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By

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ABSTRACT

ALTERNATIVE TILLAGE SYSTEMS FOR CORN PRODUCTION IN MICHIGAN

By

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Different forms of conservation tillage systems have been developed in recent years to reduce soil and water erosion problems which result when a conventional tillage/planting system is used. Conventional tillage normally refers to a full or maximum tillage program, while Conservation tillage, in contrast, is a form of non-inversion tillage which reduces soil and water loss. Conservation tillage has been encouraged in the Sagniaw Bay watershed by a cost-share program administered by the Agricultural Stabilization and Conservation Service (ASCS). This study was conducted to determine the impact of conventional and conservation tillage systems for corn production when related to erosion, machinery, labor, and timeliness costs.

Computer models were developed based upon the constraints at the farm level. Machinery, agronomic, and economic proper sets of data were collected and used for development of the models. A machinery replacement model analyzed the economic feasibility of a conservation tillage system through determining the switching and trading times when switching from a conventional to a conservation tillage system. Linear programming models were also formulated to determine the optimum machinery sets for commercial corn tillage systems and as input set of data for the machinery replacement model. The extra amount of corn residues on the soil surface can be reduced by an optimizing linear programming model.

The economics and cost advantages of chisel plow tillage systems were compared to conventional systems for common crop rotations.

The results indicate that conservation tillage systems have economic advantages to farmers. This can be, for example, indicated by the machinery replacement model presenting that conventional tillage systems are not profitable for farmers to continue due to higher machinery costs and the reduction in soil productivity from soil erosion.

Approved Larry Segerlind
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Approved Donald M Edwards
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To My Mother

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CHAPTER 1

INTRODUCTION

Different forms of conservation tillage systems have been introduced to farmers in recent years due to the soil and water erosion problems that resulted from the conventional or moldboard plowing system.

Conventional tillage is the combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop in a given geographical area. Conventional tillage also refers to a full or maximum tillage program consisting of both primary tillage (moldboard plowing) and secondary tillage (disking, harrowing or cultivating).

Moldboard plowing is mainly used on fine-textured soils in the northern corn belt. It produces considerably high yields due to simplicity of secondary tillage operations, but on the other hand damages the soil structure and increases the erosion (Larson and Hanway 1977).

Conservation tillage is any tillage sequence which reduces loss of soil or water relative to conventional tillage. Various forms of conservation tillage can reduce erosion on many soils 50 to 90 percent (Myers, 1983). Conservation tillage is a form of non-inversion tillage that retains protective amounts of residue mulch on the surface throughout the year (Cook and Robertson, 1979).

Conservation tillage has been primarily accepted by farmers for the following reasons.

1. There is a large amount of soil loss each year from the cropland. The farmers are looking for techniques to conserve both soil and soil moisture.
2. Conservation tillage provides benefits to the farmers: lower costs for equipment, labor , and fuel; increases soil moisture retention and the greater land use flexibility.

The rate of soil erosion depends mainly on tillage practices and amounts of crop residue on the soil surface. Soil erosion increases as the number of tillage operations increases, and decreases as the amount of crop residue increases.

The success of conservation tillage especially no-tillage, depends on many factors such as the quantity and amount of plant residues on the soil surface, soil texture and moisture (Fenser 1977).

The large volume of crop residue may intensify the soil moisture problem and retard evaporation rates (Robertson et. al., 1976). It may keep the soil cooler during the spring which can delay planting (Newcomer, 1978).

The heavy concentration of crop residues on the soil surface may adversely affect the equipment performance making it difficult to control the seed depth. Excessive residue absorbs soil applied herbicides, interferes with desired operation of the fluted coulter, and results in poor seed soil contact.

The chisel tillage is an effective method for reducing wind and water erosion because it leaves a major portion of crop residues on the surface and often provides a rougher, more porous surface. This system is less costly than conventional tillage and it is adapted to well drained soils. Chisel plow systems are the most extensively used conservation tillage systems in Michigan.

The no-tillage system is another form of conservation system that greatly reduces soil erosion. The seed is directly planted into untilled sod, stubble or residue from the previous crop. The economic analysis of conservation tillage systems indicates that the no-till is the most cost effective of any practice commonly used. Factors that will influence the rate of adoption of no-till practice include technology development and transfer, economic advantages, education and training programs, and the gradual change in farm culture.

Voluntary adoption of conservation tillage by farmers is uncertain because of the lack of knowledge of the economic impacts of such practices by farmers (Rotz, et. al., 1983).

Several research needs for conservation tillage practices were identified by Muthar (1982) such as:

1. There are other conservation tillage systems on the market that may prove to be beneficial and need to be tried.
2. More machinery management data is needed, such as fuel consumption, draft, speeds, and slippage, etc. for various soils and tillage systems. This data needs to be collected.
3. The question of machinery rotations needs to be answered. Is there a need for a multiple machinery system on one farm?
4. 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.

CHAPTER 2

OBJECTIVES

The objective of the research was to study conventional and conservation tillage practices for corn production in Michigan. This study evaluates the impact of alternative tillage systems on machinery complements, labor, timeliness, and soil erosion on the fine texture soils of Saginaw Bay. To develop the research the following specific objectives were defined:

1. To formulate linear programming models to optimize machinery sets for alternative commercial corn tillage systems including conventional (using moldboard plows), chiseling (using chisel plows), and no-tillage.
2. To determine timeliness costs based upon planting and harvesting time constraints.
3. To develop a machinery replacement model for the process of switching from conventional to a conservation tillage system and specify the switching and trading times.
4. To evaluate the economic differences between conventional and chisel plow tillage systems for common crop rotations in Michigan.
5. To formulate a linear programming model to optimize the amount of corn residue (corn stover) on the soil surface and select the optimum harvesting systems.

This study is limited to the on farm economic and environmental issues of the problem. Although, off farm social and political basis are among the key factors, they are beyond the scope of this study. The economic and environmental perspectives of the research are conducted within a framework of cost analysis for tillage systems about machinery utilization and soil erosion.

CHAPTER 3

LITERATURE REVIEW

3.1 Conventional tillage

Conventional tillage is the combined primary and secondary tillage operation normally performed in preparing a seedbed for a given crop grown in a given geographical area (Cook and Robertson, 1979). Following the corn harvest, the stalks are shredded and primary operations started using a moldboard plow and a tandem disk to till the soil. Tandem disks and spike tooth harrows are used for pre-planting operations in the spring. Rotary hoe and sweep cultivators are used for cultivating operations (Jolly, et. al., 1983).

Conventional tillage is also referred to as the moldboard plowing (about mid-April) and disking (about mid-May) as pre-planting operations. Weeds are controlled with cultivators and herbicides in pre-emergent and post-emergent spray form. Nitrogen and phosphorus should be applied adequately for the optimum production (Burwell and Kramer, 1983).

Moldboard plowing (fall plowing) is mainly used on fine-textured soils in the northern corn belt. This method produced high yields due to the simplicity of secondary tillage operations. On the other hand, this method damages the soil structure and increases the erosion (Larson and

Hanway, 1977). Oschwald (1973) showed that moldboard plowing combined with secondary tillage implements in Illinois had a higher grain yield on poorly drained soils compared to other methods. A six year study of corn production in Ohio from 1962 - 1967 indicated that the conventional method using a plow had a lower average yield than the non-plow method (Triplett et. al., 1969).

Moldboard plowing is a suitable method for the level fields, but the crop will be exposed to weather damages until it has established a desirable cover. The soil moisture losses can also be excessive due to secondary tillage operations after moldboard plowing. The success of secondary tillage practices depends directly on the soil texture. Producing large clods on the soil surface and especially the hard layer below the surface, which is due to heavy equipment utilizations and excessive operations, are the other important problems indicated in moldboard plowing. Soil crusting is usually produced in very fine textured soils due to moldboard plowing practices (Erdmann, et. al., 1981).

A study of a four year conventional corn planting in Indiana showed that the yields from spring moldboard plowing are equal or greater than other non-moldboard plowing methods such as strip rotary and no-tillage. The higher yield advantage from moldboard plowing is especially due to better weed control practices (Griffith, et. al., 1973). Many research studies have been done to compare the fall and spring plowing. The results indicate a small difference in favor of fall plowing. Fall plowing allows farmers to have an earlier spring planting than when spring plowing is required. Winter weather usually improves the soil's physical conditions, especially when the soil has been relatively wet or dry at the plowing time. A desirable soil structure is produced due to continuous freezing and thawing, wetting and drying of large clods during winter. Such a situation cannot happen in spring, and the spring plowed soil remains cloddy. The high silt content soils should not be fall plowed. The soil granules are weakly held together so that in the spring they are separated and destroyed and, therefore, a very compact soil layer is produced (Aldrich, et. al., 1976).

Larson (1973) studied the conventional corn production and Allarmous, et. al. (1972) compared the corn yield of fall plowing with spring plowing. They found that the fall plowing also had a higher yield than spring plowing in southwestern Minnesota and eastern South Dakota. The temperature in fall plowed soils was also higher.

Robertson, et. al. (1977) studied the relation between tillage systems and soil air space in Michigan soils. The loam soil before plowing had 23% (3.8 centimeters) soil air space. When applying only a moldboard plow for a minimum tillage, the soil air space was increased to 48% (11.4 centimeters). This method effectively reduced soil and water erosion so that the soil was able to absorb more than 10 centimeters of water. Thus, moldboard plowing can also be considered as a temporary method for reducing the erosion. With the possibility of plowing and planting in one operation, the soil dries rapidly and, therefore, prevents the new weed germination.

Moldboard plowing also has some disadvantages such as high power requirements, undesirable performance due to speed fluctuations, and equipment calibration. The equipment transports large volume of soils with forward, lateral, and upward motions which increases the power requirements. Moldboard plows are usually designed to work at a particular speed. At low speeds, the incomplete soil cutting surface results, while at high speeds the soil particles are scattered over a greater area. Equipment calibration and adjustments need good training programs for operators before operation. Increased power requirements, incomplete soil fracture, excessive wear, and incomplete cover residues are the result of improper equipment calibration (Robertson, et. al., 1979).

Moldboard plowing is also a combination of cutting, lifting, shearing and turning the top soil layer. The soil moisture content at plowing time should be adequate, especially in dry soils to provide a desired tilled layer. The heavy grass sod needs a long moldboard plow in order to turn over the furrow slice. The research experiments in the eastern part of the United States show that the optimum depth for moldboard plowing is about 20 centimeters. The yield may also increase slightly for depths greater than 20 centimeters, but the optimum depth is indicated to be from 20 to 25 centimeters (Aldrich, et. al., 1976).

The experience shows that a three percent slope is the estimated limit for fall plowing in non-contouring soils. However, in the northern corn belt this level is increased to seven percent for contour lands (Aldrich, et. al., 1976).

3.2 Planting Date

Scientists have found that early corn planting has better yield advantages for farmers. The early planting date has been practically increasing because of effective application of chemicals for weed control, seed treatment, and the improved seed varieties. However, the best criteria for planting time is the soil temperature. The optimum soil temperature for corn planting is 15^{o}C at the 7.6 cm depth. Rossman, et. al. (1966) found that the average corn yield over a 10 year period in Michigan was 9% higher for a 1st through the 9th day of May planting time than for the 12th to 20th of May, 16% higher than planting between May 22 to 31, and 27% higher than June planting times of June 1 through 11.

The recommended planting time in lower Michigan for sandy soil is April 15th to May 5th and for other soil types, it would be April 25th to May 10th. The corn planted in April produces less vegetative growth (plant residues) than the late planted corn. The corn silking on July 15th receives about 26,200 Langely energy units in 55 days when compared to corn silking on August 15th which absorbs only about 20,800 units. The corn planted on April 20th will utilize only about 56 degree days by May 4th. The adverse weather conditions after May 4th require early planting (Lucas et. al., 1978).

The problems related to early planting include poor soil and seed stand due to the cold and the soil moisture, weed problems when the wet soil prevents cultivation and frost injury. The earliest planting date in Michigan starts on April 16th. The crop yield will decline if the planting operation starts after May 12th. The weed problem can be improved through effective application of pre-emergence herbicides. Damages resulting from the wet soil and frost have been relatively lowered in recent years because of modern seed treatment techniques. However, the inadequate stand can be improved by a replanting operation which is an efficient method if the first planting operation was not satisfactory. The modern hybrids are resistant to undesirable conditions such as soil disease and cold, so that they facilitate the early planting practice (Aldrich et. al., 1976).

The depth of planting usually depends on soil and weather conditions. Considering soil moisture content and temperature, an optimum depth is required for a high percentage of germination and emergence. Allesi, et. al., (1971) made a growth room experiment and found that an 80% emergence needed a time period from 4 to 24 days. A time period of about 8 to 13 days was observed in field experiments in North Dakota for 80% emergence.

Increasing the seed depth by 2.5 cm lowered the emergence by one day. Aldrich, et. al. (1978) indicated that in the corn belt area with adequate soil moisture content, a 5 cm depth would be optimum, based upon the average planting time.

Thirty years of planting data at Michigan State University (1948-1980) show the yield advantage for corn planting in late April or early May. The results also recommend corn planting in late April. The average corn planted in early May is about 100 bushels. The yield decreases by one bushel per acre per day for delayed planting. Early planting results in earlier maturity in the fall which reduces the cost of drying. The weather data indicates that the first week of May is usually drier than the second week and, therefore, more suitable days are available for early planting. For early planting, the corn seed should have the highest quality with the cold test germination of 70 percent or better. The seed population should also be 15 to 20 percent higher than the desired plant population. Spring frost causes severe damage to the plant if the growing point remains below ground with the soil temperature below 32^{o}F. Since the cultivated organic soils are cool and dry the frost damages to the planted corn are greater than if the soil is left undisturbed (Erdmann, et. al., 1981).

The optimum seed depth for early planting is found to be 1.9 to 3.8 centimeters for cool soils. A deeper seed placement of 3.8 to 6.4 centimeters is recommended for late planting in fine textured soils and also the deeper ranges are considered for coarse texture soils (Erdmann, et. al., 1981).

3.3 Plant Population

The corn population for grain production depends on several factors such as genetic characteristics, climatical conditions, soil textures, row width, soil fertility, and moisture content. Larson and Hanway (1977) found that the optimum population varies from about 40,000 to 100,000 plants per hectare. Lucas, et. al. (1978) recommended 64,246 plants per hectare at harvest for irrigated soils with 75 centimeter rows. The average yield of this population is estimated to be 11.6 tons per hectare. However, the 54,362 plants per hectare are recommended for those areas with a water shortage and problems with irrigation schedules. To obtain the desired plant population at harvesting time, an increase of 15 percent for seeding rate is necessary. Erdman, et. al. (1981) found that the optimum plant population in Michigan soils ranges from 44,478 to 49,420 plants per hectare. The results of a five year study of irrigated and non-irrigated corn with four different plant populations of 37,806; 47,443; 57,574; and 67,953 per hectare indicated that the irrigated corn with the 57,574 plant populations per hectare had the highest yield of 10.7 tons per hectare (15% moisture) while 37,806 had the lowest yield of 5.7 tons per hectare. Stickler (1964) found that the maximum yield for non-irrigated corn in Kansas resulted from the 40,000 plant population per hectare and for the irrigated corn, it was indicated to be from 48,000 to 59,000 plant population per hectare.

The optimum plant populations for the northern states and Canada have been higher than those in the southern states. Early planting is an important factor in increasing the plant population. A two year research in Minnesota showed that through providing the crop water requirement, plant population increased from 44,640 to 74,100 per hectare (Hicks et. al., 1970).

3.4 Fertilizer Application

The use of commercial fertilizers has increased rapidly in recent years. The fertilizer supply in Michigan usually includes 97.3 kg N, 37.3 kg P, and 50 kg K/ha (Hargett, 1973). The rate and method of fertilizer application depends on the materials, farmers' preferences and cultural practices. For the cool regions with early planting practices, N, P, and K fertilizers are applied in bands 5 cm to the side and 3 to 5 cm below the seed at planting. Fertilizers are applied in various methods such as broadcasting using moldboard plows or disks before planting, injecting the gas into the soil before or after planting, or sidedressing between the rows after planting. The foliar application is an efficient method after the leaf development process is completed (Larson, et. al., 1977). Soil sampling and testing are also a reliable method for providing the adequate information for fertilizer application and recommendations.

Results of the studies on nitrogen fertilizers in irrigated areas indicate that pre-planting and sidedressing are more effective than the broadcasting method which is applied in the fall (Larson, et. al., 1977).

A nitrogen fertilizer study in Ontario showed that the spring-applied N, produced from 370 to 2610 kg/ha more yield on clay soils than fall-applied N (Stevenson, et. al., 1969). The research in Illinois indicated that the spring applied N at application rates of 67 and 134 kg/ha produced 10 to 20% higher yields than the fall applied. Yields were the same for the application rates of 201 and 268 kg/ha in several other locations (Welch, et. al., 1971).

Vitosh, et. al. (1979) studied the economics of fertilizer N on different soils in Michigan. The results indicated that most profitable rates of nitrogen for the loamy sand soil, sandy loam, and clay loam with the potential yields of 4.4, 6.3 and 8.2 tons per hectare were 89.7, 131.1, and 162.5 kg per hectare respectively. He also indicated that soils with higher yield potentials needed more N fertilizers.

Research in Michigan has showed that spring applications of ammonia N are more efficient than the fall applications. Fall losses on fine and medium textured soils are 5-10%, and for coarse textured soils are about 10-30%. Fall applications of nitrogen, especially on coarse texture soils causes groundwater contamination and the fall applications should only be used on fine and medium textured soils (Vitosh, et. al., 1979).

Nitrogen fertilizers are acid forming and affect the phosphorus availability in the soil surface due to change in soil PH. It is recommended that lime be applied more frequently or to use moldboard plowing every three to four years to mix the lime and nitrogen fertilizers (Vitosh and Warncke, 1981).

Anhydrous ammonia can be easily incorporated into the soil. It reduces the need for lime application. This is an efficient method for no-till systems. Applicators should have a rolling coulter ahead of each knife and a packer wheel behind to lower the ammonia losses into the air. When heavy residues are available on the surface, ammonium nitrate can be the most efficient fertilizer (Vitosh and Warncke, 1980).

Organic residues provide a cool temperature medium that reduces evaporation or volatization. On the other hand, a major amount of the nutrients are lost through run-off and leaching. Therefore, 10 to 20 percent more nitrogen may be required when the plant residues are considered (Vitosh and Warncke, 1980).

Superphosphates and ammonium phosphates are the two important sources of phosphorus fertilizers for corn production. The commercial superphosphates contain about

8.8% P (20% P_2o_5) and concentrated superphosphates contain 20 to 22% P(45 to 50% P_2o_5). Superphosphates are mainly used as a single source of P while the ammonium phosphates fertilizer is a combination of different materials produced by the ammoniation of phosphoric acid.

Phosphorus fertilizers are applied in broadcast form in the fall or spring, when using plow or disk at the tillage. Side dressing is also used at the time of planting for row application. If the soil has a moderate fixing capacity, the phosphorus can be applied prior to planting and if the soil has a large P fixing capacity, phosphorus should be applied in a band five cm to the side and five cm below the row (Larson, et. al., 1978).

The phosphorus requirement of corn could be estimated by soil test and crop response concerning the other factors such as yield desired, solubility of the phosphorus in the fertilizer, and method of application.

Phosphorus fertilizers call for fast growth of small seedlings, especially at low soil temperatures. For corn and other grain corps, when the soil temperature is low, at least 28 kg P205/ha is recommended in the early stages which could be applied in bands near the seed. In the successive stages of growth, the plants will be able to properly utilize the phosphorus available in lower depths (Warncke and Christenson, 1981).

Most of Michigan's soils have a high amount of phosphorus and are well-suited to production of no-till corn. Soil test results indicate that over 50 percent of all soils have phosphorus levels greater than 67.3 kg per hectare. This level of phosphorus is estimated to produce 6.3 tons of corn per hectare. When the solid phosphorus level is medium to high, all the phosphorus requirements should be applied in bands five cm to the side and five cm below the seed at planting time (Vitosh and Warncke, 1981).

Potassium chloride is the commercial form of K which can be used as a single or a mixed fertilizer. It can be used before planting in broadcast form and mixed into the soil by plows or disks. It can be applied also in bands near the seed at the time of planting. Potassium fertilizer is usually applied based upon the soil fixing ability. It may be applied every year or in larger amounts once in several years. The side dressing is more effective for low application rates (Larson and Hanway, 1977).

The crop seedling requirement for potassium is less than for phosphorus. The crop potassium utilization increases when the plant starts to grow rapidly. Potassium removal is also high when the corn plant is removed for Silage or Stover feedstuff. The row application of potassium is more effective than the broadcast form. The amount of potassium applied near the seed should not exceed a certain level due to salt injuries to the seed (Warncke and Christensen, 1981).

3.5 Chiseling System

Chisel tillage is a less costly method than the conventional system and is well adapted to soils with good drainage characteristics. It is an effective method for reducing soil and water erosion problems because it keeps a considerable amount of plant residue on the soil surface. Chisel tillages leave a rough or porous soil that reduces soil and water losses.

Chisel plows are heavy pieces of equipment with shanks spaced at 30 centimeters apart and equipped with 5 centimeter chisels and up to 46 centimeter shovels. The chisel points may be single or double-pointed, shovels, spikes, or small sweeps (Mannering and Fenser, 1983).

The success of conservation tillage for controlling erosion depends upon the proportion of plant residue saved on the soil surface. The amount of plant residue left depends upon the type of chisel plow used and the crop residue. Using a 10 centimeter twisted shank on a corn field, 10 to 20 percent of the residue left, while with narrow points, this amount may exceed 50 percent (Moldenhauer, et. al., 1983).

The results from a four year grain yield research in Indiana indicate lower yields on fine soils for chiseling than for moldboard plowing, but on coarse soils the yield resulting from the chiseling method was significantly higher than from moldboard plowing (Larson and Hanway, 1977).

Soil moisture characteristics are considered the major criteria for dividing the soils into several management groups. These soil groups are defined as well-drained, moderately well-drained, somewhat poorly drained, and poorly drained (Cosper, 1983).

Each tillage system causes limited physical changes in the soil due to the soil and residue mixing operation. However, reduced crop yields resulting from conservation systems are related to the limitation of soil physical properties. These include drainage problems, soil wetness levels, degree and frequency of wetness, structural stability, water percolation, impervious or restrictive layers in the profile, and surface soil texture (Cosper, 1983).

Chisel plowing is the most extensive conservation method used in Michigan. The crop yield from the chiseling system is not different from moldboard plowing. Chisel plows significantly reduce water and soil losses, especially from sloping lands. The rate of soil and water losses through chisel plowing depends directly on the proportion of crop residues left on the soil surface and the number and kind of operation after moldboard plowing (Cook and Robertson, 1979).

Conservation tillage systems may affect the implement in two ways: the type of implement used and the way they are adjusted and operated. The physical characteristics of the soil before tillage may be different. The plant residue on the soil may block the implement or affect the operation of the machine. Tillage equipment can be modified for operating in plant residues by adding rolling coulters to cut residues. Rolling coulters can be flat disks, with either smooth, notched, rippled, or fluted edges, or they may be concave disk blades with smooth or notched edges (Erbach, et. al., 1983).

Conventional planters can be practically modified to conservation planters in order to improve their operation. The commercially available coulters can be placed in front of the furrow opener to cut the plant residue and provide a narrow strip of soil for seed placement. Such coulters can be in various shapes such as smooth, notched, rippled, and fluted forms. The capability of coulters depends upon the residue and soil conditions. A rippled coulter is recommended for soft soils while a fluted coulter is practically suitable to work on hard soils (Erbach, et. al., 1983).

3.6 No-tillage System

> No-tillage is a procedure whereby a crop is planted directly into a seedbed not tilled since harvest of the previous crop, and no-tillage occurs during the growing and maturing season. More specifically, no-till is the planting of a crop into sod, previous crop stubble or a cover crop where only the immediate seed zone is disturbed (Anon., 1983).

A narrow slot is provided by the no-tillage method in undisturbed soil so that the seed can be placed. No other tillage operations are necessary. No-tillage practices can be used when proper herbicides are used for weed controls (Nelson, et. al., 1976).

No-till is considered as one of the most effective practices developed in corn production for controlling wind and water erosion. Such practices result in the conservation of soil nutrients and in the reduction of air and water erosion problems. In no-till production, frequency of farming operations are lowered so that the time, labor, and energy requirements are greatly reduced (Robertson, et. al., 1976).

Various studies and research experiences show that no-till is best suited to coarse and medium textured soils with well-drained characteristics. However, no-till practice may not be successful when one or more of these soil conditions are present: (1) fine texture soil; (2) poor structure; (3) inadequate drainage; (4) underestimated organic matters; (5) eroded soil; (6) low fertility levels and soil acidity; (7) herbicide ineffectiveness due to soil texture and weather conditions. These conditions can be evaluated with soil test levels (Robertson, et. al., 1976).

Several factors have increased the rate of adoption of no-till such as improvements in planting equipment, new chemicals, technology transfer, and environmental concerns. Other factors like economics of agriculture, educational methods, and gradual change in farm culture will have major roles on the development of no-till farming. Economic analysis of various conservation tillage systems indicate that no-till is the most cost-effective method commercially used (King, 1983).

Nowak (1983) identified problems for management decisions on adoption of conservation tillage. Such problems are directly related to the timing and sequence of operations including incorporating chemicals and nutrients relative to the amount of crop residue left on the soil surface, controlling pest and weed problems adjusting or modifying implements, and selecting new seed varieties adaptable to different environments.

No-till planters should be capable of performing planting operations under various soil conditions. No-till planters also need special features in addition to those for conventional seeding. These features include:

1. A rolling or fluted coulter is placed ahead of the furrow opener which will cut through the crop residues and penetrate the soil to a uniform depth of 5 to 6 centimeters.
2. A seed opener with a positive planting depth control is used to place seeds at an optimum depth.
3. A press wheel is placed behind the planter to firm the soil over the seed.
4. A separate coulter is also used to put the fertilizer properly in banded forms during planting operations.

The no-till planters put the seed in undisturbed soils under conditions which are different from the conventional system. The soil is usually covered with residue or sod which is wet, firm, or rough. Thus, the planter should be capable of planting through residues with a uniform depth and with good seed to soil contact. The planter should be heavy and strong enough to cut through crop residues properly (Anon., 1983).

Coulters will work successfully if they are operated at seed depth. If coulters are not penetrating enough, residues are not cut, and additional weights are required to provide a downward force for desired penetration. Such a force can be provided with weights, tanks of water, weighted frame members, or with transfer of planter weight from transport wheels to the coulters. A force of 2224 N per blade in hard soils is needed for an optimum penetration (Erbach, et. al., 1983).

If fluted coulters fail to cut the plant residues due to inadequate penetration, the reside may enter the soil opening. Fluted coulters will hairpin the tough residue into the soil when the soil is wet. Therefore, the seed will be in close contact with the residue which will result in poor germination, emergence and early growth. Phytotoxic materials that are released from the residues will damage the seed growth. Phytotoxicity is produced when continuous corn, sorghum, or wheat is planted (Erbach, et. al., 1983).

No-till planters should be operated at a speed of 4.8 to 5.6 km/hr comparing to 7.2 to 8.0 km/hr for a conventional system. The planting hopper should be larger to maintain the same seeding rates. Fertilizer attachments should be adjusted to place fertilizer 2.5 to 5 centimeters to the side and 5 centimeters below the seed (Nelson et al., 1976).

Soil moisture is increased when using no-tillage because of the crop residue which reduces surface run off. The residue lowers the rainfall intensity and increases the soil infiltration. Soil temperature is also lowered which reduces moisture evaporation and improves soil moisture capacity (Knapp, 1983).

No-till farming is not always an effective method for controlling surface runoff. Many research reports from the corn belt indicate that the water runoff resulted from no-tillage was almost equivalent to the conventional systems. A no-till system will produce a firm layer which is impervious to water and increases the surface runoff. Such conditions will happen when the soil surface does not contain adequate crop residues to lower the flow velocity. A no-tillage method may not be effective to control erosion when a complete harvesting of crop residues for animal consumption occurs (Lindstrom and Onstad, 1984).

Conservation tillage, especially no-till, provides a suitable environment for growing pests and disease organisms due to the crop residues left on the soil surface. In a conventional system, the soil is turned over by moldboard plowing which destroys the insects. Such a soil inversion operation will not occur in no-till which keeps the insect larvae on the soil surface for growing (Anon., 1983).

A no-tillage system is primarily accepted as an effective method for reducing erosions on sloping lands. The intensity of erosion depends on the length of slope, slope gradient, soil properties such as texture, structure, organic matter, rainfall intensity, and cropping and tillage systems. Sloping lands will not have any drainage problem because the water accumulation in rainy seasons is prevented (Phillips, et. al., 1984).

3.7 Weed Control

No-till farming needs better management and planning than a conventional system. Weed control practices cannot be done by cultivators after the planting operation. A farmer must know in advance about the types of weeds on his farm in order to prepare a herbicide program to match the weed problems.

A successful weed control program should meet several criteria: (1) controlling existing weeds, (2) controlling germinating weeds and especially root growing weeds, (3) avoiding injuries to the present crop, and (4) preventing injuries to the succeeding crop. These objectives are met if the following procedure is considered (Cook and Robertson, 1979):

1. Proper herbicides should be selected to control weeds on the farm.
2. Sprayers should be properly calibrated to provide a uniform herbicide application throughout the planting seasons.

The effect of herbicides on weed control practices depends primarily on the chemical properties of herbicides, rate of application, soil PH, soil organic matter content, amount of surface plant residue, temperature, rainfall and microbial decomposition. The production of continuous no-till corn lowers the soil PH compared to the conventional system. The amount of residue on the soil surface depends on the type of crop material remaining from the previous crop or from the existing crop. Plant residue burning is also a common practice for removing extra plant material from the land surface and is an effective method to control some of the weeds that cannot be controlled by herbicides (Philips, et. al., 1984).

Two types of herbcides are usually required for a no-till planting system. The first type is called a contact herbicide which controls the existing residues and the second type is called residual which controls grass and weeds that may germinate after the crop is planted. Paraquate and Lorox are the two types of contact and residual, respectively, used for soybean weed control. Other pre-emergence herbicides like Lasso and Amiben are recommended on sandy soils where Lorox may produce injuries to the crop (Clapp, 1972).

Herbicides used for no-till can be used in conventional, but the reverse is not always true. Some herbicides should be mechanically incorporated into the soil and are not suitable for no-till systems. The no-till herbicides should be applied without soil incorporation. In addition to the contact and pre-emergence, the post-emergence herbicides are also used in no-tillage practices. Following is a short description and some examples of several herbicides used in no-tillage (Anon., 1983).

1. Contact herbicides are used before, during, or after planting, but before crop emergence, such as:

HERBICIDE	CONTROLS
Paraquat	Emerged annual grasses, broadleaf weeds
Roundup	Emerged annual grasses, broadleaf weeds
2,4-D	Broadleaf weeds

2. Pre-plant or pre-emergence residual herbicides are applied before crop emergence. Incorporation is not usually required except for some of them with rainfall. A list of these herbicides are indicated as:

HERBICIDE	CONTROLS
Altrazine	Annual broadleaves and grasses
Bicep	Annual broadleaves and grasses
Bladex	Annual broadleaves and grasses
Dual	Most annual grasses
Dyanap	Broadleaves, some grasses
Lasso	Annual grasses, nutsedge, nightshade
Lorox	Broadleaves, some grasses
Princep	Annual broadleaves, some grasses
Prowl	Most annual grasses, some broadleaves
Ramrod	Annual grasses, certain broadleaves
Surflan	Annual grasses, certain broadleaves

3. Post-emergence herbicides are used after crop emergence. They may be used over the crop or to the weed.

HERBICIDES	**CONTROLS**
Altrazine	Annual broadleaves, some grasses
Banvel	Broadleaf weeds
Bicep	Annual broadleaves, grasses
Dual	Most annual grasses
Lasso	Annual grasses
Lorox	Broadleaves, some grasses
Prowl	Annual weeds
Ramrod	Annual weeds
2,4-D	Broadleaf weeds

The rate of herbicide application for a conservation tillage depends upon the weed problem, crop rotation, knowledge of the manager, and the timeliness of operations. A conservation tillage farmer may not have many options available to correct mistakes. A combination of herbicides and cultivators may be recommended for weed control programs in conservation systems (Hayes, 1983).

The timing of an operation is an important factor in herbicide application programs. Weeds should be at the proper stage of growth in order to be controlled with the contact or translocated herbicides. The herbicide effectiveness may be reduced for tall weeds, or clipped weeds or when the weeds are drought-stressed. The pre-emergent residual herbicides should be applied at the planting time. The early application of the pre-emergent herbicide may reduce the length of control while the late application may allow the weeds to germinate and emerge.

Certain weed problems such as purple nutsedge and horsenettle cannot be controlled in conservation tillage with herbicides. These problems are controlled by incorporating herbicides and soil through other tillage methods before conservation tillage practices are attempted (Anon., 1983).

3.8 Insects and Diseases

Conventional and conservation tillage systems have similar pest and disease control problems, except for those insecticides which require soil incorporation. Farm managers and farmers may use different techniques and cultural practices on insecticides and pest management programs. Many sources like extension specialists, farm chemical suppliers, crop consultants, and agricultural colleges are available to provide suitable information on insecticides and pesticide problems.

Major no-till corn insects are described under two categories of soil insects and above-ground insects. Seed corn maggot, wireworm and seed corn beetle are the major soil insects. These pests attack the corn seed when the cool soil temperature causes slow germination. Insecticides can be applied in attachment units at the planting time to control these insects. Rootworm, white grub and sod webworm are the other important soil insects which may destroy the corn plant completely. Root worm is found in the corn belt when the continuous corn crop is grown. Crop rotation is considered the best method to control rootworm. The life cycle of rootworm is broken when corn is rotated with another corp like soybean. Rootworms can be controlled with insecticides which should be applied in a band and incorporated with soil. The soil incorporated insecticides may be difficult to use in no-till method (Anon., 1983).

The late seed germination resulting from the lower soil temperatures provides a suitable environment for seed corn beetle and seed corn maggot. The larva development of these two pests starts at 10°C and higher. Early organophosphate seed treatments will provide satisfactory results on controlling these two pests (Phillips, et. al., 1984).

Major above-ground corn insects are indicated as armyworm, cutworm, common stalk borer, and European corn borer. Foliar-applied insecticides are used to control these insects with the same methods used in a conventional system. The most appropriate method to control above-ground insects include a proper scouting program and the personal knowledge to identify the pest and the method to apply the insecticide (Anon., 1983).

In addition to insecticides, other methods and practices are recommended to control insects under a no-tillage cropping sequence. These methods include: (1) possible increase in predator and/or parasite activity; (2) selection of resistant varieties; (3) using a multiple crop rotation sequence; and (4) proper fertilizers with increasing seeding rates and lower row spacing (Phillips, et. al., 1984).

CHAPTER 4

LINEAR PROGRAMMING MODEL

4.1 Introduction

Linear programming models are means for conducting research studies associated with policy issues for resource utilization and allocation. Linear programming deals with problems of limited resources among competing activities in the best possible (optimal) way.

One of the important decisions of the farmer is to select the machinery complement required for annual operation within a suitable time period. Failure of timely operation for planting, cultivating, and harvesting results in certain amount of crop losses.

To make a reasonable comparison between conventional and conservation tillage systems, optimum sized machinery complements are needed for each tillage system under a suitable time period. Interactions among machines, land, weather, and capital investment create a problem which can be properly solved by a Linear Programming Model.

Studies on implements used on farms indicate that machines are not properly matched to one another nor to the available power on the farm. Farmers usually do not buy a complete set of well-matched machines for their farming operations at a particular time. They buy machines when needed and attempt to match the new machines to their present machinery sets (Rotz et. al., 1983).

Several machinery selection models have been developed to deal with the machinery complements required on a farm. Muhtar (1982) developed a computer simulation model to select a set of machines for a group of crop rotations in Michigan. Computer simulation models for machinery selection have some limitations which are complex due to computer algorithm and very expensive data processing. Computer simulation models usually do not generate optimum solutions.

Amir, et. al. (1978) formulated a mixed integer programming model to select an optimum dry hay system among the various alternative systems. The model maximizes profit for annual harvesting of dry hay relative to a series of constraints. It is used to examine the interaction of six different hay packing methods in Southern Ontario. Various quantities of dry hay ranging from 100 to 1500 tons were evaluated relative to operating costs and the resultant benefit. The mixed integer model was a proper method for determining the feasibility of machinery complements. The harvesting system include nine operations starting from cutting to feeding and each operation consisted of many activities representing machinery and complements.

Danok, et. al. (1978) made a regional study to develop a linear programming model to select a set of machinery complements for a cropping plan from several resources. The mixed integer programming model maximizes profit from harvesting crops related to the costs of implements and tractors used. The resource constraints are considered to be land, irrigation, available power sources, and the minimum number of implements required. The model estimated a major reduction in hired temporary labor achieved by substitution of capital through mechanization of harvesting crops and through planning of better utilization of permanent labor. The optimal results showed a higher farm income with less hired labor requirement than for the real situation. In addition, comparison between the optimal and actual results indicated more machinery complements with a lower number of tractors required for optimal situation.

Yang and Sowell (1981) developed a mixed integer programming model for scheduling the harvest of flue-cured tobacco. The model maximized profits from the harvested crop, harvester, and storage capacities. Leaf harvesting is a sensitive process in a flue-cured production system which affects the quantity and quality of the product. This situation calls for a desired harvesting schedule. The model objective function presents the total net return from tobacco harvested from all fields. The barn capacity was considered to be a major constraint due to the capacity and the curing time for tobacco. The net return was the difference between the total gross return and the harvesting cost.

Witson, et. al. (1981) developed a profit maximization model to include weather risk for machinery selection. The model was used for two crops of cotton and grain sorghum for farms of 1000 hectares or larger. The result was non integer solutions for machinery complements generated by the model.

A linear programming model is formulated to select optimum machinery complements for conventional, chiseling and no-tillage practices as a basis for economic comparison. This method is used as an alternative for a simulation model that is expensive and complex algorithm.

The proposed linear programming model has been developed based upon the following objectives:

1. To select optimum machinery sets for commercial corn tillage systems such as conventional, chiseling, and no-till in Michigan.
2. To compare the tillage systems and determine the most feasible system using an economic comparison.

Capacity and power match, and cost analysis are major factors in the selection process. Capacity matching represents the interrelation between operation and time. In sequential operations, the time should be independently divided between them. Parallel operations should be done within the same time period so that the time requirement for individual operation is equal.

Farm implements should match the power size of the tractor as well as possible. Oversized and undersized implements result in inefficient use of the tractor and damages to the machines. If several implements are pulled by the same tractor, their power requirement should be similar.

The timeliness is defined as the loss in crop value when the farm operations, especially planting and harvesting are not completed within the same time period. The planting and harvesting machines selected by the model are used to calculate the daily timeliness costs.

It is also possible to develop individual linear programming models based on single constraints like suitable weather, land, labor, capital investment, or power requirement but the results of the model are more realistic when the interaction between several constraints is considered.

4.2 Model Formulation

The proposed linear programming model has the general formulation minimize

$$C = \sum_{i=1}^{m} \sum_{j=1}^{n} CjXij$$

subject to

$$\sum_{i=1}^{m} \sum_{j=1}^{n} AijXij \leq Bi \quad \text{for } i=1 \text{ to } m,\ j=1 \text{ to } n$$

and $$Xij \geq 0 \quad \text{for } i=1 \text{ to } m,\ j=1 \text{ to } n$$

in which

Xij = Variables which refer to the number of market size machines ranging from the highest to the lowest size.

Cj = The total average annual cost of each machine. It includes annual ownership and operating cost.

Bi = Resource constraints that include suitable hours, land, minimum size tractor, labor, and machinery investment.

Aij = Variable coefficients which represent maximum annual operating hours, maximum annual coverable land, power requirement, annual operating hours, annual ownership cost, and annual repair and maintenance costs for individual machines.

<u>Variables Used in the Conventional System</u>

Variable	Moldboard Plow
X1	12-Bottom
X2	9-Bottom
X3	7-Bottom
X4	5-Bottom
X5	3-Bottom
X6	2-Bottom
	Tandem Disk
X7	4.9m
X8	4.3m
X9	3.7m
X10	3.0m
X11	2.4m
X12	1.8m

Variables Used in the Conventional System, cont'd.

Variable	Spring Tooth Harrow
X13	6.0m
X14	5.5m
X15	4.9m
X16	4.3m
X17	3.7m
X18	3.0m
	Row Cultivator
X19	12-Row
X20	8-Row
X21	6-Row
X22	5-Row
X23	4-Row
	Fertilizer Spreader
X24	6.0m
X25	5.5m
X26	4.9m
X27	4.3m
X28	3.7m
X29	3.0m
	Sprayer
X30	11.0m
X31	10.7m
X32	9.2m
X33	8.3m
X34	7.6m
X35	6.4m
	Field Cultivator
X36	7.9m
X37	6.0m
X38	4.9m
X39	4.3m
X40	3.7m
X41	2.4m
	Sub Soiler
X42	3-units
X43	2-units
X44	1-unit
	Combine
X45	12-row
X46	8-row
X47	6-row

Variables Used in the Conventional System, Cont'd.

Variable	Combine
X48	5-row
X49	4-row
	NH_3 Applicator
X50	10-knives
X51	9-knives
X52	8-knives
X53	7-knives
X54	6-knives
X55	5-knives
	Row Planter
X56	12-row
X57	8-row
X58	6-row
X59	5-row
X60	4-row

	Tractor		
	C	M	F
X61	40kw	40kw	40kw
X62	50kw	45kw	50kw
X63	55kw	50kw	55kw
X64	60kw	60kw	60kw
X65	70kw	70kw	70kw
X66	85kw	75kw	85kw
X67	95kw	80kw	100kw
X68	115kw	85kw	115kw
X69	125kw	90kw	125kw
X70	150kw	95kw	150kw

C, M, and F indicate Coarse, Medium and Fine Soil respectively.

Variables Used in the Chiseling System

Variable	Chisel Plow
X1	7.9m
X2	4.9m
X3	3.0m
X4	2.7m
X5	2.4m
X6	1.8m

Variables Used in the Chiseling system cont'd.

Variable	Tandem Disk
X7	4.9m
X8	4.3m
X9	3.7m
X10	3.0m
X11	2.4m
X12	1.8m
	Row Cultivator
X13	12-row
X14	8-row
X15	6-row
X16	5-row
X17	4-row
	Fertilizer Spreader
X18	6.0m
X19	5.5m
X20	4.9m
X21	4.3m
X22	3.7m
X23	3.0m
	Sprayer
X24	11.0m
X25	10.7m
X26	9.2m
X27	8.3m
X28	7.6m
X29	6.4m
	Field Cultivator
X30	7.9m
X31	6.0m
X32	4.9m
X33	4.3m
X34	3.7m
X35	2.7m
	Sub Soiler
X36	3-units
X37	2-units
X38	1-unit
	Combine
X39	12-row
X40	8-row
X41	6-row

Variables Used in the Chiseling System, Cont'd.

Variable	Combine
X42	5-row
X43	4-row

	NH_3 Applicator
X44	10-knives
X45	9-knives
X46	8-knives
X47	7-knives
X48	6-knives
X49	5-knives

	Row Planter
X50	12-row
X51	8-row
X52	6-row
X53	5-row
X54	4-row

	Tractor		
	C	M	F
X55	40kw	40kw	40kw
X56	45kw	50kw	50kw
X57	50kw	55kw	55kw
X58	55kw	60kw	60kw
X59	60kw	70kw	70kw
X60	65kw	85kw	85kw
X61	70kw	100kw	100kw
X62	75kw	115kw	115kw
X63	80kw	125kw	125kw
X64	85kw	150kw	150kw

C, M, and F indicate Coarse, Medium and Fine Soil respectively.

Variables Used in the No-till System

Variable	Field Cultivator
X1	0
X2	0
X3	0
X4	0
X5	0
X6	0

Variables Used in the No-till system cont'd.

