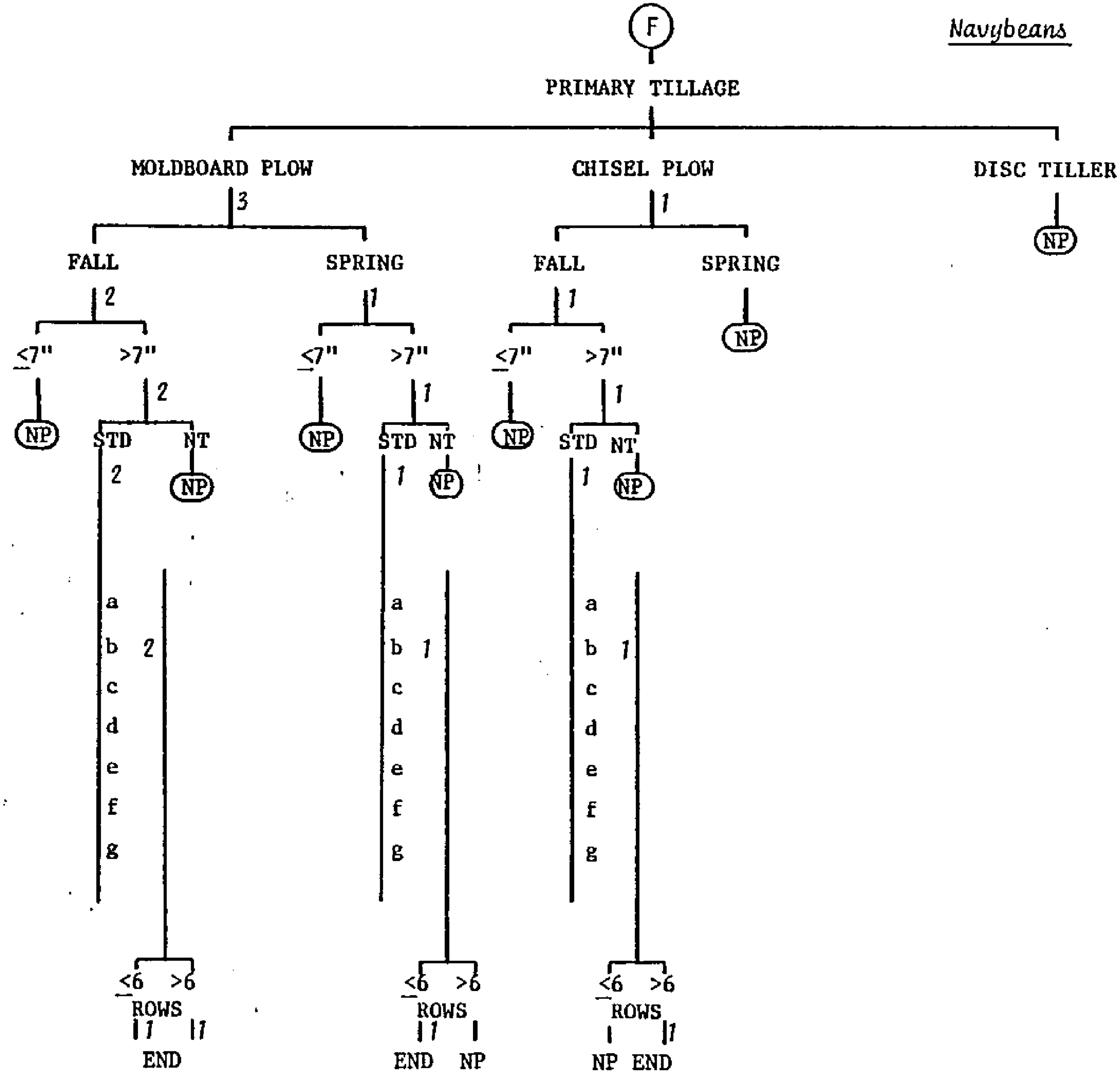

Navybeans
C
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
≤7"
>7"
STD
NT
NP
a
b
c
d
e
f
g
≤6
>6
ROWS
END

Navybeans

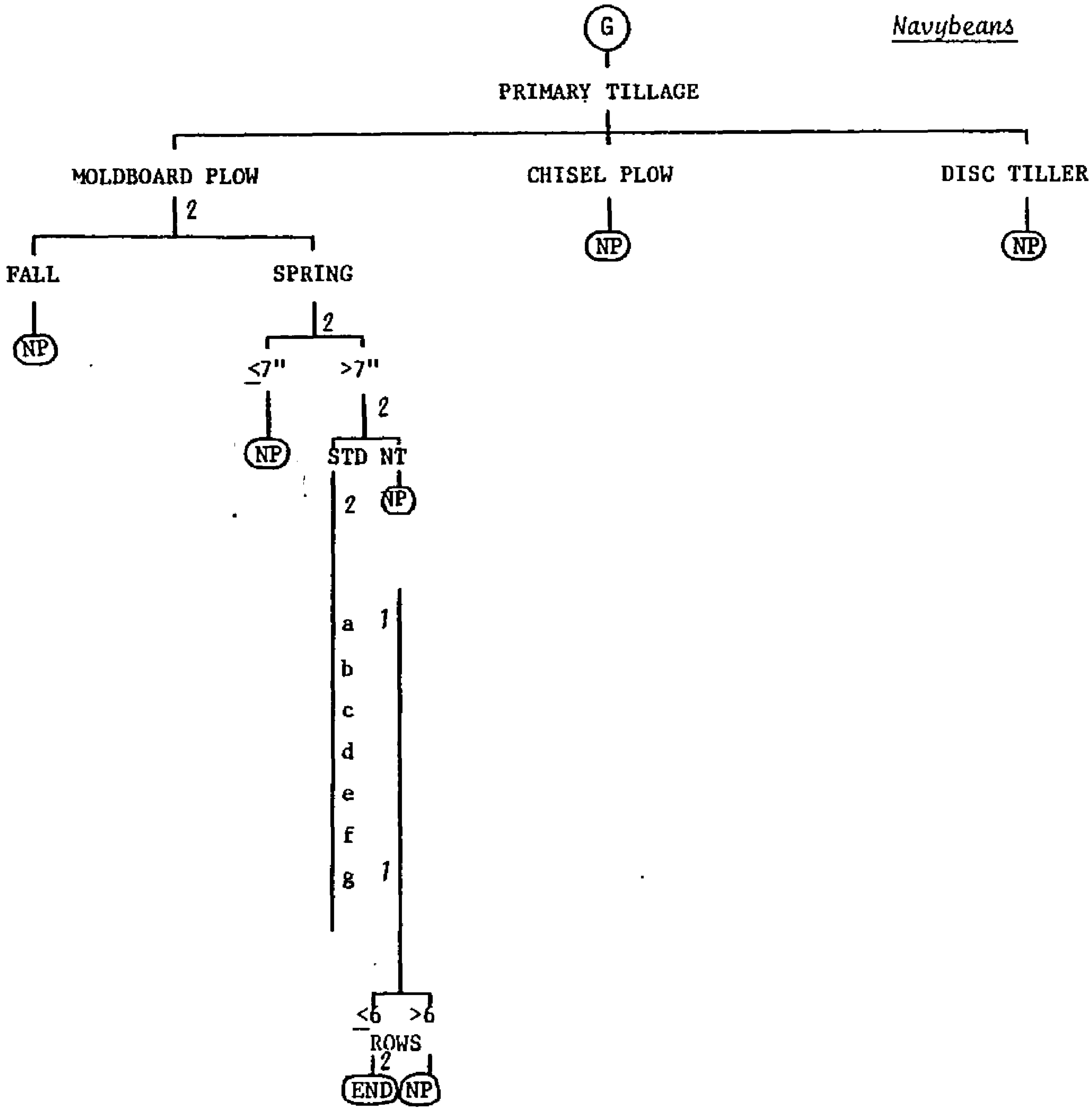

D
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
1
FALL
SPRING
NP
NP
NP
1
≤7"
>7"
1
NP
STD
NT
1
NP
a
b
c
d
e
f
g
1
≤6
>6
ROWS
1
END
NP


E
Navybeans
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
STD
NT
NP
a
b
c
d
e
f
g
≤6 >6
ROWS
END

Navybeans

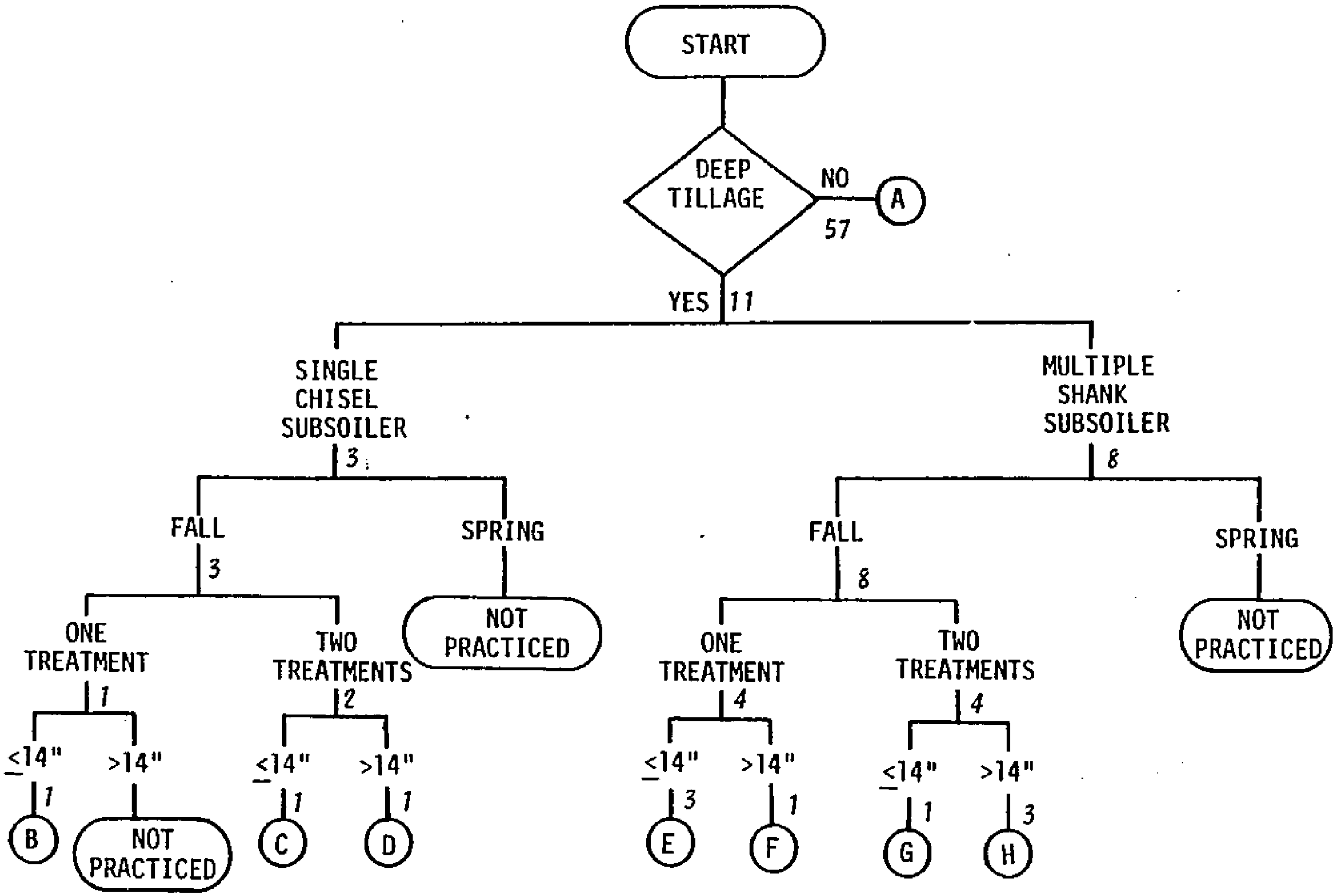

F
PRIMARY TILLAGE
MOLDBOARD PLOW
3
CHISEL PLOW
1
DISC TILLER
NP
FALL
2
SPRING
1
FALL
1
SPRING
NP
≤7"
>7"
2
NP
STD
NT
2
NP
a
b
c
d
e
f
g
2
≤6 >6
ROWS
1 1
END
≤7"
>7"
1
NP
STD NT
1
NP
a
b
c
d
e
f
g
1
≤6 >6
ROWS
1
END NP
≤7"
>7"
1
NP
STD NT
1
NP
a
b
c
d
e
f
g
1
≤6 >6
ROWS
1
NP END