Variable	Fertilizer Spreader
X7	6.0m
X8	5.5m
X9	4.9m
X10	4.3m
X11	3.7m
X12	3.0m
	Boom Sprayer
X13	11.0m
X14	10.7m
X15	9.2m
X16	8.3m
X17	7.6m
X18	6.4m
	Row Cultivator
X19	0
X20	0
X21	0
X22	0
X23	0
	No-till Planter
X24	12-row
X25	8-row
X26	6-row
X27	5-row
X28	4-row
	NH_3 Applicator
X29	10-knives
X30	9-knives
X31	8-knives
X32	7-knives
X33	6-knives
X34	5-knives
	Combine
X35	12-row
X36	8-row
X37	6-row
X38	5-row
X39	4-row

	Subsoiler
X40	3-units
X41	2-units
X42	1-unit

		Tractor	
	C	M	F
X43	40kw	40kw	40kw
X44	45kw	50kw	50kw
X45	50kw	55kw	55kw
X46	55kw	60kw	60kw
X47	60kw	70kw	70kw
X48	65kw	85kw	85kw
X49	70kw	100kw	100kw
X50	75kw	115kw	120kw
X51	80kw	125kw	125kw
X52	85kw	150kw	150kw

C, M, and F indicate Coarse, Medium and Fine Soil respectively.

4.2.1 Objective Function Coefficients

The linear programming model is a cost minimizing model and the objective function coefficients represent the total annual equivalent cost (including ownership and operation) of machines. The machinery cost model, a computer simulation model that includes inflation, is used to calculate the annual equivalent cost of individual machines (Rotz, et. al., 1981).

Major economic input parameters which determine the annual costs are initial prices, discount rate and inflation rates. Machine initial costs were provided from commercial suppliers of farm machinery. A survey was taken on initial prices for various market size implements (Tables 4.4-4.7). Tables 4.1-4.3 and 4.8-4.10 indicate speeds, draft, and power requirement. Machine inflation rates, discount rate, and interest rate are given in Table 4.11. Machinery prices will also increase over a period of time.

The major costs of agricultural machinery determined by the machinery cost model are capital investment, interest, property tax, insurance, shelter, repair and maintenance, and fuel and lubrication. The income tax deductions represent a benefit or saving to the owner. The cost to the owner for owning the machine is determined as the sum of the down payment plus all principal interest payments for the purchase of the machine, minus the remaining value at the end of its life. The down payment is determined in terms of the present value. Average annual costs represent a uniform series of costs that can be converted to present value. The remaining value of a machine represents a cost in the future that can be discounted to the present value.

Table 4.1
Machinery Speeds and Capacities for the Coarse Soil

Implement	Size (m)	FE (%)	Speed* (Km/hr) High	Low	Med.	EFC (Ha/hr)	Max. Ann. Use (Hours) 400 (Ha)	200 (Ha)
MB. Plow(m):								
12-Bottom,0.56	6.7	85	9.7	4.8	7.2	4.1	98	49
9-Bottom,0.41	3.7	85	9.7	4.8	7.2	2.3	174	87
7-Bottom,0.41	2.8	85	9.7	4.8	7.2	1.7	235	118
5-Bottom,0.41	2.0	85	9.7	4.8	7.2	1.2	333	167
3-Bottom,0.36	1.0	85	9.7	4.8	7.2	0.6	667	334
2-Bottom,0.36	0.7	85	9.7	4.8	7.2	0.4	1000	500
Tandem Disk(m):								
5.00	5.0	80	9.7	5.3	7.6	3.0	133	67
4.30	4.3	80	9.7	5.3	7.6	2.6	154	77
3.70	3.7	80	9.7	5.3	7.6	2.2	182	91
3.00	3.0	80	9.7	5.3	7.6	1.8	222	111
2.40	2.4	80	9.7	5.3	7.6	1.5	267	134
1.80	1.8	80	9.7	5.3	7.6	1.0	400	200
Offset Disk(m):								
8.5	8.5	80	9.7	7.4	8.5	5.8	69	35
7.3	7.3	80	9.7	7.4	8.5	5.0	80	40
6.0	6.0	80	9.7	7.4	8.5	4.0	100	50
3.7	3.7	80	9.7	7.4	8.5	2.5	160	80
3.0	3.0	80	9.7	7.4	8.5	2.0	200	100
2.4	2.4	80	9.7	7.4	8.5	1.6	250	125
Chisel Plow(m):								
7.9	7.9	80	9.6	4.5	7.2	4.6	87	44
4.9	4.9	80	9.6	4.5	7.2	2.8	143	72
3.0	3.0	80	9.6	4.5	7.2	1.7	235	118
2.7	2.7	80	9.6	4.5	7.2	1.6	250	125
2.4	2.4	80	9.6	4.5	7.2	1.4	286	143
1.8	1.8	80	9.6	4.5	7.2	1.0	400	200
Spring Tooth Harr(m):								
6.0	6.0	80	8.5	4.8	7.0	3.4	118	59
5.5	5.5	80	8.5	4.8	7.0	3.0	133	67
4.9	4.9	80	8.5	4.8	7.0	2.7	148	74
4.3	4.3	80	8.5	4.8	7.0	2.4	167	84
3.7	3.7	80	8.5	4.8	7.0	2.0	200	100
3.0	3.0	80	8.5	4.8	7.0	1.7	235	118
Row Cultivator(m):								
16-Row, 0.76	12.2	80	8.0	4.4	6.5	6.3	63	32
12-Row, 0.76	9.1	80	8.0	4.4	6.5	4.7	85	43
10-Row, 0.76	7.6	80	8.0	4.4	6.5	4.0	100	100
8-Row, 0.76	6.0	80	8.0	4.4	6.5	3.1	129	65
6-Row, 0.76	4.6	80	8.0	4.4	6.5	2.4	167	83
5-Row, 0.76	3.8	80	8.0	4.4	6.5	2.0	200	100
4-Row, 0.76	3.0	80	8.0	4.4	6.5	1.6	250	125
Fertilizer Spreader(m):								
6.0	6.0	60	8.9	4.7	7.6	2.7	148	74
5.5	5.5	60	8.9	4.7	7.6	2.5	160	80
4.9	4.9	60	8.9	4.7	7.6	2.2	182	91
4.3	4.3	60	8.9	4.7	7.6	2.0	200	100
3.7	3.7	60	8.9	4.7	7.6	1.7	235	118
3.0	3.0	60	8.9	4.7	7.6	1.4	286	143
Boom Sprayer(m):								
11.0	11.0	60	11.3	4.8	7.2	4.8	83	42
10.7	10.7	60	11.3	4.8	7.2	4.6	87	43
9.2	9.2	60	11.3	4.8	7.2	4.0	100	50
8.3	8.3	60	11.3	4.8	7.2	3.6	111	56
7.6	7.6	60	11.3	4.8	7.2	3.3	121	61
6.4	6.4	60	11.3	4.8	7.2	2.8	143	71
Field Cultivator(m):								
7.9	7.9	80	9.6	6.2	8.5	5.4	74	37
6.0	6.0	80	9.6	6.2	8.5	4.0	100	50
4.9	4.9	80	9.6	6.2	8.5	3.3	121	61
4.3	4.3	80	9.6	6.2	8.5	2.9	138	69
3.7	3.7	80	9.6	6.2	8.5	2.5	160	80
2.4	2.4	80	9.6	6.2	8.5	1.6	250	125
Subsoiler(m):								
3-Unit	3.0	80	8.6	5.8	7.2	1.7	235	118
2-Unit	2.0	80	8.6	5.8	7.2	1.2	333	167
1-Unit	1.0	80	8.6	5.8	7.2	0.6	667	334
Combine(m):								
12-Row	9.0	70	6.4	3.2	4.0	2.5	160	80
8-Row	6.0	70	6.4	3.2	4.0	1.7	235	118
6-Row	4.5	70	6.4	3.2	4.0	1.3	308	154
5-Row	3.8	70	6.4	3.2	4.0	1.0	400	200

Table 4.1
Machinery Speeds and capacities for the coarse Soil

			Speed* (Km/hr)				Max. Ann. Use (hours)	
Implement	Size (m)	FE (%)	High	Low	Med.	EFC (Ha/hr)	400 (Ha)	200 (Ha)
Combine (m):								
4-Row	3.0	70	6.4	3.2	4.0	0.8	500	250
NH3 Applicator (m):								
10-Knife	8.2	60	7.5	5.8	6.2	3.0	133	67
9-Knife	6.4	60	7.5	5.8	6.2	2.4	167	84
8-knife	5.5	60	7.5	5.8	6.2	2.0	200	100
7-Knife	4.6	60	7.5	5.8	6.2	1.7	235	118
6-Knife	3.7	60	7.5	5.8	6.2	1.4	286	143
5-Knife	2.7	60	7.5	5.8	6.2	1.0	400	200
No-Till Planter (m):								
16-Row,0.76	12.2	65	6.4	4.2	6.2	4.9	82	41
12-Row,0.76	9.1	65	6.4	4.2	6.2	3.7	108	54
10-Row,0.76	7.6	65	6.4	4.2	6.2	3.0	133	67
8-Row,0.76	6.0	65	6.4	4.2	6.2	2.4	167	84
6-Row,0.76	4.6	65	6.4	4.2	6.2	1.9	210	105
5-Row,0.76	3.8	65	6.4	4.2	6.2	1.5	267	134
4-Row,0.76	3.0	65	6.4	4.2	6.2	1.2	333	167
Row Planter (m):								
16-Row,0.76	12.2	65	10.0	3.5	6.4	5.0	80	40
12-Row,0.76	9.1	65	10.0	3.5	6.4	3.8	105	53
10-row,0.76	7.6	65	10.0	3.5	6.4	3.2	125	63
8-Row,0.76	6.0	65	10.0	3.5	6.4	2.5	160	80
6-Row,0.76	4.6	65	10.0	3.5	6.4	1.9	210	105
5-Row,0.76	3.8	65	10.0	3.5	6.4	1.6	250	125
4-row,0.76	3.0	65	10.0	3.5	6.4	1.2	333	167

* Source: White,1978; White,1977; Hunt,1977; Self,1983; Vaughan,1978; Frisby,1978; Smith,1980; Fornstrom,1977; Kepner,1978; Wilkinson,1982; Agricultural Engineering Yearbook,1983; John Deere Publications,1981.

Table 4.2
Machinery Speeds and Capacities for the Medium Soil

			------Speed*------ (Km/hr)				Max. Ann. Use (Hours)	
Implement	Size (m)	FE (%)	High	Low	Med.	EFC (Ha/hr)	400 (Ha)	200 (Ha)
MB. Plow (m):								
12-Bottom, 0.56	6.7	85	8.0	4.0	7.1	4.0	100	50
9-Bottom, 0.41	3.7	85	8.0	4.0	7.1	2.2	182	91
7-Bottom, 0.41	2.8	85	8.0	4.0	7.1	1.7	235	118
5-Bottom, 0.41	2.0	85	8.0	4.0	7.1	1.2	333	167
3-Bottom, 0.36	1.0	85	8.0	4.0	7.1	0.6	667	334
2-Bottom, 0.36	0.7	85	8.0	4.0	7.1	0.4	1000	500
Tandem Disk (m):								
5.00	5.0	80	8.2	5.3	7.2	2.8	143	72
4.30	4.3	80	8.2	5.3	7.2	2.5	160	80
3.70	3.7	80	8.2	5.3	7.2	2.1	190	95
3.00	3.0	80	8.2	5.3	7.2	1.7	235	118
2.40	2.4	80	8.2	5.3	7.2	1.4	286	143
1.80	1.8	80	8.2	5.3	7.2	1.0	400	200
Offset Disk (m):								
8.5	8.5	80	8.0	5.6	7.2	4.9	82	41
7.3	7.3	80	8.0	5.6	7.2	4.2	95	48
6.0	6.0	80	8.0	5.6	7.2	3.5	114	57
3.7	3.7	80	8.0	5.6	7.2	2.1	190	95
3.0	3.0	80	8.0	5.6	7.2	1.7	235	118
2.4	2.4	80	8.0	5.6	7.2	1.4	286	143
Chisel Plow (m):								
7.9	7.9	80	8.0	4.5	7.2	4.6	87	44
4.9	4.9	80	8.0	4.5	7.2	2.8	143	72
3.0	3.0	80	8.0	4.5	7.2	1.7	235	118
2.7	2.7	80	8.0	4.5	7.2	1.6	250	125
2.4	2.4	80	8.0	4.5	7.2	1.4	286	143
1.8	1.8	80	8.0	4.5	7.2	1.0	400	200
Spring Tooth Harr (m):								
6.0	6.0	80	7.4	3.8	6.8	3.3	121	61
5.5	5.5	80	7.4	3.8	6.8	3.0	133	67
4.9	4.9	80	7.4	3.8	6.8	2.7	148	74
4.3	4.3	80	7.4	3.8	6.8	2.3	174	87
3.7	3.7	80	7.4	3.8	6.8	2.0	200	100
3.0	3.0	80	7.4	3.8	6.8	1.6	250	125
Row Cultivator (m):								
16-Row, 0.76	12.2	80	7.5	4.2	5.6	5.5	73	37
12-Row, 0.76	9.1	80	7.5	4.2	5.6	4.0	100	50
10-Row, 0.76	7.6	80	7.5	4.2	5.6	3.4	118	59
8-Row, 0.76	6.0	80	7.5	4.2	5.6	2.7	148	74
6-Row, 0.76	4.6	80	7.5	4.2	5.6	2.0	200	100
5-Row, 0.76	3.8	80	7.5	4.2	5.6	1.7	235	118
4-Row, 0.76	3.0	80	7.5	4.2	5.6	1.3	308	154
Fertilizer Spreader (m):								
6.0	6.0	60	8.9	4.7	7.6	2.7	148	74
5.5	5.5	60	8.9	4.7	7.6	2.5	160	80
4.9	4.9	60	8.9	4.7	7.6	2.2	182	91
4.3	4.3	60	8.9	4.7	7.6	2.0	200	100
3.7	3.7	60	8.9	4.7	7.6	1.7	235	118
3.0	3.0	60	8.9	4.7	7.6	1.4	286	143
Boom Sprayer (m):								
11.0	11.0	60	11.3	4.8	7.2	4.8	83	42
10.7	10.7	60	11.3	4.8	7.2	4.6	87	43
9.2	9.2	60	11.3	4.8	7.2	4.0	100	50
8.3	8.3	60	11.3	4.8	7.2	3.6	111	56
7.6	7.6	60	11.3	4.8	7.2	3.3	121	61
6.4	6.4	60	11.3	4.8	7.2	2.8	143	71
Field Cultivator (m):								
7.9	7.9	80	8.9	7.7	8.2	5.2	77	39
6.0	6.0	80	8.9	7.7	8.2	3.9	103	53
4.9	4.9	80	8.9	7.7	8.2	3.2	125	63
4.3	4.3	80	8.9	7.7	8.2	2.8	143	72
3.7	3.7	80	8.9	7.7	8.2	2.4	167	84
2.4	2.4	80	8.9	7.7	8.2	1.6	250	125
Subsoiler (m):								
3-Unit	3.0	80	8.2	5.0	7.0	1.7	235	118
2-Unit	2.0	80	8.2	5.0	7.0	1.1	363	182
1-Unit	1.0	80	8.2	5.0	7.0	0.6	667	336
Combine (m):								
12-Row	9.0	70	6.4	3.2	4.0	2.5	160	80
8-Row	6.0	70	6.4	3.2	4.0	1.7	235	118
6-Row	4.5	70	6.4	3.2	4.0	1.3	308	154
5-Row	3.8	70	6.4	3.2	4.0	1.0	400	200

Table 4.2
Machinery Speeds and Capacities for the Medium Soil

Implement	Size (m)	FE. (%)	------Speed*------ (Km/hr) High	Low	Med.	EFC (Ha/hr)	Max. Ann. Use (Hours) 400 (Ha)	200 (Ha)
Combine(m):								
4-Row	3.0	70	6.4	3.2	4.0	0.8	500	250
NH3 Applicator(m):								
10-Knife	8.2	60	6.3	5.0	5.5	2.7	148	74
9-Knife	6.4	60	6.3	5.0	5.5	2.1	190	95
8-knife	5.5	60	6.3	5.0	5.5	1.8	222	111
7-Knife	4.6	60	6.3	5.0	5.5	1.5	267	134
6-Knife	3.7	60	6.3	5.0	5.5	1.2	333	167
5-Knife	2.7	60	6.3	5.0	5.5	0.9	444	222
No-Till Planter(m):								
16-Row,0.76	12.2	65	4.8	4.3	4.0	3.2	125	63
12-Row,0.76	9.1	65	4.8	4.3	4.0	2.4	167	84
10-Row,0.76	7.6	65	4.8	4.3	4.0	2.0	200	100
8-Row,0.76	6.0	65	4.8	4.3	4.0	1.6	250	125
6-Row,0.76	4.6	65	4.8	4.3	4.0	1.2	333	167
5-Row,0.76	3.8	65	4.8	4.3	4.0	1.0	400	200
4-Row,0.76	3.0	65	4.8	4.3	4.0	0.8	500	250
Row Planter(m):								
16-Row,0.76	12.2	65	8.0	4.0	5.5	4.4	91	46
12-Row,0.76	9.1	65	8.0	4.0	5.5	3.3	121	61
10-row,0.76	7.6	65	8.0	4.0	5.5	2.7	148	74
8-Row,0.76	6.0	65	8.0	4.0	5.5	2.1	191	96
6-Row,0.76	4.6	65	8.0	4.0	5.5	1.6	250	125
5-Row,0.76	3.8	65	8.0	4.0	5.5	1.4	286	143
4-row,0.76	3.0	65	8.0	4.0	5.5	1.0	400	200

* Source: See Table 4.1

Table 4.3
Machinery Speeds and Capacities for the Fine Soil

			------Speed*------ (Km/hr)				Max. Ann. Use (Hours)	
Implement	Size (m)	FE (%)	High	Low	Med.	EFC (Ha/hr)	400 (Ha)	200 (Ha)
MB. Plow (m):								
12-Bottom, 0.56	6.7	85	8.0	4.0	6.7	3.8	105	53
9-Bottom, 0.41	3.7	85	8.0	4.0	6.7	2.1	190	95
7-Bottom, 0.41	2.8	85	8.0	4.0	6.7	1.6	250	125
5-Bottom, 0.41	2.0	85	8.0	4.0	6.7	1.1	364	182
3-Bottom, 0.36	1.0	85	8.0	4.0	6.7	0.6	667	334
2-Bottom, 0.36	0.7	85	8.0	4.0	6.7	0.4	1000	500
Tandem Disk (m):								
5.00	5.0	80	7.2	6.4	7.1	2.8	143	72
4.30	4.3	80	7.2	6.4	7.1	2.4	167	84
3.70	3.7	80	7.2	6.4	7.1	2.1	190	95
3.00	3.0	80	7.2	6.4	7.1	1.7	235	118
2.40	2.4	80	7.2	6.4	7.1	1.4	286	143
1.80	1.8	80	7.2	6.4	7.1	1.0	400	200
Offset Disk (m):								
8.5	8.5	80	7.9	5.6	6.4	4.4	91	46
7.3	7.3	80	7.9	5.6	6.4	3.7	108	54
6.0	6.0	80	7.9	5.6	6.4	3.0	133	67
3.7	3.7	80	7.9	5.6	6.4	1.9	210	105
3.0	3.0	80	7.9	5.6	6.4	1.5	267	134
2.4	2.4	80	7.9	5.6	6.4	1.2	333	167
Chisel Plow (m):								
7.9	7.9	80	8.0	4.5	7.2	4.6	87	44
4.9	4.9	80	8.0	4.5	7.2	2.8	143	72
3.0	3.0	80	8.0	4.5	7.2	1.7	235	118
2.7	2.7	80	8.0	4.5	7.2	1.6	250	125
2.4	2.4	80	8.0	4.5	7.2	1.4	286	143
1.8	1.8	80	8.0	4.5	7.2	1.0	400	200
Spring Tooth Harr (m):								
6.0	6.0	80	6.8	3.5	5.2	2.5	160	80
5.5	5.5	80	6.8	3.5	5.2	2.3	174	87
4.9	4.9	80	6.8	3.5	5.2	2.0	200	100
4.3	4.3	80	6.8	3.5	5.2	1.8	222	111
3.7	3.7	80	6.8	3.5	5.2	1.5	267	134
3.0	3.0	80	6.8	3.5	5.2	1.2	333	167
Row Cultivator (m):								
16-Row, 0.76	12.2	80	4.2	2.5	4.0	3.9	103	51
12-Row, 0.76	9.1	80	4.2	2.5	4.0	2.9	138	69
10-Row, 0.76	7.6	80	4.2	2.5	4.0	2.4	167	83
8-Row, 0.76	6.0	80	4.2	2.5	4.0	1.9	211	105
6-Row, 0.76	4.6	80	4.2	2.5	4.0	1.5	267	133
5-Row, 0.76	3.8	80	4.2	2.5	4.0	1.2	329	164
4-Row, 0.76	3.0	80	4.2	2.5	4.0	1.0	400	200
Fertilizer Spreader (m):								
6.0	6.0	60	8.9	4.7	7.6	2.7	148	74
5.5	5.5	60	8.9	4.7	7.6	2.5	160	80
4.9	4.9	60	8.9	4.7	7.6	2.2	182	91
4.3	4.3	60	8.9	4.7	7.6	2.0	200	100
3.7	3.7	60	8.9	4.7	7.6	1.7	235	118
3.0	3.0	60	8.9	4.7	7.6	1.4	286	143
Boom Sprayer (m):								
11.0	11.0	60	11.3	4.8	7.2	4.8	83	42
10.7	10.7	60	11.3	4.8	7.2	4.6	87	43
9.2	9.2	60	11.3	4.8	7.2	4.0	100	50
8.3	8.3	60	11.3	4.8	7.2	3.6	111	56
7.6	7.6	60	11.3	4.8	7.2	3.3	121	61
6.4	6.4	60	11.3	4.8	7.2	2.8	143	71
Field Cultivator (m):								
7.9	7.9	80	8.9	4.2	8.0	5.0	77	40
6.0	6.0	80	8.9	4.2	8.0	3.8	103	53
4.9	4.9	80	8.9	4.2	8.0	3.1	125	65
4.3	4.3	80	8.9	4.2	8.0	2.8	143	71
3.7	3.7	80	8.9	4.2	8.0	2.4	167	83
2.4	2.4	80	8.9	4.2	8.0	1.5	250	133
Subsoiler (m):								
3-Unit	3.0	80	7.8	4.8	6.8	1.6	250	125
2-Unit	2.0	80	7.8	4.8	6.8	1.0	400	200
1-Unit	1.0	80	7.8	4.8	6.8	0.5	800	400
Combine (m):								
12-Row	9.0	70	6.4	3.2	4.0	2.5	160	80
8-Row	6.0	70	6.4	3.2	4.0	1.7	235	118
6-Row	4.5	70	6.4	3.2	4.0	1.3	308	154
5-Row	3.8	70	6.4	3.2	4.0	1.0	400	200

Table 4.3
Machinery Speeds and Capacities for the fine Soils

Implement	Size (m)	FE (%)	Speed* (Km/hr) High	Low	Med	EFC (Ha/hr)	Max. Ann. Use (Hours) 400 (Ha)	200 (Ha)
Combine (m):								
4-Row	3.0	70	6.4	3.2	4.0	0.8	500	250
NH3 Applicator (m):								
10-Knife	8.2	60	5.8	4.8	5.2	2.6	154	77
9-Knife	6.4	60	5.8	4.8	5.2	2.0	200	100
8-knife	5.5	60	5.8	4.8	5.2	1.7	235	118
7-Knife	4.6	60	5.8	4.8	5.2	1.4	286	143
6-Knife	3.7	60	5.8	4.8	5.2	1.2	333	167
5-Knife	2.7	60	5.8	4.8	5.2	0.9	444	222
No-Till Planter (m):								
16-Row,0.76	12.2	65	4.4	3.2	3.8	3.0	133	67
12-Row,0.76	9.1	65	4.4	3.2	3.8	2.2	182	91
10-Row,0.76	7.6	65	4.4	3.2	3.8	1.9	211	106
8-Row,0.76	6.0	65	4.4	3.2	3.8	1.5	267	134
6-Row,0.76	4.6	65	4.4	3.2	3.8	1.1	364	182
5-Row,0.76	3.8	65	4.4	3.2	3.8	0.9	444	222
4-Row,0.76	3.0	65	4.4	3.2	3.8	0.7	571	286
Row Planter (m):								
16-Row,0.76	12.2	65	4.7	3.7	4.3	3.4	118	59
12-Row,0.76	9.1	65	4.7	3.7	4.3	2.5	160	80
10-row,0.76	7.6	65	4.7	3.7	4.3	2.1	190	95
8-Row,0.76	6.0	65	4.7	3.7	4.3	1.7	235	118
-6-Row,0.76	4.6	65	4.7	3.7	4.3	1.3	308	154
5-Row,0.76	3.8	65	4.7	3.7	4.3	1.0	400	200
4-row,0.76	3.0	65	4.7	3.7	4.3	0.8	500	250

* Source: See Table 4.1

Table 4.4
Projected System Costs (Coarse Soils)

			Projected System Costs ($)					
Implement	Size (m)	New Price ($) *	Ownreship Cost	Repair & Maint.	Fuel	Labor	Tot. P.V.	Aver. Annual
MB. Plow (m):								
12-Bottom, 0.56	6.7	23467	23467	9498	-	-	21356	2378
9-Bottom, 0.41	3.7	18873	18873	22244	-	-	28130	3132
7-Bottom, 0.41	2.8	12199	12199	23746	-	-	25209	2806
5-Bottom, 0.41	2.0	9483	9483	33825	-	-	31121	3465
3-Bottom, 0.36	1.0	4033	4033	50094	-	-	40017	4455
2-Bottom, 0.36	0.7	1477	1477	34861	-	-	27042	3011
Tandem Disk (m):								
5.00	5.0	10415	10415	3052	-	-	8607	958
4.30	4.3	9428	9428	3450	-	-	8305	925
3.70	3.7	4794	4794	2265	-	-	4607	513
3.00	3.0	2939	2939	1983	-	-	3270	364
2.40	2.4	2889	2889	2849	-	-	3890	433
1.80	1.8	1028	1028	1653	-	-	1864	208
Offset Disk (m):								
8.5	8.5	31808	31808	3021	-	-	21557	2400
7.3	7.3	27130	27130	3338	-	-	18958	2110
6.0	6.0	22641	22641	3888	-	-	16647	1853
3.7	3.7	13474	13474	5263	-	-	12119	1349
3.0	3.0	9681	9681	5401	-	-	9922	1105
2.4	2.4	6510	6510	5307	-	-	7929	883
Chisel Plow (m):								
7.9	7.9	8314	8314	2624	-	-	7011	781
4.9	4.9	3915	3915	2412	-	-	4183	466
3.0	3.0	3134	3134	3837	-	-	4778	532
2.7	2.7	2649	2649	3758	-	-	4426	493
2.4	2.4	2143	2134	3586	-	-	3990	444
1.8	1.8	1562	1562	3911	-	-	3881	432
Spring Tooth Harr (m):								
6.0	6.0	10326	10326	4983	-	-	10000	1113
5.5	5.5	8566	8566	4669	-	-	8698	968
4.9	4.9	6510	6510	4172	-	-	7077	788
4.3	4.3	6089	6089	4685	-	-	7208	802
3.7	3.7	5271	5271	5005	-	-	6951	744
3.0	3.0	4265	4265	5432	-	-	6661	742
Row Cultivator (m):								
16-Row, 0.76	12.2	11500	10326	2047	-	-	7798	868
12-Row, 0.76	9.1	8900	7991	2388	-	-	6638	739
10-Row, 0.76	7.6	6199	5566	2140	-	-	4981	555
8-Row, 0.76	6.0	4734	4251	2276	-	-	4285	477
6-Row, 0.76	4.6	3615	3246	2521	-	-	3860	430
5-Row, 0.76	3.8	2933	2633	2672	-	-	3602	401
4-Row, 0.76	3.0	2250	2020	2854	-	-	3367	375
Fertilizer Spreader (m):								
6.0	6.0	3180	3246	3806	-	-	4824	537
5.5	5.5	2689	2325	3272	-	-	3865	430
4.9	4.9	2089	1876	3365	-	-	3662	408
4.3	4.3	1374	1234	2912	-	-	2933	326
3.7	3.7	1199	1077	3481	-	-	3266	364
3.0	3.0	503	425	2270	-	-	1977	220
Boom Sprayer (m):								
11.0	11.0	4564	4098	1250	-	-	3423	381
10.7	10.7	4250	3816	1294	-	-	3286	366
9.2	9.2	4150	3726	1433	-	-	3336	371
8.3	8.3	3550	3187	1504	-	-	3061	341
7.6	7.6	2750	2469	1218	-	-	2411	268
6.4	6.4	2230	2002	1235	-	-	2141	238
Field Cultivator (m):								
7.9	7.9	8853	7949	1989	-	-	6313	703
6.0	6.0	5498	4937	1815	-	-	4356	485
4.9	4.9	4784	4295	2097	-	-	4178	465
4.3	4.3	3423	3073	1802	-	-	3216	358
3.7	3.7	2864	2572	1861	-	-	2956	329
2.4	2.4	1665	1495	1983	-	-	2394	267
Subsoiler (m):								
3-Unit	3.0	1985	1782	2182	-	-	2718	303
2-Unit	2.0	1350	1212	2618	-	-	2700	301
1-Unit	1.0	995	893	5092	-	-	4362	486
Combine (m):								
12-Row	9.0	150000	138921	42415	20836	8693	139920	15577
8-Row	6.0	95600	88539	60600	27276	12768	130270	14502
6-Row	4.5	82000	24995	74690	38841	55906	105229	11715
5-Row	3.8	87000	80574	168507	36614	21732	219998	24492

Table 4.4
Projected System Costs (coarse Soils)

Implement	Size (m)	New Price($)*	Projected System Costs($)					
			Owner. Cost	Repair& Maint.	Fuel	Labor	Tot. P.V.	Aver. Annual
4-Row	3.0	60700	56217	187844	43880	27165	228954	25489
NH3 Applicator(m):								
10-Knife	8.2	7800	7003	6535	-	-	9149	1019
9-Knife	6.4	7600	6824	10715	-	-	12176	1355
8-knife	5.5	7400	6644	14343	-	-	14788	1646
7-Knife	4.6	7200	6465	20310	-	-	19154	2132
6-Knife	3.7	7000	6285	31192	-	-	27206	3029
5-Knife	2.7	6800	6106	58724	-	-	47746	5315
No-Till Planter(m):								
16-Row,0.76	12.2	35800	32144	13681	-	-	29756	3313
12-Row,0.76	9.1	33000	29630	18780	-	-	32055	3569
10-Row,0.76	7.6	30200	27116	25088	-	-	35262	3926
8-Row,0.76	6.0	17000	15264	23201	-	-	26658	2968
6-Row,0.76	4.6	13000	11672	30997	-	-	30327	3376
5-Row,0.76	3.8	11250	10056	39888	-	-	36015	4009
4-Row,0.76	3.0	9500	8530	55583	-	-	46861	5217
Row Planter(m):								
16-Row,0.76	12.2	25000	22447	7191	-	-	19007	2116
12-Row,0.76	9.1	21000	18855	11180	-	-	19821	2207
10-row,0.76	7.6	18500	16611	14377	-	-	20857	2322
8-Row,0.76	6.0	15000	13468	19151	-	-	22532	2508
6-Row,0.76	4.6	11500	10326	14682	-	-	17274	1923
5-Row,0.76	3.8	10100	9069	33650	-	-	30738	3422
4-row,0.76	3.0	8700	7812	47619	-	-	40452	4503

* Source: Farm Machinery Dealers,1983.

Table 4.5
Projected System Costs (Medium Soils)

Implement	Size (m)	New Price($)*	Ownreship Cost	Repair & Maint.	Fuel	Labor	Tot. P.V.	Aver. Annual
			Projected System Cost($)					
MB. Plow(m):								
12-Bottom,0.56	6.7	23467	23467	9741	-	-	21538	2398
9-Bottom,0.41	3.7	18873	18873	22811	-	-	28555	3179
7-Bottom,0.41	2.8	12199	12199	24351	-	-	25663	2857
5-Bottom,0.41	2.0	9483	9483	34688	-	-	31768	3537
3-Bottom,0.36	1.0	4033	4033	51372	-	-	40975	4562
2-Bottom,0.36	0.7	1477	1477	35750	-	-	27709	3085
Tandem Disk(m):								
5.00	5.0	10415	10415	3346	-	-	8827	983
4.30	4.3	9428	9428	3782	-	-	8555	952
3.70	3.7	4794	4794	2483	-	-	4770	531
3.00	3.0	2939	2939	2174	-	-	3413	380
2.40	2.4	2889	2889	3124	-	-	4096	456
1.80	1.8	1028	1028	1812	-	-	1983	221
Offset Disk(m):								
8.5	8.5	31808	31808	4006	-	-	22296	2482
7.3	7.3	27130	27130	4426	-	-	19774	2201
6.0	6.0	22641	22641	5155	-	-	17598	1959
3.7	3.7	13474	13474	6978	-	-	13405	1492
3.0	3.0	9681	9681	7162	-	-	11243	1252
2.4	2.4	6510	6510	7037	-	-	9226	1027
Chisel Plow(m):								
7.9	7.9	8314	8314	2624	-	-	7011	781
4.9	4.9	3915	3915	2412	-	-	4183	466
3.0	3.0	3134	3134	3837	-	-	4778	532
2.7	2.7	2649	2649	3758	-	-	4426	493
2.4	2.4	2143	2134	3586	-	-	3990	444
1.8	1.8	1562	1562	3911	-	-	3881	432
Spring Tooth Harr(m):								
6.0	6.0	10326	10326	5190	-	-	10155	1130
5.5	5.5	8566	8566	4863	-	-	8843	984
4.9	4.9	6510	6510	5129	-	-	7795	868
4.3	4.3	6089	6089	4879	-	-	7353	819
3.7	3.7	5271	5271	5212	-	-	7106	791
3.0	3.0	4265	4265	5657	-	-	6830	760
Row Cultivator(m):								
16-Row, 0.76	12.2	11500	10326	2522	-	-	8154	908
12-Row, 0.76	9.1	8900	7991	2942	-	-	7035	785
10-Row, 0.76	7.6	6199	5566	2673	-	-	5354	596
8-Row, 0.76	6.0	4734	4251	2804	-	-	4681	521
6-Row, 0.76	4.6	3615	3246	3106	-	-	4298	479
5-Row, 0.76	3.8	2933	2633	3292	-	-	4067	453
4-Row, 0.76	3.0	2250	2020	3517	-	-	3863	430
Fertilizer Spreader(m):								
6.0	6.0	3180	3246	3806	-	-	4824	537
5.5	5.5	2689	2325	3272	-	-	3865	430
4.9	4.9	2089	1876	3365	-	-	3662	408
4.3	4.3	1374	1234	2912	-	-	2933	326
3.7	3.7	1199	1077	3481	-	-	3266	364
3.0	3.0	503	425	2270	-	-	1977	220
Boom Sprayer(m):								
11.0	11.0	4564	4098	1250	-	-	3423	381
10.7	10.7	4250	3816	1294	-	-	3286	366
9.2	9.2	4150	3726	1433	-	-	3336	371
8.3	8.3	3550	3187	1504	-	-	3061	341
7.6	7.6	2750	2469	1218	-	-	2411	268
6.4	6.4	2230	2002	1235	-	-	2141	238
Field Cultivator(m):								
7.9	7.9	8853	7949	2091	-	-	6390	711
6.0	6.0	5498	4937	1909	-	-	4426	493
4.9	4.9	4784	4295	2206	-	-	4260	474
4.3	4.3	3423	3073	1895	-	-	3286	366
3.7	3.7	2864	2572	1957	-	-	3028	337
2.4	2.4	1665	1495	2085	-	-	2471	275
Subsoiler(m):								
3-Unit	3.0	1985	1782	2270	-	-	2784	310
2-Unit	2.0	1350	1212	2723	-	-	2779	309
1-Unit	1.0	995	893	5297	-	-	4515	503
Combine(m):								
12-Row	9.0	150000	138921	42415	20836	8693	139920	15577
8-Row	6.0	95600	88539	60600	27276	12768	130270	14502
6-Row	4.5	82000	24995	74690	38841	55906	105229	11715
5-Row	3.8	87000	80574	168507	36614	21732	219998	24492

Table 4.5
Projected System Costs (Medium Soils)

			Projected System Costs ($)					
Implement	Size (m)	New Price ($) *	Owner. Cost	Repair& Maint.	Fuel	Labor	TOt. P.V.	Aver. Annual
4-Row	3.0	60700	56217	187844	43880	27165	228954	25489
NH3 Applicator (m):								
10-Knife	8.2	7800	7003	8405	-	-	10551	1175
9-Knife	6.4	7600	6824	13781	-	-	14475	1611
8-knife	5.5	7400	6644	18446	-	-	17865	1989
7-Knife	4.6	7200	6465	26120	-	-	23511	2617
6-Knife	3.7	7000	6285	40115	-	-	33899	3774
5-Knife	2.7	6800	6106	75523	-	-	60345	6718
No-Till Planter (m):								
16-Row,0.76	12.2	35800	32144	27631	-	-	40218	4477
12-Row,0.76	9.1	33000	29630	47140	-	-	53325	5937
10-Row,0.76	7.6	30200	27116	62975	-	-	63676	7089
8-Row,0.76	6.0	17000	15264	58237	-	-	52935	5893
6-Row,0.76	4.6	13000	11672	77807	-	-	65435	7285
5-Row,0.76	3.8	11250	10056	100124	-	-	81192	9039
4-Row,0.76	3.0	9500	8530	139520	-	-	109813	12225
Row Planter (m):								
16-Row,0.76	12.2	25000	22447	9886	-	-	21028	2341
12-Row,0.76	9.1	21000	18855	15370	-	-	22963	2556
10-row,0.76	7.6	18500	16611	19765	-	-	24898	2772
8-Row,0.76	6.0	15000	13468	26327	-	-	27914	3108
6-Row,0.76	4.6	11500	10326	35264	-	-	32711	3642
5-Row,0.76	3.8	10100	9069	46260	-	-	40195	4475
4-row,0.76	3.0	8700	7812	65463	-	-	53835	5993

* Source: Farm Machinery Dealers,1983.

Table 4.6
Projected System Costs (Fine Soils)

			Projected System Cost($)					
Implement	Size (m)	New Price($)*	Ownreship Cost	Repair & Maint.	Fuel	Labor	Tot. P.V.	Aver. Annual
MB. Plow(m):								
12-Bottom,0.56	6.7	23467	23467	10812	-	-	22342	2487
9-Bottom,0.41	3.7	18873	18873	25321	-	-	30437	3388
7-Bottom,0.41	2.8	12199	12199	27030	-	-	27672	3081
5-Bottom,0.41	2.0	9483	9483	38504	-	-	34630	3855
3-Bottom,0.36	1.0	4033	4033	57023	-	-	45214	5034
2-Bottom,0.36	0.7	1477	1477	39683	-	-	30659	3413
Tandem Disk(m):								
5.00	5.0	10415	10415	3427	-	-	8887	989
4.30	4.3	9428	9428	3873	-	-	8623	960
3.70	3.7	4794	4794	2543	-	-	4815	536
3.00	3.0	2939	2939	2226	-	-	3453	384
2.40	2.4	2889	2889	3199	-	-	4152	462
1.80	1.8	1028	1028	1856	-	-	2016	224
Offset Disk(m):								
8.5	8.5	31808	31808	4103	-	-	22368	2490
7.3	7.3	27130	27130	5407	-	-	20510	2283
6.0	6.0	22641	22641	5279	-	-	17691	1969
3.7	3.7	13474	13474	7146	-	-	13531	1506
3.0	3.0	9681	9681	7334	-	-	11372	1266
2.4	2.4	6510	6510	7207	-	-	9353	1041
Chisel Plow(m):								
7.9	7.9	8314	8314	2624	-	-	7011	781
4.9	4.9	3915	3915	2412	-	-	4183	466
3.0	3.0	3134	3134	3837	-	-	4778	532
2.7	2.7	2649	2649	3758	-	-	4426	493
2.4	2.4	2143	2134	3586	-	-	3990	444
1.8	1.8	1562	1562	3911	-	-	3881	432
Spring Tooth Harr(m):								
6.0	6.0	10326	10326	7555	-	-	11929	1328
5.5	5.5	8566	8566	7079	-	-	10505	1169
4.9	4.9	6510	6510	6324	-	-	8692	968
4.3	4.3	6089	6089	7103	-	-	9021	1004
3.7	3.7	5271	5271	7588	-	-	8888	989
3.0	3.0	4265	4265	8235	-	-	8764	976
Row Cultivator(m):								
16-Row, 0.76	12.2	11500	10326	4039	-	-	9292	1034
12-Row, 0.76	9.1	8900	7991	4712	-	-	8381	933
10-Row, 0.76	7.6	6199	5566	4223	-	-	6544	728
8-Row, 0.76	6.0	4734	4251	4491	-	-	5947	662
6-Row, 0.76	4.6	3615	3246	4974	-	-	5700	635
5-Row, 0.76	3.8	2933	2633	5273	-	-	5553	618
4-Row, 0.76	3.0	2250	2020	5632	-	-	5450	607
Fertilizer Spreader(m):								
6.0	6.0	3180	3246	3806	-	-	4824	537
5.5	5.5	2689	2325	3272	-	-	3865	430
4.9	4.9	2089	1876	3365	-	-	3662	408
4.3	4.3	1374	1234	2912	-	-	2933	326
3.7	3.7	1199	1077	3481	-	-	3266	364
3.0	3.0	503	425	2270	-	-	1977	220
Boom Sprayer(m):								
11.0	11.0	4564	4098	1250	-	-	3423	381
10.7	10.7	4250	3816	1294	-	-	3286	366
9.2	9.2	4150	3726	1433	-	-	3336	371
8.3	8.3	3550	3187	1504	-	-	3061	341
7.6	7.6	2750	2469	1218	-	-	2411	268
6.4	6.4	2230	2002	1235	-	-	2141	238
Field Cultivator(m):								
7.9	7.9	8853	7949	2165	-	-	6445	717
6.0	6.0	5498	4937	1976	-	-	4447	498
4.9	4.9	4784	4295	2283	-	-	4318	481
4.3	4.3	3423	3073	1962	-	-	3336	371
3.7	3.7	2864	2572	2025	-	-	3079	343
2.4	2.4	1665	1495	2159	-	-	2526	281
Subsoiler(m):								
3-Unit	3.0	1985	1782	2364	-	-	2854	318
2-Unit	2.0	1350	1212	2836	-	-	2863	319
1-Unit	1.0	995	893	5517	-	-	4680	521
Combine(m):								
12-Row	9.0	150000	138921	42415	20836	8693	139920	15577
8-Row	6.0	95600	88539	60600	27276	12768	130270	14502
6-Row	4.5	82000	24995	74690	38841	55906	105229	11715
5-Row	3.8	87000	80574	168507	36614	21732	219998	24492

Table 4.6
Projected System Costs (Fine Soils)

Implement	Size (m)	New Price($)*	Projected System Costs($) Owner. Cost	Repair& Maint.	Fuel	Labor	Tot. P.V.	Aver. Annual
4-Row	3.0	60700	56217	187844	43880	27165	228954	25489
NH3 Applicator(m):								
10-Knife	8.2	7800	7003	9455	-	-	11339	1262
9-Knife	6.4	7600	6824	15503	-	-	15766	1755
8-knife	5.5	7400	6644	20752	-	-	19594	2181
7-Knife	4.6	7200	6465	29385	-	-	25960	2890
6-Knife	3.7	7000	6285	45129	-	-	37660	4193
5-Knife	2.7	6800	6106	84963	-	-	67426	7506
No-Till Planter(m):								
16-Row,0.76	12.2	35800	32144	30733	-	-	42575	4740
12-Row,0.76	9.1	33000	29630	52502	-	-	57346	6384
10-Row,0.76	7.6	30200	27116	70134	-	-	69048	7687
8-Row,0.76	6.0	17000	15264	64860	-	-	57903	6446
6-Row,0.76	4.6	13000	11672	88656	-	-	72072	8023
5-Row,0.76	3.8	11250	10056	111511	-	-	89733	9990
4-Row,0.76	3.0	9500	8530	155388	-	-	121714	13550
Row Planter(m):								
16-Row,0.76	12.2	25000	22447	16577	-	-	24046	2900
12-Row,0.76	9.1	21000	18855	25772	-	-	30764	3425
10-row,0.76	7.6	18500	16611	33141	-	-	34930	3889
8-Row,0.76	6.0	15000	13468	44145	-	-	41277	4595
6-Row,0.76	4.6	11500	10326	59131	-	-	50611	5634
5-Row,0.76	3.8	10100	9069	77568	-	-	63677	7089
4-row,0.76	3.0	8700	7812	109767	-	-	87063	9692

* Source: Farm Machinery Dealers,1983.

Table 4.7
Estimated Costs for tractors

Tractors (KW)	Initial Price ($)
40	26500
45	27650
50	28800
55	31000
60	37000
65	40000
70	43000
75	44700
85	48000
90	51300
100	58000
105	58500
115	59500
120	60300
125	61000
150	98000
300	125000

Source: Farm Machinery Dealers,1983.

Table 4.8
Draft and Power Requirement Parameters for the coarse soil

Implement	Size (m)	KN/m*			KW/m			Implement Power Reqt. (KW)
		High	Low	Median	High	Low	Median	
MB. Plow(m):								
12-Bottom,0.56	6.7	22.8	2.7	6.3	50.6	3.0	12.6	84
9-Bottom,0.41	3.7	22.8	2.7	6.3	50.6	3.0	12.6	47
7-Bottom,0.41	2.8	22.8	2.7	6.3	50.6	3.0	12.6	35
5-Bottom,0.41	2.0	22.8	2.7	6.3	50.6	3.0	12.6	25
3-Bottom,0.36	1.0	22.8	2.7	6.3	50.6	3.0	12.6	13
2-Bottom,0.36	0.7	22.8	2.7	6.3	50.6	3.0	12.6	9
Tandem Disk(m):								
5.00	5.0	4.2	0.7	1.9	11.3	1.1	4.0	20
4.30	4.3	4.2	0.7	1.9	11.3	1.1	4.0	17
3.70	3.7	4.2	0.7	1.9	11.3	1.1	4.0	15
3.00	3.0	4.2	0.7	1.9	11.3	1.1	4.0	12
2.40	2.4	4.2	0.7	1.9	11.3	1.1	4.0	10
1.80	1.8	4.2	0.7	1.9	11.3	1.1	4.0	7
Offset Disk(m):								
8.5	8.5	9.8	1.8	3.6	26.4	3.6	8.5	72
7.3	7.3	9.8	1.8	3.6	26.4	3.6	8.5	62
6.0	6.0	9.8	1.8	3.6	26.4	3.6	8.5	51
3.7	3.7	9.8	1.8	3.6	26.4	3.6	8.5	32
3.0	3.0	9.8	1.8	3.6	26.4	3.6	8.5	26
2.4	2.4	9.8	1.8	3.6	26.4	3.6	8.5	20
Chisel Plow(m):								
7.9	7.9	7.8	2.9	4.0	20.8	3.6	8.0	63
4.9	4.9	7.8	2.9	4.0	20.8	3.6	8.0	39
3.0	3.0	7.8	2.9	4.0	20.8	3.6	8.0	24
2.7	2.7	7.8	2.9	4.0	20.8	3.6	8.0	22
2.4	2.4	7.8	2.9	4.0	20.8	3.6	8.0	19
1.8	1.8	7.8	2.9	4.0	20.8	3.6	8.0	14
Spring Tooth Harr(m):								
6.0	6.0	3.9	3.0	3.4	9.2	4.0	6.6	40
5.5	5.5	3.9	3.0	3.4	9.2	4.0	6.6	37
4.9	4.9	3.9	3.0	3.4	9.2	4.0	6.6	33
4.3	4.3	3.9	3.0	3.4	9.2	4.0	6.6	29
3.7	3.7	3.9	3.0	3.4	9.2	4.0	6.6	25
3.0	3.0	3.9	3.0	3.4	9.2	4.0	6.6	20
Row Cultivator(m):								
16-Row, 0.76	12.2	1.0	0.6	0.9	2.2	0.7	1.7	21
12-Row, 0.76	9.1	1.0	0.6	0.9	2.2	0.7	1.7	16
10-Row, 0.76	7.6	1.0	0.6	0.9	2.2	0.7	1.7	13
8-Row, 0.76	6.0	1.0	0.6	0.9	2.2	0.7	1.7	10
6-Row, 0.76	4.6	1.0	0.6	0.9	2.2	0.7	1.7	9
5-Row, 0.76	3.8	1.0	0.6	0.9	2.2	0.7	1.7	7
4-Row, 0.76	3.0	1.0	0.6	0.9	2.2	0.7	1.7	5
Fertilizer Spreader(m):								
6.0	6.0	1.2	0.3	0.6	3.0	0.4	1.3	8
5.5	5.5	1.2	0.3	0.6	3.0	0.4	1.3	7
4.9	4.9	1.2	0.3	0.6	3.0	0.4	1.3	6
4.3	4.3	1.2	0.3	0.6	3.0	0.4	1.3	6
3.7	3.7	1.2	0.3	0.6	3.0	0.4	1.3	5
3.0	3.0	1.2	0.3	0.6	3.0	0.4	1.3	4
Boom Sprayer(m):								
11.0	11.0	1.7	0.1	0.9	5.3	0.1	1.8	20
10.7	10.7	1.7	0.1	0.9	5.3	0.1	1.8	19
9.2	9.2	1.7	0.1	0.9	5.3	0.1	1.8	17
8.3	8.3	1.7	0.1	0.9	5.3	0.1	1.8	15
7.6	7.6	1.7	0.1	0.9	5.3	0.1	1.8	14
6.4	6.4	1.7	0.1	0.9	5.3	0.1	1.8	12
Field Cultivator(m):								
7.9	7.9	9.8	0.9	5.3	26.1	1.6	12.5	99
6.0	6.0	9.8	0.9	5.3	26.1	1.6	12.5	75
4.9	4.9	9.8	0.9	5.3	26.1	1.6	12.5	61
4.3	4.3	9.8	0.9	5.3	26.1	1.6	12.5	54
3.7	3.7	9.8	0.9	5.3	26.1	1.6	12.5	46
2.4	2.4	9.8	0.9	5.3	26.1	1.6	12.5	30
Subsoiler(m):								
3-Unit	3.0	21.0	6.3	10.0	25.7	7.7	20.0	60
2-Unit	2.0	21.0	6.3	10.0	25.7	7.7	20.0	40
1-Unit	1.0	21.0	6.3	10.0	25.7	7.7	20.0	20
NH3 Applicator(m):								
10-Knife	7.3	5.1	-	5.1	8.8	-	8.8	60
9-Knife	6.4	5.1	-	5.1	8.8	-	8.8	53
8-knife	5.5	5.1	-	5.1	8.8	-	8.8	45
7-Knife	4.6	5.1	-	5.1	8.8	-	8.8	38
6-Knife	3.7	5.1	-	5.1	8.8	-	8.8	31

Table 4.8
Draft and Power Requirement Parameters for the Coarse Soil

Implement	Size (m)	KN/m* High	KN/m* Low	KN/m* Median	KW/m High	KW/m Low	KW/m Median	Implement Power Reqt. (KW)
NH3 Applicator (m):								
5-Knife	2.7	5.1	-	5.1	8.8	-	8.8	23
No-Till Planter (m):								
16-Row,0.76	12.2	1.2	-	1.2	2.0	-	2.0	22
12-Row,0.76	9.1	1.2	-	1.2	2.0	-	2.0	18
10-Row,0.76	7.6	1.2	-	1.2	2.0	-	2.0	15
8-Row,0.76	6.0	1.2	-	1.2	2.0	-	2.0	12
6-Row,0.76	4.6	1.2	-	1.2	2.0	-	2.0	9
5-Row,0.76	3.8	1.2	-	1.2	2.0	-	2.0	8
4-Row,0.76	3.0	1.2	-	1.2	2.0	-	2.0	6
Row Planter (m):								
16-Row,0.76	12.2	1.1	0.5	0.8	3.0	0.5	1.2	15
12-Row,0.76	9.1	1.1	0.5	0.8	3.0	0.5	1.2	11
10-row,0.76	7.6	1.1	0.5	0.8	3.0	0.5	1.2	9
8-Row,0.76	6.0	1.1	0.5	0.8	3.0	0.5	1.2	7
6-Row,0.76	4.6	1.1	0.5	0.8	3.0	0.5	1.2	6
5-Row,0.76	3.8	1.1	0.5	0.8	3.0	0.5	1.2	5
4-row,0.76	3.0	1.1	0.5	0.8	3.0	0.5	1.2	4

* Source: See Table 4.1

Table 4.9
Draft and Power Requirement Parameters for the medium soil

Implement	Size (m)	KN/m High	KN/m Low	KN/m Median	KW/m High	KW/m Low	KW/m Median	Implement Power Reqt. (KW)
MB. Plow(m):								
12-Bottom,0.56	6.7	27.9	4.8	9.5	62.0	5.3	18.7	126
9-Bottom,0.41	3.7	27.9	4.8	9.5	62.0	5.3	18.7	70
7-Bottom,0.41	2.8	27.9	4.8	9.5	62.0	5.3	18.7	53
5-Bottom,0.41	2.0	27.9	4.8	9.5	62.0	5.3	18.7	38
3-Bottom,0.36	1.0	27.9	4.8	9.5	62.0	5.3	18.7	19
2-Bottom,0.36	0.7	27.9	4.8	9.5	62.0	5.3	18.7	13
Tandem Disk(m):								
5.00	5.0	6.6	1.1	3.0	15.0	1.6	6.0	30
4.30	4.3	6.6	1.1	3.0	15.0	1.6	6.0	26
3.70	3.7	6.6	1.1	3.0	15.0	1.6	6.0	23
3.00	3.0	6.6	1.1	3.0	15.0	1.6	6.0	18
2.40	2.4	6.6	1.1	3.0	15.0	1.6	6.0	15
1.80	1.8	6.6	1.1	3.0	15.0	1.6	6.0	11
Offset Disk(m):								
8.5	8.5	10.5	2.7	5.9	23.3	4.2	11.8	101
7.3	7.3	10.5	2.7	5.9	23.3	4.2	11.8	87
6.0	6.0	10.5	2.7	5.9	23.3	4.2	11.8	71
3.7	3.7	10.5	2.7	5.9	23.3	4.2	11.8	44
3.0	3.0	10.5	2.7	5.9	23.3	4.2	11.8	36
2.4	2.4	10.5	2.7	5.9	23.3	4.2	11.8	29
Chisel Plow(m):								
7.9	7.9	21.0	2.9	8.4	46.7	3.6	16.8	133
4.9	4.9	21.0	2.9	8.4	46.7	3.6	16.8	83
3.0	3.0	21.0	2.9	8.4	46.7	3.6	16.8	51
2.7	2.7	21.0	2.9	8.4	46.7	3.6	16.8	46
2.4	2.4	21.0	2.9	8.4	46.7	3.6	16.8	41
1.8	1.8	21.0	2.9	8.4	46.7	3.6	16.8	31
Spring Tooth Harr(m):								
6.0	6.0	4.0	3.4	3.6	8.2	3.6	6.8	41
5.5	5.5	4.0	3.4	3.6	8.2	3.6	6.8	38
4.9	4.9	4.0	3.4	3.6	8.2	3.6	6.8	34
4.3	4.3	4.0	3.4	3.6	8.2	3.6	6.8	30
3.7	3.7	4.0	3.4	3.6	8.2	3.6	6.8	26
3.0	3.0	4.0	3.4	3.6	8.2	3.6	6.8	21
Row Cultivator (m):								
16-Row, 0.76	12.2	2.8	0.9	1.4	5.8	1.0	2.2	27
12-Row, 0.76	9.1	2.8	0.9	1.4	5.8	1.0	2.2	20
10-Row, 0.76	7.6	2.8	0.9	1.4	5.8	1.0	2.2	17
8-Row, 0.76	6.0	2.8	0.9	1.4	5.8	1.0	2.2	13
6-Row, 0.76	4.6	2.8	0.9	1.4	5.8	1.0	2.2	11
5-Row, 0.76	3.8	2.8	0.9	1.4	5.8	1.0	2.2	9
4-Row, 0.76	3.0	2.8	0.9	1.4	5.8	1.0	2.2	7
Fertilizer Spreader(m):								
6.0	6.0	1.2	0.3	0.6	3.0	0.4	1.3	8
5.5	5.5	1.2	0.3	0.6	3.0	0.4	1.3	7
4.9	4.9	1.2	0.3	0.6	3.0	0.4	1.3	6
4.3	4.3	1.2	0.3	0.6	3.0	0.4	1.3	6
3.7	3.7	1.2	0.3	0.6	3.0	0.4	1.3	5
3.0	3.0	1.2	0.3	0.6	3.0	0.4	1.3	4
Boom Sprayer(m):								
11.0	11.0	1.2	0.3	0.6	5.3	0.1	1.8	20
10.7	10.7	1.2	0.3	0.6	5.3	0.1	1.8	19
9.2	9.2	1.2	0.3	0.6	5.3	0.1	1.8	17
8.3	8.3	1.2	0.3	0.6	5.3	0.1	1.8	15
7.6	7.6	1.2	0.3	0.6	5.3	0.1	1.8	14
6.4	6.4	1.2	0.3	0.6	5.3	0.1	1.8	12
Field Cultivator(m):								
7.9	7.9	8.6	2.7	5.9	21.3	5.8	13.4	106
6.0	6.0	8.6	2.7	5.9	21.3	5.8	13.4	81
4.9	4.9	8.6	2.7	5.9	21.3	5.8	13.4	66
4.3	4.3	8.6	2.7	5.9	21.3	5.8	13.4	58
3.7	3.7	8.6	2.7	5.9	21.3	5.8	13.4	50
2.4	2.4	8.6	2.7	5.9	21.3	5.8	13.4	33
Subsoiler(m):								
3-Unit	3.0	34.6	7.5	13.0	42.3	9.2	25.3	76
2-Unit	2.0	34.6	7.5	13.0	42.3	9.2	25.3	51
1-Unit	1.0	34.6	7.5	13.0	42.3	9.2	25.3	26
NH3 Applicator(m):								
10-Knife	7.3	6.2	2.4	5.8	12.4	4.8	8.9	65
9-Knife	6.4	6.2	2.4	5.8	12.4	4.8	8.9	57
8-knife	5.5	6.2	2.4	5.8	12.4	4.8	8.9	49
7-Knife	4.6	6.2	2.4	5.8	12.4	4.8	8.9	41
6-Knife	3.7	6.2	2.4	5.8	12.4	4.8	8.9	33

Table 4.9
Draft and Power Requirement Parameters for the medium Soil

Implement	Size (m)	KN/m* High	KN/m* Low	KN/m* Median	KW/m High	KW/m Low	KW/m Median	Implement Powrer Reqt. (KW)
NH3 Applicator (m):								
5-Knife	2.7	6.2	2.4	5.8	12.4	4.8	8.9	24
No-Till Planter (m):								
16-Row,0.76	12.2	2.4	-	2.4	2.7	-	2.7	33
12-Row,0.76	9.1	2.4	-	2.4	2.7	-	2.7	25
10-Row,0.76	7.6	2.4	-	2.4	2.7	-	2.7	21
8-Row,0.76	6.0	2.4	-	2.4	2.7	-	2.7	17
6-Row,0.76	4.6	2.4	-	2.4	2.7	-	2.7	12
5-Row,0.76	3.8	2.4	-	2.4	2.7	-	2.7	10
4-Row,0.76	3.0	2.4	-	2.4	2.7	-	2.7	8
Row Planter (m):								
16-Row,0.76	12.2	1.2	0.7	1.0	2.7	0.8	1.5	18
12-Row,0.76	9.1	1.2	0.7	1.0	2.7	0.8	1.5	14
10-row,0.76	7.6	1.2	0.7	1.0	2.7	0.8	1.5	11
8-Row,0.76	6.0	1.2	0.7	1.0	2.7	0.8	1.5	9
6-Row,0.76	4.6	1.2	0.7	1.0	2.7	0.8	1.5	7
5-Row,0.76	3.8	1.2	0.7	1.0	2.7	0.8	1.5	6
4-row,0.76	3.0	1.2	0.7	1.0	2.7	0.8	1.5	5

* Source: See Table 4.1

Table 4.10
Draft and Power Requirement Parameters for the fine soil

Implement	Size (m)	KN/m*			KW/m			Implement Power Reqt. (KW)
		High	Low	Median	High	Low	Median	
MB. Plow(m):								
12-Bottom,0.56	6.7	32.6	6.9	11.0	72.4	7.7	20.5	138
9-Bottom,0.41	3.7	32.6	6.9	11.0	72.4	7.7	20.5	76
7-Bottom,0.41	2.8	32.6	6.9	11.0	72.4	7.7	20.5	58
5-Bottom,0.41	2.0	32.6	6.9	11.0	72.4	7.7	20.5	41
3-Bottom,0.36	1.0	32.6	6.9	11.0	72.4	7.7	20.5	21
2-Bottom,0.36	0.7	32.6	6.9	11.0	72.4	7.7	20.5	15
Tandem Disk(m):								
5.00	5.0	8.8	1.5	4.2	17.6	2.3	8.3	41
4.30	4.3	8.8	1.5	4.2	17.6	2.3	8.3	36
3.70	3.7	8.8	1.5	4.2	17.6	2.3	8.3	31
3.00	3.0	8.8	1.5	4.2	17.6	2.3	8.3	25
2.40	2.4	8.8	1.5	4.2	17.6	2.3	8.3	20
1.80	1.8	8.8	1.5	4.2	17.6	2.3	8.3	15
Offset Disk(m):								
8.5	8.5	10.5	3.4	7.2	23.3	5.3	12.8	109
7.3	7.3	10.5	3.4	7.2	23.3	5.3	12.8	94
6.0	6.0	10.5	3.4	7.2	23.3	5.3	12.8	77
3.7	3.7	10.5	3.4	7.2	23.3	5.3	12.8	48
3.0	3.0	10.5	3.4	7.2	23.3	5.3	12.8	39
2.4	2.4	10.5	3.4	7.2	23.3	5.3	12.8	31
Chisel Plow(m):								
7.9	7.9	24.2	1.9	10.2	53.8	2.4	20.4	162
4.9	4.9	24.2	1.9	10.2	53.8	2.4	20.4	100
3.0	3.0	24.2	1.9	10.2	53.8	2.4	20.4	62
2.7	2.7	24.2	1.9	10.2	53.8	2.4	20.4	56
2.4	2.4	24.2	1.9	10.2	53.8	2.4	20.4	49
1.8	1.8	24.2	1.9	10.2	53.8	2.4	20.4	37
Spring Tooth Harr(m):								
6.0	6.0	4.7	4.0	4.5	10.4	4.6	7.0	42
5.5	5.5	4.7	4.0	4.5	10.4	4.6	7.0	39
4.9	4.9	4.7	4.0	4.5	10.4	4.6	7.0	35
4.3	4.3	4.7	4.0	4.5	10.4	4.6	7.0	31
3.7	3.7	4.7	4.0	4.5	10.4	4.6	7.0	26
3.0	3.0	4.7	4.0	4.5	10.4	4.6	7.0	21
Row Cultivator(m):								
16-Row, 0.76	12.2	3.4	1.2	2.4	4.0	0.8	2.7	33
12-Row, 0.76	9.1	3.4	1.2	2.4	4.0	0.8	2.7	25
10-Row, 0.76	7.6	3.4	1.2	2.4	4.0	0.8	2.7	21
8-Row, 0.76	6.0	3.4	1.2	2.4	4.0	0.8	2.7	17
6-Row, 0.76	4.6	3.4	1.2	2.4	4.0	0.8	2.7	13
5-Row, 0.76	3.8	3.4	1.2	2.4	4.0	0.8	2.7	10
4-Row, 0.76	3.0	3.4	1.2	2.4	4.0	0.8	2.7	9
Fertilizer Spreader(m):								
6.0	6.0	1.2	0.3	0.6	3.0	0.4	1.3	8
5.5	5.5	1.2	0.3	0.6	3.0	0.4	1.3	7
4.9	4.9	1.2	0.3	0.6	3.0	0.4	1.3	6
4.3	4.3	1.2	0.3	0.6	3.0	0.4	1.3	6
3.7	3.7	1.2	0.3	0.6	3.0	0.4	1.3	5
3.0	3.0	1.2	0.3	0.6	3.0	0.4	1.3	4
Boom Sprayer(m):								
11.0	11.0	1.2	0.3	0.6	5.3	0.1	1.8	20
10.7	10.7	1.2	0.3	0.6	5.3	0.1	1.8	19
9.2	9.2	1.2	0.3	0.6	5.3	0.1	1.8	17
8.3	8.3	1.2	0.3	0.6	5.3	0.1	1.8	15
7.6	7.6	1.2	0.3	0.6	5.3	0.1	1.8	14
6.4	6.4	1.2	0.3	0.6	5.3	0.1	1.8	12
Field Cultivator(m):								
7.9	7.9	16.6	2.7	6.8	41.0	3.2	15.1	106
6.0	6.0	16.6	2.7	6.8	41.0	3.2	15.1	93
4.9	4.9	16.6	2.7	6.8	41.0	3.2	15.1	80
4.3	4.3	16.6	2.7	6.8	41.0	3.2	15.1	67
3.7	3.7	16.6	2.7	6.8	41.0	3.2	15.1	54
2.4	2.4	16.6	2.7	6.8	41.0	3.2	15.1	40
Subsoiler(m):								
3-Unit	3.0	48.0	8.9	16.2	58.7	10.9	30.6	92
2-Unit	2.0	48.0	8.9	16.2	58.7	10.9	30.6	62
1-Unit	1.0	48.0	8.9	16.2	58.7	10.9	30.6	31
NH3 Applicator(m):								
10-Knife	7.3	7.3	-	7.3	14.5	-	14.5	106
9-Knife	6.4	7.3	-	7.3	14.5	-	14.5	93
8-knife	5.5	7.3	-	7.3	14.5	-	14.5	80
7-Knife	4.6	7.3	-	7.3	14.5	-	14.5	67
6-Knife	3.7	7.3	-	7.3	14.5	-	14.5	54

Table 4.10
Draft and Power Requirement Parameters for the fine Soil

Implement	Size (m)	KN/m* High	KN/m* Low	KN/m* Median	KW/m High	KW/m Low	KW/m Median	Implement Power Reqt. (KW)
NH3 Applicator (m):								
5-Knife	2.7	7.3	-	7.3	14.5	-	14.5	40
No-Till Planter (m):								
16-Row,0.76	12.2	3.2	0.8	2.0	3.9	0.7	3.4	38
12-Row,0.76	9.1	3.2	0.8	2.0	3.9	0.7	3.4	31
10-Row,0.76	7.6	3.2	0.8	2.0	3.9	0.7	3.4	26
8-Row,0.76	6.0	3.2	0.8	2.0	3.9	0.7	3.4	21
6-Row,0.76	4.6	3.2	0.8	2.0	3.9	0.7	3.4	16
5-Row,0.76	3.8	3.2	0.8	2.0	3.9	0.7	3.4	13
4-Row,0.76	3.0	3.2	0.8	2.0	3.9	0.7	3.4	11
Row Planter (m):								
16-Row,0.76	12.2	3.4	0.8	1.5	4.4	0.8	1.8	22
12-Row,0.76	9.1	3.4	0.8	1.5	4.4	0.8	1.8	16
10-row,0.76	7.6	3.4	0.8	1.5	4.4	0.8	1.8	14
8-Row,0.76	6.0	3.4	0.8	1.5	4.4	0.8	1.8	11
6-Row,0.76	4.6	3.4	0.8	1.5	4.4	0.8	1.8	8
5-Row,0.76	3.8	3.4	0.8	1.5	4.4	0.8	1.8	7
4-row,0.76	3.0	3.4	0.8	1.5	4.4	0.8	1.8	5

* Source: See Table 4.1

Table 4.11
Economic Parameters of Machines

Income Tax Rate	.25
Down Payment	.20
Current Interest Rate	.14
Discount Rate	.12
Machine Inflation Rate	.10
Fuel Inflation Rate	.15
Labor Inflation Rate	.08

Source: Dr. Rotz, 1983; Agricultural Engineering Department, Michigan State University.

The machinery cost model (developed by Rotz, et. al., 1981) calculates the annual cost based upon the following equations

The future cost in year j is

$\text{Future cost}_j = \text{current cost } (1 + \text{Inflation Rate})^j$ 1

The present value of a cost in year j is

$\text{Present value}_j = \text{Future cost}/\ (1 + \text{Inflation Rate})^j$

or $\text{current cost} \left(\dfrac{1 + \text{Inflation Rate}}{1 + \text{Discount Rate}}\right)^j$ 2

The relationship for determining the ownership cost before income tax deductions is indicated by

$\text{ownership} = DB + P \left[\dfrac{(1 + i)^m - 1}{i(1 + i)^m}\right] - RV \left(\dfrac{1 + a}{1 + i}\right)^n$ 3

where DP = downpayment

P = principal and interest loan payment

m = loan term in years

i = annual discount rate

a = annual inflation rate for general equipment, insurance, etc.

and RV = remaining value

$= RV_1 (RV_2)^n (IC)$ 4

where RV1 and RV_2 = remaining value factors

IC = initial cost of machine

n = number of years analyzed (machine age).

The tax, insurance and shelter cost is considered as a constant portion of the initial cost of the machine. It is the current value which should be inflated to future cost and discounted to present value

$$\text{Tax, insurance and shelter} = S(IC)\sum_{j=1}^{n}\left(\frac{1 + a}{1 + i}\right)^{j} \qquad 5$$

where S = portion of initial cost.

Repair and maintenance costs are determined in terms of current value.

Repair and Maintenance =

$$RC_1\sum_{j=1}^{n}\left[\left(\frac{USE(j)}{1000}\right)^{RC2} - \left(\frac{USE(j-1)}{1000}\right)^{RC_2}\right]\left(\frac{1 + a}{1 - i}\right)^{j} \qquad 6$$

where RC_1 and RC_2 = repair and maintenance constants

USE = annual use of machine (h)

Fuel costs are calculated as the product of fuel price, fuel consumption factor for the tractor or self-propelled machine, power rating of the machine and its annual use.

$$\text{Fuel and Lub} = 1.15(FP)(HP)(FF)(USE)\sum_{j=1}^{n}\left(\frac{1 + b}{1 - i}\right)^{j} \qquad 7$$

where FP = current fuel price

HP = power of tractor or self-propelled machine

FF = fuel consumption factor

b = annual inflation rate of fuel

The machine labor requirement is given by

$$\text{Labor} = 1.1(W)(USE)\sum_{j=1}^{n}\left(\frac{1 + c}{1 + i}\right)^{j} \qquad 8$$

where W = wage rate

C = annual inflation rate of labor costs

The income tax benefits received by the owner are determined by

Tax benefits =

$$C+t\sum_{j=1}^{n}\frac{Dj + Ij + (TISj+RMj)(1+a)^{j} + Fj(1+b)^{j} + Lj(1+c)^{j}}{(1+i)j} \qquad 9$$

where

C = investment credit (0.10 * initial cost)

t = income tax rate of owner

Dj = accelerated cost recovery deduction during year j

Ij = interest paid during year j

TIS = current cost of tax, insurance, and shelter

RM = current cost of repair and maintenance

F = current cost of fuel and lubrication

L = current cost of labor

Subtracting the tax benefits from the sum of all costs produces the net present value cost of owning and operating of a machine during its lifetime. Thus, (10) is a combination of equations 3 through 9

$$PVC = DP + P\left[\frac{(1+i)^m-1}{i(1+i)^m}\right] - RV\left(\frac{1+a}{1+i}\right)^n$$
$$+\sum_{j=1}^{n} \frac{(TISj+RMj)(1+a)^j + Fj(1+b)^j + Lj(1+c)^j}{(1+i)j}$$
$$-C - t\sum_{j=1}^{n} \frac{Dj + Ij(TISj+RMj)(1+a)^j + Fj(1+b)^j + Lj(1+C)^j}{(1+i)^j} \quad (10)$$

where PVC = total present value of all costs and benefits.

Multiplying the present value cost by the capital recovery factor results in the annual equivalent cost

$$AEC = PVC\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

The result of the machinery cost model is presented in Tables 4.4 - 4.6 which include projected system costs of ownership, operating, and the average equivalent costs for different sets of equipment.

4.2.2. Model Constraints

Major constraints included in the model are suitable days, land, labor, capital investment, and power requirements. A proper set of data on each of the resources and constraints were collected and used for the formulation process.

Weather variation and its impact on the number of suitable days available for soil preparation, planting, spraying, cultivating, and harvesting, is a primary factor in a machinery selection model. Machinery complements are selected based on a framework through which the assigned operations are done within a predicted time period with certain probability levels. The probability of 70%, for example, means 7 out of 10 years. Rosenberg, et. al. (1981) developed a computer model to simulate the impact of weather variation on the number of suitable days available for field operation in different locations in Michigan. As a part of the analysis, the model also considers the various soil textures.

The data generated from the Rosenberg model are used by the linear programming model for various field operations. These operations are indicated as soil preparating, planting, spraying, cultivating and harvesting. This data is given in Tables 4.12, 4.13 and 4.14.

The labor constraint consists of total annual operating and hired labor used for primary and secondary farm operations. Data on labor were collected for three average sizes of large, medium, and small corn farms in Michigan, Table 4.15. Such farms do not have the same set of operators each year.

The model assumes a budget as a constraint for annual machinery investment. This value represents the purchasing power of a farmer on machinery investment which depends on the farm size.

Table 4.12
The Maximum Annual Coverable Land (Hectares) in a Suitable Time Period.

Implement	Size (m)	Soil Type		
		Coarse	Medium	Fine
MB. Plow (m):				
12-Bottom, 0.56	6.7	400	400	400
9-Bottom, 0.41	3.7	400	400	400
7-Bottom, 0.41	2.8	400	400	400
5-Bottom, 0.41	2.0	400	400	351
3-Bottom, 0.36	1.0	232	215	192
2-Bottom, 0.36	0.7	155	144	128
Tandem Disk (m):				
5.00	5.0	400	400	400
4.30	4.3	400	400	400
3.70	3.7	400	400	400
3.00	3.0	400	400	400
2.40	2.4	400	400	340
1.80	1.8	290	254	226
Offset Disk (m):				
8.5	8.5	400	400	400
7.3	7.3	400	400	400
6.0	6.0	400	400	400
3.7	3.7	400	400	400
3.0	3.0	400	400	400
2.4	2.4	400	400	400
Chisel Plow (m):				
7.9	7.9	400	400	400
4.9	4.9	400	400	400
3.0	3.0	400	400	400
2.7	2.7	400	400	400
2.4	2.4	400	400	400
1.8	1.8	352	340	326
Spring Tooth Harr (m):				
6.0	6.0	400	400	400
5.5	5.5	400	400	400
4.9	4.9	400	400	400
4.3	4.3	400	400	400
3.7	3.7	400	400	400
3.0	3.0	400	400	271
Row Cultivator (m):				
16-Row, 0.76	12.2	400	400	400
12-Row, 0.76	9.1	400	400	400
10-Row, 0.76	7.6	400	400	343
8-Row, 0.76	6.0	400	394	272
6-Row, 0.76	4.6	355	292	215
5-Row, 0.76	3.8	296	248	172
4-Row, 0.76	3.0	236	189	143
Fertilizer Spreader (m):				
6.0	6.0	400	400	400
5.5	5.5	400	400	400
4.9	4.9	400	400	400
4.3	4.3	400	400	396
3.7	3.7	400	382	336
3.0	3.0	336	315	277
Boom Sprayer (m):				
11.0	11.0	400	400	400
10.7	10.7	400	400	377
9.2	9.2	400	380	328
8.3	8.3	370	342	295
7.6	7.6	339	314	270
6.4	6.4	288	266	230
Field Cultivator (m):				
7.9	7.9	400	400	400
6.0	6.0	400	400	400
4.9	4.9	400	400	398
4.3	4.3	400	384	355
3.7	3.7	367	328	305
2.4	2.4	235	219	203
Subsoiler (m):				
3-Unit	3.0	400	400	400
2-Unit	2.0	400	395	320
1-Unit	1.0	232	215	160
Combine (m):				
12-Row	9.0	400	400	400
8-Row	6.0	400	400	400
6-Row	4.5	347	347	347
5-Row	3.8	267	267	267
4-Row	3.0	214	214	214

Table 4.12
The Maximum annual Coverable Land (Hectares) in a Suitable Time Period.

Implement	Size (m)	Soil Type Coarse	 Medium	 Fine
NH3 Applicator (m):				
10-Knife	7.3	400	400	400
9-Knife	6.4	400	400	400
8-Knife	5.5	400	400	400
7-Knife	4.6	331	328	295
6-Knife	3.7	166	164	163
5-Knife	2.7	110	109	107
No-Till Planter (m):				
16-Row,0.76	12.2	400	400	400
12-Row,0.76	9.1	400	400	400
10-Row,0.76	7.6	400	400	400
8-Row,0.76	6.0	400	400	400
6-Row,0.76	4.6	400	371	326
5-Row,0.76	3.8	400	309	266
4-Row,0.76	3.0	384	247	207
Row Planter (m):				
16-Row,0.76	12.2	400	400	400
12-Row,0.76	9.1	400	400	400
10-row,0.76	7.6	400	400	400
8-Row,0.76	6.0	400	400	400
6-Row,0.76	4.6	400	400	384
5-Row,0.76	3.8	400	400	296
4-row,0.76	3.0	384	309	236

Table 4.13
Total Suitable Days for Field Operations on Three Soil Types
and three Probability Levels (in Bad Axe Michigan).

	80			50			30		
Time	Fine	Medium *	Coarse	Fine *	Medium *	Coarse	Fine *	Medium *	Coarse *
Apr. 20-30	3.0	3.6	4.2	4.4	5.1	5.8	6.2	6.5	6.8
May 1-10	4.2	4.6	5.0	5.2	5.9	6.6	6.8	7.3	7.8
May 11-20	5.5	5.5	5.5	5.8	6.8	7.7	7.9	8.9	9.9
May 21-31	7.7	7.8	7.8	7.2	7.5	7.7	7.8	8.0	8.2
June 1-15	10.7	10.9	11.0	11.4	11.9	12.3	12.5	13.0	13.6
June 16-30	7.7	8.0	8.3	9.2	10.3	11.3	11.5	13.0	14.4
July 1-15	11.7	11.7	11.7	11.8	12.2	12.5	12.7	13.0	13.3
July 16-31	12.0	12.0	12.0	12.2	12.8	13.4	13.6	14.2	14.8
Aug. 1-15	12.0	12.1	12.2	12.2	12.4	12.6	12.8	13.3	13.8
Aug. 16-31	11.0	11.7	12.2	12.4	12.6	13.3	13.6	14.3	14.9
Sept. 1-15	11.1	11.3	11.4	11.5	11.7	11.9	12.0	12.2	12.4
Sept.16-30	9.0	9.4	9.8	10.2	11.0	11.8	12.2	13.0	13.8
Oct. 1-15	8.6	9.3	10.0	10.4	10.9	11.4	11.8	12.3	12.8
Oct. 16-31	9.6	10.3	11.0	11.1	11.3	11.5	11.8	12.4	13.0
Nov. 1-15	8.9	9.8	9.8	10.0	10.7	11.3	11.6	12.2	12.8
Nov. 16-30	0.8	1.8	2.7	3.2	3.9	4.5	5.2	5.8	6.3

Modified from: Rosenberg,1982.
* Estimated based upon the other values.

Table 4.14
Total Suitable Hours for Field Operations on Three Soil Types
and three Probability Levels (in Bad Axe Michigan).

	80			50			30		
Operation	Fine	* Medium	Coarse	* Fine	* Medium	Coarse	* Fine	* Medium	* Coarse
Harvesting	220	250	267	279	293	308	563	593	624
Fert. Appl.	198	225	240	251	264	277	507	534	562
Fall Disk.	226	254	290	271	288	302	315	333	351
Plowing	320	359	358	404	437	471	733	776	820
Spring Disk.	326	340	352	358	393	424	435	463	492
Field Cult.	127	137	147	154	178	201	209	227	245
Planting	296	309	320	325	356	358	395	420	445
Spraying	97	101	105	110	127	143	147	162	177
Row Cult.	143	146	148	152	160	167	169	182	187
NH3 Appl.	268	273	276	278	292	303	308	308	322
Chis. Plow.	320	359	387	404	437	471	733	776	820
Spr. T. Harr.	320	359	387	404	437	471	733	776	820

Modified from: Rosenberg,1982.
* Estimated based upon the other values.
(Fert. Appl.= Fertlizer Application, Fall Disk.=Fall Disking, Spr. Disk.=Spring Disking, Field Cult.=Field Cultivating, Row Cult.=Row Cultivating, NH3 Appl.=NH3 Application, Chis. Plow.=Chisel Plowing, Spr. T. Harr.=Spring Tooth Harrow).

Table 4.15
Labor Hours Used for Corn Operations in Diffrent Years in Michigan

Year	Labor (Hours)				Land (Ha)
	Operator	Family	Hired	Total	
1975	1030	236	226	1492	85.10
1975	2049	830	1898	4777	214.45
1975	1560	2455	3565	7850	550.83
1976	1949	707	984	3640	206.19
1976	1576	362	152	2086	111.29
1976	1743	1911	2990	6644	512.67
1977	1562	274	263	2099	102.16
1977	1767	385	477	2699	221.61
1977	1988	2645	2410	7043	549.70
1978	1356	207	613	2176	93.08
1978	1989	708	721	3418	220.96
1978	2125	2155	3094	7374	583.25
1979	1383	195	59	1637	92.72
1979	2026	689	854	3569	214.12
1979	2306	2586	2618	7510	608.26
1980	1455	237	171	1863	104.00
1980	1800	558	1124	3842	230.51
1980	1957	1943	3412	7312	578.19
1980	2306	408	1139	3853	113.56
1980	2219	880	1183	4282	232.82
1980	2357	2999	2501	7857	485.23
1981	1043	286	254	1583	96.96
1981	1788	663	624	3076	229.83
1981	2389	2307	3160	7856	510.60

Source: Agricultural Economic Reports(1975-81).Tel Farm.Department of Agricultural Economics,Michigan State University.

Another constraint included in the model is the minimum size tractor for each tillage and utility tractor.

4.2.3 Variable Coefficients (Aij)

The first set of variable coefficients are the maximum annual operating hours which each implement can use. These values are determined by the machine effective field capacity, EFC,

$$EFC = \frac{WSE}{10}$$

where

EFC = Effective Field Capacity of Machine (Ha/Hr).

S = Speed of Operation (km/hr).

E = Field Efficiency (%).

Maximum Annual Use (hours) = A/EFC

where

A = Land (hectares).

The second set of coefficients are the land covered by each machine within a time constraint.

Annual Land Covered (ha) = EFC x H

where

H = Annual hours available for each operation.

The total amount of operating hours for tillage and utility tractors are set equal to the operating hours of tillage and utility operations and are the other set of coefficients.

The annual repair and maintenance and ownership costs, and the implement power requirements are among the major variable coefficients used by the model.

4.3 Power Requirement

The power requirement is a critical parameter in a farm machinery selection model. Farm implements should be properly well-matched to the tractors based upon their individual power requirements. Oversized implements will cause tractor overloading, excessive tire slippage, higher incidence of tractor breakdowns, and unsatisfactory operation. Undersized implements on the other hand, will result in inefficient operation, low production, and increased costs.

Tractors are the power components in machinery systems. If several machines are pulled by the same tractor, their power requirements should be similar. This relation causes a constraint on the implement selected.

The maximum drawbar power is normally a good criterion on the performance of farm tractors. The drawbar pull is affected by soil type and soil conditions. Soil conditions in the field vary from firm, compact soil to very loose, freshly tilled soil. It may also be dry or wet at different times of the year.

Timeliness is a major factor in estimating the size of equipment which directly specifies the tractor capacity.

Larger size machines and tractors are required to do the job when only a few days are available for field operations.

It is also difficult to obtain proper data on the power requirement for various machines and soil types for one location. Many sources, including textbooks and research papers are available to provide such data, but they do not present a standard form for various machines. Data collected from several sources shows a wide range of variation between machines and across soil types and will lead to inconsistency. Unrealistic results on the number of machines selected by the model will be obtained due to inaccurate values on the collected data. A small error on power requirement data will result in considerable changes on the number and sizes of machinery selected. Field measurement on power requirement is considered to be the best method for a location under the study.

Many scientists have performed research studies on power requirement measurements in various locations. Vaughan, et. al. (1978) made a set of tests to measure the energy requirements of several primary tillage machines including moldboard plowing, chisel plowing, disking, and no-tillage planting both with and without under-row ripping. Fuel and labor were considered to be the main inputs used in the system. The time constraint of the field operation or timliness was included in the study. The results on fuel requirements ranged from 18.0 to 68.1 liters of diesel fuel/hectacre. The study also indicated that the moldboard plowing system with under-row ripping needed the highest overall energy requirement (3492.5 kwh/ha or 307.1 liters/hectacre of diesel fuel), while no-tillage production required the least (2944.9 kwh/ha or 258.9 liters of diesel fuel/hectacre). The indirect energy inputs for pesticide, fertilizer, and machinery production were also considered in this system.

Self, et. al. (1983) made a field measurement on draft and power requirements for various implements related to the area of minimum tillage in Oklahoma soils. The primary and secondary tillage implements used in the experiment were (a) the moldboard plow, (b) a chisel plow with points on 30.5 cm centers, (c) a chisel plow with sweeps on 30.5 cm centers, (d) a chisel plow with points on 51 centers, (e) a tandem disk, (f) an offset disk, and (g) a V-blade plow. The machines and tillage systems used in each location were similar to those that are used in this study. The fuel consumption was chosen as a basis for power measurement. The fuel consumption equation developed by Self, et. al., (1983) is

$$\frac{\text{Liters}}{\text{Hectare}} = \frac{\text{PTO(kw/m)width(m)}}{\text{(ha/h)}2.7\text{(kwh/L)}}$$

PTO (kw/m) is found by dividing drawbar kw by the width of the implement in meters and by a constant used for soil texture and tractor. These constants for firm soils and tilled soils were estimated to be 0.64 and 0.55, respectively.

The test results on the silt loam soil indicated that the moldboard plow needed the highest power requirement (16.9 kw/m at 25-28cm depth); and the chisel plow with 51 cm centers required the lowest power requirement (3.9 kw/m at 13 cm depth). The chisel plow with points, chisel plow with sweeps and tandem disk drawbar powers consisted of 7.6, 7.8, and 9.1 kw/m, respectively. The results on the sandy loam soil showed that the offset disk at 15 cm depth and tandem disk at 8-10 cm depth required about 7.3 and 3.7 kw/m drawbar power, respectively. The drawbar required for V-Blade on loamy fine sand at 8 cm was 10.3 kw/m and at 8-13 cm depth was about 7.3 kw/m. On the silt loam soil at 8-10 cm depth, the offset disk used 7.8 kw/m while the tandem disk used 8.8 kw/m. V-Blades at 10 cm needed about 11.0 kw/m drawbar power. The comparison of primary tillage implements for the four locations consisted of 15.6 kw/m for moldboard plow (the highest drawbar power needed) and 3.9 kw/m for chisel plow (the lowest drawbar power used).

Frisby and Summers (1978) tested the energy requirements of tillage and planting implements operated on

Missouri soils. A modified strain gauge dynamometer was used to measure the drawbar power. The three soil types clay, loam, and sand were tested for implement operation. The implements studied were (a) a moldboard plow (1.07 m width and 20.51 cm depth), (b) a chisel plow (3.07 m width and 30.76 cm depth), (c) a field cultivator (3.69 m width and 20.51 cm depth), (d) a tandem disk (3.97 m width and 10.25 cm depth), (e) a row planter (3.89 m width and 5.12 cm depth), (f) a grain drill (2.33 m width and 5.12 cm depth), (g) a row crop cultivator (1.94 m width and 7.69 cm depth, and (h) a seed-bed ripper (0.97 m width and 41.02 cm depth).

The draft comparison results showed that the moldboard plow had a greater energy requirement (17.3, 15.2, 14.4 kN/m on clay, loam and sandy soils, respectively) than the chisel plow (6.0, 6.0, 3.5 kN/m on clay, loam, and sandy soils). The seed-bed ripper had 15.0, 6.1, and 8.8 kN/m energy requirements for clay, loam, and sandy soils, respectively. The row crop planter also had a greater energy requirement than the no-till planter. The draft and fuel consumption of the field cultivator were greater in sandy soils than in clay soils and it was the reverse for the chisel plow.