Navybeans



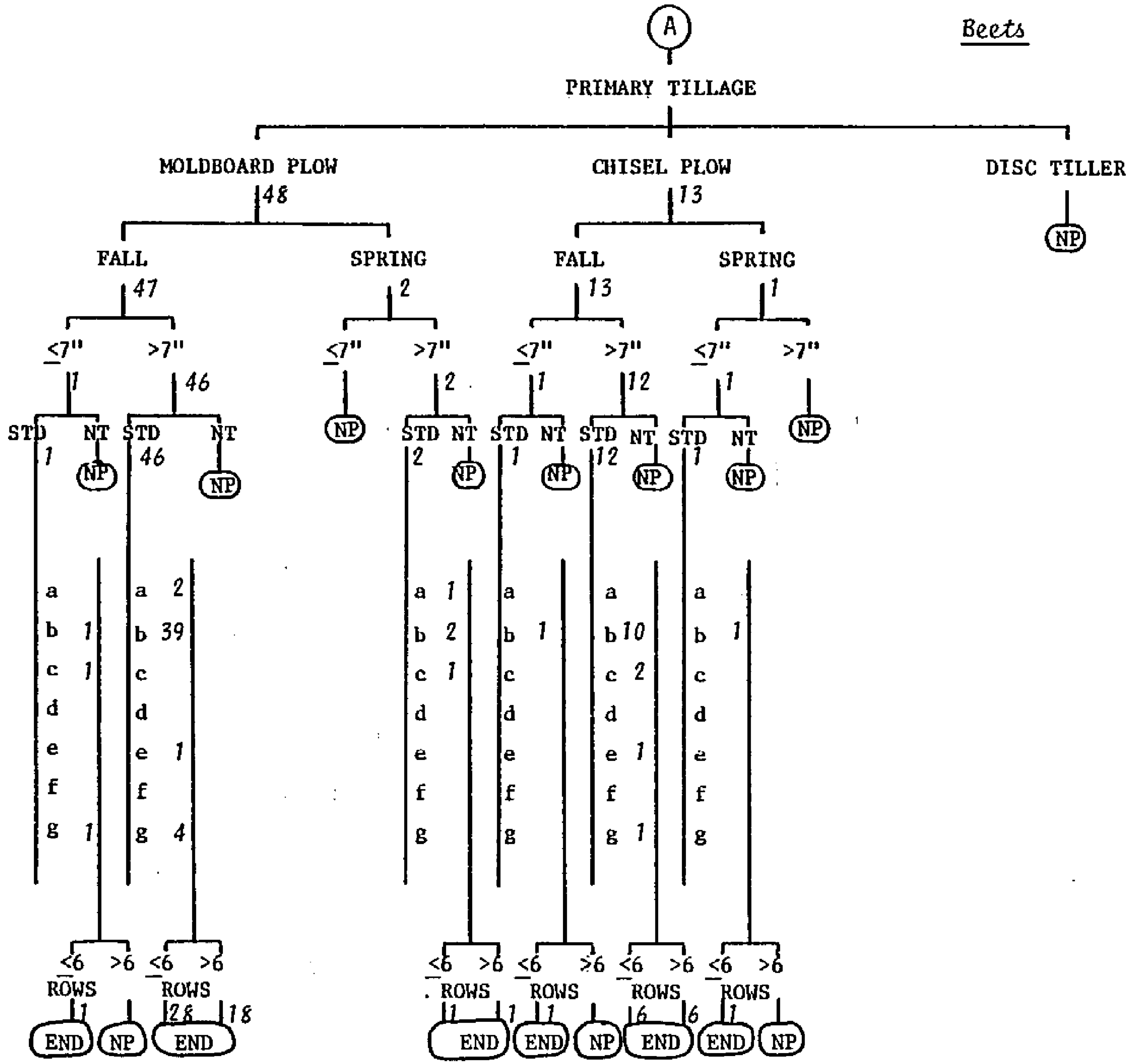
G
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
2
FALL
SPRING
NP
NP
NP
2
≤7"
>7"
2
NP
STD
NT
2
NP
a
b
c
d
e
f
g
1
1
≤6
>6
ROWS
2
END
NP

CROP *Beets*

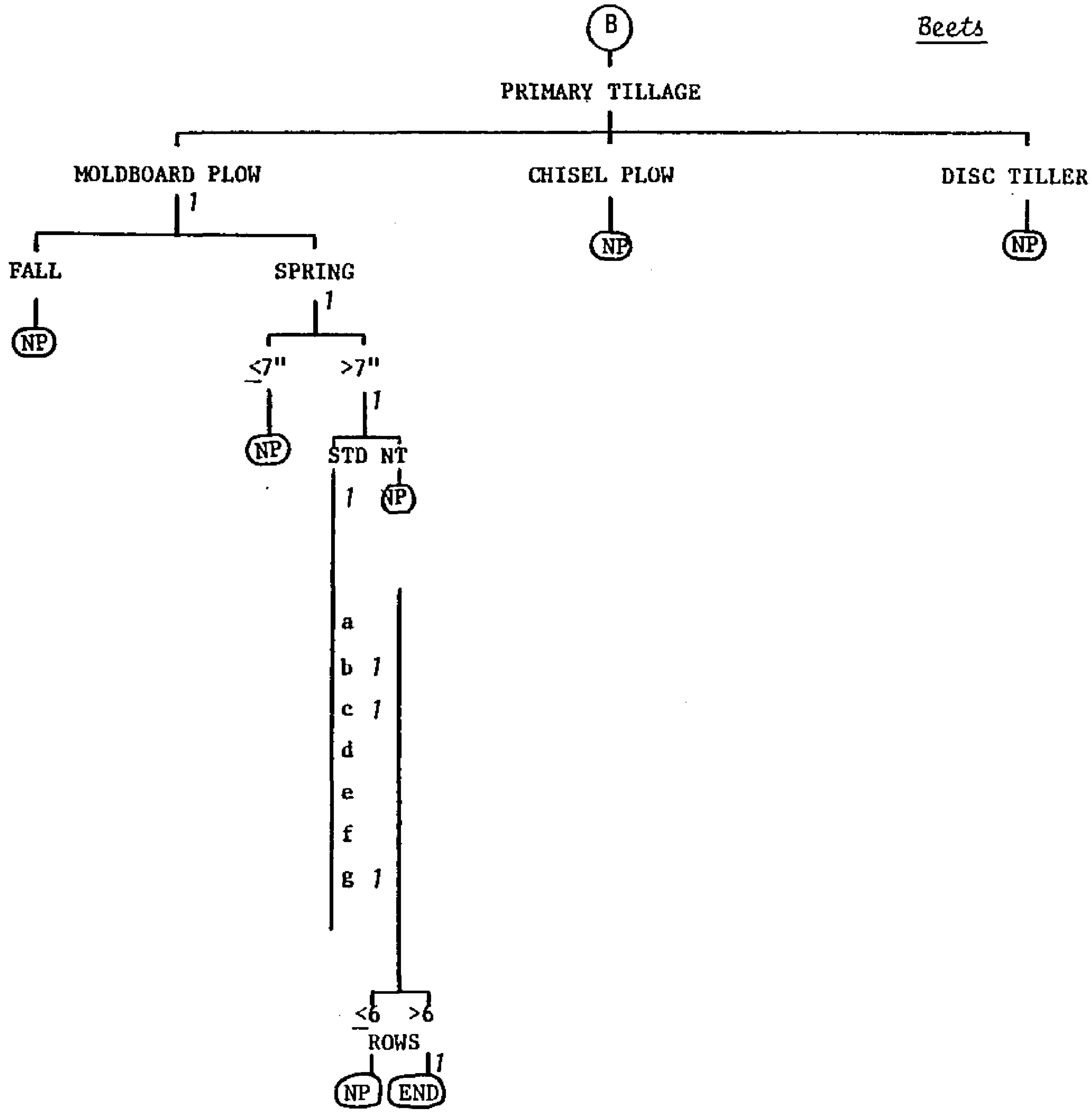


START
DEEP TILLAGE
NO
57
A
YES
11
SINGLE CHISEL SUBSOILER
3
MULTIPLE SHANK SUBSOILER
8
FALL
3
SPRING
NOT PRACTICED
ONE TREATMENT
1
TWO TREATMENTS
2
≤14"
>14"
1
1
1
B
NOT PRACTICED
C
D
FALL
8
SPRING
NOT PRACTICED
ONE TREATMENT
4
TWO TREATMENTS
4
≤14"
>14"
3
1
1
3
E
F
G
H

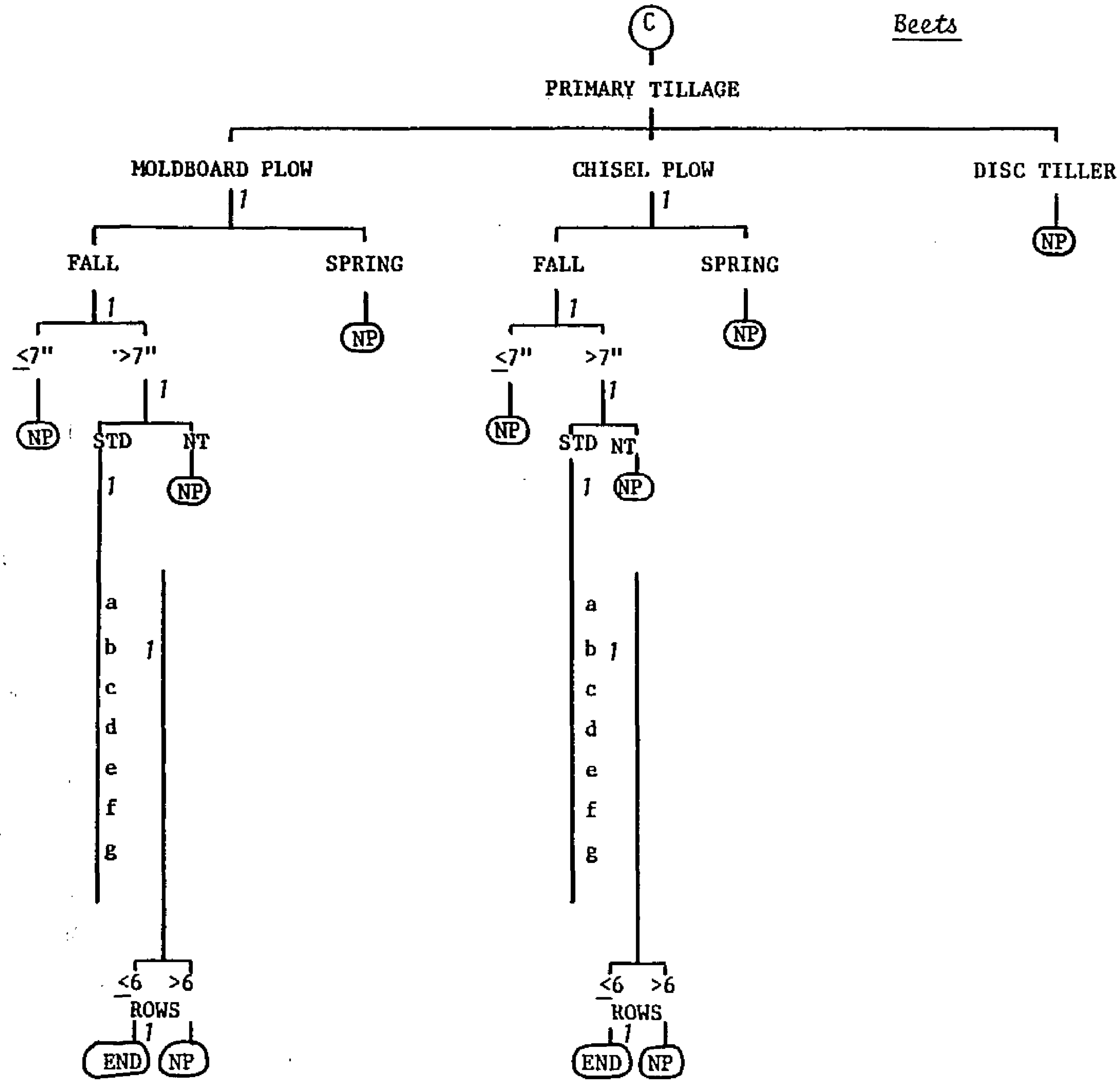
Beets



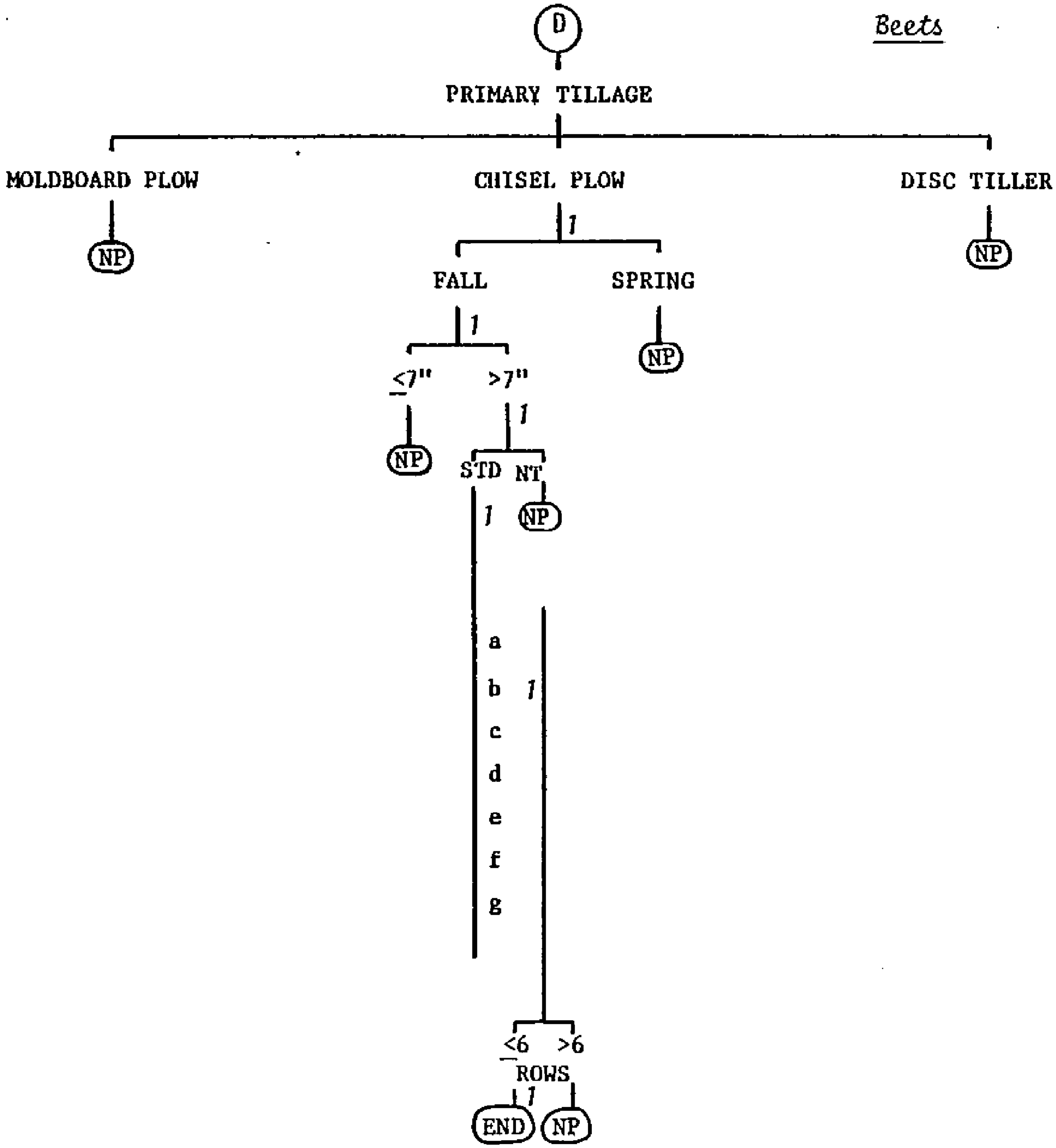
A
PRIMARY TILLAGE
MOLDBOARD PLOW
48
CHISEL PLOW
13
DISC TILLER
NP
FALL
47
SPRING
2
FALL
13
SPRING
1
≤7"
>7"
1
46
2
1
12
STD
NT
1
46
2
12
NP
a
b
c
d
e
f
g
a 2
b 39
e 1
g 4
b 1
c 1
g 1
a 1
b 2
c 1
b 10
c 2
e 1
g 1
<6
>6
ROWS
1
28
18
6
END


Beets
B
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
1
NP
NP
FALL
SPRING
NP
1
≤7"
>7"
NP
1
STD
NT
1
NP
a
b 1
c 1
d
e
f
g 1
≤6
>6
ROWS
1
NP
END

Beets

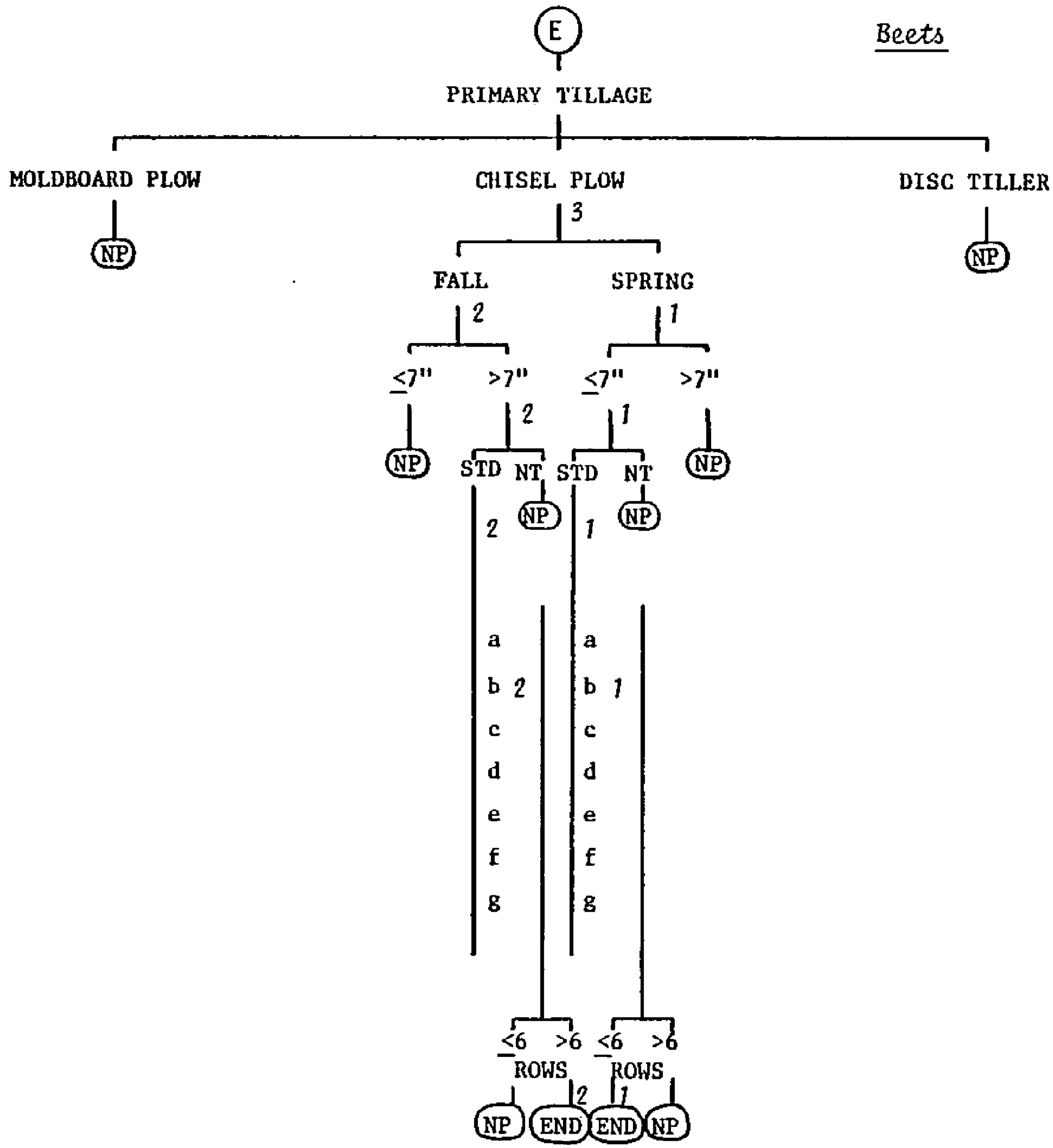

C
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
FALL
SPRING
NP
NP
NP
≤7"
>7"
≤7"
>7"
NP
STD
NT
NP
STD
NT
NP
a
b
c
d
e
f
g
a
b
c
d
e
f
g
≤6 >6
ROWS
END
NP
≤6 >6
ROWS
END
NP

Beets

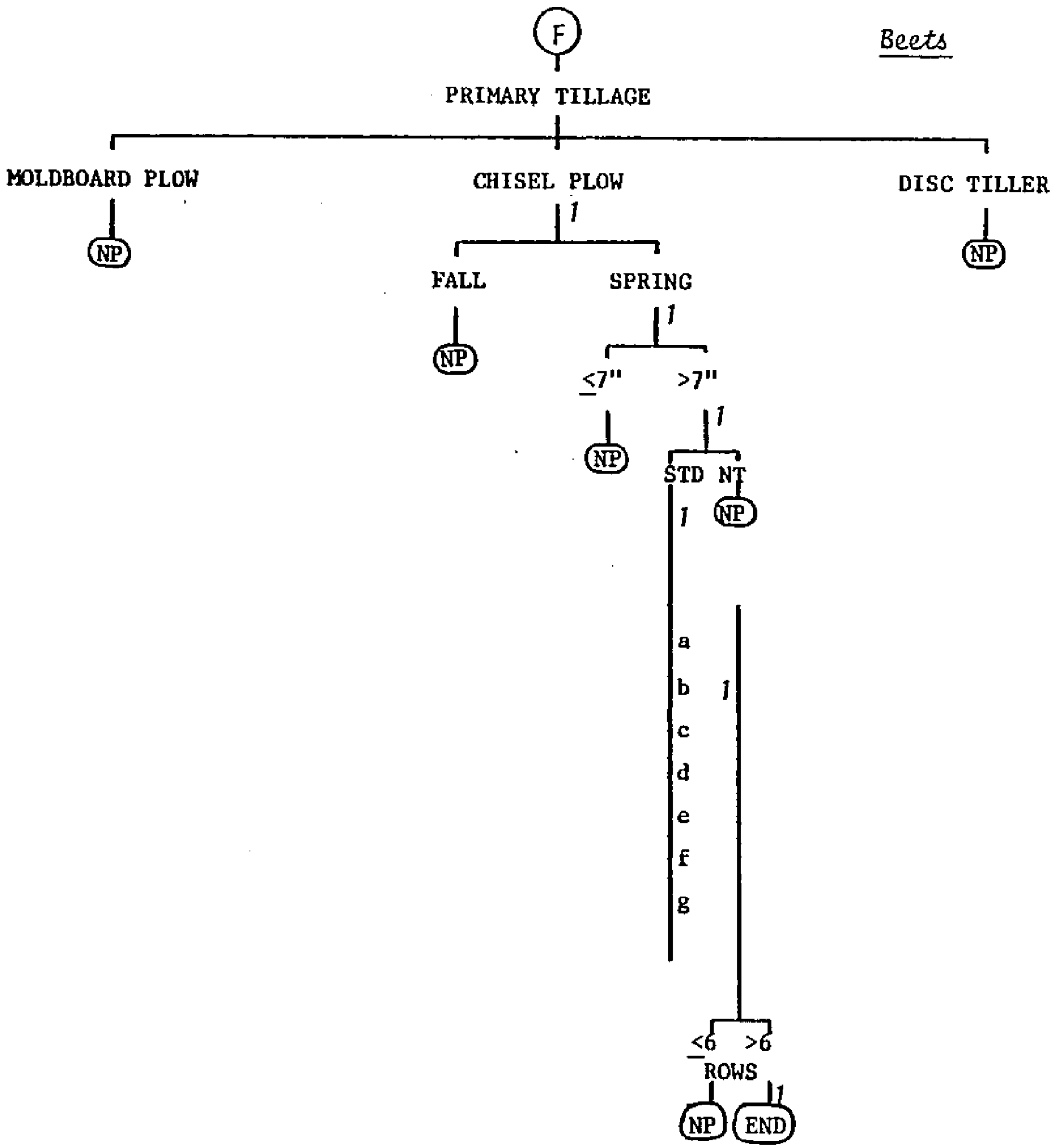


D
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
1
FALL
SPRING
NP
1
≤7"
>7"
NP
1
STD
NT
1
NP
a
b
c
d
e
f
g
1
≤6
>6
ROWS
1
END
NP

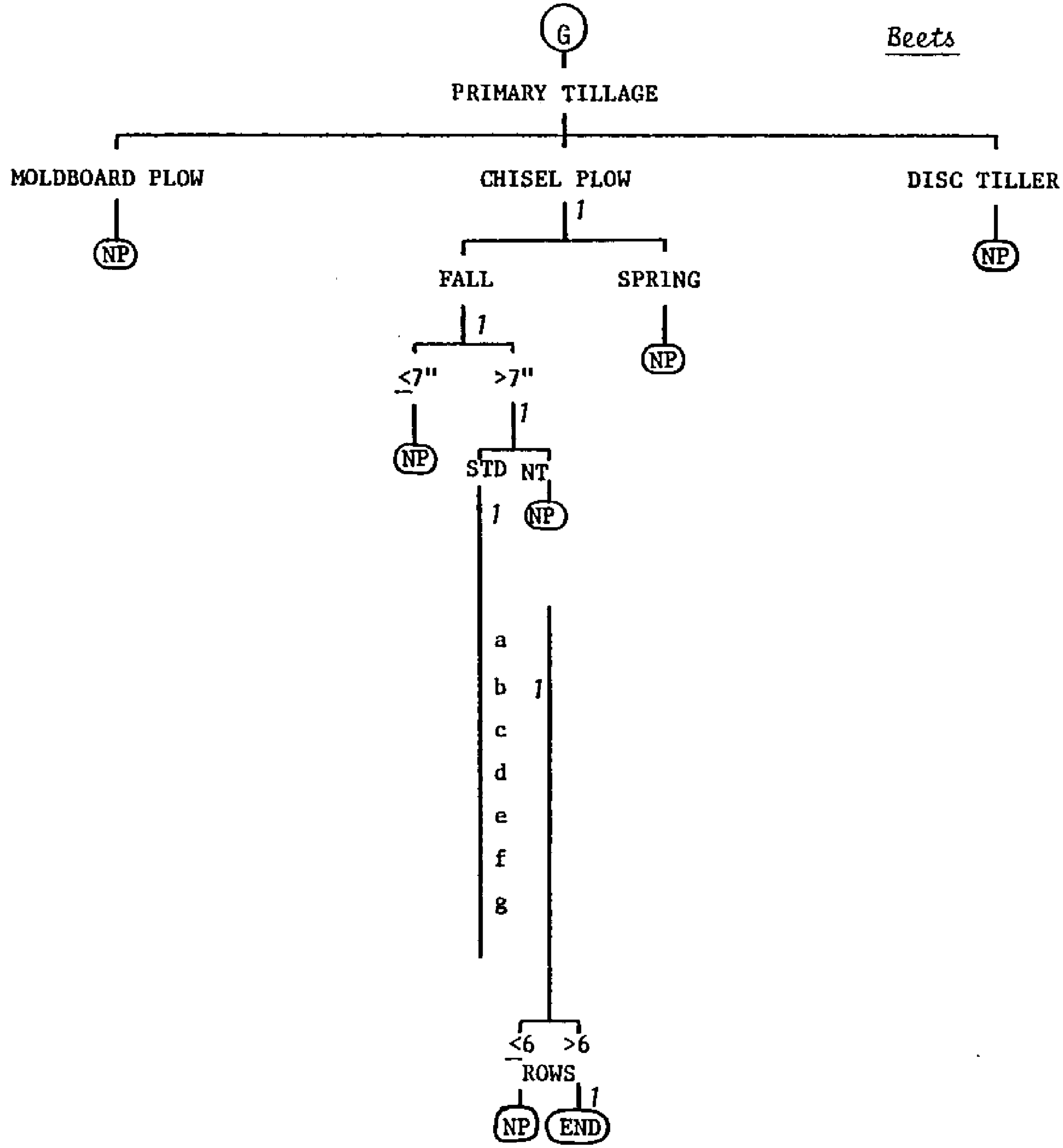
Beets



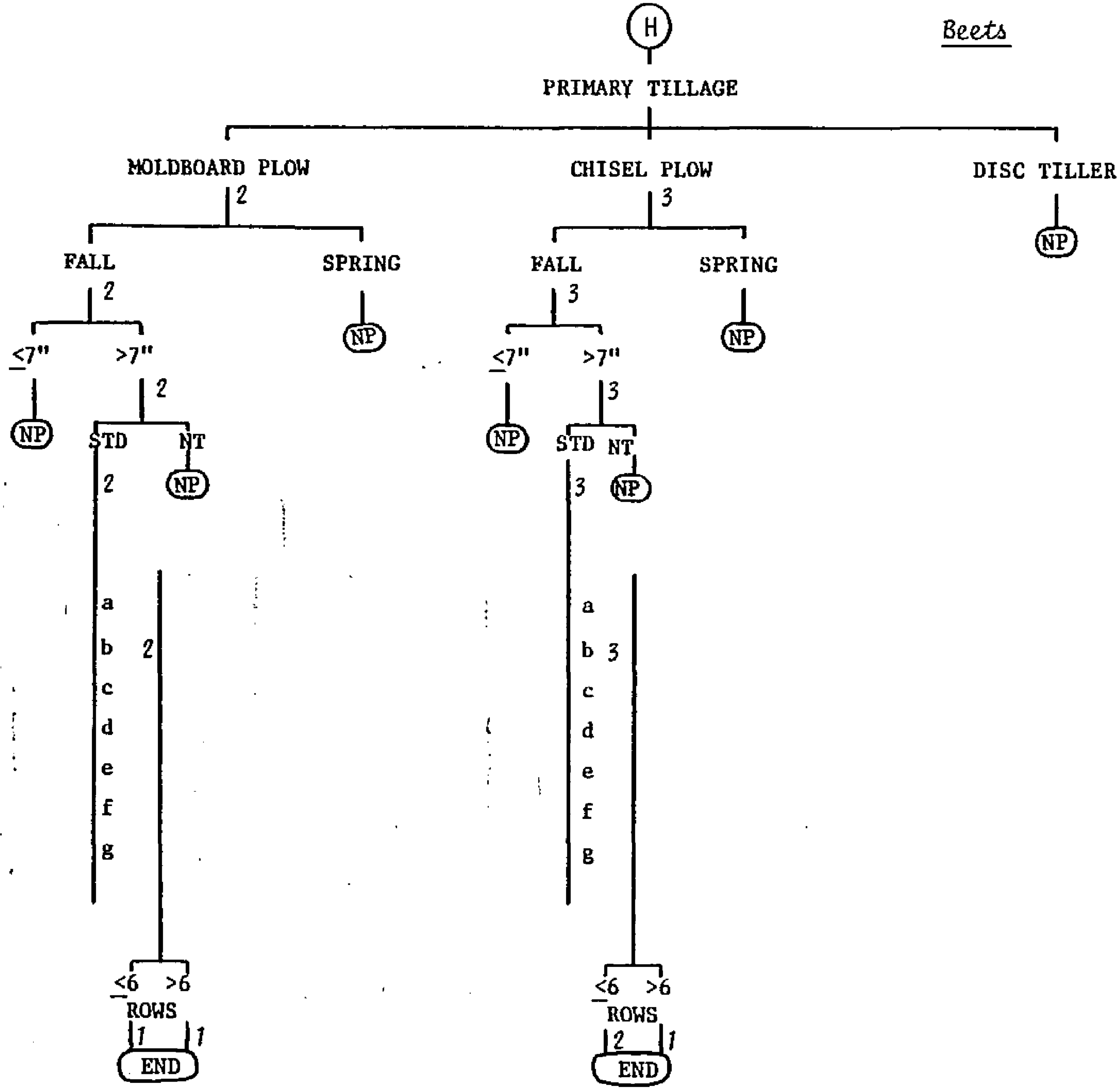
E
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
3
NP
FALL
SPRING
2
1
≤7"
>7"
≤7"
>7"
2
1
NP
STD
NT
STD
NT
NP
NP
NP
2
1
a
b 2
c
d
e
f
g
a
b 1
c
d
e
f
g
≤6
>6
≤6
>6
ROWS
ROWS
2
1
NP
END
END
NP