Fornstrom and Becker (1977) studied the energy requirements and machinery operation for four summer fallow methods based on the soil moisture content. A large variation in the power requirement was observed when the machines were used on the same soil.

Data from various sources on speeds and draft across the soil types were collected and pulled together. The median values were selected as a proper set of parameters for determining the implement power requirement based upon the following relation

$$DPB = \frac{DxS}{3.6}$$

where

DBP = Drawbar power requirement of the implement (kw/m)

D = Draft requirement (kN/m)

S = Speed of operation (km/hr)

The drawbar power requirements obtained from the above relation were used as a set of variable coefficients by the model. The tractor size for utility and tillage operations was determined using

Tractor size (kw) = 1.25 x Implement Power Requirement (kw).

Tables 4.1 - 4.3 and 4.8 - 4.10 summarize the data on speeds, draft, the power requirement.

4.4 Model Results

The optimum machinery complements selected by the model for conventional, chiseling, and no-tillage on three types of soils are presented in Tables 4.16, 4.17, and 4.18. These are the results of interaction of all resource constraints used by the model. Changing one or more of the constraints will effectively change the size and number of machines. In comparison with simulation models, linear programming provides results in an optimum basis which is a realistic approach to solve farming problems.

Tractors and implements are well matched together based on their power requirements across the soil types from coarse to fine texture. In conventional corn, for example, a 90 kw tillage tractor is selected to do all of the tillage operations on the coarse texture soil. The field cultivator (6m), used on coarse texture soils, is the largest power requirement unit which needs 75 kw draft power. The field cultivator also specifies the size of tillage tractor. In medium and fine texture soils, the implements are also properly matched. The tillage tractors selected for medium and fine texture soils are 95 and 120 kw respectively. The 3 unit subsoilers used in medium and fine soils of the conventional system are required to have the largest power units. Utility tractors are also properly matched to the utility implements used in the system. Similar conclusions can be drawn for chiseling and no-tillage systems.

Table 4.16
The Optimum Number of Machines for A 400 Hectare Conventional Corn Farm With 80% Weather Probability Level and Three Soil Types.

	Soil Type					
	Coarse		Medium		Fine	
Machine	Number	Size	Number	Size	Number	Size
MB-Plow	1	3.7 m	1	3.7 m	1	3.7 m
Tandem Disk	1	4.9 m	1	4.9 m	1	4.3 m
Spr. Tooth Harrow	1	6.0 m	1	6.0 m	1	6.0 m
Row Cultivator	1	8-Row	1	12-Row	1	12-Row
Fertilizer Spreader	1	5.5 m	1	6.0 m	1	6.0 m
Boom Sprayer	1	11.0 m	1	11.0 m	1	11.0 m
Field Cultivator	1	6.0 m	1	4.9 m	1	4.9 m
Sub Soiler	1	2-Units	1	3-Units	1	3-Units
Combine	1	8-Row	1	12-Row	1	12-Row
NH3-Applicator	1	6.4 m	1	7.3 m	1	6.4 m
Row Planter	1	8-Row	1	12-Row	1	12-Row
Tillage Tractor	1	90-KW	1	95-KW	1	120-KW
Utility Tractor	1	40-KW	1	60-KW	1	60-KW

Table 4.17
The Optimum Number of Machines for A 400 Hectare Chiseling Corn Farm With 80% Weather Probability Level and Three Soil Types.

Machine	Soil Type					
	Coarse		Medium		Fine	
	Number	Size	Number	Size	Number	Size
Chisel PLow	1	4.9 m	1	4.9 m	1	3.0 m
Tandem Disk	1	4.9 m	1	4.9 m	1	4.3 m
Row Cultivator	1	12-Row	1	12-Row	1	12-Row
Fertilizer Spreader	1	4.9 m	1	6.0 m	1	6.0 m
Boom Sprayer	1	10.7 m	1	11.0 m	1	11.0 m
Field Cultivator	1	4.3 m	1	6.0 m	1	4.9 m
Sub Soiler	1	3-Units	1	2-Units	1	3-Units
Combine	1	12-Row	1	12-Row	1	12-Row
NH3-Applicator	1	7.3 m	1	7.3 m	1	5.5 m
Row Planter	1	12-Row	1	12-Row	1	12-Row
Tillage Tractor	1	85-KW	1	105-KW	1	105-KW
Utility Tractor	1	60-KW	1	60-KW	1	60-KW

Table 4.18

The Optimum Number of Machines for A 400 Hectare No-Till Corn Farm With 80% Weather Probability Level and Three Soil Types.

	Soil Type					
	Coarse		Medium		Fine	
Machine	Number	Size	Number	Size	Number	Size
Fertilizer Spreader	1	6.0 m	1	6.0 m	1	6.0 m
Boom Sprayer.	1	11.0 m	1	11.0 m	1	11.0 m
No-Till Planter	1	12-Row	1	8-Row	1	12-Row
NH3-Applicator	1	7.3 m	1	7.3 m	1	5.5 m
Combine	1	12-Row	1	8-Row	1	12-Row
Sub Soiler	1	3-Units	1	3-Units	1	3-Units
Tillage Tractor	1	85-KW	1	100-KW	1	115-KW
Utility Tractor	1	45-KW	1	45-KW	1	50-KW

An economic comparison of three tillage systems indicates that chiseling and no-tillage have the most cost advantages to farmers (Table 4.19). Machinery costs are reduced when changing from the conventional to the no-tillage system. No-tillage has the lowest annual ownership and operating costs of all three types of soils. The total annual system cost for no-tillage on coarse, medium, and fine soils are 85, 100 and $107/ha respectively, compared to 123, 130, and $153/ha for the conventional system. The chiseling system has a medium cost value compared to the other systems. Machine costs across the soil textures from coarse to fine texture increase because of larger tractor size requirements.

4.5 Timeliness Costs

Timeliness costs were calculated after the optimum size of planters and combines was determined using the model. Edwards, et. al., (1980) studied the agronomic loss factors for different planting and harvesting times for corn production. These factors were used to estimate the planting and harvesting timeliness costs. It is indicated, for example, that there is no corn yield reduction for corn planting before May 4. Timeliness costs were also determined indirectly by machine capacity for daily planting and harvesting operations. The timeliness costs were estimated based on the relations

Table 4.19
Average Annual Machinery Costs ($) for Three Tillage Systems

Soil Type	Conventional	Chiseling	No-Till
Coarse	123	107	85
Medium	130	116	100
Fine	153	131	107

$$DC = R \times Y \times P$$

$$TC = \frac{A}{D} \times DC \times TI$$

where

DC = Timeliness cost factor (dollars per hectare per day).

R = Yield reduction (% per day)

Y = Yield (tons per hectare)

P = Corn price (dollars per ton)

TC = Timeliness costs (dollars)

A = Area (hectares)

D = Harvesting or planting period (days)

TI = Time increment (days)

The daily timeliness cost for planting and harvesting times are presented in Tables 4.20 - 4.23. The timeliness costs are low at the early days of operation and increase relative to a daily time increment. The average timeliness cost of conventional corn planting on coarse soil is about 56.5 dollars per hectare while for the no-till and chiseling systems, the cost is 39.9 dollars per hectare.

The daily timeliness costs of planting on coarse, medium and fine soils are 39.9, 43.2 and $56.5/ha respectively. The average timeliness cost of no-till on medium and fine soils is greater than the average timeliness cost of conventional and chiseling systems on similar soils. The no-till system uses smaller size

Table 4.20
The Daily Planting Timeliness Cost for The Conventional System After May 4 (400 Hectares).

Daily Operation	Soil Type		
	Coarse*	Medium**	Fine**
1	166.25	221.67	166.25
2	332.50	443.33	332.50
3	498.75	665.00	498.75
4	665.00	886.67	665.00
5	831.25	1108.33	831.25
6	997.50	1330.00	997.50
7	1163.75	1551.67	1163.75
8	1330.00	1773.33	1330.00
9	1496.25	1995.00	1496.25
10	1662.50	2216.67	1662.50
11	1828.75	2438.33	1828.75
12	1995.00	2660.00	1995.00
13	2161.25	-	2161.25
14	2327.50	-	2327.50
15	2493.75	-	2493.75
16	2660.00	-	2660.00
Total ($):	22610.00	17290.00	22610.00
Average ($/Ha)	56.50	43.22	56.50

* Using An 8-Row Planter.
** Using A 12-Row Planter.

Table 4.21
The Daily Planting Timeliness Cost for The Chiseling System After May 4 (400 Hectares).

	Soil Type		
Daily Operation	Coarse	Medium	Fine
1	241.82	221.67	166.25
2	483.64	443.33	332.50
3	725.45	665.00	498.75
4	967.27	886.67	665.00
5	1209.09	1108.33	831.25
6	1450.91	1330.00	997.50
7	1692.73	1551.67	1163.75
8	1934.55	1773.33	1330.00
9	2176.36	1995.00	1496.25
10	2418.18	2216.67	1662.50
11	2660.00	2438.33	1828.75
12	-	2660.00	1995.00
13	-	-	2161.25
14	-	-	2327.50
15	-	-	2493.75
16	-	-	2660.00
Total ($)	15960.00	17290.00	22610.00
Average ($/Ha)	39.90	43.22	56.50

Each Soil Type Used A 12-Row Planter.

Table 4.22
The Daily Planting Timeliness Cost for The No-Till System After May 4 (400 Hectares).

Daily Operation	Soil Type Coarse	Soil Type Medium	Soil Type Fine
1	241.82	156.47	147.78
2	483.64	312.94	295.56
3	725.45	496.41	443.33
4	967.27	625.88	591.11
5	1209.09	782.35	738.89
6	1450.91	938.82	886.67
7	1692.73	1095.29	1034.44
8	1934.55	1251.76	1182.22
9	2176.36	1408.24	1330.00
10	2418.18	1564.71	1477.78
11	2660.00	1721.18	1625.56
12	-	1877.65	1773.33
13	-	2034.12	1921.11
14	-	2190.59	2068.89
15	-	2347.06	2216.67
16	-	2503.53	2364.44
17	-	2660.00	2512.22
18	-	-	2660.00
Total ($)	15960.00	23967.00	25270.00
Average ($/Ha)	39.90	59.90	63.18

Each Soil Type Used A 12-Row Planter.

Table 4.23
The Daily Harvesting Timeliness Cost for Two Different Combines After October 24 (400 Hectares).

	Combine	
Daily Harvesting	8-Row	12-Row
1	110.83	166.25
2	221.67	332.50
3	332.50	498.75
4	443.33	665.00
5	554.17	831.25
6	665.00	997.50
7	775.83	1163.75
8	886.67	1330.00
9	997.50	1496.25
10	1108.33	1662.50
11	1219.17	1828.75
12	1330.00	1995.00
13	1440.83	2161.25
14	1551.67	2327.50
15	1662.50	2493.75
16	1773.33	2660.00
17	1884.17	-
18	1995.00	-
19	2105.83	-
20	2216.67	-
21	2327.50	-
22	2438.33	-
23	2549.17	-
24	2660.00	-
Total ($)	33250.00	22610.00
Average ($/Ha)	83.10	56.50

planters which results in longer time with greater timeliness costs.

Harvesting timeliness costs were estimated based on different harvesting and planting times. A timeliness cost is estimated when harvesting starts from October 24th relative to the planting time of May 25th-June 4th (Table 4.23).

CHAPTER 5

MACHINERY REPLACEMENT MODEL

5.1 Model Description

Conservation tillage practices have been considered as effective methods in reducing soil and water erosion problems resulting from practices traditionally used by farmers. Farmers may not be certain about the voluntary adoption of conservation practices because of the lack of economic knowledge and management information. Thus, a study was conducted to do an economic analysis for machinery replacement problems.

Perrin (1972) formulated a general mathematical model to study replacement problems. The decision criterion was maximizing the present value of future earnings.

The purpose of this study was to develop a computer simulation model as a useful tool for researchers, extension agents, and farmers for machinery replacement problems based on the following objectives:

1. To make economic assessments for switching from conventional to conservation systems so as to verify the best time to switch to a conservation system and the optimum replacement time to keep the modified or new tillage system in service.
2. To determine reduction in soil productivity resulting from moldboard plowing or other tillage systems.

Farmers use various sets of machines for their annual farming practices and they need to know the length of time to keep the machines in service. The machinery useful life can be considered as an index for keeping a machinery set in service. Machines also can be kept for a longer time by increasing the annual repair and maintenance costs. The commercial useful life of a machine may not be a good criteria for keeping a machinery system because it does not indicate a relation between time and costs.

The economics of continuing with a conventional set of machines or switching to one of the commercial forms of conservation tillage needs to be verified. Conservation tillage lowers the soil and water erosion, but in some regions it may still be profitable to continue with conventional systems.

In switching from a conventional to a conservation tillage system, farmers need to know whether to purchase a new set of machines or trade or modify some of the conventional machines. The model algorithms are so developed that one can have various choices when switching from conventional to a conservation system such as:

1. To keep the old conventional system and sell some of the extra machines like the moldboard plow, the field cultivator, or the row cultivator and purchase some new implements like chisel plows and sprayers.

2. To use a combination of old (conventional) and new machines for the conservation system.
3. To replace the whole conventional machinery set with a new conservation set.

Soil erosion resulted from the utilization of tillage systems, especially moldboard plowing, lowers the top soil which reduces the soil productivity. Thus, the reduction of soil productivity is considered as a portion of the total annual cost.

5.1.1 Program TRDMACH

The TRDMACH Model determines the switching point and trading time based on an economic analysis for a set of crop rotations through a cash flow method (Fig. 5.1 and 5.2). The linear programming model described in Chapter Four and the multiple crop machinery selection model (Rotz, et. al., 1983) will provide a proper set of input data for the model. The process of cost analysis starts with computing the initial costs of keeping or new machines. Keeping machines are the existing machines used for a continuous conventional system or for a conservation tillage system without modifications (except for conventional row planters). New machines are purchased from the market and used for the conservation tillage system (chisel plows, sprayers, etc.). Row planters can be modified to no-till planters by adding some attachments like roller

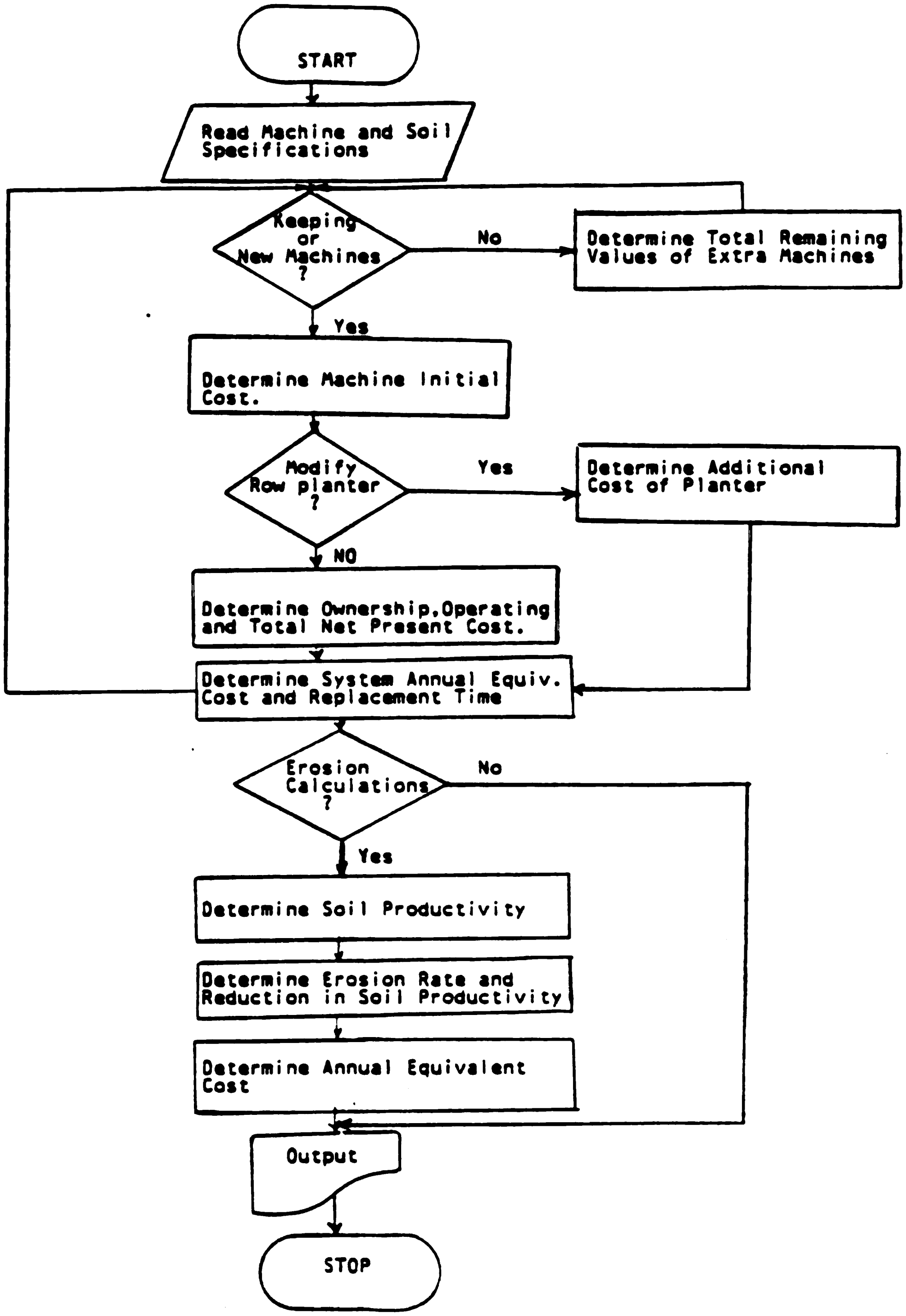

Fig. 5.1 Flowchart of Machinery Replacement Model.

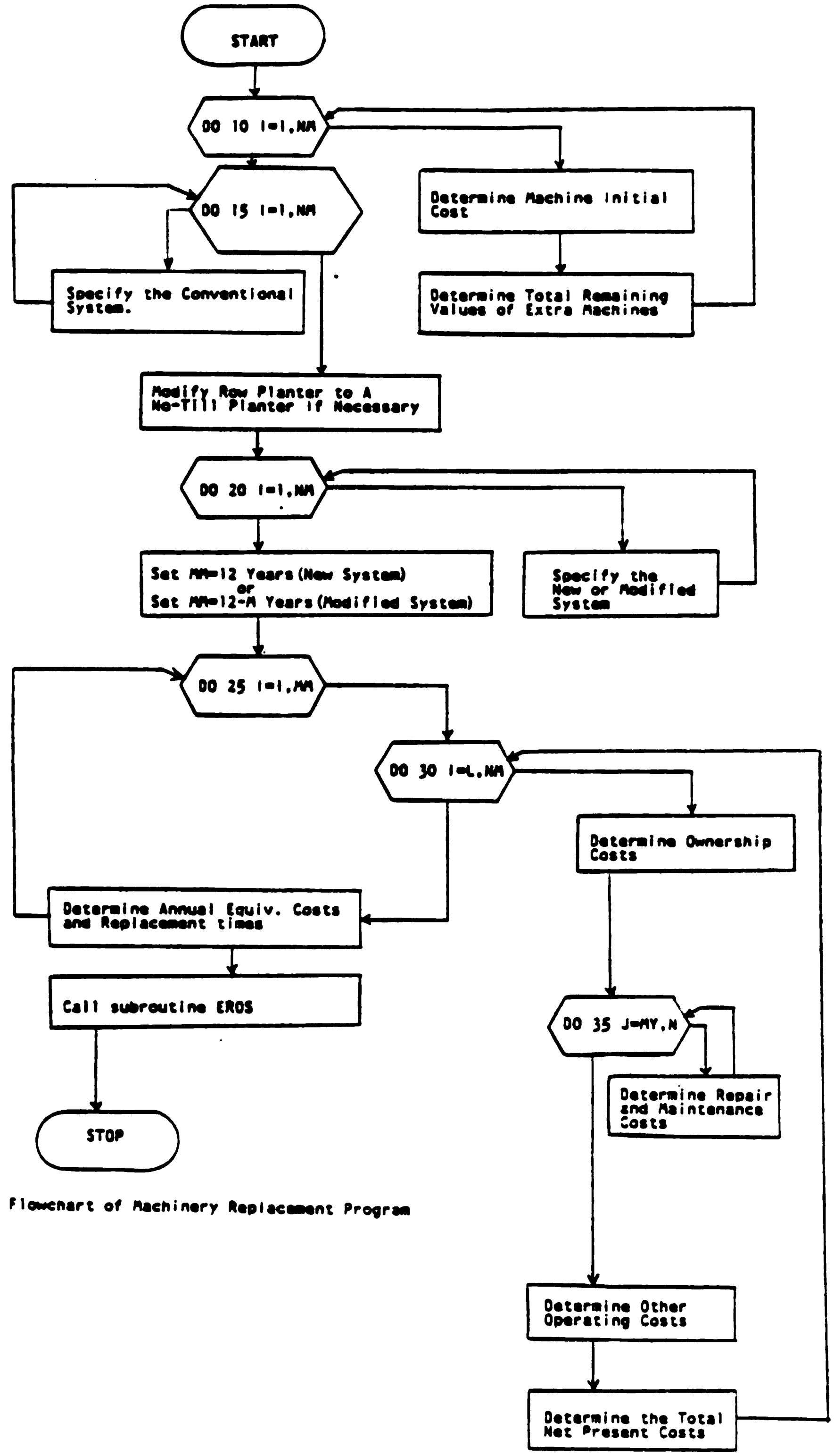

Fig. 5.2 Flowchart of Machinery Replacement Program

colters to the units. Extra machines are not used for a conservation system and removed from the system (moldboard plows, field cultivators, etc.). The total present values of a machinery set including ownership and operating costs are determined for life cycles from 1 to 12 years based upon an infinite time horizon (Perrin's principle of cash flow cost analysis). Ownership costs are considered as down payment, loan payments, tax, insurance and shelter. Operating costs include repair and maintenance, fuel and lubrication, and labor. Tax benefits are considered as incomes to the owner and deducted from the total present value of machinery sets. The total net present value of each set of machines (after deducting from the total remaining values of extra machines) is annualized for each replacement time cycle to present the annual equivalent costs. Subroutine EROS calculates the erosion rate and change in soil productivity on an annual equivalent cost basis. The switching is needed if the summation of two annual equivalent costs of machinery and reduction in soil productivity for a conventional system is greater than the total annual equivalent cost of a conservation system.

5.1.2 Subroutine EROS

Subroutine EROS quantifies soil productivity based on Pierce's model which describes soil as a major determinant of crop yield due to the environment it provides for root growth. Several soil parameters, sufficiency of available water, sufficiency of bulk density (adjusted for permeability), sufficiency of pH, and weighting factors are used in EROS subroutine to determine the soil productivity index of each horizon. The soil productivity is also a summation of horizons productivity indexes. The changes in crop yield can be estimated due to soil erosion resulting from tillage systems (Fig. 5.3). The economic value of soil productivity is determined by the gross return of the crop. The net present value of soil productivity is calculated by discounting the soil productivity at the end of each year to the present. The reduction in soil productivity is annualized based upon the difference of the original and present value of soil productivity for the subsequent years of using moldboard plowing. The annual equivalent cost is also determined relative to each replacement time of a machinery tillage system.

5.2 Model Equations

The first set of equations used by the model are cash flow equations to calculate ownership and operating costs and annual equivalent costs of machines (described in Chapter Four). Initial cost of each machine is estimated by

$$\text{Initial Cost } \$ = A + B \times S$$

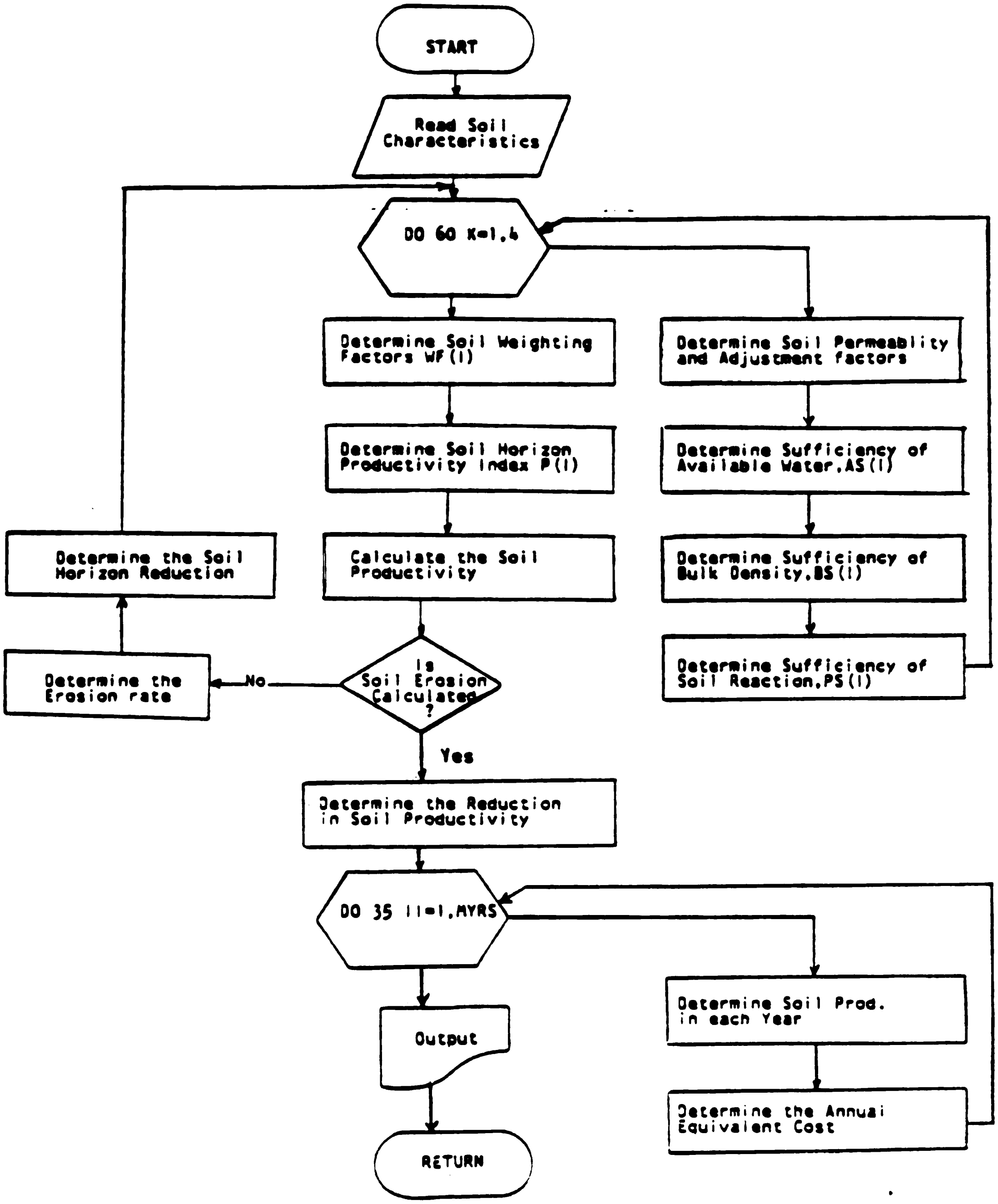

Fig. 5.3 Flowchart of Subroutine EROS.

where

A and B are initial cost factors (Table 5.1) and S is the machine size.

The second set of equations are related to soil productivity and erosion calculations. The soil productivity index is described by Pierce, et. al. (1983) as

$$PI = \sum_{i=1}^{r} (AS_i \times BS_i \times PS_i \times WF_i)$$

where

AS_i = Sufficiency of available water.

BS_i = Sufficiency of bulk density (adjusted for permeability).

PS_i = Sufficiency of pH.

WF_i = Soil weighting factor

r = number of horizons in depth of rooting.

Response of each soil parameter was normalized to range from 0.0 to 1.0. The variables used in the soil productivity calculation are

$$AS = 5 \times AW$$

where

AW = Available water (if available water is greater than or equal to 0.2, then AS = 1.0. If available water is less than or equal to 0.03, then AS = 0.0).

$$BS = (1-adj) + (adj \times c)$$

$$C = slop.1 \times BD + Inter.1$$

where

$BD < CBD$

BD = Bulk density

CBD = Critical bulk density

and

$C = Slop.2 \times BD + Inter.2$

where

$BD > CBD$

If BS is greater than 1.0, then Bs = 1.0. If BS is less than zero, then BS = 0.0.

The sufficiency of pH is determined by the following set of equations:

$PS = 1$
$(pH > 5.5)$

$PS = 0.12 + 0.16pH$
$(5.0 < pH < 5.5)$

$PS = -1.31 + 0.446pH$
$(2.9 < pH < 5.0)$

$PS = 0.0$
$(pH < 2.9)$

where

pH = Soil reaction in each horizon.

The weighting factor for any horizon is the integral of the curve between the upper and lower boundary (cm) of the horizon.

$$WF = 0.35 - 0.152\log (D + (D^2 + 6.45)^{1/2}$$

where:

D = Depth in centimeters

The soil loss equation due to water erosion was determined by Tilman (1976) as

$A = R \times K \times LS \times C \times P$

where

A = Amount of soil loss in tons per acre per year

R = Rainfall factor

K = Soil erodibility factor

LS = Topographic factor

C = Cropping management factor

P = Erosion control practices factor

The rainfall factor, R, is a composite measure of the annual average intensity, duration and erosive force of rainfall. This value ranges in Michigan from 40 to 155.

The K value can be estimated by examining five soil properties: percent silt and very fine sand; percent sand (coarser than very fine sand); percent organic matter; soil structure, and soil permeability.

LS is the interrelation between slope-length factor, L, and the slope-gradient factor, S. The L and S factors can be combined into a composite topographic factor, LS.

The cropping-management factor, C, is the effect on soil erodibility from the kind of crop, tillage operation, length of exposure, vegetation or cover on the site. This is the most sensitive factor which changes the landscape characteristics affecting soil erosion.

The erosion control practices factor, P, represents the influence of various erosion control devices and procedures such as diversion ditchs and counter plowing. If there is no erosion control devices used the P value becomes unity ($P = 1$) and

$$AA = A \times \left(\frac{0.01}{BD}\right)$$

where

AA = Top soil reduced due to erosion in centimeters.

PRLND = YILD x PRCE

where

PRLND = Land productivity ($/ha)

YILD = Crop yield (t/ha)

PRCE = Crop price ($/t)

5.3 Model Parameters

Machinery and soil parameters indicated in the model are listed as:

1. Machine initial cost and repair factors (Table 5.1).
2. Economic parameters (Table 5.2).
3. Codes used for various soil types (Table 5.3).
4. Critical bulk densities for each family texture class (Table 5.4).
5. Coefficients of equations for calculating sufficiency of bulk density (Table 5.5).

Table 5.1
Machine Initial Cost and Repair Factors

Implement	Code	Initial Cost Factors A ($)	Initial Cost Factors B ($/m)	Repair Factors A	Repair Factors B
Combine	1	59936	9740.8	0.12	2.1
Bean Puller	2	4367	1378.0	0.20	1.6
Beet Topper	3	4000	1640.4	0.26	1.6
Beet Lifter	4	5500	2952.8	0.23	1.4
Soil Saver	5	14000	4593.2	0.19	1.4
Subsoiler	6	1794	1230.3	0.38	1.4
Fert. Spread.*	7	1236	1788.1	0.95	1.3
Chisel Plow	8	-1606	2793.5	0.38	1.4
Moldboard Plow	9	-2128	5213.3	0.43	1.8
Disk Harrow	10	-3741	2693.6	0.18	1.7
Heavy Disk	11	-1906	2601.7	0.18	1.7
Field Cultivator	12	-3491	1463.3	0.30	1.4
Grain Drill	13	1236	1788.1	0.54	2.1
Row Planter	14	-4520	4038.7	0.54	2.1
Min-Till Planter	15	-2704	4045.3	0.54	2.1
Sprayer	16	606	275.6	0.41	1.3
Row Cultivator	17	-1634	1099.1	0.22	2.2
Ammonia Applic.*	18	604	275.6	0.38	1.4
Utility Tractor	19	0	500.0/KW	0.012	2.0
Tillage Tractor	20	0	500.0/KW	0.012	2.0

Source: Black et. al (1984)
* Initial cost factors are estimated for fertilizer spreader and ammonia applicator.

Table 5.2
Economic Parameters

Parameter	Value	
Machine Useful Life	12 Years	
Fuel Price	$0.32/Liter	
Labor Price	$7.7/hour	
Remaining Value Factors	A	B
Combine	0.75	0.88
Tractor	0.75	0.87
Implements	0.70	0.90

Source: Black et. al (1984)

Table 5.3
Codes Used for Soil Types

Soil Type	Code
Sandy	1
Coarse loamy	2
Fine Loamy	3
Coarse Silty	4
Fine Silty	5
Clayed:35-45%	6
>45%	7

Table 5.4
Critical Bulk Densities for Each Family Texture Class

Family Texture Class	Critical Bulk Density(g/cm3)
Sandy	1.69
Coarse Loamy	1.63
Fine Loamy	1.67
Coarse Silty	1.67
Fine Silty	1.54
Clayed: 35-45%	1.49
>45%	1.39

Source: Pierce et. al (1983)

Table 5.5
Coefficients of Equations Used for Calculating Sufficiency of Bulk Density

Family Texture Class	Low		High	
	Slope	Intercept	Slope	Intercep
Sandy	-1.933	4.093	-5.163	9.551
Coarse Loamy	-1.160	2.717	-4.859	8.746
Fine Loamy	-0.829	2.210	-7.509	13.866
Coarse Silty	-0.725	2.037	-6.883	12.321
Fine Silty	-0.870	2.166	-7.509	12.389
Clayed: 35-45%	-1.933	3.706	-9.178	14.500
>45%	-1.933	3.513	-10.325	15.178

Source: Pierce et. al (1983)

6. Adjustment factors for calculating sufficiency of bulk density (Table 5.6).
7. Soil weighting factors for first 100 cm of top soil (Table 5.7).
8. Characteristics of shebeon loam soil (0-2% slope) in Saginaw Bay (Table 5.8).

5.4 Model Inputs

Two different sets of data inputs are used by the model. Machinery inputs are provided by the Linear Programming Model (described in Chapter 4) or the multiple Crop Machinery Selection Model (Rotz, et. al., 1983). The output of those two models can be used as proper sets of input to the model. Examples are indicated in Tables 5.9 - 5.14.

The second set of input data includes soil factors that are provided by soil management groups and soil conservation service publications (Table 5.15). The rainfall factor (R) varies across the state but it can be considered uniform over a county wide area. The soil erodibility index (k) measures the influence of physical and organic properties on a soil's susceptibility to erosion. Loam and silt loam soils and sandy loam soils are considered as the most erodible soils while loamy sands and sands are the least erodible soils due to coarse texture and high permeability. The topographic factor, LS, is a

Table 5.6
Adjustment Factors for Calculating Sufficiency of Bulk Density

Family Texture Class	Permeablity(in/hr)				
	<.06	.06-.2	.2-.6	.6-2	>2
Fine Loamy	1.0	1.0	0.9	0.7	0.5
Coarse Silty	1.0	1.0	1.0	0.9	0.7
Fine Silty	1.0	1.0	0.9	0.7	0.5
Clay: 35-60%	1.0	0.9	0.7	0.6	0.5
>60%	1.0	0.8	0.6	0.5	0.4

Source: Pierce et. al (1983)

Table 5.7

Soil Weighting Factors for 100 Centimeters of Soil Layers

CM	WF	CM	WF	CM	WF
0	0.000000	34	0.499657	68	0.793882
1	0.044522	35	0.509912	69	0.801180
2	0.063886	36	0.520044	70	0.808414
3	0.083008	37	0.530057	71	0.815587
4	0.101641	38	0.539954	72	0.822699
5	0.119708	39	0.549737	73	0.829751
6	0.137211	40	0.559410	74	0.836743
7	0.154180	41	0.568976	75	0.843678
8	0.170655	42	0.578436	76	0.850554
9	0.186675	43	0.587794	77	0.857374
10	0.202276	44	0.597052	78	0.864137
11	0.217489	45	0.606212	79	0.870845
12	0.232344	46	0.615276	80	0.877498
13	0.246864	47	0.624246	81	0.884097
14	0.261073	48	0.633125	82	0.890642
15	0.274990	49	0.641914	83	0.897135
16	0.288631	50	0.650614	84	0.903576
17	0.302014	51	0.659229	85	0.909965
18	0.315152	52	0.667758	86	0.916303
19	0.328057	53	0.676205	87	0.922591
20	0.340741	54	0.684570	88	0.928829
21	0.353214	55	0.692856	89	0.935018
22	0.365486	56	0.701062	90	0.941159
23	0.377566	57	0.709192	91	0.947251
24	0.389461	58	0.717246	92	0.953296
25	0.401179	59	0.725225	93	0.959293
26	0.412727	60	0.733132	94	0.965244
27	0.424111	61	0.740966	95	0.971149
28	0.435337	62	0.748729	96	0.977009
29	0.446411	63	0.756423	97	0.982823
30	0.457336	64	0.764048	98	0.988593
31	0.468120	65	0.771605	99	0.994318
32	0.478765	66	0.779096	100	1.000000
33	0.489276	67	0.786521		

Source: Pierce, et. al. (Jan. - Feb., 1983)

Table 5.8
characteristics of Shebeon Loam Soil (0-2% Slope)
in Saginaw Bay.

Horizon	Depth (cm)	Bulk Density	Perm.	Avail. water
1	27.9	1.58	1.3	0.185
2	30.5	1.63	1.3	0.155
3	25.4	1.63	1.1	0.135
4	68.6	1.91	1.0	0.060

Table 5.9
A Machinery Set used for a Continuous Corn Rotation
When Switching from Conventional to No-Till System
(150 Hectares).

Machine	Size (m)	NO.	Hours	State*
Till. Tractor	76.3 KW	1	104.4	2
Util. Tractor	35.8 KW	1	197.8	2
Combine	3.0	1	124.6	2
Fert. spread.	12.2	1	19.1	2
MB. Plow	2.0	1	-	1
Field cult.	4.7	1	-	1
Row Planter	3.0	1	100.4	2
Row Cult.	3.0	1	-	1
NH3 Applicator	3.0	1	104.4	2
Sprayer	6.0	1	78.3	3

*1,2,and 3 indicate extra machines ,keeping machines,and new machines respectively.

Table 5.10
A Conventional Set Of Machines Used in A Continuous Corn Rotation(150 Hectares).

Machine	Size(m)	NO.	Hours	State*
Till. Tractor	76.3 KW	1	312.9	2
Util. Tractor	35.8 KW	1	210.2	2
Combine	3.0	1	124.6	2
Fert. spread.	12.2	1	19.1	2
MB. Plow	2.0	1	117.7	2
Field cult.	4.7	1	90.9	2
Row Planter	3.0	1	85.5	2
Row cult.	3.0	1	105.6	2
NH3 Applicator	3.0	1	104.4	2

* See Table 5.9

Table 5.11
A Set of Machines Used for A Corn-Navy Bean-Sugar Beet-Rotation When Switching from Conventional to the Chiseling System(500 Hectares).

Machine	Size(m)	NO.	Hours	State*
Till. Tractor	105.8 KW	1	447.7	2
Util. Tractor	57.3 KW	1	437.6	2
Combine	6.0	1	155.6	2
Bean Pulier	4.5	1	70.6	2
Beet Topper	3.0	1	70.6	2
Beet lifter	3.0	1	80.7	2
Fert. spread.	12.2	1	31.8	2
MB. Plow	2.8	1	-	1
Field Cult.	6.6	1	126.7	2
Grain Drill	6.1	1	41.5	2
Row planter	6.0	1	125.4	2
Sprayer	12.2	1	97.7	2
Row cult.	6.0	1	-	1
NH3 Applicator	6.0	1	43.4	2
Chisel Plow	3.0	1	196.9	3

* See Table 5.9

Table 5.12
A Conventional Set of Machines Used for Corn-Navy Bean-Wheat-Sugar Beet Rotation(500 Hectares).

Machine	Size	NO.	Hours	State*
Till. Tract.	105.8 KW	1	499.4	2
Util. Tract.	57.3 KW	1	505.0	2
Combine	6.0	1	155.6	2
Bean Puller	4.5	1	70.6	2
Beet Topper	3.0	1	70.6	2
Beet Lifter	3.0	1	80.7	2
Fert. Spread.	12.2	1	31.8	2
MB. Plow	2.8	1	211.7	2
Field Cult.	6.6	1	163.6	2
Grain Drill	6.1	1	33.2	2
Row Planter	6.0	1	106.7	2
Sprayer	12.0	1	16.3	2
Row Cult.	6.0	1	175.8	2
NH3 Applicator	6.0	1	43.4	2

* See Table 5.9

Table 5.13
A Set of Machines Used for A Corn-Navy Bean-Sugar Beet Rotataion When Switching from Conventional to the Chiseling system(500 Hectares).

Machine	Size	NO.	Hours	State*
Till. Tract.	135.3 KW	1	494.3	2
Util. Tract.	57.3 KW	2	242.9	2
Combine	6.0	1	138.4	2
Bean Puller	4.5	2	47.0	2
Beet Topper	3.0	1	94.0	2
Beet Lifter	3.0	1	107.9	2
Fert. spread.	12.2	1	21.2	2
MB. Plow	3.7	1	-	1
Field Cult.	8.4	1	109.2	2
Row Planter	6.0	1	167.4	2
Row Cult.	6.0	1	-	1
NH3 Applicator	6.0	1	58.1	2
Chisel Plow	3.7	1	219.1	3
Sprayer	12.2	1	108.8	3

* See Table 5.9

Table 5.14
A Conventional Set of Machines Used for A Corn-Navy Bean-Sugar Beet Rotation (500 Hectares).

MACHINE	SIZE	NO.	HOURS	STATE
Till. Tractor	135.3 KW	1	527.5	2
Util. Tractor	57.3 KW	2	293.4	2
Combine	6.0	1	138.4	2
Bean Puller	4.5	2	47.0	2
Beet Topper	3.0	1	94.4	2
Beet Lifter	3.0	1	107.9	2
Fert. Spread.	12.2	1	21.2	2
MB. Plow	3.7	1	219.1	2
Field Cult.	8.4	1	142.4	2
Row Planter	6.0	1	142.5	2
Row Cult.	6.0	1	234.7	2
NH3 Applicator	6.0	1	58.1	2

Table 5.15
Erosion Parameters for Shebeon Loam
(0-2% Slope) in Saginaw Bay

Tillage System	R	K	LS	P	C
No-Till (C)	75	0.32	0.30	1	0.06
Conventional (C)	75	0.32	0.30	1	0.30
Chiseling (C-N-W-S)	75	0.32	0.30	1	0.15
Conventional (C-N-W-S)	75	0.32	0.30	1	0.23
Chiseling (C-N-S)	75	0.32	0.30	1	0.15
Conventional (C-N-S)	75	0.32	0.30	1	0.23

Source: Tilman et. al (1976) and Soil Conservation Service.
Crop Rotations: C=Corn, N=Navy Bean, W=Wheat, S=Sugar Beet.

function of slope-length, L, and percent slope, S. The amount of vegetative cover on the soil surface determines the cropping factors (c-values). Sufficient data is not available for erosion control practices factor (P-values) due to complexity and variety of control devices. The P value becomes unity (P=1) when no erosion control devices have been used.

5.5 Model Assumptions

The model has been developed based upon several assumptions and limitations in order to provide acceptable results.

1. The LP model and the multiple crop machinery selection model provide proper sets of data about machinery complements. Such data is processed by the model (Tables 5.9 - 5.14).
2. The cash flow method is used primarily as a commercial method to calculate the system cost (Rotz, et. al., 1981).
3. Inflation, discount, and interest rates are assumed to be constant within the period of analysis. These values may change on a short or long term basis.
4. The useful life of machines is equal to 12 years which is equivalent to the maximum replacement time.
5. The model has also assumed a complete trading for a set of machines for each replacement time.

6. Seven soil types starting from coarse to fine textures are considered in the model (Table 5.3).
7. The soil productivity index calculation is based upon Pierce's equations using Various Soil Parameters (Tables 5.4 - 5.7).
8. The annual soil erosion assessment was based on the method used by Tilman and Mokma (1976).
9. Pierce and Larson (1983) had estimated the soil weighting factor relative to each centimeter increment of soil horizon. For low erosion rates, weighting factor measurements in millimeters were required.
10. The crop revenue was estimated by the average price for a replacement time period.
11. The amount of soil loss due to wind erosion for conservation practices is relatively low which is not considered in calculations.