F
Beets
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
1
FALL
SPRING
NP
<7"
>7"
STD
NT
a
b
c
d
e
f
g
<6
>6
ROWS
END

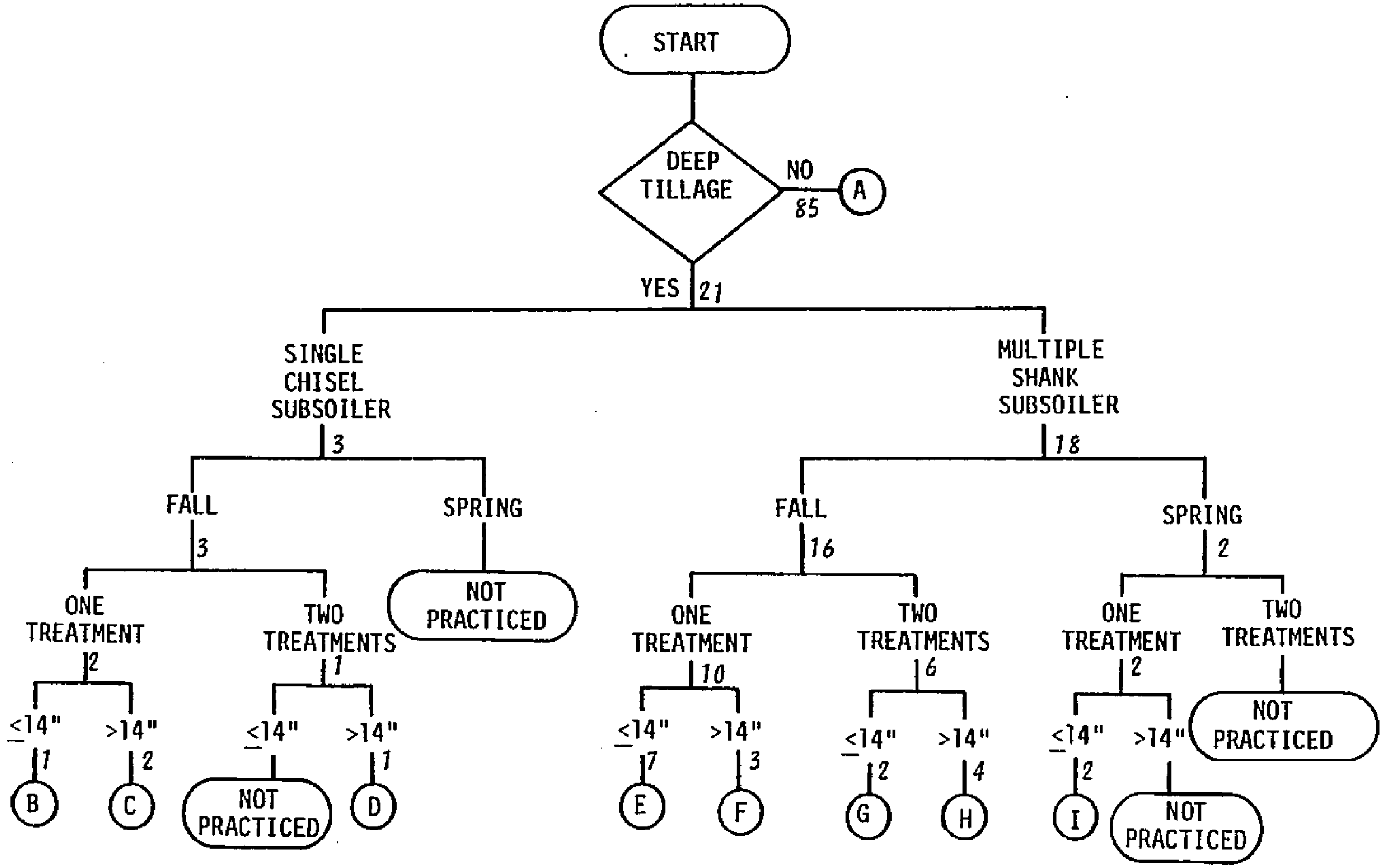
Beets

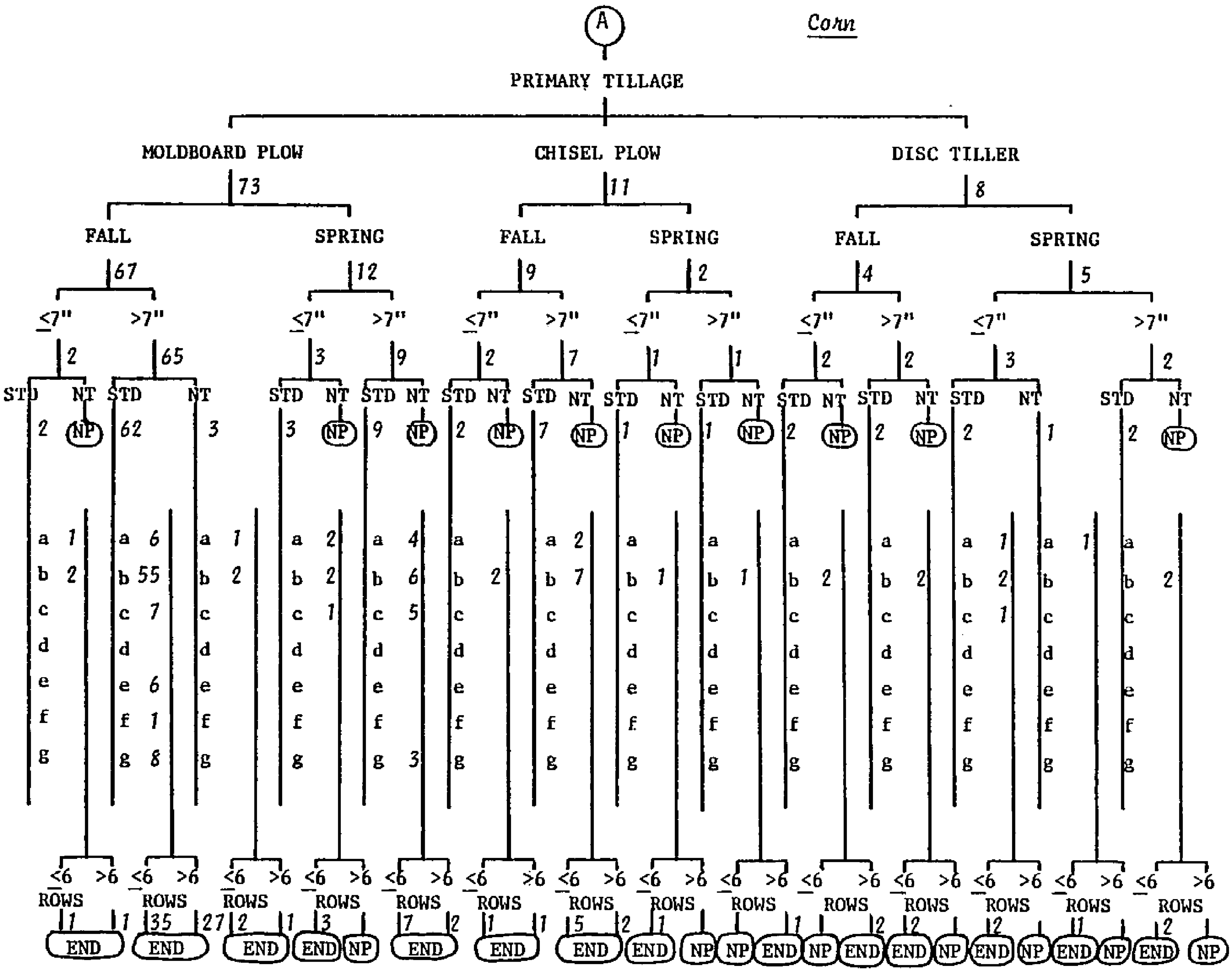

G
PRIMARY TILLAGE
MOLDBOARD PLOW
NP
CHISEL PLOW
1
FALL
1
≤7"
NP
>7"
1
STD
1
a
b
c
d
e
f
g
NT
NP
1
≤6
>6
ROWS
NP
1
END
SPRING
NP
DISC TILLER
NP

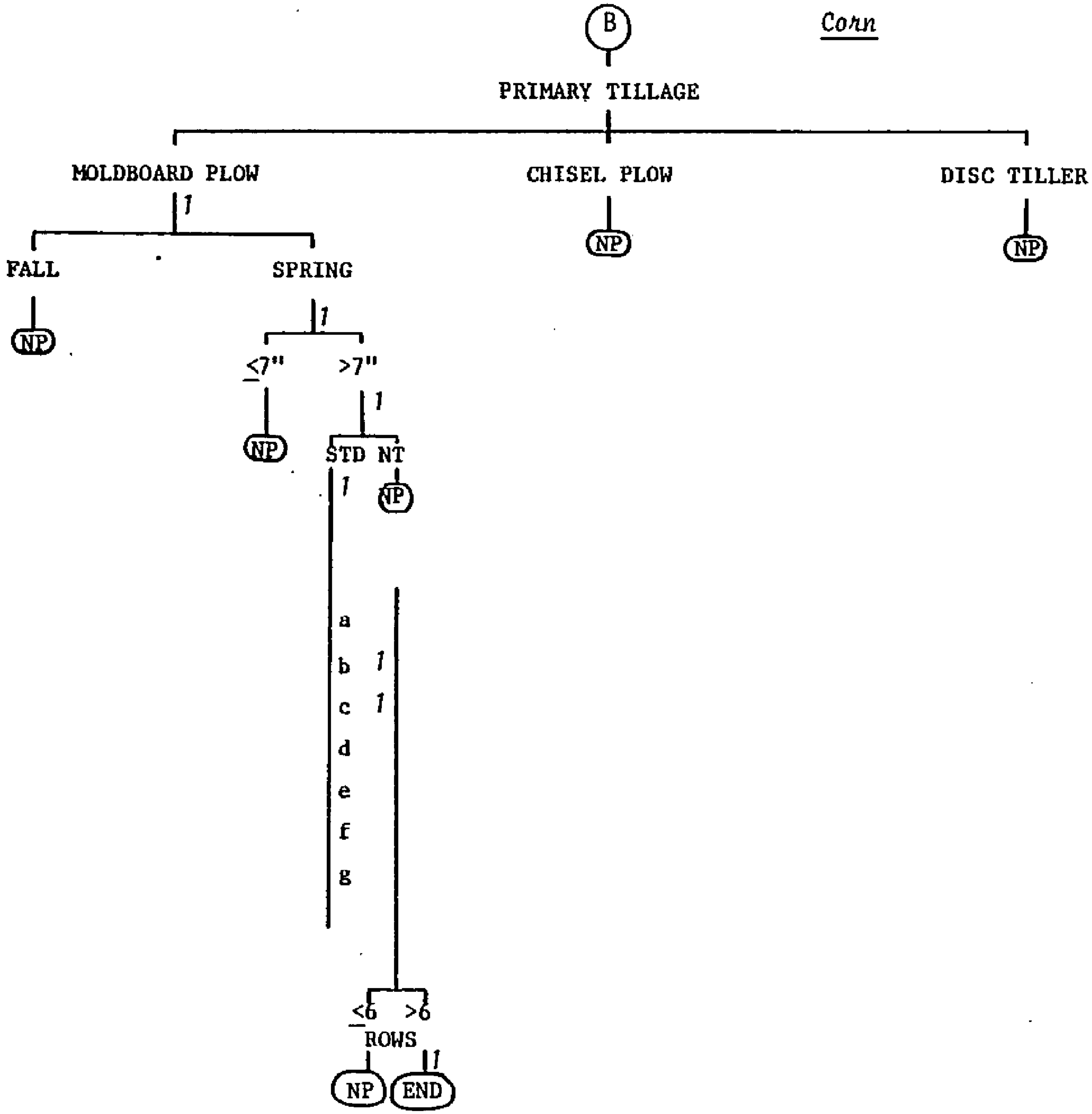
Beets

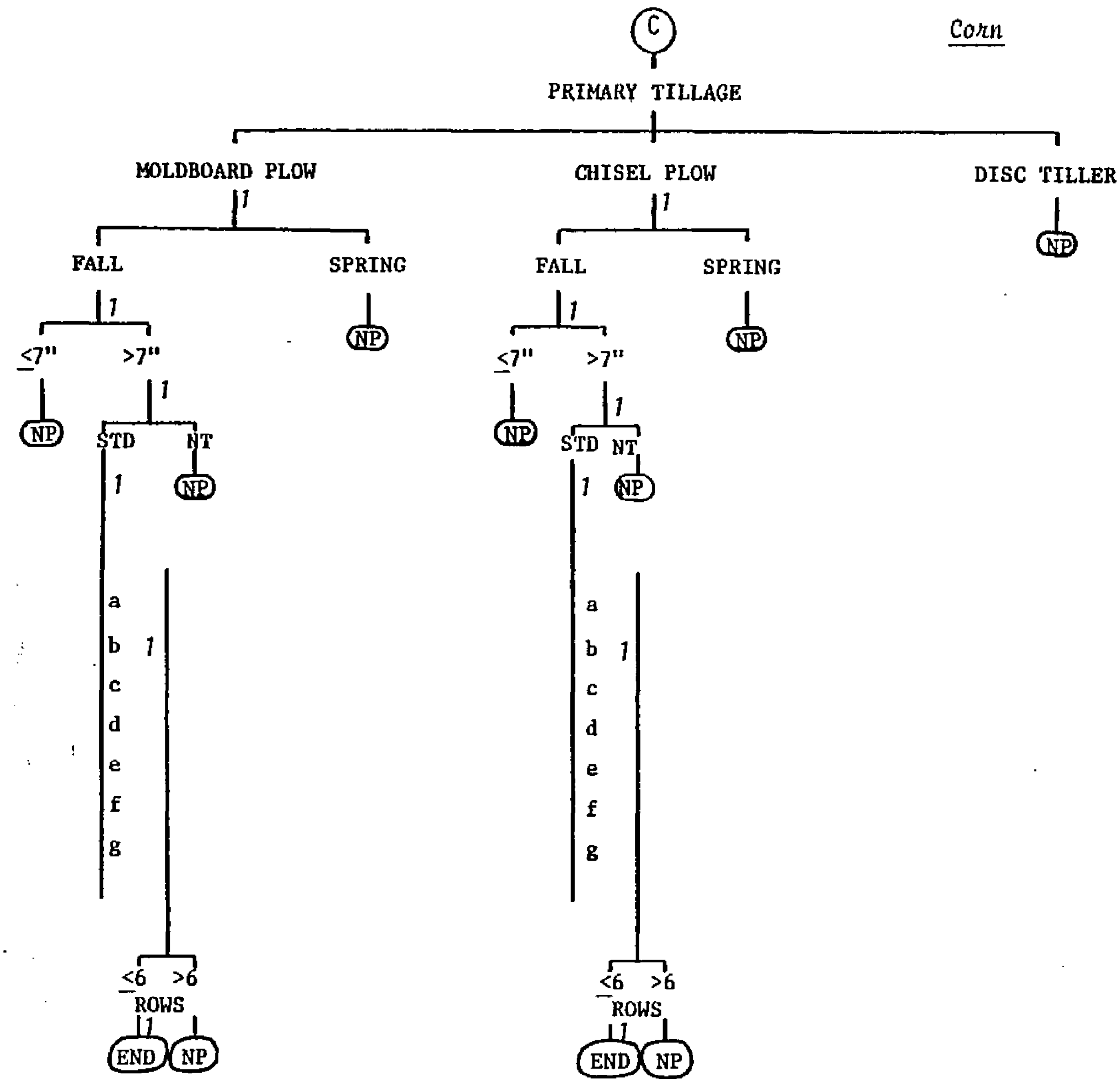

H
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
NP
<7"
>7"
STD
NT
a
b
c
d
e
f
g
<6 >6
ROWS
END

CROP *Corn*

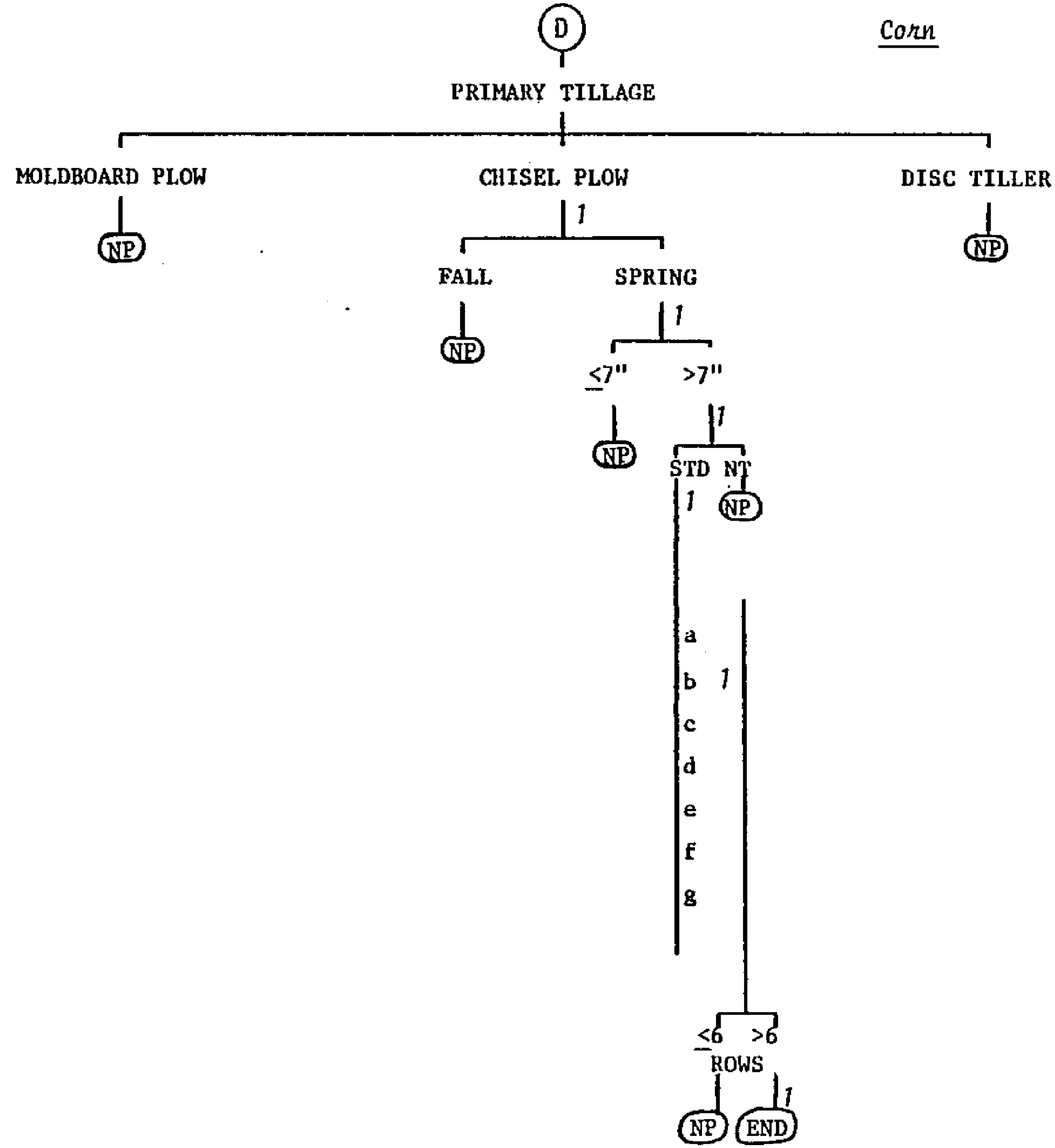

START
DEEP TILLAGE
NO
85
A
YES
21
SINGLE CHISEL SUBSOILER
3
MULTIPLE SHANK SUBSOILER
18
FALL
3
SPRING
NOT PRACTICED
ONE TREATMENT
2
TWO TREATMENTS
1
≤14"
1
>14"
2
≤14"
NOT PRACTICED
>14"
1
B
C
D
FALL
16
SPRING
2
ONE TREATMENT
10
TWO TREATMENTS
6
≤14"
7
>14"
3
E
F
≤14"
2
>14"
4
G
H
ONE TREATMENT
2
TWO TREATMENTS
NOT PRACTICED
≤14"
2
>14"
NOT PRACTICED
I

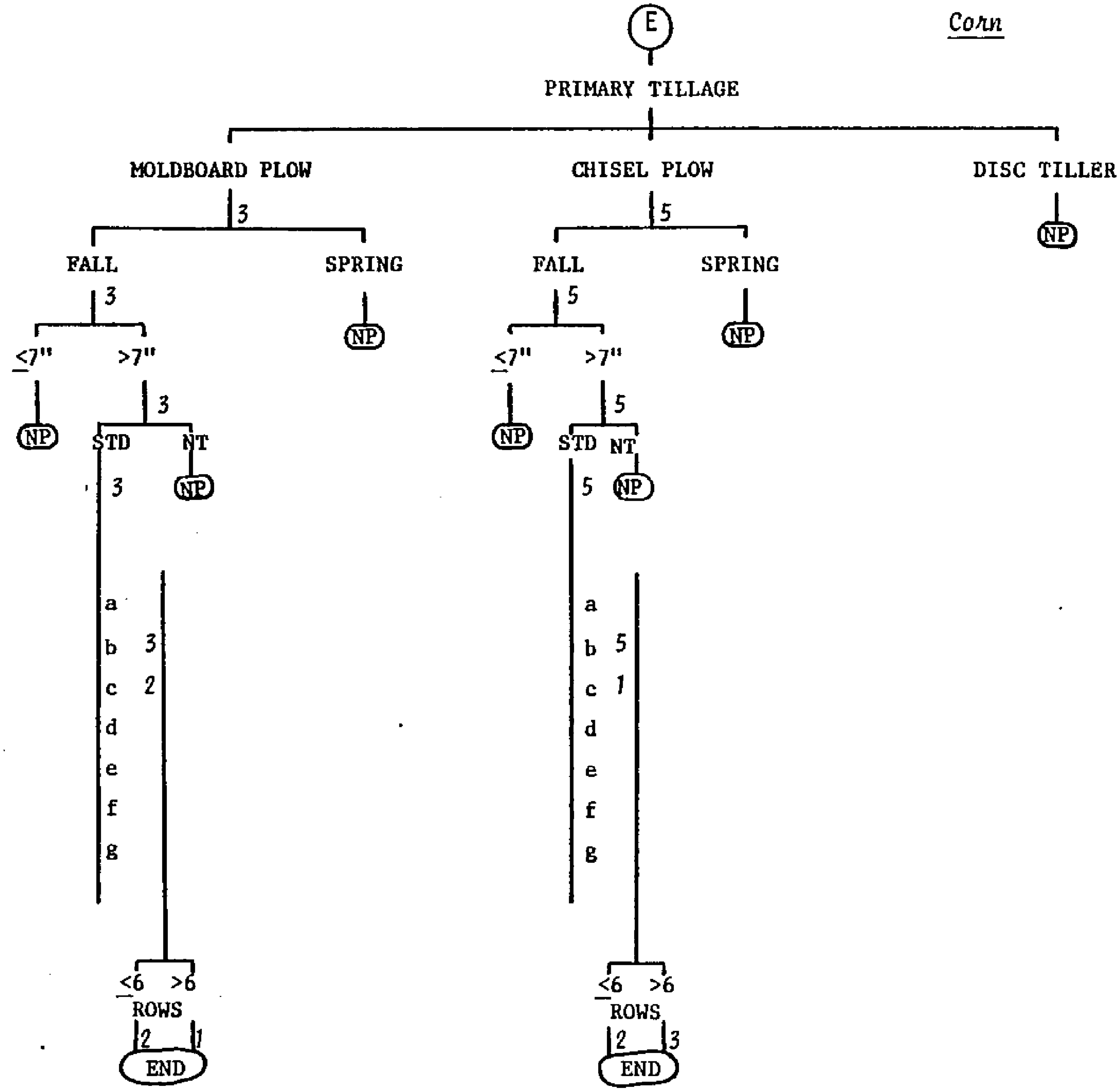

A
Corn
PRIMARY TILLAGE
MOLDBOARD PLOW
73
CHISEL PLOW
11
DISC TILLER
8
FALL
67
SPRING
12
FALL
9
SPRING
2
FALL
4
SPRING
5
≤7"
>7"
STD
NT
NP
a
b
c
d
e
f
g
<6
>6
ROWS
END
NP

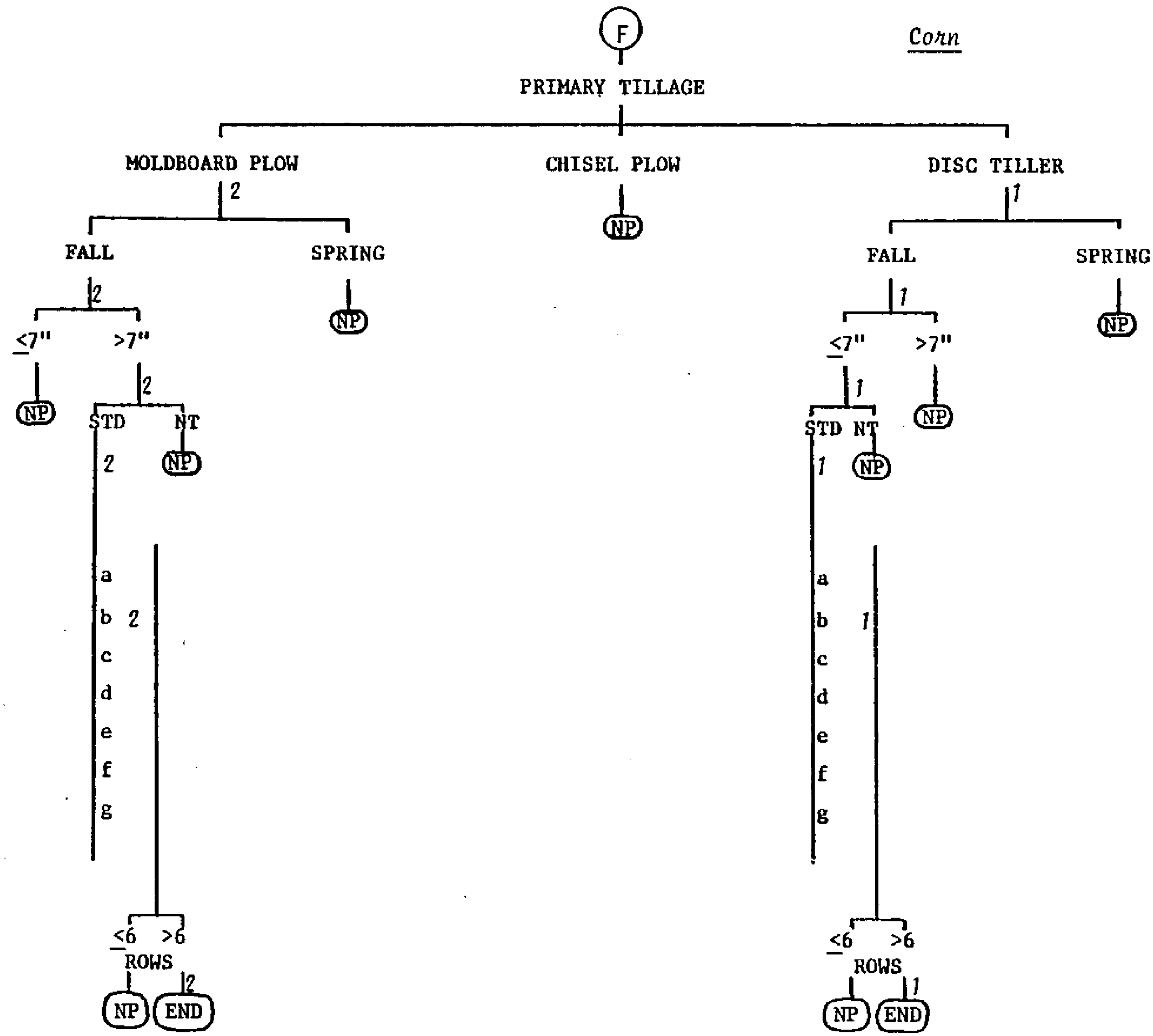

B
Corn
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
1
FALL
SPRING
NP
NP
NP
1
≤7"
>7"
NP
1
STD
NT
1
NP
a
b 1
c 1
d
e
f
g
≤6
>6
ROWS
1
NP
END