5.6 Model Results

The model described has the flexibility for use in conducting machinery replacement problems for a wide range of crop rotations. The optimum replacement time ($\hat{t}$) is the time period in which the annual equivalent cost for a set of machines is minimum. The machinery costs for two tillage systems of conventional and no-till corn are presented in Table 5.16. The reduction of soil productivity due to moldboard plowing is indicated in Table 5.17.

Table 5.16
Machinery Costs and Replacement Times for A Conventional or A Modified No-Till System Using the Continuous Corn Rotation(150 Hectares).

Replacement Time* (years)	---Moldboard Plowing--- NPV($)	AEC($/ha)	---Modified No-till- NPV($)	AEC($/ha)
1	64786.49	440.54	58629.96	347.22
2	98686.37	338.86	88031.93	276.28
3	126394.70	292.18	111122.21	239.38
4	154455.01	270.42	133948.75	221.27
5	185398.39	262.23	158707.90	213.77
6	221456.29	263.57	187247.47	213.85
7	265215.80	273.19	221668.56	220.54
8	319930.27	291.16	264595.23	233.91
9	389798.13	318.38	319406.96	254.70
10	480285.59	356.46	390503.58	284.21

*The Conventional system has been used for two years.

Table 5.17
Reduction of Soil Productivity due to the Moldboard Plowing System.

Time (Years)	Soil Productivity ($/ha)	Soil Productivity PV($/ha)	AEC ($/ha)
1	655.91	585.63	85.98
2	649.41	517.71	85.61
3	642.92	457.62	85.26
4	636.43	404.46	84.92
5	629.93	357.44	84.60
6	623.44	315.85	84.29
7	616.94	279.07	83.99
8	610.45	246.55	83.71
9	603.96	217.79	83.44
10	597.46	192.37	83.19

Change in annual soil Productivity ($/ha): 6.49

Original Soil Productivity ($/ha): 662.40

PV: Present Value
AEC: Average Equivalent Cost

The model also determines erosion rates for different tillage systems and crop rotations (Table 5.18). The optimum replacement time for a set of no-till system is 5 years with the annual equivalent cost of 213.77 ($/ha). The annual equivalent cost for the conventional system is determined by adding the annual equivalent cost due to reduction in soil productivity to the annual equivalent cost of machines (Table 5.19).

Table 5.19 shows when a farmer should continue with conventional practices or switch to the no-tillage system. The AEC values for each replacement time in the conventional system is greater than of that of the no-till system. Therefore, the tillage system should be switched to the no-till. These costs start from 526.52 ($/ha) to 439.65 ($/ha) for the conventional system compared to 347.22 to 284.21 ($/ha) for the no-till system. Thus, it is not profitable to continue the conventional method. The optimum replacement time for the no-till system is 5 years ($\hat{t}$) which is the maximum time period to keep machines. Similar analysis can be used after 5 years as to whether to continue with this modified conservation machinery set or to purchase a new set. The change in soil productivity is estimated from the annual erosion rate which determines the future potential soil productivity. The difference between the discounted future soil productivity and the original

Table 5.18
Erosion Rates Resulted from Serval
Tillage Systems and Crop Rotations.

Tillage System	Erosion (Rainfall)* (t/ha)	Erosion (Wind)** (t/ha)	Total (t/ha)
No-Till (C)	1.06	-	1.06
Conventional (C)	5.34	7.0	12.43
Chiseling (C-N-W-S)	2.67	-	2.67
Conventional (C-N-W-S)	4.09	7.0	11.18
Chiseling (C-N-S)	2.67	-	2.67
Conventional (C-N-S)	4.09	7.0	11.18

* Estimated by the model.
** Estimated by the soil conservation service.

Table 5.19
A Comparison of Annual Equivalent Cost of Conventional and Modified No-Till System.

Replacement Time (Years)	Conventional AEC ($/ha)*	Modified No-Till AEC ($/ha)
1	526.52	347.22
2	424.47	276.28
3	377.44	239.38
4	355.34	221.27
5	346.83	213.77
6	347.86	213.85
7	357.18	220.54
8	374.87	233.91
9	401.82	254.70
10	439.65	284.21

* It includes annual equivalent cost of reduction in soil productivity.

soil productivity specified on an annual equivalent basis determines the reduction in soil productivity (Table 5.17). The cost of reduction in soil productivity of conservation systems is not considered in the cost analysis because of the low amount of soil erosion.

The conventional system of corn, navy bean, sugar beet and corn, navy bean, wheat, sugar beet should be switched to chiseling systems because of the higher costs of conventional systems (Tables 5.20 and 5.21). The annual equivalent costs of the machinery systems (without incorporating the soil reduction costs) of conventional tillage are greater than the annual equivalent costs of the chiseling system. Therefore, the conventional systems are not economically feasible to continue. The optimum replacement time ($\hat{t}$) to keep each of the chiseling system is 4 years.

5.7 Sensitivity Analysis

The most sensitive parameter to the model is the total time period to keep the conventional system in service before changing to a conservation system. A comparison of three replacement times for a modified no-tillage system is presented in Table 5.22. The first system shows that if a conventional system is kept in service for one year and then switched to a conservation tillage system, the optimum replacement time will be 6 years and the annual equivalent

Table 5.20
Machinery Costs and Replacement Times for A Conventional or A Modified Chiseling System for the Corn-Navy Bean-Sugar Beet Rotation (500 Hectares).

Replacement Times	---- Conventional----		--Modified Chiseling--	
(Years)	NPV($)	AEC($/ha)	NPV($)	AEC($/ha)
1	131977.70	897.45	124784.74	763.24
2	207796.24	713.50	195202.32	627.19
3	276578.43	639.37	257186.60	565.54
4	352577.06	617.30	324128.54	545.53*
5	442994.10	626.57	402333.34	551.32
6	555252.26	660.85	498084.74	577.88
7	698490.82	719.50	619036.91	624.74
8	884478.12	804.93	775014.24	693.90
9	1128558.41	921.77	978818.03	789.22
10	1450805.66	1076.75	1247201.17	916.33

The conventional system has been used for two years.

Table 5.21
Machinery Costs and Replacement Times for A Conventional or A Modified Chiseling System for the Corn-Navy Bean-Wheat-Sugar Beet Rotation(500 Hectares).

Replacement Times	---- Conventional----		--Modified Chiseling--	
(Years)	NPV($)	AEC($/ha)	NPV($)	AEC($/ha)
1	114852.94	781.00	108762.65	672.38
2	180599.21	620.12	169892.23	549.42
3	239993.73	554.79	223715.22	494.31
4	305424.83	534.75	281870.63	476.20*
5	383082.20	541.83	349832.29	480.82
6	479315.72	570.47	433054.19	503.65
7	601934.76	620.04	538180.83	544.19
8	760993.65	692.55	673742.16	604.16
9	969603.48	791.94	850854.29	686.88
10	1244920.11	923.95	1084065.95	797.23

The conventional system has been used for two years.

Table 5.22
A Comparison of three Replacement Times for a Modified No-Till System.

Replacement Time (Years)	Annual Equivalent Cost ($/ha) A	B	C
1	252.20	434.43	673.16
2	228.86	322.29	471.22
3	206.13	273.80	403.78
4	193.48	251.96	383.34*
5	187.58	244.41*	388.15
6	186.89*	246.86	411.57
7	190.95	257.97	-
8	199.94	277.82	-
9	214.48	307.39	-
10	235.60	-	-
11	264.73	-	-
Soil Productivity($/ha):	585.63	457.62	315.85
Annual Equivalent Cost($/ha):	85.98	85.26	84.29
Original Soil Productivity($/ha):	662.40	662.40	662.40

A,B,and C indicate switching from a conventional system to a modified no-till system after using the conventional system for 1,3,and 6 years respectively from the present time.

cost will include 186.89 ($/ha). The potential soil productivity will be reduced from 662.40 ($/ha) to 585.63 ($/ha). However, keeping the conventional system for three years before switching to the conservation system, changes the optimum replacement life to 5 years but the minimum annual cost increases to 244.41 ($/ha). The soil productivity is also reduced to 457.62 ($/ha). The annual equivalent cost will increase to 383.34 ($/ha) with the 4 years of optimum replacement age if the conventional system is kept for 6 years before switching to the chiseling system. The soil productivity will be lowered to 315.85 ($/ha).

5.8 Summary

The results of the various data analyzed by the model indicate that conventional systems are not economically feasible to be continued in cropping systems. First, the machinery costs are higher for conventional systems because of the annual costs of some of the tillage units such as moldboard plows, row cultivators, or field cultivators. Utilization of moldboard plowing reduces soil productivity which increases the annual system cost.

The early switching from a conventional to a conservation system reduces the annual system cost and increases the optimum replacement time. Thus, the conservation system can be kept with lower costs and a larger time.

CHAPTER 6

IMPACT OF CONVENTIONAL AND CHISELING TILLAGE SYSTEMS ON MACHINE SIZE FOR COMMON CROP ROTATIONS

6.1 Introduction

Least cost machinery sets were developed for a group of common crop rotations found on the naturally poorly drained, fine textured soils in the Saginaw Bay area of Michigan. Both conventional moldboard plow and conservation (chisel plow) tillage systems were developed. Farm sizes from 150 to 500 ha at 50 ha increments were examined for 4, 6 and 8 row machinery sets. Machinery size and cost are influenced by the size of farm and the type and number of operations that must be covered within a time constraint.

To compare the economic advantages of conservation tillage systems to conventional systems, properly sized machinery sets for each tillage system in relation to different soil types and crop rotations should be determined. Rotz, et. al. (1983) designed a multiple crop machinery selection model that considered factors such as acreage to be farmed, soil type and drainage, weather, labor, and interactions among machines. The model selected the optimum machinery complements for specified farm sizes and crop rotations. The objective of this study was to use this model to examine the impact of farm size on machinery size and costs for conventional and conservation tillage of a variety of crop rotations in Michigan.

6.2 Multiple Crop Machinery Selection

6.2.1 Machinery Selection Algorithm

The multiple crop machinery selection model described above was improved for power requirement parameters in the selection of a set of machines for conventional or conservation tillage systems (Rotz and Black, 1984). The model algorithm integrates capacity and power matching and cost analysis for a selection process. Crop rotation, land area, and soil type are the major farm parameters used by the model (Rotz, et. al., 1984).

6.2.2 Farm Parameters

The machinery selection model was used to evaluate machinery requirements for various farm sizes and crop rotations for both conventional and conservation tillage systems. Farm sizes used were from 150 to 500 ha at 50 ha increments. The following crop rotations were analyzed for each farm size:

1. Corn - Corn
2. Corn - Navy bean
3 Corn - Soybean
4. Corn - Corn - Navy Bean
5. Corn - Corn - Soybean
6. Corn - Navy Bean - Sugar Beet
7. Corn - Navy Bean - Wheat - Sugar Beet
8. Corn - Navy Bean - Soybean - Sugar Beet

9. Corn - Corn - Navy Bean - Wheat
10. Corn - Corn - Navy Bean - Sugar beet

Weather and soil conditions were set for Eastern Michigan which included a 80% probability level for suitable days and a fine textured clay soil.

6.2.3 Economic Parameters

Economic parameters used by the model are machinery initial costs, cumulative repair factors, and remaining value factors. Such parameters are also used by the machinery replacement model (Tables 5.1 and 5.2).

6.2.4 Machine Parameters

Machine parameters used by the model were commercial sizes, field efficiency, and field speed and power requirements.

6.3 Results and Discussion

Major factors that will influence the machinery size and costs are time constraint, farm size, conventional vs. conservation tillage, and the type of crop and crop rotation.

Time constraint determines the machinery capacity in order to cover a field for annual operations. The machine size can be smaller and the cost reduced if sufficient time is available for desired farming operations. But, machinery size and costs increase if the effective time is reduced. In continuous corn farms (Figures 6.1 and 6.2), for example, time is not restricted for farm practices below 300 hectares. In conventional corn farms, four, six, and eight row machines are used effectively but with higher costs for four and eight row machines. Four row sets are not capable of covering a farm larger than 300 hectares and also six row sets for farms below 450 hectares. In corn corn soybean rotation, four row and six row sets can be technically used for farms below 250 and 350 hectares respectively (Figures 6.3 and 6.4). Although the machinery performances are not physically restricted to cover the larger farms, due to the high timeliness costs, they are not profitable for farmers to continue. The time constraint for all crop rotations were assigned based upon the agronomic loss factors to reduce the timeliness cost as low as possible.

In corn, navy bean and corn, corn, navy bean rotations, only six and eight row sets are the least cost for almost all the farms (Figures 6.5 - 6.8). For corn, navy bean rotation, six row equipment is least cost for farms less than 250 hectares and eight row sets for farms larger than 250 hectares. For the corn, corn, navy bean rotations, four row equipment is less costly for farm sizes less than 170 hectares, six row sets cost less up to 325 ha (conservation) and for farms greater than 300 hectares,

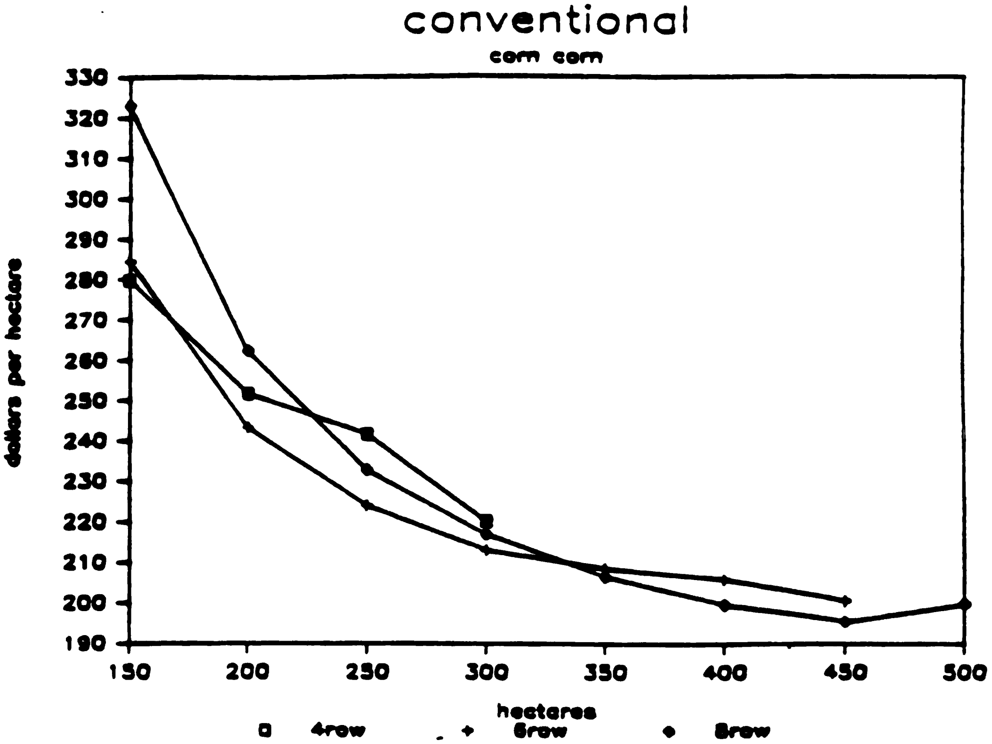

Figure 6.1. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Continuous Corn.

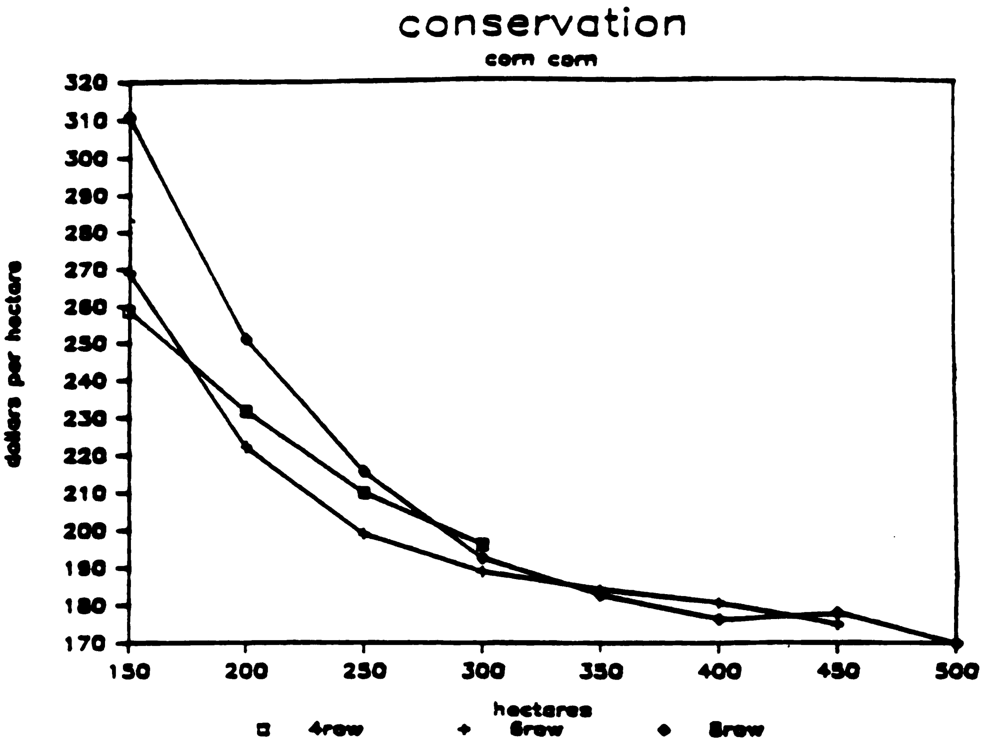

Figure 6.2. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conservation Continuous Corn.

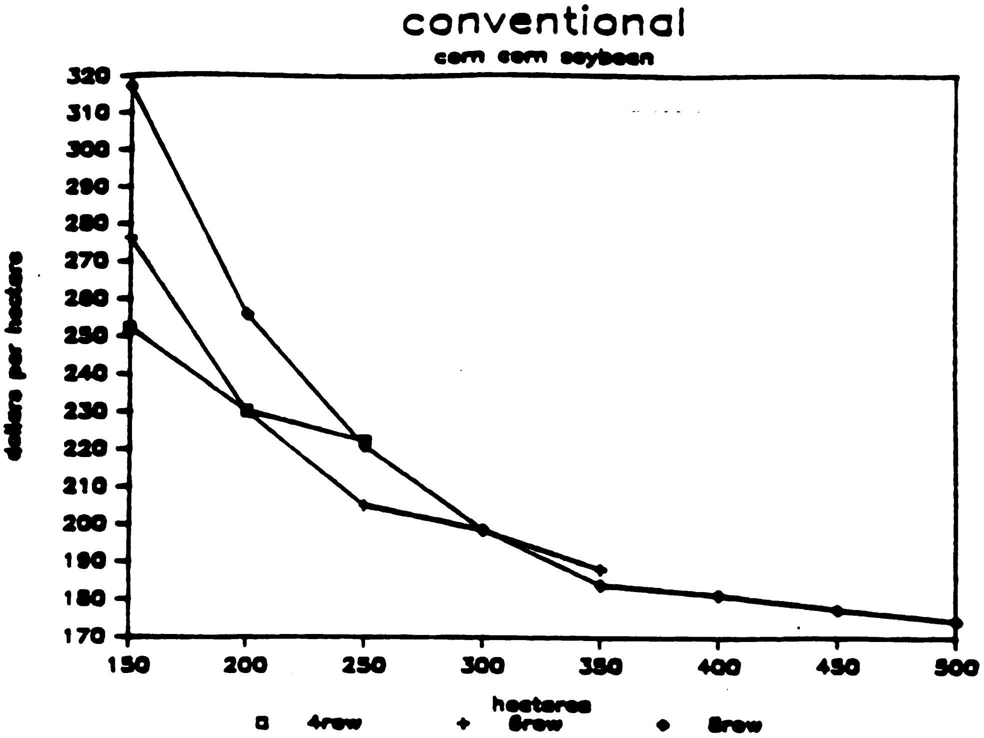

Figure 6.3. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Corn-Soybean.

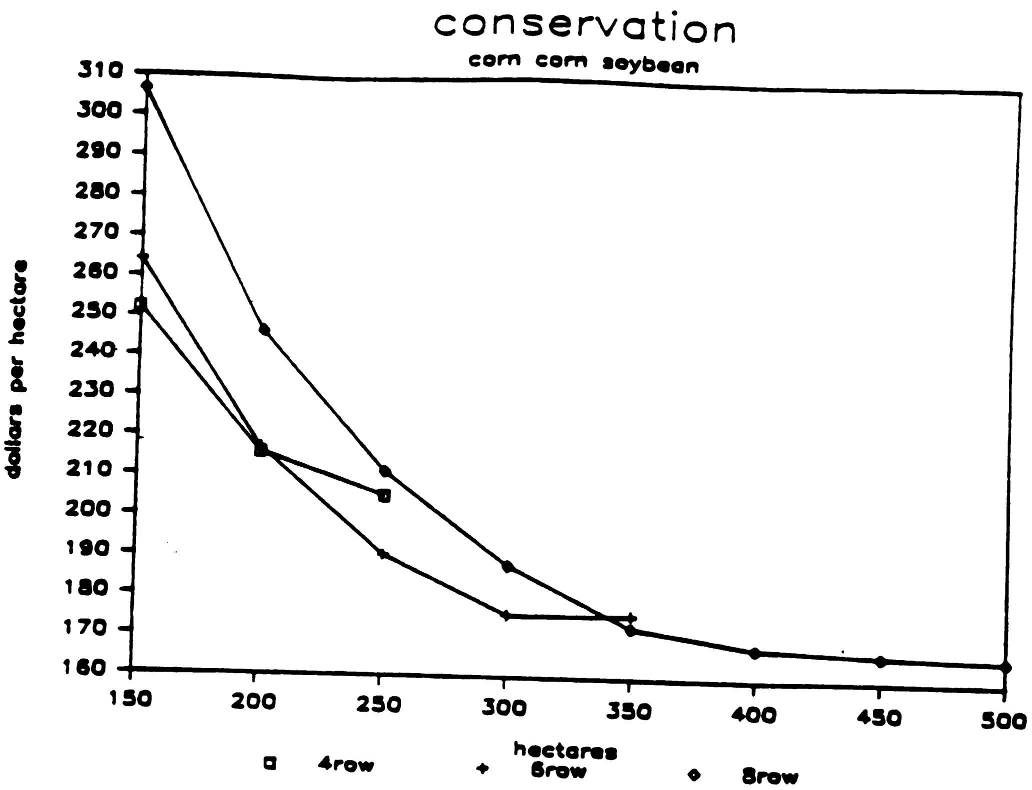

Figure 6.4. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conservation Corn-Corn-Soybean.

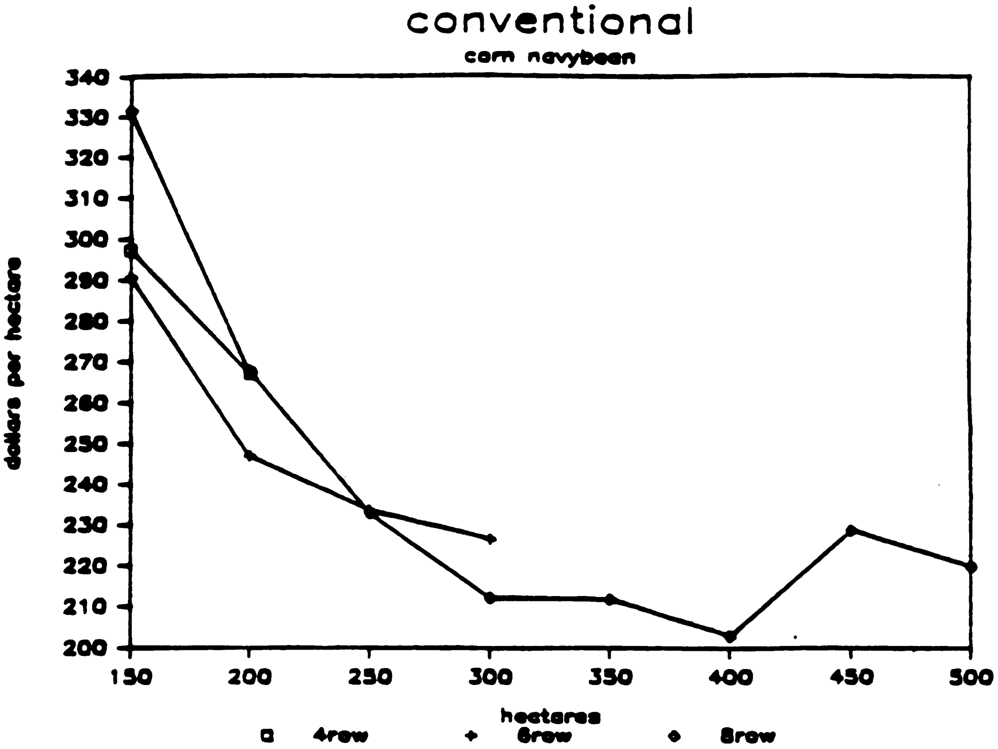

Figure 6.5. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Navy bean.

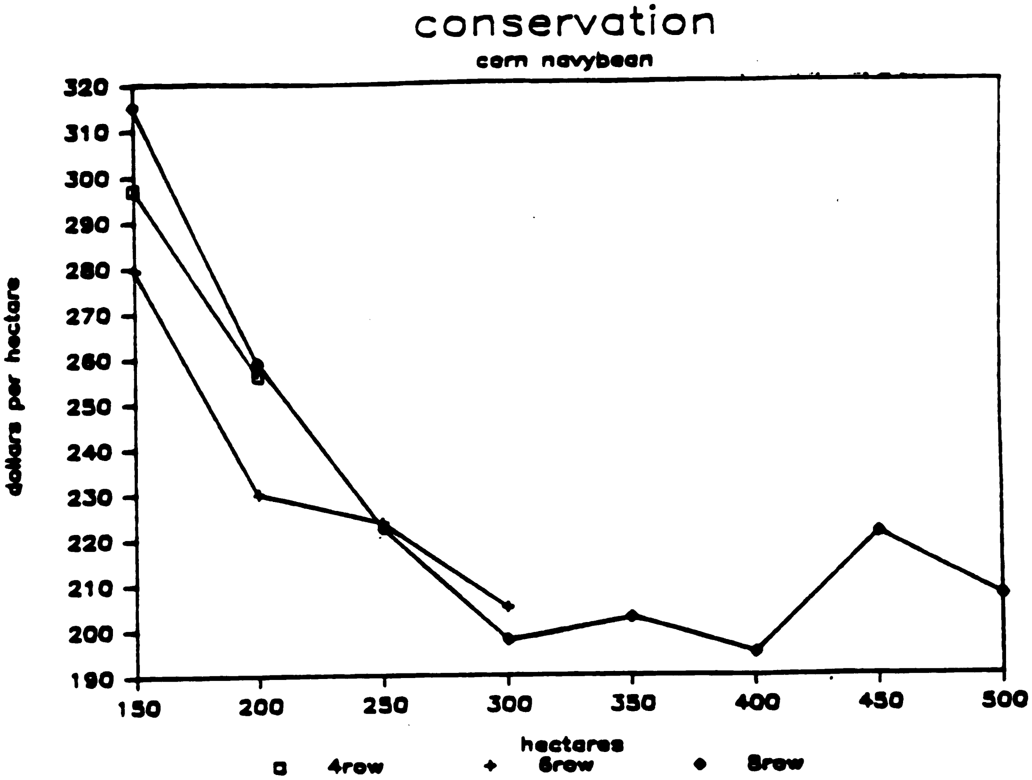

Figure 6.6. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conservation Corn-Navy bean.

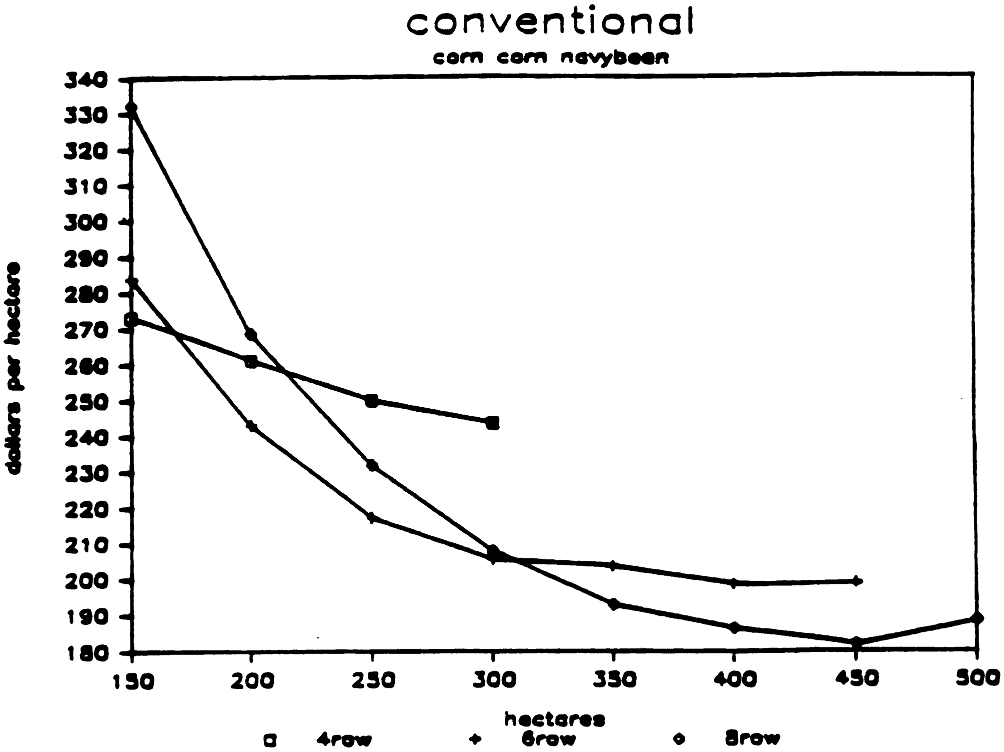

Figure 6.7. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Corn-Navy bean.

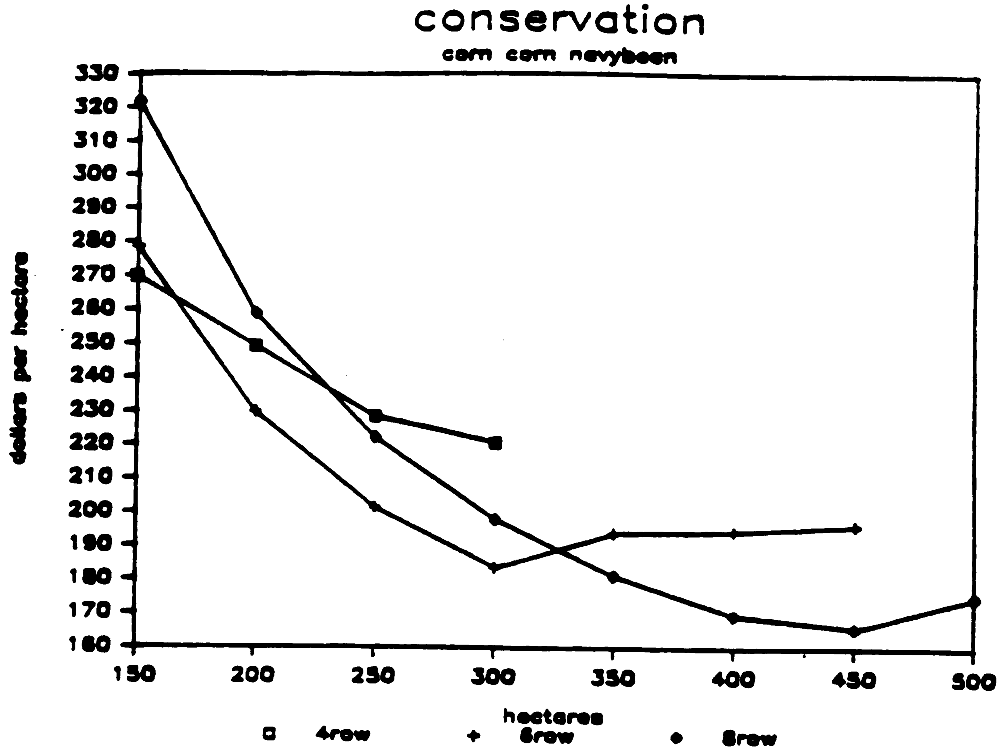

Figure 6.8. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conservation Corn-Corn-Navy bean.

eight row sets cost less. In corn corn navy bean wheat rotation, most of the farms are least cost for four row and six row machines (Figures 6.9 and 6.10).

In corn, navy bean, sugar beet, the time constraint allows only eight row machines to be selected on most of the farms. Crop rotations having navy bean and sugar beet eight row sets are economically feasible for most of the farms (Figures 6.11 - 6.18). Eight row sets are least cost for farms greater than 200 hectares. Four row sets are only least cost for farms less than 200 hectares which include a small portion of the farms. In corn soybean rotations, four row machines are only least cost for 150 hectares and for larger farms six and eight row machines can be used (Figures 6.19 and 6.20).

Time constraint is identified by the probability of weather risk in a certain location. The model can select machinery sets based upon three probability levels of 30, 50, and 80 percent. The higher the probability level, the shorter the time constraint, which calls for larger machinery sets with greater annual costs.

The total time available for continuous corn operations is relatively short which demands a higher machinery set, especially for the conventional system. The benefit of conservation tillage is greater with a saving of machinery costs of, for example, $25/ha on 250 ha farms and $30/ha on

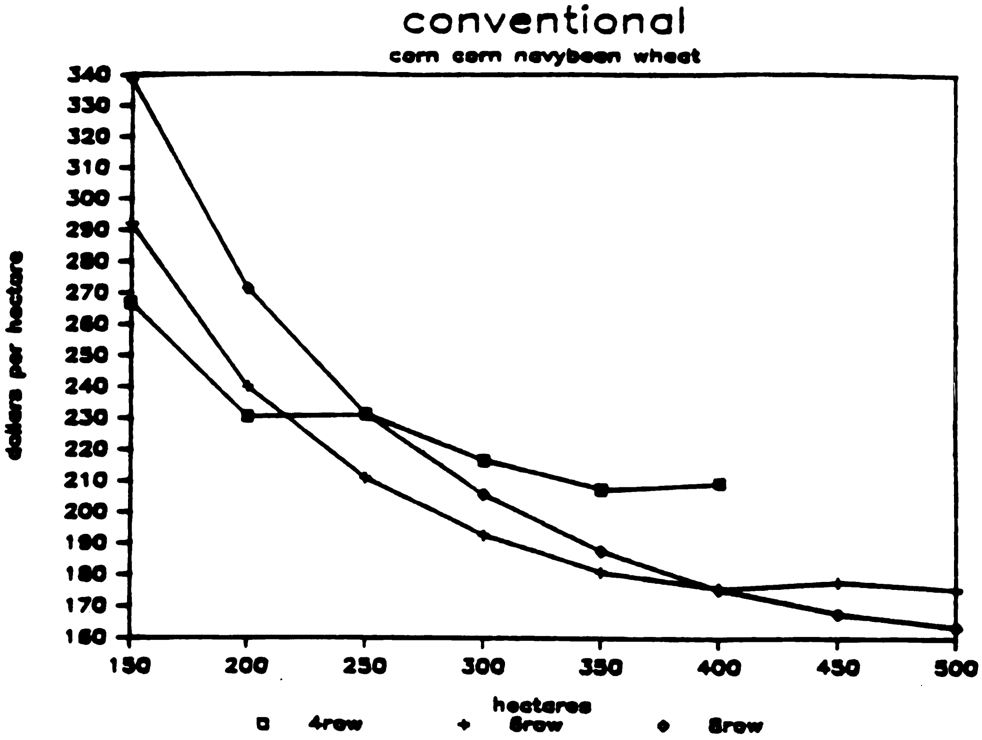

Figure 6.9. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Corn-Navy bean-Wheat.

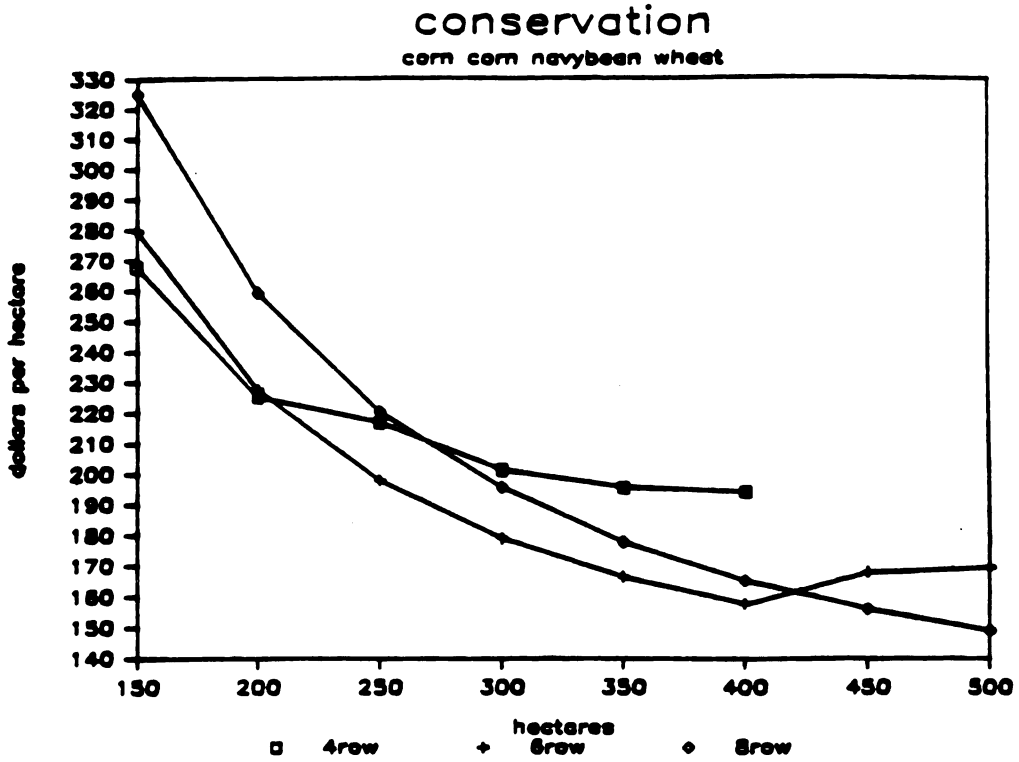

Figure 6.10. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravaticn Corn-Corn-Navy bean-Wheat.

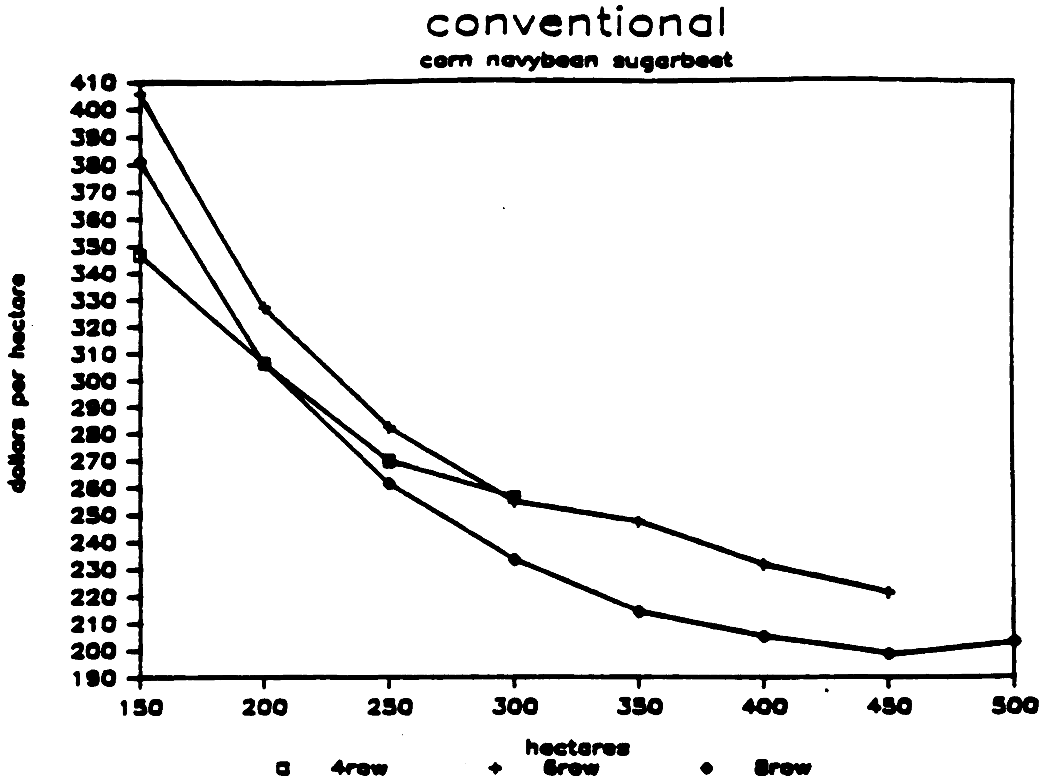

Figure 6.11. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Navy bean-Sugar beet.

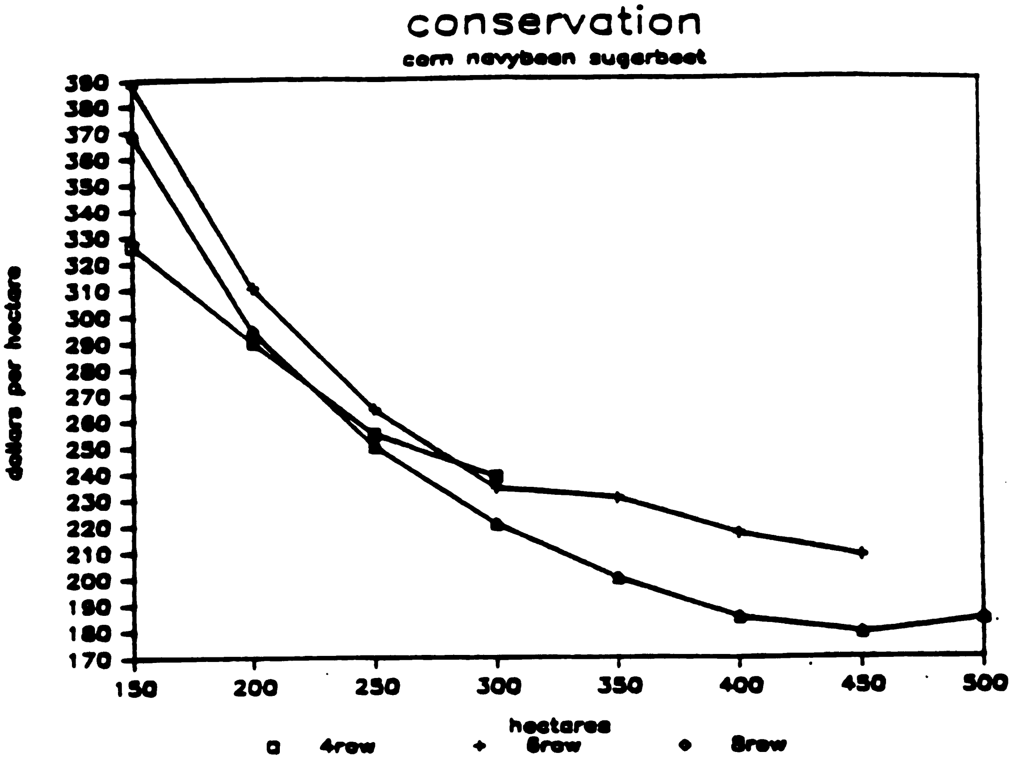

Figure 6.12. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravation Corn-Navy bean-Sugar beet.