C
Corn
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
FALL
SPRING
NP
≤7"
>7"
NP
≤7"
>7"
NP
NP
STD
NT
NP
STD
NT
NP
NP
a
b
c
d
e
f
g
a
b
c
d
e
f
g
≤6 >6
ROWS
END
NP
≤6 >6
ROWS
END
NP

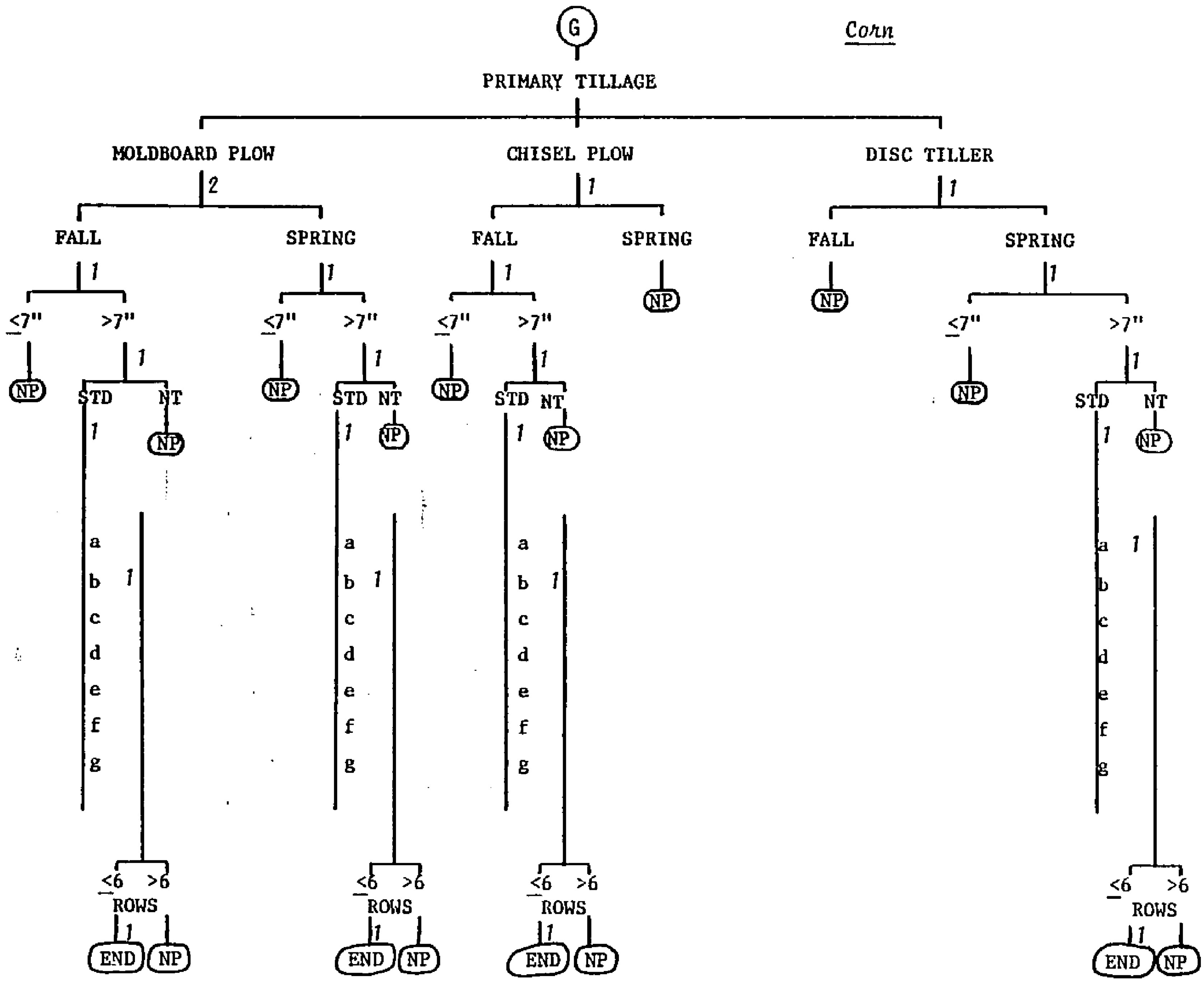
Corn


D
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
1
NP
FALL
SPRING
NP
1
≤7"
>7"
NP
1
STD
NT
1
NP
a
b
c
d
e
f
g
1
≤6
>6
ROWS
1
NP
END

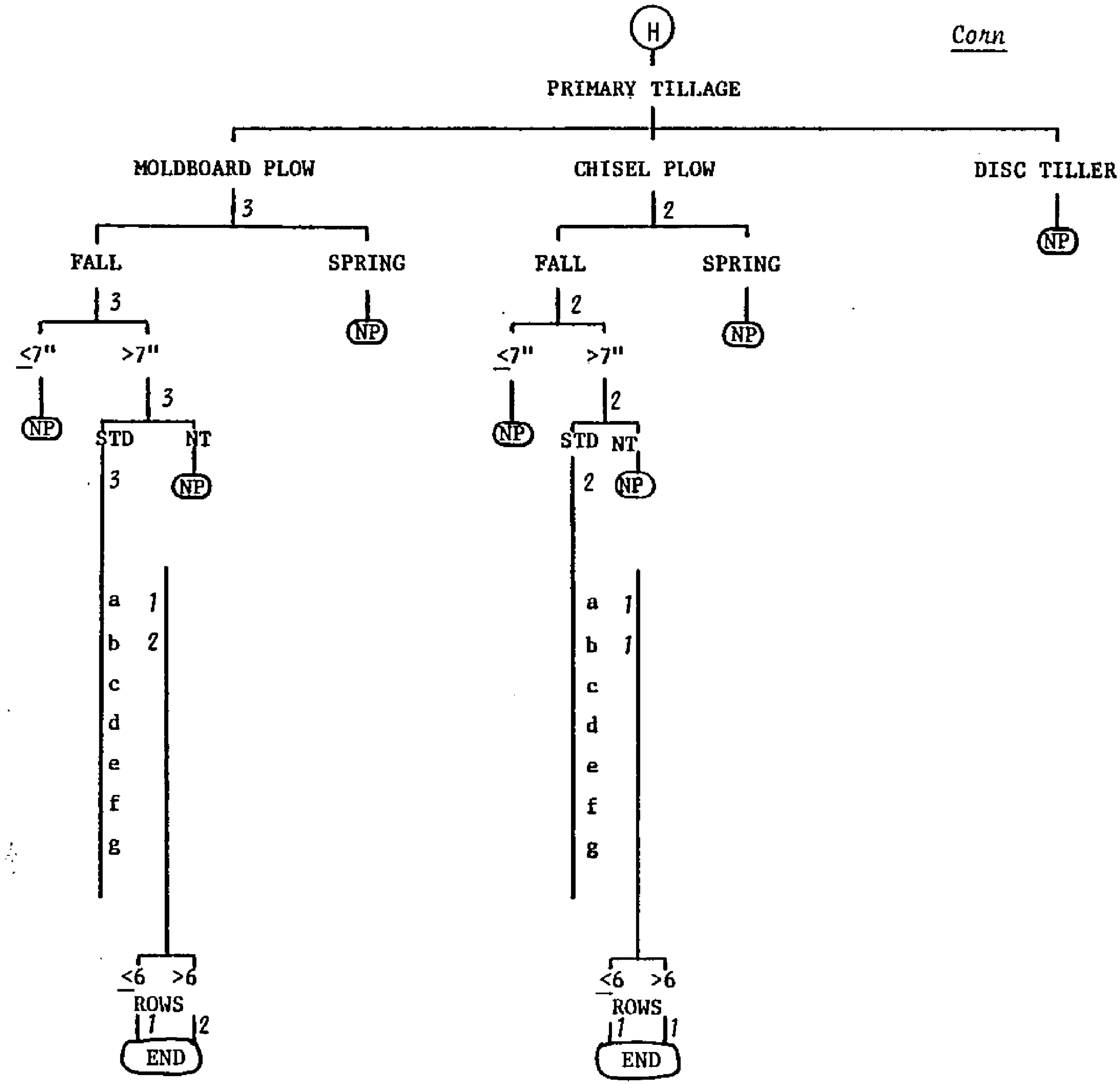

E
Corn
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
3
5
FALL
SPRING
FALL
SPRING
NP
3
5
<7"
>7"
<7"
>7"
NP
NP
3
5
NP
NP
STD
NT
STD
NT
3
NP
5
NP
a
b
c
d
e
f
g
3
2
a
b
c
d
e
f
g
5
1
<6
>6
ROWS
2
1
END
<6
>6
ROWS
2
3
END


F
Corn
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
≤7"
>7"
STD
NT
NP
a
b
c
d
e
f
g
≤6 >6
ROWS
END
1
2

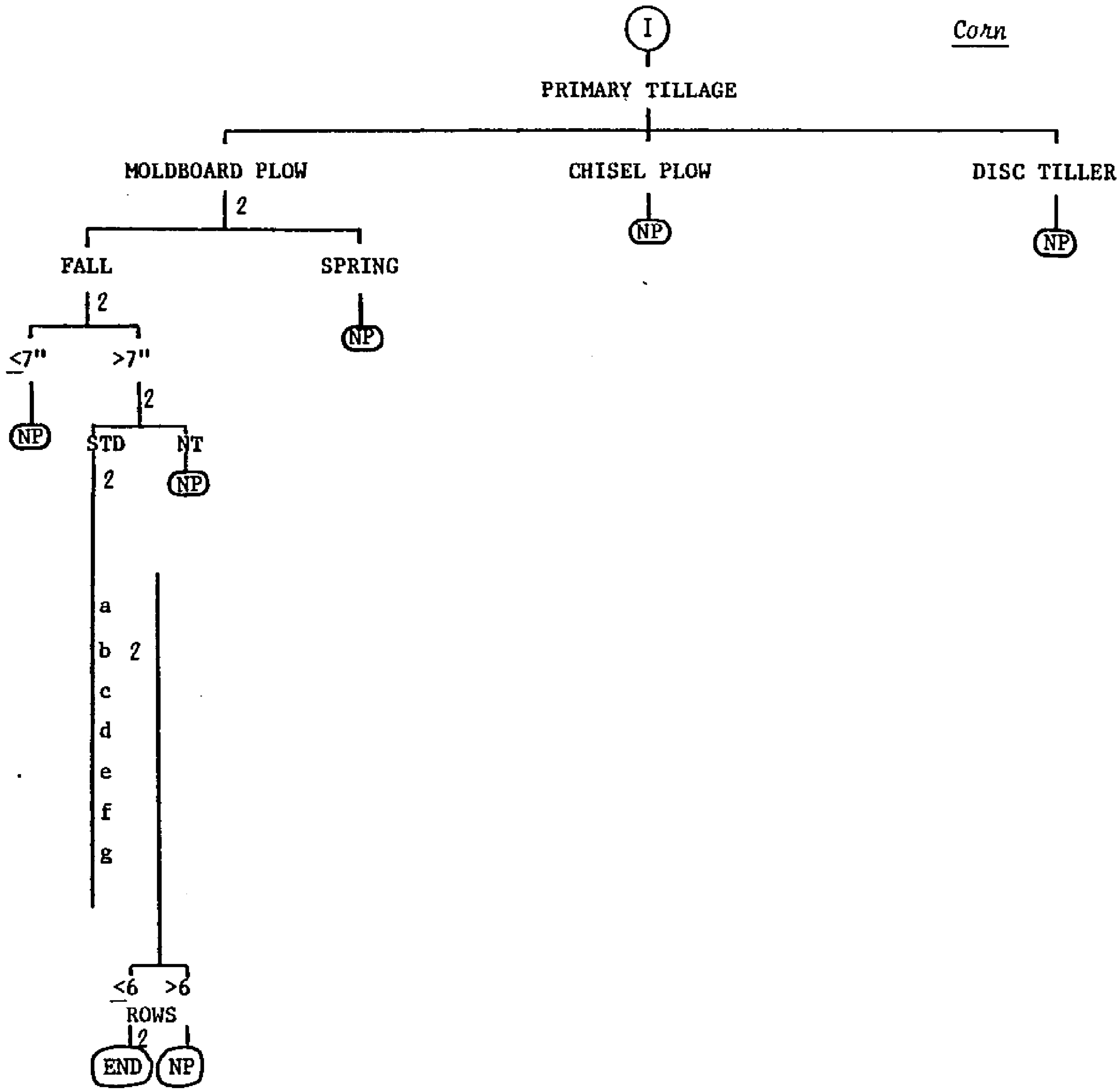
Corn


G
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
≤7"
>7"
STD
NT
NP
a
b
c
d
e
f
g
≤6 >6
ROWS
END
1
2