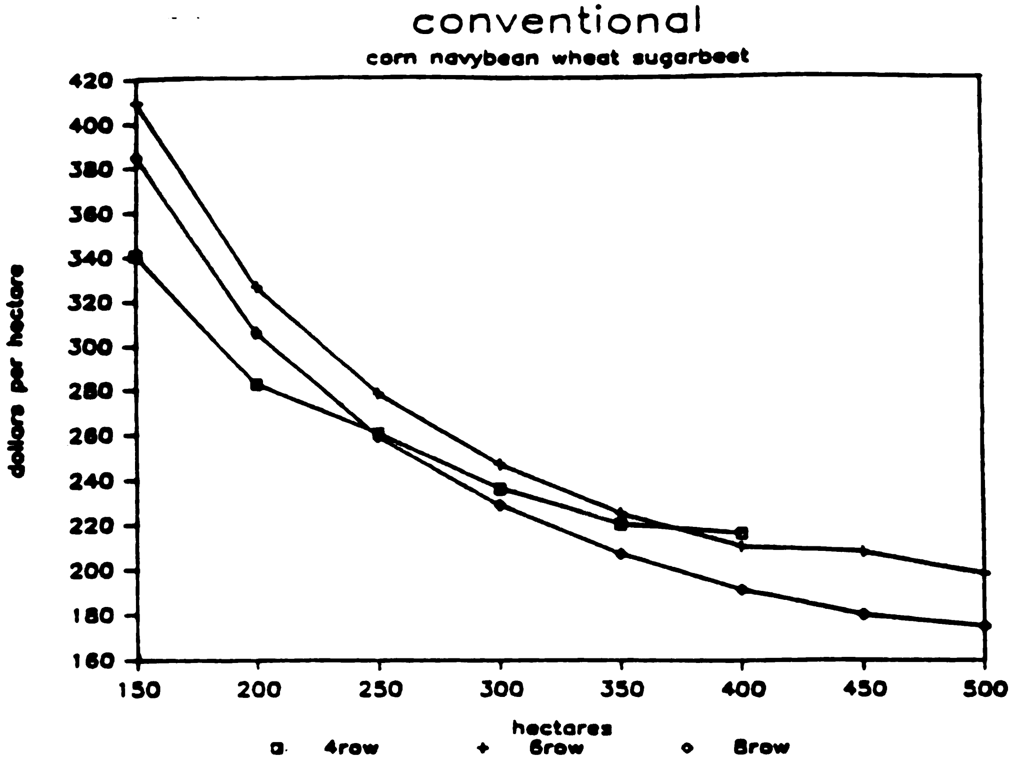

Figure 6.13. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Navy bean-wheat-Sugar beet.

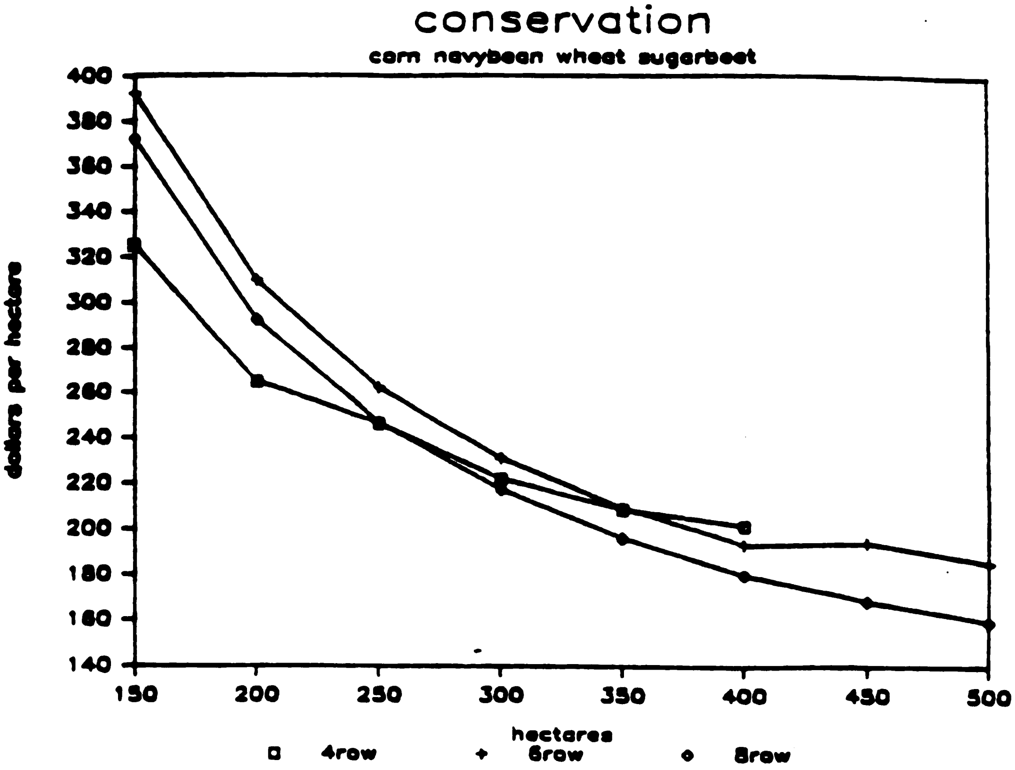

Figure 6.14. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravation Corn-Navy bean-Wheat-Sugar beet.

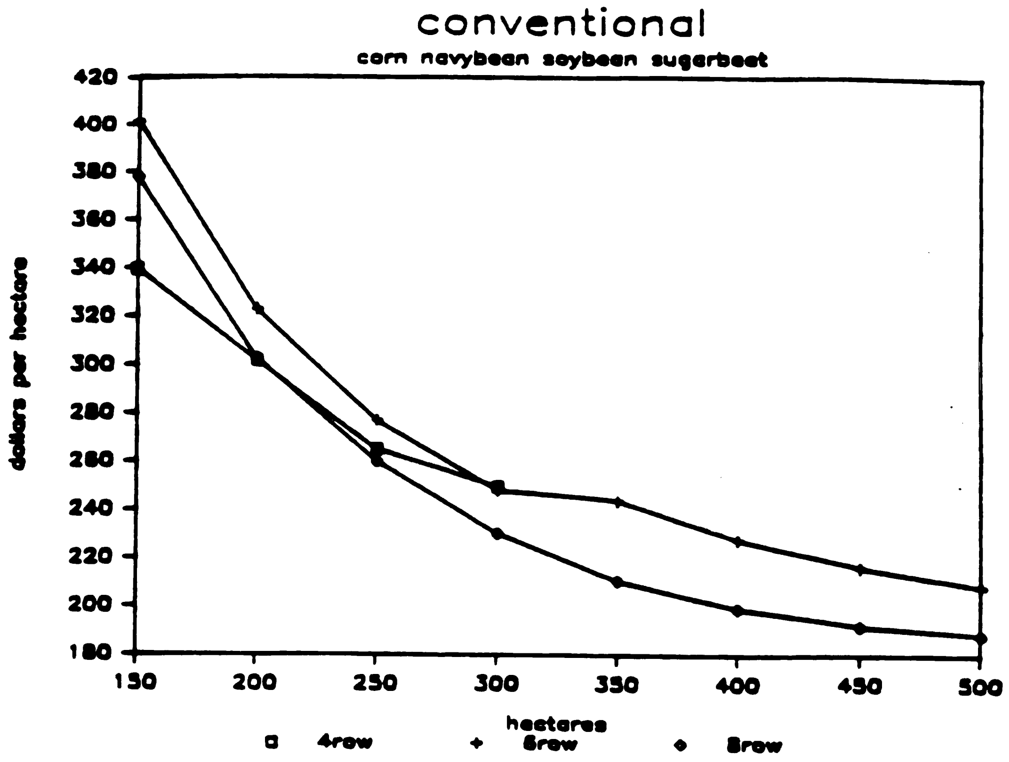

Figure 6.15. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Navy bean-Soybean-Sugar beet.

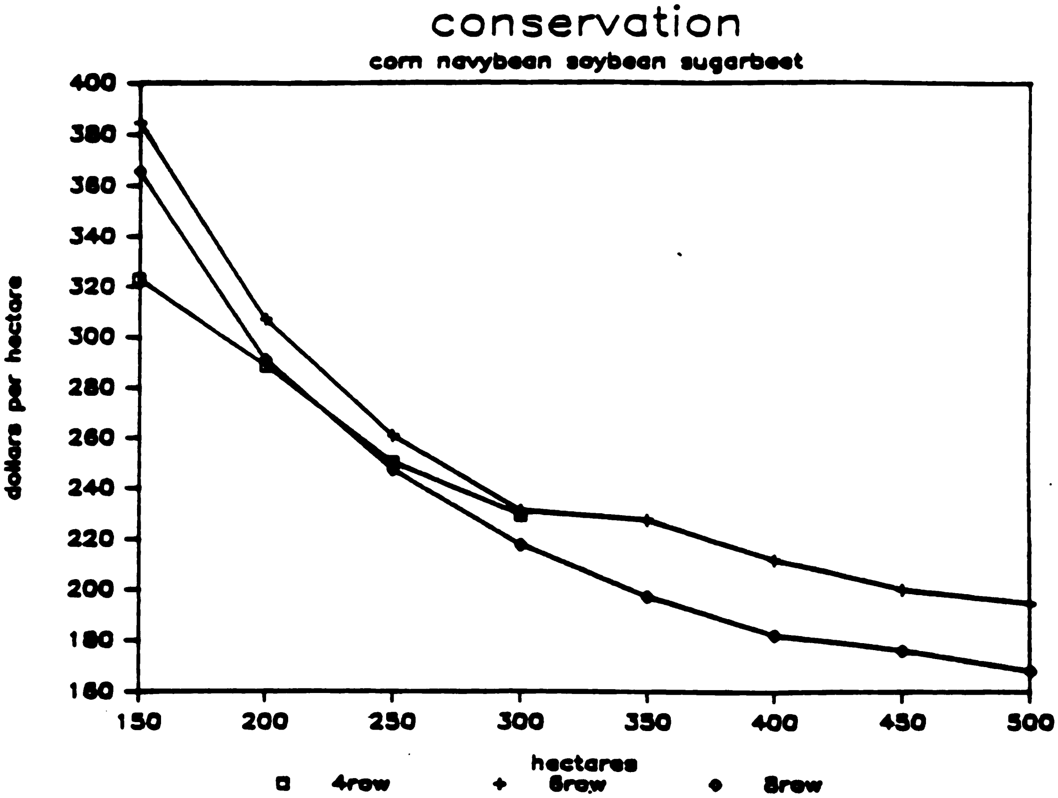

Figure 6.16. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravation Corn-Navy bean-Soybean-Sugar beet.

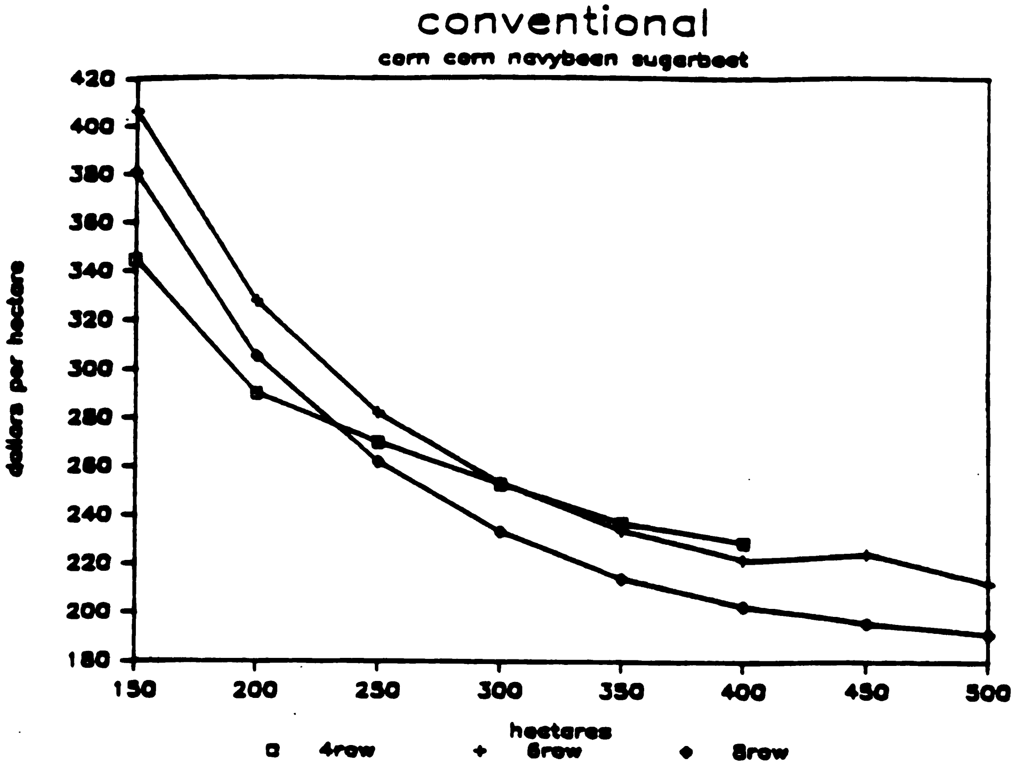

Figure 6.17. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Corn-Navy bean-Sugar beet.

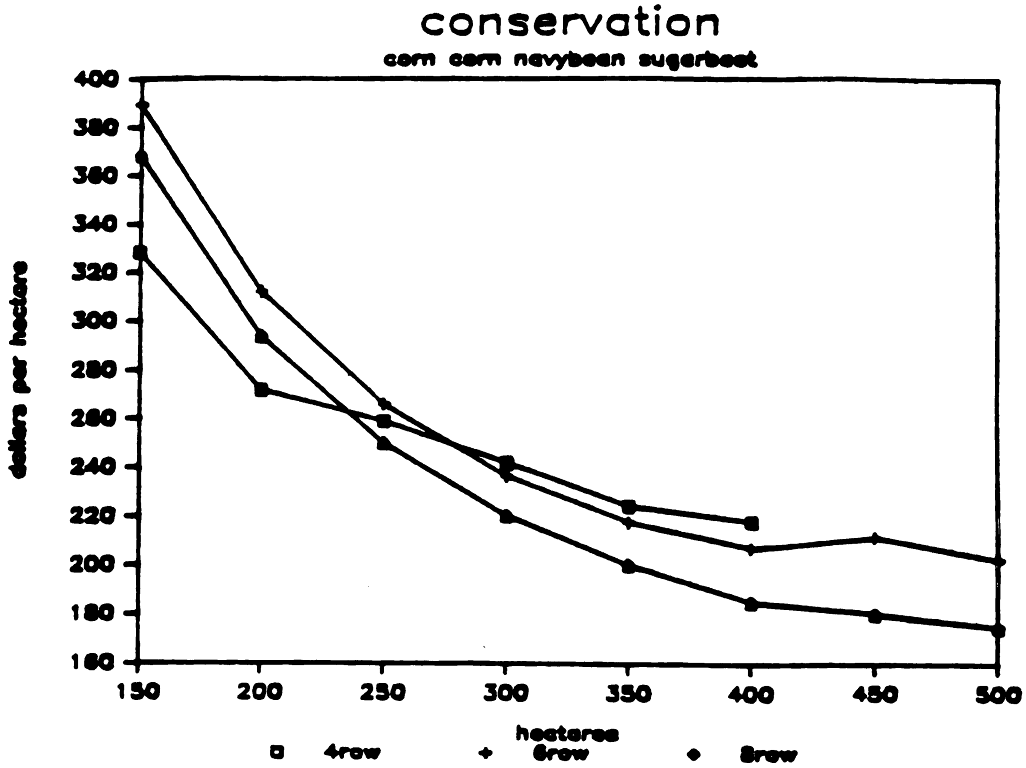

Figure 6.18. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravation Corn-Corn-Navy bean-Sugar beet.

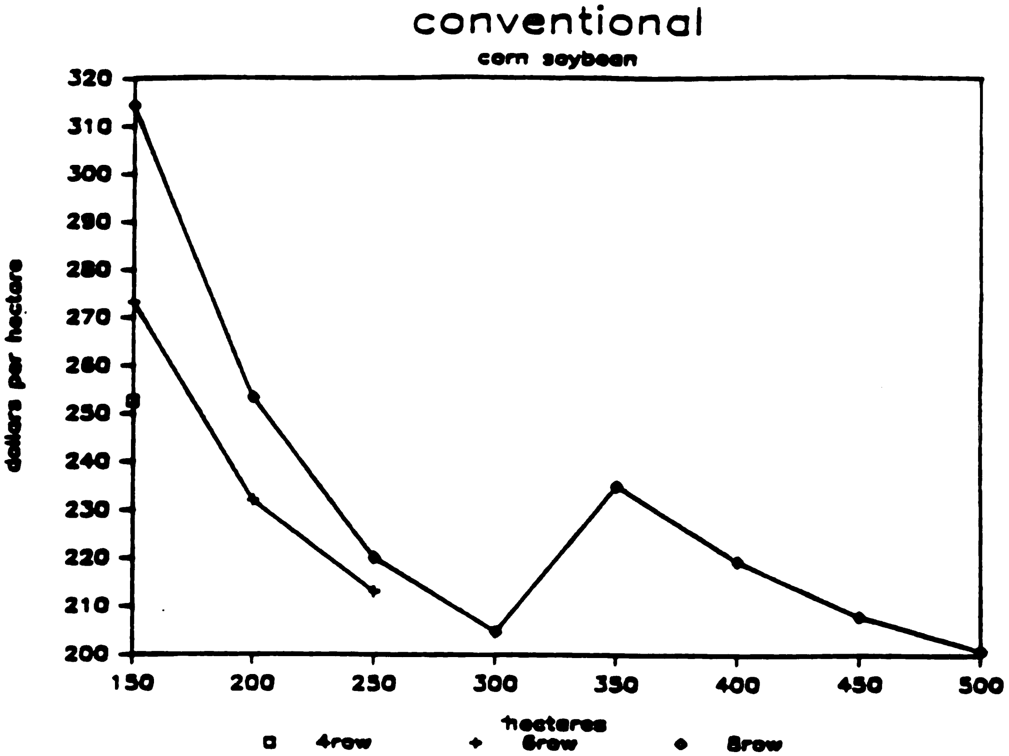

Figure 6.19. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conventional Corn-Soybean.

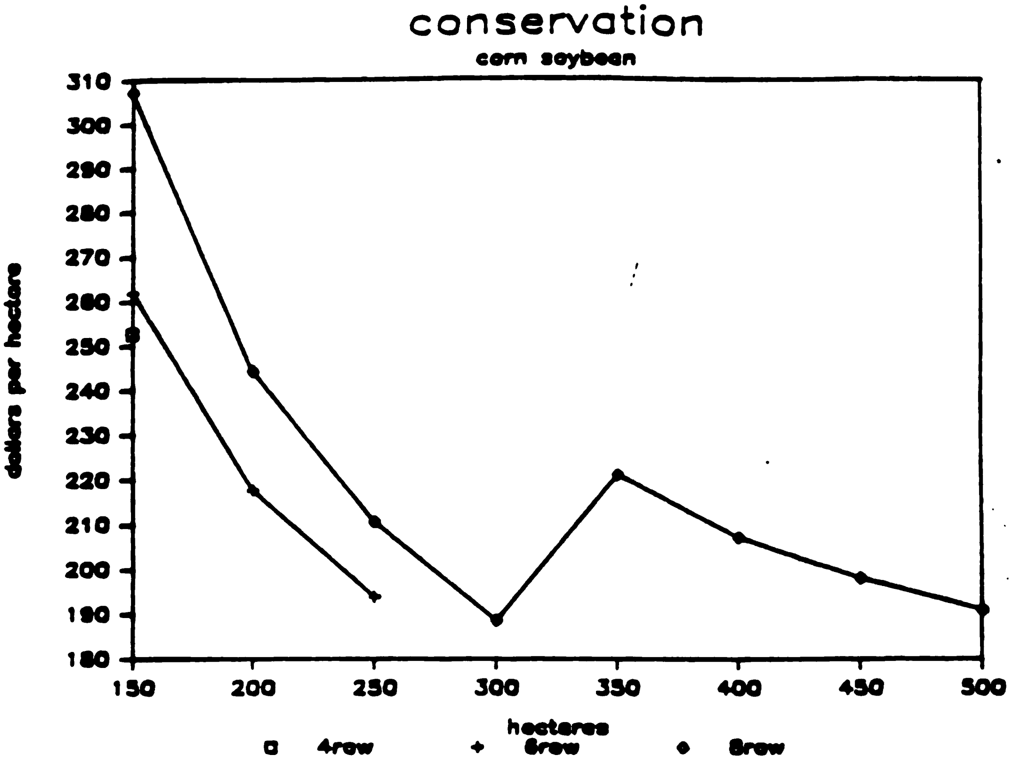

Figure 6.20. Annual Costs of Three Machinery sets for Various Farm Sizes Using Conseravation Corn-Soybean.

500 ha farms (Table 6.1). The continuous corn offers more benefit for conservation in almost all of the farms.

Diversification of crop mix, providing planting and harvest period overlap, significantly reduce machinery cost per hectare. For the 150 ha farm, using conventional minimum cost for the continuous corn rotation is \$280/ha vs. \$252.30/ha for the corn-corn-soybean rotation. For the 300 ha farm using conventional tillage, the respective costs are \$213.0/ha and \$198.0/ha. On a 500 ha farm, the respective costs are \$200/ha and \$174.50/ha.

Table 6.1

Economic Advantages of Conservation Tillage vs. Conventional Tillage for Selected Rotations (\$/ha)

Farm (ha)	Continuous Corn	Corn Corn Navy bean	Corn Soybean	Corn Navy bean Wheat Sugar beet	Corn Corn Navy bean Sugar beet
150	21.1	3.4	0	15.4	16.5
200	21.2	13.1	14.3	17.2	18.4
250	25.0	15.8	19.2	13.5	11.8
300	24.0	21.9	16.2	10.9	12.9
350	23.6	11.7	13.9	10.8	13.7
400	23.3	16.8	12.0	11.1	17.5
450	17.2	16.1	10.0	11.7	15.1
500	30.0	13.2	10.0	11.6	16.6

Four row equipment is economically superior for both tillage systems under the continuous corn rotation up to 150 ha, while for corn, corn, soybean rotation, four row is superior up to 200 ha. Six row machine sets are superior between 200 and 300 ha for the corn, corn, soybean rotations. Note that over wide ranges in size that there is little difference in cost between six and eight row equipment. Eight row machinery sets are used at the limit of their capacity in all corn rotation so that additional units of tillage equipment must be purchased for farms larger than 450 ha which causes a sharp increase in machinery cost.

Larger equipment is often used more efficiently on large farms. For example, assume that the total annual operating hours of an eight row combine with an effective field capacity of 1.3 ha/hr is 350 hours. If a 150 hectare farm is harvested by this machine, the total time required will be 115 hours. For 300 and 450 ha farms, the machine will spend 231 and 346 hours respectively to cover the land. Thus, by increasing farm size, the additional capacity of machine will be used on the farm which provides more efficient use of machines. A major part of the machinery cost is ownership cost which is fixed over the life of the machine. The total cost, therefore, drops when the reserve capacity of machines is spread over larger farms.

The total costs and machinery requirements drop considerably when shifting from corn, navy bean to corn, corn, navy bean and corn, corn, navy bean, wheat rotations. The proportion of acreage devoted to navy bean decreases as more crops are added which results in fewer machinery operations. The total machinery costs respectively, for the conventional corn, navy bean and corn, corn, navy bean rotations are $247/ha and $243/ha, on the 200 hectare farm; $212/ha and $193/ha on the 350 hectare farm; and $220/ha and $189/ha on the 500 hectare farm. As farm size is increased, the cost of conservation tillage drops more than the cost of conventional tillage.

As a result, large machinery size with higher costs are incorporated when fewer crops are grown on the farm. Introducing more crops to the rotation divides the suitable time constraint into different periods which results in smaller machines with lower costs.

The total costs and machinery requirements for rotations which contain navy bean and sugar beets are high due to many operations required for these crops and the competition for time between them. Eight row machines are lowest in cost for most farm sizes in those rotations. Four row machine sets cost less for farms less than 200 or

250 ha. The total machinery cost for corn, navy bean, sugar beet when using conventional tillage for farms of 200 and 500 ha are $306/ha and $203/ha, respectively.

In farms where there is no competition between crops, small differences in annual cost over the large farm sizes is observed. In both conventional and conservation continuous corn, the cost differences are high at 150 hectare farms and gradually decrease over the larger farms (Fig. 6.1 and 6.2).

Conservation tillage has a significant cost advantage over conventional tillage due to lower ownership and operating costs (Table 6.1). The ownership cost is fixed over the life of a machine while the operating cost changes relative to the annual hours of operation. Several tillage operations like moldboard plowing and row cultivating are removed from the conventional system while some new operations like chisel plowing and spraying are added to the conservation system. The total annual hours required for moldboard plowing and field cultivating are greater than the total annual hours required for chisel plowing and spraying. The operating cost of a machine is a combination of repair and maintenance, fuel and lubrication, and labor costs. Since the total number of annual operating hours for conservation tillage is less than for conventional tillage, the annual operating costs will be reduced. In addition, due to lower draft requirements for conservation tillage implements, smaller tractors are selected which greatly reduces the annual ownership costs.

The minimum cost of each machinery size is inversely proportional to the acreage. Machinery cost starts decreasing in proportion to the acreage. Machinery cost starts decreasing up to the minimum because of the fact that ownership cost is divided on more acreage. Increasing the total cost beyond the minimum point is due to purchasing more new machinery units to the system or due to keeping the same machinery set with greater annual operating costs. The operation of small machinery sets are limited beyond a certain acreage because of the time constraint. In conventional continuous corn, four row machines can be operating up to 300 hectares while six row machines can be operated up to 450 hectares due to limitations on machinery capacity. Four and six row machines will not reach minimum points for annual costs due to the time constraint of operation.

CHAPTER 7

CORN STOVERS

7.1 Introduction

The success of conservation tillage depends primarily on leaving a proper amount of crop residues on the soil surface. A surplus amount of corn residues will cause physical and biological problems such as lower soil temperature, reduction of soil evaporation, undesirable equipment performance, poor seed soil contact and undesirable depth control. The excess amount of residue can be removed from the field without increasing the soil erosion.

The Corn Belt has a large supply of corn plant material remaining after grain harvest. Harvesting of corn stover and using it for farm animals is a possibility. Although it has a lower feed quality than grass legume hay, some farm animals such as beef and dairy cows can utilize it effectively with proper feed supplementation. Apart from the corn grain and stovers, another possible byproduct of the corn harvest is the cobs.

Increasing feed cost exposed the relative importance of alternative sources of nutrients and roughage in animal production. Corn byproducts such as stovers are readily available and they are cheap sources of food to the farm. Corn plant could be harvested by a number of alternative systems, and this study will attempt to find the optimum harvesting systems. Among the different possible systems, the following were evaluated: systems for chopped stovers, stover in square bales, stovers in round bales and stack stovers.

A linear programming model is developed to optimize the return above annual cost of harvesting systems and cost of supplemental rations. A dairy operation with 400 hectares of corn as source of feed was assumed. The corn field products would be corn, grain, stalkage and cobs. Silage is a possible alternative product from the corn field and could be used as animal feed.

7.2 Model

The Lp model developed has the detached form as given in Table 7.1.

7.2.1 Constraints

1. Land: The total field area for growing corn is 400 hectares.
2. Operating hours: The farm operation of harvesting grain and the stovers are limited by the number of hours for machine operations available for the months of September to November. Harvesting of grain will be given priority and remaining operating hours would be allocated to the stalkage harvesting operation. The available suitable hours are based on an 80% probability level as in Table 7.2. The time

Table 7.1
Variables and Operations Indicated in the Model.

Variable	Operation*
X1	Grain
X2	Stover (Round Bales)
X3	Stover (Round Bales)
X4	Stover (Round Bales)
X5	Stover (Round Bales)
X6	Stover (Round Bales)
X7	Stover (Round Bales)
X8	Stover (Rectangular Bales)
X9	Stover (Rectangular Bales)
X10	Stover (Rectangular Bales)
X11	Stover (Rectangular Bales)
X12	Stover (Rectangular Bales)
X13	Stover (Rectangular Bales)
X14	Stover (Stacks)
X15	Stover (Stacks)
X16	Stover (Stacks)
X17	Stover (Stacks)
X18	Stover (Stacks)
X19	Stover (Stacks)
X20	Stover (Chopping)
X21	Stover (Chopping)
X22	Corn Silage (Chopping)
X23	Corn Silage (Chopping)
X24	Cob Saver
X25	Selling Grain
X26	Return (Round Bales)
X27	Return (Round Bales)
X28	Return (Round Bales)
X29	Return (Round Bales)
X30	Return (Round Bales)
X31	Return (Round Bales)
X32	Return (Rectangular Bales)
X33	Return (Rectangular Bales)
X34	Return (Rectangular Bales)
X35	Return (Rectangular Bales)
X36	Return (Rectangular Bales)
X37	Return (Rectangular Bales)
X38	Return (Stacks)
X39	Return (Stacks)
X40	Return (Stacks)
X41	Return (Stacks)
X42	Return (Stacks)
X43	Return (Stacks)
X44	Return (Chopping Stover)
X45	Return (Chopping Stover)
X46	Return (Corn Silage)
X47	Return (Corn Silage)
X48	Price (Corn Cob)
X49	Buy (N)
X50	Buy (P205)
X51	Buy (K20)

* Operations 1 to 24 are determined in dollars per hectare. Operations 25 to 48 are in dollars per ton, and operations 49 to 51 are in dollars per Kg.

constraint of 371 hours is based on 80% probability level of suitable hours for harvesting corn and stover. Corn silage and corn stover do not compete for the same time constraint.

3. Fertilizer level: The productivity of the field responds to N, P205, and K20. Thus, fertilizer will be a contributory factor if the corn is harvested as grain and stover or as corn silage. The requirement for levels of N, P205, and K20 for corn grain, stover, and corn silage is indicated in Table 7.3
4. Storage: If chopped stovers or corn silage are produced, storage space is required. Available storage space is assumed to be 2445 m^3. Table 7.4 shows the specifications of two different storages of bunker silos and upright silos. Bunker silo is used as a practical storage for both stover and corn silage.
5. Yield: The yields for the different products are given in Tables 7.5-7.7.

Table 7.2
Suitable Days Estimated for Harvesting Corn and Stover in Michigan (Bad Axe) at 0.5 and 0.8 Probability Levels.

Period	Probability Level 0.5	0.8
Sept. 16-31	12.6	12.3
Oct. 1-15	11.4	10.2
Oct. 16-31	12.0	10.6
Nov. 1-15	12.6	11.7
Nov. 16-30	11.7	11.4
Total Days after Oct. 10	40.1	37.1
Total Hours after Oct. 10	401.0	371.0

Source: Rosenberg(1980).

Table 7.3
Fertilizer Recommendations for Corn Grain, Stover, and Corn Silage (Kg).

Grain	151	71	45
Stover	112	41	163
Silage	263	101	219

Source: Extension Bulletin E-550 and Extension Bulletin E-802, Michigan State University.
* The estimated prices of N, P205, and K20 are 0.18,.21, and .26($/Kg) respectively.

Table 7.4
Storage sizes Used for Stalkage

	Quantity (tons)			Corn Silage	Stover
Year	Dry	Wet	Size of Silo*	m3/ha	
		Stalkage (Banker Silo)			
1973	89	255	100*23*7.5	102.3	9.1
1974	86	245	100*23*7.5	105.3	9.4
1975	94	305	100*23*7.5	84.2	7.5
		Stalklage (Upright Silo)			
1973	31	103	14*60	135.4	12.0
1974	21	70	14*60	198.6	17.6
1975	32	83	14*60	169.3	15.0

* Silo dimensions are in feet.
Adapted from: Smith with mdifications, 1976.

Table 7.5
Stover Yield and Losses(14-33% M.C.)

Stover	Kg/Ha
Original Yield	8787.3
Remaining Material	2303.3
Losses(combining and wind rowing)	1748.5
Collected Material	4735.5

Source: Richey,1980.

Table 7.6
Corn Silage and Grain Yield(30-40% D.M. for Green Weight)

Factor	Average for All Hybrids	Low Producers	High Producers
Green Weight(t/ha)*	53.12	29.40	76.35
Dry Weight(t/ha)*	17.30	12.36	21.00
Grain Yield(t/ha)**	7.23	5.98	8.30

Source:* Extension Bulletin E-1139,Michigan State University;
** Edwards,1980.

Table 7.7
Corn Cob Yield and Production Costs.

Kg/Ha*	% Moisture of Cobs*	Harvest and Transportation($/Ha)	Return above Cost($/ton)
465	14	14.88	65.12
758	15	20.16	59.84
675	14	19.50	60.50

Source:* Bargiel,1979.

7.2.2 Objective Function

The model is designed to maximize return above machines, supplement rations and fertilizer costs. In formulating the model, it is assumed that all other farm operations will remain constant with exception of annualized machine costs, cost of supplement rations and fertilizer costs. Annualized machine costs will differ according to the different systems of harvesting used.

Many different market size machines are introduced to be used by the model (Table 7.8). These machinery complements are grouped into different harvesting systems based on harvesting time, transportation time, and the average annual costs. The field capacity, material capacity, and the power requirement for each unit are also considered (Table 7.9). To provide alternative machinery systems, various machines are matched together based on their capacities and power requirements. Field and material capacities, total power requirement, yield, time study results, total annual suitable hours, farm size, and machinery costs are the major criteria used in matching the machine sizes included in a system.

Richey, et. al. (1976) used time study methods for both round bales and large stacks. A baler was operated at 5.6 kph while collecting a windrow from 6-0.75m rows. The average time was used for a yield of HR (Harvestable

Table 7.8
Machinery Comlements which Can Be Used for A 400 Corn Stover Farm.

Implement	Size (Number)
Windrower, Flail Pick-up, m	5.49 (1), 4.57 (1)
Big Roll Bailer, m	4.57 (1), 3.66 (1)
Self Loading Bale Trailer, tons	2.25 (1), 4.5 (1)
Tractors, Kw	40 (4), 40 (3)
....	
Windrower, Flail Pick-up, m	5.49 (1)
Rec. Balers, m	6.2 (3), 5.3 (3)
Self-Propelled, Bale Wagons, tons	5 (1)
Tractors, Kw	40 (4)
....	
Windrower, Flail Pick-up, m	4.57 (1), 3.66 (1), 2.74 (1)
Stackers & Wagons, tons	4 (1), 2 (2)
Tractors, Kw	40 (2), 40 (3)
....	
Choppers, Rows	2 (3), 3 (2), 4 (2)
Wagons, tons*	4 (3), 4 (2), 4 (1),
Wagons, tons**	4 (1)
Tractors, Kw	40 (7), 40 (5), 40 (1)

Table 7.9
Machine Capacities and Power Requirement

Implement (size)	List Price ($)	Speed (Km/Hr)	Field Eff. (%)	EFC (Ha/Hr)	EMC (T/Hr)	Annual* Hours	TFC (Ha/Hr)	PTO Power. (Kw)	DB Power (kw)
Windrower, Flail Pick-up,m.:									
5.49	8064	6.6	80	2.9	13.7	137.9	3.6	18.7	2.7
4.57	6720	6.6	80	2.4	11.4	166.7	3.0	15.3	2.3
3.66	5376	6.6	80	1.9	9.0	210.5	2.4	12.4	2.0
2.74	4032	6.6	80	1.4	6.6	285.7	1.8	9.3	1.8
Big Roll Baler,m.:									
4.57	11215	5.6	85	2.2	10.4	181.8	2.6	19.2	5.6
3.66	7477	5.6	85	1.7	8.0	235.3	2.0	15.4	4.5
2.74	5982	5.6	85	1.3	6.2	307.7	1.5	11.5	3.4
Self Loading Bale Trailer, tons:									
2.25	5280	5.6	-	-	-	-	-	-	-
4.50	7392	5.6	-	-	-	-	-	-	-
Rec. Baler, m.:									
1.69	8000	5.6	85	0.8	3.8	500.0	0.94	6.7	1.4
1.90	9500	5.6	85	0.9	4.3	444.4	1.10	8.0	1.6
Choppers:									
2-Row	2100	4.0	60	0.4	1.7	111.0	0.6	4.0	1.3
3-Row	2400	4.0	60	0.5	2.6	741.0	0.9	6.0	1.7
4-Row,sp	102000	4.0	60	0.7	3.4	556.0	1.2	-	-
6-Row,sp	126000	4.0	60	1.0	5.1	370.0	1.8	-	-
Stacker, tons:									
2	18000	5.6	85	1.3	6.2	307.7	1.5	9.9	6.1
4	25000	5.6	85	1.7	8.0	235.3	2.0	7.3	10.7
Wagons, tons:									
2	4200	5.6	-	-	-	-	-	-	6.0
2*	4200	4.0	-	-	-	-	-	-	4.4
4	6500	5.6	-	-	-	-	-	-	7.6
4*	6500	4.0	-	-	-	-	-	-	14.5

Source: White,1980; Richey,1980; New Holland and JohnDeere Publications; Farm Trader,1984.

Residue) tons per acre and bales weighing 900 lb. (0.45T) dry as follows:

Travel time $= \frac{0.45(43560)}{HR(15)(3.5)(88)} = \frac{4.24}{HR}$ min. per bale

Turning at field ends, 1 est. at 0.4 min = 0.4 min per bale

Tie, 12 bale revolutions = 1.0 min. per bale

Eject = 0.42 min. per bale

TOTAL = 1.82 + $\frac{4.24}{HR}$ min. per bale

The time studies were used for stacker system to determine an average time for a yield of HR tons per acre and stacks weighing two tons dry as:

Field Travel $= \frac{43560(2)}{15(330)HR} = \frac{17.6}{HR}$ min. per stack

Compressions, 4 at 0.6 = 2.4 min. per stack

Turns, 1 turn per 3/8 mile at 7 min. = 2.1 min. per stack

Travel to roadside 1/2 mile at 7mph = 4.5 est. min. per stack

Eject Stack = 1.75 min. per stack

Return to field, 1/2 mile at 10mph = 3.00 est. min. per stack

TOTAL = 13.55 + $\frac{17.6}{HR}$ minutes per stack

The results of the time studies for round bales are given in Table 7.10. These time measurements are directly proportional to the material weight, moisture content, and density. Table 7.11 and Table 7.12 present the physical characteristics of stover stacks and round bales used in the time studies.

Table 7.10
The Time Study of Transporting Round Bales to Storage

Operation	Minutes/Load
Load 5 bales at 1 minute	5.0
Haul .8 Km at 11.27 Km/Hr	4.3
Unload 5 bales at .6 minutes	5.3
Travel back to field .8 Km at 16.1 Km/Hr	3.0
Total	15.3

Modified from: Richey, 1980.

Table 7.11
Corn Stover Stacks for Different Harvesting Dates

Date	11-16-79	11-20-79
Number of Stacks	3	2
Moisture Content,%	30	30
Stack Weight,Kg	2260.3	2318.8
Stack Weight,Kg(Dry)	1582.1	1623.0
Stack Density,Kg/m3(Dry)	39.9	42.8
Yield in Stacks,Kg/Ha(Dry)	2150.9	2941.1
Gleanings,Kg/Ha(Dry)	2215.9	1673.4
Total,Kg/Ha(Dry)	4366.8	4614.5

Modified from: Richey,1980.

Table 7.12
The Transporting Time to Storage for Different Wagon Sizes

Wagon Size(tons)	Time(Minutes/Load)
2.25	15.3
4.50	23.8
7.00	32.3

Source: Richey, 1980.

The machinery cost model (Rotz et. al., 1981) is used to calculate the average annual cost of each machine using the cash flow method. The model was designed to provide annual cost, a total present value cost, and an average annual equivalent cost for each machine. Table 7.13 shows the ownership and operating costs and the average annual cost for each unit. The system cost is a summation of individual machines indicated in a system. For example, system number 10 is a combination of one windrower and flail pickup, four 40 kw utility tractors, three rectangular balers, and one self-propelled bale wagon. The total annual cost for this system includes about 25,376 dollars. This method is, therefore, used to calculate the annual costs for other alternative systems.

Cost of supplement rations changes with the source of forage or fibers. Yield of milk also varies with the feedstuff used. Return of milk from feeding one ton of harvested materials with the supplement rations is considered as return to the feedstuff. An experiment was conducted by Hargreaves et. al. (1982) on production performances of dairy cows when corn stover was substituted as a source of roughage. The experiment was conducted on dairy cows and ration was based on 25% corn silage or chopped corn stovers and supplemented by 25% alfalfa hay and 50% feed concentrate supplements. The percentages are in terms of dry matter. The results are given in Tables

Table 7.13
Harvesting Systems and Projected Costs.

	Size	Number	Hours*	------Projected System Costs**--------						
				A	B	C	D	E	F	G+
Big Roll Balers,m	4.56	1	182	10070	9678	-	-	13366	1488	1
Tractors, Kw	40	1	182	24995	772	8793	12690	32343	3601	
Big Roll Balers,m	3.65	1	235	6713	9623	-	-	11289	1257	2
Tractors, Kw	40	1	235	24995	1288	11345	16385	37442	4166	
Big Roll Balers,m	2.74	1	308	5371	12964	-	-	12981	1445	3
Tractors, Kw	40	1	308	24995	2212	14881	21475	44578	4963	
Windrowers, Flail Pick-Up,m	5.47	1	138	7240	2829	-	-	6514	725	4
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Self-Loading Bale Trailers, tons	2.25	2	108	1088	205	-	-	-	1293	
Tractors, Kw	40	2	108	4990	544	10436	15060	50834	5660	
Windrowers, Flail Pick-Up,m	5.47	1	138	7240	2829	-	-	6514	725	5
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Self-Loading Bale Trailers, tons	4.5	1	167	761	222	-	-	-	983	
Tractors, Kw	40	1	167	24995	650	8069	11644	30924	3443	
Windrowers, Flail Pick-Up,m	4.56	1	167	6034	3162	-	-	6031	671	6
Tractors, Kw	40	1	167	24995	650	8069	11644	30924	3443	
Self-Loading Bale Trailers, tons	2.25	1	215	544	204	-	-	-	748	
Tractors, Kw	40	1	215	24995	1078	10388	14991	35494	3951	
Windrowers, Flail Pick-Up,m	4.56	1	167	6034	3162	-	-	6031	671	7
Tractors, Kw	40	1	167	24995	650	8069	11644	30924	3443	
Self Loading Bale Trailers, tons	4.5	1	167	761	222	-	-	-	983	
Tractors, Kw	40	1	167	24995	650	8069	11644	30924	3443	
Windrowers,	3.65	1	211	4827	3608	-	-	5634	627	8

Table 7.13
Harvesting Systems and Projected Costs.

	Size	Number	Hours*	-------Projected System Costs**-------						
				A	B	C	D	E	F	G+
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Self Loading Bale Trailers, tons	2.25	1	215	544	204	-	-	-	748	
Tractors, Kw	40	1	215	24995	1078	10388	14991	35494	3951	
....										
Windrowers, Flail Pick-up, m	3.65	1	211	4827	3608	-	-	5634	627	9
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Self Loading Bale Trailers, tons	4.5	1	167	761	222	-	-	-	983	
Tractors,	40	1	167	24995	650	8069	11644	30924	3443	
....										
Windrowers, Flail Pick-up, m	5.47	1	138	7240	2829	-	-	6514	725	10
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Rec. Balers, m	1.89	3	148	25590	16449	-	-	54612	6081	
....										
Windrowers, Flail Pick-up, m	5.47	1	138	7240	2829	-	-	6514	725	11
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Rec. Balers, m	1.61	3	167	21549	18873	-	-	27228	3030	
Tractors, Kw	40	3	167	74985	1950	24207	34932	92772	10329	
SP Bale Wagons, tons	5	1	150	71688	17674	-	17844	73227	8152	
....										
Windrowers, Flail Pick-Up, m	4.56	1	114	6034	3162	-	-	6031	671	12
Tractors, Kw	40	1	114	24995	303	5508	7949	25971	2891	
....										
Windrowers, Flail Pick Up, m	4.56	1	114	6034	3162	-	-	6031	671	13
Tractors, Kw	40	1	114	24995	303	5508	7949	25971	2891	
Stackers, tons	2	2	179	16162	11202	-	-	18204	2027	
Tractors, Kw	40	2	179	49990	1494	17296	24962	64118	7138	
....										
Choppers, Rows	2	3	370	5658	10197	-	-	1079	1233	14

Table 7.13
Harvesting Systems and Projected Costs.

	Size	Number	Hours*	------Projected	System	Costs**	-------			
				A	B	C	D	E	F	G+
Wagons, tons	4	3	370	3367	1299	-	-	-	4665	
Tractors,	40	3	370	74985	9387	53631	77394	152406	16968	
Wagons, tons	4	3	107	1122*	108*	-	-	-	1230	
Tractors, Kw	40	1	107	24995	267	5170	7460	25324	2819	
....										
Choppers, Rows	3	2	371	4310	7804	-	-	8468	942	15
Wagons, tons	4	2	371	2245	748	-	-	-	2993	
Tractors, Kw	40	2	371	49990	6418	35850	51736	101806	11334	
Wagons, tons	4	1	107	1122	108	-	-	-	1230	
Tractors, Kw	40	1	107	24995	267	5170	7460	25324	2819	
....										
Corn Silage:										
Choppers, Rows	2	3	370	5658	10197	-	-	11079	1233	16
Wagons, tons	8	3	370	3367	1299	-	-	-	4665	
Tractors, Kw	104	3	370	168366	21501	139437	77394	284175	31635	
Wagons, tons	8	12	313	13464	4394	-	-	-	17858	
Tractors, Kw	40	12	313	299940	27408	181476	261888	540900	60216	
....										
Corn Silage:										
Choppers, Rows	3	2	371	4310	7804	-	-	8468	942	17
Wagons, tons	8	2	371	2245	748	-	-	-	2993	
Tractors, Kw	145	2	371	184872	23738	129956	51736	269830	30040	
Wagons, tons	8	10	375	11220	4340	-	-	-	15560	
Tractors, Kw	40	10	375	249950	32790	181180	261460	513090	57120	
....										
Windrowers, Flail Pick-up, m	4.56	1	167	6034	3162	-	-	6031	671	18
Tractor, Kw	40	1	167	24995	650	8069	11644	30924	3443	
Rec. Balers, m	1.89	3	148	25590	16449	-	-	54612	6091	
Tractors, Kw	40	3	148	74985	1533	21453	30957	87411	9732	
SP Bale Wagons, tons	5	1	150	71688	17674	-	17844	73227	8152	

Table 7.13
Harvesting Systems and Projected Costs.

	Size	Number	Hours*	A	B	C	D	E	F	G+
				------Projected System Costs**--------						
Windrowers, Flail Pick-Up,m.	4.56	1	167	6034	3162	- .	-	6031	671	19
Tractors, Kw	40	1	167	24995	650	8069	116444	30924	3443	
Rec. Balers, m	1.6	3	167	21549	18873	-	-	27228	3030	
Tractors, Kw	40	3	167	74985	1950	24207	34932	92772	10329	
SP Bale Wagons, tons	5	1	150	71688	17674	-	-	73227	8152	
....										
Windrowers, Flail Pick-Up,m	3.65	1	211	4827	3608	-	-	5634	627	20
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Rec. Balers, m	1.86	3	148	25590	16449	-	-	54612	6081	
Tractors, Kw	40	3	148	74985	1533	21453	30957	87411	9732	
SP Bale Wagons, tons	5	1	150	71688	17674	-	17844	73227	8152	
....										
Windrowers, Flail Pick-Up,m	3.65		211	4827	3608	-	-	5634	627	21
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Rec. Balers, m	1.61	1	167	21549	18873	-	-	27228	3030	
Tractors, Kw	40	3	167	24985	1950	24207	34932	92772	10329	
SP Bale Wagons, tons	5	3	150	71688	17674	-	17844	73227	8152	
....										
Windrowers, Flail Pick-Up,m	5.47	1	138	7240	2829	-	-	6514	725	22
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Stackers, Kw	4	1	179	22447	32175	-	-	37745	4202	
Tractors, Kw	40	1	179	24995	747	8648	12481	32059	3569	
....										
Windrowers, Flail Pick-Up,m.	5.47	1	138	7240	2829	-	-	6514	725	23
Tractors, Kw	40	1	138	24995	444	6668	9622	28202	3140	
Stackers, tons	2	2	179	16162	11202	-	-	18204	2027	
Tractors, Kw	40	2	179	4990	1494	17296	24962	64118	7138	

Table 7.13
Harvesting Systems and Projected Costs.

	Size	Number	Hours*	------Projected System Costs**-------						
				A	B	C	D	E	F	G+
Windrowers, Flail Pick-UP,m.	12	1	211	4827	3608	-	-	5634	627	24
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Stackers, tons	4	1	179	22447	32175	-	-	37745	4202	
Tractors, Kw	40	1	179	24995	747	-	8648	12481	32059	
....										
Windrowers, Flail Pick-Up,m	3.65	1	211	4827	3608	-	-	5634	627	25
Tractors, Kw	40	1	211	24995	1038	10195	14712	35110	3909	
Stackers, tons	2	2	179	16162	11202	-	-	18204	2027	
Tractors, Kw	40	2	179	4990	1494	17296	24962	64118	7138	

* Annual Hours Per Machine

** A=Ownership Costs, B=Repair Costs, C=Fuel Costs, D=Labor Costs, E=Total Present Values, F=Average Annual Costs.

\+ Numbers indicate harvesting systems.

Trailer and Wagon Costs Were Estimated by the Fixed Cost Method.

7.14 and 7.15. The equivalent milk production of the feedstuff in rations for corn silage and chopped stovers are calculated based upon the data available in Table 7.14. The cost of feed supplement also includes the cost of corn stover transport to storage and the costs for storing and feeding. This data is indicated in Tables 7.16 and 7.17. Thus, the values per unit of different products for corn silage, chopped stover, stacked stover, rectangular bales, and round bales are assumed to be the return above feed supplement cost. In addition, the values per ton of corn grain and corn cobs are 92 and 80 dollars per ton, respectively. The values for stovers are based on milk equivalent values as return from feeding the cow. The value for corn cobs is based on the value of saving if it is used as fertilizer. Table 7.18 presents the annual system cost for harvesting, transporting, storing, and feeding of the product.

7.2.3 Variable Coefficients

The variable coefficients are listed as the average operating hours per hectare per each system, which refers to the effective field capacity of the largest or the most expensive machine in each system under study (Table 7.19). The yield of different products (t/ha) for corn grain, corn silage, and stover are the other major coefficients. The different rates of fertilizer (kg/ha) and the amount of space required (m^3/ha) to store the available corn stover

Table 7.14
The Daily Corn Silage and Chopped Stover Intake for Milk Production.

Roughage Source	Corn Silage	Chopped Stover
DMI (Kg/Day)	20.0	16.9
Milk Production (Kg/Day)	26.6	24.2

Source: Hargareaves, 1982.

Table 7.15
Milk Production and Return for Corn Silage and Stovers*

	Corn Silage	Chopped Stover	Stacked Bales	Rectangular Bales	Round Bales
Milk Production (Kg)**	399.0	572.8	1094.0	1094.0	1094.0
Value of Milk at 0.55($/Kg)	219.5	315.0	601.7	601.7	601.7
Cost of Feed Supplement($)	6.5	10.7	6.8	7.0	7.0
Return above Feed Supplement Cost($)	213.0	308.0	594.9	594.7	594.7

* The M.C. of green corn silage and chopped stover is 60-70% and of stacked or baled stover is about 14-33%.
** Equivqlent milk production for one ton feed stuff in ration.

Table 7.16
Corn Stover Transport to Storage

Operation	Labor in Man-Hours/ Acre	Disel Fuel in Gallons/ Acre	Equipment Cost in $/ton	Total Cost*
Transport Bales to Plant	HR(0.127+7D) *	HR(0.194+0.56D)	1.46+0.108D	2.29+.2D
Transposrt stacks to Plant	HR(0.104+0.106D)	HR(0.1D)	0.43+.265D	0.95+0.445D

Source: Richey, 1980.

* HR is harvestable residue in dry tons per acre and D is one-way haul distance to storage in miles.

Table 7.17
The Estimated Total Storing and Feeding Cost Per ton of Corn Forage($)*.

Storing and Feeding Systems.	Tons Harvested Per Year 100	200	300	500	700	1100	1500
Corn Silage, Upright Silo		29.98	18.74	12.63	10.03	7.62	6.48
Corn Silage, Bunker Silo	31.00	18.70	13.40	9.07	7.22	5.47	4.68
Cornstalk Silage, Bunker Silo	35.12	21.91	15.01	11.63	9.64	7.81	7.01
Add Cost to Move Large Packages for Feeding:							
Round Bale	3.64	3.46	3.39	3.35	3.33	3.31	3.30
1-ton Stack	3.94	3.28	3.06				
3-ton Stack							

Source: Ayres, 1976.
* One ton of corn forage equals one ton of corn silage at 65% moisture, or baled or stacked cornstalks at 35% moisture.

Table 7.18
Annual System Costs

Systems	Harvesting			Transport to Storage ($/ton)	Storing & Feeding ($/ton)*	Total ($/ton)
	($/Yr.)	($/ha)	($/ton)			
Round Bales:						
1,4	15907	39.8	8.4	3.7	3.3	15.4
2,5	13714	34.3	7.3	3.7	3.3	14.3
3,6	15221	38.0	8.0	3.7	3.3	15.0
1,7	13629	34.0	7.2	3.7	3.3	14.2
2,8	14658	36.6	7.7	3.7	3.3	14.7
3,9	14904	37.3	8.0	3.7	3.3	15.0
Rec. Bales:						
10	27830	69.6	14.7	3.7	3.3	21.7
11	25376	63.4	13.4	3.7	3.3	20.4
18	28079	70.2	14.8	3.7	3.3	21.8
19	25625	64.0	13.5	3.7	3.3	20.5
20	28501	71.3	15.0	3.7	3.3	22.0
21	26047	65.1	13.7	3.7	3.3	20.7
Stackers:						
12	11333	28.3	6.0	4.1	2.7	12.8
13	12727	31.8	6.7	4.1	2.7	13.5
22	11636	29.0	6.1	4.1	2.7	12.9
23	13030	32.6	6.9	4.1	2.7	13.7
24	12307	30.8	6.5	4.1	2.7	13.3
25	13701	34.3	7.2	4.1	2.7	14.0
Choppers (Stover):						
14	26915	67.3	14.2	3.7	7.0	24.9
15	19318	48.3	10.2	3.7	7.0	20.9
Choppers (Corn Silage):						
16	115607	289.0	5.4	-	6.5	11.9
17	106655	266.0	5.0	-	6.5	11.5

Modified from: Ayres, 1976.

* The Storage cost is only considered for chopped stover and corn silage.

Table 7.19
The Effective Field Capacity of the Largest Machine in the system.

System	Hr/Ha
Round Bales:	
1,4	0.5
2,5	0.9
3,6	0.8
1,7	0.5
2,8	0.9
3,9	0.8
Rectangular Bales:	
10	0.4
11	0.4
18	0.4
19	0.4
20	0.4
21	0.4
Stackers:	
12	0.6
13	0.8
22	0.6
23	0.8
24	0.6
25	0.8
Choppers:	
14	0.9
15	0.9
Choppers:	
16	0.9
17	0.9

and corn silage are the other important parameters in equations.

7.3 Solution to the Model

The model results for a 400 and 300 hectare farm are presented in Tables 7.20 and 7.21. The gross return above harvesting ration and fertilizer for a 400 hectare farm is about 1,603,825.09 dollars. In order to maximize the return over specified cost, the model selected 376.71 hectares for grain production and 23.29 hectares for silage production. The best system chosen to harvest the stovers after grain harvesting is the stacking system. The amount of corn grain estimated to be produced and sold is 2,712.34 tons and the tonnage cobs would be 177.06 tons. The stovers harvested by the stacking system are 1770.56 tons. The amount of N,P_{205}, and K_{20} fertilizers required are 105,200; 44,543.86 and 83,456.14 Kg respectively.

The gross return above harvesting ration and fertilizer for a 300 hectare farm is about 1,247,128 dollars.

7.4 Sensitivity Analysis

The important parameters included in the model are the harvesting costs and the return costs specified by the objective function coefficients. For example, by increasing the harvesting cost of the stacking system by 10 dollars per hectare, the alternative operation would be the

Table 7.20
Activities in Solution

Activity Number	Description	Level
X1	Grain Harvested by Combine	376.71 (Ha)
X14	Stover Harvested by Stacking	376.71 (Ha)
X23	Corn Silage	23.29 (Ha)
X24	Corn Cobs	376.71 (Ha)
X25	Grain Sold	2712.34 (tons)
X38	Stack Stovers	1770.56 (tons)
X46	Corn Silage	1236.47 (tons)
X48	Corn Cobs	177.06 (tons)
X49	N Fertilizer*	105200.00 (Kgs)
X50	P205 Fertilizer*	44543.00 (Kgs)
X51	K20 Fertilizer*	83456.14 (Kgs)

* These amounts of fertilizers should be purchased.

Table 7.21
Activities in Solution(300 Hectares)

Activity Number	Description	Level
X1	Grain Harvested by Combine	276.71 (Ha)
X14	Stover Harvested by Stacking	276.71 (Ha)
X23	Corn Silage	23.29 (Ha)
X24	Corn Cobs	276.71 (Ha)
X25	Grain Sold	1992.34 (tons)
X38	Stack Stovers	1300.56 (tons)
X46	Corn Silage	1236.47 (tons)
X48	Corn Cobs	130.06 (tons)
X49	N Fertilizer*	78900.00 (Kgs)
X50	P205 Fertilizer*	33343.86 (Kgs)
X51	K20 Fertilizer*	62656.14 (Kgs)

* These amounts of fertilizers should be purchased.

round baling system and the total return decreases from 1,603,825.09 to 1,601,323.70 dollars for 400 hectares farm compared to the farm when using the stacking method. On the other hand, if the harvesting cost of the round baling method were reduced by 30 dollars per hectare, the rectangular baling would enter as another alternative method to the solution and the total return would include about 1,601,549.70 dollars. Thus, by changing the cost or return for each harvesting system, other alternative operations would be selected as the optimum system.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

The major focus of this research was to do a comprehensive economic study on conventional and conservation tillage systems for corn production in Michigan. This study was conducted based upon the recommendations and suggestions for further research on conservation tillage systems commercially used by farmers.

To develop the research, several models were formulated based upon farm constraints and resources. A linear programming model was developed to generate the optimum size machines for specific tillage systems. Although simulation models were developed in the past to select proper machinery sets, due to certain limitations, they may not be applicable to farmers. Such limitations are indicated as complexity of model algorithms, cost of computations, and the desired optimum solutions.

A computer simulation model was also developed to examine the economics of switching and trading machines from conventional to a conservation tillage system. This model determines the switching and trading time based upon the data generated from the machinery selection models.

The interrelation of corn and other crops in a sequential crop rotation was evaluated through least cost machinery sets on the fine texture soils in the Saginaw Bay

Area of Michigan. Farm sizes from 150 to 500 ha at 50 ha increments were examined for 4, 6, and 8 row machinery sets.

The formulated linear programming model on machinery selection was used to study machinery systems for specific conventional and conservation corn tillage systems in Michigan. To obtain realistic results, appropriate sets of data on the farm basis for various parameters were collected and used. One of the sensitive parameters to the model is the implement power requirement on different soil textures. Implements are well matched to tractors based on their power requirements. Since tractors are the most expensive component in the system, a small change in power requirement data will result in a considerable change in the size of the machinery selected.

The solutions obtained from the formulated linear programming model are in real values rather than in mixed integers. The real solutions are then partially revised to generate the integer numbers for implements. LINDO, an interactive computing package, was used to solve the linear programming model.

The economic results of conventional and conservation tillage systems indicate that annual system costs will decrease across the tillage systems from conventional to no-tillage. For a 400 hectare corn farm with 80% weather probability the annual costs of conventional, chiseling, and no-till systems on coarse soil type are 123, 107, and 85 dollars per hectare respectively. For the medium soils the respective costs are 130, 116, and 100 dollars per hectare. For the fine soils, the respective costs are 153, 131, and 107 dollars per hectare.

The timeliness cost of operation is directly related to the machine capacity operated within a time constraint. The average timeliness cost for a 12 row planter on coarse soils for a chiseling system after May 4 is 39.9 dollars per hectare. The respective costs for medium and fine soils are 43.2 and 56.5 dollars per hectare respectively.

The 12 year useful life of machines (Table 5.2) in the Machinery Replacement Model was selected by dividing the wear-out life of an individual machine by the annual operating horus. The wear-out life of each machine was estimated by Kepner, et. al. (1978). The useful life of a group of machines was calculated from which the minimum was choosen as a parameter for the model.

Results of the machinery replacement model show that conventional systems are not profitable for farmers to continue because of higher machinery costs and reduction in soil productivity. The total annual erosion rate for conventional systems using continuous corn, corn, navy bean, wheat, sugar beet, and corn, navy bean, sugar beet are 12.43, 11.18, and 11.18 tons per hectare. The associated annual soil productivity reduction is 6.49

dollars per hectare. The soil productivity decreases from 662.40 to 192.37 dollars per hectare after 10 years of moldboard plowing. There is, however, no economic value associated with reduction in soil productivity of conservation systems due to very low amounts of soil erosion. A comparison of the annual equivalent costs of moldboard plowing and no-till systems indicate that moldboard plowing should be switched to no-till. The annual equivalent cost of moldboard plowing for each replacement time is greater than the annual cost of chisel plowing. The annual equivalent cost of moldboard plowing for the first replacement cycle is 526.52 dollars per hectare compared to 347.22 dollars per hectare for a modified no-till. The respective costs for a 10 year cycle are 439.65 and 284.21 dollars per hectare. The trading time is also 5 years for no-tillage after switching from a conventional system. Similar switching time resulted for corn, navy bean, sugar beet rotation when changing the system from conventional to chiseling. The trading time is four years with an annual cost of 545.53 dollars per hectare.

The sensitivity analysis results of the machinery replacement model indicate that the shorter time to keep the moldboard plow in farming, the longer trading time with lower system costs will result.

The linear programming model (Chapter Four) was developed to select specifically the optimum size machines for commercial tillage systems based on corn farm constraints. The model structure is also flexible so it can be used with other specific crops and multiple crop rotations. The transition from the linear programming model to the multiple crop machinery selection model (Chapter 6) was due to the availability of this model for multiple crop rotation studies.

Several factors will influence machinery size and costs when incorporating corn in rotation with other crops. These factors are indicated as time constraint, farm size, conventional and conservation tillage, and the type of crop and competition between crops.

Larger machinery size with higher annual costs results when certain operations are done within a relatively short time constraint. The economic results of several crop rotations indicate that four row machines can be used only in small farms while six and eight row machines are extended to larger farms.

Conservation tillage systems are operated with lower ownership and operating costs. The economic advantages of conservation tillage systems, for example, for corn, corn, navy bean on 200 and 500 hectares are 13.1 and 13.2 dollars per hectare respectively. The respective costs for corn, soybean are 14.3 and 10 dollars per hectare and for corn,

corn, navy bean, sugar beet they are 18.4 and 16.6 dollars per hectare.

A linear programming model was also formulated to harvest the surplus corn residues from the field. The stacking system was selected to be the most economical among the various harvesting systems used by the model. By increasing the cost of the stacking system, other alternative systems will be selected.

The estimated gross return of stover resulted by the model is relatively high which is due to the lack of a market price for corn stover. The economic value of corn stover was estimated when considering corn stover as a component of the feed stuff for milk production. Thus, proper results can be obtained if a commercial price for corn stover is determined.

8.2 Conclusions

1. Conservation tillage systems, especially no-tillage, have the most machinery and labor cost advantages and soil erosion reduction benefits to farmers.
2. Determining planting and harvesting timeliness costs on a daily basis can be an effective method for timeliness costs calculations within a time constraint.
3. The soil erosion due to conventional tillage systems will reduce the soil productivity. This can be represented, for example, by the machinery replacement

model indicating that the change in gross revenue resulted from the reduction in soil productivity is 6.49 dollars per hectare. The economic value of soil productivity reduction on farmer's short term decisions may not be a determinant factor, but the long term economic and environmental impacts are very important.

4. Increasing the farm size results in larger size machines with lower per unit area costs. On large farms, machines are used towards their limit in capacity and investment cost per unit area drops.
5. Machinery size and costs are influenced by the time constraint of operation. Crop rotations having competitive crops for annual operations calls for larger machinery size with higher machinery costs. In crop rotations without such a competition for annual operations, the difference in costs between machinery sizes over the large farms are lowered.

8.3 Recommendations for Future Research

1. The system boundaries of the machinery replacement model can be expanded by adding some agronomic components to the system to include seeds, fertilizers, and chemicals (herbicides and insecticides) for annual cost comparison for conventional and conservation tillage systems.

2. The machinery remaining value equation used in cost analysis was a function of the age (in years) of machines. However, the remaining value of a machine should be determined relative to the number of hours of operation and the age of machine. This is important since the switching and trading points of machinery sets are determined relative to the annual system costs.
3. Data on wind erosion rates for specific conservation tillage systems needs to be determined.

APPENDIX A

MACHINERY REPLACEMENT MODEL: FORTRAN CODE AND DEFINITIONS OF VARIABLES

```
C          ================================================
C          *   PROGRAM TO DETERMINE MACHINERY REPLACEMENT  *
C          *   FOR TILLAGE SYSTEMS IN MICHIGAN             *
C          *                                               *
C          ================================================
      PROGRAM TRDMACH(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION ICOD(30),SIZE(30),NUM(30),HOUR(30),ISTAT(30),COSTINT(30)
     +,ACOST(30),BCOST(30),SV(30),RV1(30),RV2(30)
      TOTSEL=RPC=ZS=ZF=ZL=TAXBFT=PVC1=ZZ=0
C         A=MACHINERY INFLATION RATE
      A=.10
C         D=DISCOUNT RATE
      D=.12
C         FP=FUEL PRICE
      FP=.32
C         FF=FUEL FACTOR
      FF=.25
C         B=FUEL INFLATION RATE
      B=.15
C         W=LABOR WAGE
      W=7.7
C         C=LABOR INFLATION RATE
      C=.08
      T=.30
      DINT=.2
C         GI=GENERAL INFLATION RATE
      GI=.10
      VI=.04

      ITILNEW=0
      KX=0
      IFLAG=0
C         DATA INITIAL COST FACTORS OF MACHINES
      DATA (ACOST(KL),KL=1,20)/59936.0,4367.0,4000.0,5500.0,14000.,1794.
     +,1236.,-1606.,-2128.,-3741.,-1906.,-3491.,1236.,-4520.,-2704.,604.
     +,-1634.,604.,0.,0./
C         DATA INITIAL COST FACTORS OF MACHINES
      DATA (BCOST(LK),LK=1,20)/9740.8,1378.,1640.4,2952.8,4593.2,1230.3,
     +1788.1,
     +2793.5,5213.3,2693.6,2601.7,1463.3,1788.1,4038.7,4045.3,275.6,1099
     +.1,275.6,500.,500./
C         DATA REPAIR FACTORS OF MACHINES
      DATA (RV1(IJ),IJ=1,20)/.12,.2,.26,.23,.19,.38,.95,.38,.43,.18,.18,
     +.3,.54,.54,.54,.41,.22,.38,.012,.012/
C         DATA REPAIR FACTORS OF MACHINES
      DATA (RV2(JI),JI=1,20)/2.1,1.6,1.6,1.4,1.4,1.4,1.3,1.4,1.8,1.7,1.7
     +,1.4,2.1,2.1,2.1,1.3,2.2,1.4,2.,2./
      READ(5,100) NM,M,MF
  100 FORMAT(I2,1X,I2,1X,I2)

      WRITE(6,190)
      WRITE(6,192)
      WRITE(6,200)
      WRITE(6,202)
      DO 10 I=1,NM
      READ(5,*) ICOD(I),SIZE(I),NUM(I),HOUR(I),ISTAT(I)
      II=ICOD(I)
      COSTINT(I)=ACOST(II)+BCOST(II)*SIZE(I)
      IF(II.EQ.1) THEN
      ASAL=.75
      BSAL=.88
      ELSE IF((II.EQ.19).OR.(II.EQ.20)) THEN
      ASAL=.75
```

```
      BSAL=.87
      ELSE
      ASAL=.7
      BSAL=.9
      ENDIF
      SV(I)=ASAL*BSAL**M
      IF(ISTAT(I).EQ.1) THEN
C        DETERMINE TOTAL SALE COSTS OF EXTRA MACHINES
      TOTSEL=TOTSEL+SV(I)*COSTINT(I)*NUM(I)
      ENDIF
 10   CONTINUE

      DO 15 I=1,NM
      IF(ISTAT(I).EQ.2)THEN
      KX=KX+1
      IF(KX.EQ.NM)ITILL=1
      ENDIF
      IF(ICOD(I).EQ.14)THEN
      ICH=I
      ENDIF
 15   CONTINUE

C        MODIFY ROW PLANTER TO A NO-TILL PLANTER
      EXCOST=SIZE(ICH)/.75*273.
      IF(ITILL.EQ.1.OR.ISTAT(ICH).EQ.3)EXCOST=0
      COSTINT(ICH)=COSTINT(ICH)+EXCOST

      DO 20 I=1,NM
      IF(ISTAT(I).NE.2)THEN
      ITILNEW=ITILNEW+1
      IF(ITILNEW.EQ.NM)NTILL=0
      ENDIF
 20   CONTINUE
      IF(NTILL.EQ.0)THEN
      JYR=12
      ELSE
      JYR=12-M
      ENDIF
      DO 25 MM=1,JYR

      Z1=((1+A)/(1+D))**MM
      Z2=((1+C)/(1+D))**MM
      Z3=((1+B)/(1+D))**MM
      Z4=(1+D)**MM
      ZS=ZS+Z1
      ZL=ZL+Z2
      ZF=ZF+Z3
      ZZ=ZZ+Z4

      DO 30 L=1,NM
      NN=ICOD(L)
      IF(NN.EQ.1)THEN
      ASAL=.75
      BSAL=.88
      ELSEIF((NN.EQ.19).OR.(NN.EQ.20))THEN
      ASAL=.75
      BSAL=.87
      ELSE
      ASAL=.7
      BSAL=.9
      ENDIF
```

```
      IF(ISTAT(L).EQ.1) GOTO 30
      II=ICOD(L)
      IF(ISTAT(L).EQ.2) THEN
      IFLAG=1
      N=M+MM
      MY=M+1
      ELSE
      N=MM
      MY=1
      ENDIF
C        DETERMINE THE MACHINERY COSTS
      OWNSHP=COSTINT(L)-ASAL*BSAL**N*COSTINT(L)

      DO 35 J=MY,N
      RP=((HOUR(L)*J/1000.)**RV2(II)-(HOUR(L)*(J-1)/1000.)
     +**RV2(II))*(((1+A)/(1-D))**J)
      RPC=RPC+RP
 35   CONTINUE
C        DETERMINE REPAIR COSTS
      REPMAN=RV1(II)*RPC*COSTINT(L)
      RPC=0.

      IF((II.EQ.1).OR.((II.EQ.19).OR.(II.EQ.20))) THEN
      IF(II.EQ.1) WK=SIZE(L)/.75*15.
      IF(II.EQ.19) WK=SIZE(L)
      IF(II.EQ.20) WK=SIZE(L)
C        DETERMINE FUEL COSTS
      FULB=1.15*FP*WK*FF*HOUR(L)*ZF

C        DETERMINE LABOR COSTS
      XLAB=1.1*W*HOUR(L)*ZL

      ELSE
      FULB=XLAB=0.
      ENDIF

C        DETERMINE TAX INSURANCE AND SHELTER COSTS
      TII=.01*COSTINT(L)*ZS

      TBF=T*((.2+DINT)*COSTINT(L)/ZZ+TII+REPMAN+FULB+XLAB)
C        DETERMINE TAX BENEFIT COSTS
      TAXBFT=.1*COSTINT(L)+TBF

      PC=OWNSHP+REPMAN+FULB+TII+XLAB-TAXBFT

C        DETERMINE TOTAL NET PRESENT COSTS
      PVC1=PVC1+NUM(L)*PC
C      WRITE(6,*) OWNSHP,TII,XLAB,FULB,REPMAN,TAXBFT
 30   CONTINUE
      Y=D-GI
      ZARB=((Y*(1+Y)**MM)/((1+Y)**MM-1))
      ZARB1=((VI*(1+VI)**MM)/((1+VI)**MM-1))
      PVC=PVC1
      AEC=PVC*ZARB
      ARV=TOTSEL*ZARB
C        DETERMINE ANNUAL EQUIVALENT COSTS
      AFB=AEC-ARV
      PVC1=0.
      WRITE(6,201) MM,PVC,AEC,ARV,AFB
 25   CONTINUE
190   FORMAT(' ','-------------------------------------------------------
```

```
     +-------------------')
192   FORMAT(1X,'TIME',9X,'NPV',14X,'AEC1',14X,'AEC2',14X,'AEC')
200   FORMAT(' ','(YRS)',8X,'($)',14X,'($)',15X,'($)',15X,'($)')
202   FORMAT(' ','--------------------------------------------------------
     +-------------------')
201   FORMAT(2X,I2,3X,4(F13.2,4X))
      WRITE(6,203)
203   FORMAT(' ','--------------------------------------------------------
     +-------------------')
      WRITE(6,204)TOTSEL
204   FORMAT(1X,'TOTAL SALE IS:$',F12.2)
      CALL EROS(MF)
      STOP
      END
C         ======================================================
C         *            SUBROUTINE EROS                          *
C         ======================================================
C        SUBROUTINE EROS DETERMINES THE REDUCTION IN LAND
C        PRODUCTIVITY FOR USING MOLDBOARD PLOWING
      SUBROUTINE EROS(MYRS)
      INTEGER X
      DIMENSION CBD(7),SLPL(7),XINTL(7),SLPH(7),XINTH(7),WF(100),ADJ(7),
     +AW(7),BD(7),PH(7),IA(7),AS(7),BS(7),PI(7),PS(7),PERM(7),PPRLND(15)
      REAL DUMMY1(7),DUMMY2(7),DUMMY3(7),DUMMY4(7),DUMMY5(7)
C        J=SOIL TYPE
      J=3
      IJK=J
      TOT=0
C        YILD=CORN YIELD
      YILD=7.2
C        PRCE=CORN PRICE
      PRCE=92.0
C      WE=WIND EROSION RATE(T/HA)
      WE=7.09
C        RI=DISCOUNT RATE
      RI=.12
C        DATA CRITICAL BULK DENSISTIES OF SOILS
      DATA (CBD(J),J=1,7)/1.69,1.63,1.67,1.67,1.54,1.49,1.39/
C        DATA SOIL SLOPE FACTORS
      DATA (SLPL(J),J=1,7)/-1.933,-1.16,-.829,-.725,-.870,-1.933,-1.933/
C        DATA INTERCEPT VALUES
      DATA (XINTL(J),J=1,7)/4.093,2.717,2.210,2.037,2.166,3.706,3.513/
C        DATA SOIL SLOPE FACTORS
      DATA (SLPH(J),J=1,7)/-5.163,-4.859,-7.509,-6.883,-7.509,-9.178,
     +-10.325/
C        DATA SOIL INTERCEPT VALUES
      DATA (XINTH(J),J=1,7)/9.551,8.746,13.366,12.321,12.389,14.5,
     +15.178/
C        DATA SOIL AVAILABLE WATER
      DATA (AW(K),K=1,4) /.185,.155,.135,.06/
C        DATA SOIL BULK DENSITIES
      DATA (BD(K),K=1,4)/1.58,1.63,1.63,1.91/
C        DATA SOIL PH VALUES
      DATA (PH(K),K=1,4)/7.2,7.2,7.9,7.9/
C        DATA SOIL LAYERS
      DATA (IA(K),K=1,4)/28,31,25,69/
C        DATA SOIL PERMEABLITY
      DATA (PERM(K),K=1,4)/1.3,1.3,1.1,1.0/
      DATA  DUMMY1/0,0,1,1,1,1,1/
      DATA  DUMMY2/0,0,1,1,1,.9,.8/
      DATA  DUMMY3/0,0,.9,1,.9,.7,.6/
```

```
      DATA  DUMMY4/0,0,.7,.9,.7,.6,.5/
      DATA  DUMMY5/0,0,.5,.7,.5,.5,.4/
C        DATA SOIL WEIGHTING FACTORS
      DATA (WF(I),I=1,100)/.044522,.063886,.083008,.101641,.119708,
     +.137211,.154180,.170655,.186675,.202276,.217489,.232344,.246864,
     +.261073,.274990,.288631,.302014,.315152,.328057,.340741,.353214,
     +.365486,.377566,.389461,.401197,.412727,.424111,.435337,.446411,
     +.457336,.468120,.478765,.489276,.499657,.509912,.520044,.530057,
     +.539954,.549737,.559410,.568976,.578436,.587794,.597052,.606212,
     +.615276,.624246,.633125,.641914,.650614,.659229,.667758,.676205,
     +.684570,.692856,.701062,.709192,.717246,.725225,.733132,.740966,
     +.748729,.756423,.764048,.771605,.779096,.786521,.793882,.801180,
     +.808414,.815587,.822699,.829751,.836743,.843678,.850554,.857374,
     +.864137,.870845,.877498,.884097,.890642,.897135,.903576,.909965,
     +.916303,.922591,.928829,.935018,.941159,.947251,.953296,.959293,
     +.965244,.971149,.977009,.982823,.988593,.994318,1./

      READ(5,*)R,BK,BLS,P,CC

      DO 60 K=1,4
      IF(PERM(K).LE..06)THEN
      DO 65 KK=1,7
   65 ADJ(KK) = DUMMY1 (KK)
      ELSE IF(PERM(K).GT.0.06.AND.PERM(K).LE.0.2)THEN
      DO 70 KK=1,7
   70 ADJ(KK) = DUMMY2 (KK)
      ELSEIF(PERM(K).GT..2.AND.PERM(K).LE..6)THEN
      DO 75 KK=1,7
   75 ADJ(KK) = DUMMY3 (KK)
      ELSEIF(PERM(K).GT..6.AND.PERM(K).LE.2.)THEN
      DO 80 KK=1,7
   80 ADJ(KK) = DUMMY4 (KK)
      ELSEIF(PERM(K).GT.2.)THEN
      DO 85 KK =1,7
   85 ADJ(KK) = DUMMY5 (KK)
      ENDIF

      AS(K)=5.*AW(K)
      IF(AW(K).GE.0.2)AS(K)=1.0
      IF(AW(K).LE.0.03)AS(K)=0
      IF(BD(K).LT.CBD(J))THEN
      C=(SLPL(J)*BD(K)+XINTL(J))
      ELSEIF(BD(K).GT.CBD(J))THEN
      C=(SLPH(J)*BD(K)+XINTH(J))
      END IF

      BS(K)=(1-ADJ(IJK))+(ADJ(IJK)*C)
      IF(BS(K).GT.1.0)BS(K)=1.0
      IF(BS(K).LT.0)BS(K)=0

      IF(PH(K).GE.8.)PS(K)=.75
      IF(PH(K).LT.8..AND.PH(K).GT.6.5)PS(K)=2.086-(.167*PH(K))
      IF(PH(K).LE.6.5.AND.PH(K).GT.5.5)PS(K)=1.0
      IF(PH(K).LE.5.5.AND.PH(K).GT.5.)PS(K)=.12+(.16*PH(K))
      IF(PH(K).LE.5.0.AND.PH(K).GT.2.9)PS(K)=(.446*PH(K))-1.31
      IF(PH(K).LE.2.9)PS(K)=0
   60 CONTINUE

   90 IF(IA(1).GE.100)THEN
      IA(1)=100
      I=IA(1)
```

```
      TPI=AS(1)*BS(1)*PS(1)*WF(I)

      ELSEIF((IA(1)+IA(2)).GE.100)THEN
      I=IA(1)
      PI(1)=AS(1)*BS(1)*PS(1)*WF(I)
      WF(I)=WF(100)-WF(I)
      PI(2)=AS(2)*BS(2)*PS(2)*WF(I)
      TPI=PI(1)+PI(2)

      ELSEIF((IA(1)+IA(2)+IA(3)).GE.100)THEN
      I=IA(1)
      PI(1)=AS(1)*BS(1)*PS(1)*WF(I)
      LL=IA(1)+IA(2)
      MM=IA(1)
      WF(I)=WF(LL)-WF(MM)
      PI(2)=AS(2)*BS(2)*PS(2)*WF(I)
      WF(I)=WF(100)-WF(LL)
      PI(3)=AS(3)*BS(3)*PS(3)*WF(I)
      TPI=PI(1)+PI(2)+PI(3)

      ELSEIF((IA(1)+IA(2)+IA(3)+IA(4)).GE.100)THEN

      I=IA(1)
      PI(1)=AS(1)*BS(1)*PS(1)*WF(I)

      LL=IA(1)+IA(2)
      MM=IA(1)
      WF(I)=WF(LL)-WF(MM)
      PI(2)=AS(2)*BS(2)*PS(2)*WF(I)
      NN=IA(1)+IA(2)+IA(3)
      WF(I)=WF(NN)-WF(LL)
      PI(3)=AS(3)*BS(3)*PS(3)*WF(I)
      WF(I)=WF(100)-WF(NN)
      PI(4)=AS(4)*BS(4)*PS(4)*WF(I)
      TPI=PI(1)+PI(2)+PI(3)+PI(4)
      ENDIF

      IF(TOT.EQ.0)ZZ=TPI

      TOT=-TPI-TOT

      IF(KFLAG.EQ.4)GO TO 95

C        DETERMINE THE ANNUAL EROSION RATE
      A=2.471*R*BK*BLS*P*CC+WE
      AA=A*(.01/BD(1))
      X=AA
      IF(AA.LT.1.)X=1
      IF(AA.GE.((X*1.)+.5))X=X+1

      IF(X.LE.IA(1))THEN
      IA(1)=IA(1)-X
      KFLAG=4

      ELSEIF(X.LE.(IA(1)+IA(2)).AND.X.GT.IA(1))THEN
      IA(2)=IA(1)+IA(2)-X
      IA(1)=0
      KFLAG=4

      ELSEIF(X.LE.(IA(1)+IA(2)+IA(3)).AND.X.GT.(IA(1)+IA(2)))THEN
      IA(3)=IA(1)+IA(2)+IA(3)-X
```

```
      IA(1)=0
      IA(2)=0
      KFLAG=4

      ELSEIF(X.LE.(IA(1)+IA(2)+IA(3)+IA(4)).AND.X.GT.(IA(1)+IA(2)+IA(3))
     +)THEN
      IA(4)=IA(1)+IA(2)+IA(3)+IA(4)-X
      IA(1)=0
      IA(2)=0
      IA(3)=0
      KFLAG=4
      ENDIF
      GO TO 90
  95  PP=TOT
C        DETERMINE THE CHANGE OF SOIL PRODUCTIVITY
      CHPRD=(PP/ZZ)*YILD*PRCE

      PRLND=YILD*PRCE
      XPRLND=PRLND
      IF(MYRS.NE.0)THEN
      WRITE(6,200)
 200  FORMAT(' ','-------------------------------------------------------
     +-------------------')
      WRITE(6,201)
 201  FORMAT(' ',9X,'LAND',16X,'PRESENT VALUE OF',8X,'REDUCTION OF LAND
     +')
      WRITE(6,202)
 202  FORMAT(' ','TIME',5X,'PRODUCTIVITY',8X,'LAND PRODUCTIVITY',7X,'PRO
     +DUCTIVITY')
      WRITE(6,203)
 203  FORMAT(' ','(YRS)',8X,'($/HA)',16X,'($/HA)',16X,'($/HA)')
      WRITE(6,223)
 223  FORMAT(' ','-------------------------------------------------------
     +-------------------')
      ENDIF
      DO 35 II=1,MYRS
      PPRLND(II)=PRLND-CHPRD
      PRS=PPRLND(II)*(1/(1+RI))**II
C        DETERMINE ANNUAL REDUCTION OF LAND PRODUCTIVITY
      RDLND=(XPRLND-PRS)*(RI*(1+RI)**II/((1+RI)**II-1))
      WRITE(6,224)II,PPRLND(II),PRS,RDLND
 224  FORMAT(' ',I2,8X,F8.2,14X,F8.2,14X,F8.2)
      PRLND=PPRLND(II)
  35  CONTINUE
      WRITE(6,225)
 225  FORMAT(' ','-------------------------------------------------------
     +-------------------')
      IF(MYRS.NE.0)THEN
      WRITE(6,226)A
 226  FORMAT(' ','ANNUAL EROSION RATE(T/HA)=',F8.2)
      WRITE(6,227)XPRLND
 227  FORMAT(' ','ORIGINAL LAND PRODUCTIVITY($/HA)=',F8.2)
      WRITE(6,228)CHPRD
 228  FORMAT(' ','CHANGE IN ANNUAL LAND PRODUCTIVITY($/HA)=',F8.2)
      WRITE(6,229)
 229  FORMAT(' ','-------------------------------------------------------
     +-------------------')
      ENDIF
      RETURN
      END
```

APPENDIX B

LINEAR PROGRAMMING MODEL: CONVENTIONAL TILLAGE SYSTEM AND COARSE SOIL

```
MIN -2378X1-3132X2-2806X3-3465X4-4455X5-3011X6-958X7-925X8
-513X9-364X10-431X11-208X12-1113X13-968X14-788X15
-802X16-774X17-742X18-739X19-477X20-430X21
-401X22-375X23-537X24-430X25-408X26-326X27-364X28
-220X29-381X30-366X31-371X32-341X33-268X34-238X35
-703X36-485X37
-465X38-358X39-329X40-267X41-303X42-301X43-486X44
-14577X45-14502X46
-11715X47-24492X48-25489X49-1019X50-1355X51-1646X52-2132X53
-3029X54-5315X55-2207X56-2508X57-1923X58-3422X59
-4503X60-7716X61-11793X62-12454X63-17039X64
-18965X65-21185X66-15664X67-25876X68-27054X69-35334X70
ST
98X1+174X2+235X3+333X4+667X5+1000X6<387
133X7+154X8+182X9+222X10+267X11+400X12<290
118X13+133X14+148X15+167X16+200X17+235X18<387
85X19+129X20+167X21+200X22+250X23<148
148X24+160X25+182X26+200X27+235X28+286X29<240
83X30+87X31+100X32+111X33+121X34+143X35<105
74X36+100X37+121X38+138X39+160X40+250X41<147
235X42+333X43+667X44<387
160X45+235X46+308X47+400X48+500X49<267
133X50+167X51+200X52+235X53+286X54+400X55<276
80X56+160X57+210X58+250X59+333X60<320
400X1+400X2+400X3+400X4+232X5+155X6<400
400X7+400X8+400X9+400X10+400X11+290X12<400
400X13+400X14+400X15+400X16+400X17+400X18<400
400X19+400X20+355X21+296X22+236X23<400
400X24+400X25+400X26+400X27+400X28+336X29<400
400X30+400X31+400X32+370X33+339X34+288X35<400
400X36+400X37+400X38+400X39+367X40+235X41<400
400X42+400X43+236X44<400
400X45+400X46+347X47+267X48+214X49<400
400X50+400X51+400X52+331X53+166X54+110X55<400
400X56+400X57+400X58+400X59+384X60<400
X1+X2+X3+X4+X5+X6-X63-X64-X65-X66-X67-X68=0
X7+X8+X9+X10+X11+X12-X61-X62-X63-X64-X65-X66=0
X13+X14+X15+X16+X17+X18-X62-X63-X64-X65-X66-X67=0
X19+X20+X21+X22+X23-X61-X62-X63-X64-X65=0
X24+X25+X26+X27+X28+X29-X61-X62-X63-X64-X65-X66=0
X30+X31+X32+X33+X34+X35-X61-X62-X63-X64-X65-X66=0
X36+X37+X38+X39+X40+X41-X64-X65-X66-X67-X68-X69=0
X42+X43+X44-X61-X62-X63=0
X50+X51+X52+X53+X54+X55-X61-X62-X63-X64-X65-X66=0
X56+X57+X58+X59+X60-X61-X62-X63-X64-X65=0
X45-X56=0
X46-X57=0
X47-X58=0
X48-X59=0
```

```
X49-X60=0
X19-X56=0
X20-X57=0
X21-X58=0
X22-X59=0
X23-X60=0
84X1+47X2+35X3+25X4+13X5+9X6<85
20X7+17X8+15X9+12X10+10X11+7X12<40
40X13+37X14+33X15+29X16+25X17+20X18<85
16X19+10X20+9X21+7X22+5X23<40
 8X24+7X25+6X26+6X27+5X28+4X29<40
20X30+19X31+17X32+15X33+14X34+12X35<40
99X36+75X37+61X38+54X39+46X40+30X41<85
60X42+40X43+20X44<85
60X50+53X51+45X52+38X53+31X54+23X55<85
11X56+8X57+6X58+5X59+4X60<40
98X1+174X2+235X3+333X4+667X5+1000X6+133X7+154X8
+1842X9+222X10+267X11
+400X12+118X13+133X14+148X15+167X16+200X17+235X18
+85X19+129X20+167X21
+200X22+250X23+148X24+160X25+182X26+200X27+235X28
+286X29+83X30+87X31
+100X32+111X33+121X34+143X35+74X36+100X37+121X38
+138X39+160X40+250X41
+235X42+333X43+667X44+160X45+235X46+308X47+400X48
+500X49+133X50+167X51+200X52+235X53
+286X54+400X55+80X56+160X57+210X58+250X59+333X60<2357
2347X1+1887X2+1220X3+948X4+403X5+148X6+1042X7+943X8
+479X9+294X10
+289X11+103X12+1033X13+857X14+651X15+609X16+527X17
+427X18+799X19
+425X20+325X21+263X22+202X23+325X24+233X25+188X26
+123X27+108X28+45X29
+410X30+382X31+373X32+319X33+247X34+200X35+795X36
+494X37+430X38+307X39
+257X40+150X41+178X42+121X43+89X44+13892X45
+8854X46+2500X47+8057X48
+5621X49+700X50+682X51+664X52+647X53+629X54
+611X55+1886X56+1347X57
+1032X58+907X59+781X60+2500X61+2717X62+2924X63
+3490X64+4056X65+4526X66
+5150X67+5612X68+5753X69+9243X70<39500
950X1+2224X2+2375X3+3383X4+5009X5+3486X6+305X7
+345X8+227X9+198X10
+285X11+165X12+498X13+467X14+417X15+469X16+501X17
+543X18+239X19
+228X20+252X21+267X22+285X23+381X24+327X25+337X26
+291X27+348X28
+227X29+125X30+129X31+143X32+150X33+122X34+124X35
```

```
+199X36+182X37
+210X38+180X39+186X40+198X41+218X42+262X43+509X44
+4242X45+6060X46
+2469X47+16851X48+18784X49+654X50+1072X51+1434X52
+2031X53+3119X54
+5872X55+221X56+251X57+192X58+342X59+450X60+1031X61
+2262X62+2436X63+4480X64
+5206X65+5811X66+3029X67+7207X68+7385X69+11865X70<38500
X2=1
X19=0
X20=1
X25=1
X29=0
X36=0
X37=1
X67=1
X42=1
X44=0
X53=0
X55=0
X51=1
X54=0
X70=0
```