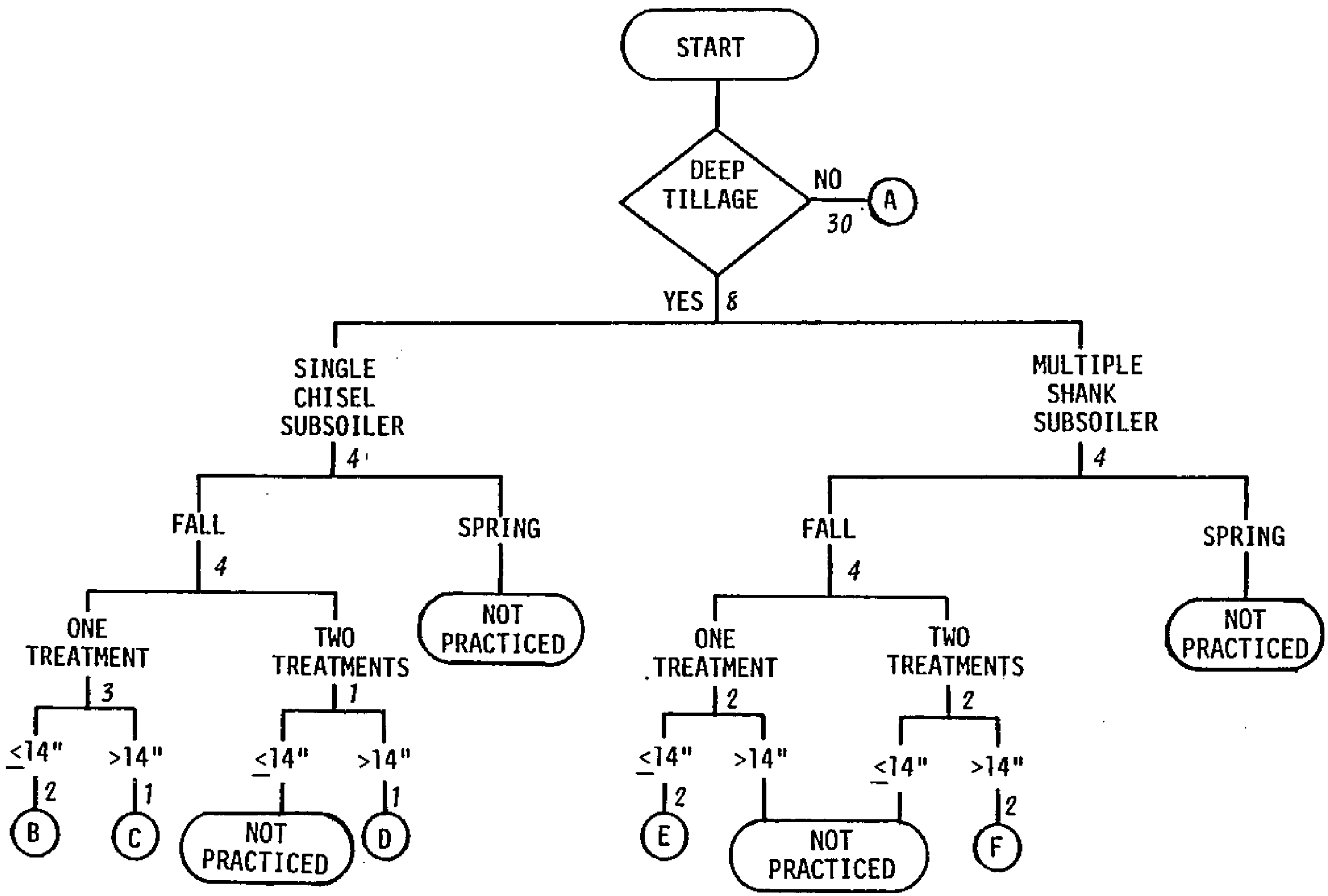
Corn


H
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
3
2
FALL
SPRING
FALL
SPRING
NP
3
2
NP
NP
≤7"
>7"
≤7"
>7"
3
2
NP
NP
STD
NT
STD
NT
3
NP
2
NP
a 1
b 2
c
d
e
f
g
a 1
b 1
c
d
e
f
g
≤6
>6
ROWS
1
2
END
≤6
>6
ROWS
1
1
END

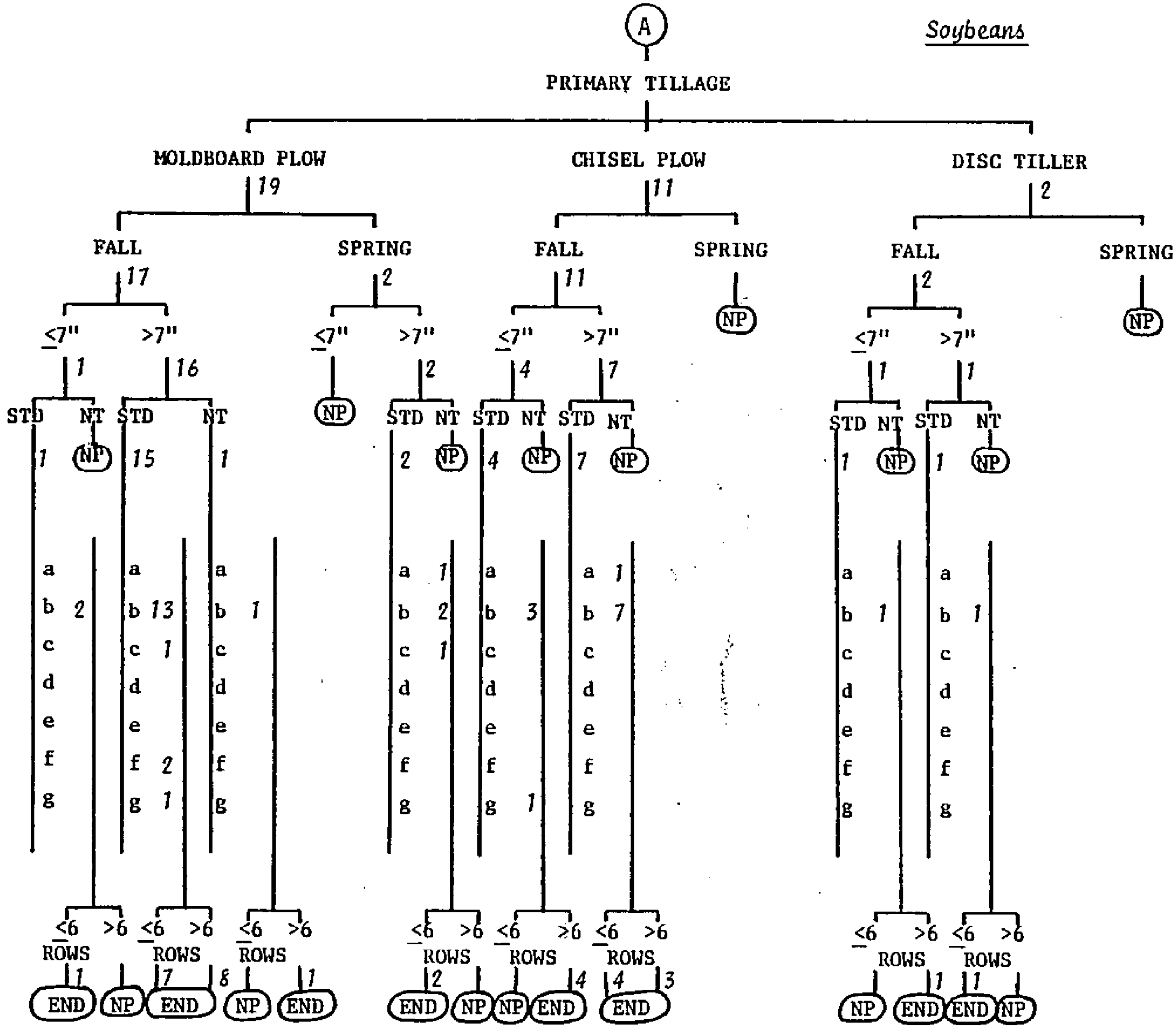
Corn

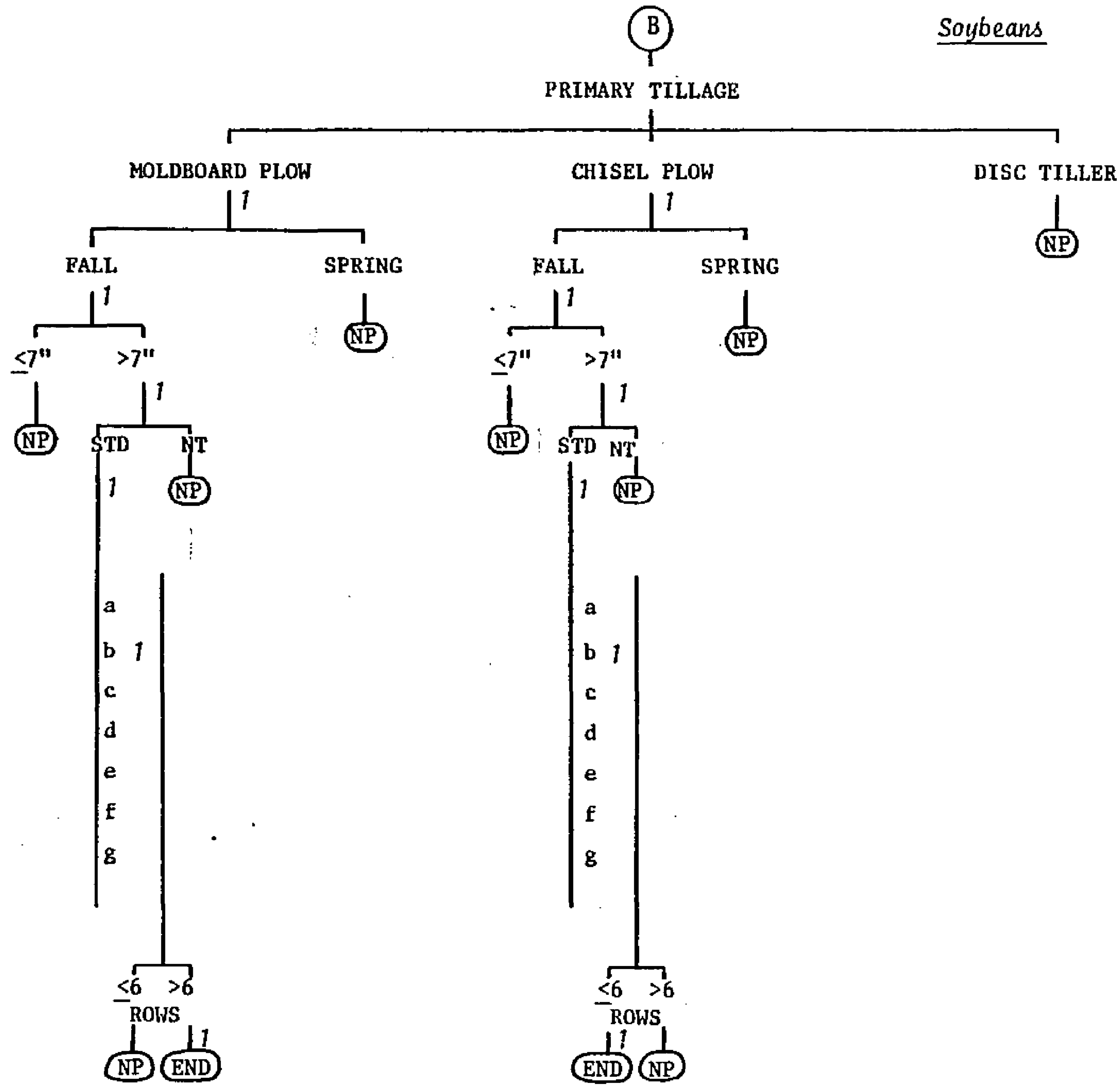

I
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
2
FALL
SPRING
NP
NP
NP
2
≤7"
>7"
NP
2
STD
NT
NP
2
a
b
c
d
e
f
g
2
≤6
>6
ROWS
2
END
NP

CROP *Soybeans*

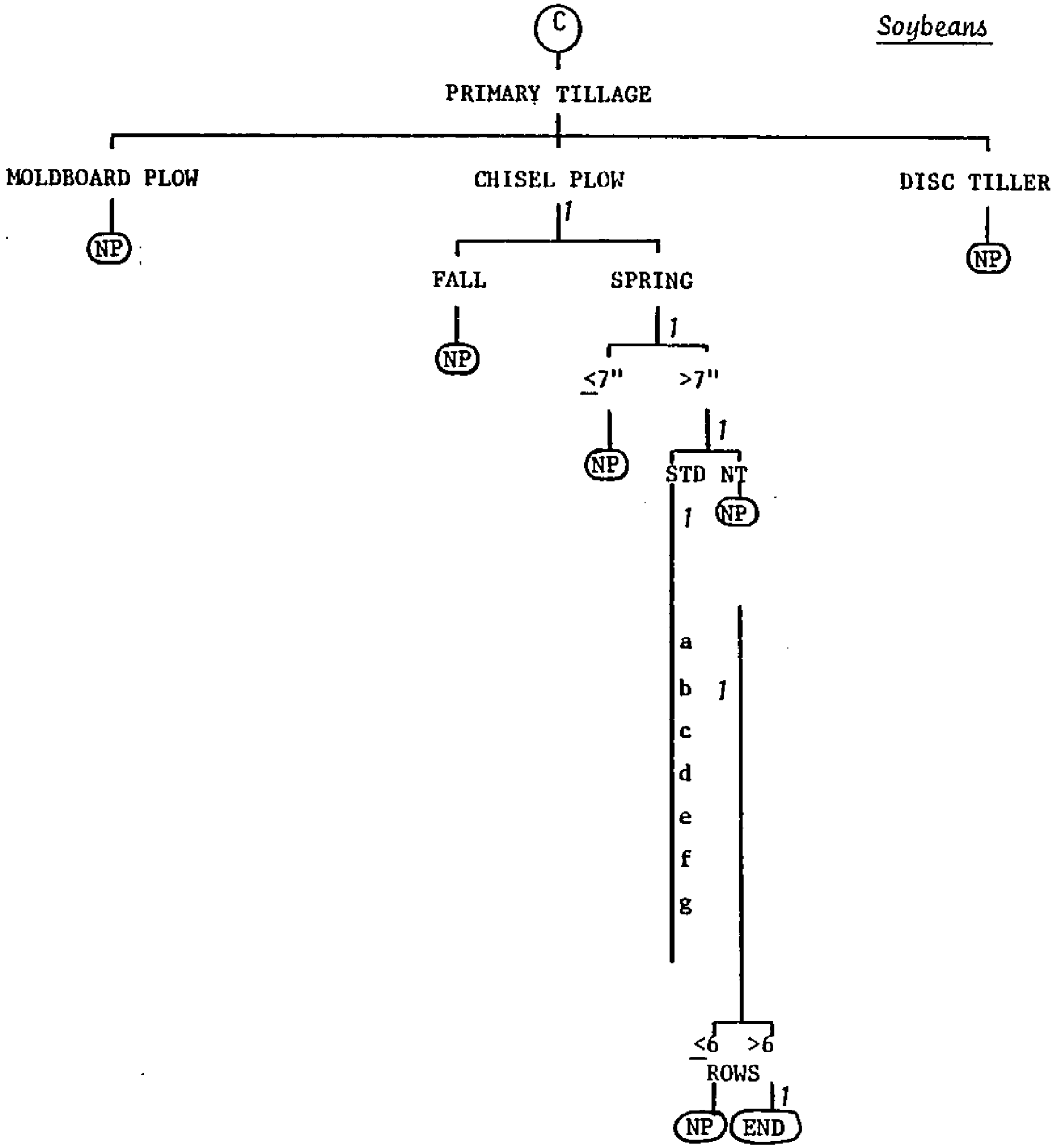


Soybeans


A
PRIMARY TILLAGE
MOLDBOARD PLOW
19
CHISEL PLOW
11
DISC TILLER
2
FALL
17
SPRING
2
FALL
11
SPRING
NP
FALL
2
SPRING
NP
≤7"
>7"
STD
NT
a
b
c
d
e
f
g
≤6
>6
ROWS
END
NP

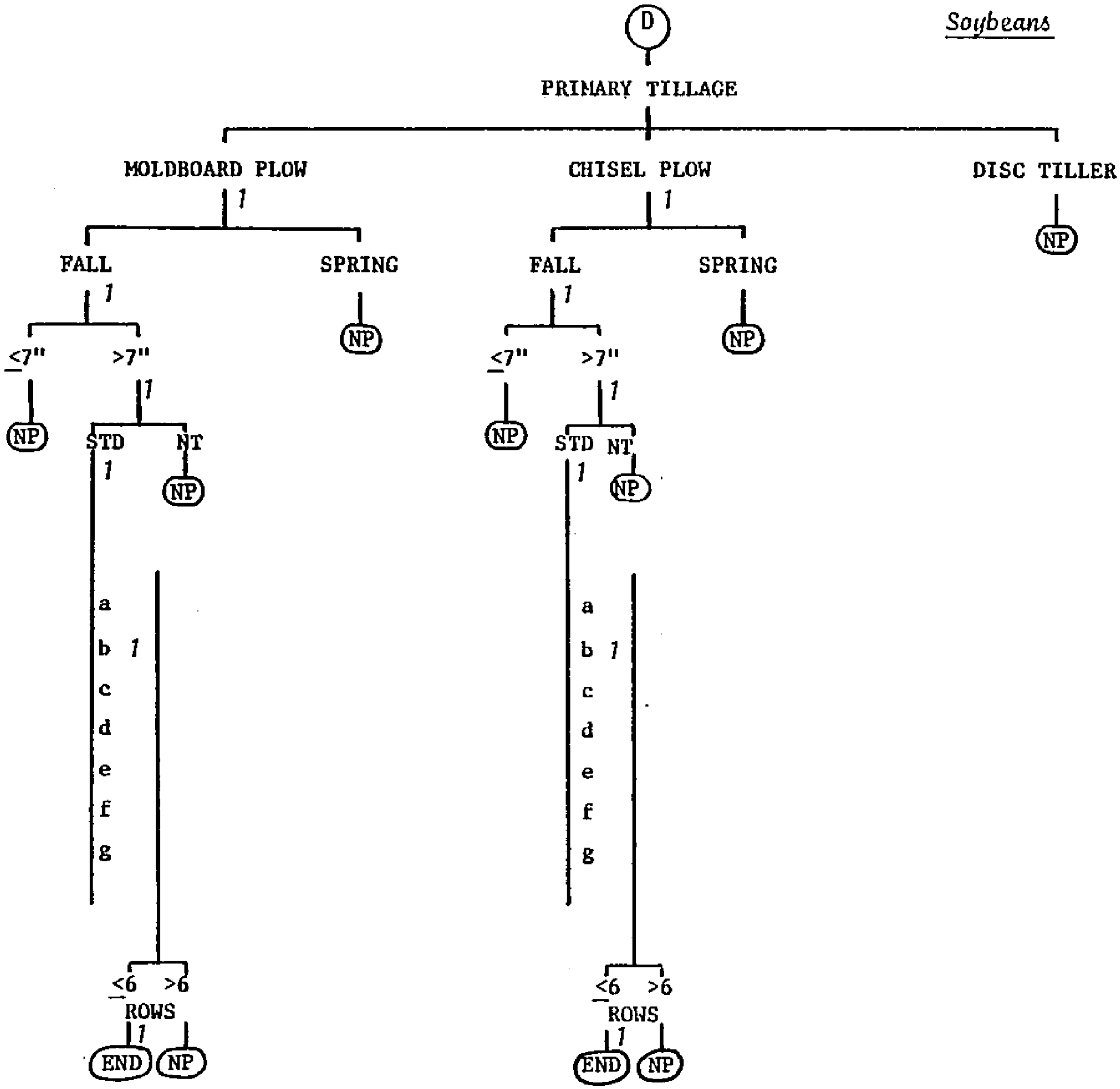

B
Soybeans
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
FALL
SPRING
NP
≤7"
>7"
NP
≤7"
>7"
NP
NP
STD
NT
NP
STD
NT
NP
a
b
c
d
e
f
g
≤6 >6
ROWS
NP
END
END
NP

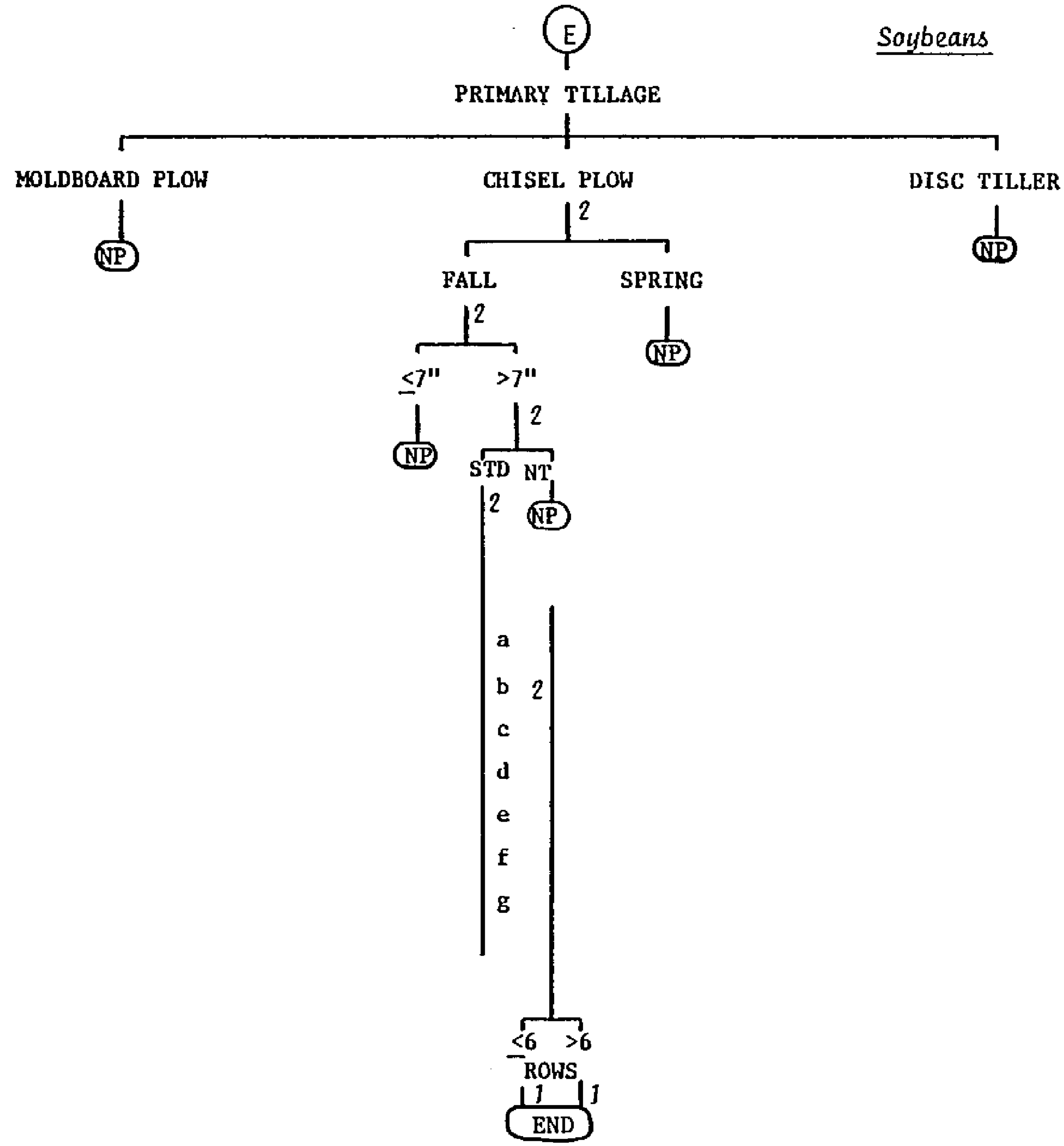
Soybeans



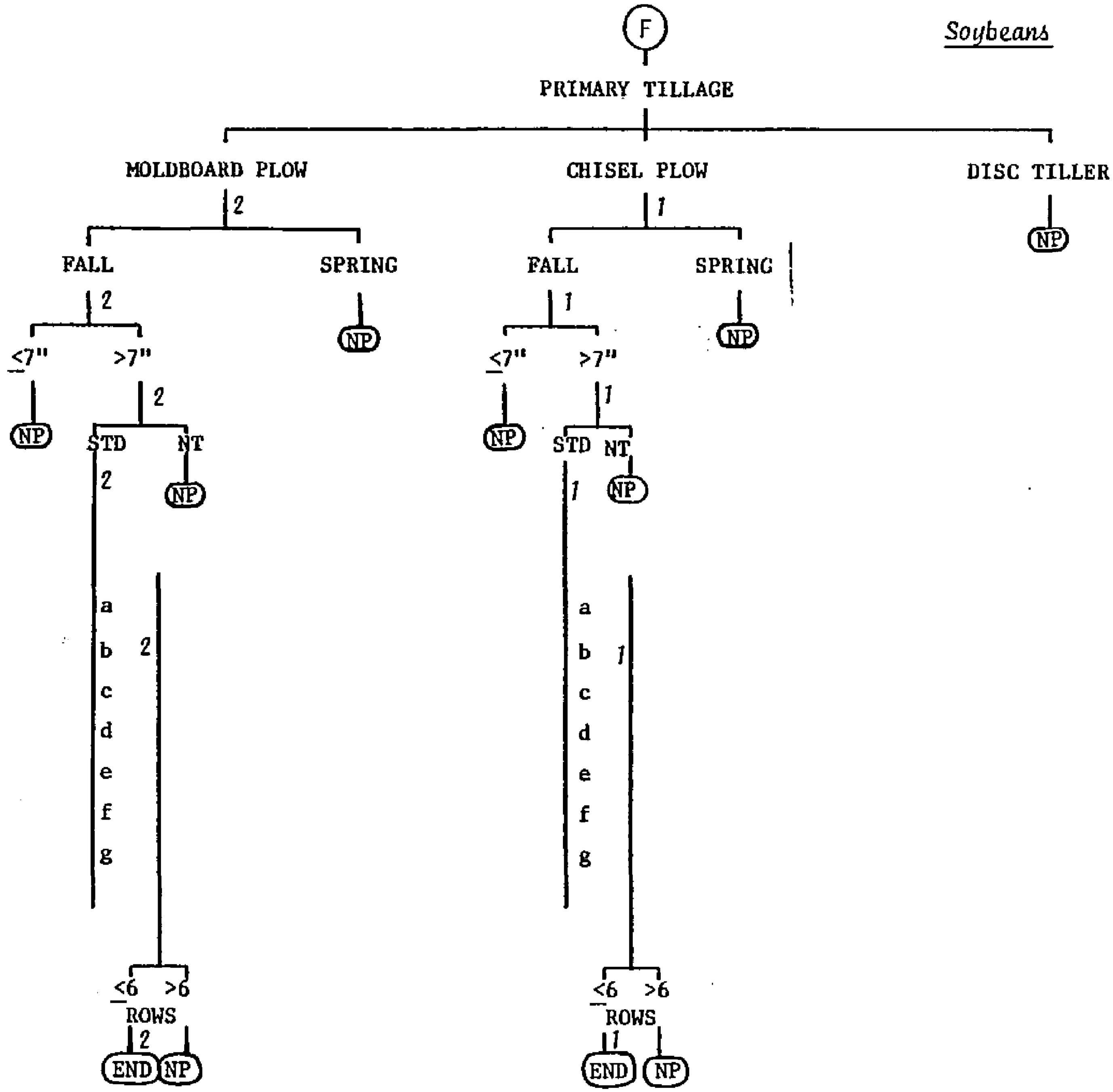
C
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
1
FALL
SPRING
NP
1
≤7"
>7"
NP
1
STD
NT
NP
1
a
b
c
d
e
f
g
1
≤6
>6
ROWS
NP
1
END

Soybeans


D
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
FALL
SPRING
≤7"
>7"
STD
NT
a
b
c
d
e
f
g
≤6 >6
ROWS
END
NP
1


E
Soybeans
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
NP
2
FALL
SPRING
NP
2
≤7"
>7"
NP
2
STD
NT
NP
2
a
b
c
d
e
f
g
2
≤6
>6
ROWS
1
1
END

Soybeans


F
PRIMARY TILLAGE
MOLDBOARD PLOW
CHISEL PLOW
DISC TILLER
2
1
NP
FALL
SPRING
FALL
SPRING
2
NP
1
NP
≤7"
>7"
≤7"
>7"
NP
2
NP
1
STD
NT
STD
NT
2
NP
1
NP
a
b
c
d
e
f
g
2
a
b
c
d
e
f
g
1
≤6
>6
ROWS
2
END
NP
≤6
>6
ROWS
1
END
NP