APPENDIX C

LINEAR PROGRAMMING MODEL: CONVENTIONAL TILLAGE SYSTEM AND MEDIUM SOIL

```
MIN -2398X1-3179X2-2857X3-3537X4-4562X5-3085X6-983X7
-952X8-531X9-380X10-456X11-221X12
-1130X13-984X14-868X15-819X16-791X17-760X18-785X19
-521X20-479X21-453X22-430X23-537X24-430X25-408X26
-326X27-364X28
-220X29-381X30-366X31-371X32-341X33-268X34-238X35
-711X36-493X37
-474X38-366X39-377X40-275X41-310X42-309X43-503X44
-15577X45-14502X46
-11715X47-24492X48-25489X49-1175X50-1611X51-1989X52
-2617X53-3774X54
-6718X55-2556X56-3108X57-3642X58-4475X59-5993X60
-11715X61-12285X62
-12856X63-8907X64-21380X65-22220X66-23061X67-23883X68
-25030X69-15978X70
ST
100X1+182X2+235X3+333X4+667X5+1000X6<359
143X7+160X8+190X9+235X10+286X11+400X12<254
121X13+133X14+148X15+174X16+200X17+250X18<359
100X19+148X20+200X21+235X22+308X23<146
148X24+160X25+182X26+200X27+235X28+286X29<225
83X30+87X31+100X32+111X33+121X34+143X35<105
77X36+103X37+125X38+143X39+167X40+250X41<137
235X42+343X43+667X44<359
160X45+235X46+308X47+400X48+500X49<250
148X50+190X51+222X52+267X53+333X54+444X55<273
121X56+191X57+250X58+286X59+400X60<309
400X1+400X2+400X3+400X4+215X5+144X6<400
400X7+400X8+400X9+400X10+400X11+254X12<400
400X13+400X14+400X15+400X16+400X17+400X18<400
400X19+394X20+292X21+248X22+189X23<400
400X24+400X25+400X26+400X27+382X28+315X29<400
400X30+400X31+380X32+342X33+314X34+266X35<400
400X36+400X37+400X38+384X39+328X40+219X41<400
400X42+395X43+215X44<400
400X45+400X46+347X47+267X48+214X49<400
400X50+400X51+400X52+328X53+164X54+109X55<400
400X56+400X57+400X58+400X59+309X60<400
X1+X2+X3+X4+X5+X6-X65-X66-X67-X68-X69-X70=0
X7+X8+X9+X10+X11+X12-X61-X62-X63-X64-X65-X66=0
X13+X14+X15+X16+X17+X18-X63-X64-X65-X66-X67-X68=0
X19+X20+X21+X22+X23-X61-X62-X63-X64-X65=0
X24+X25+X26+X27+X28+X29-X61-X62-X63-X64-X65-X66=0
X30+X31+X32+X33+X34+X35-X61-X62-X63-X64-X65-X66=0
X36+X37+X38+X39+X40+X41-X65-X66-X67-X68-X69-X70=0
X42+X43+X44-X64-X65-X66=0
X50+X51+X52+X53+X54+X55-X61-X62-X63-X64-X65-X66=0
X56+X57+X58+X59+X60-X61-X62-X63-X64-X65=0
X45-X56=0
```

```
X46-X57=0
X47-X58=0
X48-X59=0
X49-X60=0
X19-X56=0
X20-X57=0
X21-X58=0
X22-X59=0
X23-X60=0
126X1+70X2+53X3+38X4+19X5+13X6<85
30X7+26X8+23X9+18X10+15X11+11X12<40
41X13+38X14+34X15+30X16+26X17+21X18<85
20X19+13X20+11X21+9X22+7X23<40
8X24+7X25+6X26+6X27+5X28+4X29<40
20X30+19X31+17X32+15X33+14X34+12X35<40
106X36+81X37+66X38+58X39+50X40+33X41<85
76X42+51X43+26X44<85
65X50+57X51+49X52+41X53+33X54+24X55<85
14X56+9X57+7X58+6X59+5X60<40
100X1+182X2+235X3+333X4+667X5+1000X6+143X7
+160X8+190X9+235X10+286X11
+400X12+121X13+133X14+148X15+174X16+200X17
+250X18+100X19+148X20+200X21
+235X22+308X23+148X24+160X25+182X26+200X27
+235X28+286X29+83X30+87X31
+100X32+111X33+121X34+143X35+77X36+103X37
+125X38+143X39+167X40+250X41
+235X42+363X43+667X44+160X45+235X46+308X47+400X48
+400X48+500X49+148X50+190X51
+222X52+267X53+333X54
+444X55+121X56+191X57+250X58+286X59+400X60<2357
2347X1+1887X2+1220X3+948X4+403X5+148X6+1042X7
+943X8+479X9+294X10
+289X11+103X12+1033X13+857X14+651X15+609X16
+527X17+427X18+799X19
+425X20+325X21+263X22+202X23+325X24+233X25
+188X26+123X27+108X28+45X29
+410X30+382X31+373X32+319X33+247X34+200X35
+795X36+494X37+430X38+307X39
+257X40+150X41+178X42+121X43+89X44+13892X45
+8854X46+2500X47+8057X48
+5621X49+700X50+682X51+664X52+647X53+629X54
+611X55+1886X56+1347X57
+1032X58+907X59+781X60+2500X61+2608X62+2717X63
+3490X64+4056X65+4216X66
+4377X67+4526X68+4839X69+5150X70<39500
974X1+2281X2+2435X3+3469X4+5137X5+3575X6
+335X7+378X8+248X9+217X10
+312X11+181X12+519X13+486X14+513X15+488X16
```

```
+521X17+566X18+294X19
+280X20+311X21+329X22+352X23+381X24+328X25
+337X26+291X27+348X28
+227X29+125X30+129X31+143X32+150X33+122X34
+124X35+209X36+191X37
+221X38+190X39+196X40+209X41+227X42+272X43
+530X44+4242X45
+6060X46+2469X47+16851X48+18784X49+841X50
+1378X51+1845X52
+2612X53+4012X54+7552X55+1537X56+2633X57
+3526X58+4626X59+6546X60
+2469X61+2576X62+2683X63+1153X64+6473X65+6729X66
+6985X67+7226X68+7723X69+3160X70<38500
X2=1
X7=1
X19=1
X38=1
X42=1
X50=1
X70=1
```

APPENDIX D

LINEAR PROGRAMMING MODEL: CONVENTIONAL TILLAGE SYSTEM AND FINE SOIL

```
MIN -2487X1-3388X2-3081X3-3855X4-5034X5-3413X6
-989X7-960X8-536X9-384X10-462X11-224X12-1328X13
-1169X14-968X15-1004X16-989X17-976X18-933X19
-662X20-635X21-618X22-607X23-537X24-430X25
-408X26-326X27-364X28
-220X29-381X30-366X31-371X32-341X33-268X34
-238X35-717X36-498X37
-481X38-371X39-343X40-281X41-318X42-319X43
-521X44-15577X45-14502X46
-11715X47-24492X48-25489X49-1262X50-1755X51
-2181X52-2890X53-4193X54
-7506X55-3425X56-4595X57-5634X58-7089X59
-9692X60-12576X61
-13790X62-10293X63-11258X64-23300X65-26027X66
-29815X67-31801X68
-20697X69-43855X70
ST
105X1+190X2+250X3+364X4+667X5+1000X6<320
143X7+167X8+190X9+235X10+286X11+400X12<226
160X13+174X14+200X15+222X16+267X17+333X18<320
138X19+211X20+267X21+329X22+400X23<143
148X24+160X25+182X26+200X27+235X28+286X29<198
83X30+87X31+100X32+111X33+121X34+143X35<105
77X36+103X37+125X38+143X39+167X40+250X41<127
250X42+300X43+500X44<320
160X45+235X46+308X47+400X48+500X49<220
154X50+200X51+235X52+286X53+333X54+444X55<268
80X56+118X57+154X58+200X59+250X60<296
400X1+400X2+400X3+351X4+192X5+128X6<400
400X7+400X8+400X9+400X10+340X11+226X12<400
400X13+400X14+400X15+400X16+400X17+271X18<400
400X19+272X20+215X21+172X22+143X23<400
400X24+400X25+400X26+396X27+336X28+277X29<400
400X30+377X31+328X32+295X33+270X34+230X35<400
400X36+400X37+400X38+355X39+305X40+203X41<400
400X42+320X43+160X44<400
400X45+400X46+347X47+267X48+214X49<400
400X50+400X51+400X52+295X53+163X54+107X55<400
400X56+400X57+384X58+296X59+236X60<400
X1+X2+X3+X4+X5+X6-X65-X66-X67-X68-X69-X70=0
X7+X8+X9+X10+X11+X12-X63-X64-X65-X66-X67-X68=0
X13+X14+X15+X16+X17+X18-X63-X64-X65-X66-X67-X68=0
X19+X20+X21+X22+X23-X61-X62-X63-X64-X65=0
X24+X25+X26+X27+X28+X29-X61-X62-X63-X64-X65-X66=0
X30+X31+X32+X33+X34+X35-X61-X62-X63-X64-X65-X66=0
X36+X37+X38+X39+X40+X41-X65-X66-X67-X68-X69-X70=0
X42+X43+X44-X68-X69-X70=0
X50+X51+X52+X53+X54+X55-X65-X66-X67-X68-X69-X70=0
X56+X57+X58+X59+X60-X61-X62-X63-X64-X65=0
```

```
X45-X56=0
X46-X57=0
X47-X58=0
X48-X59=0
X49-X60=0
X19-X56=0
X20-X57=0
X21-X58=0
X22-X59=0
X23-X60=0
138X1+76X2+58X3+41X4+21X5+15X6<100
41X7+36X8+31X9+25X10+20X11+15X12<50
42X13+39X14+35X15+31X16+26X17+21X18<100
25X19+21X20+17X21+13X22+9X23<50
8X24+7X25+6X26+6X27+5X28+4X29<50
20X30+19X31+17X32+15X33+14X34+12X35<50
120X36+91X37+74X38+65X39+56X40+37X41<100
92X42+62X43+31X44<100
106X50+93X51+80X52+67X53+54X54+40X55<100
17X56+11X57+9X58+7X59+6X60<50
105X1+190X2+250X3+364X4+667X5+1000X6+143X7+167X8
+190X9+235X10+286X11
+400X12+160X13+174X14+200X15+222X16+267X17+333X18
+138X19+211X20+267X21
+329X22+400X23+148X24+160X25+182X26+200X27+235X28
+286X29+83X30+87X31
+100X32+111X33+121X34+143X35+77X36+103X37+125X38
+143X39+167X40+250X41
+250X42+400X43+800X44+160X45+235X46+238X47+400X48
+500X49+154X50+200X51
+235X52+286X53+333X54
+444X55+80X56+118X57+154X58+200X59+250X60<2357
2347X1+1887X2+1220X3+948X4
+403X5+148X6+1042X7+943X8+479X9+294X10
+289X11+103X12+1033X13+857X14+651X15+609X16
+527X17+427X18+799X19
+425X20+325X21+263X22+202X23+325X24+233X25
+188X26+123X27+108X28+45X29
+410X30+382X31+373X32+319X33+247X34+200X35+795X36
+494X37+430X38+307X39
+257X40+150X41+178X42+121X43+89X44+13892X45+8854X46
+2500X47+8057X48
+6521X49+700X50+682X51+664X52+647X53+629X54+611X55
+1886X56+1347X57
+1032X58+907X59+781X60+2500X61+2717X62+2924X63+3490X64
+4056X65+4526X66
+5470X67+5612X68+5688X69+9243X70<39500
1081X1+2532X2+2703X3+3850X4+5702X5+3968X6+342X7+387X8
+387X8+254X9+223X10
```

```
+320X11+186X12+756X13+708X14+632X15+710X16+759X17+824X18
+471X19+450X20+497X21+527X22+563X23+381X24+328X25
+337X26+291X27
+348X28+227X29+125X30+129X31+143X32+150X33+122X34
+124X35+217X36
+198X37+228X38+196X39+203X40+216X41+236X42+284X43
+552X44+4242X45
+6060X47+2469X47+16851X48+18784X49+946X50+1550X51
+2075X52+2939X53
+4513X54+8496X55+2577X56+4415X57+5913X58+7757X59
+10977X60+2827X61
+3072X62+1643X63+1961X64+7533X65+8409X66+10161X67
+10424X68+4540X69+17168X70<38500
X2=1
X8=1
X19=1
X38=1
X42=1
X69=1
X50=0
X51=1
```

APPENDIX E

LINEAR PROGRAMMING MODEL: CHISELING TILLAGE SYSTEM AND COARSE SOIL

```
MIN -781X1-466X2-532X3-493X4-444X5-432X6-958X7
-925X8-513X9-364X10
-433X11-208X12-739X13-477X14-430X15-401X16
-375X17-537X18-430X19
-408X20-326X21-364X22-220X23-381X24-366X25
-371X26-341X27-286X28
-238X29-703X30-485X31-465X32-358X33-329X34
-267X35-303X36-301X37
-486X38-15577X39-14502X40-11715X41-24492X42
-25489X43-1019X44-1355X45-1646X46
-2132X47-3029X48-5315X49-2207X50-2508X51
-1923X52-3422X53-4503X54
-10746X55-11270X56-11795X57-12454X58-8559X59
-18002X60-18965X61
-19710X62-20456X63-11932X64
ST
87X1+143X2+235X3+250X4+286X5+400X6<320
133X7+154X8+182X9+222X10+267X11+400X12<226
85X13+129X14+167X15+200X16+250X17<143
148X18+160X19+182X20+190X21+235X22+286X23<198
83X24+87X25+100X26+111X27+121X28+143X29<105
74X30+100X31+121X32+138X33+160X34+250X35<147
235X36+333X37+667X38<320
160X39+235X40+308X41+400X42+500X43<220
133X44+167X45+200X46+235X47+286X48+400X49<268
80X50+160X51+210X52+250X53+333X54<296
400X1+400X2+400X3+400X4+400X5+387X6<400
400X7+400X8+400X9+400X10+400X11+290X12<400
400X13+400X14+355X15+296X16+236X17<400
400X18+400X19+400X20+400X21+400X22+336X23<400
400X24+400X25+400X26+370X27+339X28+288X29<400
400X30+400X31+400X32+400X33+367X34+235X35<400
400X36+400X37+236X38<400
400X39+400X40+347X41+267X42+214X43<400
400X44+400X45+400X46+331X47+166X48+110X49<400
400X50+400X51+400X52+400X53+400X54<400
X1+X2+X3+X4+X5+X6-X56-X57-X58-X59-X60-X61=0
X7+X8+X9+X10+X11+X12-X55-X56-X57-X58-X59-X60=0
X13+X14+X15+X16+X17-X55-X56-X57-X58-X59=0
X18+X19+X20+X21+X22+X23-X55-X56-X57-X58-X59-X60=0
X24+X25+X26+X27+X28+X29-X55-X56-X57-X58-X59-X60=0
X30+X31+X32+X33+X34+X35-X58-X59-X60-X61-X62-X63=0
X36+X37+X38-X58-X59-X60=0
X44+X45+X46+X47+X48+X49-X55-X56-X57-X58-X59-X60=0
X50+X51+X52+X53+X54-X55-X56-X57-X58-X59=0
X39-X50=0
X40-X51=0
X41-X52=0
X42-X53=0
```

```
X43-X54=0
X13-X39=0
X14-X40=0
X15-X41=0
X16-X42=0
X17-X43=0
133X1+83X2+51X3+46X4+41X5+31X6<85
20X7+17X8+15X9+12X10+10X11+7X12<40
16X13+10X14+9X15+7X16+5X17<40
8X18+7X19+6X20+6X21+5X22+4X23<40
20X24+19X25+17X26+15X27+14X28+12X29<40
99X30+75X31+61X32+54X33+46X34+30X35<85
60X36+40X37+20X38<85
60X44+53X45+45X46+38X47+31X48+23X49<85
11X50+8X51+6X52+5X53+4X54<40
87X1+143X2+235X3+250X4+286X5+400X6+133X7+154X8
+182X9+222X10+267X11
+400X12+85X13+129X14+167X15+200X16+250X17+148X18
+160X19+182X20+200X21
+235X22+286X23+83X24+87X25+100X26+111X27+121X28
+143X29+74X30+100X31
+121X32+138X33+160X34+250X35+235X36+333X37+667X38
+160X39+235X40+308X41
+400X42+500X43+133X44+167X45+200X46+235X47+286X48
+400X49+80X50+160X51
+210X52+250X53+333X54<2357
8314X1+3915X2+3134X3+2649X4+2134X5+1562X6+1042X7
+943X8+479X9+294X10
+289X11+103X12+799X13+425X14+325X15+263X16+202X17
+325X18+233X19+188X20+123X21+108X22
+45X23+410X24+382X25+373X26+319X27+247X28+200X29
+795X30+494X31+430X32+307X33+257X34+150X35+178X36
+121X37+89X38+13892X39
+8854X40+2500X41+8057X42+6521X43+700X44+682X45+664X46
+647X47+629X48
+611X49+1886X50+1347X51+1032X52+907X53+781X54+2500X55
+2608X56+2717X57
+2924X58+3490X59+3773X60+4056X61+4216X62+4377X63
+4528X64<39500
262X1+241X2+384X3+376X4+359X5+391X6+305X7+345X8
+227X9+198X10
+285X11+165X12+239X13+228X14+252X15+267X16+285X17
+381X18+327X19
+337X20+291X21+348X22+227X23+125X24+129X25+143X26
+150X27+122X28
+124X29+199X30+182X31+210X32+180X33+186X34+198X35
+218X36+262X37
+509X38+4242X39+6060X40+2469X41+16851X42+18784X43
+654X44+1072X45+1434X46
```

```
+2469X47+16851X48+5872X49+118X50+1915X51+1468X52
+3365X53+4762X54
+2082X55+2173X56+2263X57+2436X58+1047X59+4843X60
+5206X61+5412X62+5618X63
+1779X64<38500
x2=1
x13=1
x10=0
x12=0
x9=0
x11=0
X20=1
X21=0
X25=1
X33=1
X31=0
X36=1
X30=0
X44=1
X32=0
X64=1
x34=0
x63=0
x35=0
x62=0
X59=1
```

APPENDIX F

LINEAR PROGRAMMING MODEL: CHISELING TILLAGE SYSTEM AND MEDIUM SOIL

```
MIN -781X1-466X2-532X3-493X4-444X5-432X6-983X7-952X8
-531X9-380X10
-456X11-221X12-785X13-521X14-479X15-453X16
-430X17-537X18-430X19
-408X20-326X21-364X22-220X23-381X24-366X25-371X26
-341X27-268X28
-238X29-711X30-493X31-474X32-366X33-377X34-275X35
-310X36-309X37
-503X38-15577X39-14502X40-11715X41-24492X42-25489X43
-1175X44-1611X45-1989X46
-2617X47-3774X48-6718X49-2556X50-3108X51-3642X52
-4475X53-5993X54
-11715X55-12856X56-13577X57-8907X58-21380X59
-23883X60-14177X61
-29176X62-30494X63-40154X64
ST
87X1+143X2+235X3+250X4+286X5+400X6<359
133X7+154X8+182X9+222X10+267X11+400X12<254
100X13+148X14+200X15+235X16+308X17<146
148X18+160X19+182X20+200X21+235X22+286X23<225
83X24+87X25+100X26+111X27+121X28+143X29<105
77X30+103X31+125X32+143X33+167X34+250X35<137
235X36+263X37+667X38<359
160X39+235X40+308X41+400X42+500X43<250
148X44+190X45+222X46+267X47+333X48+444X49<273
121X50+191X51+250X52+286X53+400X54<309
400X1+400X2+400X3+400X4+400X5+359X6<400
400X7+400X8+400X9+400X10+400X11+254X12<400
400X13+400X14+292X15+248X16+189X17<400
400X18+400X19+400X20+400X21+382X22+315X23<400
400X24+400X25+380X26+342X27+314X28+266X29<400
400X30+400X31+400X32+384X33+328X34+219X35<400
400X36+400X37+215X38<400
400X39+400X40+347X41+267X42+214X43<400
400X44+400X45+400X46+328X47+164X48+109X49<400
400X50+400X51+400X52+400X53+309X54<400
X1+X2+X3+X4+X5+X6-X59-X60-X61-X62-X63-X64=0
X7+X8+X9+X10+X11+X12-X55-X56-X57-X58-X59-X60=0
X13+X14+X15+X16+X17-X55-X56-X57-X58-X59=0
X18+X19+X20+X21+X22+X23-X55-X56-X57-X58-X59-X60=0
X24+X25+X26+X27+X28+X29-X55-X56-X57-X58-X59-X60=0
X30+X31+X32+X33+X34+X35-X59-X60-X61-X62-X63-X64=0
X36+X37+X38-X59-X60-X61=0
X44+X45+X46+X47+X48+X49-X55-X56-X57-X58-X59-X60=0
X50+X51+X52+X53+X54-X55-X56-X57-X58-X59=0
X39-X50=0
X40-X51=0
X41-X52=0
X42-X53=0
```

```
X43-X54=0
X13-X39=0
X14-X40=0
X15-X41=0
X16-X42=0
X17-X43=0
63X1+39X2+24X3+22X4+19X5+14X6<85
20X7+17X8+15X9+12X10+10X11+7X12<40
16X13+10X14+9X15+7X16+5X17<40
8X18+7X19+6X20+6X21+5X22+4X23<40
20X24+19X25+17X26+15X27+14X28+12X29<40
99X30+75X31+61X32+54X33+46X34+30X35<85
60X36+40X37+20X38<85
60X44+53X45+45X46+38X47+31X48+23X49<85
11X50+8X51+6X52+5X53+4X54<40
87X1+143X2+235X3+250X4+286X5+400X6+133X7+154X8+182X9
+222X10+267X11
+400X12+85X13+129X14+167X15+200X16+250X17+148X18+160X19
+182X20+200X21
+235X22+286X23+83X24+87X25+100X26+111X27+121X28+143X29
+74X30+100X31
+121X32+138X33+160X34+250X35+235X36+333X37+667X38+160X39
+235X40+308X41
+400X42+500X43+133X44+167X45+200X46+235X47+286X48
+400X49+80X50+160X51
+210X52+250X53+333X54<2357
8314X1+3915X2+3134X3+2649X4+2134X5+1562X6+1042X7+943X8
+479X9+294X10
+289X11+103X12+799X13+425X14+325X15+263X16+202X17
+325X18+233X19
+188X20+123X21+108X22+45X23+410X24+382X25+373X26
+319X27+347X28+200X29
+795X30+494X31+430X32+307X33+257X34+150X35+178X36+121X37
+89X38+13892X39
+8854X40+2500X41+8057X42+6521X43+700X44+682X45+664X46
+647X47+629X48
+611X49+1886X50+1347X51+1032X52+907X53+781X54+2500X55
+2717X56+2924X57+3490X58+4056X59
+4528X60+5518X61+5612X62+5753X63+9243X64<39500
262X1+241X2+384X3+376X4+359X5+391X6+305X7+345X8
+227X9+198X10
+285X11+165X12+239X13+228X14+252X15+267X16+285X17
+381X18+327X19
+337X20+291X21+348X22+227X23+125X24+129X25+143X26
+150X27+122X28
+124X29+199X30+182X31+210X32+180X33+186X34+198X35
+218X36+262X37
+509X38+4242X39+6060X40+2469X41+16851X42+18784X43
+841X44+1378X45+1845X46
```

```
+2612X47+4012X48+7552X49+1537X50+2633X51+3526X52
+4626X53+6546X54
+2469X55+2683X56+2888X57+1153X58+6473X59+7226X60
+2222X61+8957X62+9183X63
+14753X64<38500
X2=1
X7=1
X13=1
X30=0
X31=1
X37=1
X44=1
X58=1
```

APPENDIX G

LINEAR PROGRAMMING MODEL: CHISELING TILLAGE SYSTEM AND FINE SOIL

```
MIN -781X1-466X2-532X3-493X4-444X5-432X6-989X7
-960X8-536X9-384X10
-462X11+224X12-933X13-662X14-635X15-618X16
-607X17-537X18-430X19
-408X20-326X21-364X22-220X23-381X24-366X25-371X26
-341X27-268X28
-238X29-717X30-498X31-481X32-371X33-343X34-281X35
-318X36-319X37
-521X38-15577X39-14502X40-11715X41-24492X42
-25489X43-1262X44-1575X45-2181X46
-2890X47-4193X48-7506X49-3425X50-4595X51-5634X52
-7089X53-9692X54
-12567X55-13790X56-14565X57-9171X58-23300X59
-26027X60-17739X61
-31801X62-33231X63-43855X64
ST
87X1+143X2+235X3+250X4+286X5+400X6<320
143X7+167X8+190X9+235X10+286X11+400X12<226
138X13+211X14+267X15+329X16+400X17<198
148X18+160X19+182X20+200X21+235X22+286X23<198
83X24+87X25+100X26+111X27+121X28+143X29<105
77X30+103X31+125X32+143X33+167X34+250X35<127
250X36+310X37+680X38<320
160X39+235X40+308X41+400X42+500X43<220
154X44+200X45+235X46+286X47+333X48+444X49<268
80X50+118X51+154X52+200X53+250X54<296
400X1+400X2+400X3+400X4+400X5+320X6<400
400X7+400X8+400X9+400X10+340X11+226X12<400
400X13+272X14+215X15+172X16+143X17<400
400X18+400X19+400X20+396X21+336X22+277X23<400
400X24+377X25+328X26+295X27+270X28+230X29<400
400X30+400X31+400X32+355X33+305X34+203X35<400
400X36+320X37+160X38<400
400X39+400X40+347X41+267X42+214X43<400
400X44+400X45+400X46+295X47+163X48+107X49<400
400X50+400X51+384X52+296X53+236X54<400
X1+X2+X3+X4+X5+X6-X59-X60-X61-X62-X63-X64=0
X7+X8+X9+X10+X11+X12-X55-X56-X57-X58-X59-X60=0
X13+X14+X15+X16+X17-X55-X56-X57-X58-X59=0
X18+X19+X20+X21+X22+X23-X55-X56-X57-X58-X59-X60=0
X24+X25+X26+X27+X28+X29-X55-X56-X57-X58-X59-X60=0
X30+X31+X32+X33+X34+X35-X59-X60-X61-X62-X63-X64=0
X36+X37+X38-X59-X60-X61=0
X44+X45+X46+X47+X48+X49-X59-X60-X61-X62-X63-X64=0
X50+X51+X52+X53+X54-X55-X56-X57-X58-X59=0
X39-X50=0
X40-X51=0
X41-X52=0
X42-X53=0
```

```
X43-X54=0
X13-X39=0
X14-X40=0
X15-X41=0
X16-X42=0
X17-X43=0
162X1+100X2+62X3+56X4+49X5+37X6<100
41X7+36X8+31X9+25X10+20X11+15X12<50
25X13+21X14+17X15+13X16+9X17<50
8X18+7X19+6X20+6X21+6X22+4X23<50
20X24+19X25+17X26+15X27+14X28+12X29<50
120X30+91X31+74X32+65X33+56X34+37X35<100
92X36+62X37+31X38<100
106X44+93X45+80X46+67X47+54X48+40X49<100
11X50+8X51+6X52+5X53+4X54<50
87X1+143X2+235X3+250X4+286X5+400X6+143X7+167X8
+190X9+235X10+286X11
+400X12+138X13+211X14+267X15+329X16+400X17+148X18
+160X19+182X20+200X21
+235X22+286X23+83X24+87X25+100X26+111X27+121X28
+143X29+77X30+103X31
+125X32+143X33+167X34+250X35+250X36+400X37+800X38
+160X39+235X40+308X41
+400X42+500X43+154X44+200X45+235X46+286X47+333X48
+444X49+80X50+118X51
+154X52+200X53+250X54<2357
8314X1+3915X2+3134X3+2649X4+2134X5+1562X6+1042X7
+943X8+479X9+294X10
+289X11+103X12+799X13+425X14+325X15+263X16+202X17
+325X18+233X19
+188X20+123X21+108X22+45X23+410X24+382X25+373X26
+319X27+347X28+200X29
+795X30+494X31+430X32+307X33+257X34+150X35+178X36
+121X37+89X38+13892X39
+8854X40+2500X41+8057X42+6521X43+700X44+682X45
+664X46+647X47+629X48+611X49
+1886X50+1347X51+1032X52+907X53+781X54+2500X55
+2717X56+2924X57+3490X58+4056X59
+4528X60+5517X61+5612X62+5753X63+9243X64<39500
262X1+241X2+384X3+376X4+359X5+391X6+343X7+387X8
+254X9+223X10
+320X11+186X12+471X13+449X14+497X15+527X16+563X17
+381X18+328X19
+337X20+291X21+348X22+227X23+125X24+129X25+143X26
+150X27+122X28
+124X29+217X30+198X31+228X32+196X33+203X34+216X35
+236X36+284X37
+552X38+4242X39+6060X40+2469X41+16851X42+18784X43
+946X44+1550X45+2076X46
```

```
+2939X47+4513X48+8496X49+2577X50+4415X51+5913X52
+7757X53+10977X54
+2827X55+3072X56+3307X57+1235X58+7533X59+8409X60
+3676X61+10424X62
+10686X63+17168X64<38500
x3=1
x8=1
x13=1
x32=1
x36=1
x46=1
X58=1
```

APPENDIX H

LINEAR PROGRAMMING MODEL: NO-TILLAGE SYSTEM AND COARSE SOIL

```
MIN -537X7-430X8
-408X9-326X10-364X11-220X12-381X13
-366X14-371X15-341X16-268X17-238X18
-3569X24-2968X25-3376X26
-4009X27-5217X28-1175X29-1611X30-1989X31
-2617X32-3774X33-6718X34-15577X35-14502X36-11715X37
-24492X38-25489X39-310X40-309X41-503X42-10746X43-4791X44
-11795X45-12454X46
-7035X47-18002X48-18965X49-19710X50-20546X51-7768X52
ST
148X7+160X8+182X9+200X10+235X11+286X12<240
83X13+87X14+100X15+111X16+121X17+143X18<105
108X24+167X25+210X26+267X27+333X28<320
133X29+167X30+200X31+235X32+286X33+400X34<276
160X35+235X36+308X37+400X38+500X39<267
235X40+333X41+667X42<387
400X7+400X8+400X9+400X10+400X11+336X12<400
400X13+400X14+400X15+370X16+339X17+288X18<400
400X24+400X25+400X26+400X27+384X28<400
400X29+400X30+400X31+328X32+164X33+109X34<400
400X35+400X36+347X37+267X38+214X39<400
400X40+400X41+236X42<400
X7+X8+X9+X10+X11+X12-X43-X44-X45-X46-X47-X48=0
X13+X14+X15+X16+X17+X18-X43-X44-X45-X46-X47-X48=0
X24+X25+X26+X27+X28-X43-X44-X45-X46-X47=0
X29+X30+X31+X32+X33+X34-X43-X44-X45-X46-X47-X48=0
X40+X41+X42-x50-x51-x52=0
X24-X35=0
X25-X36=0
X26-X37=0
X27-X38=0
X28-X39=0
8X7+7X8+6X9+6X10+5X11+4X12<40
20X13+19X14+17X15+15X16+14X17+12X18<40
18X24+12X25+9X26+8X27+6X28<40
60X29+53X30+45X31+38X32+31X33+23X34<85
60X40+40X41+20X42<85
148X7+160X8
+182X9+200X10+235X11
+286X12+83X13+87X14+100X15+111X16+121X17+143X18
+108X24+167X25+210X26+267X27+333X28
+133X29+167X30+200X31
+235X32+286X33+400X34+160X35+235X36+308X37+400X38
+500X39+235X40+333X41
+667X42<2357
318X7+269X8
+209X9+137X10
+120X11+50X12+456X13+425X14+415X15+335X16+275X17
+223X18
```

```
+2963X24+1526X25+1167X26+1006X27+853X28+700X29
+686X30+664X31+647X32+629X33+611X34+13892X35
+8854X36
+2496X37+8057X38+5622X39+178X40+121X41+89X42
+2500X43+2608X44+2717X45+2924X46+3490X47+3772X48
+4056X49+4216X50+4377X51+4528X52<39500
381X7+327X8
+337X9+291X10
+348X11+227X12+125X13+129X14+143X15+150X16+122X17
+124X18
+1878X24+2320X25+3100X26
+3989X27+5558X28
+654X29+1072X30+1434X31+2031X32+3119X33+5872X34
+4242X35+6060X36+2469X37+16851X38+18784X39+218X40
+262X41+509X42+2082X43+280X44+2263X45+2436X46
+6303x47+4843X48+5206X49+5412X50+5618X51+572X52<38500
x52=1
x51=0
x49=0
x44=1
x50=0
x48=0
x40=1
x24=1
x29=1
```

APPENDIX I

LINEAR PROGRAMMING MODEL: NO-TILLAGE SYSTEM AND MEDIUM SOIL

```
MIN-537X7-430X8
-408X9-326X10-364X11-220X12-381X13
-366X14-371X15-341X16-268X17-238X18
-5937X24-5893X25-7285X26
-9039X27-12225X28-1175X29-1611X30-1989X31
-2617X32-3774X33-6718X34-15577X35-14502X36-11715X37
-24492X38-25489X39-310X40-309X41-503X42-11715X43-6175X44
-7154X45-19200X46
-21380X47-23883X48-11120X49-29176X50-30494X51-40154X52
ST
148X7+160X8+182X9+200X10+235X11+286X12<198
83X13+87X14+100X15+111X16+121X17+143X18<105
167X24+250X25+333X26+400X27+500X28<309
148X29+190X30+222X31+267X32+333X33+444X34<273
160X35+235X36+308X37+400X38+500X39<250
235X40+363X41+667X42<359
400X7+400X8+400X9+400X10+382X11+315X12<400
400X13+400X14+380X15+342X16+314X17+366X18<400
400X24+400X25+326X26+266X27+207X28<400
400X29+400X30+400X31+328X32+164X33+109X34<400
400X35+400X36+347X37+267X38+214X39<400
400X40+320X41+160X42<400
X7+X8+X9+X10+X11+X12-X43-X44-X45-X46-X47-X48=0
X13+X14+X15+X16+X17+X18-X43-X44-X45-X46-X47-X48=0
X24+X25+X26+X27+X28-X43-X44-X45-X46-X47=0
X29+X30+X31+X32+X33+X34-X43-X44-X45-X46-X47-X48=0
X40+X41+X42-X47-X48-X49=0
X24-X35=0
X25-X36=0
X26-X37=0
X27-X38=0
X28-X39=0
8X7+7X8+6X9+6X10+5X11+4X12<40
20X13+19X14+17X15+15X16+14X17+12X18<40
25X24+17X25+13X26+10X27+8X28<40
65X29+57X30+49X31+41X32+33X33+24X34<85
76X40+51X41+26X42<85
+148X7+160X8
+182X9+200X10+235X11
+286X12+83X13+87X14+100X15+111X16+121X17+143X18
+167X24+250X25+333X26+400X27+500X28
+148X29+190X30+222X31
+267X32+333X33+444X34+160X35+235X36+308X37+400X38
+500X39+235X40+363X41+667X42<2357
+318X7+269X8
+209X9+137X10
+120X11+50X12+456X13+425X14+415X15+335X16+275X17
+223X18
+2963X24+1526X25+1167X26+1006X27+853X28+700X29
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+686X30+664X31+647X32+629X33+611X34+13892X35+8854X36
+2496X37+8057X38+5622X39+178X40+121X41+89X42
+2500X43+2608X44+2924X45+3489X46+4055X47+4528X48
+5470X49+5612X50+5753X51+9244X52<39500
+381X7+327X8
+337X9+291X10
+348X11+227X12+125X13+129X14+143X15+150X16+122X17
+124X18
+4714X24+5824X25+7781X26
+10012X27+13952X28
+841X29+1378X30+1845X31+2612X32+4012X33+7552X34
+4242X35+6060X36+2469X37+16851X38+18784X39+227X40
+272X41+530X42+2469X43+563X44+710X45+5570X46
+6473X47+7226X48+1286X49+8957X50+9183X51+14753X52<38500
x51=0
x49=1
x50=0
x44=1
x52=0
x40=1
x36=1
X29=1
```

APPENDIX J

LINEAR PROGRAMMING MODEL: NO-TILLAGE SYSTEM AND FINE SOIL

```
MIN-537X7-430X8
-408X9-326X10-364X11-220X12-381X13
-366X14-371X15-341X16-268X17-238X18
-6384X24-6446X25-8023X26
-9990X27-13550X28-1262X29-1755X30-2181X31
-2890X32-4193X33-7506X34-15577X35-14502X36-11715X37
-24492X38-25489X39-310X40-319X41-521X42-12567X43-5755X44
-14565X45-8362X46
-23620X47-26027X48-29815X49-11535X50-35356X51-43855X52
ST
148X7+160X8+182X9+200X10+235X11+286X12<198
83X13+87X14+100X15+111X16+121X17+143X18<105
182X24+267X25+364X26+444X27+571X28<296
154X29+200X30+235X31+286X32+333X33+444X34<268
80X35+118X36+154X37+200X38+250X39<220
250X40+400X41+800X42<320
400X7+400X8+400X9+396X10+336X11+277X12<400
400X13+377X14+328X15+295X16+270X17+230X18<400
400X24+400X25+326X26+266X27+207X28<400
400X29+400X30+400X31+295X32+163X33+107X34<400
400X35+400X36+347X37+267X38+214X39<400
400X40+320X41+160X42<400
X7+X8+X9+X10+X11+X12-X43-X44-X45-X46-X47-X48=0
X13+X14+X15+X16+X17+X18-X43-X44-X45-X46-X47-X48=0
X24+X25+X26+X27+X28-X43-X44-X45-X46-X47=0
X29+X30+X31+X32+X33+X34-X47-X48-X49-X50-X51-X52=0
X40+X41+X42-x50-x51-x52=0
X24-X35=0
X25-X36=0
X26-X37=0
X27-X38=0
X28-X39=0
8X7+7X8+6X9+6X10+5X11+4X12<50
20X13+19X14+17X15+15X16+14X17+12X18<50
31X24+21X25+16X26+13X27+11X28<50
106X29+93X30+80X31+67X32+54X33+40X34<100
92X40+62X41+31X42<100
+148X7+160X8
+182X9+200X10+235X11
+286X12+83X13+87X14+100X15+111X16+121X17+143X18
+182X24+267X25+364X26+444X27+571X28
+154X29+200X30+235X31
+286X32+333X33+444X34+80X35+118X36+154X37+200X38
+250X39+250X40+400X41+800X42<2357
+318X7
+269X8+209X9+137X10
+120X11+50X12+456X13+425X14+415X15+335X16+275X17
+223X18
+2963X24+1526X25+1167X26+1006X27+853X28+700X29
```

```
+686X30+664X31+647X32+629X33+611X34+13892X35+8854X36
+2496X37+8057X38+5622X39+178X40+121X41+89X42
+2500X43+5612X44+2924X45+3489X46+4055X47+4528X48
+5470X49+2717X50+6455X51+9244X52<39500
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+129X14+143X15+150X16+122X17+124X18
+5250X24+6486X25
+8866X26+11151X27+15539X28
+946X29+1550X30+2075X31+2939X32+4513X33+8496X34
+4242X35+6060X36+2469X37+16851X38+18784X39+236X40
+284X41+552X42+2827X43+1232X44+3307X45+988X46
+7533X47+8409X48+10161X49+432X50+11982X51
+17168X52<38500
x50=1
x40=1
x44=1
x35=1
x31=1
```

```
MAX -38.9X1-39.8X2-34.3X3-38X4-34X5-36.6X6-37.7X7
-69.6X8-63.4X9-70.2X10-64X11-71.3X12-65.1X13-28.3X14
-31.8X15-29X16-32.6X17-30.8X18-34.3X19-67.3X20
-48.3X21-289X22-266X23+13.2X24+92X25+594.7X26
+594.7X27+594.7X28+594.7X29+594.7X30+594.7X31
+594.7X32+594.7X33+594.7X34+594.7X35+594.7X36
+594.7X37+594.9X38+594.9X39+594.9X40+594.9X41
+594.9X42+594.9X43+308X44+308X45+213X46+213X47
+80X48-.18X49-.21X50-.26X51
ST
X1+X22+X23<400
-X1+X2+X3+X4+X5+X6
+X7+X8+X9+X10+X11+X12
+X13+X14+X15+X16+X17+X18
+X19+X20+X21<0
.5X2+.9X3+.8X4+.5X5+.9X6+.8X7+.4X8+.4X9+.4X10+.4X11+.4X12
+.4X13+.6X14+.8X15+.6X16+.8X17+.6X18+.8X19+.9X20+.9X21
+.9X22+.9X23<371
-7.2X1+X25<0
-4.7X2-4.7X3-4.7X4-4.7X5-4.7X6-4.7X7+X26+X27+X28+X29+X30+X31<0
-4.7X8-4.7X9-4.7X10-4.7X11-4.7X12-4.7X13+X32+X33+X34+X35
+X36+X37<0
-4.7X14-4.7X15-4.7X16-4.7X17-4.7X18-4.7X19+X38+X39
+X40+X41+X42+X43<0
-4.7X20-4.7X21+X44+X45<0
-53.1X22-53.1X23+X46+X47<0
-.47X24+X48<0
-151X1-112X2-112X3-112X4-112X5-112X6-112X7-112X8-112X9
-112X10-112X11-112X12-112X13-112X14-112X15-112X16
-112X17-112X18-112X19-112X20-112X21-263X22-263X23+X49<0
-71X1-41X2-41X3-41X4-41X5-41X6-41X7-41X8-41X9-41X10
-41X11-41X12-41X13-41X14-41X15-41X16-41X17-41X18
-41X19-41X20-41X21-101X22-101X23+X50<0
-45X1-163X2-163X3-163X4-163X5-163X6-163X7-163X8
-163X9-163X10-163X11-163X12-163X13-163X14-163X15
-163X16-163X17-163X18-163X19-163X20-163X21-219X22-219X23+X51<0
9.4X20+9.4X21+105X22+105X23<2442
-X1+X24<0
X22-X23<0
```

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APPENDIX K

LINEAR PROGRAMMING MODEL: CORN STOVER SYSTEM

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